# 2007 Argentine Congress on Computer Science (Congreso Argentino en Ciencias de la Computación - CACIC 2007)

# Capa Física y de Enlace de la Tecnología PLC (Physical and Link Layer in Power Line Communications Technologies)

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## ABSTRACT

PLC technology[1] - Power Line Communications- refers to the transmission of data using the domestic as well as the low-voltage electrical net. Depending on the type of network used as support it is divided in PLC indoor and outdoor. The first refers to the use of the domestic network and uses higher frequencies (5 MHz to 30 or 40 MHz). Outdoor PLC uses the distribution network and low frequencies of 1 MHz to 5 or 10 MHz. It employs the OFDM multiplexation technique- Orthogonal Frequency Division Multiplexing- which divides the frequency spectrum in narrow channels with independent carriers. At the level of media access protocol, it generally uses those which are compatible with the IEEE 802 norm, with controlled access to avoid collisions. OFDM modulation achieves transmission speeds which are suitable for multimedia services and applications as well as those of critical mission currently used, and with security conditions when facing a noisy channel such as the power network.

**KEYWORDS: PowerLine Communications, OFDM, MAC, CSMA/CA, Last Mile.**

## 1. INTRODUCTION.

Currently, the market offers a wide range of last mile technologies. Not only will technology provide telephone services, but also broadband services, offering added value to providers and users.

[1] Also known as PLT - PowerLine Telecommunications- o BPL -Broadband PowerLine.

A variety of connectivity models can be developed based on the different technologies aiming to satisfy user's needs, interconnecting voice and data networks, or both services separately. We could mention, for instance, Voice over IP, TV or Video on Demand, analogical or digital, low cost local wireless links. This work deals with PLC technology – PowerLine Communications- which uses the low voltage domestic electrical distribution network as a support for data, Internet, voice, video, and video-on-demand transmission.

Experimental systems which use power grid for high speed data transmission have been developed at the telecommunications level. The development possibilities for this technology are significant considering the rising demand of broadband internet services.

A straightforward advantage is the possibility to offer telephone service, internet access, interactive TV, domotics, and others wherever electrical power is present. More than 3.5 billion people have electrical power at home, as opposed to 1.8 billion who have access to telephone services. Practically every room of a house or store has an electrical outlet for 220 VAC or 110 VAC.

Additional advantages are the rapid expansion (no need to build ducts if compared to cable operators), and the fact that is does no require a frequency assignment, as opposed to wireless technologies.

The most important advantages of PowerLine Communications are worldwide availability, low cost, and easy installation. In addition, it cannot be ignored the convenience of connecting any device to an electrical outlet which would allow to surf the web, receive videos, transmit data, and speak over the phone.

Since 1997, United Utilities from Canada and Northern Telecom from England have introduced a technology which could give Internet access through power lines: PLC – PowerLine Communications. By late 1999 and the beginning of the year 2000, Spain also joined this trend with Endesa. The U.S. has also developed several initiatives; although they never accomplished satisfactory commercial results. Nevertheless, ever since then, electrical companies have been interested in taking better advantage from their networks through numerous projects to develop communication services.

On the other hand, big technological corporations such as 3COM, AMD, Cisco Systems, Compaq, Conexant, Enikia, Intel, Intellon, Motorola, Panasonic, Diamond Multimedia, and RadioShack created and alliance called ***HomePlug PowerLine***. The main objective was to create devices and to promote the rapid growth of the technology in homes.

## 2. PLC TRANSMISSION

As mentioned, PLC is implemented in two forms: ***indoor systems*** also known as ***last meter or last inch***, which use the users´ indoor network, and the ***outdoor systems*** which work with the electric distribution grid in the ***last mile.***

To operate simultaneously on both systems, different carrier frequencies are used over the same power lines. Usually, last mile systems use low frequencies to the loss of signal due to attenuation. Meanwhile, in the case of a building interior, higher frequencies can be used because the higher attenuation from high frequency use is compensated by the lower distances the signal travels.

For a long time, power companies have used networks, transmission and distribution, to send electricity and telecommunication signals. Consequently, PLC has been used for a while, but only for the transmission of control signals with very low bandwidth. These networks are used for monitoring and long distance control as well as supervision from equipment used in electrical distribution[2]. With these systems, power companies have an extremely cheap means of sending monitoring and control signals.

