Computer Science

Final Project Report

Smart Home Kit

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Contents

1. Problem Statement

Nowadays most people are not yet very familiar with the concept of having an automated home system. The main reason why this technology didn't become something mainstream just yet is because of its complexity and cost [1]. Such a system consists of various IOT (Internet of Things) devices that are connected to the same internet network. This would allow all these devices to communicate between them and also with the user, giving him the chance to monitor and manage them remotely from a single control interface. At the moment there are a lot of manufacturers that offer these devices at a cheap price, but it doesn't make it any easier for common people to choose the right devices that are compatible with one another in order to create a simple and functional system.

Here is where the group members are coming up with a solution than would improve the user experience and would help all types of users to benefit from such a great technology. A Smart Home Kit that allows the users to control their homes with a simple mobile application. The system could contain any number of smart lightbulbs which are Wi-Fi enabled and a Raspberry Pi used as a server to control everything. The Raspberry Pi is working as a server implemented in NodeJS which is receiving commands from the native iOS/Android applications, developed in React Native. All the smart devices are Wi-Fi enabled and have open API. The server receives instructions from the mobile clients in the form of HTTP requests and sends commands to the LED using the SDK.

By directly offering a smart home kit which would include all the necessary hardware and software components, the user won't have to worry about anything else, the smart home kit would be easy to set up and it would also let the user to further extend the system with other functionality for other household appliances.

The complexity and cost of various new technologies is often the impediment that stops the benefits of them from being brought to the hands of people. This is also the case for IoT which could bring massive improvements into the everyday life of people, especially to elderly and disable people who could really make use of a smart home automated system which is what the group members are trying to offer with this project.

2. The Internet Of Things (IoT) And Its Applications

2.1 Key features

The huge hype of the new Internet of Things technology [2] has been going around for some time and yet not so many people got the chance to experience and get familiar with the potential of this technology and the benefits it can bring to us and to the environment around us. Through the various IoT applications that are currently under development in different industries, we would be able to become more efficient in the different activities of our daily lives. People of various ages and medical conditions would have a more comfortable and enjoyable life while at the same time the negative impact that we have on our environment would be lower. Probably the most important key aspects of the Internet of Things [2] and what makes is such a unique and disruptive technology are presented as follows:

- Artificial Intelligence (AI) – Bringing the power of such an amazing technology into different applications of IoT enhances its capabilities even more. Objects that we would use on a daily basis would truly become smart by gaining the ability to not only gather information based on how the user is using that object, but also to make decisions by itself based on the previous user interactions. Improving over time while also providing suggestions to the user for a better everyday experience.

- Connectivity – Being able to connect a multitude of devices all together into the same network it's already a great achievement, but when the devices can interact and communicate between them, then that is when these devices can bring an even more powerful value to its users by giving him the possibility of controlling and monitoring them from a single standing or even mobile interface.

- Sensors – These are the components of a smart system that really give the capability of the smart devices within the system to interact and gather data from the real world. Without them, the usability of such a system would be greatly decreased.

2.2 Advantages

At the moment, the Internet of Things is still considered to be at the early stages of its development and therefore it comes with some advantages and disadvantages that have a very big influence on the way it's perceived by regular people and also by companies that would like to integrate it into their businesses.

Here are some of the most important advantages of IoT [3], starting with the foremost of them:

- Reduced Waste – Through the multitude of sensors within devices that would deliver real-time data, companies and also simple consumers would have an efficient way to better manage their resources and therefore reduce the amount of waste that would be produced. This could lead to a greener environment where the negative impact on our climate change would significantly decrease.

- Improved Data Collection – Nowadays data collection is not considered to be of a very great importance, it sure is important, but the approach to it is a bit passive since the quality of data gathered is often lower than expected which eventually leads to lower quality results.

- Greater Costumer Engagement – With the ability of gathering more data about each individual costumer and their preferences, the possibility of offering a better costumer experience would definitely increase while also increasing the engagement of the costumers knowing that these services would better serve their needs.

- Technology Optimisation – Innovative products would appear on the market since companies would better understand their costumers and be able to adapt their products and services according to the costumer's behaviour and preferences.

2.3 Disadvantages

Despite the fact that IoT has a great potential to bring major improvements into our lives, there are a few aspects that could be considered as disadvantages of this technology. Or at least just for now, since most companies don't have the expertise or experience necessary to avoid mistakes that would impact its implementation costs and therefore the rate at which this technology would develop.

- Security – Having multiple devices connected at the same network increases the risk of vulnerability since some of these devices might represent a potential security breach for attackers who would probably be able to corrupt the entire network and eventually lead to user's data to be exposed.

- Privacy – The amount of user data that some IoT systems would contain represents a risk factor that can't be overlooked, but on the other hand some of the technology advancement would otherwise not be possible.

- Complexity – At the moment most IoT systems could be considered complicated or too complex especially for someone who would try to develop a DIY system by himself for cost reasons, but eventually the maturity of the technology would evolve, and certain standard protocols and framework would appear to stabilise and simplify the process of developing and owning such a system.

- Flexibility – For now, a lot of smart devices that appeared on the market might not be so easy to integrate with some other devices to form a network. This is mainly because of the many companies that tried to bring something to market as soon as possible in order to take advantage of this huge trend while avoiding many security and flexibility aspects.

- Compliance – Every new technology faces difficulties in complying with present regulations, but compared to other technologies, IoT is facing most of these issues not only on the software part but also on the hardware part of it making it a bit more difficult.

2.4 Consumer applications

What separates the different types of IoT applications between them is the difference of who can make use of such applications and it basically consists of 3 types: the consumer applications, the industrial applications and the infrastructure applications.

There are a lot of applications that could be created for consumer use and all of them would bring a new and innovative user experience, for example the wearable devices such as smart watches and activity trackers. These devices can help people track their heart rate, blood sugar levels or other health related statistics in real-time through different sensors in order to prevent unexpected health problems. Probably the most popular IoT application nowadays is the possibility of having an automated home or a so called Smart Home [4] where many, if not all the household appliances within the house would be connected to the Internet through Wi-Fi and form a network. From kitchen appliances, media or entertainment devices to lighting devices, all of them would then be able to communicate their state in between them and to the user who would control and monitor them from a single mobile interface.

By having a Smart Home system, a lot of complications might appear and the one that might require the most attention would be the security level of such a system. We wouldn't want to create a system where anybody has access to our network of devices, especially people who don't live in our house and would have bad intentions regarding our devices. It's not the first time when people tried to implement a similar technology. Radio frequencies were used instead of Wi-Fi, as a first attempt, but the complications of security were a lot higher since

there wasn't any kind of encryption system to protect the network. Here is where Wi-Fi brought a difference through its WPA2 encryption system which can still be hacked, but there are several measures that can be taken in order to increase the security level and avoid a possible threat. Now there are also some other wireless protocols that are secure and could be used besides Wi-Fi, for example Z-Wave or ZigBee which already being used in banking systems and promise to be even more reliable. There is also a non-profit organisation called Internet of Things Security Foundation (IoTSF) that has the sole purpose of trying to solve any problems that might stand in the way of having a secure IoT solution by helping any IoT business venture to establish security principles from the very early stages of designing any IoT device or system.

Home security

The safety of a home would definitely increase when certain alarm systems with motion sensors, smoke detectors or cameras would be put together and give the owner the possibility to remotely monitor the house from anywhere, at any time. This is something that would bring a real value to people by helping them to create a safe environment and avoid possible accidents or misfortunes. [5]

Voice control

The one application that can potentially enhance the capabilities of people while using the various smart systems would be the possibility of controlling them using just their voice. This is something that has been a subject of wonder included in the many science-fiction movies from the past and even though at the moment there are a few voice recognition systems out there and we are somehow already familiar with it, its wondering effect is still the same ever since. Some of these voice recognition systems like Siri, Cortana or Google Assistant even have Artificial Intelligence integrated into them and most people already got used to using them in their daily activities such as checking the weather or asking for directions to the nearest restaurant. A smart home that would have a voice recognition system would then be able to help the user control its devices from anywhere within the house with the use of a

mobile phone and this way the ease of use of such a system would be improved so much more that anybody, no matter what technological skills they have, would be able to control it in an easy and comfortable manner. [6]

Connected car

Another very important consumer application of IoT that could really harness the capabilities of this technological advancement would be the integration of a vehicle with the Internet. Modern vehicles are already making use of the high processing power of computers to read data from their various sensors, like the tire pressure sensor, or to calculate fuel consumption and to try to provide useful information to the driver so that he could take better care and to make better use of its car. But if the car would be connected to the Internet it could communicate and make use of even more data from other vehicles or other smart devices around it. This could potentially help the transport industry to solve some of its greatest issues [7], for example:

- Safety – Most accidents today are happening because of the inability of the driver to predict the traffic behaviour or to see in blind spots and this could be solved if the vehicle would be equipped with even more sensors that could detect potential hazards and increase the awareness of the driver by helping him avoid misfortunate events ahead of time.
- Environment – If the vehicle could inform the driver ahead of time on the conditions of the traffic then he would be able to change his route to the most convenient one. Traffic congestions could be less frequent or avoided and people would therefore spend less time in traffic while at the same time reducing the fuel consumption.

2.5 Industrial applications

The Industrial Internet of Things, commonly referred to as IIoT or the so called new Industrial Revolution has its basis on the impact of the huge amount of smart devices that are expected to appear in the upcoming years into different industries [8]. Compared to the

massive growth of consumer devices and products that are yet to appear and which are mainly discussed throughout the media at the moment, the number of IIoT devices is expected to be even bigger because of the multitude of applications it can have on a worldwide scale.

Radio-frequency identification (RFID) represents the foundation on which the potential of IIoT or IoT in general started to be recognised. RFID uses wireless communication to identify and track various objects. Very small RFID chips, also called tags, with the size of a grain of rice could be implemented in many objects and even animals. This could be helpful in many industries that struggle with inventory management since the tags could be identified simultaneously compared to the current standards, such as barcodes which have to be accessed one at a time. What IoT adds to this is the ability to connect the RFID tags to the Internet and monitor them in real-time and also on a larger scale. The connectivity between more IoT systems is what really enables its capabilities and the way to do it is through M2M (Machine-2-Machine) communication.

