Add brain cells to your home

A Technical Paper prepared for the Society of Cable Telecommunications Engineers
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Overview

This paper marries two functions of convenience within a home: automation and remote-control. Home automation has been made incredibly possible by technologies such as ZigBee and Zwave.

In the world of smart phones and Wi-Fi prevalence, remotely managing a home is quite feasible. This paper discusses the ease of remote management with proper security. For operators to deliver a fully automatable home system, they will need to have an extensible server infrastructure. The remote application will need to interface with an infrastructure that could validate the user via the appropriate credentials.

To make home automation real, sensor networks will need to be carefully aligned to perform as a singular network within the home. The sensor network within a customer's home is greatly enriched by the plethora of sensing technologies available today.

In conclusion, the potential behind whole home management using centralized control is detailed with real world scenarios. The objective of this paper is to prove that scaling of such a system is possible by combining the volume of broadband with the ease of wireless technology.

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Introduction

In the last decade, global lifestyle has seen a change in social-economic structures, population structures and most importantly, use of information technology. This phenomenon combined with the increased demand for safety, comfort and efficiency has created a market for the smart home.

Home automation is the residential extension of building automation. It is automation of the home, housework or household activity. Home automation includes various categories such as centralized control of lighting, heating, ventilation and air conditioning, appliances, security locks of gates and doors and other systems, to provide improved convenience, comfort, energy efficiency and security for the smart home[1].

Home management through mobile phone, web portal, and text/email has been made possible significantly by the emergence of over-the-top (OTT) applications. In the next upcoming paragraphs, we will determine how to smarten a home using IEEE standard protocols for secure and smart communications.

ZigBee, the Protocol

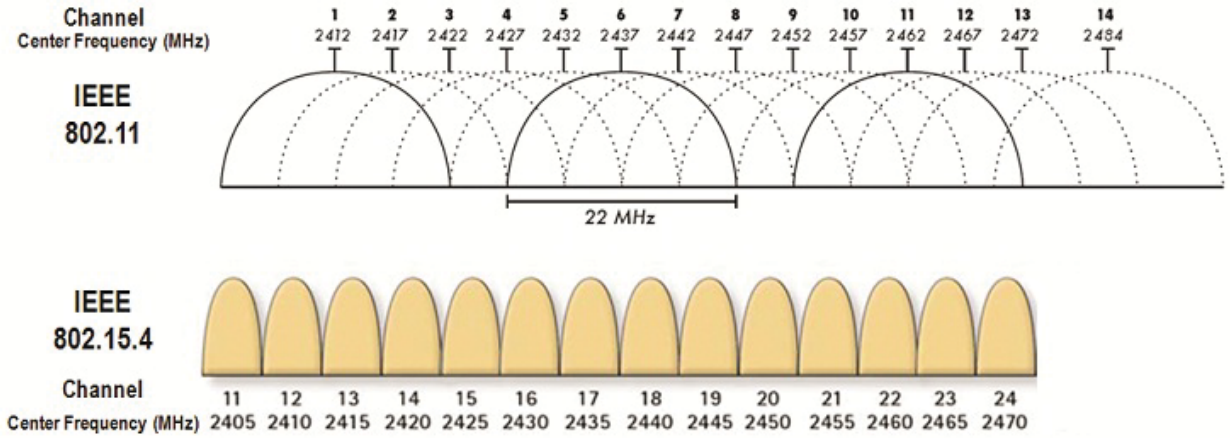
ZigBee is a specification for a suite of high level communication protocols using small, low-power digital radios based on an IEEE 802 standard for personal area networks. ZigBee devices are often used in mesh or star network form to transmit data over longer distances, passing data through intermediate devices to reach more distant ones. This allows ZigBee networks to be formed ad-hoc, with no centralized control or high-power transmitter/receiver able to reach all of the devices.

The ZigBee module conforms to the IEEE 802.15.4 standard. Operating over a 2.4 GHz spectrum, the ZigBee protocol specification allows for the use of 16 channels [2]. In the solution for home security & automation, the number of authorized ZigBee channels is kept specific to channels such as channel 15. The selection of these specific channels is because these channels are in-between other 802.11 Wi-Fi channels with almost no overlap, thus reducing or eliminating interference. The module includes logic that will allow moving communication channels between 'allowed' channels. Each channel is 5 MHz in bandwidth, and the centralized controller includes logic similar to frequency hopping that will scan channels to detect and report on RSSI/LQI values of connected devices.

