EE284A Group15

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One Unified Smart Home Ecosystem Does Matter

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1. Introduction

A unified ecosystem has always been at the heart of the concept of a smart home. Early ideas consisted of a home controlled by a computing device that used a single communication protocol to interact with a wide variety of appliances from toasters to thermostats (Andrews, 1990). The public got their first glimpse of what this looked like in the 1960's through the unveiling of the Electronic-Computer for Home Operation (ECHO) IV. This passion project consisted of a central computer that controlled a few basic functions of the home such as the television and air conditioning, and it kept track of calendar events, meteorological data, and accounting (Sutherland, 1994). Reminiscent of modern smart home systems, this development piqued the public's interest in the potential for a unified system to simplify common tasks and offer remote control.

Consequently, companies began to enter this market and worked to make smart technology a reality. They spent the next 50 years creating low energy communication protocols to enable future generations of smart devices. While this was successful, it resulted in a number of efficient and desirable protocols for companies to choose from when designing their smart home environments. The first wireless smart device, the Nest Learning Thermostat, released in 2011 and used Bluetooth Low Energy (BLE), WiFi, and Thread. The first smart light bulb, the Philips Hue, released in 2012 and exclusively used Zigbee. The first smart lock, the August

Smart Lock, released in 2013 and only used BLE. The first smart home hub, SmartThings, released in 2013 and used Zigbee and Z-Wave. Each device was only compatible with a limited number of others, and so the dream of a unified ecosystem began to crumble. Consumers then faced a dilemma of which hub device to purchase because that decision limited which third-party products they could use in their setup. They were no longer choosing what devices made their daily tasks the simplest, but instead which subset of smart devices more closely suited their needs.

Inspired by this issue and the desire to reunite the smart home industry with its founding principles of a unified ecosystem, the Connectivity Standards Alliance (CSA), formerly the Zigbee Alliance, began the development of an open-sourced connectivity standard called Matter. The goal of Matter is to allow for communication across all smart home devices and, in turn, ease the burden of interoperability on manufacturers and consumers alike. Matter is currently promoted by many of the companies leading this sector, including Amazon, Apple, Google, and Samsung.

The goal of this survey is to inform readers about how a smart home ecosystem works (devices and communication protocols) and what companies have done to implement it and improve its accessibility in order to reach the end goal of a unified smart home ecosystem.

This survey will provide an overview of the current state of smart home technology and how a unifying communication protocol will alleviate issues faced by consumers. The overview of each section is as follows:

- Section 2 will explain how each smart home ecosystem fits into a common connectivity model which will ease the implementation of a unifying communication protocol. Additionally, it will show the benefits and disadvantages of the four main smart home ecosystems
- Section 3 will address why the presence of multiple communication protocols leads to an interoperability problem in smart home ecosystems
- Section 4 will describe what the unifying communication protocol Matter is and how it solves the interoperability problem

2. Top Smart Home Ecosystems

When customers are shopping for smart home devices, they will find one or several "Works With..." stickers on the box to indicate which smart home ecosystem it is compatible with. Amazon, Apple, Google, and Samsung are now the major players in the smart home market with their cloud services, voice assistants, and smart hub devices making smart home setup and management easier.

This section firstly presents a common connectivity model to explain key components and wireless technologies of a smart home ecosystem, then introduce each smart home ecosystem of the 4 major players, i.e. Amazon Alexa, Apple Homekit, Google Assistant, and Samsung SmartThings. Due to the sheer amount of smart home devices, the figures in this section only cover the common supported use cases and devices.

2.1 A Common Connectivity Model

Home automation originally referred to a set of processes dedicated to the reduction of human labor in the performance of a function (Zemrane, 2019), for example, a light bulb turned on by an occupancy sensor. In this model, device communications are done locally and cloud services are not needed. Such an environment, however, is not considered to be a smart home. The term "smart" is used when a product or a service is connected to other products or services through a network enabled by ICT services (Serrenho, 2019). With cloud services, smart home devices are capable of performing more tasks to benefit users' daily life. A thermostat can turn on/off the HVAC system based on the user's location provided by the cloud. An armed window/door contact sensor can send alarms to the user's phone when it detects the window/door is open. The connectivity model presented in Figure 1 provides a template for how devices communicate in a smart home environment, which fits the aforementioned use cases.

