A Survey of Smart Homes Technologies

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Abstract*—Smart Homes, alias for the Automated Home, brings practical value by enabling greater convenience, comfort, safety, security and reduces operating costs. The residents can control many aspects of the home from anywhere at an time such as lighting, home appliances and entertainment by using home networking. This paper will briefly survey the various types of home networking technologies (either the wired or wireless technologies such as power line, phone line, Ultra Wide Band (UWB), and spread spectrum (SS)). The paper will critically analyse these techniques showing their advantages and shortcomings as well as how to use them to implement and control the different house appliances.

Keywords— smart home, power line communication, PLC

I. INTRODUCTION

Smart home technology is a collective term for information- and communication technology as used in houses, where the various components are communicating via a local network (1)-(3). The technology can be used to monitor, warn and carry out functions according to selected criteria. Smart home technology also makes the automatic communication with the surroundings possible, via the Internet, ordinary fixed telephones or mobile phones. Smart home technology gives a totally different flexibility and functionality than does conventional installations and environmental control systems, because of the programming, the integration and the units reacting on messages submitted through the network(4),(5)

Smart homes are just one example of a range of technologies that come under the heading of assistive or augmentative technologies (5). Smart home technology can be split into two main categories:

1) Active devices: such as control panels and switches, with which the home occupant will directly interact with and use.
2) Passive devices: such as sensors and receivers, over which the home occupant has no direct contact, function to enable and empower the living experience of the occupant.

The advantages of a home with functions that adapt and assist according to sensor measures seem numerous; however, people have very different habits and ways of leading everyday life, and applications that are developed for one lifestyle therefore might not work for another.

The illumination control and its various technologies is one of the main parts of the Smart Home systems. The illumination may for example be controlled automatically, or lamps can be lit as other things happen in the house.

In order to understand the potential of the technology, this paper will describe the different elements of a Smart Home system in section II, to which standards are relevant and what is applied throughout the whole world. This paper, also, outlines the main Home Networking technologies, in section III, used in the market while presenting a critical review of their respective points of strengths and weaknesses. Conclusions are finally drawn in section V.

II. SMART HOME TECHNOLOGIES

Home networks refer to a number of data communication and control technologies that have been developed primarily to serve applications in the home. Over several decades, these systems have evolved to provide increased convenience to home occupants in three major areas (6):

1) Simplified Remote Control of residential entertainment components and systems (TV, home theatre, audio, etc),
2) Automated Remote Control of major house sub-systems (thermostats settings, garden irrigation, security, etc) and most recently,
3) Flexible Internet Connectivity to its devices throughout the home (PCs, printers, etc).

The network that will use is compared to the standard OSI seven layer network models.

In the simplified remote control technique, all appliances and devices may be considered as receivers, and the means of controlling the system, such as remote controls or keypads, are through transmitters. If, for example, a person wants to turn off a lamp in another room, the transmitter will issue a message in numerical code that should include the following (7):

- An alert to the system that it is issuing a command,

An identifying unit number for the device that should receive the command and a code that contains the actual command, such as "turn off."

In the automated remote controlled systems, home network technologies have evolved to service a wide variety of appliances. In this case a modification to the previous case may be necessary since no longer the appliances and devices are dummy terminals. Instead they have evolved into a higher two way communication system sending raw sensory data to a main controller and receiving commands according to user preset environmental conditions. A flexible internet connectivity system of a networked home allows users to connect various devices like desktop computers, laptops, game consoles, and cameras to the Internet and to each other. It also enables users to share digital media across various devices, share a single printer, and share a broadband Internet connection. In an ideal scenario all devices should be able to interconnect seamlessly.

In order to enable the critical analysis and the proper modelling of the proposed system, the following generalised block diagram, shown in Fig.1, is introduced outlining the general components of a Smart Home system. The system is shown to be subdivided into: (6)

Sensors: monitoring and submitting messages in case of changes.

- Actuators: performing physical actions.
- Controllers: making choices based on pre-programmed rules and occurrences.
- Central unit: rendering possible programming of units in the system possible.
- Networks: allow communication between the units and possibly to the surroundings.
- Interface: the user's communication with the system.

