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INTERNET OF THINGS – WIRELESS TECHNOLOGIES IN HOME AUTOMATION SOLUTIONS

A study of Wi-Fi, ZigBee, Z-wave and Bluetooth

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ABSTRACT

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Internet of things is a growing phenomenon and home automation solutions are most likely to be customers' first introduction to this kind of technology. Radio frequency technologies are significant part of sensor network and at this point there are many technologies trying to be standard of home automation. Home automation as a business will grow rapidly in the coming years and with wireless sensors networks the possibilities just in home is enormous.

In this thesis there will be an introduction to four technologies: Wi-Fi, ZigBee, Z-wave and Bluetooth. Technologies' main aspects are explained and afterwards reviewed with available products. These products and the companies producing them are analysed with SWOT analysis and later on discussed which of these technologies have an advance upon each other.

Keywords: Internet of Things, IoT, wireless, home automation, radio frequency

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Esineiden internet on kasvava ala ja kotiautomaatioratkaisut ovat todennäköisesti kuluttajien ensimmäisiä kosketuksia tämänlaiseen teknologiaan. Radiotaajuusteknologiat ovat olennainen osa sensoriverkkoa ja tällä hetkellä moni teknologia pyrkii olemaan standardi kotiautomaatiossa. Kotiautomaatio liiketoimintana tulee kasvamaan voimakkaasti tulevina vuosina ja kehittyneillä sensoriverkoilla pelkästään kotona mahdollisuudet ovat suuret.

Tässä tutkielmassa esitellään neljä teknologiaa: Wi-Fi, ZigBee, Z-wave ja Bluetooth. Teknologioiden pääpiirteet on selitetty ja esitetty olemassa olevien tuotteiden kautta. Olen käyttänyt SWOT–analyysiä tuotteisiin ja niitä tuottaviin yrityksiin saadakseni selville, millä tekniikoista on etu muihin nähden.

Asiasanat: Esineiden internet, langaton, kotiautomaatio, radiotaajuus

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1 Introduction

What is Internet of Things (IoT)? Delicato, Pires and Batista (2013, v) see it this way:

> It consist in a world of physical objects embedded with sensors and actuators linked by wireless networks and communicating using the Internet, shaping a network of smart objects, with processing power and able to capture environmental variables and to react to external stimuli.

According to Minoli (2013), "things" can be synonyms for objects, devices, end nodes, remotes or remote sensors. Fundamentals of the IoT is monitoring and reading data from a thing to something. Not every company use the same term, e.g. Cisco uses term Internet of Everything (IoE). This means connecting people, process, data and things (Cisco, 2014). Web of Things (WoT) is another concept where using HTML, Python and JavaScript web languages smart things are connected not only into the Internet, but also into the Web and its application layer (Guinard, Trifa, & Wilde, 2010).

Machine-to-machine (M2M) communication is basically between devices (e.g. server and sensor or sensor and sensor), which communicate via communication network. M2M and IoT largely overlap, but there are some differences as well. One example where these differ is radio-frequency identification tags, which are passive objects and do not communicate upstream to the information system. (Boswarthick, Elloumi, & Hersent, 2012)

United States National Intelligence Council (NIC) foresees that IoT will, like the present Internet, contribute invaluably to the economy. NIC predicts by 2025 IoT applications will be found in everyday things – food packages, furniture, paper documents and more. Widespread IoT adaption requires different field of knowledge: telecommunications, informatics, electronics and social science. Both technological and social issues are challenging for people to accept for example trust, privacy and security. (Atzori, Iera, & Morabito, 2010)

In this thesis I will be concentrating in the field of wireless technologies in home automation systems. Home automation as a business is growing industry, as we will see in chapter three. The main reasons why I think this subject is important to study is business opportunities, benefits for common household and the amount of new innovation this line of business has developed and will de-

velop. Every day new start-up companies bring new devices to the markets and some of them are quickly sold to a bigger company. Market situation is both challenging and full of opportunities, which makes smart devices interesting area to study.

In this thesis I will be answering to these questions:

- What kinds of radio frequency technologies are in the market right now?
- How are these technologies used?
- What technologies will be the most critical in home automation solutions?

In this study I continue with analysing four wireless technologies: Wi-Fi, ZigBee, Z-wave and Bluetooth. At the beginning of the second chapter is a small discussion of what radio frequency technologies mean and opening terms. These technologies' main points are displayed and discussed. In the third chapter there are devices equipped with these wireless technologies in the market right now. In the third chapter there is SWOT analysis of these devices and how they use these technologies, including a discussion of the reasons how these technologies will develop. Fourth chapter includes conclusion, where I discuss how I have answered the research questions. Conclusion ends with a prediction: which of these technologies might gain market share and which ones might lose it. Table 1 consist of common terms that will be used in text.

Table 1 - Abbreviations

IoT	Internet of Things
M2M	Machine-to-Machine
WLAN	Wireless local area network
PAN	Personal area network
WPAN	Wireless personal area network
IEEE	Institute of Electrical and Electronics Engineers
IPv6	Internet protocol version 6
6LoWPAN	IPv6 over low-power wireless PAN
RFID	Radio frequency identification
WSN	Wireless sensor network
ISM	Industrial, scientific and medical radio bands
MAC	Medium access control
PHY	Physical layer
NWK	Network layer

2 Wireless technologies

Wireless technologies are very important for Internet of Things. For home automation solutions it is obvious that making wired connections to all devices is much more complex and harder to install. I have chosen four wireless technologies for my thesis, Wi-Fi, ZigBee, Z-wave and Bluetooth based on my research of this subject: I found these technologies to be most researched and used, based on Google Scholar's search results with a phrase " 'wireless technology' + home automation". The least results had Z-wave with about 1760. Technologies called Insteon and Wavenis was ruled out with search results with about 600 and 120, respectively.

