

# Building Energy Management System Using Powerline Communication

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**Abstract**— Energy conservation is an important aspect in today's scenario. Many systems have been developed in order to capitalize the energy consumption and conserve the energy, so that the control over energy consumption can be greatly achieved. There are various costs associated with the mismanagement of energy in commercial buildings. Even with renewable energy sources for electricity, prices rarely decrease. The increasing availability and affordability of wireless building and home automation networks has increased interest in residential and commercial building energy management. This interest has been coupled with an increased awareness of the environmental impact of energy generation and usage. Although building-level automation has been around for more than 40 years, there is renewed interest in automation for residential and commercial sites, especially around smart buildings and a smart grid. Power line communication (PLC) is today a viable technology for both low speed and high speed networking. Hence, the aim of the project is implementing building automation system using Power Line Communication. This report describes the introduction to LonWorks networks and power line communication and power line communication protocols and comparison among different power line modules, the need and importance of power line communication testing followed by simple network development for monitoring and controlling the energy usage in Building Energy Management System.

**Index Terms**— Building Automation, iLON SmartServer, LONWorks Technology, Neuron Processor, Powerline Communication, Remote Control , Web Monitoring

## 1 INTRODUCTION

Building owners need to meet constantly evolving energy standards and need to be perceived as green and that also greatly increases interest in automation [1]. More intelligent buildings attract more customers. This eventually increases competition to move towards a more energy efficient building which does less harm to the surrounding environment. The words “renewed interest” are significant, as most automation systems in the early 1990s were installed to replace aging pneumatic systems and were mostly justified on maintenance and energy savings. These original direct digital control systems are still operating, but they need to be upgraded and made web-accessible and open-protocol-friendly, while moving toward continuous commissioning. The energy Internet can rapidly interact with the supply grid. Hence, supply and demand can talk and cooperate. Therefore powerline communication is suitable for building automation to achieve faster information exchange between supply and demand. We can achieve action and reaction in real time without manual intervention. When this is coupled with real-time pricing and automated demand response (ADR) requests, we can achieve great changes within our existing electrical infrastructure. This paper is divided into five sections starting with an introduction to LonWorks networks for open protocol systems. The next section describes the role of power line communication protocols followed by its importance in the network development for building energy management. The final section describes web monitoring and control of powerline nodes followed by the conclusion.

## 2 LONWORKS TECHNOLOGY

The underlying concept of the LONWORKS platform is that the information in a sensing, monitoring, or control application is fundamentally the same across markets and industries [2]. In many ways, a LONWORKS network resembles a traditional data network. Data networks consist of computers attached to various communications media, connected by routers, which communicate with one another using a common protocol such as TCP/IP. Data networks are optimized for moving large amounts of data, and the design of data network protocols assumes that occasional delays in data delivery and response are acceptable. Even though data networks are based on open protocols, most manufacturers do not choose to develop their own data networking components such as transceivers, routers, and network operating systems—it is typically more cost effective to buy these components from a reliable supplier. Control networks contain similar components to data networks, but the control network components are optimized for the cost, performance, size, and response requirements of control. Control networks allow networked systems to extend into a class of applications where data networking technology is not appropriate. Manufacturers of control systems and devices are able to shorten their development and engineering time by designing LONWORKS components into their products. LONWORKS networks range in sophistication from small networks embedded in machines to large networks with thousands of devices controlling fusion lasers, paper manufacturing machines, energy management and building automation systems. LONWORKS networks are used in buildings, trains, airplanes, factories, and hundreds of other processes. Manufacturers are using open, off-the-shelf chips, operating systems, and parts to build products that feature improved reliability, flexibility, system cost, and performance.