The controllers outlined in Fig.1 are shown to handle both sensors as well as actuators. This is typical since both of them generally require communication with the Central Unit. In a simplified remote control system, the sensors are irrelevant since the system is mainly concerned with executing user commands. On the other hand, the automated remote control systems require the presence of the sensors in order to implement the closed loop control processes required by the user settings at the Central Controller. The advanced flexible internet connectivity system performs exactly like the previous one except that it possesses the capabilities of internet access. This is implemented by either using internet based Controllers (e.g., TCP/IP) or by enabling a user interface to connect to the internet, depending on the complexity of the system.

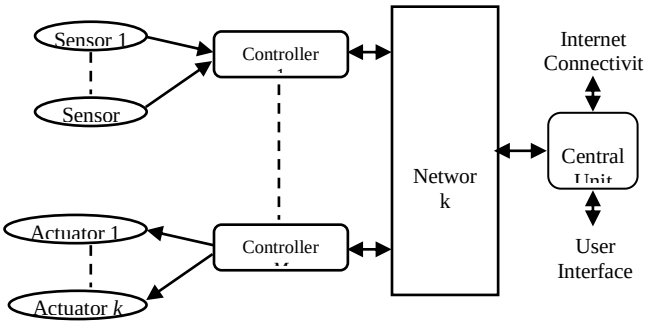

Fig.1.Smart Home Control Systems Block Diagram

III. OVERVIEW OF HOME NETWORKING TECHNOLOGIES

The above discussion, relating to the block diagram of Fig.1, shows the evolution of the network connectivity including all its task-dependent requirements. The transmission media as well as the transmission protocols are critical factors to be analysed when dealing with the possible network topologies used herein.

A plethora of network protocols as well as network topologies have been used throughout the years. In order to understand the major advantages and shortcomings of each a certain classification is due here, which is presented in Fig.2.

The subdivisions, depicted in Fig.2, classify the system into either "Wired" or "Wireless" technologies. This is the main breaking point between those two technologies.

Resulting in different prospects between the technologies. Furthermore, the "Wired" technology is subdivided into two categories either using the existing home wiring or requiring new wiring to be laid out in the house. The cost of installing new wiring is of course exorbitant especially in the case of houses, which already have been decorated. The installation time inconvenience is also a major factor governing the customer decisions. The wireless technology on the other hand circumvents this shortcoming by not requiring any installation cost or time at all. This is the new era of modern technologies incorporating "No Wires and No Installation Costs". This is contrasted with the major drawback of being unable to cover "higher grounds"; i.e., places which are within other flours or through thick concrete layers without boosting the transmission powers. The people who are paranoid with electromagnetic waves travelling freely throughout their homes would be scared to death. This is the case where the utilisation of existing wiring may be used. The existing wiring network in the house does incorporate: the existing computer network, the existing telephone network (especially in the case of the presence of a PABX), as well as the existing power line network.

A. Existing wiring

Phone line: PhoneLine or HomePNA networking works over the existing copper telephone wires in your home without interfering with voice or DSL communications uses the same basic transmission technology as traditional Ethernet (8) .Several issues that need to be addressed before the success of phone line-based home networking systems are guaranteed. These include:

- Random Wiring Topologies: Rather than the hub structure of business networks, the Home phone line wiring system is a random "tree,"
- Signal Attenuation : The random tree network topology of a phone line wiring system can cause

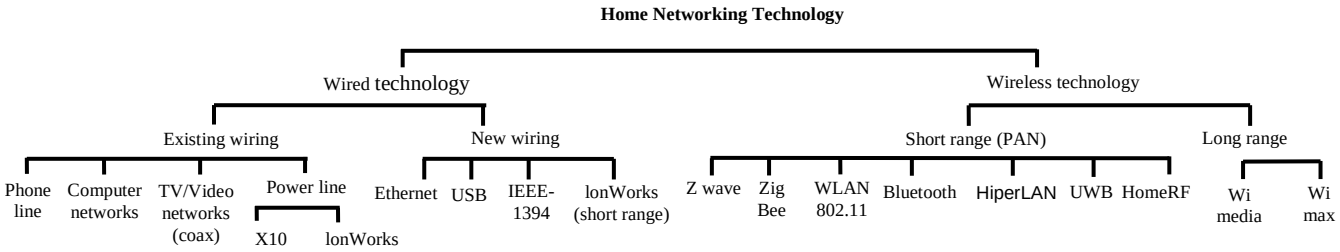

Fig.2: Home Networking Technologies Subdivisions

signal attenuation. In simple terms, attenuation means a reduction of signal strength during transmission of data across the home network. The attenuation on a phone line network is normally caused by open plugs and un-terminated appliances.