ZigBee and Wi-Fi Harmonious Coexistence:

Wi-Fi, Bluetooth, and more recently, ZigBee, operate in the unlicensed 2.4 GHz band, also known as ISM band, which has been key to the development of a competitive and innovative market for wireless embedded devices. But as with any resource held in common, it is crucial that those technologies coexist peacefully to allow users of the band to fulfill their communication goals [3]. The IEEE 802.15.4 specification augments the opportunities for smooth coexistence by dividing the 2.4 GHz band into 16 non-overlapping channels, which are 2-MHz wide and 5-MHz apart as indicated in Figure 1.

Specifically, the key reason why ZigBee and Wi-Fi operate so well together is the spacing of the frequencies as indicated in Figure1 [4].



ZigBee versus Other Home Networking Protocols:

Why did we pick ZigBee? There are several home networking protocols to choose from. In the next upcoming paragraphs, we compare the various feasible home networking protocols, specifically; the scope of comparison is ZigBee versus Wi-Fi, Bluetooth, Wireless USB, Wibree (now merged with Bluetooth LE) and Zwave.

To help make the decision making easier, we will compare these above technologies based on the following criteria:

1. Power consumption
2. Network range
3. Number of devices supported
4. Bandwidth throughput
5. Ease of development

Only ZigBee, Wi-Fi and Bluetooth have an IEEE standard assigned. Wireless USB is based on USB standards. Bluetooth LE was originally introduced under the name Wibree by Nokia in 2006, but it was merged into the main Bluetooth standard in 2010 [5].

From a power consumption perspective, Zwave and ZigBee are the lowest power hogs. They both incorporate sleep algorithms that save battery life. A common ZigBee or Zwave sensor can last up to 2 years without needing a battery change. Bluetooth also has a lower power utilization compared to Wi-Fi or wireless USB.

Based on network range, Wi-Fi and ZigBee have the longest distances. However, over ZigBee, longer distances mean that the low power rating will start to slip, because it costs more to communicate over longer distances. Typically most of the above mentioned technologies can function with a signal repeater; however, Wi-Fi and ZigBee are the most common standard repeaters in the market.

For a minimally automated home, it is usual to have ~20 sensors. A well automated home can have upwards of 100 sensors. Bluetooth can have a maximum of 7 endpoints in its low energy network. Zwave can have a max or 232 endpoints, while ZigBee can have 65,536 endpoints thanks to its ability to use IPV4 addressing.

When ZigBee matures to have IPv6 addressing, the number of endpoints per network is not even a constraint since by virtue of IPv6, virtually every device on the globe can have its own unique IP address.

With respect to bandwidth, Wi-Fi is the hands down favorite. With IEEE 802.11ac, the user can ideally achieve up to 500 Meg/sec throughput. However, bandwidth ability comes with a price on power. Bluetooth and wireless USB are also fairly high bandwidth capable. In this category, ZigBee has the lowest throughput. Luckily, home automation systems that incorporate sensing technologies do not require high throughput.

In the table below [6], clearly compares the specific items mentioned above.

Criterion	ZigBee	Wi-Fi	Bluetooth	Zwave
Power consumption	Very low	High	Medium	Very low
Network range	<100m	<100m	<10m	<100m
# of devices supported	65,535	65,535	7	232
Throughput	<250Kbps	>=500 Mbps	1Mbps	40Kbps
Ease of development	Moderate	Easy	Easy	Moderate
Selection	Best choice			

A Sensor for Every Job:

Now that we have decided ZigBee is the technology of choice, the next step will be to explore the world of sensors. Virtually every measurement within the home has a sensor that can communicate via ZigBee. Sensors are generally grouped into the following categories:

- Perimeter sensors
- Motion sensors
- Proximity sensors
- Appliance sensors
- Thermal/pressure/light sensors
- Liquid/gas sensors

Perimeter sensors

This category refers to sensors that guard and detect entry and exit. This includes door sensors, window sensors, glass break sensors, curtain sensors etc.

Motion sensors:

As the name suggests, these sensors detect movement and obstruction. Many sensors in this category are intelligent enough to distinguish based on weight (such as a pet). Some varieties look for a specific beam of light from the sensor such as a curtain sensor, while others detect IR motion. Many motion sensors are embedded within the camera.

Proximity sensors:

These detect objects as a function of distance. For example, car sensors for distance control, parking sensors, garage sensors etc.

Appliance sensors:

These turn on or off appliances such as kitchen gadgets. They normally have an ON/OFF setting which mimics a switch, or therefore a hand gesture.