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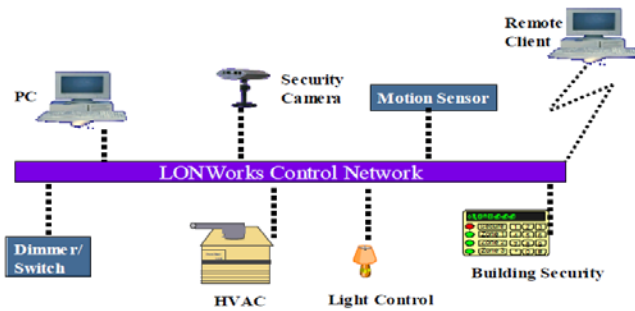


Fig. 1 LONWorks Control Network

The LonWorks protocol provides services at each layer of the OSI seven layer reference model. The protocol is open for anyone to implement, and a reference implementation in the C programming language. Since its invention, the protocol has become an ANSI standard, an IEC standard, a Chinese national standard, and recently has achieved ISO standardization. The services of LonWorks at different layers of the OSI model are explained below [3]:

- **Layer 1: Physical Layer:** Multiple physical links are supported such as RS-485, free topology, wireless, powerline communication.
- **Layer 2: Link Layer – MAC Algorithm and Bit Encoding:** The LonWorks protocol provides an innovative independent media access control (MAC) layer based on improvements made to the Carrier Sense Multiple Access (CSMA) family after Ethernet was standardized. The MAC layer combines two concepts: p-persistent CSMA and non-persistent CSMA. Beside the MAC algorithm, Layer 2 provides bit encoding and a 16-bit cyclic redundancy check (CRC).
- **Layer 3: Network Layer:** The Network Layer provides addressing. In the LonWorks protocol, addressing is hierarchical, starting with the node's domain and followed by its subnet and identification number, each expressed in eight bits. Alternatively, a node may have membership in multiple multicast groups, with each group address encoded as a single byte.
- **Layer 4: Transport Layer:** The Transport product protocol layer is where packet retransmission and duplicate detection is handled. When the station sends a packet, it specifies whether the packet is sent using unreliable or reliable services.
- **Layer 5: Session Layer:** The Session Layer is where request response services are handled. Besides sending a response, the protocol saves it, so that if a retry comes along, the response can be resent without the application needing to re-compute and re-transmit.
- **Layer 6: Presentation Layer:** The Presentation Layer header encodes the semantics of data passed in the Application Layer. It also carries the identifier of data items.
- **Layer 7: Application Layer:** The Application Layer provides data called network variables. Network variables are application

specific data types that contain semantics beyond float, integer, and Boolean. It supports a standard way to upgrade node software, so the system can evolve in response to changing needs.

### 3 POWERLINE COMMUNICATION

Power line communication (PLC) carries data on a conductor that is also used simultaneously for AC electric power transmission or electric power distribution to consumers [4]. Typically transformers prevent propagating the signal, which requires multiple technologies to form very large networks. Various data rates and frequencies are used in different situations. Power Line Communication (PLC) is a viable technology which enables sending data over existing power cables. This means that we can both power up and control/retrieve data from a device in a half-duplex manner with just the power cables. Up until recently special wiring such as twisted pairs, coaxial and fibre optic was used in most home and building automation. Recent technological developments have enabled the emergence of devices that utilize the power line to send and receive control signals with some degree of reliability. Power line communication mainly classified into two categories Narrow band and Broad band. Narrow-band PLC works at lower frequencies (3-500 kHz), lower data rates (up to 100s of kbps), and has longer range (up to several kilometers), which can be extended using repeaters. Broadband PLC works at higher frequencies (1.8-250 MHz), high data rates (up to 100s of Mbps) and is used in shorter-range applications. Recently, narrow-band Power Line Communication has been receiving widespread attention due to its applications in the Smart Grid. Power lines are a hostile environment and are not designed for data transmission use that makes the accurate propagation of communication signals difficult. Noise levels and disturbances are often excessive, and cable attenuation at the frequencies of interest is often very large. Important channel parameters such as impedance and attenuation are time varying in unpredictable ways. PLC is considered an attractive system because it can reach more homes than coaxial cable systems or telephone lines. The Power Line has been extensively studied as the media for high frequency signal transmission for use as a communications environment.