- Signal Noise : Appliances, heaters, air conditioners, consumer appliances, and telephones can introduce signal noise onto the phone wires.
- Telephone Jacks : Phone jacks are not found everywhere in the home. The physical location of those jacks with respect to the devices that need to be networked is another problem (9).

Power line: Power line Networking (also called Home Plug Networking) allows easy network setup across existing 110V electrical outlets. It works with 2 & 3 prong standard 110 volt electrical outlets, transfers data at speeds up to 14 Mbps and it is compatible with 10Mbps or 10/100, and Power line networks use a bus topology which provides a high level of reconfigure ability and the ability to control more than one device from a single controller. This controller could manage all the lights in a room or even all the lights in the home (10). Power line Based Applications in Home Networking (11):

- Lighting Control
- Temperature & Ventilation Control
- Security
- Sprinklers
- Audio/Video Control
- Sensors
- Gates & Doors Control
- Pool & Spa Control
- Phone Control
- PC Control

X-10 : is a communications protocol that allows compatible home networking products to talk to each other via the existing home electrical wiring. It is possible to control lights and virtually any other electrical device from anywhere in the house with no additional wiring. But these devices are susceptible to damage by voltage spikes. The X-10 modules are adapters connected to outlets and controlling simple devices. X-10 transmission rate is limited to only 60 bps which makes it unsuitable for carrying internet type traffic around the house. Mbps Ethernet products. (2),(7)

Ethernet : is the most popular home networking, Ethernet networks operate at 10Mbps to 100Mbps within a range of 500 feet. They can be as simple as two computers with NICs connected with a cable or as complex as multiple routers, bridges and hubs connecting many diverse network appliances. (12)

B. Wireless technology:

To provide wireless communications between home electronic devices, it is vital that technology offers (11):

- High data throughput
- Low power consumption
- Interference immunity
- Security
- Reasonable range
- Low cost.

Z-Wave: Uses a Source Routing Algorithm to determine the fastest route for messages. Each Z-Wave device is embedded with a code, and when the device is plugged into the system, the network controller recognizes the code, determines its location and adds it to the network. When a command comes through, the controller uses the algorithm to determine how the message should be sent. Z-Wave communicates using a low-power wireless technology designed specifically for remote control applications. The Z-Wave wireless protocol is optimized for reliable, low-latency communication of small data packets, unlike Wi-Fi and other IEEE 802.11-based wireless LAN systems that are designed primarily for high-bandwidth data flow. Z-Wave operates in the sub-gigahertz frequency range, around 900 MHz (13).

ZigBee : is a suite of high level communication protocols for wireless personal area networks. It uses small, low power digital radios based on the IEEE 802.15.4 standard. ZigBee protocol include the features of low power consumption, needed for only two major modes (Tx/Rx or Sleep), high density of nodes per network, low costs and simple implementation which intended to be used by home embedded appliances and operates in the unlicensed 2.4 GHz, 915 MHz and 868 MHz bands (14),(12).

Local Area Networks (WLAN, 802.11): operate at 2.4 GHz or 5 GHz ISM bands and offer speeds up to 54 Mbps. They support two modes: ad-hoc and infrastructure. The ad-hoc mode allows stations to spontaneously form a wireless LAN, in which all stations communicate with each other in peer-to-peer manner. The infrastructure mode, the network has an access point (AP), through which each client station communicates.