The use of M2M communication brings some new possibilities into industries like agriculture, manufacturing, retail, logistics and so many others. With machines and industrial robots being able to communicate between them and be remotely monitored, a lot of industrial processes would become automated and the need for human labor would decrease while at the same time the safety of how these processes operate could be increased. An example of such a process is the maintenance process where people nowadays have to make regulated maintenance checks in order to check if a machine has any damages or any signs of wearing off and to fix any broken components, but most of the time all sorts of machines just brake down from lack of frequent checks. This can lead to affecting the entire production process within the company or some other important processes that if affected, in some cases, can even take a company out of business. But then if the machines could communicate their current state, it would be so much easier to monitor them and to try to predict and prevent possible breakdowns. This way the maintenance cost would significantly decrease, and a continuous production process would be assured.

Manufacturing companies would benefit in many ways from such a great technology, particularly the production time of new products would be a lot faster since the information provided in real-time through the use of sensors, which would be connected all together and remotely monitored, will lead to better optimization of the production lines and therefore also giving the opportunity to the companies to adapt easier to the market demands or to new

regulations. A few challenges are presented when an already existing manufacturing company would try to shift to IIoT and take advantage of its benefits. The products that the company is producing would have to be redesigned from a totally different approach and developed in a way that would satisfy the customer's needs even if the new products would offer a new user experience. The challenges here would become even more complex since the company would have to invest a lot in developing a secure product that can't be exploited by hackers which could also lead to major investments into the customer relations department.

Smart supply chains

To be able to produce those new products, the companies would have to find another supply chain as well and the advancements that IIoT brings could be applied here too. Currently most companies have difficulties with balancing the demand and supply of their products because of the inconsistent forecast of the sales [9]. This makes it harder for the elements within the suppling chain to adapt to one another as for example, the manufacturing element is not aware of how marketing affects the customers. This eventually leads to more or less products being produces and therefore, depending on the case a delayed shipment of the products. A smart supply chain is going to solve this very important issue. The supply chain would become more aware of what is happening in the different elements, helping companies to better adapt to sudden variations of the customer demand and avoid possible problems like not having enough raw materials for the manufacturing element.

Smart retail

The retail industry is also one of the industries that could hugely benefit from IIoT. Stores around the world could then analyse in real-time how the customers interact with their products and how they behave inside the store. If the stores could predict when the number of customers is raising then more cash lines could open and queues would be avoided, improving the customers experience and eventually sales. Digital billboards placed inside as well as outside of the store would enhance the customers experience even more [10]. Based on the data collected from customer's behaviour, the ads would be displayed according to what the customers are interested in and no more irrelevant and annoying ads would spam

them. The ads would then be capable of helping the buyers take advantages in the best way from sales periods and create a win-win situation for everybody.

Smart farming

Agriculture is probably the most overlooked industry in which IIoT can show its benefits [11]. That is mostly because the applications of it are taking place in remote areas that don't usually appear in everyday news and as a result people are not so aware of how big of an impact the advancements of this technology can have on their lives. Smart farming will not have a direct effect upon peoples lives, but through the economies of their countries the benefits of it can be felt over time. Countries from Africa that depend their economies on agriculture because of limited ways of diversifying their economies, could gain a massive aid by implementing smart farming solutions. Some of these solutions would be livestock tracking, remote equipment monitoring, remote crop monitoring and so many others that would help the farmers to work more efficiently and take better care of their animals or lands while also saving more money. If the farmers would have the chance to monitor their livestock remotely, they could identify sick animals and separate them from the herd and this way the spread of disease could be prevented. The storage conditions of the crops could be adapted easier to climate factors like the humidity level in the air to avoid rotten crops being feed to the animals. The machines and all the equipment could be maintained easier based on the analysis of the data they would provide, and they could perform in a more efficient way, gas would be saved and the farming work itself will not be so hard anymore.

Energy & Waste management

The greater pay off that IIoT would bring to all these industries with its great connectivity and its real-time data monitoring, is the opportunity to reduce the amount of waste and energy that is being produced. Manufacturing companies could better manage their resources and counter the problem where unused raw materials that cannot be recycled would be thrown away. Smart supply chains could improve their logistics because of a better communication between its elements and a more cost-effective delivery from manufacturers to consumers would be possible. Farms could better optimise the fuel consumption of their

machines. The inefficient use of water for crops and animals or the inefficient use of electricity for big manufacturing companies could be significantly decreased, correcting the overall negative effect upon the environment and helping to solve world-wide problems like climate change.

2.6 Infrastructure applications

The expected increase in population is raising worrying concerns in municipalities around the world as some cities could become overcrowded and the infrastructures developed to sustain a good quality of life within those cities might not be able to keep up the pace [12]. Some cities already managed at the moment to find solutions to some of these overpopulation problems. For example, surveillance cameras that provide video footage in real-time to help police departments maintain a safe environment in areas with high levels of crime events. Streetlights that are able to adapt constantly to activity levels on the streets in order to optimise the energy consumption and lower the costs. Or smart traffic lights that make use of sensors to detect heavy traffic routes so that congestions and traffic delays could be avoided.

IPv6

Due to the increased number of computers and devices that are connected to the Internet nowadays, the number of IP addresses that are used to identify and locate a connection has also increased and therefore the limited number of addresses that is available has come to a close end. The current IP (Internet Protocol) version is v4 which only allows a number of 4.3 billion devices to be connected to the Internet with a unique address. As mentioned before, not only the human population is expected to grow with a fast pace, but the number of connected IoT devices would also increase drastically. The solution to this problem would be the implementation of a new IP version with a bigger capacity of connected devices and the one that is already implemented at the moment on a very small scale is IPv6. According to Wikipedia [13], the capacity of addresses of IPv6 is approximately 3.4 x 10^38 and it represents a capacity that could easily cover and handle as many IoT devices as possible without having to worry about any limitations. IPv6 does not promise only a bigger space for more addresses, but also new features that make it a more efficient internet protocol, for

example, data packets are not fragmented unless they have a very big payload compared to IPv4 where all the data packets are fragmented thus less efficient. The transition from IPv4 to IPv6 is making a slow progress because the two protocols were not designed to interoperate between each other, but more as two independent networks. This is more of a software issue than a hardware issue since most modern devices were designed to support IPv6, but the exchange of traffic between them needs transition mechanisms such as traffic tunnelling which is not very performant as latency might be increased.

Smart cities

The management of big cities can become very difficult because of the probability of having multiple problems happening at the same time or all of a sudden and it all depends on the city's capability to react as efficient as possible in order to maintain the well-being of its citizens [14]. Unexpected problems like natural disasters can have a long lasting negative impact on the resources that the city can depend so much on such as water, electricity or gas. This could only be avoided or at least to try to reduce the duration of its effects if the authorities within the city could predict such an event and prepare in time. A smart city where the police, the firefighters, the hospitals and all the other authorities that would act in a state of emergency, could better communicate between them through the connectivity that IoT provides making it a safer and more reliable city to live in.

Through the use of analysis based on real-time data instead of analysis made on data gathered over time and often times with poor research the multitude of use cases where smart cities could bring an improvement to current city's operations extends even more.

Smart power grids

The well-known event of power blackout is wide spread across many countries and is costing them a tremendous amount of money because it's quite difficult to detect and it can affect entire networks of power since it only needs one faulty element within the network and the flow of power would be over. This problem could be solved with the help of some software enhanced with IoT technology by utilising its real-time monitoring feature. The development of the power grid faces a few challenges that make its progress move with a slow pace [15].

First of all, the infrastructure needed to support the extension and improvement of the power grids would need massive investments from electricity companies which would need at first to come up with some viable solutions. One of the solutions would be to increase the flexibility of the grid by making a better use of the renewable energy resources such as wind and solar power that are available at the moment. This is often complicated because of the varying levels of power produced depending on the weather conditions, but it could be solved with a more controllable output of the power provided by the connectivity benefits of IoT. Another solution brought by the IoT technology would be the optimization of the power demand, making the electricity providers more efficient and therefore lowering the power prices.

Smart utility meters

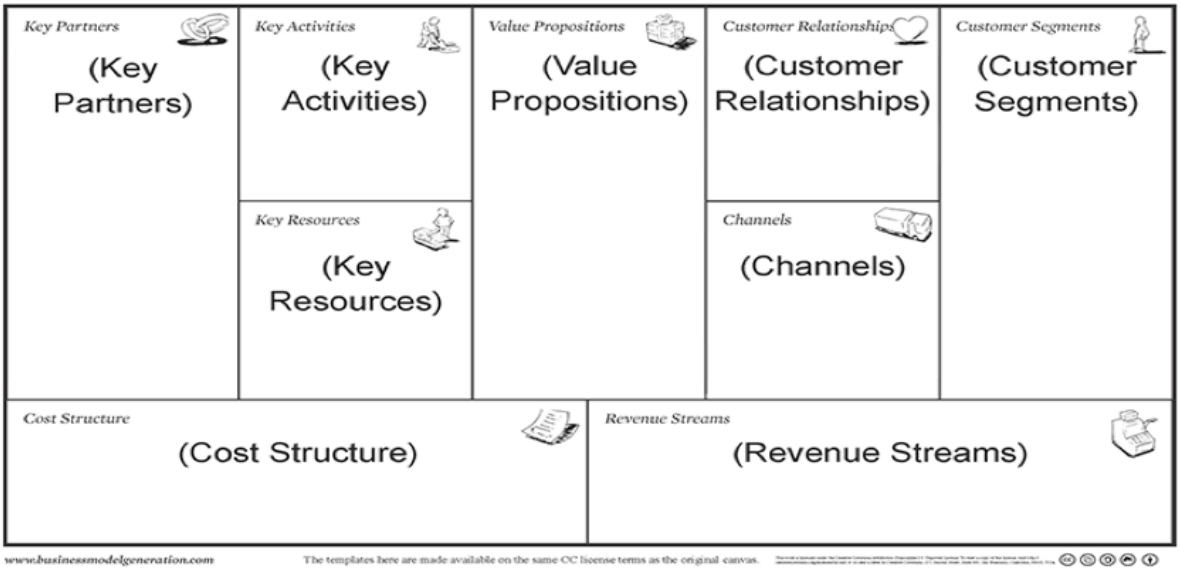
The solutions previously mentioned could help achieve a cheaper and more reliable power supply, but another great achievement could be to stop some people from committing electricity theft. This is another issue that has happened for a very long time since it cannot be easily detected, especially in areas with high power consumption, but if the electricity meters could be complemented with real-time monitoring then this problem could be a thing of the past. So many other types of meters and especially utility meters such as water, gas or heat meters, could become smart meters which would communicated the level of consumption to the utility companies for monitoring. This way the consumption levels could be precisely measured and there would be no room for theft.

