Contending With Multiple Wireless Technologies In The Connected Home

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By

Dana Blouin
PhD Candidate
SIIT – Thammasat University
Thailand
dtblouin@yahoo.com

Overview

As more devices become enabled for IP connectivity within the home the potential for wireless interference increases. Not all connected devices within the smart home operate with the same wireless technology; as a result some devices may in fact cause interference with one another. And important step can be taken to understand best practices in order to mitigate and avoid interference caused by competing devices in the connected home. This paper will explore different wireless technologies currently deployed in the smart home environment and their ideal use cases as well as best practices for resolving issues of interference to ensure a high quality customer experience.

Introduction

As society continues to see a higher adoption rate for the Internet of Things we are witnessing computing become more pervasive and ubiquitous in that everyday objects now contain sensor which allow them to gather data and report back to some common platform where the devices can be monitored and in many cases, controlled. The home has been by far one of the most interesting areas for expansion in the Internet of Things space allowing the technology to proliferate across many aspects of the connected home.

The connected home was once thought to center around the living room where entertainment was consumed. Consumer electronic items like game consoles and TVs were some of the first connected home devices, but this was just the beginning, that paradigm rapidly expanded to include the whole home. Today it is not uncommon to find a home where dozens of devices are connected to the Internet through some wireless medium, allowing the residents to monitor and manage devices remotely.

Products in the connected home have been created using a variety of wireless standards, this is in part a function of each product having a specific set of requirements for its operation and constraints it must operate under, and also part a function of there being no single defined standard for wireless communication in the connected home.

This paper will look at a select set of the various standards, which are available for wireless communication in the connected home and will highlight the instances where their use case will be optimal. This paper will also look at the commonalities between some of the different wireless technologies and instances where they might interfere with each other.

Defining The Connected Home

As the primary topics of this paper surround the overall concept of the connected home it is perhaps best that the idea first be defined. There are many definitions of what the connected home is from very simple definitions like “enabling devices to talk to each other” [1]. But such broad definitions are far too limiting to what the connected home really is, and what it really can be.

The connected home is far more than just connecting devices to a network and allowing them to talk to each other, that is just the first part of the concept. Connecting devices is where we begin. Devices can be connected either wired or wirelessly. It is not convenient to hard wire every device in a house and that limits the mobility of the device, which is in large part why the development and widespread usage of WiFi likely ignited the thought around the connected home. With wireless connectivity becoming pervasive it was now much easier to conceive of ways everyday devices could connect to the home network.

Devices connecting to the home network are not the only function of the connected home. Simply connecting devices to a network does not a connected home make. The true value and the true definition of the connected home is in how those connections are utilized and not only what the devices can do but what can be done with them, how the user can interact with the devices and how they can interact with each other. It is this connection coupled with these interactions that create an immersive technological experience for the user that embodies the concept of the connected home.

Wireless Technologies

Though it is the interactions with the devices that develop the true context of the connected home, that context cannot be achieved if the devices in question could not be connected to the network.

There is a wide range of wireless technologies that can be utilized, which operate on different mediums or in a different part of the same medium. The wireless options in the connected home can be vast; however, depending on the resources of a specific device not all options might be applicable.

This section will look at several wireless technologies, which are commonly deployed in the connected home and give an overview of their features and best use cases.

Wi-Fi (IEEE 802.11)

The IEEE 802.11 standard, which is better known as Wi-Fi is probably the most prolific example of home networking we have today. Wi-Fi technology is deployed in most homes and we can find it integrated as a connectivity technology in a great number of devices from our refrigerator to our mobile device. It was not long after the standard was first introduced in the late 90s that it started to gain popularity as the go-to home networking technology. To this day Wi-Fi dominates to home network market.

IEEE 802.11 as a standard has been updated and modified over the years to keep pace with advancing technology and consumer demand for greater speeds. The first 802.11 standard to be find its way into homes was the 802.11b standard which boasted a maximum data rate of 11Mbs. Looking back 802.11b was a far cry from todays most current standard of 802.11ac which has a maximum possible bandwidth of 866.7Mbs.

