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Received on:12/06/2017
Accepted on: 20/12/2017

The Relationship between Data Transfer Rate and Distance in Power Networks Modems

Abstract- *With the rapid growth of communication networks, reliable and economical communication systems are needed and can be implemented in buildings. PLC uses electrical wiring to transmit information and provides high-speed and cheap data communications, such as home networks and Internet access. PLC is a hostile environment for communication, making communication signals spread difficult and experiencing significant challenges such as noise, attenuation and interference. This research focus on the challenges of communications via power lines such as distance and stability. Performance factors are tested and studied through the actual application of communication networks by connecting modems and computers in the network via power sockets to test the impact of distance on information transmission. The low data transfer rate when increasing the distance was clear, which means that the data transfer is inversely proportional to the distance, there was also a difference in stability when actual data are transferred and in the case of non-actual data transfer, as described later in the practical part. In order to reduce the effect of long distances and to overcome attenuation requires the use of high-speed modems and implements advanced modulation technique such as OFDM that applied in the PLC systems.*

Keywords: *Local area network, Orthogonal frequency division multiplexing, power line communication, Power line network, Quadrature Amplitude modulation*

How to cite this article: S.H. Mahmood, “The relationship between Data Transfer Rate and Distance in Power Networks Modems,” *Engineering and Technology Journal*, Vol. 36, Part A, No. 6, pp. 620-627, 2018.

1. Introduction

In past few years there was an increase in the demand for multimedia broadband applications and continue to grow at a rapid pace. It has become the broadband Internet access is very necessary. Many techniques achieve multimedia broadband applications. One of these techniques is power lines communication (PLC). It is very important technique, because the information transfer occurs without the need for new wires. It uses the same wire used in power transmission for data transfer alongside the transfer of electrical energy. Using PLC provides cost and time, by uses the power lines as a medium for data transmission; it's an exploit a wide range of electrical power networks to provide services of high-speed broadband and multimedia in the homes or offices and other. PLC offers an effective competitive alternatives in terms of cost to access the Internet and multimedia applications. Communications over power lines are limited in scope despite their large expansion, Due to the lack of recognized universal standard, special for PLC applications. The IEEE standard has been adopted recently, its first standard for broadband communications on power lines. Electric power networks suffer from some of the technical challenges when used as a medium for the transfer of high-speed data, because its designed for power transmission and not for communications. “The biggest challenges faced in PLC are noise, attenuation, interference and security” [1]. Noise and distance are important factors that have a negative impact on the PLC. Noise is the total noise that is produced during the connection of various devices in the power outlet. Distance (D) is a key factor in increasing signal attenuation, it the major challenge in systems of communication [1]. The paper's aim is study the relationship between distance and data transfer rate as well as the stability of the PLC systems during transfer of data. There are four basic parts, which will be described in this paper in addition to the paper's original aim. Firstly, the background of PLC technology and its applications is described. Secondly, characteristics of electrical networks and coupling circuits in PLC systems are described. Thirdly, the modulation techniques of the PLC systems and Orthogonal Frequency Division Multiplexing (OFDM) modulation technique are described. Fourthly, the practical part is described. Finally,

https://doi.org/10.30684/etj.36.6A.4
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the relationship between the distance and the data transfer rate in addition to the described of PLC systems during data transfer are studied, through the results obtained, discussion, theoretical analysis and conclusions.

2. Background of PLC Technology

Communication via Power lines (PLC) is use power lines as a transmission medium for data communication. It is simply describes the use of power distribution wires to distribute power and data. That the idea of communication and data transfer during power distribution networks was not modern, in the year 1922 the first carrier frequency systems began to operate over high-voltage (HV) lines in the frequency range 15–500 kHz for telemetry applications. In the 1930s, ripple carrier signaling was introduced on the medium voltage (MV) and low voltage (LV) distribution systems [2], the development of this technology has continued until now, with increased demand for broadband multimedia services. Broadband over power-lines (BPL) services are high-speed Internet access via normal power lines. "In order to achieve high bandwidth levels, BPL operates at higher frequencies than traditional power line communications, typically in the range between 2 and 80 MHz"[3]. This means that high-speed Internet access to computers or to communications, equipment is available by connecting a BPL modem to any power outlet in the building equipped with BPL. PLC is operating by injecting and extracting the modulator carrier signal with the wiring system, Power line is considered the physical media for communications. Figure 1 shows general architecture and schematic for PLC which operates in BPL and Figure 2 shows how PLC operates in home network.