Energy & Waste management

On a city level and also depending on how big the city is, energy and waste management can have an even bigger impact on the environment. Smart waste containers around the city could connect to the fleet of waste collection vehicles and would inform them only when they would reach their full capacity [16]. In this manner the containers would be collected in a very efficient way while also cutting down the costs by reducing the number of vehicles and human labor. Energy could also be saved this way as less vehicles means less fuel needed. If the containers would use solar panels to power the sensors, then again in time a lot of energy could be saved.

3. Business Model

In order to see if selling the Smart Home Kit could make a viable business, the group members used a strategic management tool called Business Model Canvas (BMC) developed by Alexander Osterwalder.



As seen above, the BMC is compounded of nine building blocks which concern the key aspects of an organisation. Furthermore, the following paragraphs will go through all nine building blocks and apply them to the project's case in order to have an overview and asses if the business can be implemented or not.

3.1 Value proposition

Value proposition is the foundation of any organisation. According to Osterwalder (2004), value proposition is the main aspect from which an organisation differentiates from its competitors. This differentiation can be concentrated on quantity such as: price, efficiency, etc. or it can be focused on quality: design, customer experience, etc.

Thus, Smart Home Kit is a plug and play lightning system with a mobile and user friendly, single control interface. The value that the Kit brings is two-folded as it provides both practical and social advantages. One practical aspect is focused on bringing value to people with motoric disabilities and elderly people who cannot move around the house too much to turn on or off their lights. These people also face the inconvenient problem of having to move to a health care facility where they can receive special treatment. This is considered to be inconvenient because it can affect their well-being on other levels, as moving to such a facility is often not very comfortable because of the anxiety that can be brought to them by having to leave the comfort of their own home. By using the user-friendly interface of the Smart Home Kit, controlling the lights will be as easy as switching one button and it can be done from any location within the house. This can help people to get one step closer to having an automated home where elderly and disabled people can stay and won't have to leave anymore as more benefits could come with the advancement of this technology.

If the first aspect fulfils a more functional need, then another second aspect concerns more of a social need, namely self-esteem. The Smart Home Kit can bring benefits to people for whom controlling the lights in the house is not necessarily a problem, but they are looking for a more convenient way to do it and who would also like to be perceived as a modern man/woman.

Moreover, the aim is to compete with other already established companies that sell these kinds of systems by offering the lowest price on the market. Therefore, the value propositions combine both: quantitative and qualitative approaches by fulfilling the needs of the customer segments with the best value/money ratio.

3.2 Customer segments

The customer segment block, is useful in identifying the different archetypes of customers to assure that the organisation's strategy meets the characteristics and needs of each customer segment.

Given the nature of the product offered in this project, the customer base could be wide from people as young as they could afford the Smart Home Kit to old people who need a more

convenient lighting control system in their homes. But, two customer segments were identified that would need more focus, due to their needs and the value that product can bring for them.

As mentioned in the value proposition part, these two segments have different needs, therefore two marketing strategies mould for each segment's buying decision will be differentiated.

To do so, two personas were created in order to understand the main customers archetypes. Given the more obvious need for the Smart Home Kit, the first customer segment is elder men and women or people with motoric disabilities, for whom movement around the house is not as easy.

An example of a person like this would be Helle. She is 48 years old, she lives in Aarhus and has motoric disabilities. The pain of this customer segment is that moving around the house for small tasks is not so convenient, therefore controlling the power, colour and intensity of the lights in every room of the house with the Smart Home Kit would improve her life substantially.

The second customer segment, is expected to be a bigger market and their needs for a Smart Home Kit are both: functional, because they want a more efficient way of controlling their lights, especially because they don't want to interrupt their activities like reading or watching a movie.

And socially, because they want to be perceived as a modern man or woman who keeps up with the technological trend.

A person like this would be Anders. He is 28, in a relationship and lives in Aalborg. He has an income of 40.000 DKK per month. He is educated and also is interested in technology. He has a busy lifestyle, due

to his job and also his sport activity. When he is at home he wants to enjoy his time relaxing through reading or watching TV. He feels like his time is valuable and doesn't want to waste it on small tasks.

The value that Smart Home Kit brings to him is that it can change the mood of the room at a single touch on his phone or tablet therefore he doesn't have to interrupt his dinner or other evening activities. Also, it gives him social satisfaction, being perceived as a modern man, in trend with the technology.

3.3 Channels

The channels building block deals with how the customer segments are going to be reached, the buying location which can be through a website or a store, the delivery of the product, etc.

In this project, both channels will be used, selling through a website, world-wide, but also selling in physical stores through strategic partnerships with big stores, for example Bilka or Føtex.

The advantages of using both kind of channels is that through the website the Smart Home Kit is sold straight to the customer, thus a higher profit margin could be achieved from selling the product. But to make the customers aware of the website and drive clients to it, it is an expensive and time-consuming process. Therefore, having a well-established marketing strategy and strategic partnerships with big stores, that already have a big customer base, will allow the product to reach more customers, even though there will be lower profit margins. In time more attention will be focused on increasing the online sales in order to have the highest potential of turnover, but especially in the initial phase, using both channels will allow the product to reach as many customers as possible.

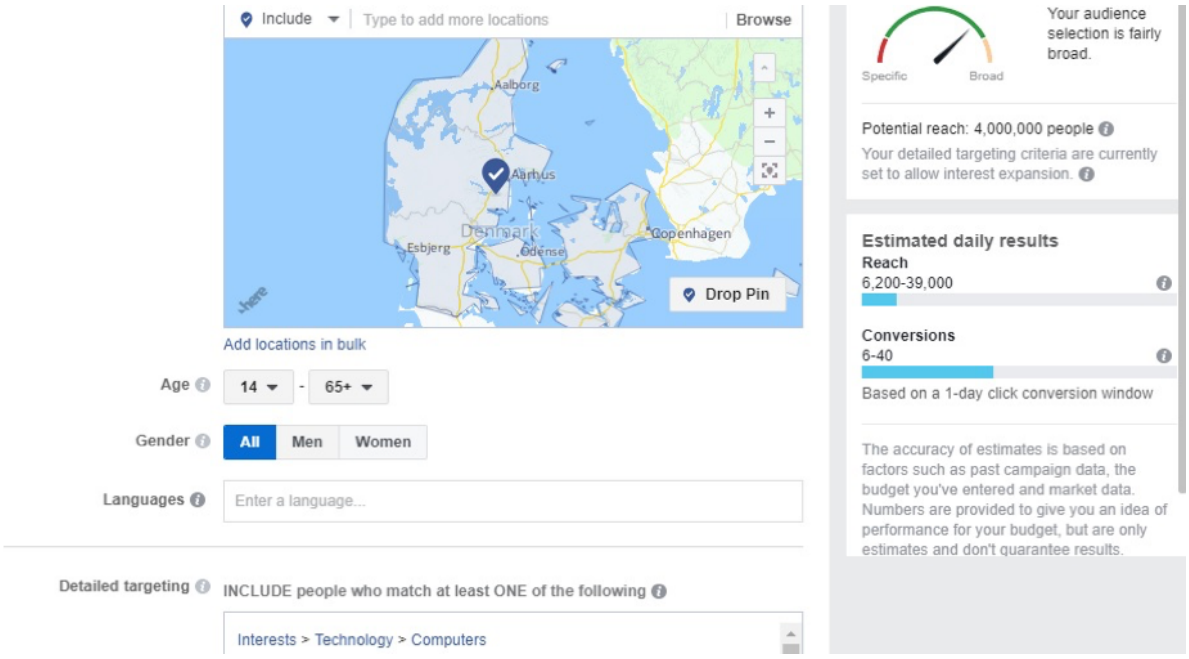
3.4 Customer relationships

After the selling channels were identified, the next building block in the BMC is the customer relationships, which deals with how to get, keep and grow the customer base.

In order to get more customers and make them aware of how the product will solve their problems, investments will be made in online marketing ads, through Facebook and will target people who are interested in technology in Denmark.

As seen in the picture below, with an investment of 5000 DKK in just one Facebook marketing campaign, between 6.200 and 39.000 people could be reached. From these numbers, it is estimated that between 6 to 40 people will be converted into buyers from the website. This Facebook campaign will target both men and women in Denmark, aged from 14 to more than 65 years old, who have an interest in technology. Even though only 6 to 40

people will buy the product from the website, the rest of the people who see the ads from this campaign, will be able to buy them from any of the physical stores that the organisation will partner with.



Another customer relationship incentive will be free delivery for people within Denmark who will choose to buy the product through the website.

3.5 Revenue streams

Revenue streams concerns the way an organisation makes an income. Because there is only one product, the revenue stream will be made through direct sales to the customers who buy online and bulk sales to the strategic partners who will have bigger orders. In the initial phase of building a customer base, there is no need to use ads for our mobile application in order to make another revenue stream neither the freemium approach where the basic app is free but an eventual premium version with more add-ons would require a monthly membership.

The price of a Smart Home Kit would be at 600 DKK including the hardware pack and software application sold through the website. Selling through external partners, the price per Smart Home Kit will be 500 DKK, where the shop can add their mark up.

3.6 Key resources

This building block refers to all the required resources which help in creating the value for the customers. These assets which are needed to support and strengthen the company can be human, financial, intellectual, etc.

The main key resources that the organisation possesses are human and intellectual. Firstly, there is the knowledge for creating the application and the system and also the approach which is different from the other companies which focus on other aspects of this business. Secondly, if it was to implement this business idea, people with different educational backgrounds would be contacted who will focus on the business aspect in terms of market research and idea validation, and also design, branding and marketing. Another key resource is the intellectual resource of making a unique Smart Home Kit that is easy to use and interactive.

Nevertheless, there will also be the website and Facebook page, which will be the channels of selling and advertising of the product and lastly, there is the physical resource of depositing bigger amounts of Smart Home Kit.

3.7 Key activities

Key activities represent the tasks that a company has to conduct in order to achieve its business goals.

The main key activities that of the organisation are continually research and developing the Smart Home Kit, to add a voice control future to the system for elder people who are not used to mobile applications, and more other functionalities that can be added to the system. The aim is to add as much value for money for the customers and that will be done through constantly development of the actual system.

Other key activities will concern marketing and selling the product. As mentioned earlier, it is important that each customer segment really understands the benefits of using our Kit, solving their problem. Therefore, the story telling and creating the video ads on online marketing will be an activity that require more focus.