The 802.11 standard specifies operation in two frequency ranges. Either in the 2.4 GHz range which spans from 2.4 – 2.5GHz or the 5 GHz range which spans from 4.915 – 5.825 GHz. 802.11b/g/n were all implemented in the 2.4 GHz rage. Where 802.11b/g utilized only 2.4GHz 802.11n made use of the both the 2.4GHz and the

5 GHz frequency ranges. 802.11 a/ac are both implemented exclusively in the 5 GHz range.

The 802.11 standard defines channels to be used for communication between devices within the frequency range defined for each iteration of the standard. In the 2.4 GHz spectrum the standard defines 14 channels that can be used for communication each of which are 22MHz wide [2]. However, only 3 of the specified channels do not overlap. Channels 1, 6 and 11 are the three channels that can be used in a Wi-Fi deployment without causing any overlap, which is RF interference that can impact the network.

For the 802.11 standards that make use of the 5 GHz spectrum channel widths vary in size as follows: 20 MHz, 40 MHz, 80 MHz and 160 MHz. Of these channel sizes available 802.11a utilizes only the 20 MHz channel, 802.11n can make use of the 40 MHz channel size, while 802.11ac can utilize any of the channel widths. The 5 GHz spectrum contains a total of 24 non-overlapping 20 MHz wide channels, which can be bonded to accommodate the larger channel widths, required in the 802.11n and 802.11ac standards (Figure 1). However due to some of the channels causing interference with radar systems many consumer grade 802.11 devices will only utilize 9 of the non-overlapping channels in the 5 GHz spectrum [3,4].

One of the large benefits of the 802.11 standard is that it utilizes CSMA/CA to help it avoid collisions during transmission, which would impact its throughput. CSMA/CA works by listening for any other transmissions on a channel before it begins to transmit. If the device detects that another device is transmitting at that time it will back off for a random interval before listening again.

Wi-Fi is undoubtedly the most widely utilized wireless technology in the connected home environment today and it has many features that make it an ideal technology for some applications. However, in many cases Wi-Fi is far too energy intensive for devices that may be operating under certain resource constraints.

	802.11a	802.11b	802.11g	802.11n	802.11ac
Frequency	2.4GHz	2.4GHz	2.4GHz	2.4GHz, 5GHz	5GHz
Max Range	120m	140m	140m	250m	250m
Max Data Rate	54 Mbps	11 Mbps	54 Mbps	150 Mbps	866.7 Mbps
Channel Width	20	22	20	20, 40	20, 40, 60, 80, 160
Power Usage	High	High	High	High	High

Figure 1: 802.11 specifications by release

IEEE 802.15.4

Another standardized technology which is begging to be utilized on an increasing basis in connected home devices is the IEEE 802.15.4 standard. The IEEE 802.15.4 standard defines layers 1 and 2 in the OSI 7 layer protocol stack and can be paired with other upper layers. As a result of this specification 802.15.4 is utilized as the layer 1 and

2 of many popular protocol stacks, two of which will be looked at in this paper: ZigBee and WirelesHart.

The 802.15.4 layer 1 design includes three distinct frequency bands one for use in Europe, one for use in the Americas, and one that is available for use worldwide. The 802.15.4 layer 1 protocol also defines the use of two specific modulation schemes to be used and which frequency bands they can be used in. Finally the 802.15.4 layer 1 protocol defines a packet design, which can be used across all frequency bands [5].

