2017 2nd International Electrical Engineering Conference (IEEC 2017)
May 19th -20th, 2017 at IEP Centre, Karachi, Pakistan

HOME AREA NETWORKS: A Cost Effective Design and Its Implementation

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Abstract: Home Area Network systems represent the forepart of smart grids. Inside the smart home, the smart devices, installed, enable energy monitoring and control operations within the households, residential and industrial structures. This paper is contemplated to provide design and implementation of a cost effective, useful and reliable Home Area Network System. The main objective is to appraise all the parameters involved in the designing of a Home Area Network and come up with a best possible solution especially for the implementation of the HAN system in developing countries.
Keywords: Home Area Network, Automation, Technology, Power monitoring, Communication protocols.

I. INTRODUCTION

Home Area Network (HAN) is a stand-alone system installed within the home of a residential electricity consumer. It allows exchange of information between electronic devices, in-home LCD screens, microcontrollers, energy management devices, load control devices, distributed energy devices and smart meters. Advanced HANs are capable to hook up lighting, entertainment systems, heating systems, security, air conditioning and other home appliances into one centrally controlled scheme. User can control and monitor power usage of electrical loads in a communal home environment to facilitate the control without considerably altering the present home infrastructure. Home Area Networks can either be wired or wireless. Wireless communication network can be designed using one or more protocols. It utilizes electrical power distribution wiring of a home for control and signaling, where signals transmitted and received are short radio frequency packets of digital messages. Just like other electronic systems, HAN can employ a number of alternative protocols for communication between electronic devices. There are many recognized communication standards used in industries for home automation systems, which are implemented over diverse carrier modes varying from power line to wireless. These technologies have evolved in the past half century considerably [7] [6].

A. Benefits of HAN systems

It is designed to be implemented in existing home settings. It provides customer autonomy and greater control of the home environment and settings. Power monitoring feature of HAN enhances home's energy usage reduction by ensuring only essential electrical energy is being consumed. These systems help to promote energy management [7] [3].

B. Main Features of HAN systems

1) Communication Network: New age automation systems are generally wireless technologies. An appropriate set of communication protocols are selected to perform wireless functions of remote devices control and information transference of power usage between rooms (room's communication modules).

2) Power Monitoring: HAN helps in energy management. Current sensors incorporated serially with each load gives information about current flowing through each load, and consequently, power usage at regular time intervals at home. Through this electricity wastage is truncated and cost of daily usage of electricity is reduced.

3) Lightning and Appliance Control: In-home, lightning and other appliances can be controlled instantaneously and remotely. Automated controls can switch machines on or off, they can be triggered on the spot or distantly through remotes or smart phone applications.

II. EVALUATION OF WIRELESS TECHNOLOGIES

The wireless Home Area Networks are more reliable, smart, and, easy to operate, To design an effective HAN, the available wireless technologies: Zig-Bee, Z-Wave, Insteon, X10, Wavenis, EnOcean, Bluetooth Wi-Fi and GSM were evaluated on the parameters of cost, range, data rate, ease of installation, and availability. This helped in the selection of best possible combination of wireless protocols for communication part of HAN system. Table. 1, provides comparison of parameters on which the above mentioned wireless technologies are evaluated. The evaluation in detail is as follows [2] [3] [5] [6].

A. Usage of energy

Energy usage is one of the major performance factor. Z-wave, INSTEON and X10 are high users of

Table. 1 Comparison of wireless technologies

Inventor	Bluetooth SIG	WI-FI NC&R Corp	GSM ETSI	Z-Wave ZenSys Corp	ZigBee ZigBee Alliance	INSTEON Smart labs inc	EnOcean EnOcean GmBH	X10 Pico electronic	Wavenis Coronis systems
Main Usage	Mobile PAN	Wireless LAN	Cellular Networks	Home Automation	Automation and Research	Home Automation	Industrial Automation	Home Automation	Automation
Data Transfer	RF	RF	RF	RF	RF	RF	RF	RF	RF
Energy Use	Low	Low	Low	High	Medium	High	Nil	High	Low
Full Duplex	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes
Range	10-100m	32m	Infinite	120m	60m	120m	>20m	30m	Up to 4km
Installation	Easy	Easy	Easy	Easy	Medium	Easy	Medium	Hard	Hard
Data Rate	2.1mbps	2mbps	270kbps	40kbps	20kbps	2000bps	125kbps	20-200bps	100kbps
Cost	<$50	$50	$50	$500	$800	$470	$370	$170	>$500