Lastly, the third activity that will need more focus, beside product development, and marketing strategies will be the customer service. It is important that the client is satisfied after their purchase and they will come back or at least will recommend the product to other people, building the customer base.

3.8 Key partners

Business partnerships are important for companies that want to reduce certain risks, by forming an alliance with another company where both parties benefit.

In developing this company, having key partners is essential, as a manufacturing company is needed, which can deliver the light bulbs and the Raspberry Pi.

The main target would be a manufacturer from China, but finding one in Europe will also be very convenient in order to avoid paying big import taxes. Since there are many companies that can produce this type of technology, but which can also develop the product according to specific requirements. So, there is a need for a partner where the language barrier and trustiness would not create a problem. Their benefit of making a partnership with the organisation is that they will sell their big inventories, in big quantities for a low price, which is convenient for the organisation, but at the same time is the risk took by trying to make it work with the other components like the mobile app and server while also selling the whole Kit to customers. For this business to be viable, it is crucial that the marketing and selling of the Kit will work.

Other partnerships that are important for the organisation, are the buyer-supplier relationship between them and big stores like Bilka for example. At least one partner as such would be needed, which would already have a customer base, to increase the chances of getting the product to the market and sell it.

3.9 Costs

This building block represents all the costs that a business can approach if used for a particular business model.

The business structure used for this company would be a cost-driven approach, where the focus is on minimising costs in a way that the product is cheaper than the competitors'.

The main costs of this business will be the purchasing of a Raspberry Pi 2 Model B which costs 250 DKK and also the Xiaomi Yeelight Smart LED RGBW light bulb which costs 80 DKK per piece.

The Smart Home Kit will cost 330 DKK to purchase in total. An initial order would amount 300 pieces, therefore the cost of inventory alone will be 99 000 DKK. Added to it will be the cost of transportation, where the group members do not have an exact estimate, and also the import tax from receiving goods outside of EU.

Given the fact that the group members can create the website themselves, will have a significant impact on the cost structure, saving a lot of money which would have been another expense.
Lastly, the cost of marketing campaigns in order to attract clients are estimated to be at 5000 DKK per month and at least 3 campaigns would be needed in order to get the product acquainted to the market segments.
The total cost of starting the business is approximated at 125 000 DKK.

3.10 Conclusion of BMC

To understand if a business is viable or not, more research needs to be done in terms of market analysis, competitor analysis, marketing strategies, budgeting, etc. The business plan made here is just formed of hypothesis which would need to be tested before the business would be implemented. Nevertheless, using the business model canvas tool, we have a blueprint of how the business model of the company would start with.
If the whole first inventory of 300 pieces would be sold through the channel which will

provide the lowest profit, namely through partners, at a price of 500 DKK each, the company would still make a profit of 25 000 DKK which can be reinvested in bigger orders.

Thus, the business could be viable, but as mentioned earlier, further research in the business aspect of this idea is needed before investing any money in it.

4. System Development

4.1 Requirements

Based on the personas that were made for the research of the business part of the project, the group members were also able to consider the personas as actors with individual behaviour that would use the system in order to achieve a personal goal. This helped to establish some specific use cases of the system and gather the functional requirements that drive the entire development process. Before the use cases were defined, the event tables, which can be found in the appendix, were created to better understand what would be the steps the user would have to make in certain events. Based on the event table that was created for the most important functionality of the system, the use cases were prioritised so that a better focus could be allocated to them in the next development phases. Therefore, in the case of the "Turn lights on/off" use case, which is considered to be the primary functionality of the system, it was decided to have a fully dressed representation made for it, where the interaction between the user and the system is more detailed.

Use case	Turn lights on/off	
Actor	User	
Pre-conditions	1. The user is not registered 2. The user did not connect any devices to the system before	
Frequency	100 times a day	
Main Success Scenario	Actor	System
	1. Use case starts with the user picking up his mobile phone	
	2. The user opens the app	The app displays the log-in form

	3. The user wants to create a new account by selecting the create a new account button displayed on the log-in page	The app provides the user with the sign-up form
	4. The user inserts the necessary personal details	The app creates a new account for the user and then it redirects him to the log-in form
	5. The user tries to log in into the app with his new credentials	The app authenticates the user and logs him in
	6. Once the user is logged in he would like to add a new device to the system by going to the Devices page	On the Devices page, the app provides the user with the process of adding a new device to the system
	7. The user then selects the device that he would like to turn on from a list of connected devices	The app displays to the user the controls available for that device
	8. The user presses the on/off switch of the device	The app reads the command and the light is turned on or off

A brief description for the other two use cases that are considered to be very important to the basic functionality of the system are presented as follows:

- Use case: Change brightness
- Description: The user is sitting at the table from the dining room together with his spouse for a romantic dinner. Everything is all set except for the lighting in the room as the lights are already turned on and the level of brightness is too high which is really not setting the mood for a romantic dinner. The user then simply takes the phone out of his pocket, enters the app where he is already logged in and then he selects the lightbulb device from the dinning room and sets the brightness to a more convenient level.

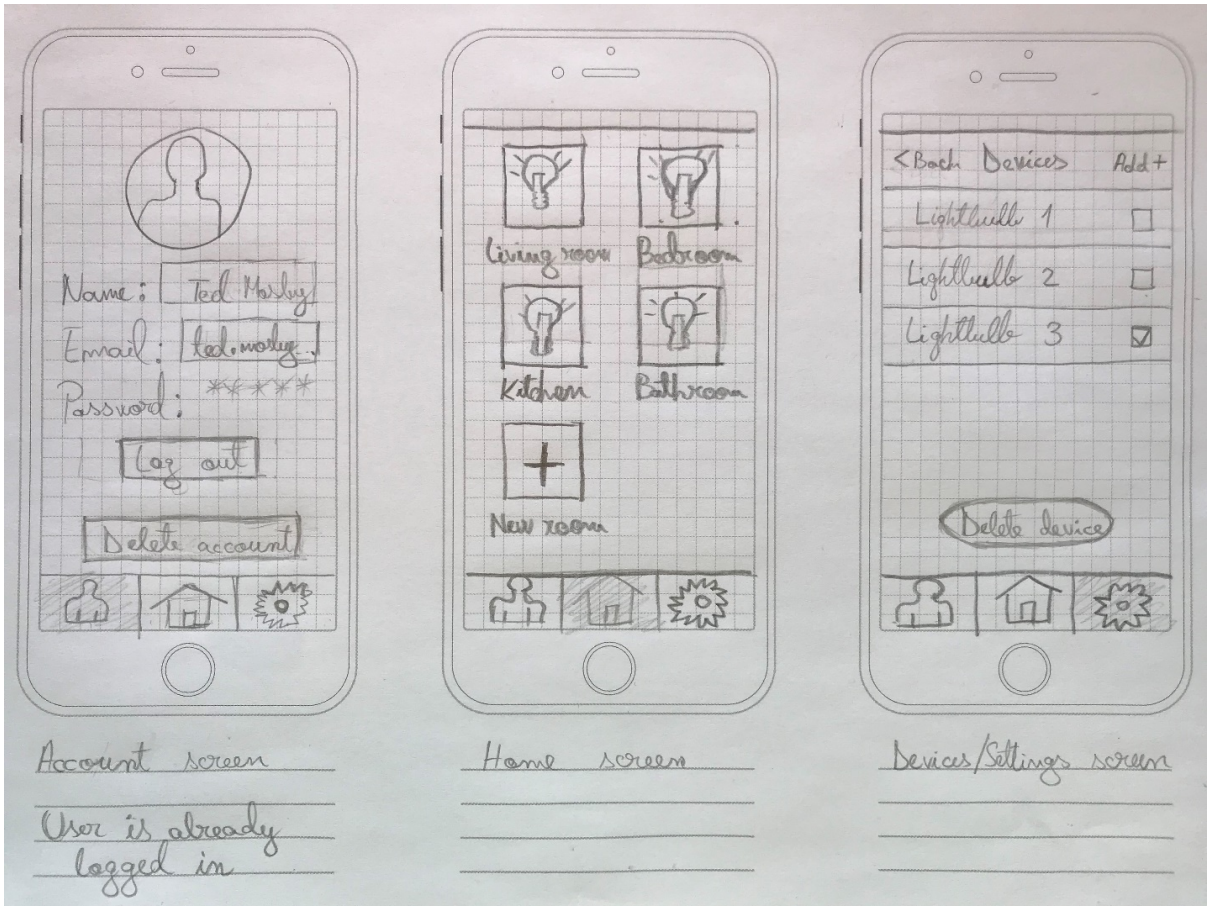
Event	Use case	Steps in use case	Actor
Change the brightness of the lights (Assumption: The user is already logged in)	Change brightness	Select the desired device from a list of devices on the home page Adjust the brightness level accordingly	User

- Use case: Change colour
- Description: The user would like to change the colour of the lightbulb to create a more appropriate atmosphere in the room as he is trying to read a book and a warmer light colour could benefit his eyes. The user then picks up the phone and since he is already logged in he just selects the lightbulb from the room he is in and picks a colour from colour wheel provided by the app.

Event	Use case	Steps in use case	Actor
Change the color of the lights (Assumption: The user is already logged in)	Change color	Select the desired device from a list of devices on the home page Select desired color from a color picker	User

4.2 Mock-ups

With the help of the requirements that were gathered in the first phase of the project development, a step further into the next phase was taken, which is actually the design phase where a more detailed representation of how the smart system was planned, started to take shape. To do that, a few Mock-ups were made, which basically represent the visual aspect of the various use cases within the system. More specifically a paper mock-up where a prototype of the system's GUI shows the steps a user would take to edit his personal information, to select the room in which he would like to turn the lights on and to add or delete more devices.



As it can be seen in the figure above, the mock-up on the left represents the Account screen where it is assumed that the user is already logged in. Here, the user is capable of changing his email or his password. He can also log out from the account, so he could log in with another one or he can just delete his entire account. The mock-up in the centre represents the Home screen. Here the user can directly access the lights from different rooms around the

house, making it very easy for everybody to make use of the app. The mock-up on the right side shows the Devices or Settings screen where a list with the available devices is displayed. The user has the option to go back to the previous screen and the option to add another new device to the current network of devices. He can also select any of the devices from the list and delete them if he wants to.