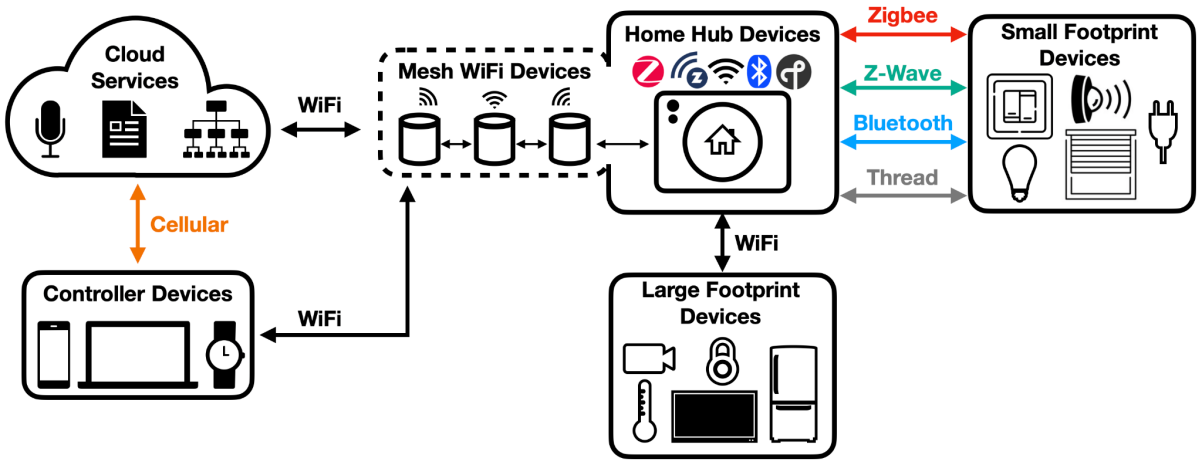

Figure 1: A Common Connectivity Model for Smart Home Ecosystem

The connectivity model consists of the following 5 components:

- Cloud Services: After buying a new smart home device, the first step for the user is to add the device to its smart home ecosystem via scanning a code (e.g. Apple HomeKit 8-digit code) (Add a HomeKit accessory to the home app, 2022) or asking a hub device to do a full discovery (e.g. Amazon Alexa Discovery) (Alexa.Discovery Interface, 2022). Users can then control and manage the device through an app or using voice. Generally, cloud services for smart homes handle voice assistants, device registration, and device management.
- Controller Devices: A smartphone, tablet, laptop, or smartwatch can function as the control device of a smart home ecosystem. It allows users to check their home status or control home devices remotely via cellular or WiFi when they are not at home.
- Home Hub Devices: A home hub device is the central component of a smart home ecosystem. It acts as an entry point for users to remotely control devices or serves as a coordinator among multiple smart home devices to create scenes or routines for sophisticated home automation scenarios. A hub device can be a speaker (e.g. Apple HomePod), a display (e.g. Amazon Echo Show), a mesh WiFi router (e.g. Samsung SmartThings WiFi), or even a combined product (e.g. Google Nest WiFi is a mesh Wifi router plus a speaker). If the hub device has mesh WiFi ability, it provides internet coverage to each corner of the home. In such a case as shown in Figure 1, we can

consider mesh WiFi devices and home hub devices as one whole component. The common wireless protocols equipped in a hub device are WiFi, Bluetooth, Zigbee, Z-Wave, and Thread. Table 1 lists supported protocols of hub devices for the 4 major smart home ecosystems.

- Large Footprint Devices: Some home devices require high network bandwidth for data transmission (such as a camera, smart TV, and smart refrigerator) or need to transmit data very frequently to the internet (such as thermostats). As all hub devices of different ecosystems support WiFi, some devices choose WiFi as the main wireless protocol to be compatible with multiple smart home ecosystems. Examples include the August WiFi Smart Lock (2022) and Philips Hue Bridge (2022). These devices can be categorized as Large Footprint Devices that use WiFi for connectivity.
- Smart Footprint Devices: Bluetooth, Zigbee, Z-Wave, and Thread are low power consumption protocols that consume power from 1 mw to 100mw (Danbatta, 2019), which are perfect for devices that can be idle (such as light bulbs, wall switches, smart plugs, and window blind) and devices using coin cell battery (such as leak detection sensor, contact sensor, and key finders). These devices are categorized as Smart Footprint Devices in this connectivity model.

		WiFi	Bluetooth	Zigbee	Z-Wave	Thread
Amazon Alexa	Eero Pro 6E	✔	✔	✔		✔
	Echo (4th Gen)	✔	✔	✔		
	Echo Dot	✔	✔			
	Echo Studio	✔	✔	✔		
	Echo Plus	✔	✔	✔		
	Echo Show 10	✔	✔	✔		
Apple HomeKit	Apple TV	✔	✔			
	iPad	✔	✔			
	HomePod mini	✔	✔			✔
Google Assistant	Nest Mini	✔	✔			
	Nest Audio	✔	✔			
	Nest Hub (2nd Gen)	✔	✔			✔
	Nest Hub Max	✔	✔			✔
	Nest WiFi	✔	✔			✔
Samsung SmartThings	Aeotec Smart Hom Hub	✔		✔	✔	
	SmartThings WiFi	✔	✔	✔	✔	