Thermal/pressure/light sensors:

These detect temperature, pressure and light. Depending on the intensity, these sensors can perform certain actions. For example, a light sensor detects light intensity of an environment and sends a modulating (on or off) command automatically according to preset devices such as curtain motors, electromagnetic valves, switch etc.

Liquid/gas sensors:

This category includes water sensors, flood detectors, humidity sensors, air quality sensors, carbon monoxide sensors, smoke detectors etc.

Build Your Own Sensor:

One could pretty much take any type of sensing technology and add a ZigBee circuit board to it and make a wireless ZigBee capable device[7]. For example, consider existing devices that determine if a furnace needs cleaning or toilet paper that needs to the refilled. These can be ZigBee capable by just adding a 2.5cm circuit board that takes the output from these modules and feeds into a ZigBee sensor to communicate back to the main control center.

Data Center Infrastructure:

Although the sensing technology above can directly interface with mobile apps, we want to build a smart home that is actually secure to control. That's where Comcast distinguishes itself from the many products available in the market today. A centralized server infrastructure is essential when one cares about the integrity of messaging about a home. The infrastructure is a set of application servers that front end a set of database servers. This infrastructure ensures that the in-home CPE communicate with these servers in an encrypted fashion. Figure 2 represents the logical composition.

The servers that are placed within the Comcast network ensure the following security attributes:

1. All logins via untethered devices or browsers are validated via the Comcast credentials, usually a username and password
2. The servers are housed in a data center and therefore are secure from most external attacks, protected within multiple layers of firewalls, intrusion detection systems and access control blockades.
3. Allows for encrypted communication between the home and the servers as compared to a non-centralized infrastructure which may be unencrypted and therefore readable by an attacker.