energy. Since the system is targeted to be energy efficient, Zig-Bee, Bluetooth and Wi-Fi are the options, in which power usage is comparatively lower. Wavenis is ultra-low power technology (17mA is the RX current and 45mA is the TX current in full run mode, 25mW is the output power). EnOcean is the most energy proficient, it is an energy harvester, so it does not require any batteries.

B. Data rate for communication

As evident from Table. 1 only Bluetooth and Wi-Fi have data transfer rates considerably high to hold up systems like HAN which favors uninterrupted automation jobs. The rate of data transmission for X10 is stumpy, that is in the order of 20 to 200 bits per second, thereof confining the technology to ON/OFF operations only.

C. Transmission range

GSM clearly stands out in this field of assessment with a range that can access HAN from anywhere across the globe. Table. 1 shows clearly shows that Zig-Bee, Z-wave, and INSTEON have considerable range of transmission. Among them Z-wave and INSTEON have the highest range of 120m. The range of Bluetooth modules can be stretched to 100m (HC-05 FC-114 modules) [4] [1].

D. Ease of Installation

The protocols which can easily be installed in home environment without substantially changing the existing wiring are the favorable ones. Zig-Bee, INSTEON, Wavenis and EnOcean are relatively arduous to set up. INSTEON and X10 based HAN are a combination of power line and wireless communication protocols, which changes the existing wiring of home and it is a critical task to implement them [4] [1].

E. Cost

Being the frequently used multi-purpose communication protocols Bluetooth and Wi-Fi are the most affordable of all (less than 100USD). This promotes the usage of these communication protocols for HAN systems in very large homes or residential buildings as mostly multiple modules are used in each of these systems. Zig-Bee and Z-wave are the most recently developed protocols introduce in this industry and they are the most expensive ones (500USD) [1] [4].

F. Popularity

Bluetooth and Wi-Fi are versatile communication protocols in the list. They are widely used for small automation projects and they can be integrated into HAN systems. Other protocols are specific to home automation industry only.

G. Conclusion reached

Based on above mentioned deductions, it is established that a combination of Bluetooth, Wi-Fi and GSM communication protocols is a suitable choice for making HAN systems. From Bluetooth to GSM range is increased from 10 m to infinite. Low cost and low power consumption benefits promises to makes HAN energy efficient system. Full duplex (two way communication) along with sensor network will facilitate control of various appliances at home coupled with power dissipation monitoring of total house loads. The top seed advantage of these systems is their cost effectiveness; they all fall under the price limit of 100USD. These technologies are flexible enough to work with any micro-controller/processor and they can integrate with any electronic component effectively.

III. SYSTEM DESIGN AND IMPLEMENTATION

Based on above conclusions a Home Area Network system using Bluetooth and Wi-Fi protocols is designed and implemented. Primary elements of our Home Area Network are:

1) The operating system (for example, a computer or a microcontroller).
2) The device being controlled and monitored (for example, a light or Air conditioners, or other appliances etc).
3) The interface, or link, between the user and the device. An interface can be a button, a keypad, or on a smart phone application based on a suitable wireless communication network.

A. Wireless Home Automation Scheme with android application

A wireless communication network that does not cause additional costs of extensive deployment would be desirable. Bluetooth technology, which came into sight in the late 1990s, is a perfect answer for this cause. Bluetooth works well with wide variety of microcontrollers and it also promptly responds to commands given to it. It is cost effective technology, thus it provides an inexpensive way to automate any size of home. Bluetooth is also attuned to work with new age smart phones [8][10]. That is why it is preferred to use Bluetooth protocol for controlling the appliances connected through the relay module to the Arduino Board (Short Range Communication). The Bluetooth module HC-05 is connected to the Arduino through its serial port. It allows the Arduino to receive and read the user commands regarding the appliance state and execute them according to the program stored in the Arduino. This setting makes our HAN system wireless and smart. A piconet is made in which the smart phone will act as a master and the HC-05 modules will work as slave.