2.1 Wireless communication

Radio frequency as a technology is electromagnetic phenomena in spectrum between 3Hz and 300 GHz (Coleman, 2004). Molisch (2011) explains how exactly radio frequency wireless communication works. With oversimplifying there are two physical components: transmitter and receiver. Between those radio waves are carrying information. The transmitters main tasks are adding error correction code, i.e. encoding, and then input to a modulator, which maps the data to output waveforms. The receiver collects the signal and demodulates it and a channel decoder eliminates the errors. The receiver is left with a bitstream, which in this case stays in digital format.

As it can be seen in Figure 1 below, there are many layers in protocol stack. A protocol stack is a way how data moves trough an operation. This example is from ZigBee's protocol stack, but when ZigBee is defined in IEEE 802.15.4, it represents part of 802.15.4's specification. In this thesis I will not focus on all the layers, but more on the physical layer (PHY), logical link control, medium access control (MAC) and network (NWK) and security.

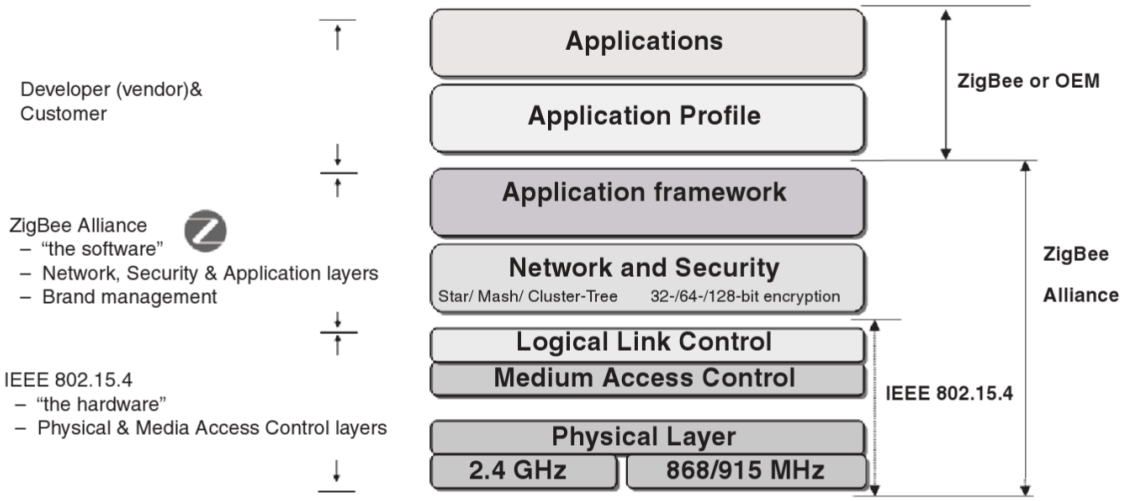

Figure 1 - Zigbee protocol stack, (Minoli, 2013, 154)

ZigBee supports three topologies (Figure 2): star, tree and mesh networks as seen in picture. ZigBee address policy is fairly simple; there are 2^{16}=65536 addresses and every router gets an address and a Cskip value. Based on coordinators Cskip value, it can give addresses to routers, which can give addresses to its end devices between coordinators Cskip value. For example coordinators address is 0 and Cskip value 6, then router B has address 7 and Cskip value 1, therefore routers' end devices get addresses between 8 and 12. After that router C get address 13 and Cskip value 1 and so on. (Xiao, Chen, & Li, 2010)

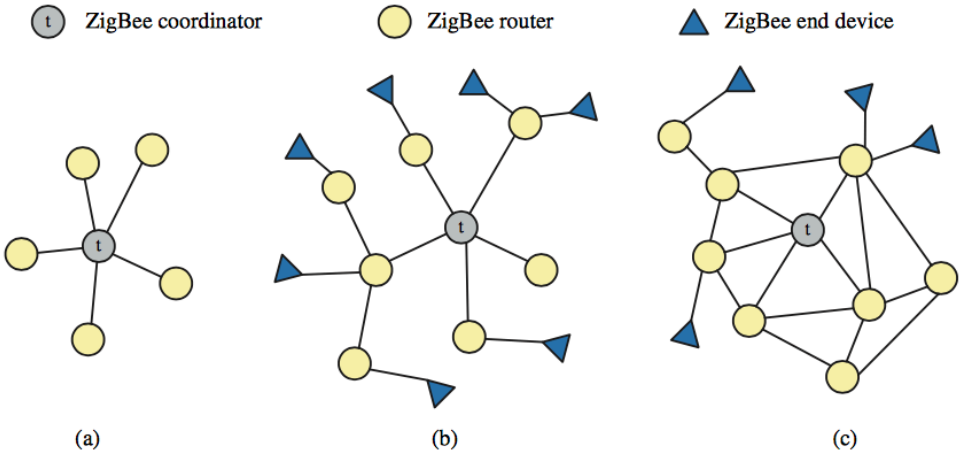

Figure 2 - ZigBee topologies, (Xiao et al., 2010, 184)

Networks topology defines how data transports between different actuators. ZigBee, Z-wave and Bluetooth supports two or more different kind of devices, which are suitable for many kinds of tasks. A home containing many different kind of sensors networks topology defines how energy-efficiently, fast and reliability data transports between sensor and central hub. ZigBee and Z-wave have their own systems how to maintain this network and especially

when network is changing, e.g. more sensors are added, the network corrects itself and it can adjust to the optimal solution possible.

