Effects of Power Lines on Performance of Home Control System

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***Abstract*--Home Control System (HCS) helps to monitor and control the home appliances as well as security aspects of the digital home that is expected to be the standard for the future home. Chiefly, HCS is an integration of Home Appliance Control Systems (HACS) and Home Security Systems (HSS). HACS enables the home-owner to control appliances such as stove, refrigerator, air-conditioner, and the like, remotely, while the HSS helps to monitor the status of various networked security devices in the home and control certain aspects of the devices. Monitoring and control may be done by a personal digital device such as a laptop, PDA, telephone, or even a cell phone. One of the technologies widely used by HCS to connect the home controller with the appliances, equipments, and devices, is the X10 protocol that uses power lines for data transmission. In this paper we analyze the performance of power lines for HCS and suggest recommendations that will help increase the performance of HCS.**

***Index Terms*--Home Control Systems, Home Appliance Control Systems, Home Security Systems, Performance, Power Lines, X10.**

I. INTRODUCTION

HOME Control System (HCS) helps to monitor and control the home appliances as well as security aspects of the digital home and digital homes are expected to be the standard for future homes [1]. Chiefly, HCS is an integration of Home Appliance Control Systems (HACS) [2] and Home Security Systems (HSS) [3]. The HCS system helps the home owner in a situation where she is miles away and recalls that she hasn't closed the stove or some other appliance, at which point she could reliably perform the desired functions remotely which helps her save money , time, and her property from potential fire, theft and public disturbances. For example, as our survey of homeowners has indicated, one of the frequently occurring problems has been the failure to close the garage door when leaving the home - open garage doors can be detected and closed remotely using the HCS: the status of the garage door can be observed on a personal digital device such as a laptop, personal digital assistant (PDA), a telephone, or even a cell phone, and, if necessary, the garage door can be remotely closed using the same digital device.

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For this to work there is at least one home controller in the house that is connected to other appliances and equipments that need to be controlled. One of the technologies widely used by HCS to interconnect the controller to the appliances and equipments is the X10 protocol [4] that uses the existing power lines for data transmission. The main advantage with this technique is that the infrastructure for connecting the controller to the appliances is readily available and therefore can potentially reduce costs for the installation of the HCS.

Performance is an important aspect of HCS – high speed of information delivery and reduced time to wait for system response are important characteristics for technology acceptance [5, 6]. Performance has been defined [7] as the accomplishment of system functions within the constraints of speed, accuracy, and memory usage. For HCS, time to respond to the user, bandwidth, cost, ease of use, and accessibility, are some of the most important aspects related to performance. We analyzed the performance of HCS using X10 protocol and we found that the HCS performance is significantly impacted using the X10 protocol on current electrical wiring in the house. In this paper we present the results of our experiments with the X10 protocol and recommend techniques to improve the performance of HCS using home electrical wiring.

Our literature survey demonstrated that very little work has been done in analyzing performance of X10 for HCS – manufacturers of X10 equipments (such as www.smarthome.com) merely list the advantages. Our previous study [3] focused on performance of different types of HCS whereas in this study we focused on the suitability of X10 technology for HCS. The paper is organized as follows: in Section 2 we discuss the HCS especially with respect to distinguishing characteristics of the HCS domain; Section 3 discusses the X10 protocol and its use for HCS; Section 4 analyses the performance of X10 technology for HCS; and Section 6 discusses the conclusions and future work.

II. HOME CONTROL SYSTEM

A Home Control System is an integration of HACS and HSS.HCS is an integration of the following technologies: home networking, smart appliances, the internet, and mobile wireless access. Home networking is the collection of elements that process, manage transport and store information enabling the connection and integration of multiple computing, control, monitoring and communication devices in the home. Home networking, in turn, has been enabled by the emergence of new trends such as broadband access, telecommuting, multi-PC households, remote home security services, remote home energy services, and even remote assistive solutions for disabled people (for example, Sensor Information Systems for Assisted Living or SISAL [8]). Home networking led to the development of the residential gateway (RG) that interfaces the home with the outside world, and the home network controller that provides the interface between the devices at home and RG.