Table 1: Supported Protocols of Hub Devices

2.2 Amazon Alexa

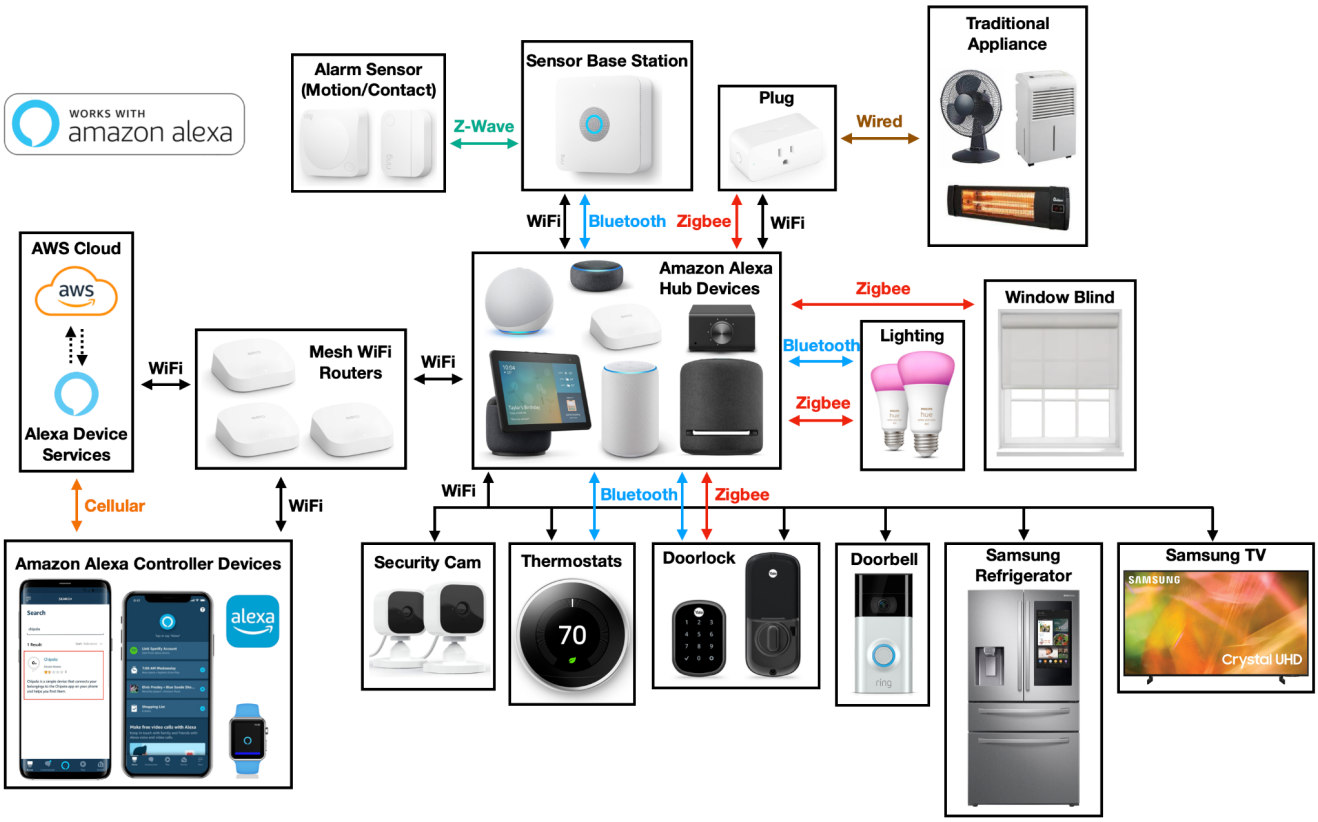

Figure 2: Amazon Alexa Connectivity Diagram

As shown in the Amazon Alexa Connectivity Diagram, Amazon has a wide range of hub devices, (e.g. Eero Pro 6E, Echo 4th Gen, Echo Studio, Echo Dot, Echo Show 10, etc.). The main connectivity protocols used in this ecosystem are WiFi, Bluetooth, and Zigbee. Additionally, users can add support for some Z-Wave devices, such as the Ring alarm sensors, through the use of a base station that acts as a bridge between the Z-Wave device and the hub.

Amazon has a wide reach in the smart home industry through its many subsidiaries which each focus on a different field. Blink, which specializes in security cameras, was acquired by Amazon in 2017. Ring LLC, which focuses on both smart doorbells and alarm systems, was bought by Amazon in 2018. Eero, which concentrates on mesh-network WiFi devices, became an Amazon subsidiary in 2019 (Amazon company - Wikipedia, 2022). Amazon Alexa, together with Amazon Web Services (AWS), provides voice control and device management services. For the fields

where Amazon has no subsidiary, it collaborates with other companies to make Alexa Built-in compatible with their smart home ecosystem, e.g. Samsung's Family Hub Refrigerator (2022).

By ceasing production of their line of smartphones, the Fire Phone, Amazon removed a product that could have improved access to the Amazon Alexa ecosystem. However, the Alexa app can be downloaded on both iOS and Android mobile devices to help with home device control and management.

Alexa Skills Kit (2022) is a major advantage of the Amazon Alexa ecosystem, which allows Alexa hub devices equipped with more skills to provide more interactions with users, e.g. food ordering, online shopping, cook instruction, etc.