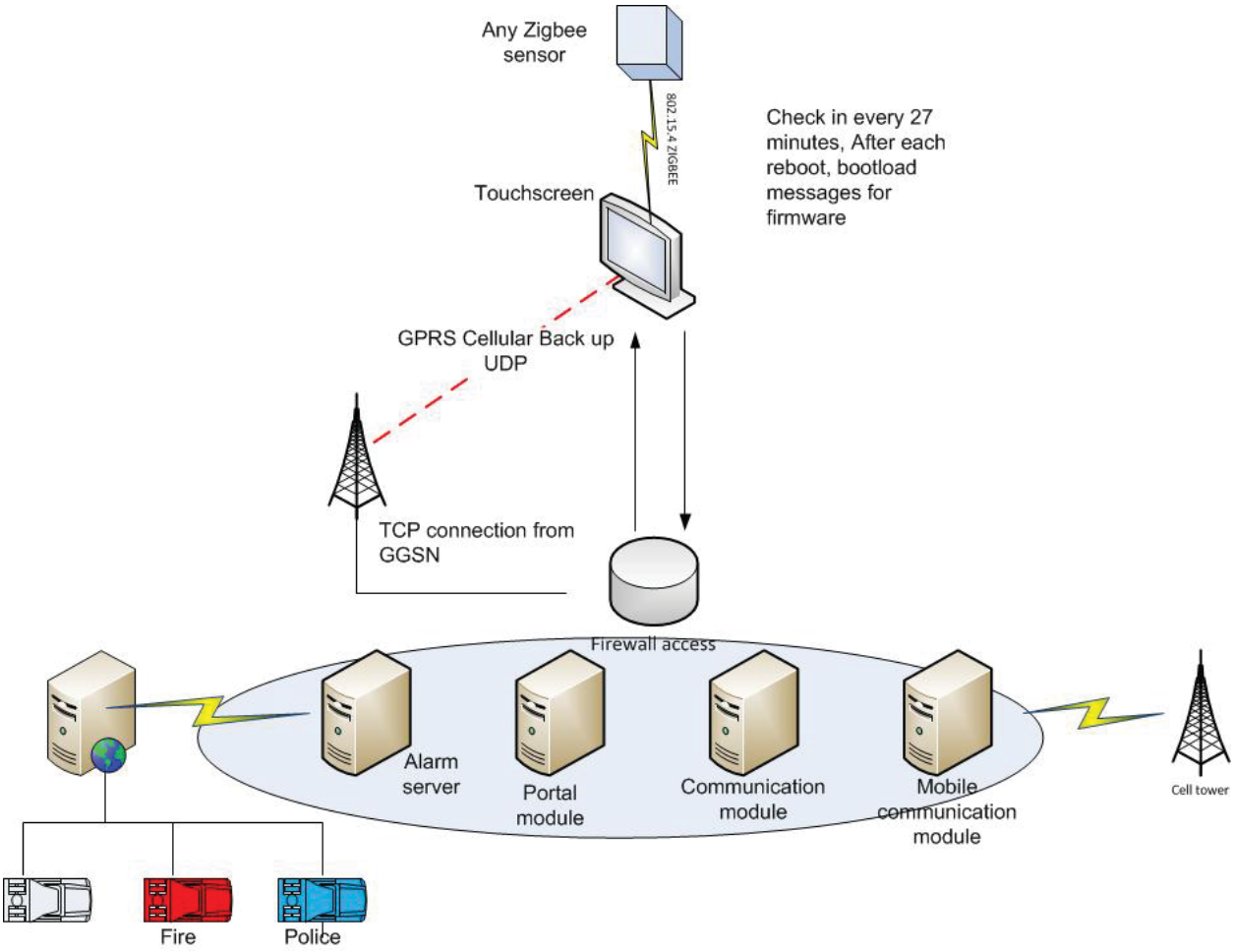


Figure 2: Data Center Infrastructure

Home-owner experience:

Imagine a normal work-day when a homeowner returns home from work. They have already received a SMS text from the home, courtesy of the door sensor, people counter and motion detector that at 3.45pm, the front door had opened and two people came in. These are their kids returning from school. Texting services were provided via Comcast's back office servers. The homeowner also has rules set up to alarm their phone in case the door does not open/close between 3.30pm and 4.00pm which is when they typically expect their kids to return from school.

Because the customer has Xfinity TV, using their app, they are also able to learn what channel is being viewed on the TV. As usual, he sees that it is the Cartoon Network.

In a second example, a homeowner completes a hard day at work, and returns home at the end of the day. Using the proximity sensor located in the smart home, the garage door will open when the homeowner's car is within 20 feet from the garage door. When

the car is inside, the motion sensor in the garage senses no motion and shuts the garage door automatically. Meanwhile, the smart door lock senses the car's proximity or user defined parameters and automatically unlocks so that the homeowner can enter the house.

In a third example, it has been a hot day at the smart home. The sprinkler/irrigation system automatically detects humidity and temperature levels and determines the duration for watering the lawn. The flower beds receive similar attention.

With the day being hot, the homeowner's smart thermostat holds a steady 68 degrees and turns off the humidifier for the home. The humidifier is turned on automatically using the humidity sensor (below 30% humidity) and the appliance control sensor. Because the day had been hot, the blinds using the ZigBee enhanced motor has automatically closed to conserve the energy usage within the home.

In a fourth example, the homeowner is now in the house with takeout from a local Chinese restaurant. Detecting people walking into the dining room, lights turn on automatically. Using the lighting sensor, the system automatically figures out the brightness level needed for lighting the room. While dinner conversations are in full swing, the doorbell rings. Fortunately, no one has to leave the table. Instead, the homeowner is sent a picture of the person ringing the doorbell, owing to intelligent rule management within the smart home. The camera on the front porch is set to take pictures any time the motion sensor on the front porch is triggered and sends the images to the homeowner in real time. This time, it is only a salesman hanging marketing material on the door knob.

These scenarios could continue, but the idea behind these examples is hopefully apparent. And unfortunately, it is beyond the scope of this paper to discuss our homeowner settling back in his easy chair as a cold beer is delivered to him by his faithful robot.

Smart Owner Tracking (SOT):