4.3 Usability testing

After the group members managed to set out the main success scenarios in which the user would successfully make use of the system without facing any challenges, alternate flows of events started to be taken into consideration, where it might be possible for the user to have a different experience and not necessarily a pleasant one. For example, for the "Turn lights on/off" use case the user might face difficulties when creating an account or to successfully log in into the app.

Based on the "GeneratingTestCasesFromUseCasesJune01" pdf file from the System Development course the group members managed to comprehend that if a clear set of scenarios that would happen alternatively to the basic flow of events, could be identified, then they would also be able to identify some test cases that could be used to test the system from an early development phase and a lot of issue could be fixed thus saving them from a lot of troubles along the way. To do it, a table that shows all the possible scenarios that could happen for the "Turn lights on/off" use case, was created.

Scenario Name	Starting Flow	Alternate
Scenario 1 – Lights are turned on/off	Basic flow	
Scenario 2 – User cannot create account	Basic flow	A1
Scenario 3 – User cannot log in	Basic flow	A2
Scenario 4 – User cannot add a new device	Basic flow	A3
Scenario 5 – User cannot turn the lights on/off	Basic flow	A4
Scenario 6 – User quits	Basic flow	A5

In order for the group members to identify the test cases that would be needed to find the conditions in which the different scenarios would be executed, another table was created to clearly show all the elements needed for the scenarios to happen.

Test Case ID	Scenario	User	Password	Working Device	Working Phone	Wi-Fi Connection	Expected Result
TC 1	Scenario 1 – Lights are turned on/off	V	V	V	V	V	Lights turn on/ off
TC 2	Scenario 2 – User cannot create account	I	I	N/A	N/A	I	Error: Back to sign-up page
TC 3	Scenario 3 – User cannot log in	I	N/A	N/A	N/A	I	Error: Back to log-in page
TC 4	Scenario 4 – User cannot add a new device	N/A	N/A	I	N/A	I	Error: Back to new device page
TC 5	Scenario 5 – User cannot turn light on/off	I	I	I	I	I	Error: Back to Devices page
TC 6	Scenario 6 – User quits	V	V	N/A	N/A	N/A	Redirect to log-in

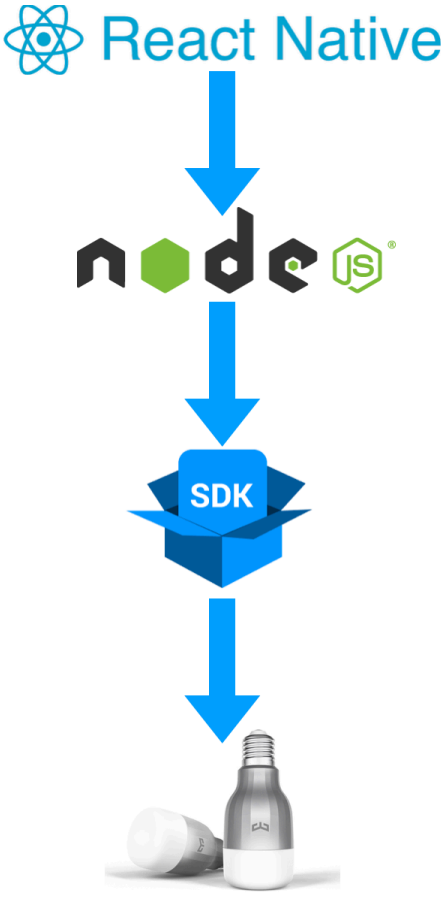
As it can be seen in the table above, in the first scenario all the elements are Valid (V) since the lights can be turned on, but on the other scenarios there is at least one element that is Invalid(I) meaning that in that scenario the system is failing. This representation shows in a

clear way where the scenarios might have a problem and then the status of the elements could be replaced with real data values that would be inserted by the person who would test the system. The group members had the chance to apply this test cases to real people along with the so called "Think Aloud Test" which basically consists on an observer or more who takes notes while a tester is using the system and expresses his opinion verbally. It was managed to get the system tested by only 3 people which is a limited number of people, but it was enough for a project of this scale since there were no cases where the system was faulty in any way. Based on the feedback received from the testers, it was found that the mobile app was performing a bit slow as the loading of a few pages was sometimes delayed. Fortunately, this is why the making of test cases based on the use cases was tried, because this can happen in the early stages of the project development and they can be fixed, keeping the overall progress of the project at a steady pace. It can be said that all the testers were impressed about how fast the light bulbs responded to the commands coming from the mobile phone. The on and off buttons had an instant effect and the other futures were not any different. Changing the color and setting the brightness level is close to instant which is a benefit that comes with having a performant hub that the devices can communicate with. Another good feedback point was that interfaces of the app seemed simple to use which is something the group members were really aiming for since the target users of the system would be elderly people that do not have very advanced technological skills. Unfortunately, the group members didn't manage to find a tester within the category mentioned before which would have brought a lot of value to their efforts if it would have happened.

5. Implementation

5.1 Architecture and design choices

The aim of the project is to create a system where the user can easily control the lighting in his living space. To achieve that a set of different technologies needs to work together. The whole project is a representation what can be achieved with a combination of open source software and hardware. The logical core of the system is the server which receives HTTP requests from the client native mobile applications and changes the state of the led bulbs. All of this is working on the lan network to optimise the performance. [21]



Technologies

After discussion about which technologies are suitable and appropriate for the project in was concluded that it is best to use already mastered and well known technologies. For the implementation of the web service it was decided to be used NodeJS with HapiJS framework for its ease of use and fast implementation. NodeJS also presented a possibility of developing the SDK and packaging and exporting it as a independent module thanks to NPM. The database was implemented on Mongoose on top of MongoDB. Once there was a server, there was a need of a clients to communicate with it. Because of the nature of the project (changing the lights at home) it was understood that in was necessary to be mobile clients. User experience is very high priority when planning the application and to make most of it it was concluded that there was a necessity of native mobile application for the two most popular mobile platforms - iOS and Android. After detailed comparison between the possible solutions React Native came on top of competition (Two separate mobile apps in Java and Swift, Xamarin, Ionic Native). There was a theme occurring - JavaScript turned out to be the core of all desired technologies. With that said, the main programming language used for implementing the project turned out to be TypeScript. TypeScript is a superset of JavaScript developed by Microsoft which compiles to a desired ECMA Script standard.

5.2 Hardware

Raspberry Pi

For a server it was used a Raspberry Pi 2 Model B. This is a single-board mini computer running linux based operating system. The Raspberry Pi is running a 900 MHz quad-core CPU backed with 1 GB of RAM. For storage is used a Class10 micro SD card to make sure the system is not bottlenecked by the read and write speeds. Additional Wi-Fi network card is plugged in one of the 4 usb ports for convenient connection to the internet. The Raspberry Pi's specs are probably too much for the project but the board was used because it was available during the implementation process. The concept of the project will work on way less powerful hardware. Because of the server is implemented on NodeJS the only requirement of the board is to run C++ code natively. Arduino board would be perfect for the scope of the project and all of the source code would be compatible with minor changes.

The RaspberryPi is accessed through SSH for ease of use.

```
→  ~ ssh pi@192.168.1.213
```

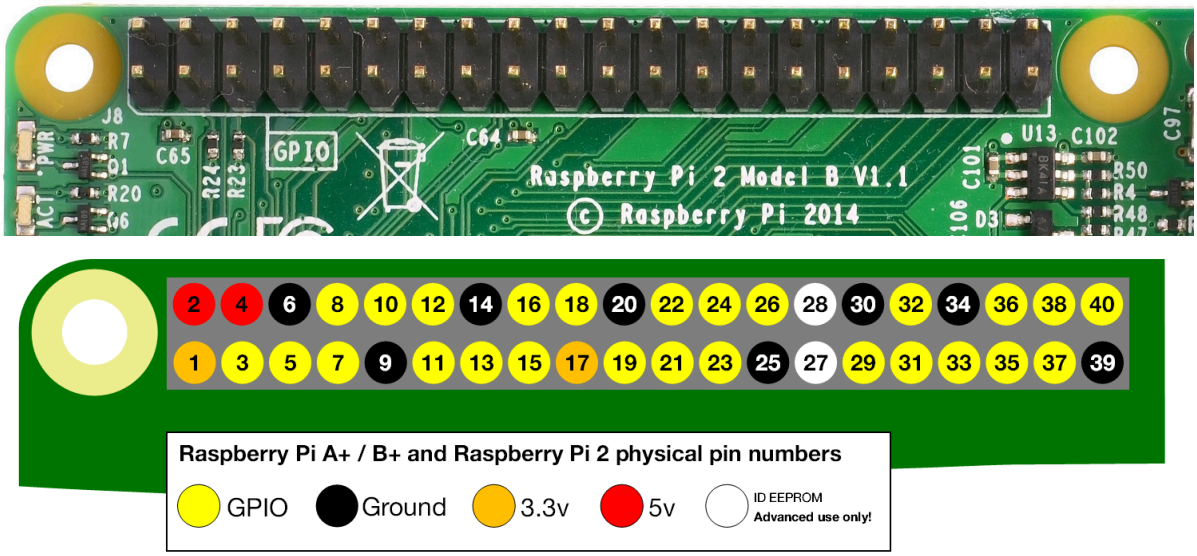
```
pi@raspberrypi:~ $ |
```

LED Bulbs

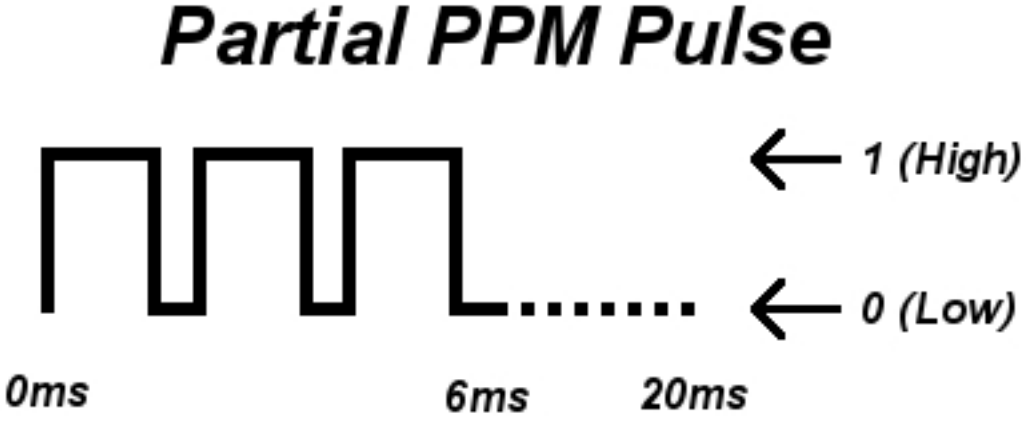
The system in its final state is using Xiaomi Yeelight RGBW Smart LED Bulbs using E27 connection. That being said, the SDK implementation has full support for all smart devices following their Inter-Operation specification. The Xiaomi lightbulbs have support for 16 million colours and their white balance can be adjusted in the range between 1700K and 6500K. With output power of 9W they are perfect for illuminating any personal living space. The bulbs have a micro controller inside which is responsible for handling the network activity of the built-in Wi-Fi card and updating the state of the LED. Once a Xiaomi Yeelight device is connected to a network it can be controlled either by the cloud or Smart HomeKit.

