Building Smart Homes with Narrowband Power Line Communication (NB-PLC) Networks: Benefits and Challenges

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Abstract*— Currently Wi-Fi is the predominant technology used for building smart homes. However, Wi-Fi in this domain has several drawbacks such as loss of wireless signal, "leaky" Wi-Fi and network security issues. Although many endpoint devices (e.g. "connected" light bulbs, thermostats) and services (e.g. voice activated devices) are now available in the market for building smart homes, still there are no homes with all or most of the defining features of a smart home because Wi-Fi cannot, in our opinion, provide a reliable and secure home network. A smart home should provide homeowners security, comfort, convenience and energy efficiency allowing them to control smart devices, often by a smart home app on their smartphone or other network device. Unlike Wi-Fi, NB-PLC network can provide a reliable and secure command and control communication network. This paper describes NB-PLC system developed using Cypress® NB-PLC modem reference design. End point devices such as electric switches, plugs, bell push, fan controller and IR Controller with embedded NB-PLC modem along with an NB-PLC modem embedded Internet of Things (IoT) gateway have been developed and they are now being marketed. Endpoint devices do not have a directly accessible IP address. Authorized smartphones can access end point devices through the home IoT gateway. Energy monitoring and standby power management are available in some devices. NB-PLC modems can be embedded in any other electronic device (i.e. air-conditioner) easily in the future. This system would be cheaper to install and own than multiple Wi-Fi devices. It can co-exist with Broadband PLC devices (i.e. HomePlug). There are challenges in deploying this technology. NB-PLC networking for smart homes is a new concept to be proven in use. A neutral wire in the switch point is needed when current standards of house wiring do not require it. Small LED spot lights (less than 5Watt), which are increasingly used in homes today, produce electrical noise, which interferes with NB-PLC data communication. This was remedied by designing suitable filters. In addition, IoT gateway has built-in monitoring of nodes to achieve reliable communication and message *delivery.

Keywords-- Smart Home; Power Line Communication; Home automation; PLC modem

I. INTRODUCTION

A smart home has some level of home automation [1]. Concept of home automation has been in our imagination for many decades and has been in science fiction writing. With the development of networking technologies by the middle of 1970s home automation became a reality and by early 2000s home automation systems were introduced in USA [2]. An automated home is often referred to as a smart home and definitions of each phrase reflect different perspectives. Home automation is the use of computers to control home functions automatically and sometimes remotely. A smart home is a home equipped with lighting, heating/cooling and electronic devices that can be controlled by smartphone or computer. Emphasis of technology spans from automation to access and control by smartphones. A much useful and clear definition is provided by the work of Department of Trade and Industry in the U.K. led DTI Smart Home Project [3]. Here, a smart home is defined as *"A dwelling incorporating a communications network that connects key electrical appliances and services, and allows them to be remotely, controlled, monitored or accessed."* Remotely in this context means both within the dwelling and from outside the dwelling. Control in this context can be by direct human intervention or by simple schedules and machine leaning (ML) and artificial intelligence (AI) powered agents in the future. One aspect that is often not mentioned is the potential value of activity data of smart homes.

Currently Wi-Fi is the predominant network technology for Smart Homes. Wired network technology for smart homes is available, established and could even be the gold standard for smart homes but the main drawback when ordinary houses are concerned is the cost. NP-PLC technology is presented here as an alternative to wired technology at an affordable cost for ordinary homes.

II. NB-PLC MODEM DESIGN

Our NB-PLC modem was developed using Cypress high voltage powerline modem reference design. We have designed our modem with the smallest possible form factor so that the modem could be embedded in standard household electrical and electronic devices.

Currently, it is the smallest PLC modem available in the market with a form factor of 40mm (L) x 18mm (H) x 10mm (W) (Fig 1).

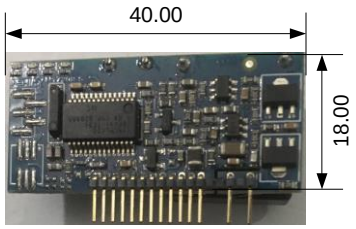

Figure 1. NB-PLC Modem (40.0 mm x 18.0 mm)

A summary of key features of the reference design [4] are:

- Integrated Powerline Modem PHY
- 2400 bps Frequency Shift Keying Modulation
- Powerline Optimized Network Protocol
- Integrates Data Link, Transport, and Network Layers
- Supports Bidirectional Half-Duplex Communication
- 8-bit CRC Error Detection to Minimize Data Loss
- I^2C enabled Powerline Application Layer
- Supports I^2C Frequencies of 50, 100, and 400 kHz
- Reference Designs for 110V to 240V AC, 12V to 24V AC/DC Powerlines
- Reference Designs Comply with CENELEC EN50065-1:2001 and FCC Part 15

We have also designed a separate power supply for the modem using Power Integration® technology, which is also with a similar form factor. Therefore, both items could be embedded in a 86 mm x 86 mm x 30 mm wall sunk box (UK Standard) together with other required control circuits to manufacture house-hold electrical devices with embedded NB-PLC communication capability. The author has applied for a patent for this design with the National Intellectual Property Office (NIPO) in Sri Lanka. This technology is branded as Ape' Smarthome [5].

III. COMMUNICATION PROTOCOL

Our communication protocol is in house developed and proprietary. It is used for communication between PLC modems embedded in PLC endpoint devices (slaves) and the PLC master modem that resides in the IoT gateway. It is a half-duplex protocol based on Cypress® Power Line Transceiver (PLT) protocol. We have developed our own PLC communication protocol based on Cypress design, which has enabled us to achieve efficient messaging with reliable duplex communication. Cypress® protocol has the following key features [4].

- Bidirectional half-duplex communication
- Master and slave as well as peer-to-peer network of Powerline nodes
- Multiple masters on Powerline network
- 8-bit logical addressing supports up to 256 Powerline nodes
- 16-bit extended logical addressing and supports up to 65536 Powerline nodes
- 64-bit physical addressing supports up to 264 Powerline nodes
- Individual broadcast or group mode addressing
- Carrier Sense Multiple Access (CSMA)
- Full control over transmission parameters (a) Acknowledged, (b) Unacknowledged, (c) Repeated transmit and (d) Sequence numbering

The payload of the PLT packet is 32 bytes. It was noted that a data packet on standard power line could be sent and received within 85~115ms between nodes and the protocol allows re-transmission of lost packets. The time delay between two data packets transmitted from a node should be 125ms.

Our experience is that a data packet on the power line could take 150~250ms for transmission between two nodes and 4~6 messages per second could be sent/received from a single node. This is quite acceptable for home automation applications. Also, the power line protocol does not require any other active devices such as controllers, repeaters, extenders to function.

IV. NETWORK TOPOLOGY

Network topology (Fig. 2) consists of NB-PLC modems emended in electric switches, plugs and other controllers (e.g. fan, air conditioners, bell-push), communicating with an IoT gateway. IoT gateway communicates with the Internet for cloud computing. Switches, plugs and other controllers can be accessed manually as usual or remotely by smartphones.

IoT gateway has Wi-Fi access and potential to integrate with other smart home protocols and for data access locally.

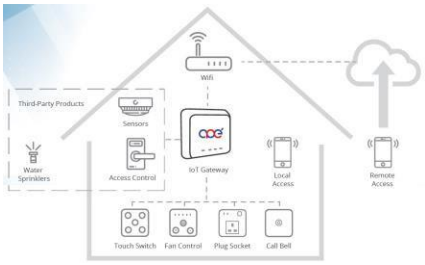

Figure 2. Ape' Smarthome network topology

V. SECURITY, SAFETY AND RELIABILITY

NB-PLC communication in this context is more reliable and consistent than current de facto Wi-Fi communication in smart homes which suffers from loss of signal due to various reasons. Unlike Wi-Fi, NB-PLC communication does not suffer from "leaky" signal and it is much safer. Endpoint devices do not have IP addresses. Therefore, devices at home are not directly accessible from outside in the same way Wi-Fi enabled home devices can be accessed compromising security.

Although the transmitted signal is radio frequency NB- PLC communication is safer as it is transmitted over physical wires. Unlike Wi-Fi, jamming PLC transmission from an external device is near impossible. The most reliable data such as telephone cables, Universal Twisted Pair (UTP), Fiber Optic Cables (FOC). In NB-PLC too, transmission takes place on a 'hard wire', which is highly reliable.

VI. SMART WIRING

NB-PLC modem enabled switch needs a neutral wire. In current home wiring practice, a neutral wire is not made available to the switch as it is not necessary but this practice is beginning to change now. Therefore, introducing this system to existing homes can be a challenge. This system is more suitable for new build homes where wiring can be carried for digital devices from ground up. More and more new buildings are deploying Smart Wiring as it allows flexibility for the home owner to deploy different smart devices and technology now and in the future.