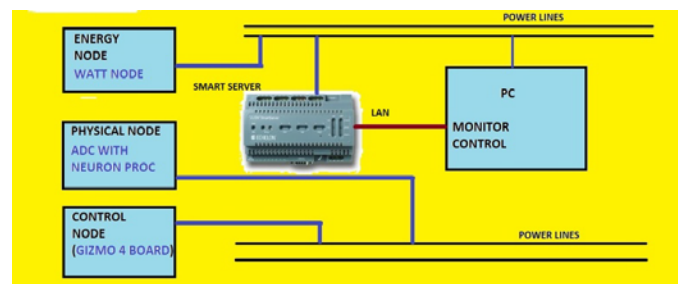


Fig. 2 Powerline network

#### Features of PLC

Unfortunately, there are some problems that have to be overcome and some aspects that have to be taken into account to realize a successful data communication. They are listed in the following:

1. **Minimum-security levels:** Data transmission over power lines

happens over a public/shared medium (the power line) thus, the information that is being exchanged is available anywhere in that medium within a certain distance and to everyone.

**2. Signal attenuation:** The signal attenuation for low voltage networks is around 100 dB/Km which leads to a need for repeaters to be plugged in at desirables weak areas. The main factors leading to signal attenuation are:

- Time dependence.
- Frequency dependence.
- Distance dependence.
- Difference between phases

**3. High costs of residential appliances:** the cost of a power line network modem is not always competitive with the cost of a standard modem used to connect to a phone line network.

**4. Noise:** the greater amount of electrical noise on the line limits practical transmission speed.

Electric Apparatus	Amplitude (mV)		Duration (µs)	
	Average Value	Standard Deviation	Average Value	Standard Deviation
(Single pulse)				
Electric Oven	329.2	431.2	1015.8	505.2
Iron	369.3	585.8	760.2	347.9
(Periodic pulses)				
Television monitor	197.2	311.3	722.4	34.3
Light dimmer	670.8	1199.3	140	7.5
(Continuous pulses)				
Vacuum cleaner	1457.5	2155.5	Always	---
Dryer	87.9	119.7	105.3	56

Fig. 3 Noise from appliances [5]

**5. Lack of global standards:** there are several different standards for power line communication, and the development of a global standard for distributing data over existing in-home power line systems does not seem to be the trend of the international market. Various standards available (limited to their regions) such CENELEC, FCC, IEEE and IEC govern data transmission over power lines.

#### 4 BUILDING ENERGY MANAGEMENT SYSTEM

A smart home is an apartment or a building that is equipped with a number of intelligent electronic devices in order to increase energy efficiency, comfort, flexibility, and security. Home networks power-line technology can control anything that plugs into an outlet, including lights, televisions, thermostats, alarms, home energy modules and so on. If there is the availability of multiple power outlets in every room, the home power line infrastructure represents an excellent network to share data among intelligent devices, also with high data transfer rate, up to a few hundreds of Mbps (mega bit per second). Power-line networking is one of several ways to connect the computer in our home. It uses the electrical wiring in our house to create a network. Like LonWorks, power-line networking is based on the concept of "no new wires." The convenience is even more obvious in this case because while not every room has a phone jack, we will always have an electrical outlet near a computer. In power-line networking, we can connect our computers to one another through

the same outlet. Because it requires no new wiring, and the network adds no cost to our electricity bill, power-line networking is the cheapest method of connecting computers in different rooms. We can connect the power line modules as well as twisted pair nodes in the power line by using a power line router which is shown below.