The method used is based on the transmission of multifrequency signals in the electric grid. Frequencies are selected in such a way that it is possible to separate them clearly to avoid interference. Frequencies of 10 to 450 kHz have been commonly used to communicate services such as ***carrier wave***, while electric signals work in a range of 50 to 60 Hz.

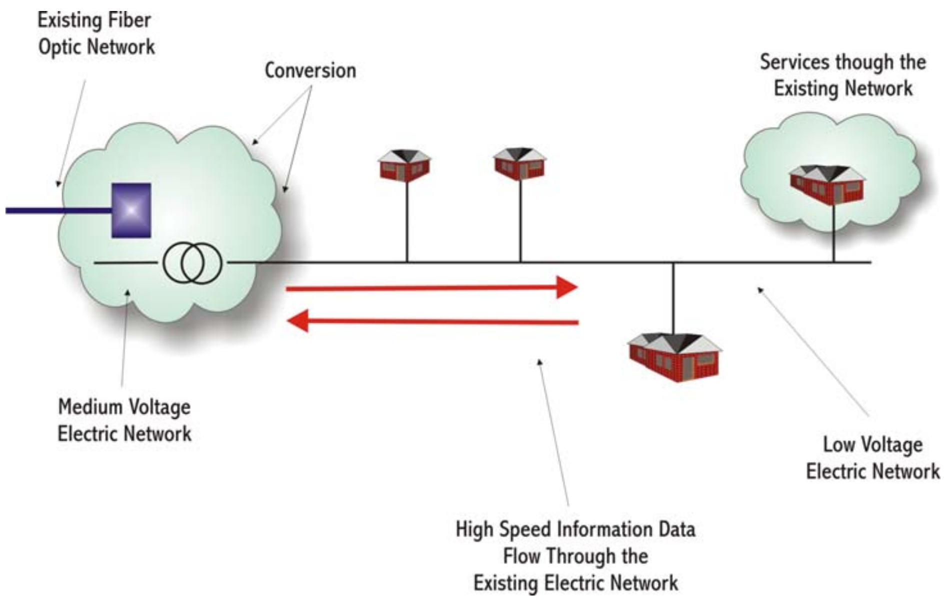


**Figure 1: Last Mile PLC Diagram**

Two fundamental elements lay in the originality of current PLC technology compared to the one which has been in use previously:

- The use higher frequencies.
- The ability to accomplish broadband transmission.

The frequencies vary from 1,7 to 30 MHz. With higher frequency use, higher transmission speeds can be reached.

However, the main disadvantage of PLC transmission lies in this use of high frequency signals for data transmission because they will not go through the ***Distribution Transformers*** - ***MT/BT***. They become like a low frequency filter with maximum cut at 20 KHz.

Thus, data signals must be separated from the electric signals with voltage transformers. At this point, signals also enter a microwave or optic fiber backbone. It is a valid technology transmitting high frequency signals for ***indoor*** or ***outdoor*** use.

[2] Such as measuring devices, switches, failure detecting devices, and so on.