2.2 Wi-Fi

Institute of Electrical and Electronics Engineers (IEEE) is high-level organization and responsible of wireless local area network (WLAN) standardization. In common language Wi-Fi and WLAN are synonymies and actually they both mean IEEE 802.11x standards. Wi-Fi is an alliance, which certificates 802.11x usage. It was established in 1999 and it has today about 600 members from all around the world (Wi-Fi Alliance, 2014).

In this thesis I will use term Wi-Fi as IEEE 802.11x wireless local area network. Below, to specific IEEE 802.11 standards are considered in more detail.

IEEE 802.11n (approved 2009) implements 2.4GHz and 5GHz frequencies and it works with 2 input and 2 output antennas, or multiple-input and multiple-output: MIMO. This standard provides data rates up to 600 Mbit/s. (Molisch, 2011)

Wi-Fi is very common in devices, for example smartphones, computers, printers and game consoles. Wi-Fi is clearly the fastest way (Table 2, page 13) to exchange data but power consumption is high; therefore it cannot be used in battery-powered devices competently. Even though smart phones are battery-powered devices, they have large batteries and they are by default charged frequently.

Wi-Fi operates in industrial, scientific and medical (ISM) frequency area, which allows anyone to use it with three limitations: emission power is restricted, rules in the signal shape and bandwidth and to use band according to the purposes by the regulators. (Molisch, 2011)

IEEE 802.11ah is currently in development and it is planned to publish in 2016 (IEEE, 2014). 802.11ah uses below 1 GHz bands, which are license-exempt and band is dependable on continent or country. Europe uses 863-868 MHz, USA 902-928 MHz and Asian countries have few other bands. As this standard is part of the 802.11, this adds enhancements to Medium Access Control (MAC) to support this PHY, and is capable of coexistence with 802.15.4 and P802.15.4g. This standard should support up to 100 kbps PHY data rate and coverage of 1km. Maximum aggregate is planned to be up to 20 Mbps with multi station mode. IEEE 802.11ah is especially designed for sensors and meters, i.e. IoT, and can extend range of Wi-Fi. When the main use cases are in IoT applications, energy-efficiency is a vital requirement. (Raeesi, Pirskanen, Hazmi, Levanen, & Valkama, 2014)

2.3 Zigbee

The ZigBee standard was released in 2004 with version 1.0 and next iteration

v1.1 was released in December 2006. Right after that, early 2007, was released next version called ZigBee Pro (Xiao et al., 2010). ZigBee's inability to work directly with Internet protocol, led to ZigBee Smart Energy 2.0. This version is based on RFC 4944 (September 2007), which included 6LoWPAN technology and ZigBee network to look like an IPv6 link (Minoli, 2013).

As it is seen in Figure 1 (page 9), ZigBee is defined using IEEE 802.15.4, but only physical layer, medium access control and logical link control. ZigBee Alliance is responsible for software layer and device manufacturers application layer.

IPv6 over low-power wireless personal area network (6LoWPAN) is defined as an IPv6 over IEEE 802.15.4. This is widely accepted approach for making for example ZigBee 2.0 device look and behave like an IPv6 link (Minoli, 2013). 6LoWPAN's relationship with ZigBee is close. They both share the same IEEE 802.15.4's PHY and MAC layers and ZigBee's Alliance has defined the top layers when Internet Engineering Task Force 6LoWPAN Working Group defines 6LoWPAN (Gomez & Paradells, 2010).

ZigBee works with three different frequencies: 868 MHZ (Europe, 20kbps), 915 MHz (USA and Australia, 40kpbs) and 2,45 GHz (World, 250kbps). ZigBee works with coordinators (ZC), routers (ZR) and end devices (ZED). First two of these are called Full-Function Devices, which is recommended to have power supply. Reduced Function Device (ZED) can be battery powered; therefore they are usually sensors or actuators. (Varchola & Drutarovský, 2007)

2.4 Z-wave

Danish company Zensys has developed Z-wave since 2005 and at the same year Sigma Designs acquired it and established the Z-wave Alliance. It is used in the same bands as some cordless telephones but it avoids Wi-Fi frequencies. (Minoli, 2013)

Z-wave uses ISM bands 868 MHz in Europe and 908 MHz in USA, with data rates from 9.6 to 40 kb/s. Z-waves 400 series chips supports 2.4 GHz band and 200 kb/s. Z-wave supports two kind of devices: controllers and slaves. Controllers' stores networks topology and when controller tries to connect with a slave, controller tries first a direct connection. If that fails packet can be delivered to the slave trough four hops. Routing slaves have ability to store static routes and can send messages to other nodes. Slaves are suitable acting as sensors, but routing slaves are more suitable for time-critical tasks. (Gomez & Paradells, 2010)

Z-wave is marketed as very energy-efficient and the ZM5101 chip has sleep current 1μA. Z-wave is not open standard, which makes it harder to study. The basic information is available, but unlike ZigBee, Z-wave is more restricted and Sigma Designs is the only chipmaker. Z-wave Alliance is an open consortium with over 250 members and over 1000 interoperable products. (Z-wave, 2014)

2.5 Bluetooth

Bluetooth is a PAN technology developed by Ericsson. It is based on IEEE 802.15.1 standard and from late 1990s it has developed to version 4.2. Bluetooth is a trademark of the Bluetooth Alliance (Minoli, 2013). Bluetooth has been developing towards IoT and version 4.2 with Bluetooth Smart they are focusing on privacy, security and energy-efficiency (Bluetooth SIG, 2014).