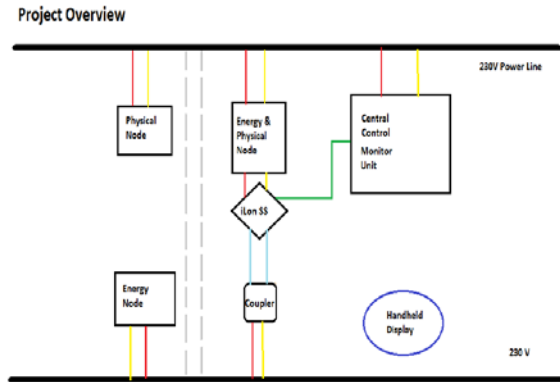


FIG. 4 BLOCK DIAGRAM REPRESENTATION OF SYSTEM

#### 5 CONTROL AND WEB MONITORING OF PL NODES

For the building automation system we used an energy node, a physical node, a Gizmo 4 board for control purpose and an iLON smart server for web monitoring. We used a commercially available energy node used for measuring the various electrical parameters of a household circuit. We developed the physical node which is capable of measuring 8 parameters like room temperature, light level, smoke level etc with the help of PL 3150 evaluation board which consist a neuron processor [6]. The block diagram of the physical node consists of a custom neuron board, signal conditioning board (ADC), display board, power supply and 4-20mA input current/voltage which is normally used in industrial sensors. SPI interface is used to connect the signal conditioning and the neuron board.

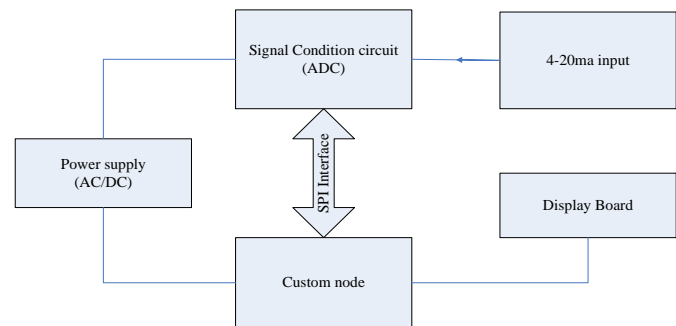


Fig.5 Physical Node Gizmo 4 Board

We used the gizmo 4 board made by Echelon for controlling the different analog and digital I/O signals [7]. The Gizmo 4 board consists the following:

- 4 row x 20 character LCD display
- 2 10-bit resolution analog inputs with screw terminal connector
- 2 8-bit resolution analog outputs with screw terminal connector



- 2 digital inputs with screw terminal connector and pushbutton
- 2 digital outputs with screw terminal connector and LED outputs
- Digital shaft encoder (quadrature encoder)
- Piezoelectric speaker
- Real-time clock
- Temperature sensor

System integration needs four different tasks to implement network control system [8]:

**System Design:** System design consists of two steps:

- Selection of LonWorks devices that incorporate the necessary I/O points and that have application programs suitable for implementing the necessary control functions such as PID loops and scheduling.
- Determination of the appropriate types and numbers of channels and then selection of routers to connect them.

**Network Configuration:** Network configuration includes the following steps:

- Assigning domain ID and logical addresses to all devices and groups of devices
- Binding the network variables to create logical connections between devices.
- Configuring the various LonWorks protocol parameters in each device for the desired features and performance, including channel bit rate, acknowledgement, authentication and priority service.

**Application Configuration:** Application configuration is the process by which the application program in each device is tailored to the desired functionality.

**Installation:** Installation consists of the following:

- Installing the physical communication media for the channels.
- Attaching the LonWorks devices, including routers to the channels.
- Attaching legacy I/O points to the LonWorks devices.
- Using a network integration tool to download the network configuration data and application configuration data to each device which is known as commissioning a device.

We used the **LonMaker** for Windows network integration tool to achieve the system integration [9]. This system is designed in a network drawing in the integration tool. A network drawing displays all the devices that are present in a network which share a common mode of communication. By this drawing we ensure that all the devices are commissioned to communicate with each other over power lines.