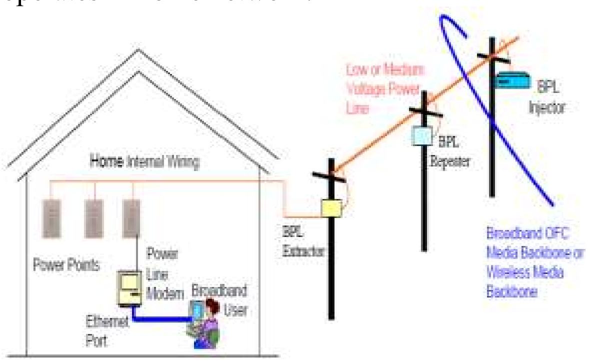

Figure 1: General architecture and schematic for PLC, which operates in BPL [3]

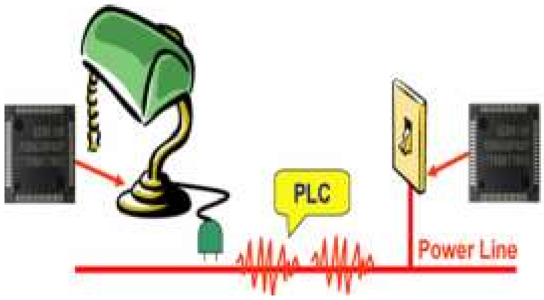

Figure 2: PLC operates in home network

There are three main types of PLC [4]

1 – Access PLC: - Uses power distribution lines, overhead wires or underground cables, to provide high-speed Internet and broadband applications for homes, offices, businesses and other of customers. It is in evolution stage currently.

2 - PLC In-building:- It's using the electrical wiring existing inside a buildings in networks communication. Most systems of PLC in buildings use Home-Plug standard from IEEE standards.

3 - PLC of control: - It is used by the transmission and distribution companies of electric power to control the use of power lines in the transmission of power, and it is operate at frequency below 500 kHz.

There are several advantages in PLC systems such, not need to new wires ,sharing Internet connection ,move your computer and appliances where you want, easy to install and use , secure data encryption, no coverage problems due to walls, not need to antennas, low cost and High speed with a long distance compare with local area network(LAN). In addition to advantages of PLC there are several disadvantages in PLC such as, noise, interference, attenuation, reflection, power loss and legal restrictions on frequency bands limit data rate.

There are two main of applications for PLC systems:

- Broadband Applications for PLC
  - a - PLC-based Local Area Networks (LAN)
  - b - Voice, Video and Multimedia
  - c - Internet Access
- Narrowband Applications for PLC:
  - a - Automation Homes and buildings.
  - b - Clean energy management.

3. Properties of Electrical Networks

PLC is the term used to describe the technology devoted to carry information by the power cable used to carry electric power. It is a very prominent technology because it allow easily create network to data transfer without needing a new cables where transmission of high frequency signal over the normal power line signal that work at 50Hz or 60 Hz. The use of power lines as a medium for data transfer is an attractive and competitive medium for high-speed communications, and communications are became available wherever power lines are available. The building of a home network communication using the electrical wiring available in the buildings easier than trying to rewire a private for communications, more secure and more reliable than wireless systems for communications, as well as relatively inexpensive. Power lines (PL) are designed primarily to transmission electricity from small number of generation sources to a large number of consumers. In fact, those towers and power lines are most robust in built structures [3]. In the electrical supply systems it is possible to distinguish three different networks levels that are used to transmission electrical power in order to distribute it to users as the homes, offices, companies and factories, and in added to indoor voltage systems, These different levels are:-

1- High- voltage networks (H.V):- These networks are for power transmission, ranging from (100-500) kV, and are not suitable for the transmission and exchange of information due to the presence of high electric field, coronal losses occur through discharge activities and this leads to energy losses.