Smart appliances is a relatively newer development and several major appliance manufacturers (Toshiba [9], Samsung [10], LG [11], and Carrier [12]) are developing internet-ready appliances such as stoves, refrigerators, washers, dryers, and the microwave, so that these smart appliances may be directly plugged-into the home network. Once these smart appliances are plugged-in, they become another element in the home network and may be controlled via the controller, either from outside or the inside of the home.

Internet has really helped propel the ability of remote control facility of the HCS. With several hand-held wireless devices being internet accessible, for example, the laptop, personal digital assistants (PDA's, such as for example, Blackberry [13]) and cell phones, the RG is now accessible via the internet from any of these hand-held devices and as such permits the access and control of devices at home from these devices remotely – while home networking enabled control from a short distance, the internet has enabled control of the home from a very large distance possibly hundreds or even thousands of miles away. Therefore, HCS provides unprecedented level of control to the home owner and as a result may increase the quality of her life.

The distinguishing features of the data sent over the HCS system are the following:

1. short bursts of control commands from the controller
2. short bursts of response commands from the appliance or equipment
3. typically several nodes connected to the system, where the node refers to a controller, appliance, or equipment
4. typically long average distance usually measured in tens of feet
5. occasionally large data transmissions
6. Repetitive use of the technology due to habit.

III. X10 FOR HOME CONTROL SYSTEMS

When different networks are joined a gate way must perform the functions of media translation, address translation, authentication/filtering and system management. The Residential Gateway (RG) performs these functions for the home [14].

One of the technologies widely used for HCS is X10 protocol which is used for data transmission. The X10 protocol [15, 16] is perhaps the oldest standard for home networking. It was introduced in 1978 for the Sears home control system and the Radio Shack plug'n'power system [17]. X10 communicates between transmitter and receiver by sending and receiving signals over the power line wiring. These signals involve short RF bursts which represent digital information. This protocol has be used as it has many advantages including being inexpensive, no new wiring required, simple to install, compatible with many products, controls up to 256 devices.

The X10 home automation system [23] provides a convenient means for interfacing the appliances in the home with the help of the RG. Household electrical wiring is used to send digital data between X10 devices. This digital data is encoded onto a 120 kHz carrier which is transmitted as bursts during the relatively quiet zero crossings of the 50 or 60 Hz AC alternating current waveform. One bit is transmitted at each zero crossing. The digital data consists of an address and a command sent from a controller to a controlled device. Controllers query equally advanced devices to respond with their status. This status may be as simple as "off" or "on", or the current dimming level, or even the temperature or other sensor reading. Devices usually plug into the wall where a lamp, television, or other household appliance plugs in; however some built-in controllers are also available for wall switches and ceiling fixtures.

The relatively high-frequency carrier frequency carrying the signal cannot pass through a power transformer or across the phases of a multiphase system. In addition, because the signals are timed to coincide with the zero crossings of the voltage waveform, they would not be timed correctly to be coupled from phase-to-phase in a three-phase power system.

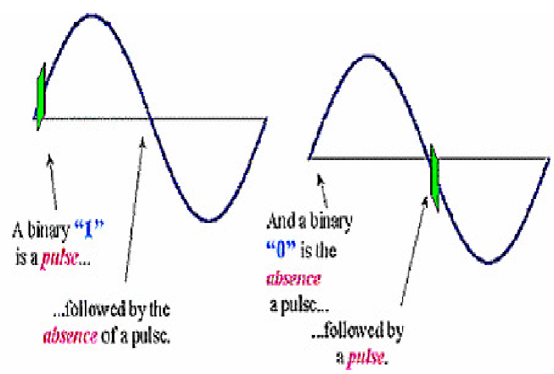

Fig. 1. Transmissions synchronized to zero crossing.

For split phase systems, the signal can be passively coupled from phase-to-phase using a passive capacitor, but for three phase systems or where the capacitor provides insufficient coupling, an active X10 repeater is sometimes used. It may also be desirable to block X10 signals from leaving the local area so, for example, the X10 controls in one house don't interfere with the X10 controls in a neighboring house. In this situation, inductive filters can be used to attenuate the X10 signals coming into or going out of the local area.

