ENERGY MANAGEMENT SYSTEM FOR EDUCATIONAL BUILDINGS USING NARROW BAND POWER LINE COMMUNICATIONS BASED ON THE PRIME STANDARD

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ABSTRACT: *The premise of this study is to save energy in educational buildings where a periodic time schedule per room is being implemented. Class schedules at De La Salle University is mostly one and a half (1 ½) hours, although there are classes scheduled for two hours, one hour, or three hours. It has been observed by the proponents that rooms that are not occupied, either because there is no scheduled class for that time period or the faculty called off the class, had its appliances left turned ON. To determine the actual power being wasted, a kW-hr meter was connected to monitor two rooms containing thirty (30) fluorescent lamps, 2 aircondtioners, and 2 electric fans. If the appliances are turned off during no class periods, the energy that would have been consumed for the one academic term comprising three months would only total 2089.7 kWhrs, however, the actual total energy consumed for one term was 2736.2 kWhrs. This gives a difference of 646.5 kWhrs that translates to an energy wastage of 26.79%. The Energy Management System developed in this study reduces this wastage by automatically turning off appliances in the room that has no scheduled class. The system can also turn off the appliances in rooms with scheduled classes but are vacant due to free cuts. This is done by installing motion sensors inside the room.*

The Energy Management System (EMS) comprises a host PC, PLC modems, motion sensors, and appliance controllers. The host PC contains the class schedules and through a Graphical User Interface (GUI) the host PC sends control signals to the appliance controllers in each room via TMDSPLCKIT-V3 PLC modems. The GUI is implemented using MATLAB. The PLC modem uses narrowband PLC PRIME standard. Three GPIO pins of the modem are used to control the appliances through relays. The motion sensor detects movements in the room and sends the information to the host PC which is the central controller of the system.

The EMS developed contains three service nodes to represent three rooms and is deployed in an actual educational in-building wiring system. For all the tests conducted, it gave an impressive reliability percentage of 100%.

Key Words: – energy management system, EMS, PRIME, power line communications, PLC, TMDSPLCKIT-V3, GUI, NBPLC

1. BACKGROUND OF THE STUDY

An Energy Management System (EMS) is a structured approach designed to control energy usage and reduce energy being used [1]. It is the process of monitoring, controlling, and reducing energy consumption in a building or organization [2]. It is suitable in any types of establishments, regardless of its size, and is really beneficial for those which uses high-energy processes. The installation cost will be quite expensive, but the energy costs that the organization pays yearly will be reduced [3].

Narrowband Power Line Communication (N-PLC) is a communication technology that uses the power line as a medium; it typically operates at frequencies up to 500 KHz. European CENELEC standard uses frequency of 148.5 KHz or less for N-PLC systems. In the CENELEC frequency range the data rates are quite modest, from 1-100Kbps which is already ideal for telemetry and control applications [4]. N-PLC mostly uses single carrier modulation, like Amplitude-Shift Keying (ASK), Frequency-Shift Keying (FSK) and Phase-Shift Keying (PSK). Another modulation scheme being used in N-PLC is Spread Spectrum Modulation (SS) where the original narrowband information is spread at a wider band of frequencies. One other modulation scheme that is of multiple carriers kind is Orthogonal Frequency Division Multiplexing (OFDM) where data is split at different frequencies called subcarriers and is transmitted [5].

Powerline Intelligent Metering Evolution (PRIME) Standard is a power line communications solution operating in the CENELEC-A band which is from 3kHz to 95kHz [6]. Within this band, PRIME operates from 42kHz to 89kHz using orthogonal frequency division multiplexing (OFDM) as the modulation technique. The signal is transmitted using 97 subcarriers; 96 for data and one pilot. The standard uses differential phase shift keying of three possible constellations: DBPSK, DQPSK, and D8PSK. This offers theoretical uncoded bitrates of 47kbps, 94kbps and 141 kbps respectively.

2. Energy Management System Components

The optimized energy management system (EMS) is designed to conserve energy for educational buildings. Energy conservation is done by turning on or off the power to the lights, fans and airconditioning unit (ACU) in classrooms through a bidirectional powerline network.