2 - Medium Voltage networks (M.V):- These networks are used to deliver power to small cities and towns, and rural areas, the medium voltage is often transferred, about 10 to 30 kV, Only underground cables are used in overpopulated urban areas. With regard to communications, it is the backbone of (PLC).

3 - Low-Voltage networks (L.V):- These networks are used to distribution of the electrical power to homes or offices and other. This power supplying at (100 to 400) volts. It's different between countries 230/400 volt, or 120 volt, are more spread of other. Therefore PLC offers an alternative solution of the realization of the so called "last mile" access [4].

4 - Indoor voltage networks (I.V):- These systems that applied in power transmission within the premises [4], and can be considered complementary to the low-voltages networks, because (I.V) is the last part of the electrical system which up to consumers. That use of power lines for broadband applications within building , it was not fully utilized because of noise and the channel characteristics is hostile for high frequency signal propagation [5].

Figure 3 shows the levels of power lines (PL) and structure of electrical power supply.

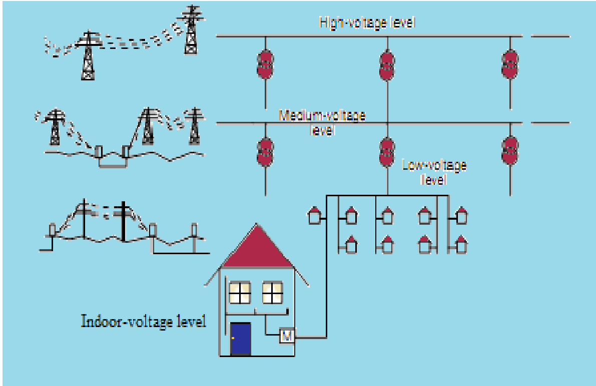

Figure 3: The levels of power line (PL) and structure of electrical power supply networks

Power lines networks (PLN) are the medium of data transmission in PLC systems, although their original design is to send electrical signals at 50 or 60 Hz and have not taken into account use their for data transfer for high frequencies, so must give an idea of the characteristics of electrical networks. Different devices connected to the electrical network receive electrical power from the distribution networks. These different devices have induction (L) and capacity (C) which depend on the current flowing in those circuits. Where an electric current (I) drives the magnetic flux (φ), the induction (L) can be defined by Eq. (1) [6]:-

$$L = \frac{\theta}{I} \quad (1)$$

In the AC circuits, when the voltage (V) and the frequency (f), it can define the induction (L) by the Eq. (2).

$$L = \frac{V}{j2\pi f I} \quad (2)$$

The capacitance is the stored energy, which originates between two adjacent conductors surfaces, with charging opposite, the capacitance can be defined in Eq. (3) where Q is a charge and V is a voltage

$$C = \frac{Q}{V} \quad (3)$$

Capacitance is defined in the case of (AC) voltage by Eq. (4).

$$C = \frac{I}{j2\pi f v} \quad (4)$$

The full opposition of current flow in AC can be measured by the impedance, which consists of three components are resistance (R), capacitance (C) and inductance (L). The impedance can be expressed in a complex form by Eq. (5):-

$$Z = R + jL2\pi f + \frac{1}{jc2\pi f} \quad (5)$$

In DC electrical circuits, the impedance is acting as of a pure resistance. In power distribution networks, the equipment are connected or turned off in the network. Therefore, the input impedance seen by the PLC devices, which connected to the network, is not fixed due to the change of load. This difference of input impedance is a challenge that impedes the development of power grids to transfer communications signals. In the case of loads in power distribution network do not correctly match with the cable impedance Properties, the reflections may occur from the loads on the cable. Reflections can be large depending on the load impedances, and can reduce the distance at which the signal is transmitted efficiently through electrical cables in PLC. Maximum signal received only when the impedance of all components (transmitter, power line, and receptor) is identical. One of the most important circuits in PLC systems is coupling circuits, which is used to connect the communication system to the power lines. It is a circuit protection interface and is located between power lines and modem circuits. It is the simplest unit, compared to other modem circuits and power line characteristics, communication channel challenges due to high voltage power lines, different resistance, high capacity and disturbances depended to time. This does not mean it is a simple but simple unit compared to the difficult characteristics of the PLC channel.