2.3 Apple Homekit

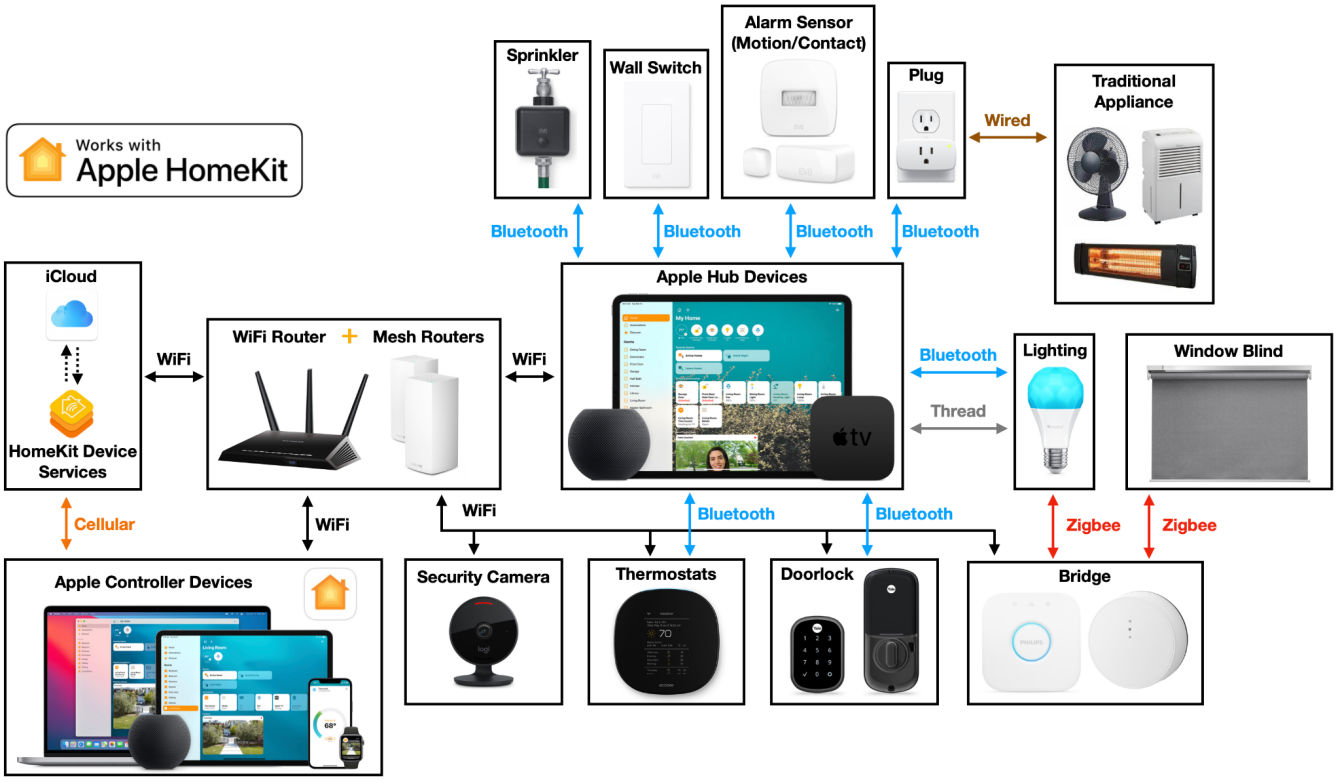

Figure 3: Apple HomeKit Connectivity Diagram

WiFi and Bluetooth are the main connectivity protocols used in the Apple Homekit ecosystem. Apple currently only has 3 types of hub devices: the Apple TV, HomePod mini, and iPad. Each of

these supports WiFi and Bluetooth, while the newly introduced HomePod mini adds support for Thread. To include Zigbee devices, however, these hubs require a bridge device.

In this ecosystem, Apple mainly focuses on developing its own devices, i.e. iPhone, iPad, Apple Watch, Apple TV, HomePod, and Mac. Other smart home devices are developed by third-party manufacturers, and Apple requires that they build their products based on the Apple Homekit Accessory Protocol Specification (HomeKit, 2022) which includes strict encryption and security standards.

The main disadvantage of the Apple Homekit ecosystem is that customers don't have many choices when shopping for compatible smart home devices. It covers the common smart home product types including cameras, doorbells, light bulbs, switches, and thermostats, however each category may only have 1 or 2 options to choose from.

While the high standards are difficult for manufacturers to implement, they greatly benefit customers by increasing security, privacy, and ease of use. Apple Homekit is considered a bulletproof platform regarding security and privacy, and it rarely suffers from dropped connections or temperamental hardware (Stables, 2021). Customers can easily start their smart home without a hub device by using an iPhone, iPad, or Macbook as a controller device, although adding a hub like an Apple TV or a HomePod mini enables useful features such as remote control, home monitoring, and location-based automation (Apple Home, 2022). Having all HomeKit products under the Home app makes usage easier and functionality seamless (Fifield, 2020).