5.3 Prototyping

Shortly after the idea for the project was born there was a primitive proof of concept implementation for validation. It was using generic LED diodes. They had a wired connection to the Raspberry Pi and it used WiringPi to control through GPIO pins (General-Purpose Input/Output). A GPIO has two modes input and output. When in input mode the if the voltage is less than 2V the pin is off and when 2-3.3V is on. If a voltage higher than 3.3V is passed there is a high chance of damaging the board. When in output mode the board passes 0/3.3V in low/high state (off/on). [12]



The Raspberry Pi 2 Model B has 26 GPIO pins [13] [14] which are all digital in comparison with Arduino which has analog pins. Analog pins allows for connecting a potentiometer and tracking its values which is impossible to do using a digital pin. Because of that it is necessary to "create" a analog to digital convertor. [15]



As mentioned, the pins of the Raspberry Pi are digital which disables the possibility of controlling their electric current and voltage. In order to control the brightness of the LED a process called modulation is used. This technology is common is modern displays for controlling the luminance levels (measured in nits). The essence of modulation is turning on and off the voltage thousands times per second. This change in the light state is too fast for the eye to process so it is perceived as lowering the brightness of the light source.

Next step is to install WiringPi to the Linux distribution of Raspberry Pi and connect the LED diode with a resistor to it. After that it is necessary to change the state of the selected GPIO - "gpio -g mode <pin number>out"

```
pi@raspberrypi:~ $ gpio -g mode 40 out
```

To turn on or off the diode on pin 40 is used "gpio -g write 40 <1 (on)> / <0 (off)>". After the diode is powered on pulse-width modulation is used to control the brightness which internally implements the mentioned modulation. The supported values are 0-1024. To dim the diode to half brightness:

```
pi@raspberrypi:~ $ gpio -g pwm 40 600
```

After the major success of the prototype the LED diode was switched with a Smart LED RGBW light bulb with Wi-Fi controller. This allowed for wireless connectivity and support for more devices.

5.4 TypeScript

"TypeScript is a typed superset of JavaScript that compiles to plain JavaScript" [16]. Being a superset it enables it to add additional features and follow the newest programming trends without breaking backward compatibility because in end product is a JavaScript file that is supported by all modern browsers. TypeScript is compiled to JavaScript using the NPM package "typescript" which can be installed with the following command:

```
→  HomeKit git:(master) npm install typescript -g
```

Once typescript is installed globally on the development machine it can be used to convert the TypeScript files into JavaScript:

```
→  HomeKit git:(master) ✗ tsc index.ts
```

This will output "index.js" in the same file directory.

Static Type-checking

The typescript compiler has support for variable typing and it will throw errors on compile time.

```
var age: number;
age = "five"; // type error, assign a string to a number type variable
```

```
interface Age {
    setAge: (name: number) => void;
    getAge: () => number;
}

var age: Age = {
    getAge: () => return "five";
}// type error, setAge function is missing in the object assigned to age
```

Class and Module Support

The most apparent example of the code simplification is in working with “classes”. Typescript supports keywords like class, interface, extends, inherits, etc. Which will output a complicated JavaScript file that is unreadable by human but perfectly understandable by every modern browser.

```
class Animal {
    private name: string;
    constructor(name) {}
}

class Dog extends Animal {
    private name: string;
    constructor(name) {
        super(name);
    }
}

console.log(new Dog("Richard")) // Richard
console.log(new Dog(123)) // Argument of type '123'
  is not assignable to parameter of type 'string'.
```

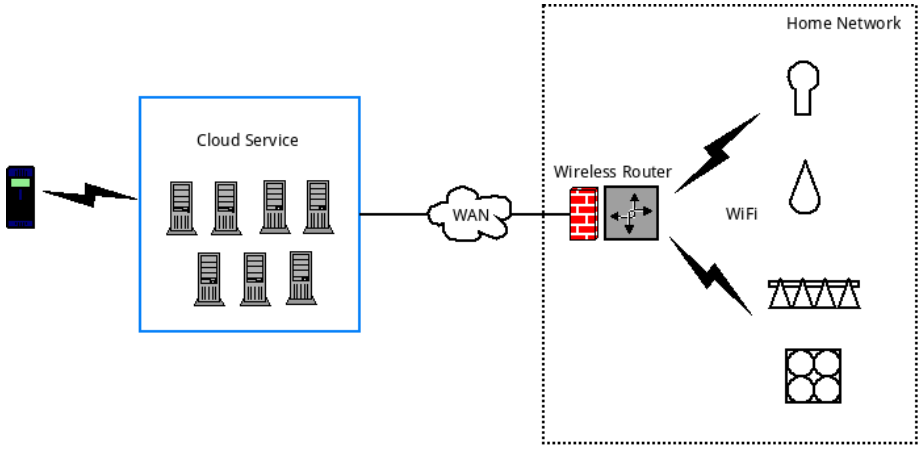
The output of this seemingly simple TypeScript file is looking like this:

```
var __extends = (this && this.__extends) || (function
  () {
    var extendStatics = Object.setPrototypeOf ||
        ({ __proto__: [] } instanceof Array && function
  (d, b) { d.__proto__ = b; }) ||
        function (d, b) { for (var p in b) if
  (b.hasOwnProperty(p)) d[p] = b[p]; };
    return function (d, b) {
        extendStatics(d, b);
        function __() { this.constructor = d; }
        d.prototype = b === null ? Object.create(b) :
  (__.prototype = b.prototype, new __());
    };
})();
var Animal = /** @class */ (function () {
    function Animal(name) {
        this.name = name;
    }
    return Animal;
}());
var Dog = /** @class */ (function (_super) {
    __extends(Dog, _super);
```

5.5 SDK

The lightbulbs of choice - Xiaomi Yeelight LED RGBW have a great open source API. Their default configuration uses external servers to control the bulbs. The main problem with this is that there is typically a delay of couple of seconds. The API uses the local network to send request directly which improves the performance significantly. The end result is a lightbulb that responds instantly to the given request from the user. When setting up the lightbulbs for first time the user need to execute SmartConfig process by providing router's SSID and password. Because of the nature of the given operation (working with sensitive information) the protocol used for the operation is proprietary. After a successful connection to the router, the light bulb can be seen from all devices in the local network which unlocks the possibility for control through 3rd party equipment.

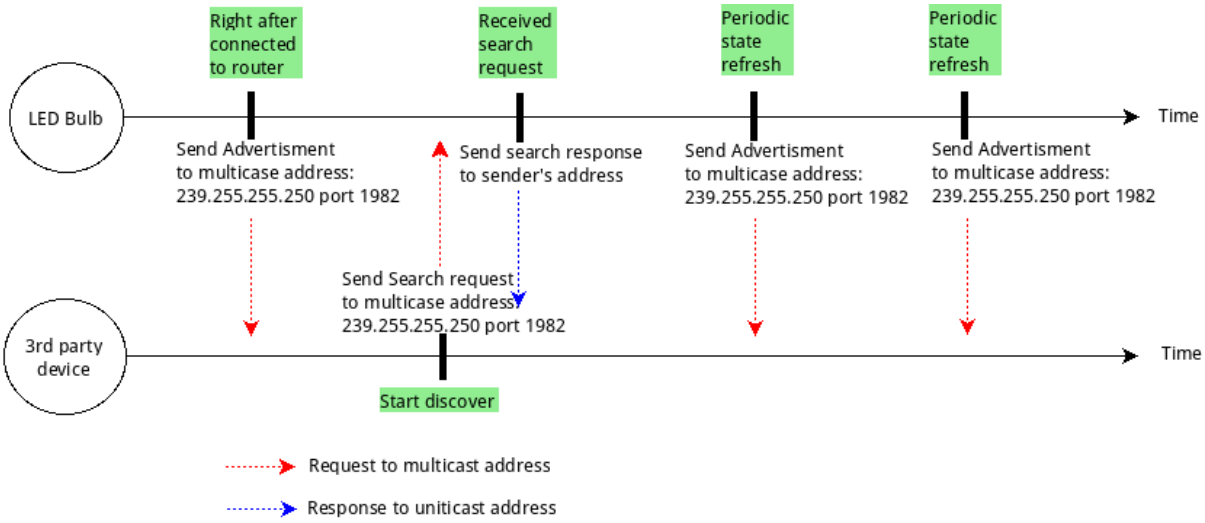
Default configuration — as mentioned before with no 3rd party local solution is established the lightbulbs are controlled through the cloud using Xiaomi Cloud Services. This results in a system that has a slow response time and is dependent on WAN. In other words — the refresh speed correlates to the network ping time to the servers located in China. Furthermore if there is no internet connection the whole system is unusable. [17]



With all that said, it is reasonable to conclude that a system built to work in the local network will have its benefits. The local control can be split into two categories - discovery procedure (using SSDP) and control procedure (JSON). After continuous searching for implementation of the documented behaviour in JavaScript it was concluded that none of the existing solutions satisfy the project's use case — they were either incomplete implementations or targeting older firmware version. So a git fork was performed on one of the existing repositories in order to reuse part of the code.