Purpose of the existence of coupling circuits is for two reasons:-

- First, they are filters for the low-frequency signal (50 or 60 Hz) used in the distribution of electrical power, and prevents their entry into communications equipment.
- Second, it certifies that the main part of the receiving / transmitting signal is within the frequency band used for communications. This increases the dynamic range of the receiver and ensures that the transmitter does not provide any interference signals on the channel.

Coupling circuits must be carefully designing in order to transfer of the required signal at the suitable bandwidth, an acceptable level of safety and according to the applicable standards, whether local or international, and must be successful to prevent the transmission of low frequency through the modems, and pass the high-frequency communication signal only. In order to be able to design an optimal coupling circuit, must choose the appropriate components and must be understand how it operated, there are types of coupling circuits, namely:-

1 - Coupling capacitors: It's widely used in communication via power lines.

2 - Coupling transformers: Its main task is to provide insulation and resistance to adaptation.

3 - Blocking inductors: It is designed to prevent saturation and prevent voltage drops.

- Resistors: “For power-line coupler circuits, in general, one strives to avoid using resistors, as a resistor, in essence, implies a loss of power, either of the communication signal or the power waveform”[7]. power wave form has low frequency and higher voltage level, therefore, first must be filter the low frequency before it enter the coupling transformer, must used LC high-pass filters and the inductive components are somewhat large when operating at low frequencies. To filter itself and remove some harmonic products that result from internal modulation, the RC type-high pass filter are used. Figure 4 illustrates Coupling transformers circuit, used to removing low frequency in power line.

4. Modulation Techniques in PLC Systems

Many modulation techniques have been studied to be suitable for communications over power lines (PLC). These modulation techniques are orthogonal frequency division multiplexing (OFDM), spread spectrum modulation (SSM), multi-carrier-code division multiple access (MC-CDMA), discrete multi-tone modulation (DMT), single carrier modulation (SCM) and quadrature amplitude modulation (QAM). OFDM system has been recognized extensively as an effective shift for wireless communications technology, uses extensively in the audio / digital video broadcast standards [6,8]. It is frequency domain approach to communications, and it has significant advantages when dealing with the nature of the selective frequency communication channels at higher data rate. Due to the increasing demand for high-speed data transmission, OFDM systems have emerged as a solution effective physical layer in their environment. The basic principle of OFDM modulation is sending the data in parallel with low-speed at multiple orthogonal sub-channels instead of sending data in sequential streams with high-speed. It is the most popular for the broadband segment. Most broadband systems are subject to multi-path and conventional solution for multi-path. The idea of transfer data in parallel is not recent, it is began in the 1950s, the first patent was in 1970, and its first applications have been implemented in military communications. Transfer of data at parallel allows to combat the inter-symbol interference (ISI) caused by multiple path delays. OFDM is a major candidate for broadband applications. In OFDM modulation technique, the frequency of the sub-carrier of each wave varies, and these frequencies were selected with an integer number of cycles in the symbol period [9], as shown in Figure 5 [10]. The orthogonal part of OFDM indicates, there is a precise mathematical relationship between the frequencies of the carriers in the system as appears in "Equation (6) which is illustrates orthogonal signals mathematically"[9]. The data is obtained by changing the amplitude or phase of each sub-carrier.

$$\int_0^T sin\frac{2\pi kt}{T}\sin\frac{-2\pi lt}{T}dt = 0, \quad k \neq 1 \qquad (6)$$

Both Discrete Fourier Transform (DFT) and Inverse Discrete Fourier Transform (IDFT) are the keys element of process in OFDM operation, implemented in practice by using Fast Fourier Transform (FFT) and inverse Fast Fourier Transform (IFFT) algorithm. The simple and efficient implementation of OFDM gives it an advantage over other multicarrier modulation schemes. Another important advantage of OFDM is it strength against multipath delay spread and resulting ISI [6] and it's efficient method in high speed data transfer, Figure 6 show block diagram of an OFDM system.