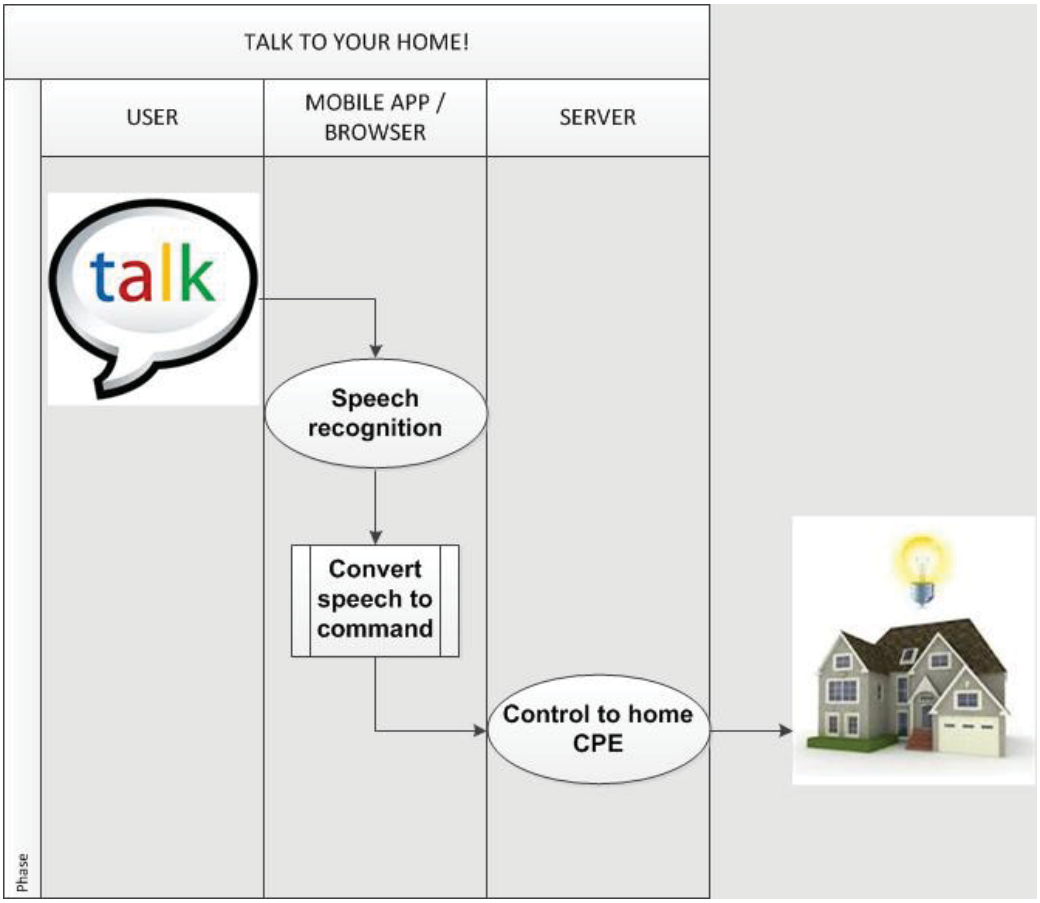
By now, it is quite evident that the smart home industry is leaning towards a new phenomenon: SOT "smart owner tracking", which tracks where people are within the home. The system also tracks their preferences. When merged with intelligently built rules, one almost can do away with light switches, legacy thermostats, garage door openers, old door locks and much more.

TTYH! Talk to Your Home:

Lastly, we discuss the voice operated home [8]. The concept allows a subscriber to say a command into their mobile app or web browser and have the system perform the function. For this function to work, the following are required:

1. Already existing mobile app or browser with application open
2. Mobile app that incorporates talk to text/command
3. The command is then sent as if it is any other request to the server to be carried out

With this set-up, the command is then sent as if it is any other request to the server to be carried out (see Figure 3). For example, a subscriber could say “night mode” via their browser/mobile app. The system kicks off night mode activities which include locking all doors, ensuring all windows are closed, switching on night time temperature controls and turning off unnecessary lighting. The home automation system will also arm the security component to night mode.



Conclusion:

The next generation of the home automation system will evolve into a second pair of eyes and hands in the house. They offer 99.99% availability with redundant connectivity options. These new installs ensure the home is always connected. Next generation of this architecture will evolve into an alternative offering with eco-friendly/energy management options and more lifestyle updates[11]. Sensors such as multi-zone thermostats, updates with video monitors, alerts splashing directly to all visible screens in the home are short term improvements upcoming in this whole home automation system.

It is very conceivable for a home to be conversing with the homeowner, very similar to the talking car, Kitt, from the 1980's TV show "Knight Rider" [9]. The homeowner would just be talking to their home and the home responding back.

Homes automated to the likes of Bill Gates' Xanadu[10] mansion may be economically feasible with the lower cost alternatives in sensing technology available today. It is all in the hands of the homeowner now. How much they want to automate is left to them. 'Smartening the home' is an almost essential building block of every hi-tech home.

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Abbreviations and Acronyms

APP	Application
CPE	Customer Premise Equipment
IEEE	Institute of electrical and electronic engineers
IP	Internet Protocol
ISM	Industrial, Scientific and Medical
LE	Low Energy
LQI	Link quality indicator
OTT	Over the top
RSSI	Received signal strength indicator
SMS	Short message service
SOT	Smart Owner Tracking
TTYH	Talk to your home
TV	Television
USB	Universal Service Bus
Wi-Fi	Wireless Fidelity