Layer 1, also commonly referred to as the physical layer is the first or foundational layer in the Open System interconnection (OSI) 7 layer model. Layer 1 defines the method used to transmit data across the actual physical medium. In the case of 802.15.4 physical medium is radio frequency (RF) or wireless communication. The 802.15.4 protocol utilizes 3 distinct frequency bands, they are: 868 - 868.6 MHz which is utilized in Europe and can make use of 3 possible channels each 2 MHz wide, 902 - 928 MHz which is used in the Americas and can make use of a possible 30 channels each 2 MHz wide, and 2400 - 2483.5 MHz which is in use worldwide and can make use of a possible 16 channels each 5 MHz wide [5,6]. (Figure 2)

Layer 2 or the Medium Access Control (MAC) layer of 802.15.4 provides two primary services: data service and management service. It is the function of the data service to deliver MAC frames to and from the layer 1 functions. The management service, which manages access to layer 1 interface and offers several services [6].

As IEEE 802.15.4 is primarily designed for utilization in a PAN network one of the main considerations is that many of the devices utilized in the network environment will be power constrained and defines a low data transfer rate of 250 kbit/s and a 10 meter transmission range to help in maintain minimal power utilization. This low power consumption is a very strong fit for devices in the connected home, which must operate without the benefit of an external power source and therefore must be powered via battery.

	802.15.4
Frequency	2.4GHz
Max Range	10m
Max Data Rate	250 Kbps
Channel Width	2, 5 MHz
Power Usage	Low

Figure 2: 802.15.4 Specifications

ZigBee

ZigBee is a suite of protocols, which is predefined and based on the IEEE 802.15.4 standards. ZigBee is often implemented to allow higher-level protocols run across its network. In the connected home many remote sensors will utilize ZigBee for communication back to their gateway.

Because ZigBee is based on the IEEE 802.15.4 standard it is constrained to a maximum data rate of 250 kbit/s. Also in keeping with the IEEE 802.15.4 standard ZigBee sensors are limited to a radio range of 10 meters. These constraints help maintain a lower power consumption for the devices which is why the Zigbee has become a popular protocol for utilization of battery operated sensors such as door and window alarms in the connected home.

ZigBee is designed to utilize a mesh topology allowing sensors to create networks that span beyond the 10-meter range from their gateway. The mesh topology of ZigBee means that each sensor can create connections with each other extending the physical range, which the network can span and still communicate back to the gateway [7,8].

ZigBee also implements its own 128 bit key encryption allowing it to security transmit data. The security architecture of ZigBee is such that the encryption key can be applied to either the whole network, or to a specific link in the network depending on its configuration [9].

Because security and privacy have become such a hot topic in the Internet of Things in general and the connected home more specifically ZigBee is well suited to address this issue. The ability of ZigBee to create mesh networks so that it can reach beyond the limits of its radio and to security transmit data with 128-bit encryption position it to become a fundamental technology of the connected home.

WirelessHART

WirelessHART is a wireless adaptation of the HART (Highway Addressable Remote Transducer) protocol. Much like ZigBee, it has been based on the layer 1 and 2 specifications laid out in the IEEE 802.15.4 standard. The difference being that in this instance the HART protocols suite is stacked on top of IEEE 802.15.4 standard. And much like ZigBee, WirelessHART is targeted for use in power constrained network environments.

One of the main features of WirelessHART that sets it apart from ZigBee or other low power standards is that all of the traffic on a WirelessHART network secured. All traffic on a WirelessHART network is secured hop-to-hop and end-to-end by use of a 128-bit symmetric key for message authentication and encryption [10].

Another feature which sets WirelessHART apart from many other low power network technologies is that it has more robust routing by default and route traffic over varying routes, this feature provides a higher instance of message delivery which gives WirelessHART enabled devices the ability to be controlled remotely [10].

WirelessHART is developed on top of the 802.15.4 standard for layer 1 and layer 2 it the same as ZigBee. It also implements a mandated security architecture to ensure that data is kept private within the connected home. WirelessHART also offers a more robust native routing option, which in turn allows it devices in this network environment to be controlled via remote operation with the device. Though WirelessHART provides a more robust communications and security network architecture for communication with devices it has not experienced the popularity of ZigBee and therefore has not seen similar adoption rates with connected home products.