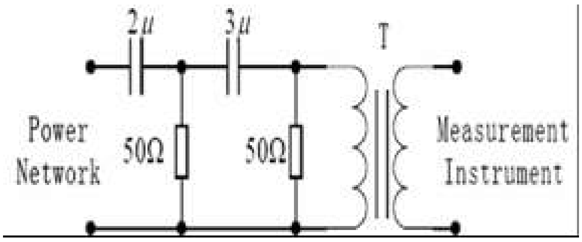

Figure 4: Shows Coupling transformers Circuit uses in plc[7]

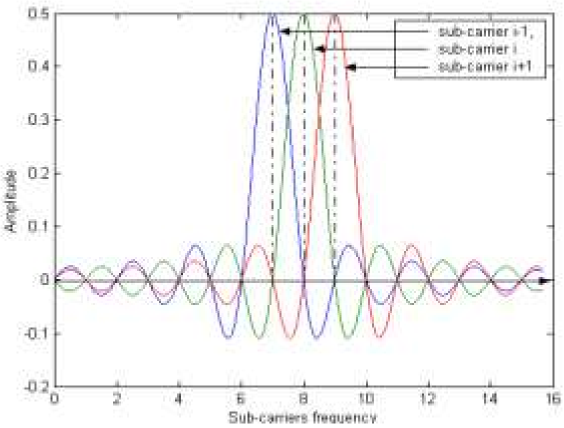

Figure 5: Three waves sub-carriers in orthogonal for OFDM technique [10]

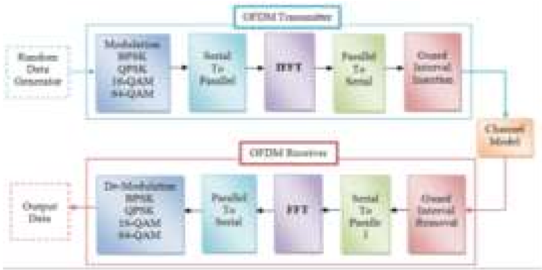

Figure 6: lock diagram of the OFDM system consists of transmitter, channel and receiver

5. Description of Practical System

For the purpose of testing the modems used in communications over power lines, the data transfer rate was measured at different distances, using the 100 m wire for the first time, the length of the wire 200 m used in the second time, used the wire length 300 m the third time, and the length of the wire 400 m used in the fourth time, two modems have been connected in sockets 1 and 2. In each test should be used at least two modems each time, as shown in Figure 7. Figure 8 shows the external shape of the modem used in these experiments, its Dlan modems, high-speed (devolo 200 Megabits per second (Mbps) AV mini starter kit)), and implements an OFDM technology. Figure 9 shows the image of the computers connected to the modem devices and shows the data transfer between them.

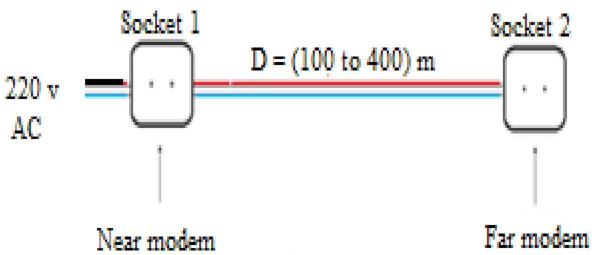

Figure 7: The practical scheme for connecting modems used two socket in tests

Figure 8: Is the external shape of one modem used in these tests

Figure 9: Practical connection of peer-to-peer PCs in PLC test

Figure 10 illustrates the transfer of data between two PCs, when modem 1 (bottom modem) is sender and modem 2 (top modem) is receiver in peer to peer connection. The transfer rate is 171 Mbps at a certain time before the data transfer rate reaches a stable state, which is 196 Mbps. Figure 11 illustrates the transfer of data between two PCs, when modem 2 (top modem) is sender and modem 1 (bottom modem) is receiver in peer to peer connection. The transfer rate is 168 Mbps, at a certain time before the data transfer rate reaches a stable state, which is 196 Mbps. The two cases mentioned in Figures 10 and 11,are shows transfer of data between two computers, fig 10 shows the data transfer when the near modem is (sender) and the far modem is (receiver) device, and Figure 11 shows the data transfer when the status is reversed to be the far modem is (sender) and the near modem is (receiver) device.