Discovery procedure

Following SSDP (Simple Service Discovery Protocol) there are two message types - searching and advertising. Searching is used while the lightbulbs are waiting for a request targeting the them. When such request is caught, the lightbulb responds with basic information about itself - IP and port, MAC address, current state and a list of supported methods. On the other hand the advertisement messages are sent when the lightbulb is connected to the local network for first time and is repeated after given period of time. [18]



A UDP search request should look like this [19]:

```
----------------------------------------------------------
M-SEARCH * HTTP/1.1
HOST: 239.255.255.250:1982
MAN: "ssdp:discover"
ST: wifi_bulb
----------------------------------------------------------
```

And the lightbulb will respond with message in the following format [20]:

```
----------------------------------------------------------
HTTP/1.1 200 OK
Cache-Control: max-age=3600
Date:
Ext:
Location: yeelight://192.168.1.239:55443
```

Server: POSIX UPnP/1.0 YGLC/1
id: 0x000000000015243f
model: color
fw_ver: 18
support: get_prop set_default set_power toggle set_bright start_cf stop_cf set_scene cron_add cron_get cron_del set_ct_abx set_rgb
power: on bright: 100 color_mode: 2 ct: 4000
rgb: 16711680
hue: 100
sat: 35
name: my_bulb

This is was implemented in the yeelight-discover NPM package. When the package is loaded in the server, the *init* function is executed which is triggering calling the *search* function every second.

```
init = () => {
    this.interval = setInterval(() =>
    {
        this.search();
    }, LOOKUP_INTERVAL) // 1000 ms
}
search = () => {
    this.ssdp = new ssdp.Client({ ssdpPort: SSDP_PORT }) // 1982
    this.ssdp.on('response', (data) =>
    {
        let light = this.lights.find(l => l.id === data.ID);
            if (light)
                light.updateBySSDPMessage(data);
    })
    this.ssdp.search('wifi_bulb');
}
```

Control procedure

After the discovery procedure is completed and the connection between a 3rd party service and the lightbulb is established, it is possible to send instructions to the smart bulbs through the local network. The communication can be established with TCP request carrying predefined JSON objects. In rare case where the lightbulb is using static local IP that is known by the 3rd party service, a telnet protocol can be used.

After the discovery an array of Yeelight objects is returned to the server. After selecting the desired object a set of instructions, implemented in yeelight.js, can be executed. Those functions generate the array of commands which are later sent to the lightbulb. Example can be given with toggling the power of the lightbulb.

```
setPower = (power, duration) => {
    //"power", "effect", "duration"
    let params = [
        this.power ? 'on' : 'off',
        (duration) ? "smooth" : "sudden",
        (duration) ? duration : 0
    ];
    return this.sendCommand('set_power', params);
}
```

First of all a JSON object containing the desired method and parameters is created. After that it is parsed to a string and concatenated with "\r\n" ending to match the API specification.

```
sendCommand = (method, params) => {
    let id = ++this.messageId,
       strObj = {
            'id': id,
            'method': method,
            'params': JSON.stringify(params)
        },
        str = strObj.stringify() + '\r\n';
.....
```

When the string containing the instruction is created, it is finally emitted to the lightbulb.

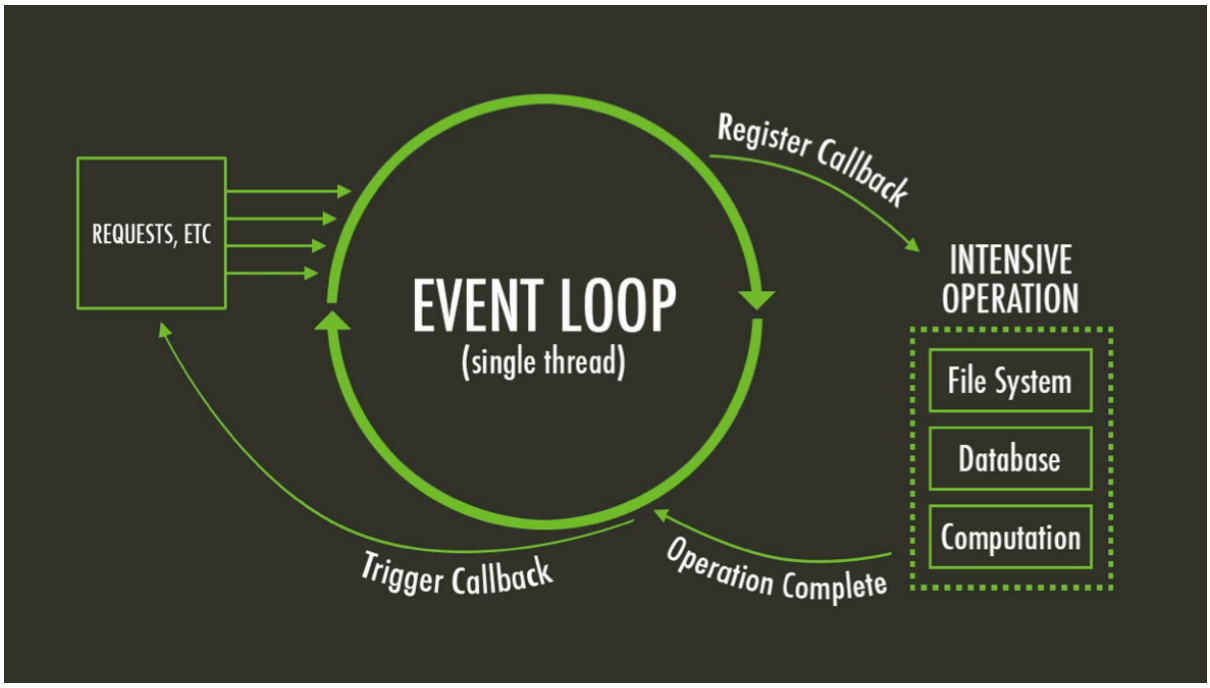
```
    return new Promise((resolve, reject) => {
        let timeout = setTimeout(() => {
            let msg = this.messages[id];
            this.emit('timeout', {
                id: msg.id,
                method: msg.method,
                params: msg.params
            });

            delete this.messages[id];
            reject("id: " + id + " timeout");

        }, REQUEST_TIMEOUT);

        this.messages[id] = {
            id: id,
            method: method,
            params: params,
            timeout: timeout,
            resolve: resolve,
            reject: reject
        };

        this.socket.write(str);
    });
```

If everything goes well throughout this process the JavaScript promise is marked as resolved inside the server and it sends HTTP response with code 200 to the client.

5.6 Server

NodeJS + HapiJS

The server is implemented on NodeJS using HapiJS framework. This combination allows for fast and easy implementation of a simple RESTful API. NodeJS is a JavaScript framework that is written in its core on C++ on top of Google's V8 render engine. It it's essence it is a single-threaded runtime environment for JavaScript with non-blocking asynchronous execution. Being single threaded does not mean NodeJS does not use multiple threads in its implementation internally, just that the developer does not have control over the threading model. This is because NodeJS's asynchronous, event-driven implementation of the Event Loop - a process that allows for non-blocking I/O operations.



If there is a operation blocking the execution of the others, it is put in the Call Stack and executed in the next cycle of the Event Loop if ready.

```
    console.log(1)
    console.log(2)
    console.log(3)
    setTimeout(() => {
        console.log(4)
    }, 1000)
```

When given similar instruction a typical synchronous execution would look like this:

```
➜  1
➜  2
➜  3
~~~ 1 second delay ~~~
➜  4
➜  5
```

When executed in NodeJS the output is the following:

```
➜  1
➜  2
➜  3
➜  5
➜  ~~~ 1 second later ~~~
➜  4
```

It is evident that the Timeout function did not block the execution of the code and the function following it did not get affected by it.

HapiJS framework was used as an addition to NodeJS for easier implantation of the RESTful API. It can be installed by running one of the following commands:

```
➜  HomeKitServer git:(master) yarn add hapi
```

```
➜  HomeKitServer git:(master) npm i hapi --save
```

A very basic HapiJS API would look like this:

```
const Hapi = require('hapi');

const server = Hapi.server( {
        host: 'localhost',
        port: 8000
});

server.route({
        method: 'GET',
        path: '/',
        handler: (request, h) =>  {
```

HapiJS is great for case where it is required to set up a fast RESTful service without a lot of features. The application uses dependency injection in its implementation to separate the programming logic between the server router and the services. This creates clean code that is easy to read and maintain. In "index.route.ts" all server routes are registered and their handler executes functions from the injected services.

```
// code snippet from "index.route.ts"
……..
handler: (request, h) =>  {
        LightsControlService.turnOn(id);
```

```
// code snippet from "services/lightsControlService.ts"
function turnOn(bulbId) {
     let bulb = lights.filter(l => l.id === bulbId)[0];
        bulb.setPower(true).then(() =>  {
                console.log('switched on');
        }).catch(error =>  { ……..
```

When combined with Boom it allows for very easy and flexible error handling. There are two options when it comes to throwing run-time errors HapiJS and Boom:

1) using a preset response

```
server.route({
        method: 'DELETE',
        path: '/{id}',
        handler: function(request, reply) {
                Boom.notImplemented('Coming soon!');
        }
```

which returns the following error message to the client:

```
{
    "statusCode": 501,
    "error": "Not Implemented",
    "message": "Coming soon!"
}
```

2) using a custom response message:

```
var error = new Error('Something went wrong');
Boom.boomify(error, { statusCode: 500 });
```

MongoDB

For the realisation of the project it was used a NoSQL database - MongoDB with models build by using Mongoose (Object-data mapping). Using the database allows for extra layer of security because of the user authentication system and for some extra features. For example, saving user preferences, custom light effects and settings is very easy to store in JSON format inside MongoDB.

Mongoose user schema:

```
let userSchema = new mongoose.Schema({
    username: {
        type: String,
        required: true,
        trim: true
    },
    hashedPassword: {
        type: String,
        select: false
    },
    passwordResetToken: String,
    passwordResetExpires: Date
})
```

5.7 Client

React Native

The mobile applications were developed using Facebook's React Native. React Native is a JavaScript framework for creating native mobile applications. The final project is indistinguishable from an app built on Java or Swift and does not suffer in the performance department like other solutions which produce hybrid mobile application. A typical app view contains the component dependant imports and a renderer that returns the view. A very simple react native application would look like this:

```
import React, { Component } from 'react';
import { Text, View } from 'react-native';

export default class App extends Component<{}> {
  render() {
    return (
      <View>
        <Text>
          Smart Home Kit!
        </Text>
      </View>
```

The project uses a UI kit called react-native-elements that implements a lot of React Native components. That makes possible to directly use components which would need a extra implementation. For example, after importing the Slider component from "react-native-elements", creating the brightness control in the application was as simple as writing the following lines and implementing the "changeBrightness()" function:

```
<Slider
  style={{marginHorizontal: 30}}
  minimumValue={1}
  maximumValue={100}
  step={1}
  value={this.state.value}
  onValueChange={(value) => this.setState({value})}
  onSlidingComplete={changeBrightness($index, value)}/>
```

The changeBrightness function receives bulb's id and brightness value and makes a HTTP GET request to the server on the "/{id}/bright/{value}" route. The server processes the request, sends the brightness information to the selected lightbulb and returns the response to the application. The beauty of running the server on the local network is that the light's state is updated instantly and there is no delay like when a cloud solution is used.