2.4 Google Assistant

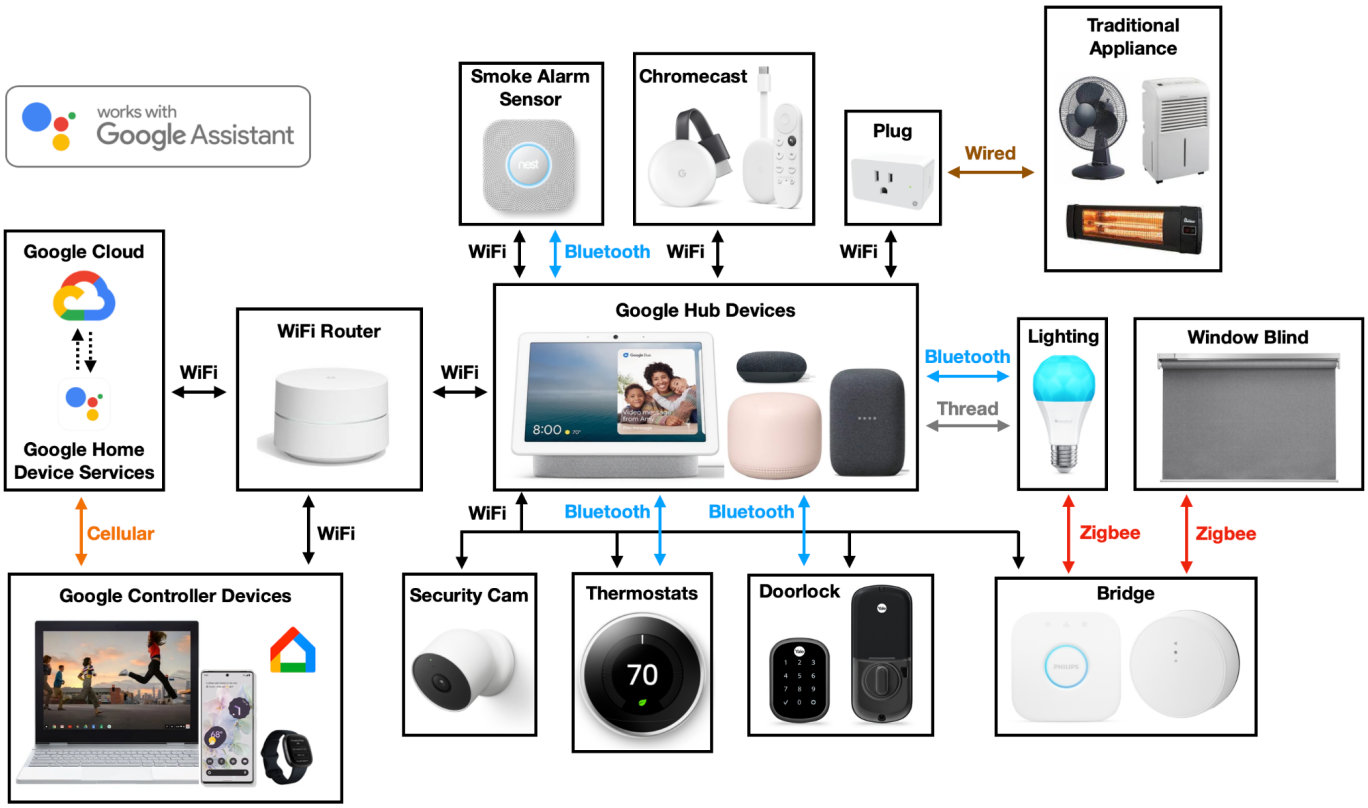

Figure 4: Google Assistant Connectivity Diagram

Although Google released "OpenThread", a BSD-licensed open-source implementation of Thread, the Thread protocol is currently not commonly used in the Google Assistant ecosystem. Google's Nest Hub 2nd Gen (2022) even mentions "802.15.4 (at 2.4 GHz) Thread - functionality not yet available" in its Tech Specs. Instead, the Google Assistant ecosystem uses WiFi and Bluetooth as the main connectivity protocols, and it requires bridges to support Zigbee devices.

Google operates within many different smart home fields with one subsidiary, Google Nest. These fields include WiFi routers, security cameras, thermostats, and security alarm systems. Starting from developing the 1st generation of learning thermostat in 2011, Google Nest gradually extends its smart home coverage such as introducing Nest Cam in 2015, Nest Secure in 2017, Nest WiFi in 2019 (Google Nest -Wikipedia, 2022). Certainly, Google Nest is not trying to

cover every single field of smart home, it still collaborates with third-party manufacturers for other smart home devices, e.g. lighting and door locks.

Android with Google Assistant natively supported has about 70% mobile OS market share until January 2022 (Mobile operating systems' market share worldwide, 2022) is the main advantage of the Google Assistant ecosystem. Another attractive aspect of Google Assistant ecosystem is that the hub devices have many Google's outstanding services built-in by default, such as Google Translation, Google Search, Youtube, etc.