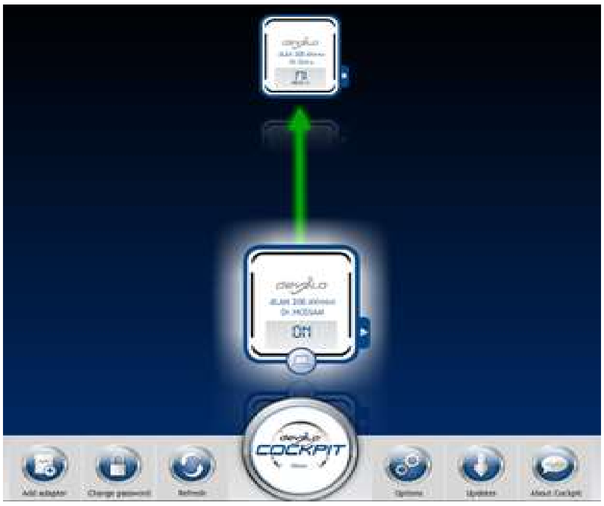

Figure 10: Transfer of data between bottom modem to top modem for two PCs

Figure 11: Transfer of data between top modem to bottom modem for two PCs

6. Results and Discussion

Through the results obtained as shown in Table 1, the data transfer rate decreases when the distance between the modems is increased in all cases, indicating that the relationship between them is inverse. Increased attenuation and decreased data transfer rate due to increased distance. As shown in Figures 12 and 13, where Figure12 illustrates the relationship between distance and data transfer rate when transfer actual data and Figure 13 shows the relationship between distance and data transfer rate when non-actual data transfer. Despite this correlation and the inverse relationship, the data transfer rate on power networks is consider a good transfer rate compared to the data transfer rate in cable allocated to LAN networks. The results also show that the data transfer rate is lower in the case of actual data transfer compared with the non-actual transfer rate as shown below in the data transfer rate calculation and stability. Equation (9) is applied to calculate the ratio of data transfer rate, which is the result of dividing the actual data transfer rate on the non-actual data transfer rate that using the results achieved as shown in Table 1 and Figures 12 and 13. Equation (10) is applied to calculate the stability ratio. This ratio is result of the actual data transfer rate when the modem started sending the data divided on the data transfer rate at the end of the test and the stability of the transfer rate, by using the results achieved as shown in Table 1 and Figure 12, and an increase in stability leads to a decrease in the bit error rate. Notes that there is a large difference between the actual data transfer rate and non-actual data transfer rate. Ratio of data transfer rate in actual to non-actual is from 39% to 46% when distance between the two modems are 100 m. In addition, ratio to be from 27.5% to 41.5% when distance between two modems are 400 m as shown below:-

$$\text{Ratio} = \frac{\text{actual data transfer rate}}{non \text{ actual data transfer rate}} * 100 \quad (7)$$

From table (1) and figures (12) and (13) At distance = 100 m

$\text{Ratio 1} = \frac{77}{196} * 100 = 0.39\%$

$\text{Ratio 2} = \frac{64}{138} * 100 = 0.46\%$

From table (1) and figures (12) and (13) At distance = 400 m

Ratio ١ $= \frac{27}{98} * 100 = 27.5\%$

$\text{Ratio 2} = \frac{25}{60} * 100 = 41.5\%$

And note that the actual transfer of data is more stable than in non-actual data transfer rate. The transfers ratio is 83% when the 100m distance. The ratio was approximately 93% when the distance of 400 m. The ratio is calculated by dividing the beginning of the data transfer to the end of the case stability (S) , as shown below:- From table (1) and figure (12)

$$\text{Ratio (S)} = \frac{\text{beginning of the data transfer}}{\text{stability of the data transfer}} * 100 \quad (8)$$