The X10 system was chosen over others primarily consists of a number of individual nodes that receive the signals transmitted by the controller. The X10 transmissions are synchronized to the zero crossing point of the AC power line "Fig. 1".Every node has a zero crossing detector that is used to detect signals transmitted by the controller. The receivers look for the signal within 0.6 microseconds of the zero crossing point.

Initiation Signal												
1	1	1	0	0	1	1	0	1	1	1	0	0
Start Signal				House Code "A"				Device Code "2"				

Command Codes		
On = 00101	All Lights On = 00011	Bright = 01011
Off = 00111	All Units Off = 00001	Dim = 01001

Fig. 2. X10 Transmission Command Codes.

The controller transmits signals to the nodes using existing electrical wiring it initiates communication by sending a start packet followed by the house code and the device code. This initiation signal is followed by a command signal that is used to control the specified node. The command codes "Fig. 2" include options for toggling nodes on/off and for dimming/brightening lamp modules.

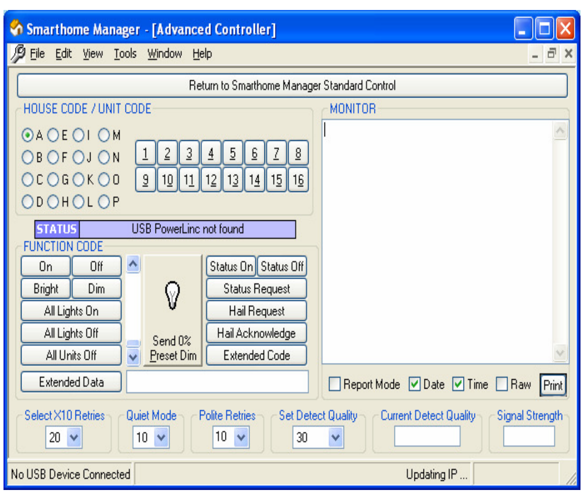

Fig. 3. X10 Advanced Integrated Controller.

By installing a series of nodes any home can be automated to a reasonable degree. The installation would only require setting a house and device code on a node and attaching the X10 node between a device and the wall outlet. The screen "Fig. 3" below shows the snapshot of the commercially available X10 systems advanced integrated controller.

IV. Performance Analysis of X10

Using internal grants, several equipments were purchased to evaluate the performance of commercial home control systems: the web server, X10 home controller, signal analyzers, X10 motion sensors, X10 telephone controller switches and X10 door sensors were purchased from Smarthome (www.smarthome.com), the cameras were purchased from Toshiba (www.toshiba.com), the laptop and the PDA were purchased from Dell (www.dell.com), while the cell phone used was Sony Ericsson's with service from T-Mobile. "Fig. 4' shows the basic configuration and the equipments that are a part of the HCS used for performance analysis.

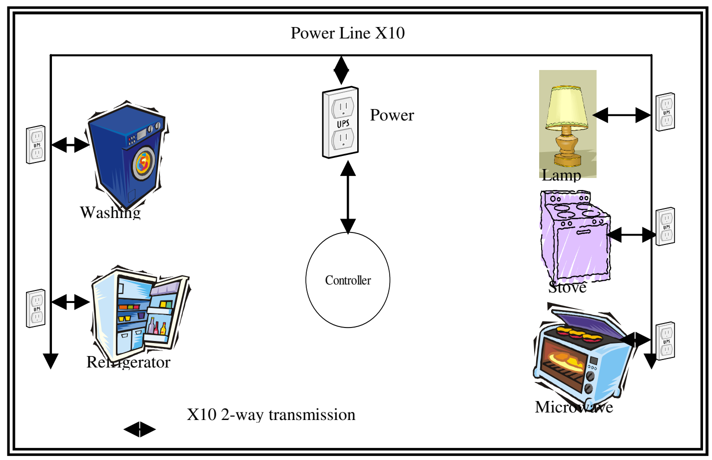

Fig. 4. Basic Configuration HCS interconnected with X10.

In the above configuration all the appliances are interconnected to the X10 advance controller with the help of the existing power line. Appliances such as washing machine, refrigerator, stove, microwave oven are connected to the appliance module where as the lamp is connected to the lamp module, both the appliance module and lamp module are bi-directional i.e. they provide two way data transmission of X10 signals.