Bluetooth offers two forms of systems, Basic Rate (BR) and Low Energy (LE). Both of these include device discovery, connection establishment and connection mechanisms. Data rates vary from BR's 721.2kbps to 2.1Mbps with Enhanced Data Rate and up to 52Mbps with the 802.11 AMP. AMP stands for alternate MAC/PHY, which consists of a Protocol Adaption Layer (PAL) on top of a MAC and PHY. LE has data speed of 1 Mbps and the system aims for lower current consumption, lower complexity and lower cost. Both of these work with either one, not depending which system the sender and the receiver use. Device supporting both of these has the most usage cases. (Bluetooth SIG, 2013b)

Bluetooth has two roles: a master and a slave. Master can have multiple slave connections and slave can have one master connection, therefore networks topology is star. Slaves are discovered with advertisement channel, where masters scan these channels and can make a connection. (Siekkinen, Hiienkari, Nurminen, & Nieminen, 2012)

Bluetooth announced version 4.2 specification 2.12.2014, where they are promising 2.5 times faster speeds and ten times capacity increase. Bluetooth SIG has developed better Internet connectivity with their Generic Attribute Profiles (GATT) for more flexibility. Newest version of Bluetooth Smart is also capable of working with IPv6/6LoWPAN. (Bluetooth SIG, 2014)

2.6 Comparison

Below there is a Table 2 from multiple sources and especially with range there was slightly deviation between the sources. The table was gathered with average values and while transmit power is not precise; they are relational to each other (except 802.11ah). Transmit power variation is generated also from chip manufacturers ability to make the chip energy-efficient. Sigma Design exclusively manufactures Z-wave, but all the open standards can be made e.g. Texas Instruments.

These four technologies have their characteristics but there can be seen that they are evolving towards similarity. Z-wave has introduced 400 series chips with 2.4 GHz band and 802.11ah will work sub-1 GHz band. At the moment 802.11ah is in development process, therefore there is not much information available. Network's size is a meaningful aspect, as we can see Bluetooth has only 8 slaves. The network's size can be increased with multiple master devices. ZigBee has the highest theoretical value, but in real applications it is hard to manage all the devices in one network.

Security is enhanced with Advanced Encryption Algorithm (AES) 128-bit key and error control is made with cyclic redundancy check (CRC) with different checksums (8, 16 and 32). The higher the checksum, the more powerful error controls (Mainetti, Patrono, & Vilei, 2011).

Table 2 - Comparison table

Name	Wi-Fi	Wi-Fi	Zigbee	Z-wave	Bluetooth LE
PHY/MAC Standard	IEEE 802.11n	IEEE 802.11ah	IEEE 802.15.4	ITU-T G.9959	IEEE 802.15.1
Network topology	Star, mesh		Tree, star, mesh	Mesh	Star
Network size	2007		65 536	232	8
Maximum data rate	600Mbps with MIMO	100 kbps + 20Mbps with multi station mode	up to 250 kbps (2.4GHz)	200 kbps	1 Mbps
Radio frequency band(s)	2.4 and 5 GHz	863-868 MHz (Europe), 902-928 MHz (USA) + Asian countries few others	868.0-868.6 MHz, 902-928 MHz and 2.4-2.4835 GHz	868.42 MHz (Europe), 908.42 MHz (USA), 921.42 MHz (Australia) and 919.82 MHz (Hong Kong), 400 series chip 2.4 GHz	2.4 GHz
Range	70m indoors and 250m outdoors	1 000m	10-100m	30m indoors and 150m in line of sight	5-100m
Error Control/Reliability	32-bit CRC		16-bit CRC, ACK, CSMA-CA	8-bit CRC, ACK, CSMA-CA	16-bit CRC
Transmit power	722.7 mW	255 mW	52.2 mW	108 mW	72 mW
Security	WPA2, EAP, TLS/SSL		AES-128	AES-128 (400-series chip)	AES-128

Sources:
Li, Frank Haizhon, Chen, Hui, Xiao, Yang (2010, 167-169)
Hersent, Boswarthick, Elloumi (2011, 93-139)
Oleskiy Mazhelis, lecture Internet of Things (February 5th, 2014, slide 21)
Wei, Rykowski, Dixit (2013, 137-143)
www.bluetooth.org, Bluetooth 4.1 Technical Description and Core v4.1 specifications
Minoli (2013, 156)
http://z-wave.sigmadesigns.com/docs/Z-Wave_Technology_Comparison.pdf
Mainetti, L., Patrono, L., & Vilei, A. (2011)
Raeesi, Pirskanen, Hazmi, Levanen, & Valkama (2014)
Rathnayaka, A. D., Potdar, V. M., & Kuruppu, S. J. (2011)

3 Wireless technologies in home automation solutions

Home automation, or Smart Home, is a concept where household devices, e.g. doors, windows, lights, electricity meters, thermostats, air conditioners and sprinklers are connected to the Internet. They can be monitored and/or controlled trough smartphones or via web application. Enabling these objects to be connected to a network allows homes to become more secure, energy-efficient, comfortable and entertaining.