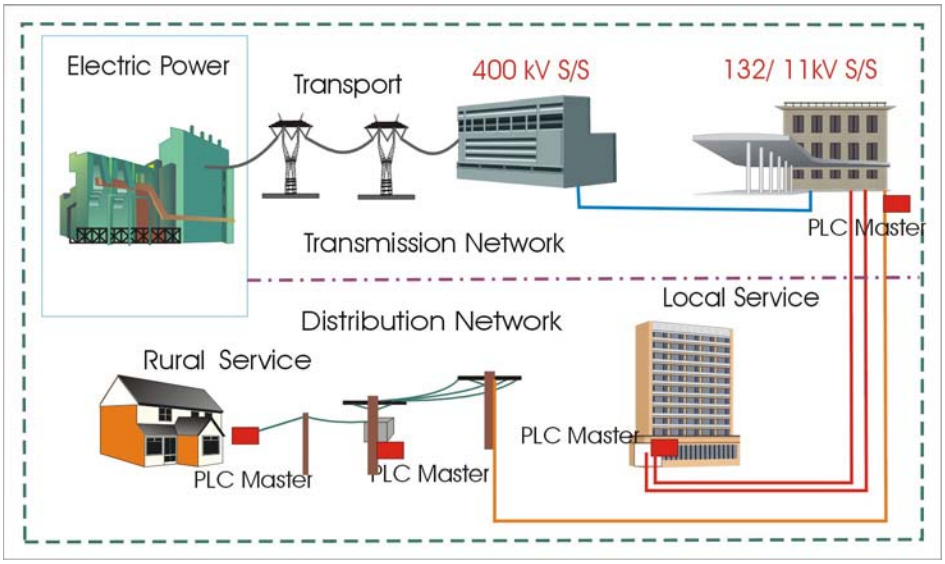


**Figure 2: Diagram of a PLC Medium and Low Voltage Network**

Figure 2 shows the diagram of a PLC network in which medium and low voltage is contemplated. Figure 3, on the other hand, depicts a diagram of PLC distribution in a user's building.

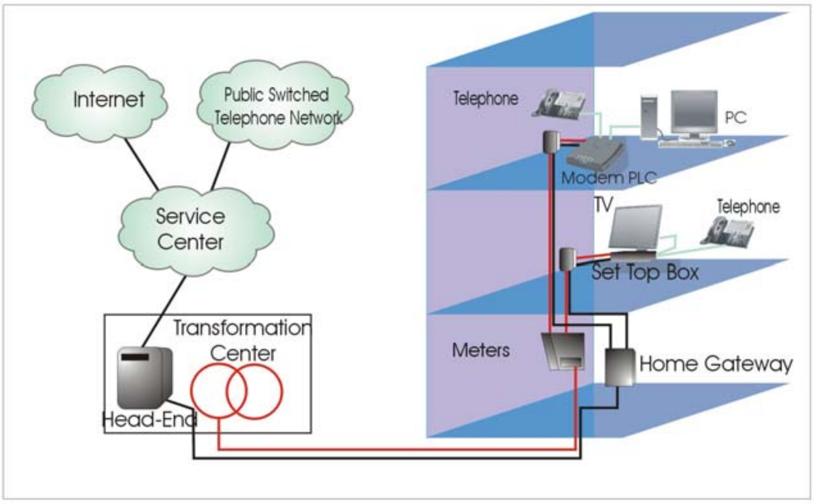


**Figure 3: Diagram of PLC Distribution in a User's Building**

In brief, the following considerations describe the architecture of this technology. Energy reaches the user as low frequency alternate current, 50 to 60 Hz, while data traveling through the same power grid using the bandwidth of 1 to 34 MHz, through the following steps:

- High Voltage, from 220 to 400 Kilovolts, which carries energy to the transport substation
- Medium Voltage, from 66 -132 Kilovolts, up to the distribution substation.
- Medium Voltage, from 10-50 Kilovolts, up to the distribution center.
- Low Voltage, from 220-380 volts, which distributes the energy in buildings and homes

## 3. RELEVANT PLC TECHNICAL INFORMATION

If we analyze the structure of communications from the OSI viewpoint, we can se that the physical and link layer show differences. Higher layers do not vary from the traditional models. Regarding the physical layer, considerations need to be made on the design for PLC modulation. Finally, the link layer develops technologies for the MAC sub layer available.

### 3.1 Physical Layer: Modulation Diagram

Distribution grids are subject to a wide range of noise. If it is greater than the signal level, the latter cannot be recovered properly and might be lost. Henceforth, simple modulation designs are not appropriate for transmission over power grids (for example FSK or PSK). The two most useful methods are: ***OFDM - Orthogonal Frequency Division Multiplexing*** and ***DSSS - Direct-Sequence Spread Spectrum***.

The main advantages of DSSS are the lack of sufficient bandwidth and the fact that the power network does not have a plain transmission characteristic in the entire assigned bandwidth. Consequently, higher levels of attenuation are found in some frequencies rather than others.

The other alternative to use in the physical layer is OFDM. An optimum design could result from OFDM at current conditions or in the future. OFDM is a well proven technique, used in applications such as ***DAB - Digital Audio Broadcasting***, and in ***ADSL - Asymmetric Digital Subscriber Line.*** OFDM will most likely be used in Digital Television standards, as would be ***DVB - Digital Video Broadcasting***[3]. OFDM is related to the ***FH technique – Frequency Hopping*** of expanded spectrum, showing strengths when considering interferences and multiple accesses.