Like regular receivers and transmitters, they can communicate on all 256 addresses. 2-Way products are helpful for status reporting and triggering other receivers to turn on, off or even run a macro event (a multi-step event run by an intelligent controller).

The homeowner can remotely control any appliance connected in this configuration using the X10 advanced controller by providing the specific house code and unit code. The user has the option to turn on or off all or specific appliances and can even check the status of the appliances. Table I highlights the results of our experiments with X10 based HCS. While speed of switching is quick for short

TABLE I

PERFORMANCE ANALYSIS RESULTS OF USING X10 FOR HCS

Row No.	**Parameter Measured**	**Time taken for the system to react**	**Comments**
1	Time taken for Telephone Controller to control	< 1 sec	Almost immediate and accurate for short distances (< 5 feet)
2	Time taken for appliance control	< 1 sec	Almost immediate and accurate for short distances (< 5 feet)
3	Bandwidth of computer accessing internet over network	12000 bps	Without X10 it is 20kbps-So sufficient redirection in bandwidth
4	Bandwidth of computer accessing another element in network	12000 bps	Without X10 (for example, using wireless) it is much faster
5	Connecting appliance more than 20 feet from controller	Very poor (does not work at all)	Data signal attenuation seems to be the issue
6	Propagation of X10 signals in case of 240 volt devices	No reliable path(does not work at all)	Low-impedance bridge between two phase wires seems to be the issue
7	Propagation of X10 signals incase of low power devices below 50 watts	May not work well	Minimum resistive loads is must for accurate signal transmission
8	Transmission of signals	One at a time	Signals can only be transmitted one after the other for proper transmission and to avoid collision

distances (less than 5 feet) as shown in rows 1 and 2 of Table I, however, over longer distances (> 20 feet) there is no signal received at all (row 5 of Table I). Moreover, bandwidth using X10 is usually considerably less than other alternatives – in fact it is only about 65% of dial-up phone connections (rows 3 and 4 of Table I). Then there is the problem of unreliable signal propagation (rows 6 and 7 of Table I) and of half-duplex transmission (row 8 of Table I). Home Control System is an integration of HACS and HSS.

As seen in table I the performance, power consumption of X10 depends on several factors apart from its advantages including being inexpensive, no new wiring required, simple to install, compatible with many products, controls up to 256 devices it has many drawbacks as well. The drawbacks of X10 are signals from a transmitter in one live conductor may not propagate through the high impedance of the distributed transformer winding to the other live conductor. Often, there's simply no reliable path to allow the X10 signals to propagate from one phase wire to the other; this failure may come and go as large 240 volt devices such as stoves or dryers are turned on and off. (When turned on, such devices provide a low-impedance bridge for the X10 signals between the two phase wires.) This problem can be permanently overcome by installing a capacitor between the phase wires as a path for the X10 signals; the manufacturers commonly sell signal couplers that plug into 240 volt sockets that perform this function. More sophisticated installations install an active repeater device between the phases, while others combine signal amplifiers with a coupling device. A repeater is also needed for inter-phase communication in homes with three-phase electric power.

Some X10 controllers may not work well or at all with low power devices (below 50 watts) or devices like fluorescent bulbs that do not present resistive loads. Use of an appliance module rather than a lamp module may resolve this problem.X10 signals can only be transmitted one command at a time. If two X10 signals are transmitted at the same time, they will collide and the receivers will not be able to decode the signal commands.

The X10 protocol is also slow. It takes roughly three quarters of a second to transmit a device address and a command. While generally not noticeable when using a tabletop controller, it becomes a noticeable problem when using 2-way switches or when utilizing some sort of computerized controller. The apparent delay can be lessened somewhat through the use of scenes and by using slower device dim rates.

These transmitters send a specially coded low-voltage signal that is super-imposed over the 120 volts on the home's electrical wires. A transmitter is usually capable of sending up to 256 different addresses on the AC line. Multiple transmitters can send signals to the same module.

Devices with this symbol receive the special signals sent by the transmitters. Once a matching signal comes in, the device responds and turns ON or OFF or dims or brightens. Receivers generally have "code dials" that are adjusted by the user to set the address. Multiple devices with the same address can co-exist in the same home.