Home automation solutions enable end users to monitor and remotely control their homes and implement rule-based operations in their homes. Location-based services can also be implemented so homes systems can recognize, learn and predict occupant's activities. (Pedrasa, Spooner, & MacGill, 2010)

As said in Gill, Yang, Yao, and Lu's (2009) research home automation systems adaption problems can be grouped into five categories: complex and expensive architecture, intrusive installation, lack of network interoperability, interface inflexibility and security and safety.

"33 billion Internet devices by 2020", predicts Strategy Analytics in 2014 (M2M World News, 2014). These kinds of market predictions are common and they all are in the same path: IoT will grow rapidly in the coming years and decades. Home automation business is not the only IoT application, but one of the biggest among with smart city and industrial usages.

Atzori et al. (2010) discusses about important differences between sensor and a smart item. They define smart item to be capable of wireless communication, memory, elaboration capabilities but also autonomous and proactive behaviour, context awareness, collaborative communication and elaboration.

3.1 Examples of Home automation

Usually home automation products have few options how they organize connection and control of the devices. A common way is a hub solution, where one central hub is connected to the Internet (Wi-Fi or LAN) and then all the devices

are connected to the hub. This way smartphone can communicate with the hub and no other means are required (Gigaom, 2013).

This makes the situation different with Wi-Fi and Bluetooth connection, because smart phones are equipped with these wireless radio frequency transmitters. The reasons why Bluetooth does not have larger market adaption are discussed in the fourth chapter.

Belkin WeMo, SmartThings and Kwikset Kevo are selected for this thesis because of two reasons: they offer different kind wireless technologies and they are not similar manufacturers. Belkin has large product catalogue and its products are available in Finland. Belkin was established in 1983, it has over 1200 employees and it operates in 21 countries (Belkin, 2014b). SmartThings has been acquired by Samsung, which means that SmartThings has market potential. Kwikset is over sixty years old company and they have good lock experience and reputation against new start-up companies' smart locks.

3.1.1 Belkin WeMo

Belkin is a USA based company producing smartphone and tablet accessories, network routers, PC and MacBook accessories and also home automation devices, called WeMo.

WeMo works with customers' own Wi-Fi router, which is required to work at 2.4 GHz with 802.11n standard. Belkin produces under their own brand WeMo light bulbs, surveillance cameras, power switches, motion sensors, insight switch (monitors power usage) and a device called maker, which is a Wi-Fi connected relay possible to be installed to a e.g. garage door. WeMo Link – device is communicating with the light bulbs trough ZigBee 1.2. Belkin sells trough their web store few products from other manufacturers, e.g. Holmes Humidifier and Mr Coffee Coffeemaker, which can be used trough WeMo smart phone application. (Belkin, 2014a)

There we can see that WeMo's uses ZigBee with only two products (light bulb + Link) and rest of the products uses Wi-Fi. Every single product is powered with a power cord or directly from power outlet. For instance Belkin's motion sensor can send on/off commands to power outlet. This works well in many cases, setting garage lights on when there is movement, but power cord and limited functionality narrows the use cases down. There can be seen direct correlation with using Wi-Fi as wireless technology and the need to power the devices constantly.

Power outlets differ around the world and WeMo provides outlets for North America, United Kingdom, Australia and Europe. This allows more customers to adapt WeMo's around the world.

3.1.2 SmartThings

SmartThings is a USA based company, making wide variety of smart devices and supporting many different manufacturers devices. They started their business with crowdfunding trough Kickstarter and pledged over 1.2 million dol-

lars when their goal was 0.25 million in September 2012 (Kickstarter, 2012). After that they have expanded rapidly and made many new products.

SmartThings Hub supports ZigBee and Z-wave at the moment and Wi-Fi connectivity is presumably dealt with the routers antennas, whereas ZigBee and Z-wave radio frequency chips are inside of the hub. SmartThings is currently working on cloud-connection possibilities. The hub connects to existing router through LAN cable. (SmartThings, 2014a)

In August 2014 SmartThings was acquired by Samsung, South Korean electronic giant, and will continue as an independent company. This allows them to integrate more to Samsung's home appliances. (Hawkinson, 2014)

SmartThings own products are: SmartSense motion sensor (ZigBee, battery), SmartSense Temp/Humidity sensor (ZigBee, battery), SmartPower Outlet (ZigBee, AC power) and there are few other using ZigBee. There we can see that their own products are using only ZigBee, which means that as their Hub supporting Z-wave is only for other companies' products. SmartThings sells directly from their web store FortezZ's, Aeon's, General Electric's, Kwikset's (not Kevo smart lock), Schlage's and Evolve's products. Products are only for USA and Canada. (SmartThings, 2014b)

Their aim is not to be dominant company providing all the products, but to develop a big community where many companies can benefit and customers are not depended only on one company. This can be seen from their web sites community part, where SmartThings employers can chat with developers, customers and cooperation companies. (SmartThings, 2014c)