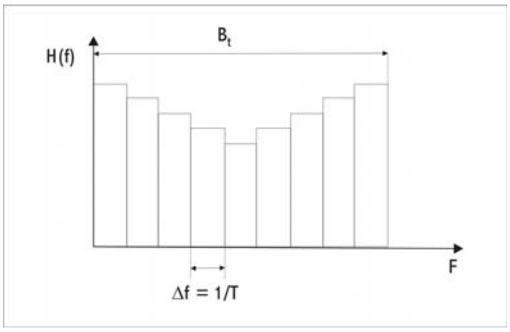


**Figure 4: Bandwidth Subdivision**

In OFDM, the available frequency spectrum ($B_t$) is segmented in several narrow channels. A data stream is transmitted by frequency multiplexation using N carriers with parallel frequencies $f_1$, $f_2$,... $f_N$. Figure 4 depicts the sub channels where each one will have a bandwidth equal to:

$$\Delta f = \frac{B_t}{N}$$

[3] Known as European standard

Attenuation and group delay are constant en each channel. Figure 5 shows the OFDM diagram and advantages.

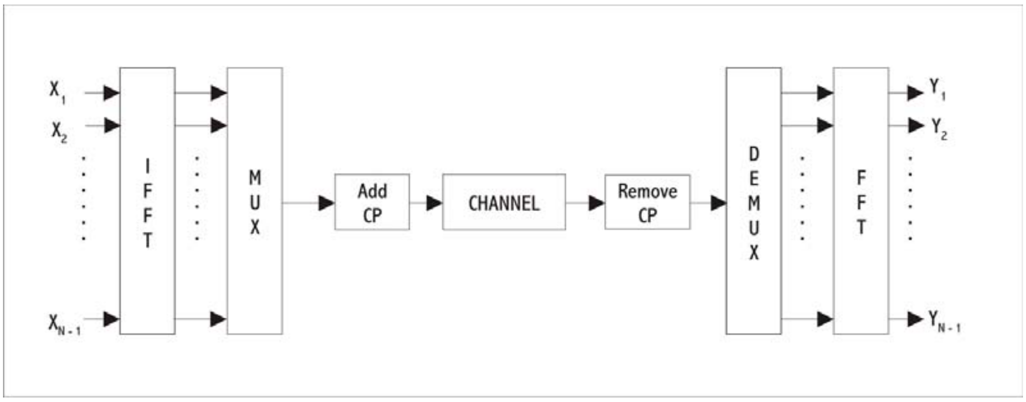


**Figure 5: OFDM Diagram**

Advantages:

- Dispersion effect decrease in time domain.
- Interference reduction among narrow bands
- High efficiency in the use of the bandwidth.
- Transmission speed scalability for growing transmission rates.
- Flexibility and adaptability according to modulation, data rates and bit charge.
- Excellent ICI response
- No need for channel equalization
- Not requiring hook-up in the oscillators phase

In this way, equalization, understood as the signal distortion compensation, has the advantage in OFDM that its circuits are simple. Besides, OFDM avoids extreme conditions, such as high frequency attenuation, narrow band interferences, and selective vanishing due to multipaths. This is the result from taking each carrier as a narrow band signal with a modulation speed instead of a broadband signal with a high modulation speed.

Low modulation speed allows for a carrier interval which eliminates interference between symbols or carriers (ICI). Equalization, in this case, will be the inverse of the channel transference function. With a known sequence, it is possible to determine the channel transference function. Afterwards, the inverse of that function is calculated to obtain the equalization values.

A typical OFDM signal in the domain of time, $S_{OFDM}$ (t), can be depicted as follows:

$$S_{OFDM}(t) = A.\ \mathrm{rect}\left[\frac{t}{T}\right]\cdot\sum_{i=1}^{N} sen\left[2\pi\left(f_0+\left[i-\frac{N+1}{2}\right]\cdot\Delta f\right)\cdot t\right]$$

The minimum frequency spacing is equal to $\Delta f = 1 / T$, where T is the period of the wave. This equation describes a frequency pack in the range:

$$f_0 - [(N-1)/2].\ \Delta f = f_0 - (B_t - \Delta f) / 2 \text{ up to } f_0 + [(N-1)/2].\ \Delta f = f_0 + (B_t - \Delta f) / 2$$