WLAN may not be applicable for wireless device-to device communication because of high power consumption, requiring line power or power over Ethernet (PoE). The expense of providing the power lines may limit the size of the network. (15)

UWB : is a short-range technology based on transmission of impulses lasting only fractions of nanoseconds emitted in periodic sequences. IEEE 802.15.3 specification defines the physical layer for UWB.

also a Radio Frequency (RF) technology that transmits binary data, using low energy and extremely short duration impulses or bursts (in the order of picoseconds) over a wide spectrum of frequencies. It delivers data over 15 to 100 meters and does not require a dedicated radio frequency (16)

Bluetooth : also known as the IEEE 802.15.1 standard is based on a wireless radio system designed for short-range (10cm - 100m) with bandwidth less than 1Mbit/s and increased bandwidth limit up to 2.1 Mbit/s and cheap devices to replace cables for computer peripherals, such as mice, keyboards, joysticks, and printers. This range of applications is known as wireless personal area network (WPAN) . Bluetooth protocol operates in the license-free 2.4 GHz band. In order to avoid interfering with other protocols which use the same frequency, Bluetooth uses frequency-hopping technique. It divides the band into 79 channels (each 1 MHz wide) and changes channels up to 1600 times per second (17).

WiMedia : range 7.5 GHz frequency divided into 5 band groups with 14 sub-bands (18).

WiMax : (Worldwide Interoperability for Microwave Access) that is largely based on the wireless interface defined in the IEEE 802.16 standard. Designed to deliver next-generation, high-speed mobile voice and data services and wireless backhaul connections that could potentially displace a great deal of existing radio air network (RAN) infrastructure. Also it is a new wireless technology which provides Mobility, Coverage, Maintainability; Roaming Services etc. WiMax network provides accurate proficiency in telecommunications and latest technology of hub and routers to get best result during broadcasting. WiMax services make available a customized network for home. (19) Mobile WiMAX operates in licensed frequency bands in the range of 2 to 6 MHz (20) and its characteristics are long distance transmissions and high data capabilities. WiMAX coverage can reach up to 50 kilometres and the capacity of network backbone can be increased to 75 Mbps (21)

The previous techniques are summarised in Table 1.From the previous discussion, it is clear that the Power Line Communications (PLC) techniques surpass the other rivalling techniques due to several advantages among which the fact that the whole place is covered with existing power wiring and no new devices are needed since all devices are pluggable into the power outlet. PLC techniques also surpass the wireless technologies since they do not require the presence of routers/switches in every part of the house in order to ensure proper signal reception.

The following section discusses further the Power Line Communication technologies in order to get a better insight into such techniques.

TABLE 1
COMPARISON BETWEEN VARIOUS SMART HOME NETWORKING TECHNOLOGIES

Differentiator	**Structured wiring**				**Existing wiring**				**Wireless**						
	Ethernet	***USB 2.0***	***IEEE -1394***	***LonWorks***	***Phone line***	***Computer networks***	***Coax***	***Power line***	***Z wave***	***Zig Bee***	***WLAN 802.11***	***Bluetooth***	***UWB***	***Wi media***	***Wi max***
Best uses	New construction and remodelling				Interconnecting stationary				Mobile devices such as laptops, palmtops and web pads						
Cost	High for installation				Low				Low						
Useful lifetime	Very long				Relatively short			Medium	Short						
Number and location of outlets	Wherever needed				Multiple electrical outlets in every room; many rooms with telephone outlets; few rooms with coax outlets				Ideally throughout the home						
Maximum Current data rate (Mb/s)	100	480	800	100	160	1-14	100	30–60	100	250 Kbps	54	2.1	480	53.3 to 480	15
Maximum Future data rate (Mb/s)	1000 Mbps	5Gb/s	1000 Mbps		30-250 Mbps				100	250 Kbps	300Mbps	24Mbps	1.6 Gbps	280Mbps	40
Security	High secure				Less secure			High secure	Less secure						
Standardization	Well-defined global standards				Competing standards				Competing standards						
Operating Frequency band	600 MHz	5GHz	800	100MHz	4 to 10 MHz	100MHz	100MHz	500KHz	2.4GHz	2.4 GHz	5 GHz	2.4 GHz	10.6 GHz	7.5 GHz	5.8 GHz

IV. POWER LINE COMMUNICATION

Communications over Power line is different than communications over dedicated network wirings (for example, UTP, STP, Fiber etc.). Power line presents a difficult medium for transmission of information. Communication over the AC power line is difficult because of the unpredictable noise and interference caused from sources such as halogen lamps, vacuum cleaners, blenders, washing machines, hair dryers, microwave ovens, etc. Also, the power line is not controlled or constant over time. As compared to the Ethernet cabling, which is clean and has consistent characteristics, the power line can have numerous appliances and equipment plugged in at any time (turned on or off any time, run for any length of time). The constant plugging and unplugging of various home electric devices, turning them on and off, causes the power line characteristics to vary constantly and significantly. PLC is a technology that uses power distribution wires to transmit data simultaneously. PLC carrier is able to transfer data by overlaying an analog signal over the alternating current (AC) distributed by the power wires. The frequency of the alternation is usually 50 or 60 Hz (22).