RFID

RFID or Radio Frequency Identification is a low power wireless technology, which is primarily used for tracking items and inventory control and operates by transmitting low power RF signals, though these are not the only uses for RFIDs. RFID tags are very common to find integrated into many products one might find on a store shelf. RFID are considered to be part of the AIDC (Automatic Identification and Data Capture), which also includes such technologies as barcodes, QR codes and Biometric information.

RFID architecture generally consists of 3 major components, RFID Tags, a RFID reader or transceiver, and an inelegancy system. The RFID tags can be either passive or active. Passive tags have no on board power supply and capture energy from the magnetic field generated by the reader when it sends out a signal for the tag to respond to. As a result passive RFID tags have a very low range, less than 10 meters and are more likely to experience interference as they transmit with significantly lower power levels. Active tags will have an onboard battery, which allows them to transmit to a further range, and also as a result of higher transmission power will allow them to transmit through great interference than passive tags [11].

The transceiver in the RFID network architecture is an active device, which is more than likely not power constrained. It will send out periotic signals to query any RFID tag that is in the nearby area. Any tags that the transceiver can reach, will communicate back with their preconfigured information. The transceiver will then forward this information to the intelligence system, which will process and store the data received from the RFID tag [11,12]

The RFID intelligence system will be sent information from the RFID transceiver, which it has in turned received from tags responding to its query. The intelligence system will then process the data received and if relevant store the information for later use [12].

RFID commonly operates in 3 distinct frequency bands. LF (Low Frequency): 125 -134.2 kHz and 140 – 148.5 kHz, HF (High Frequency): 13.56 MHz and UHF) Ultra High Frequency): 868 – 928 MHz. Though there are other application specific frequencies, which RFID might operate in these are the 3 most common ranges that will be used for the majority of applications [13] (figure: 3).

Though the vast majority of applications for RFID have thus far been in a commercial or industrial network environment there are increasing use cases where RFID is being utilized in the connected home. One area where RFID has the potential to make the largest impact in the connected home is tracking and monitoring food products in the home where a connected refrigerator or cupboard would be able to monitor items that have been placed in and track how long it has been there and give the user updates based on this collected data.

RFID	LF	LF	HF	UHF
Frequency	125 - 134.2 kHz	140 - 148.5 kHz	13.56 MHz	868 - 928 MHz
Max Range	< 10 m	< 10 m	< 10 m	< 10 m
Power Usage	Very Low	Very Low	Very Low	Very Low

Figure 3: RFID Specifications

Bluetooth

Bluetooth is a wireless technology mostly commonly known today for its utilization by mobile devices for creating a PAN to connect to peripheral devices such as headsets, keyboards and speakers. Though Bluetooth is most commonly known for its utilization in the mobile space it has applications in the connected home environment as well.

Bluetooth; which was originally standardized as IEEE 802.15.1; however, the standard was later abandoned so that the SIG (Special Interest Group) could drive the standard under the name Bluetooth. Currently the SIG maintains the standard and must certify devices that wish to use Bluetooth technology.

As a wireless standard Bluetooth is defined to operate in the frequency range of 2.4 – 2.485 GHz. Bluetooth utilizes a 1 MHz wide channel for a total of 79 channels in the spectrum. The newest standard for Bluetooth, Bluetooth 4.0 makes use of 2 MHz spacing, which drops the possible channel allocation to 40 channels in the frequency range [14]. (Figure 4)

Bluetooth uses a modulation scheme known as FHSS (Frequency Hopping Spread Spectrum) to transmit data. In the FHSS modulation scheme all of the data to be transmitted is broken into packets and each packet is transmitted on a different 1MHz wide channel in the allocated spectrum, the hops take place sequentially. In general the performance rate for Bluetooth FHSS is 1600 hops per second. Bluetooth can provide a data rate of up to 24 Mbit/s in its most current standard [15].

The current landscape for Bluetooth in the connected home is to utilize this connection technology for connected mobile devices to various other devices within the home. Some examples are: audio systems, lighting controls, entry locks, and TVs. In most applications our mobile devices are streaming data, such as audio via Bluetooth to a device so that media can be consumed. Given Bluetooth's short range and inability to create mesh networks to extend its reach it has a limited application in the connected home but has a well established usage for interacting with connected devices which require a higher data rate than IEEE 802.15.4 can provide.