2.5 Samsung SmartThings

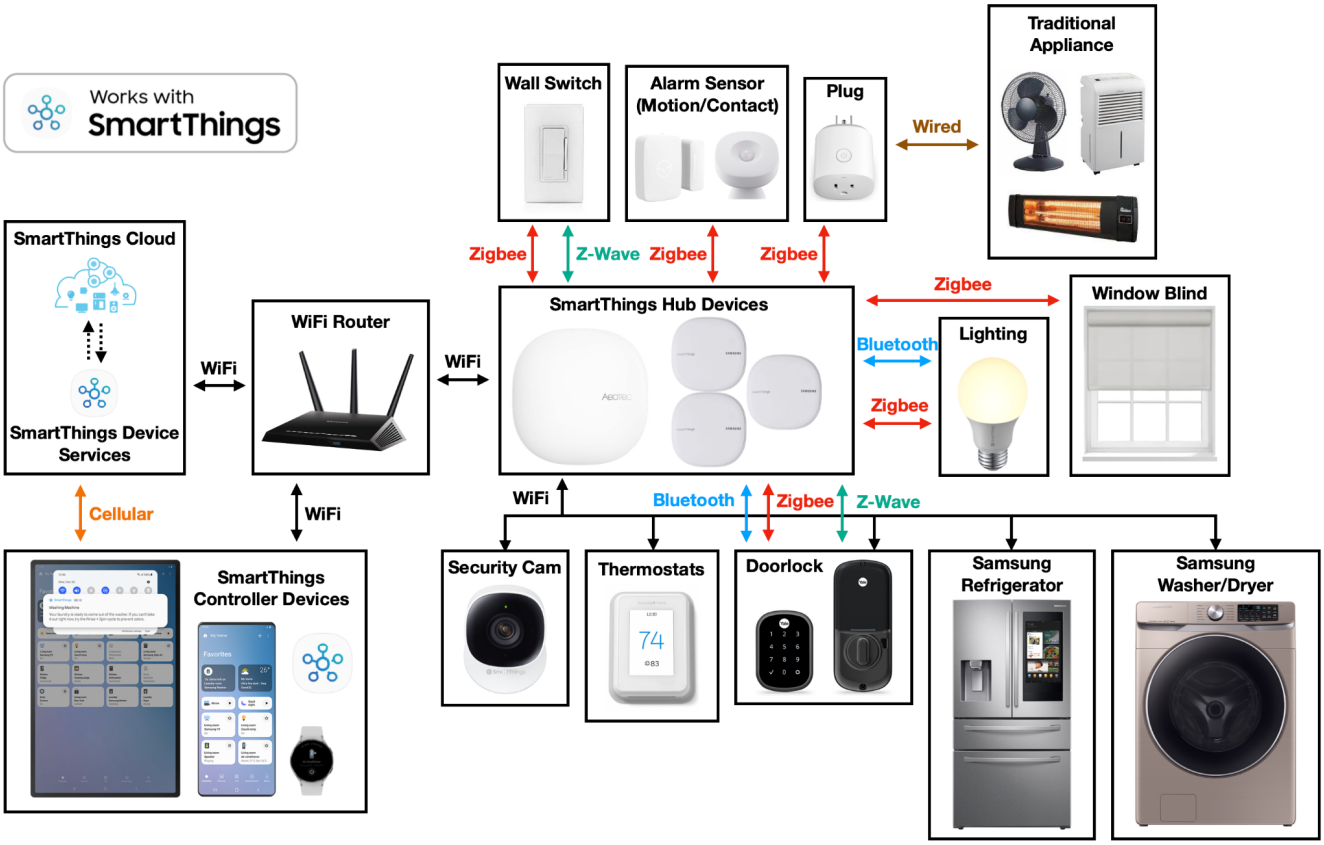

Figure 5: Samsung SmartThings Connectivity Diagram

In the Samsung SmartThings ecosystem, customers typically don't need to buy additional bridge devices because Samsung equips its hub devices with many different wireless protocols. For example, the Samsung SmartThings Wifi supports mesh WiFi, Bluetooth, Zigbee and Z-Wave. Most smart home devices are able to connect with the Samsung SmartThing WiFi directly.

Hence, Samsung SmartThings ecosystem is an inclusive platform that directly supports WiFi, Bluetooth, Zigbee and Z-Wave devices.

Similar to Google's work with Nest, Samsung worked with SmartThings to produce a suite of smart home devices including security cameras, light bulbs, and smart sensors. However, SmartThings announced that it would pivot away from hardware manufacturing and focus on software services in June 2020 (SmartThings - Wikipedia, 2022) with hopes to partner with additional third-party manufacturers to develop more compatible products. As a result, the hub devices in the SmartThings ecosystem would support many different wireless protocols.

As SmartThings focuses on software services, the "webCoRE" rule engine is the major advantage of the SmartThings ecosystem. "webCoRE" is an advanced web-based rule engine that allows customers to use a pseudo scripting language to create more customized automation scenarios across different brands of devices. For example, a user is able to pair a door lock from Yale and a smart light bulb from Philips Hue to the SmartThings platform so that your light will be turned on once the user comes home and opens the door (Lamkin, 2022). Samsung SmartThings can also be an add-on to the existing Amazon Alexa or Google Assistant smart home ecosystem to use Amazon Alexa and Google Assistant as the voice assistant instead of using Samsung's Bixby.

Customers, especially techie tinkerers, will enjoy the openness and inclusivity of Samsung SmartThings ecosystem if they are willing to put time and effort to get things set up.

3. A Pain Point for Smart Home: Interoperability

When taking a look at smart home technology over the past 10 years, it started with one company, Nest. Developed by former Apple engineers and then being bought by Google, Nest had the original idea of a smart home, and at the time meant all devices relating to IoT had to ensure that all devices were compatible with only Nest. Around the same time Google bought Nest, Apple developed Homekit which had a completely different architecture and Amazon rolled out its Echo products. When more companies jump into the smart home business, they all

want to create products using a controlled ecosphere, which makes it hard for any other developers to compete since all these ecospheres are so enclosed.

3.1 Protocols

The first obstacle to allowing all smart home devices to talk to each other is a common communication protocol. Taking a look at some of those diagrams above, with each different color arrow, a different protocol is needed to enable the smart device. Most devices utilize wifi/internet connections and Bluetooth, however, those can be more complex to connect since internet connection generally means connecting to a server, whether it is AWS, Google Cloud, etc. With Bluetooth, not all devices can natively communicate with each other to provide seamless use, for example, an Apple Homekit hub, to a Google Home drive such as a lock or thermostat.

All of these different protocols utilize a different frame payload to enable other IoT devices. Bluetooth uses a GATT-based profile (Rahman, 2018) whereas Zigbee has its own application profile using the Zigbee Cluster Library (Levin, 2010). Many different protocols being used is a clear indication that one of the biggest issues with connecting all of these different devices is just implementing a specific protocol for everyone to follow.

Some of these devices shown in the diagram do utilize Zigbee which is a step in the right direction. The Zigbee alliance allowed for cooperating companies such as Phillips, Honeywell, Amazon Alexa, etc to interface with each other despite being competitors. Unfortunately, not all major companies decided to implement Zigbee and some instead plan to move to a more unified version of Zigbee called Matter.