Any product displaying this symbol transmits & receives X10 signals. These devices both send and receive X10 signals. Like regular receivers and transmitters, they can communicate on all 256 addresses. 2-Way products are helpful for status reporting and triggering other receivers to turn on, off or even run a macro event (a multi-step event run by an intelligent controller).

Based on this analysis we feel that X10 negatively impacts the performance of HCS due to the following reasons:

1. Time to respond to the user is fast for short distances – however, over the typical average long distances between the controller and the appliance encountered at home, the time to respond increases rapidly; the signal is sometimes so weak at the receiver that the receiver is not able to detect the signal at all.
2. Bandwidth is significantly reduced with X10 mainly due to the overhead involved – one may argue that since the average data lengths are short whether bandwidth is an issue: this advantage is quickly overcome by the fact that the communication is half duplex and that when several nodes try to communicate the bandwidth becomes a liability.
3. Cost is usually low since no connectors need be installed between the controller and the appliance – however, amplifiers and noise filters are needed to send signals properly to distant nodes on the network and this quickly drives up the cost.
4. Ease of use may initially appear to be a strong point of the X10 technology – however, if the signal attenuation due to distance and line quality is significant then the system may well become unusable.
5. This technology is only accessible from home and not from outside – some form of converter will need to be used between outside connections and internal wiring; for example, if one requires that an appliance respond to commands from laptop in the homeowner's office, then the commands will have to be received over DSL or cable modem at the home and converted into X10 signals for transmission over home wiring which not only adds to the cost but could also result in undesirable delays.
6. Presence of noise and other disturbances on the power lines significantly impact the performance of HCS negatively: X10 devices such as lights are triggered randomly without any control command being sent to them. Heating pads and fluorescent lights also seem to affect X10 devices. An experiment that used a USB connection between the computer and the power line also did not alleviate the problems due to power line disturbances.

A. Suggested Improvements to HCS

Based on our experiments we would like to suggest the following improvements to the technology of using power lines as connectors for HCS:

1. Use of different protocol such as PL-201 [34] or BPL (Broadband over Power Line) [36] for HCS – this could significantly improve bandwidth and access of the line for the nodes.
2. Change of the protocol frame structure so that overhead is reduced and thereby possibly increasing throughput.
3. Possibly adopting different wiring standards (similar to the Home plug initiative [36]) for homes in the future so that the capabilities of the power line are increased for broadband internet access as well.
4. Use power line noise eliminators for reducing effects of power line disturbances on X10 devices. Ground fault circuit detectors may also help to reduce this problem.

V. Conclusion and Future Work

Home Control Systems (HCS) are expected to be increasingly prevalent in future homes. HCS is an integrated system that includes HACS and HSS. HCS is expected to improve quality of life for the people living in the future home by giving them unparalleled ability to remotely control their way of life at home. Performance related measurements of HCS are important to the industry and consumers so that concerned stakeholders may make the appropriate choice of HCS for their homes.

We have procured some of the commercial HCS equipments and evaluated their performance aspects. A commonly used technology in HCS for communicating with household appliances and equipments is the power line infrastructure at home. The X10 protocol is used to communicate between the controller and the appliance over the power line. While this technology is cost effective and relatively easy to use, the performance of this technology has considerable scope for improvement. During our experiments we observed the problem is weakening of X10 signal due to distance from the transmitter, reduction in bandwidth compared to even analog telephone line for data transmission, and inability to easily switch from one phase to another. Our recommendation is that HCS may need to use another type of protocol such as the PL-201 [35, 36] to the receiver, possible change of protocol frame so that overhead is reduced and possible adoptions of better wiring standards for the home. Noise and other disturbances in power lines negatively affect X10 devices by spuriously triggering the devices.

For the future we plan to study the application of the improvements suggested above for practical HCS including techniques to mitigate the effects of power line disturbances.

Also integrated approaches that use different types of technologies for HACS and HSS may need to be used so that case one system fails the others may step in (in the spirit of the view-based approach [2]) – this is similar in concept to the INSTEON technology [37]. Finally, we would like to adopt the HCS technologies to other larger networks such as the LAN, MAN, WAN, and finally the Internet itself.

VI. ACKNOWLEDGEMENT

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VIII. BIOGRAPHIES

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