3.1.3 Kwikset smart locks

Kwikset is an over sixty years old USA based company providing locks and door handles. Kwikset has three different smart locks available: Smartcode with ZigBee or Z-wave and Kevo, smart lock with Bluetooth and Wi-Fi connectivity. (Kwikset, 2014)

Kevo is the Bluetooth connected smart lock, which makes it compatible with smart phones, but only Apple's iPhones 4S or newer. Kevo uses Bluetooth LE and smart phone operation system Android is not supported at the moment. The lock can be used also with a traditional key or with a Kevo Fob, a Bluetooth key. The lock can be used without touching a phone or Fob, because Bluetooth connection can be made to near by objects and Kevo's system allows lock to be unlocked. Security feature detects whether the smartphone or Fob is inside or outside of the house preventing unintentional unlocks. The lock itself must be touched in order to make the connection and entrance to be granted. Kevo's four AA batteries are predicted to last one year and user will be notified when batteries power is low. (Kwikset, 2014)

Smartcode locks with ZigBee or Z-wave are basically the same kind of locks. Difference is that smartphones do not have either wireless connectivities and therefore direct communication to the lock is not possible. Kwikset does not offer any other home automation devices and it may affect inoperational

issues with other vendors. Even if the wireless standard is the same, it does not mean that devices can operate seamlessly together.

3.2 SWOT analysis

Strengths, weaknesses, opportunities and threats (SWOT) is an analysing method and it is from the 1960s, developed in Harvard Business School among other business schools. This method uses four aspects: two from outside of the company (threats and opportunities) and two from inside of the company (strengths and weaknesses). (Hill & Westbrook, 1997)

Innovation is highly present with these products, therefore an aspect I will use in these SWOT analyses is based on two factors: First environmental factors and second radio frequency technologies factors.

Eight environmental factors are technological, economical, competitive, labour, resource, customer, legal & regulatory and global factors (Desai, 2013). In the SWOT analyses Desai's technological, competitive, legal & regulatory and global factors will be used. Desai (2013) defines these factors as follows: The technological factors where new technologies cause new products, competitive factors involve threats from innovative competitors, legal & regulatory factors cause increased costs and product liabilities. The last, global factors, contains distribution, customers and competitors location around the world and international strategic alliances. In these SWOT analyses technical, competitive, legal & regulatory and global factors are observed with how the used RF technology may affect the companies' situation.

Table 3 will consist of Belkin WeMo's analysis, Table 4 will consist of SmartThings' analysis and Table 5 will consist of Kwikset's analysis.

Table 3 - Belkin WeMo's SWOT analysis

Strengths	Weaknesses
• Hub required only with light bulbs, Wi-Fi connectivity. • 21 countries. • WeMo licenced products.	• Wi-Fi technology's power requirements. • Narrow product scale.
Opportunities	**Threats**
• Global distribution before many competitors. • Growing home automation business.	• Cooperation with other vendors

Belkin WeMo's products are relying on Wi-Fi and that narrows down the scale they can offer at the moment. Their light bulbs with ZigBee is used with a hub, therefore they have the means to widen the product scale, but it means hub becomes obligatory. Their market consists of 21 countries, which is bigger than the competitors have. Couple of vendors are making WeMo compatible devices but

Wi-Fi's constant power narrows the possibilities. A smart phone application If this then that (IFTTT) makes WeMo devices compatible with wider scale of products, for example SmartThings motion detector can trigger WeMo light switch on/off. Overall Belkin is making globally available decent products, which can operate with existing Wi-Fi router and they offer basic functionality. These factors are reflected with unavailability of battery-powered devices and limited cooperation.

Table 4 – SmartThings' SWOT analysis

Strengths	Weaknesses
• Three RF's support. • Central hub solution with multiple device support. • Hub is not obligatory. • Innovative. • Wide device support. • Samsung cooperation	• Products are limited to North America. • Regulatory process outside of North America. • Compatibility with other vendors is not locking customers to SmartThings.
Opportunities	Threats
• Growing home automation business. • Open community thinking does not restrict only for SmartThings products.	• Community is not developing towards general acceptance. • Open community thinking does not restrict only for SmartThings products.

SmartThings hub can communicate with three radio frequency technologies: Wi-Fi, ZigBee and Z-wave. For their own devices they use ZigBee, for Belkin WeMo's the hub uses Wi-Fi and for Kwikset ZigBee or Z-wave. This is the biggest advantage of SmartThings, open perspective for other vendors in order to serve customer the best way possible. Tight collaboration with Samsung's popular electronic devices makes implementation process easier. At the moment SmartThings is only for North America and open community makes SmartThings products also replaceable with other vendors' products, so customers have a choice which vendors products they use. Open community thinking acts both as an opportunity and as a threat.

Table 5 – Kwikset's SWOT analysis

Strengths	Weaknesses
• Smart phone compatible Bluetooth • Electronic key possibility • Three RF's support • Long experience with locks	• Narrow product scale • Lack of other home automation products and narrow smart phone support.
Opportunities	Threats
• Growing home automation business. • Few smart lock competitors	• Competitors with wider product scale can have significant advance.