B. Android application to control the data transfer

The smart phone application is used to control various appliances that are connected to digital pins of Arduino through relays switches. When the ON OFF toggle buttons on the android application are pressed, synonymous signals are sent from application to the Bluetooth modules hooked up to Arduino device. There are predefined signals values stored in Arduino program. The micro-controller compares signal value sent with that assigned for each appliance. When it recognizes that signal, then the Arduino energizes the respective relay coil connected to its digital pin by passing 5V through it. Thus the appliance connected to relay is switched ON. To switch it OFF, Arduino passes logic low to its digital pin. Fig. 1 shows android application as designed for our system. LIGHT 1~5 labels are used, which corresponds to five appliances in a room, (names can be changed according to appliances controlled).

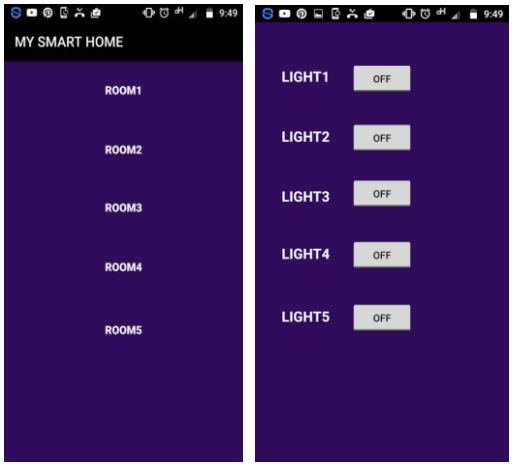

Fig. 1 Android Application.

C. Installation of Relay Modules

A relay module for interfacing the appliances with the Arduino (microcontroller) is installed in each room. It consists of an NPN transistor based Relay Switching Circuit. The working of this circuit is described below.

A typical relay switch circuit has the coil driven by base of an NPN transistor, which depends on the input voltage level. When the base voltage of the transistor is less than 0.7V, the transistor is operating in cut off region and switch acts as open. This situation signifies that no collector current flows, and the relay coil is not energized, being current devices, if no current flows into the base then zero current will flow through collector and emitter, and similarly through the relay coil. If a large positive current is now coerced into the base, the transistor's base is saturated, the current flows from the base to emitter and controls the huge relay coil current flowing from the collector to emitter of the transistor. For nearly all transistors switches which are bipolar, the total of coil current flowing into the collector would be up to 800 times that of the essential base current to force the transistor into saturation.

As each relay in the module is interfaced with the appliance through Arduino digital pins, thus it operates only when Arduino allows it to operate depending upon the type of command given by the user through android application to any appliance. This gives a smart control of appliance to the user.

The above proposed design is implemented on a five room home, with five loads in each room. Each room has its own relay modules connected to the main switch boards through which the switching of appliances of that particular room will be controlled. A single android application is developed in which each room's Bluetooth module address is programmed to its corresponding room button. When user enters any room through the application, an automatic communication link is made between the room and smart phone.

D. Power Monitoring Scheme

This distinctive home power monitoring system includes a data communication system, sensors and a display to collect and view the information. Monitoring using sensors is done at each point of measurement. The sensors are hard-wired to an Arduino device and local display. The wireless monitoring of electrical power meter using ACS712 current sensor is proposed. This research project used the Hall Effect current sensor to monitor the value on real-time function and to facilitate easy interpretation of the electrical power meter. The end part of this current sensor and Arduino configuration sends the data to the central LCD screen and on our smart phone application, which can communicate with the reader several meters away.

E. Arduino integrated with hall-effect current sensor configuration

The very cheap ACS712 current sensor modules are available all over the world. So, it is a familiar electronic component to use. The ACS712 device consists of a accurate, low-offset, linear Hall circuit. Near the surface of a die, its copper conduction path is positioned. It is an isolated path device, it monitors mains current or else any other high voltage path that is secluded from the system. Magnetic field is generated by the applied current that is flowing through the ACS712 copper conduction path, which the hall IC converts into a relative voltage value. Accuracy of the device is optimized through the thorough proximity of the magnetic indication to the Hall transducer. The output of ACS712 is an analogue signal, VOUT varies linearly with the AC or DC primary current, which can be both uni or bi-directional. A power supply of 5v (Vcc) is required and a couple of capacitors to filter power supply and output. ACS712 current board has 3 different variants, it depends on the highest measured current: 5A 20A or 30A. 5 amps module is used in the proposed system [9].