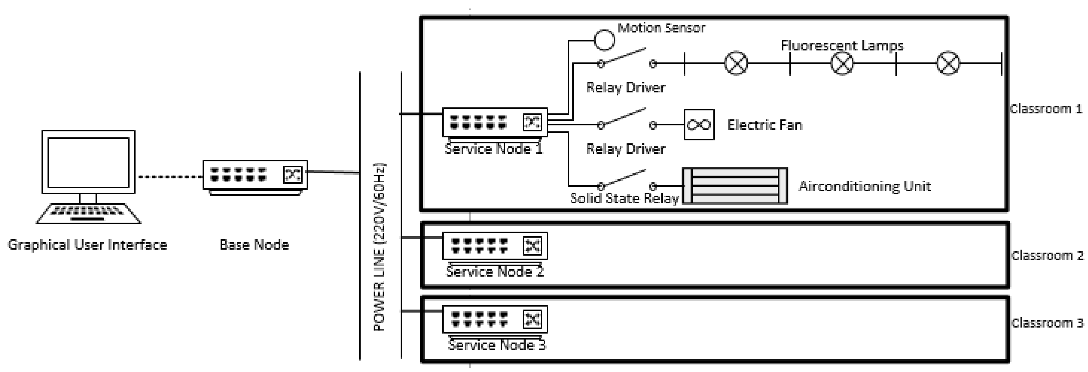

Figure 1. Block diagram of the EMS

The said system has three main components namely the host PC with the designed graphical user interface (GUI), the PLC Modems, and the appliance controllers. The GUI was developed using Matlab and through it the user can view and modify the class schedules. For the PLC Modems, one modem was configured as a base node while three were service nodes wherein each service nodes is assigned to a specific classroom. Appliance controllers on the other hand include the relays responsible in driving the appliances on or off.

As illustrated in Figure 1, the host pc was directly connected to the base node through a USB/JTAG cable. The base node was connected to the service nodes via the common power line (220V/60Hz). Two I/O pins of the service node modem were connected to three relays; one for the five fluorescent lamps, one for the electric fan and one solid state relay for the air conditioning unit. Since the lights and fans were used together in typical classroom setup in DLSU, they were triggered by only one I/O pin. A motion sensor was also connected to another I/O pin of the modem to detect the presence of people inside the classroom.

2.1 GRAPHICAL USER INTEFACE

The GUI is the one that controls the system. It is where the commands come from. It sends a command to the modem to turn on or off an appliance, to start checking whether there are people using the room, and to tell the status of the room, whether it is being used or not. The commands that are being sent by the GUI depend on the schedule of that specific room in the GUI. In the GUI, the user can set the COM Port number where the modem is connected, edit the schedule of each room from Monday to Sunday where each day has 12 slots that the user can insert a schedule, enable or disable the room, enable or disable a specific time slot, rename the rooms and building name, lock the status of a specific time slot so that those who are not authorized or does not have admin function cannot make any alterations.

The color of the room push buttons also changes depending on the status of the room and whether the acknowledgement coming from the modem is correct after sending a command. It will be green if the room is not being used and the acknowledgement was received, red if the room is being used and the acknowledgement was received, gray if the room is disabled, and orange if after sending the command, there was no acknowledgement received after ten tries.

Handshaking, an automated process of negotiation in communications, was used for the acknowledgement. Every time the GUI sends a command to the modem, it will wait for an acknowledgement first before sending the next command. By using this process, a more reliable communication is made between the two modems.

The GUI sends a command to the base node modem to turn ON the airconditioner ten (10) minutes before the start of class to give time for it to cool the room. At the start of the class time, the GUI sends a command to the modem to turn ON the lightings and fans. After thirty (30) minutes, the GUI tells the modem to start checking the status of the room by sending the status of the motion sensor. If the motion detector does not sense any movement, the GUI prompts the modem to turn off all the appliances in the room, else it will do nothing. After the class period, the GUI checks if there is a next class. If there is and the time difference from the immediately prior class is more than 30 minutes, the command to turn off all the appliance is sent. If the difference is less than 30 minutes, only the lights and fans are turned off. Airconditioners should not be tured ON immediately after turning it OFF to avoid damaging it.