BLE (Bluetooth Low Energy)

While Bluetooth is already a low energy wireless protocol, BLE is an even more power-constrained version of this protocol. BLE operates in the same frequency spectrum as Bluetooth. The difference being that BLE utilizes the 2 MHz channel spacing of Bluetooth 4.0 and as a result only has 40 channels available to it instead of the standard implantation of 79. Though these channels are twice as wide as they would be otherwise [16]. (Figure 4)

As BLE is a much lower power version of standard Bluetooth there are some significant compromises that are made to achieve such a power-constrained operation. BLE has a much lower data rate than Bluetooth, which can reach a data rate of 24 Mbit/s, by comparison BLE has a maximum data rate of 1 Mbit/s. As a result of the lower data rate BLE cannot support services such as voice and audio streaming that traditional Bluetooth can [17].

While BLE does not have the same application of traditional Bluetooth does in the connected home it does have a space within the connected home. Ultra low power technology like BLE has a place for applications like access control and indoor navigation. As connected locks become more commonplace the primary technology for communicating with those devices is BLE, and though beaconing has been primarily deployed in commercial settings there are some applications for that technology in the connected home that would utilize BLE for their implantation.

	Bluetooth	Bluetooth 4.0	BLE
Frequency	2.4GHz	2.4GHz	2.4GHz
Max Range	120m	140m	140m
Max Data Rate	24 Mbps	24 Mbps	1 Mbps
Channel Width	1Mhz	2 MHz	2 MHz
Power Usage	Low	Low	Very Low

Figure 4: Bluetooth and BLE specifications

Li-Fi

Li-Fi is an implementation of a VLC (Visible Light Communication) technology, which can be utilized as either a supplement to conventional RF communication or in some instances and use cases as a full replacement for RF technology.

Li-Fi operatives in the visible light spectrum, which is 10,000 times larger than the entirety of the RF spectrum and allows for the potential of much higher data rates. Li-Fi technology has produced data rates of up to 10 Gbit/s at short range. Li-Fi does this by modulating the LEDs inside the light on and off, or close to off without actually shutting off. The modulation happens at such a high rate that it is undetectable by the human eye, but sensitive sensors can pickup the changing in light intensity and interpret it as data [18, 19].

While Li-Fi does offer some amazing speeds, it also has some very stark limitations. Unlike RF based wireless communications Li-Fi cannot pass through walls, it requires line of sight for high data rate operation. Because it is not broadcasting information in the same manner as RF based wireless communication it has a higher basic level of security. Li-Fi has a maximum range of 30 meters for its lower data rate applications and only 0.5 meters for its highest data rates [18, 20].

Though the primary uses for Li-Fi have been focused on areas where RF wireless communication will interfere with or cause issues with some type of equipment, like on airplanes or in hospitals, Li-Fi has a clear place in the connected home. Within the connected home Li-Fi can be used as a supplement to a technology such as Wi-Fi to help mitigate interference with other wireless technology operating in the same spectrum or just to alleviate some of the traffic on the Wi-Fi Network. Deploying Li-Fi in the home could be used for streaming large files to mobile devices instead of doing so over Wi-Fi, or for covering a single room with a Li-Fi transceiver connected to the network.

	Li-Fi
Frequency	Visual Light
Max Range	0.5 - 30m
Max Data Rate	10 Gbps
Power Usage	Low

Figure 5: Li-Fi Specification

Interference issues

Many of the wireless technologies that have been covered thus far operate within the same RF spectrum in the connected home. Though many utilize different modulation and channel widths. In instances where these devices are located in close proximity to one another they can cause interference with each other, limiting the effectiveness of the connected device.