3.2 Hubs

Ordinarily, many of these smart home devices require a hub to connect everything to. These hubs tend to be sold by each company as a way to tempt the user into purchasing products from the company that sold the hub. This problem relates to protocols, and many of these hubs will only allow specific connections, which is consistent across many of their other IoT products (e.g a Google Home hub will generally connect to other Google Home products such as lights and locks much easier since they all use the same set of protocols).

To get around some of these obstacles, third-party developers created bridges to convert APIs only used by someone such as Apple, into recognizable software by someone else such as Google. All of these companies would be designated a different free plugin that would be easy to download. Essentially, this is what matter is attempting to fix on a much larger scale. If these devices could natively support one protocol in the application layer, it would allow for all devices from any company to be compatible with each other.

4. Connected Home over IP: Matter

With the interoperability issues mentioned in section 3, figuring out which products work with which ecosystem and then troubleshooting those connections is a time-consuming process for consumers. This has prevented them from embracing smart home technologies and resulted in a slow smart home adoption.

The idea of Matter, formerly called "Project Chip" (Connected Home over IP) to the public and initially known as "Project Unity" internally, was conceived during a dinner hosted by the president of the Zigbee Alliance together with some engineers from Google, Apple, and Amazon (Tuohy, 2022). The aim of Matter is to fix the smart home with a single unified connectivity standard that will catapult smart home technology to mass household adoption.

4.1 What is Matter?

Matter is not a smart home ecosystem like the 4 ecosystems described in Section 2 so it doesn't automate or control the smart home. Matter is not a network protocol like WiFi, Bluetooth, or Zigbee that defines a whole stack from the physical layer to the application layer. A network protocol is used to establish connections between different devices. To achieve something useful over those connections, devices need to speak the same language, i.e. the application layer, so that they can understand each other. For example, many smart home devices are using WiFi today, but the device manufacturers still need to implement different application layers for different ecosystems. Hence, Matter is a common application layer and data model running on top of the IPv6-based transport protocols. Devices running on different network protocols can speak Matter as the common language so as to understand each other.

4.2 How does Matter Stack Up?

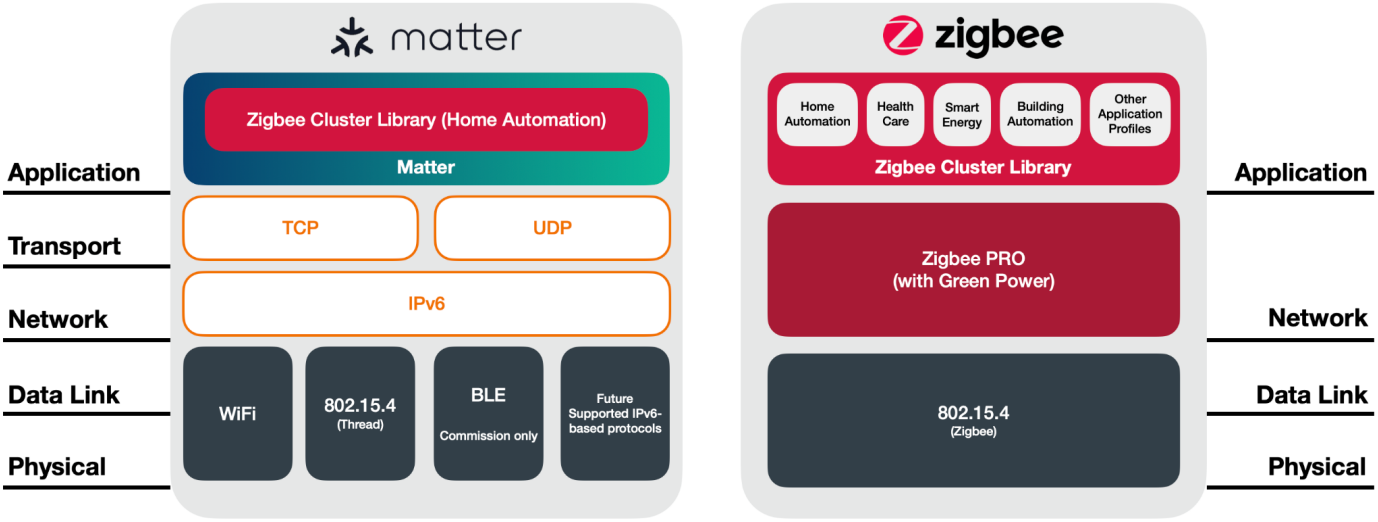

Figure 6: Architecture Comparison between Matter and Zigbee

As shown in Figure 6, Matter takes advantage of many existing market-proven technologies instead of reinventing everything so that it can simplify smart home adoption and matter devices can seamlessly blend into the current existing smart home ecosystems.

- Application Layer: Matter was called Project CHIP and was part of the Zigbee Alliance, then the Zigbee Alliance was rebranded to Connectivity Standards Alliance (CSA) in May 2021 and Project CHIP was renamed to Matter (Connectivity Standards Alliance - Wikipedia, 2022). Thus, Matter has a close relationship with Zigbee. In fact, Matter adopts the existing Zigbee Cluster Library (ZCL) from Zigbee in the application layer. As Matter is currently focusing on the smart home, it borrows clusters from Zigbee's Home Automation application profile and makes it fit over the IP layer. In Matter's GitHub (2022), we can find the ZCL-related codes, such as the ZAP (ZCL Advanced Platform) tool.
- Transport and Network Layer: Matter is built on top of IPv6-based transport protocols, i.e. TCP and UDP, and use IPv6 as the network layer, which means Matter uses the same mechanism to communicate as the Internet and all Matter devices are extensible to the cloud to provide more operations or services. By using IPv6 in the network layer, the

application layer is agnostic about the physical layer. Any IPv6-based protocols can be run as the data link and physical layer.