Fig.6 PL Network drawing

In this integration tool, we were able to monitor the different electrical parameters as well as the output for the developed physical node. Temperature sensor, light level sensor and humidity sensor are connected to the physical node. This node gives the environmental parameters of the room. With the help of **gizmo 4 board**, we developed a simple control mechanism for the ambient room condition using Neuron C language and loaded the code with the LonMaker tool [10]. The control mechanism controls the basic output devices and shows the status of the room. The room temperature is measured by the temperature sensor present in the gizmo board. If the room temperature is above the ambient level an alarm turns on which is indicated by turning on the LED and buzzer on the board. This alarm updates the variable for fan control which in turn switches on the fan which results in bringing the temperature level to normal condition. Similarly, a simple mechanism was built to get the occupancy status of the room. The two push buttons in the gizmo board are connected to switches present both inside and outside of the room. When the switch present outside the room is pressed the occupancy state of the room is incremented and if the switch is pressed inside the room the value is decremented. It is analogous to opening the door from outside and inside. The above stated method is effective only if we assume that a single person enters or leaves the room while pushing the switch. When the switch is pressed a time stamp is updated which is related to any activity involving the room. The timer is designed to turn on the Air Conditioner depending on the occupancy status of the room. Moreover, a delay is added for the AC control so as to minimize the turn on/off losses for the air conditioner. Finally we used the iLON smart server for web monitoring, logging and control of the different parameters.

### iLON SmartServer

The role of **iLON SmartServer** is to monitor the data over internet [11]. The SmartServer can be linked to the network drawing as well as other smart servers and plays a big role in overall management of the devices in a building. The SmartServer includes built-in applications for alarming, scheduling, logging, translating, and performing arithmetic, logical and statistical functions on data types. It also includes a Web binder for bridging multiple LONWORKS domains. The SmartServer also includes built-in I/O for reading pulse meters and digital inputs, and for switching local loads. All data points and built-in I/O are accessible through either the LONWORKS or Web interfaces.

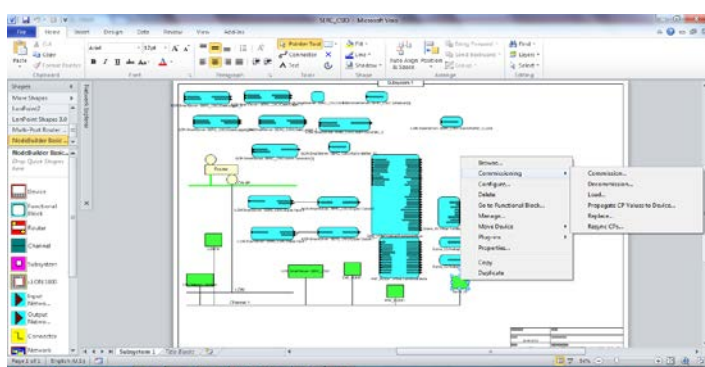


Fig.7 Network setup

We used the SmartServer in building automation for the following:

- **Scheduling of tasks related to automation:** Scheduling of digital outputs, data loggers
- **Exterior and interior lighting control:** Lighting control is achieved by linking the digital outputs of the SmartServer to lighting switches. The exterior lighting is controlled according to the real time scheduler for sunset and sunrise. Interior lighting is controlled according to the room status or daily routine.
- **Logging of data from different nodes:** Logging of data from energy and physical nodes for analysis and report generation. Based on the logged data, we can interpret the average energy consumption per load and patterns of routines of different workers which helps in better usage of electric power and scheduling of light and fans.
- **Alarm generation based on activity:** Alarm generation based on different nodes for emergency conditions and informing the operator to take actions accordingly.

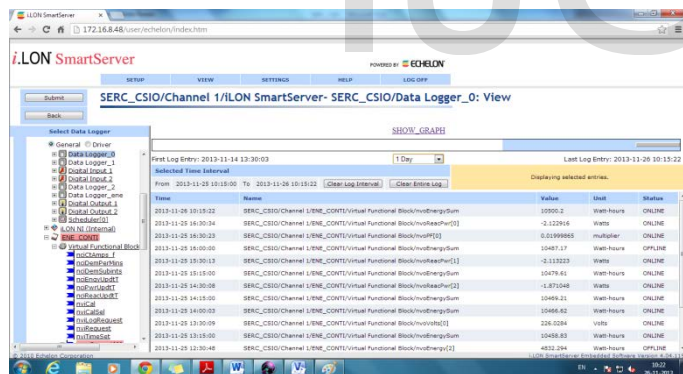


Fig.8 Logged data for lamp control

The following table illustrates the example of lamp load connected to the energy node. The energy data for the load was logged over a turn on/off cycle of 4 hours with data being logged in every 15 minutes for a period of 1 month.