PLC as a home network facilitates data exchange between traditional data processing devices such as PCs and computer peripherals (10),(23),(24).

Fig.3 below shows a digital communication system using the power-line as a communication channel. A coupling circuit is used to connect the communication system to the power-line. The purpose of the coupling circuits is two-fold. Firstly, it prevents the damaging 50Hz signal, used for power distribution, to enter the equipment. Secondly, it certifies that the major part of the received/transmitted signal is within the frequency band used for communication. This increases the dynamic range of the receiver and makes sure the transmitter introduces no interfering signals on the channel.

To modulate digital signals onto the power lines, we can use many of the same techniques widely implemented in wireless communication. Basic modulation techniques such as (24):

- phase shift keying (PSK)
- frequency shift keying (FSK)
- minimum shift keying (MSK)
- Gaussian minimum shift keying (GMSK) can be used for low-data-rate communication.

Other more advanced techniques such as:

- M-ary PSK (MPSK),
- M-ary quadrature amplitude modulation (MQAM),
- M-ary FSK(MFSK)
- Orthogonal frequency-division multiplexing (OFDM) can be used when higher data rates are desired.

LONWORKS (Local Operation Networks)

The LonWorks technology, developed by Echelon and it is a general purpose control network technology that can be used to monitor sensors and control outputs in a wide variety of applications. With the power line transceiver, control networks can be implemented through the same AC or DC mains wiring that powers the equipment under supervision (9),(25),(26),(27).

A control network is any group of devices working in a peer-to-peer fashion to monitor sensors, control actuators, communicate reliably, manage network operation, and provide complete access to network data.

The LonWorks technology is comprised of following major elements:

- Neuron Chip control processors and transceivers
- LonTalk communication protocol
- LonWorks Network Services (LNS)

Neuron Chip control processor is the physical core of every LonWorks device. It is a system-on-chip with multiple microprocessors, read-write and read-only memory (RAM and ROM), communication and I/O interface ports (28).

Each Neuron Chip contains a unique-in-all-the-world 48-bit code, called the Neuron ID. Available in a large family with different speeds, memory type and capacity, and interfaces, the Neuron Chips are jointly designed by Echelon and its semiconductor partners Motorola and Toshiba (29).

A transceiver is an electronic module that provides the physical interface between the communications port of the Neuron Chip and a physical medium, called a channel, which transports the digital communication packets to other devices. All devices connected to a specific channel must have compatible transceivers running at the same bit rate (27),(30).

The LonTalk protocol, which supports a wide range of applications, is designed to support all communications on the LonWorks network. Examples include electronic home appliances, factory automation equipment, motor vehicle control equipment, building control equipment, and home automation equipment. The LonTalk is a full 7-layer protocol as defined by the Open Systems Interconnection (OSI) reference model of the International Standards Organization (ISO).The LONWORKS protocol uses a unique media access control (MAC) algorithm, called the predictive p-persistent CSMA protocol that has excellent performance characteristics even during periods of network overload (27).

V. CONCLUSION

This paper reviewed different types of networking technologies suitable for smart home applications and compared between them regarding their uses, cost, security, transmission range and their advantages and disadvantages. Power line communication brings practical value in Smart Homes by enabling greater convenience, comfort, safety, security and reduces operating costs.

ACKNOWLEDGMENT

This work would not have been completed without help and support of my advisors Dr. Mohamed El-Habrouk and Dr. Farouk AbdAllah, without them achieving this work just wouldn't have been possible, I would like to thank them for providing me an opportunity to conduct my master's research under their guidance, support and valuable suggestions, Special thanks to Dr. Mohamed El-Habrouk for his constant support during this work and for giving me a lot of his valuable time..

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