2.2 Power Line Network

The power line network has two main components: a Base Node and a Service Node. Both are based on the C2000 Power Line Modem Developer's Kit, differing primarily in the firmware and the driven I/O ports. A simplified diagram is shown in the figure below.

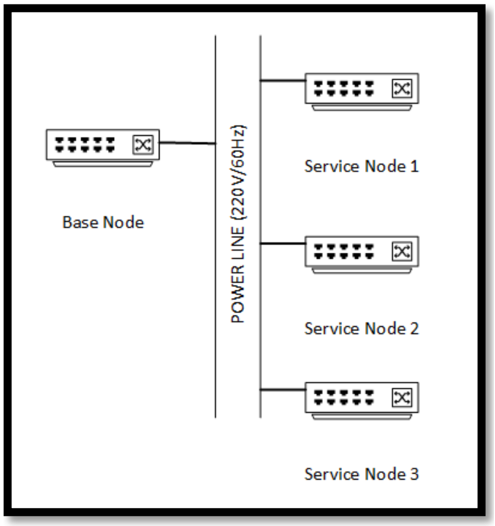

Figure 2. Implemented power line network

The Base Node has two primary functions, namely maintain communication with the host PC and maintain the power line network of Service Nodes. It receives commands to switch appliances on and off for particular classrooms from the host PC using a USB/JTAG interface. Upon reception of a command, it injects a packet for Service Nodes to receive, indicating a packet type (command), source and destination address and the command itself. After transmission, the Base Node then listens over the powerline for a reply.

The Service Nodes listen over the powerline for transmitted packets. Upon reception of one, each checks the destination address against its own. If they match, the command is executed, else, the packet is discarded. After execution, a reply packet is injected in the line, with the source address as its own and the destination address as that of the Base Node.

If the Base Node receives the reply packet, it reports successful transmission to the host PC. If it does not receive a reply after a short period, it retransmits until it either receives a packet or maxes out its counter, which is set to ten, i.e. a maximum of ten retransmissions before transmission is declared a failure.

2.3 Appliance Controllers

The hardware interfaces between the modem and the appliances include, a PIR motion sensor, relay card, solid state relay (SSR) and driver, and the power supply for these electronic circuits.

The PIR motion sensor is used to detect movement inside the classroom. No movement detected (logic low) suggests a free cut, therefore the lights, fans and air conditioner must be turned off. A movement detected (logic high) implies that the room is in use, therefore the lights, fans, and air conditioner must remain on.

The relay card and SSR were used as switches. The relay card is the switch that turns on or off the lights and fans. The relay card receives the command from the modem, when it receives logic high it turns on the connected appliance, and turns the appliances off when it receives a logic low. The SSR and its driver circuit was used turn on and off the air conditioner. A SSR was used since it can handle the high current needed to power up and run the air conditioner. The SSR's driver receives the signal from the modem, like the relay card, it turns on the air conditioner when the driver receives logic high, and turns it off when it receive logic low.

The power supply is the one that supply voltage to the PIR motion sensor, relay card and SSR and its driver. The power supply outputs 12VDC, 5VDC and 2VDC. The 12V is needed for the PIR motion sensor, relay card and SSR. The other voltages are needed for the driver circuit.

3. DATA AND RESULTS

One of the vital elements in this system is the PLC modem. Instead of installing new wires, the power lines are utilized as the communications medium. However, there is a need to separate the low voltage control signal from the damaging high voltage (220V) 60 Hz electrical energy. Before putting together all the components of the EMS, the modem is first characterized. Then the whole system is constructed and implemented in an actual building wiring installation.

3.1 Modem Characterization

The parameters measured in the characterization of the modem are the signal to noise ratio (SNR) and the received signal level (RSL). One of the modems is configured as a transmitter while the other modem is configured as the receiver. The test set-up is shown in Figures 3 and 4. They are practically the same except the distance between the receiver, Rx, and the transmitter, Tx. For each of the test set-up, the transmitter sends a signal to the receiver for three times and the corresponding SNR and RSL are averaged. This is done for various modulation techniques that include DQPSK and D8PSK + FEC.