Features of ACS712 Hall effect current sensor:

1) Supply voltage (VCC) 5VDC
2) Measurement Range -5 to +5A
3) Voltage at 0A VCC/2
4) Scale factor 185mV/A (5 A variant)
5) Variant ACS712ELC-05A

Each 5A module is connected in series with each load. The measured values of sensors are given as an input to the analog pins of Arduino board. Through proper calculations using sensor constants, current flowing across each load is calculated. The measured values of currents are used to calculate power dissipation across each load. The entire calculations performed on measured values to calculate power usage are programmed onto the Arduino.

Fig. 2 illustrates main system architecture as implemented in one room. Same design is implemented in all five rooms.

F. Information transfer from CLIENT ESP8266 Wi-Fi modules to SERVER ESP8266 Wi-Fi module

The Wi-Fi Module ESP8266 is a self enclosed system on chip. It is integrated with TCP/IP protocol stack that gives a extensive variety of microcontrollers a way in to Wi-Fi networks. The ESP8266 is competent to either host an application or off-loading all Wi-Fi networking jobs from a different application processor. An AT command set firmware is already programmed into every ESP8266 module, user can simply connect it to the Arduino device and get about as much Wi-Fi facility as a Wi-Fi Shield offers. The ESP8266 module is a very cost effective board with a vast and ever rising