Kwikset has three different RF technologies: Bluetooth, ZigBee and Z-wave. Bluetooth can operate directly with a smart phone, which makes the usage easy but also limited. ZigBee and Z-wave requires a central hub, for example SmartThings hub. Kwikset produces only locks, which means their smart locks depend on others home automation solutions. Kwikset has long experience among locks and on the market there are not many smart lock vendors and most of them are small start-ups. These start-ups can be a significant threat if Kwikset's products does not evolve and adjust to customers needs. Long experience can also be a sign of long traditions and lack of innovation, when smaller start-ups with better product surpass Kwikset.

3.3 Technological situation and the future predictions

Home automation has been a long process to develop. Before this millennium couple of companies tried to automate homes with wired connections, which never was successful in a large scale. They had problems with wiring the devices, controlling them and it was too expensive. Later with smart phones and fast and energy-efficient wireless technologies companies can offer consumers relatively cheap, secure and interoperable systems. Computing power has developed how Gordon E. Moore predicted transistor count to increase, which makes small smart devices more powerful. Transistor count is not only aspect to discuss; therefore this thesis was about wireless technologies.

Internet of Things is full of standards and protocols, which makes many big companies, e.g. Cisco, IBM and Intel to make common standards to support wide adaption of IoT devices. This thesis' wireless technologies are trying hard to become one of those standards. The race to become the most widely used wireless standard in home automation solutions is hard and will not end soon.

Bluetooth Special Interest Group made their newest core specification 2.12.2014, which proceeded toward IoT. Bluetooth is the oldest technology compared to Z-wave and ZigBee and it has a big benefit: Smart phone connectivity. Even though Bluetooth is the oldest and for long the technology has been found in cell phones, their approach to IoT has not been very rapid. The difference between Bluetooth and Z-wave/ZigBee might be the starting point, where Bluetooth was used for connecting speakers to smart phone, the other companies was developing IoT compatible technologies. When many different companies and organizations make these technologies, the developing process is slow. Bluetooth is clearly behind in terms of home automation product support from Z-wave/ZigBee, but the development speed is increasing and hundreds of millions smart phones support Bluetooth.

ZigBee's wireless technology might end up into Samsung's smart phones. This would affect in my opinion hugely how ZigBee gains market share and how customers adapt to ZigBee's devices. This correlates contrariwise to Blue-

tooth's situation, where smart phones are equipped with Bluetooth but not many home automation devices support it.

Wi-Fi can be found from hundreds of millions devices and as we saw Wi-Fi is great technology with high speed and long distance but its power consumption is too high for battery-powered devices. Belkin WeMo's web cameras are using Wi-Fi for streaming high quality video and surveillance cameras are expected to be powered with cord. When considering small sensors: in a mailbox there is a small motion sensor, which sends a notification to your smart phone when there is a new mail. This kind of device cannot be power with cord; even a little solar panel might be expensive and complicated. A battery, small AAA size not rechargeable battery is cheap and could last one year, therefore it would be practical and would need only little maintenance. Wi-Fi can not offer this kind of energy-efficiency, but in order to send the notification to the smart phone it would need a Bluetooth or with hub structure Z-wave or ZigBee. Bluetooth 4.2 is driving toward to this kind of energy-efficiency, hubless connectivity directly to smart phone. When 802.11ah standard is completed and utilized, Wi-Fi might have countless new applications and use cases.

Wi-Fi's biggest benefit is the wide adaption of suitable routers. When a suitable hub can be found from homes already makes it easier to buy remote control power outlets and set up in the existing Wi-Fi network.

Home automation business is growing fast. Today's standards are compelling with each other but also they are completing for richer environment. Technologies are evolving fast and customers want to make sure older standards work with newer ones. Flexibility, interoperability and versatility are terms, which customer's value and want. SmartThings has understood importance of these aspects and it can be seen in their products. Their open community and multiple radio frequency support is driving their products to success. Samsung's acquirement might rise questions from some of the customers, but SmartThings are promising that they are just owned by Samsung but they work as independent company. When SmartThings is expanding to rest of the world, they will come across competition but their product range and multiple RF hub could effortlessly work with customers existing devices.

4 Conclusion

In order to answer the research questions I have reviewed four radio frequency technologies and how they are used in products available today. Those four radio frequency technologies are from different companies or alliances, from all around the world and developed in different ways. All of these but Z-wave are open standards and their development process is scattered.

These technologies can be found in home in every corner. The reviewed products display representative of use cases but these wireless technologies' possibilities are enormous. For basic consumer remote control power outlets might be the first introduction, but in short time these technologies will be found from watches to dog collars.

The question about what technologies will be the most critical in home automation solutions cannot be answered entirely, but according to previous technological and business aspects in chapter 3.3 Wi-Fi and ZigBee are the most promising and Z-wave and Bluetooth will be less meaningful technologies. Especially Bluetooth is not going to vanish but the technology is not at the moment as suitable as ZigBee is. Z-waves biggest downside is closed technology and centralized chip manufacturing where wider implementation is more difficult to accomplish.

Internet of Things and sensor networks are important area to study and subjects focusing on energy-efficiency, security and interoperability are meaningful areas of further study. Energy-efficiency is essential for long battery life. Security is meaningful for customers trust in this kind of technology and interoperability allows customers to adapt faster different products.