After conducting the tests for the SNR and RSL, the data obtained were varying on each one of the tests even when the modulation scheme is being altered as illustrated in Figures 5 and 6; however it was observed that the lowest possible RSL acquired was 78.6 dBuV. Fortunately, the modem's receiver has a sensitivity of 20 dBuV, hence, it was able to detect all transmissions reliably.

3.2 Reliability Test and System Implementation

Three tests were conducted to demonstrate the reliability and limitations of the implemented EMS using the optimized powerline communications modems; a System Reliability Test, Complete System Implementation and Whole Day Testing.

The objective of the System Reliability Test was to meet at least 90% reliability. To know the system's reliability eight modulation schemes were tested each having 36 commands within a powerline network consisting of one base node and

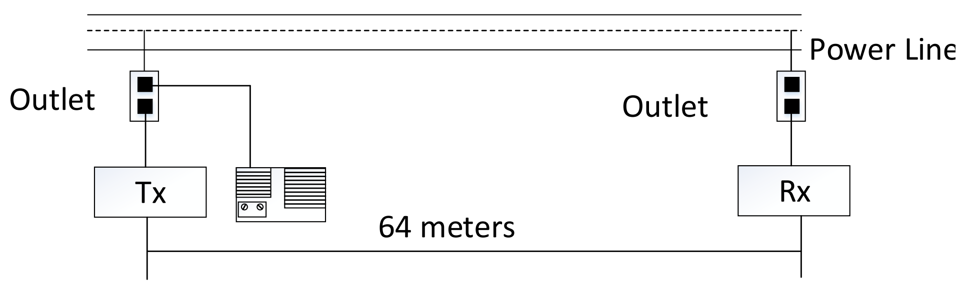

Figure 3. Setup 1 -Modem characterization with separation of the two modems at 64 meters. An air conditioner is placed near the transmitter side

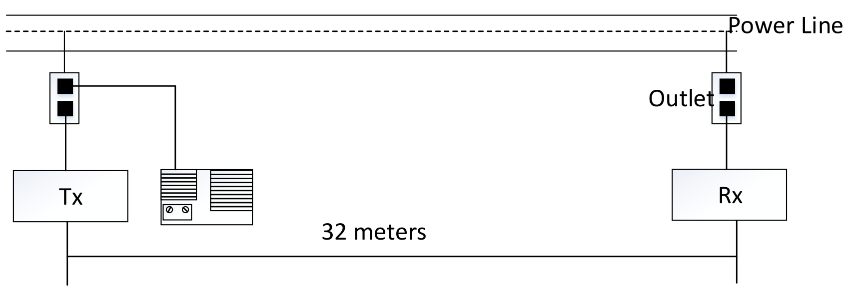

Figure 4. Set-up 2 - The separation between the transmitter and receiver was reduced to 32 meters still with the airconditioner near the transmitter

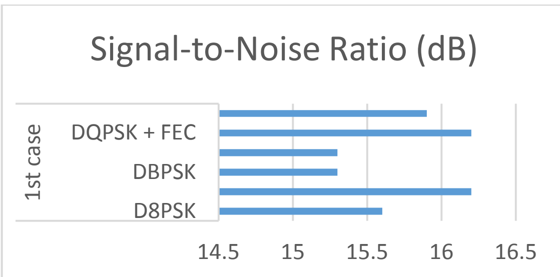

Figure 5. The Signal-to-Noise Ratio (SNR) of each modulation scheme applied to the 1st case

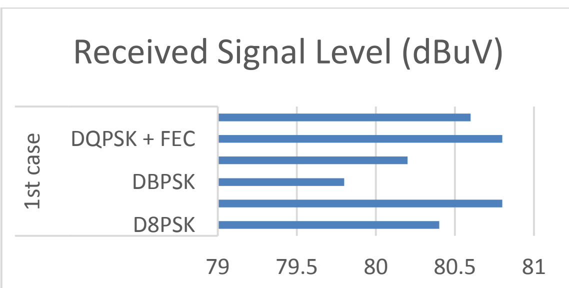

Figure 6. The Received Signal Level (RSL) of each modulation scheme applied to the 1st case

three service nodes. Each service nodes has its own LED indicators. The measurement of their reliability is based on the correct execution of the transmitted command.