As NB-PLC Modem could be connected to any digital or analog device with a suitable interface and the data from the device could be transmitted over existing power lines. Smart Wiring in this case becomes much simpler as potential future wiring options would be limited. Typical applications possible with NB-PLC are security door / window sensors, gas/water leak detectors, smoke detectors and water sprinklers.

As NB-PLC make use of existing power lines, the total installation cost can sometimes off-set the cost of NB-PLC modems, in addition to reducing the cost of cabling, conduits and other components.

A fixed soft Infra-Red (IR) remote controller device with an embedded NB-PLC modem has been designed which works independent to the handheld remote. In the case of security cameras and voice control devices NB-PLC can be used to switch on / off but for image and voice communication broadband PLC (BB-PLC) or Wi-Fi network is required.

VII. ENERGY MONITORING

NB-PLC modems have been used for deploying Automatic Meter Reading (AMR) solutions in many countries in the world. However, NB-PLC modem has not been widely used for Energy Monitoring in homes. In fact, NB-PLC is the ideal solution for home energy monitoring as the data transport can take place on the same electrical wiring infrastructure. In addition, in-built NB-PLC modem within a plug socket could relay information for monitoring efficient use of electrical and electronic appliances in homes.

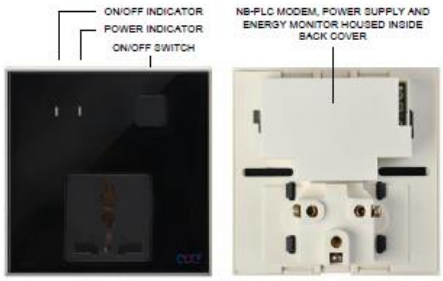

Figure 3. Smart Plug Socket with NB-PLC

Managing standby power (or "leaky power") is another function a smart plug socket with an embedded NB-PLC modem could do by shutting-off power to any appliance consuming standby power and thereby saving energy.

Due to extremely small foot print, we have been able to embed the NB-PLC modem with a separate PCB to handle standby power detection and energy monitoring inside the back cover of a power plug. This entire assembly is installed inside a standard sunk box (Fig. 3).

With built-in power isolation functionality that can be automated can make homes safer. In addition, it could be deployed to separate critical and non-critical loads during power failure and back-up power restoration. In fact, this technology is the only technology available today for existing installations to separate critical and non-critical loads, when installing back-up power supplies without having to re-wire the building for instance in the case of home solar power systems.

VIII. COST OF OWRNERSHIP

The cost of manufacturing a NB-PLC modem in Sri Lanka is around US$ 30, which is quite competitive when its versality is considered. Deploying smart home systems with

NB-PLC technology does not require additional wiring (except neutral wire to switch in existing homes) and devices such as centralized wireless and other controllers of wired systems. Therefore, NB-PLC smart home solutions are cost effective and easy to deploy

The above cost benefits are enhanced if and when the owner has a need to separate critical and non-critical loads to deploy back-up power systems.

IX. CHALLENGES NOTED

The major challenge that we have encountered during our research is the noise that is created by Switch Mode Power Supplies (SMPS) that are used in LED lights, Laptop and mobile phone chargers. We have seen that the noise interference is significant in LED lights that are less than 5Watt and non-branded. Most LED lights that are manufactured by reputed manufacturers do not usually pose a problem.

We have found that heavy drilling equipment creates noise that is harmful and, in most cases, the entire power line communication could be affected to the extent that NB- PLC modems were frozen. As a remedial course of action, we are able to use noise filters to filter noise generated from the above devices. A suitable noise filter needs to be deployed at the power source.

Setting up power line networks in buildings that are with 3-phase power supply creates an issue where the power line signal does not travel between phases. This is overcome by deploying a 3-Phase coupler at the distribution board or immediately after the energy meter.

X. CONCLUSIONS

True digital switches that can replace 100-year-old mechanical electric switches and digital power sockets with new functionality such as standby power detection, energy metering, remote switching and power isolation has been developed in Sri Lanka and commercially manufactured now. Core innovation is the NB-PLC modem developed on top of Cypress PLC modem reference design. A proprietary communication protocol has been developed. NB-PLC technology described here is reliable, safe and cost effective to build smart homes. This technology can co-exist and be integrated with Wi-Fi smart home protocols now and in the future. NB-PLC could challenge the dominant position of Wi-Fi networks in smart homes.

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