Figure 6, illustrates the spectral condition for N= 7

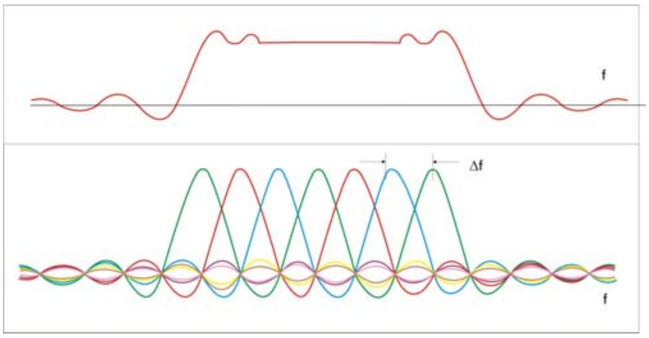


**Figure 6: Spectral Distribution of 7 channels in OFDM [1]**

An excellent use of the spectrum is achieved in this way, enabling the use of high speeds. It has a double characteristic: low passing and at the same time a filtering effect limiting the range of usable frequency. Frequencies in OFDM are transmitted sequentially. The main difference is that each carrier is modulated, carrying a piece of the data package, and that a great number of carriers, hundreds generally, are transmitted in a parallel way.

The transmitted signal will be the sum of many modulated carriers. The synthesis of an OFDM signal can be carried out by the Inverse of Fourier Discrete Transfer, and in the receptor, the complementary operation from this function will be carried out.

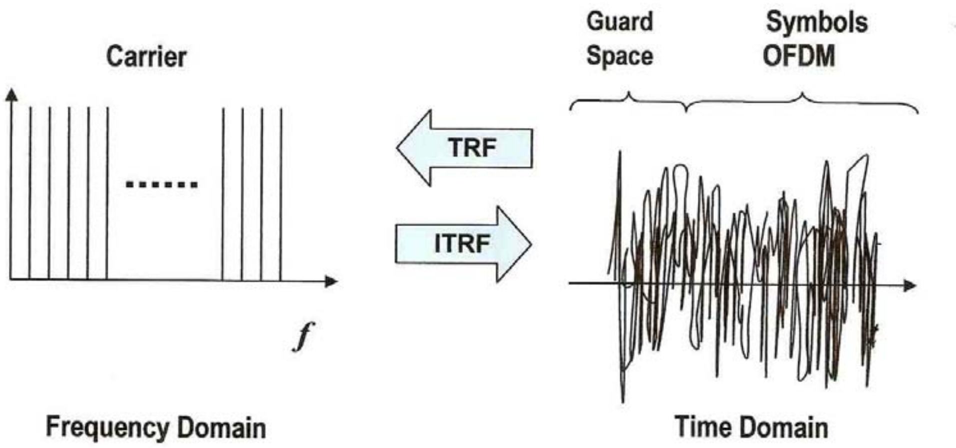


**Figure 7: Same Signal Representation in Time and Frequency Domain through Fourier Transform**

The complex processes of modulating and demodulating thousands of carriers simultaneously are fortunately equivalent to the operations in a Fourier Discrete Transform, FFT. An algorithm has been developed, called Fast Fourier Transform, FFT. In this way, the implementation of OFDM demodulators allows for the existence of series receptors.

As mentioned before, each OFDM carrier transports part of the data stream. Data does not need to be equally distributed among carriers; nor does it need the same modulation process. Considerable advantages can be obtained from the properties of the channel. If the transmission band has low attenuation and low interference levels, the carriers in that range can be modulated with complex modulation processes such as QAM. In other parts, where the values of the signal/noise relation are deficient, BPSK or similar might be used.

Note that IFFT, as well as FFT, take significant processing and must be carried out in less than T time. Therefore, modern digital signal processors need to be used. This also improves transmission speed. Finally, HomePlug has chosen OFDM as the core technology for PLC high speed networks which could lead them to great success [5].