The reliability test was conducted in two different educational buildings namely Velasco Hall and the Science and Research Technology Center (STRC). In each building, the system was tested under unloaded and loaded conditions. For the loaded condition, an ACU and two blenders were utilized.

Table 1 Reliability measurement for the STRC setup

Modulation Coding Scheme	Unloaded	Loaded
D8PSK	100%	100%
DQPSK	100%	100%
DBPSK	100%	100%
D8PSK+FEC	100%	100%
DQPSK+FEC	100%	100%
DBPSK+FEC	100%	100%

Table 2 Reliability Measurement for Velasco Set-up

Modulation Coding Scheme	Unloaded	Loaded
D8PSK	100%	100%
DQPSK	100%	100%
DBPSK	100%	100%
D8PSK+FEC	100%	100%
DQPSK+FEC	100%	100%
DBPSK+FEC	100%	100%

For the tests done in the two buildings, a reliability of 100% was achieved and this is true for both unloaded and loaded conditions.

The Complete System Implementation (CSI) tests the continuous functionality of the entire EMS, from the GUI to the powerline network to the appliances. This test was conducted in first-floor corridor of STRC. Only one Service Node has the relays and appliances while the rest have LED indicators, this is due to logistical constraints. To shorten the testing period, classes were also adjusted to a period of ten minutes with a break from five to ten minutes.

On the first test of CSI, a hardware problem occurred with the ACU. The SSR failed to drive the said appliance. After it was replaced, it was discovered that the voltage amplifier failed to turn the ACU off but even though that the ACU was not properly triggered it was observed that there was no problem with the power line communication. A second CSI was conducted and the system has successfully switch appliances on and off without human intervention.

The last test was the Whole Day Testing, this was conducted to verify the timing functionality of the EMS. Thus actual DLSU class duration was implemented i.e. class hours ranging from 1 to 1.5 hours with breaks ranging from ten minutes to fifteen minutes. The test was conducted on both Velasco Building and STRC. Again, due to logistical constraints, one service node drove relays while the other two service nodes drove LEDs. In this test, the system had successfully executed actual class periods.

3.3 Energy Consumption

In order to determine the energy saving (with EMS) or energy wastage (without EMS), for one academic term, kilowatt hour-meters were installed in one room. The class schedule for the whole term was noted and used in computing for the desired ideal energy consumption. The reading of the kWhr meter is then compared with the ideal value to find the supposedly savings had the EMS been implemented.

Three (3) kilowatt hour-meters were installed in the room to read the energy consumption. The room has two airconditioners and each one is installed with the meter while the fans and lights are connected to one kWhr meter. Figure 7 shows the installation of the three meters.

Figure 7. (Left) Kilowatt-hour meter was used for the lights and fans (Right) Two kilowatt hours attached into the connection

The room where the energy consumption is monitored has a total of 30 fluorescent lights, 2 fans and 2 airconditioners. The actual power rating of each of the appliances is used in the computation.

The total ideal value computed for the term was 2089.7 kW while the meter reading was 2736.2 kW. This translates to an energy wastage (without EMS) or energy saving (with EMS) is 26.79%.

$$Total\ Savings = \frac{|Actual - Ideal|}{Average}\ x\ 100$$

4. CONCLUSION

An Energy Management System (EMS) for education buildings was developed using the TMDSPLCKIT-V3 through the means of powerline communication (PLC). The system was comprised of three main components namely: the Graphical User Interface (GUI) that's applied to the host PC, the OFDM powerline communications network, and the hardware appliances for the interfacing of the appliances.

After characterizing each one of the modulation schemes, it can be said that the DBPSK + FEC is suitable for the application, since the data being sent does not need to have a high throughput rate, only a reliable transmission is required. It was also taken into account that higher order modulation schemes tend to be less robust to noise, and applying FEC into the modulation scheme results to having better protection against noise present within the powerline.

The reliability of the whole EMS was pegged at 100%. The energy savings depend on the schedule of the classroom, a heavily scheduled classroom obviously would have less savings while a lightly scheduled room would have more savings. However, regardless how small the saving is for one term per room, the impact of the saving for the whole year plus compounding all the savings of all the rooms is really huge. In this study, the savings could have been 26.79% of its total consumption and this is just for one room.

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