Table 1

Logged Energy values for 100W load at an interval of 15 minutes

DATE - TIME	ENERGY VALUE LOGGED	CONSUMPTION WATT-HOURS
2013-10-29 T15:45:01.290	8426.055	00.000
2013-10-29 T16:00:03.170	8495.823	69.768

2013-10-29 T16:15:00.350	8564.854	69.031
2013-10-29 T16:30:03.120	8634.3	69.446
2013-10-29 T16:45:01.420	8703.711	69.411
2013-10-29 T17:00:08.970	8773.456	69.745
2013-10-29 T17:15:00.530	8773.456	00.000
2013-10-30 T14:15:51.090	8828.291	54.835
2013-10-30 T14:30:36.990	8896.479	69.188
2013-10-30 T14:45:33.700	8965.035	68.556
2013-10-30 T15:00:36.200	9034.395	69.360
2013-10-30 T15:15:51.360	9098.008	53.513
2013-10-30 T15:30:08.350	9169.973	71.965
2013-10-30 T15:45:00.420	9238.115	68.142
2013-10-30 T16:00:03.230	9307.235	69.120

**Calculations:**

Considering 3- Phase power supply for the lamp load:

**Theoretical**

Average Phase Voltage = 240 V  
Average Load Current = 0.40 A  
Average Energy Consumption = 288 W Hr

**Experimental**

Average Phase Voltage = 225.926 V  
Average Load Current = 0.41 A  
Average Energy Consumption = 277.88 W Hr

15 Minutes Scheduled Lamp load energy consumption = 0.07 kW-Hr

**Assumption:**

A minimum of 10 rooms per building with a single lamp load  
Energy Saved for a period of 15 minutes = 0.7 kW-Hr  
Let average cost per unit energy consumed = INR 3  
Money saved on just efficient scheduling of bulb = INR 756/ year

The above value corresponds to the savings generated by controlling a 100W bulb. The control can be applied to heavier loads such as AC, television sets and refridgerators which will improve the efficiency of home energy management. By the data we got we can conclude that switching of the lights according to scheduler as well as the automatic control of the room air conditioner by the help of occupancy status of the room produced a significant reduction in the power usage of the building. A small setup for control is shown in Fig. 7 which controls the room lighting and fan and also gives the

occupancy status of the room.

### Web Monitoring

Although web monitoring is possible with the iLON SmartServer, it gives the user more information than he needs. Hence there is a need for a custom web page which allows us to monitor and control the devices. A custom web page was created using **iLON Vision** so as to monitor and control the various parameters from the internet. iLON vision is used to create custom Web pages for monitoring and controlling the data points on the SmartServer [12]. With the help of smart server we were able to link all the parameters and control switches to a common page. The software gives an easy link up between the SmartServer variables and images to publish on internet.



Fig.9 Custom webpage built with iLON vision

## 6 CONCLUSION

In this paper the importance of power line communication in building energy management system is discussed. The development and application of different powerline nodes is mentioned. The paper also discusses simple control mechanisms opted in building automation system so as to increase the energy efficiency of the building. Web monitoring of the above mentioned powerline nodes is done. Finally, a prototype for building automation using powerline communication is developed.

## ACKNOWLEDGMENT

We thank director CSIR-CSIO Chandigarh, for providing the infrastructures, facilities and encouragement to work in this area of powerline communication technology. This research was supported by CSIR network projects. We also thank the members of CSIR-CSIO Chennai for the help and support to set up the model for the project.

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