A brief summary of OFDM technology follows:

- The idea of dividing the spectrum in several narrow bands.
- Frequencies are superposed and orthogonal to obtain spectrum efficiency.
- For each sub-band, well known modulation techniques are used, such as BPSK, QPSK y QAM.
- Equalization is reduced by placing sub-carriers very close to each other.
- OFMD modulation is generated by FFT process – Fast Fourier Transform.
- Equalization is reduced, placing sub-carriers close together:

$$M = N \times B$$

  Where:
  - ✓ M = quantity of coded bits
  - ✓ N = quantity of sub. carriers
  - ✓ B = number of bits per modulation symbol.

  Ex.: B=2 in QPSK

- The FFT inverse is calculated to obtain several sub-carriers which altogether will determine a domain in simple time.
- A cyclic prefix is added..
  - ✓ It eliminates carrier interference maintaining orthogonality.
  - ✓ It removes Inter Symbolic Interference.
- On the other end, CP is extracted and FFT is applied to later decode, analyzing the different phases and amplitudes of sub-carriers.
- To eliminate multiple path reflexes, interleaving and error correction techniques may be used.

### 3.2 MAC Technology in PLC:

Medium Access Layer – MAC, is used to transfer data between the physical layer and the LLC sublayer of the link layer. Given that the power grid is ***shared***, a special organization for access is required. Manufacturers and cooperating organizations in PLC standardization processes do not use standards for the MAC layer yet.

For ***outdoor*** systems, HomePlug PorweLine Alliance has not set standards yet; although it is expected to be done this year. In the ***indoor*** case, a MAC layer standard has been established: the use of ***CSMA/CA - Carrier Sense Multiple Access / Collision Avoidance***.

The level of noise in PLC is significantly greater then in Ethernet. Thus, ***collision avoidance*** instead of ***collision detection*** becomes relevant - the latter assumes that each node can listen to every other node.

Another alternative is **CDMA – Code Division Multiple Access**, considered more appropriate for PLC due to its robustness when facing noise and unwanted signals. It allows a station to transmit at all times and through the entire frequency spectrum. It separates multiple and simultaneous transmissions using codification theory. The technique does not need global coordination or synchronicity. Supposedly, the streams that collide do not suffer distortions but multiple signals are added in a linear fashion. CDMA technology is based on data transmission followed by a bit stream or code recognized by the receptor. Henceforth, the receptor carries out a Fourier transform to detect data. In this way, several channels can transmit at the same time and the same frequency but each carrying a different code.

Some manufacturers have developed their own techniques to access the medium such as DS2 [3] and Plus Net de Maint.net [8]. They use intelligent repetition which, aided by distribution network attenuation, forms cells where different PLC systems work. Units use point-multipoint protocols of own design, resulting in a completely transparent IP system for the final user.

Note that presently there is no MAC protocol for the link layer, in this sense ETSI 102 249 V1.1.1 (2005-06) standard, paragraph 6, which points out that the MAC sub layer must follow the practices of 802.Consequently frame delimiter, origin, and destination identification, transmission access control have to be full filled. These conditions are basic requirements to access the medium but do not define a specific protocol.

A similar case can be argued for the OPERA Consortium ***Open PLC European Research Alliance*** [9], which presents a point multipoint protocol based on TDMA with a net administrator. For that purpose, ***TDD - Time Division Duplex***, or ***FDD - Frequency Division Duplex*** is used as established in the standard OPERA D47 [D]. The first shares the channel mainly in transfer systems of asymmetric information. The latter shares the channel with standard frequencies, especially appropriate for symmetric transfers. These techniques could handle the different types of service qualities considered by OPERA

## 4. STANDARIZATION

Standards such as HomePlug HP 1.0 apply OFDM modulation with a total of 84 carriers in the frequency range of 4,5 MHz a 21 MHz, and due to the need for channel separation in this frequency band 76 carriers are available, using differential PSK modulation, as shown in Table 1. ***ROBO - Robust-OFDM*** is a modulation design developed by HomePlug with information bit repetition in each OFDM symbol, especially for specific information like broadcast packages which cannot be transmitted in the chosen modulation for each network member.