REFERENCES

Atzori, L., Iera, A., & Morabito, G. (2010). The internet of things: A survey. Computer Networks, 54(15), 2787-2805. doi:http://dx.doi.org/10.1016/j.comnet.2010.05.010

Bluetooth SIG (2013a). Bluetooth 4.1 Technical Description. Downloaded 20.11.2014

https://www.bluetooth.org/en-us/Documents/Bluetooth%204.1%20Technical%20Description.pdf

Bluetooth SIG (2013b) Core v4.1. Downloaded 20.11.2014 https://www.bluetooth.org/DocMan/handlers/DownloadDoc.ashx?doc_id=282159

Bluetooth SIG (2014) v4.2 Specification. Downloaded 3.12.2014

http://www.bluetooth.com/SiteCollectionDocuments/4-2/bluetooth4-2.aspx#faster

Boswarthick, D., Elloumi, O., & Hersent, O. (2012). M2M communications : A systems approach. Hoboken N.J.: ETSI.

Coleman, C. (2004). An introduction to radio frequency engineering. Cambridge UK ; New York: Cambridge University Press.

Desai, J. (2013). Innovation engine : Driving execution for breakthrough results. Hoboken N.J.: John Wiley & Sons, Inc.

Gill, K., Yang, S. H., Yao, F., & Lu, X. (2009). A zigbee-based home automation system. Consumer Electronics, IEEE Transactions on, 55(2), 422-430.

Gomez, C., & Paradells, J. (2010). Wireless home automation networks: A survey of architectures and technologies. IEEE Communications Magazine, 48(6), 92-101.

Guinard, D., Trifa, V., & Wilde, E. (2010). A resource oriented architecture for the web of things. Internet of Things (IOT), 2010, 1-8.

Hill, T., & Westbrook, R. (1997). SWOT analysis: It's time for a product recall. Long Range Planning, 30(1), 46-52. doi:http://dx.doi.org/10.1016/S0024-6301(96)00095-7

IEEE (2014). Timetable
http://grouper.ieee.org/groups/802/11/Reports/802.11_Timelines.htm

Mainetti, L., Patrono, L., & Vilei, A. (2011). Evolution of wireless sensor networks towards the internet of things: A survey. Software, Telecommunications and Computer Networks (SoftCOM), 2011 19th International Conference On, 1-6.

Minoli, D. (2013). Building the internet of things (IoT) with IPv6 and MIPv6. Hoboken New Jersey: John Wiley & Sons, Inc.

Molisch, A. F. (2011). Wireless communications (2nd ed. ed.). Chichester West Sussex U.K.: Wiley.

Pedrasa, M. A. A., Spooner, T. D., & MacGill, I. F. (2010). Coordinated scheduling of residential distributed energy resources to optimize smart home energy services. Smart Grid, IEEE Transactions On, 1(2), 134-143.

Raeesi, O., Pirskanen, J., Hazmi, A., Levanen, T., & Valkama, M. (2014). Performance evaluation of IEEE 802.11 ah and its restricted access window mechanism. Communications Workshops (ICC), 2014 IEEE International Conference On, 460-466.

Siekkinen, M., Hiienkari, M., Nurminen, J. K., & Nieminen, J. (2012). How low energy is bluetooth low energy? comparative measurements with ZigBee/802.15. 4. Wireless Communications and Networking Conference Workshops (WCNCW), 2012 IEEE, 232-237.

Varchola, M., & Drutarovský, M. (2007). Zigbee based home automation wireless sensor network. Acta Electrotechnica Et Informatica No, 7(1), 4.

Wifi Alliance (2014). Read 21.10.2014

http://www.wi-fi.org

Xiao, Y., Chen, H., & Li, F. H. (2010). Handbook on sensor networks. Hackensack NJ: World Scientific.

COMMERCIAL REFERENCES

Belkin (2014a). WeMo home automation. Read 3.12.2014
http://www.belkin.com/us/Products/home-automation/c/wemo-home-automation/

Belkin (2014b). About us. Read 16.12.2014

http://www.belkin.com/us/aboutUs/

Cisco (2014). Internet of Everything FAQ. Read 26.11.2014

http://internetofeverything.cisco.com/learn/ioe-faq

Hawkinson A. (2014, 14.8.2014). SmartThings blog. Read 1.12.2014
http://blog.smartthings.com/news/smartthings-updates/smartthings-samsung-open-platform/

Higginbotham S. (2013, 12.12.2013). Gigaom article. Read 1.12.2014
https://gigaom.com/2013/12/12/the-gigaom-smart-home-hub-review-guide/

Kickstarter (2012). SmartThings crowdfunding website. Read 2.1.2015
https://www.kickstarter.com/projects/smartthings/smartthings-make-your-world-smarter

Kwikset (2014). Products catalog. Read 3.12.2014

http://www.kwikset.com/products/overview.aspx

M2M World news, (2014, 15.10.2014). Article. Read 11.11.2014
http://m2mworldnews.com/2014/10/15/19878-33-billion-internet-devices-by-2020-four-connected-devices-for-every-person-in-the-world-says-strategy-analytics/

SmartThings (2014a), Support. Read 1.12.2014

https://support.smartthings.com/hc/en-us/articles/200901150-What-Protocols-Does-it-Support-

SmartThings (2014b). Shop. Read 3.12.2014

https://shop.smartthings.com/#!/products

SmartThings (2014c). Community. Read 3.12.2014

http://community.smartthings.com

Z-wave (2014). Press release. Read 2.12.2014

http://www.z-wavealli-ance.org/index.php?option=com_content&view=article&id=572:sigma-designs-launches-latest-high-performance-z-wave-transceivers-into-volume-production&catid=27:member-press-releases&Itemid=118