$\text{Stability 1} = \frac{64}{77} * 100 = 83\%$ at D = 100 m

$\text{Stability 2} = \frac{42}{53} * 100 = 79\%$ at D = 200 m

$\text{Stability 3} = \frac{35}{42} * 100 = 83\%$ at D = 300 m

$\text{Stability 4} = \frac{25}{27} * 100 = 93\%$ at D = 400 m

$\text{Average stability} = \frac{0.83+0.79+0.83+0.93}{4} = 0.845$

Table (1) Results obtained during the data transfer rate on the transmission network with different distances illustrates effect of data transfer rate with distance

Distance between modems	Without actual data Transfer rate	With actual date transfer rate
100 m	(138 → 196) Mbps	→ 77) (64
200 m	(81 → 152) Mbps	Mbps (42 → 53)
300 m	(70 → 126) Mbps	Mbps (35 → 42)
400 m	(60 → 98) Mbps	Mbps (25 → 27) Mbps

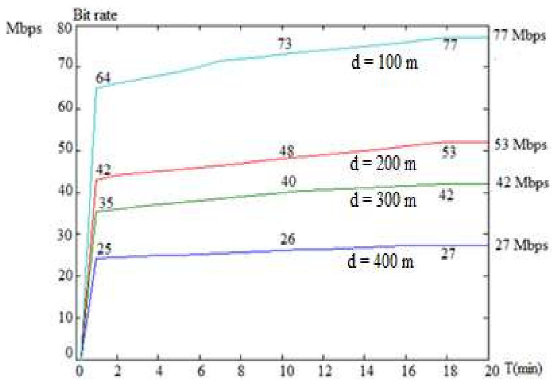

Figure 12: The relation between distance and data transfer rate in PLC with actual transfer rate

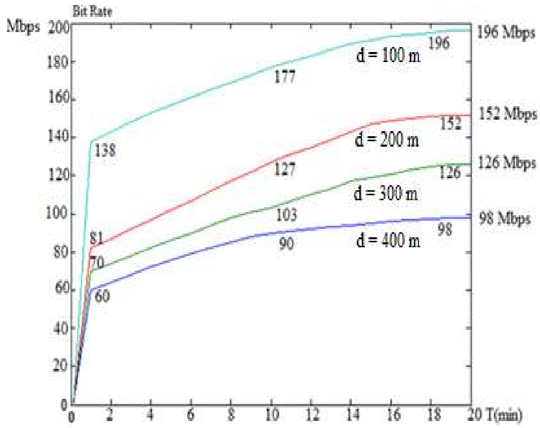

Figure 13: the relation between distance and data transfer rate in PLC without actual transfer rate

7. Theoretical Analysis

Through the results obtained show that the data transfer rate decreases with increasing distance due to increased attenuation and vice versa, where data transfer is increased by reducing the distance between sender and receiver . Equations 9 and 10 show the relationship between energy and distance, at the best and worst channel cases., where (p) is the power transmitted, (s) is received signal powers and (d) is the distance between sender and receiver. It's possible to avoid attenuation by increase the transmitted power.

$s = \text{P} * 10^{-0.004*\text{d}}$ watt at best (d) (9)

$s = \text{P} * 10^{-0.010*\text{d}}$ watt at wrost (d) (10)

8. Conclusions

This paper discusses the relationship between the distance and data transfer rate in the modems used in communications over power lines, which are used in the transmission and exchange of information between at least two sides. Two of these devices have been used for testing. Through the practical test of these devices connected to the power line from the port and computers from another port, the inverse relation between the distance and data transfer rate was verified. It was also found that the actual data transmission is less than the non-actual transport but the stability is better when transferring the actual information. These modems can be used to transfer and exchange information on more than two sides and have been proven to be highly efficient and can be implemented in place of normal local area networks (LAN) after further practical testing to ascertain other factors affecting on data transfer rate and efficiency of communications system, such as the number of nodes in the network and the number of branches in one node and the other factors.

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