- Data Link and Physical Layer: The first Matter specification (Matter 1.0) supports WiFi for Large FootPrint Devices, Thread for Small Footprint Devices, and Bluetooth Low Energy used for commissioning only to onboard new devices (Matter, 2022). Zigbee uses IEEE 802.15.4 as the Data Link and the Physical layer and Matter take advantage of Zigbee's application layer, but Zigbee is not IPv6 based so it is not in the scope of Matter. Instead, Matter chooses Thread, another network protocol based on IEEE 802.15.4 for low-power mesh networking.

4.3 How does Matter Unify Smart Home Ecosystems?

The common connectivity model presented in Section 2 still holds true after Matter devices are introduced to the smart home market. The differences would be: The "Apple Controller Devices" in Figure 3 would be "Matter Controller Devices made by Apple" and the "Google Hub Devices" in Figure 4 would be "Matter Hub Devices made by Google". Matter allows users to connect their devices to any controller or ecosystem based on their choice thanks to the "Multi-Admin" feature (CSA, 2022).

As shown in Figure 7, a Matter thermostat and a Matter plug can be configured to join ecosystem 1 or ecosystem 2, or even both ecosystems simultaneously depending on how the user registers the device. In terms of non-Matter devices (e.g. devices on a Zigbee network), they can still perfectly fit in and communicate with Matter devices if the hub device or the bridge device supports Matter. The "Multi-Admin" feature enables consumers to keep using existing non-Matter devices together with Matter devices to reduce smart home fragmentation, which provides the foundation for Matter to unify smart home ecosystems.

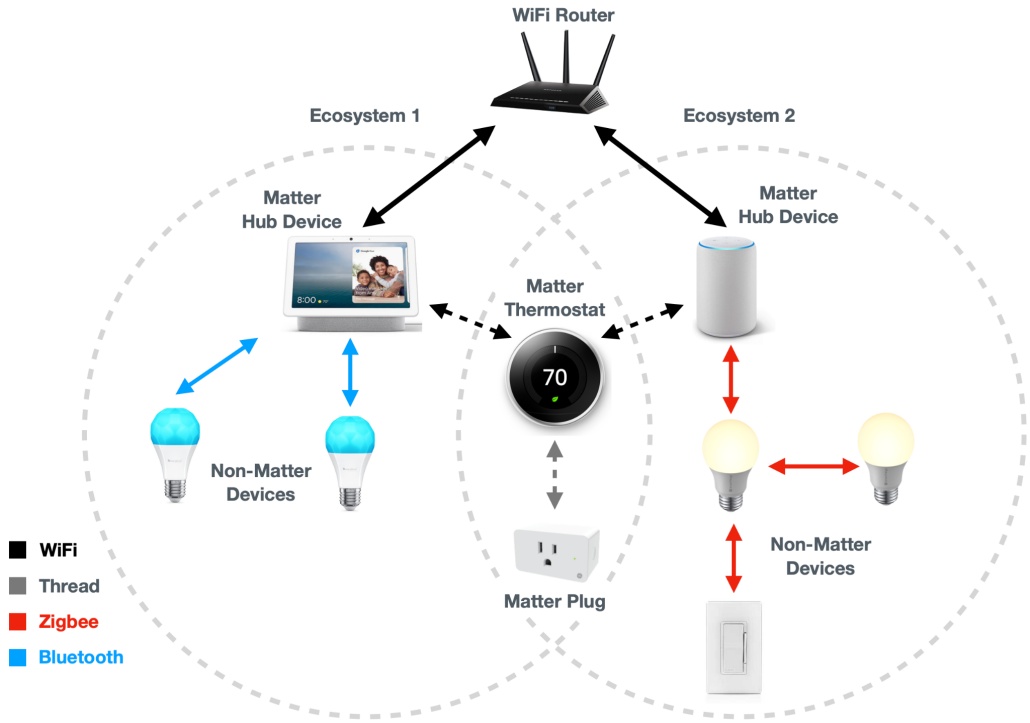

Figure 7: The Multi-Admin Feature of Matter

5. Conclusion

Smart home technology has significantly progressed since the ECHO IV, and has finally begun to reunite with its founding concepts of a unified home ecosystem. In its current state, users are able to simplify their lives through an abundance of smart devices that efficiently communicate with each other via a hub device that allows for cloud processing and remote control. Despite the presence of many different smart home ecosystems, each one fits into a common connectivity model that provides a way to solve interoperability issues between suits of devices that have no overlap in their communication protocols. A Matter-enabled hub device, then, is the solution to this problem because Matter is an application layer technology and smart devices communicate through a hub device. Matter will effectively translate incoming and outgoing communications to ensure that all endpoint devices can interpret the data and commands being sent to them. With this scheme, future smart home ecosystems will be seamlessly integrated and wholly unified, and will free users of restrictions on the kinds of devices that they can use to enhance their lives.

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