The standard established a protocol ***CSMA/CA*** link layer, determining two ways of medium occupation: ***PCS – Medium Carrier Detection, on the physical layer,*** and ***VCS – Virtual Carrier Census*** which is established in the thread head and processed at the link layer level. This enables the emission of data burst from a network component to complete data transmission.

| Modulación | | Corrección de error hacia adelante | Velocidad de la Capa Física en Mbps |
|---|---|---|---|
| DQPSK 3/4 | DQPSK | Código de convolución 3/4 | 13,78 |
| DQPSK ½ | DQPSK | Código de convolución ½ | 9,19 |
| DBPSK ½ | DBPSK | Código de convolución ½ | 4,5 |
| ROBO | DBPSK | Código de convolución ½ y cada bit es repetido cuatro veces | 1,0 |

**Table 1: Modulation Diagram And Error Correction**

A priority mechanism is also set through the Standard, following the 802.1Q norm, VLAN tags, where the tagged threads inform the priority level.

This requires a priority resolution period which takes place after obtaining the thread reply with the data received free of errors. Retransmission is not necessary. At that point, there are two competence periods. In the first, higher priority threads compete; lower priority threads will follow, allowing higher level traffic to interrupt lower level traffic burst. In this way, high quality of service (QoS) can be established for the traffic which needs low delay as voice or video[4].

## 5. ADVANTAGES AND DISADVANTAGES OF PLC

| VENTAJAS | DESVENTAJAS |
|---|---|
| Low cost | Yield is subject to home appliance use |
| Use of existing cables. | Old cables might affect yield |
| Electric outlets are present in every room. | Data security is difficult. |
| Very easy to install | QoS issues when constant bandwidth is required. |
| Every data device requires connection to the electrical network, even without using this technology. | Scarce competition and limited equipment manufacturing |

## 6. MAIN APPLICACIONS OF PLC

- **Telephones**
  In VOIP – Voice over IP – mode. Some modems incorporate the VOIP gateway. Systems are designed to guarantee quality of service.

- **Internet Access**
  Broadband internet access is ***the*** PLC application most requested from client viewpoint. The nature of traffic bursts enables an effective multiplexation in the available bandwidth.

- **Interactive Services (games, e-learning, and others)**
  Interactive services can comprehend all sorts of Media on Demand, such as Media, Video, Music, News, and so on, with different degrees of interactivity. In any event, bandwidth guarantee and adequate delay times are required. In the case of network games, no special demands might impose the need for a service design with players connecting to a ***Game Room***

4 Isochronous traffic

and exchanging moving commands and actions over pre-established scenarios, except for maintaining low delay.

- **Others (Videoconferences, VPN, Peer to peer applications, and so on)**
  These services are commonly born at the IP level for authentification functions and security access which reside in the Broadband Access Servers.

## 7. CONCLUSION.

The most convenient modulation technique for this technology is OFDM with a carrier modulation of higher bit quantity to achieve greater speed, but accounting for the interference and noise level of the network.

Even when several corporations have developed their own link layer protocols, such as Intellon or DS2, all of them converge in following the 802.3 standard in search for compatibility and transmission efficiency among the different networks in a MAN or WAN.

Although this is valid for ***PLC indoor*** and ***PLC outdoor***, it should be noted that the critical technology is outdoor due to the structure of the distribution grid with a high number of clients and wide signal radios and because of the greater interference and higher potency levels.

These issues require modulation systems robust to noise levels, and consequently slower. When this is considered with the electromagnetic compatibility issues and the lack of standards and regulation, it is clear that the market tends to choose alternative technologies such as XDSL. Currently in our country, broadband Internet access is provided by ADSL Technologies, cable modem – CATV and optic fiber – FTTx, and for the moment in a lesser degree, through wireless technolgies[5]. In this context, PLC is a developing experimental stage technology.

The future of indoor PLC might not be the same because its advantages and the possibility to reach greater speeds allow it to compete with wireless links and wiring, especially in the SOHO market sector.

In sum, based on the use of the low voltage power grid, PLC technology offers a solution to geographic dispersion, nationwide service, integration of low income households, price according to income, broadband internet access and so on. This is why we wonder if PLC will provide the answers in the issues that other technologies failed; and if it will finally break social, geographic and technological barriers which have stagnated the development and expansion of telecommunication networks in unprotected and discriminated areas by lack of sufficient resources. May this technology grant more households in the country with broadband access services.

## 8. ACKNOWLEDGEMENTS.

The financial support provided by Agencia Nacional para la Promoción Científica y Tecnológica and CITEFA (Project PICTO 11-18621, Préstamo BID 1728 OC-AR) is gratefully acknowledged.

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