It is clear to see that the 2.4 GHz spectrum is the most congested area in the connected home (Figure 6). Many technologies operate in this frequency space and this is where the most devices operating. Since WiFi is the most prevalent wireless technology and most of its previous iterations have occupied the 2.4 GHz spectrum it will likely be some time before home devices migrate to the 5 GHz band easing some of the congestion in the 2.4 GHz frequency band.

Though Wi-Fi network deployments can be configured to operate in the same space and not interfere with each other due to none overlapping channels 1, 6, and 11 that is not the case when other technologies are deployed in the same area. The technologies based on 802.15.4 and Bluetooth technologies all operate within the same 2.4 GHz spectrum and when all operate within proximity of each other the result can be interference with transmissions [21, 22].

In the connected home deploying multiple wireless technologies will often times be the only option as not every solution will fit for each situation. While steps can be taken to mitigate interference form wireless technologies operating in the same frequency spectrum it is always best practice to attempt to segregate the wireless technologies when at all possible [21]. Figure 6 indicates which frequency spectrum technologies operate in as well as their power utilization.

A device that is beginning to become a more common occurrence in the connected homes is a smart gateway, which operates radios for several different wireless technologies. When a single device operates the radios for various technologies it can manage which the antennas best to ensure that they do not interfere with each other while transmitting and receiving information for the devices that are active on their network. This is most commonly accomplished by powering down the antennas when another is transmitting or receiving as to not cause interference, as well as managing which specific channel of the spectrum the devices are utilizing at any given time as to mitigate as much interference as possible [22].

	Frequency	Power Usage
802.11a/b/g	2.4GHz	High
802.11n	2.4GHz, 5GHz	High
802.11ac	5GHz	High
802.15.4	2.4GHz	Low
ZigBee	2.4GHz	Low
WirelessHart	2.4GHz	Low
RFID LF	125 - 134.2 kHz	Very Low
RFID LF	140 - 148.5 kHz	Very Low
RFID HF	13.56 MHz	Very Low
RFID UHF	868 - 928 MHz	Very Low
Bluetooth	2.4GHz	Low
Bluetooth 4.0	2.4GHz	Low
BLE	2.4GHz	Very Low
Li-Fi	Visual Light	Low

Figure 6: Comparison of frequency and power usage

Conclusions

As the Internet of Things continues to gain steam in the market and more manufactures are designing devices for use in the connected home the spectrum that is utilized by these devices will continue to get more crowded. Understanding the best use of each wireless technology and how it impacts and exists alongside others will help to best manage the devices and the available spectrum in the connected home.

Given the high utilization of the 2.4 GHz band the two technologies that have the greatest chances to alleviate much of the congestion will be the 802.11ac standard which moves Wi-Fi traffic to the 5 GHz band in its entirety and Li-Fi which does not pollute the RF spectrum as it utilizes visible light and can be used as a supplement to other wireless technologies, allowing devices to receive data on a secondary medium other than RF. It will be these types of blending of technology that will allow the connected home to further develop into and drive innovation.

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Abbreviations & Acronyms

802.11	The IEEE wireless standard commonly referred to as WiFi
802.15.4	An IEEE low power, short-range wireless standard
AIDC	Automatic Identification and Data Capture
BLE	Bluetooth Low Energy
bps	Bits Per Second
CSMA/CA	Carrier Sense Multiple Access / Collision Avoidance
FHSS	Frequency Hopping Spread Spectrum
GHz	Gigahertz
HART	Highway Addressable Remote Transducer
HF	High Frequency
kbit/s	Kilobits per second
LED	Light Emitting Diodes
LF	Low Frequency
Li-Fi	Light Fidelity
MAC	Medium Access Control
Mbit/s	Megabits Per Second
MHz	Megahertz
OSI	Open System Interconnect
PAN	Personal Area Network
RF	Radio Frequency
RFID	Radio Frequency Identification
SIG	Special Interest Group
UHF	Ultra High Frequency
VLC	Visible Light Communication
Wi-Fi	Common name for the IEEE 802.11 standard
WSN	Wireless Sensor Network