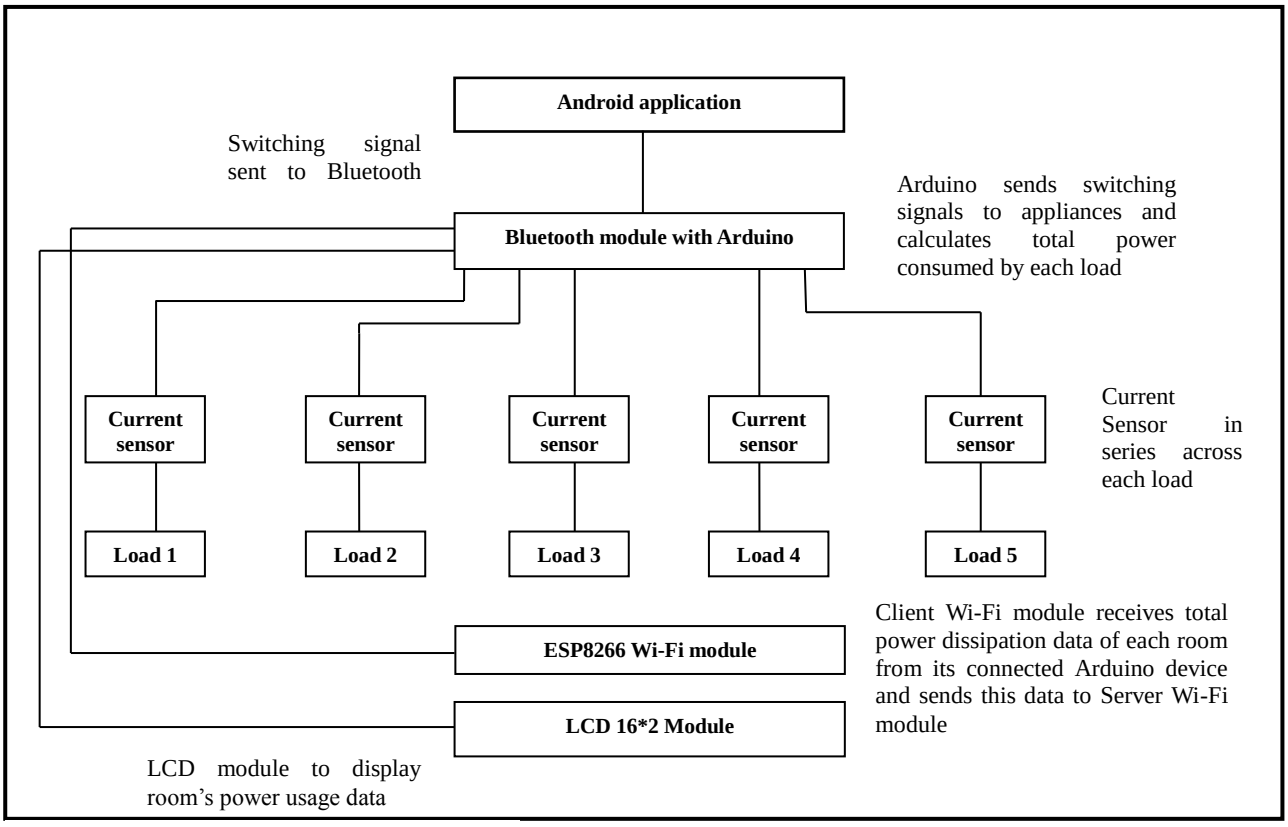

Fig. 2 Room Architecture

community.

Since a HAN system which is cost effective is targeted, ESP8266 modules are used to transfer power usage data from each room to central ESP8266 module connected with LCD. Fig. 2 shows ESP8266 Wi-Fi module integrated with Arduino. A server–client network will be established in our home area network. Fig. 3, explains how a wireless communication network using sever-client topology will be established between rooms. Since data regarding current from sensors would be analog, Arduino would be used to collect and combine data from all the current sensors connected across each load. Through wired serial communication data from Arduino will be sent to ESP8266 modules. Central ESP8266 will act as a server, while rest of the rooms will work as clients. After regular intervals of time power data from each room will be sent to server. At regular intervals of time the power data will be displayed on screens present in each room and combined power figures will be displayed on central LCD screen.

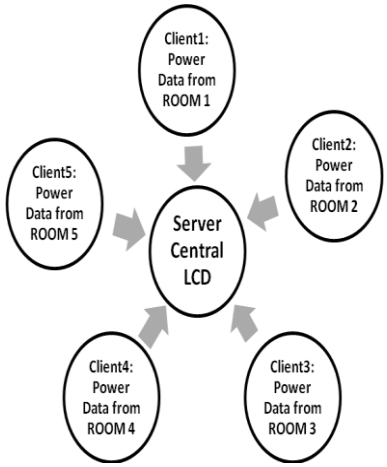

Fig. 3 Server Client network flow diagram.

G. Data from ARDUINO to LCD displays

Power consumption data of each room will also be displayed simultaneously on LCD placed in each room and subsequently on the central LCD. The necessity for having a computer or any other device is eliminated due to availability of LCD module connected with Arduino to display the power data. The basic Arduino board does not have a LCD module integrated into it originally, it is connected superficially to display data. The LCD module is approached easily with the help of libraries in the Arduino IDE software.

H. Data Transfer to Smart Meters

Power consumption data of entire house load is also send to the smart meters installed in homes. This makes HAN systems an integral part of smart grid.

IV. CONCLUSION

In this paper, a comprehensive evaluation of widespread Home Area Network communication technologies along with design and implementation of a cost effective HAN System is proposed. Home Area Network systems are products primarily launched under the banner of smart grids (integrated with smart meters). It is concluded that a combination of Bluetooth, Wi-Fi and GSM communication protocols is a apposite choice for making HAN systems. In this paper, a design for HAN system is proposed using Bluetooth and Wi-Fi protocol. Range of Bluetooth modules (HC-05) can be increased easily according to the size of the complete infrastructure. Low cost and low power consumption benefits of the technologies used promises to makes HAN energy efficient system. Full duplex (two way communication) with server client network is also possible. The systems are implemented on the embedded system platform of Arduino devices. These systems can integrate with any electronic components efficiently. This will help to make wide-ranging, interactive, energy efficient and affordable HAN products, which would be easily implemented in differently sized homes. The forerunner advantage of these systems is their cost effectiveness, they all fall under the price limit of 400USD. The proposed HAN system is certainly cost effective, reliable and user-friendly. It is concluded that hybrid communication networks are a likely future scheme of these products.

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