```
function changeBrightness(id, value) {
  return fetch(baseUrl + "/" + id + "/bright/" + value)
  .then((response) => {
    if(response.status === 200) {
      showSuccessMessage();
    }
  }).catch((error) => {
    console.log(error);
```

There are two major steps when beginning to develop a React Native application. It begins with creating an Expo application which is very similar to a hybrid app. The benefits approach are that it is very fast way to bootstrap the development. To create an "expo app" you have to install the "create-react-native-app" NPM package globally to your system and to execute the following commands:

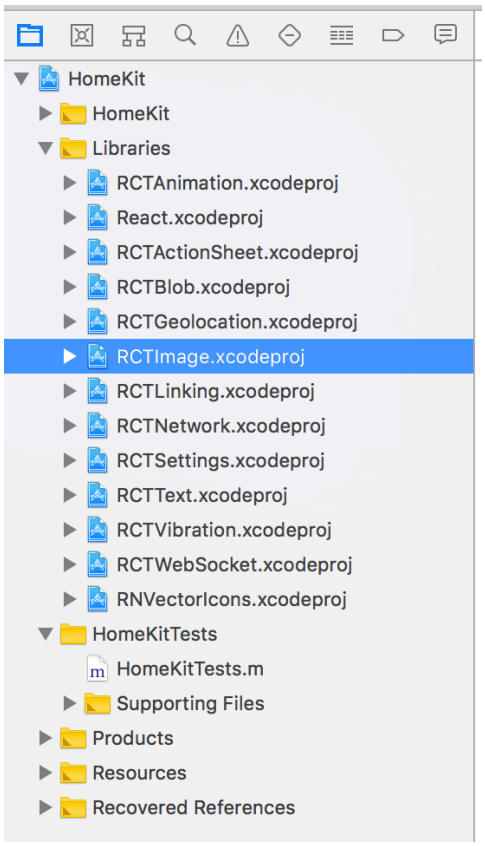
```
→  HomeKitClient git:(master) create-react-native-app demo
```

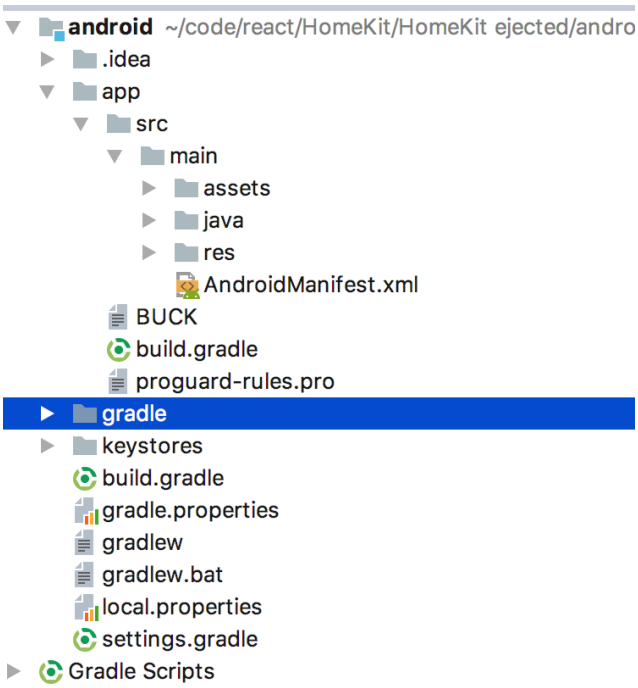
```
→  demo git:(master) yarn start
```

This will create the application, install its dependencies and run it in the Expo development environment. Then the application is going to be loaded on a device or simulator / emulator. The root of the project is the App.js file and this is the place which is going to make calls to the other react components in the app. No matter how easy and fast it is to develop the application in the Expo environment, when the implementation reaches its final moments the application needs to be converted to a "real" react native application. This is a process known as ejecting. This step requires installing globally "react-native-cli" as the product of this operation is irreversible and resembles a React Native application created by running "react-native init <project-name>". Ejecting to a regular react native application happens by running the following command:

```
→  demo git:(master) yarn run eject
```

This creates two new folders — ios and android. After completing this process the two new applications are developed separately and can be ran and deployed by opening the projects in their IDEs - Xcode and Android Studio.





5.8 Testing

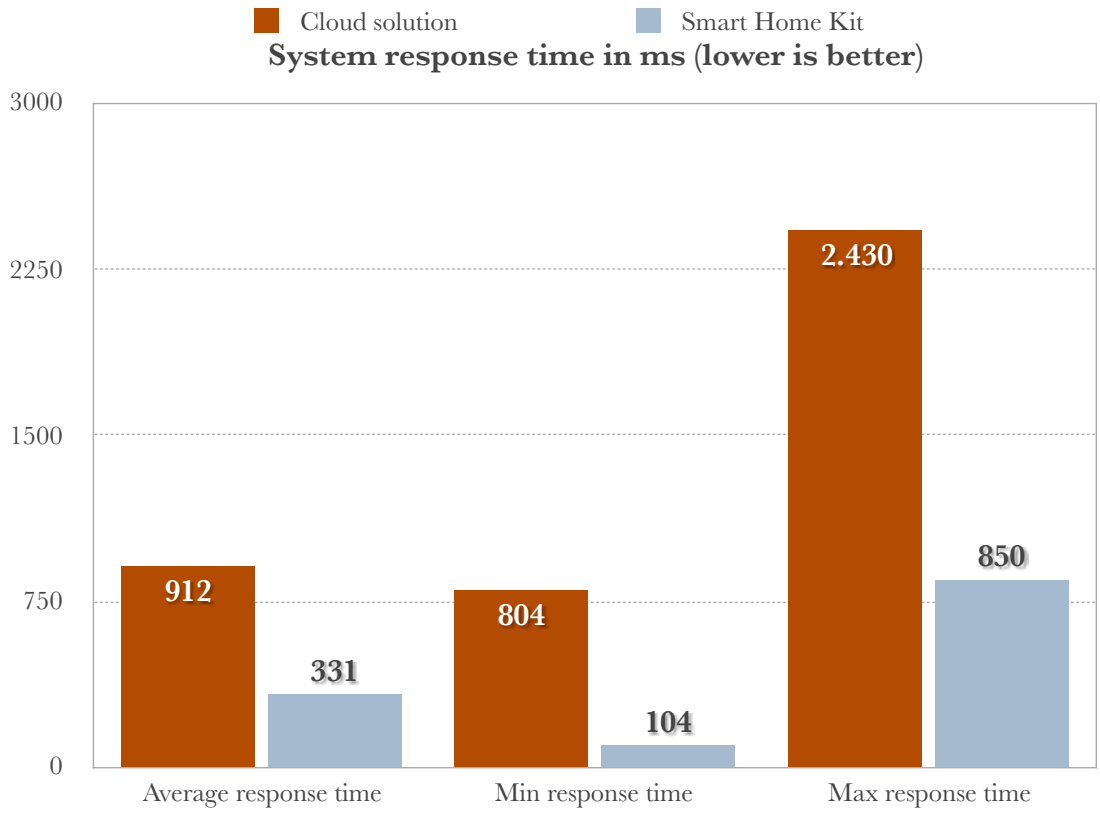
Series of unit tests were ran accepting every git commit. That was achieved by setting up a Jenkins Continuous Integration service in the GitHub repository.

Mocha and Chai were the JavaScript frameworks used to create the unit tests for the NodeJS server and React Native clients.

```
exports.createUser = function(next) {
   var user = new User(userData(
      'username-test',
      'password-test'
   ));
   user.save(function(err, createdUser) {
      if (err)
         return next(err)
   var accessToken = 'Basic ' +
          new Buffer(createdUser.username + ':' +
          createdUser.password).toString('base64')
      return next(null, user, accessToken)
   })
}
```

Performance Comparison

As it was mentioned in the beginning on of the key aspects was to make the application considerably faster. Because it is using the local network to handle the request and it is not waiting for a remote cloud solution, the request ping time was reduced. The following data was gathered by running 100 identical request and running a stopwatch service, implemented on a firmware level in the Xiaomi Yeelight Smart bulbs.



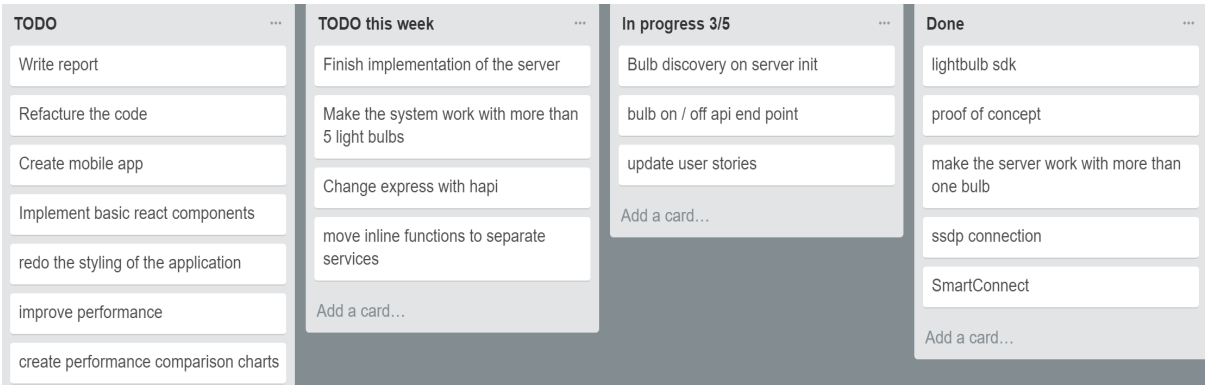
5.9 Workflow and style

Visual Studio Code

Having all the project developed in TypeScript/JavaScript helped when deciding to choose a text editor over an IDE. The preferred editor was Visual Studio Code because it was used from the group members during their internships. VS Code offers great performance and huge selection of plugins. Using it in combination TypeScript Lint ensured the style quality of the code. VS Code was especially helpful when developing the NodeJS server. Development of NodeJS on VS Code is a joy as the text editor allows debugging using breakpoints and variable watching.

Kanban

The main reason why the group members chose to use Kanban as the development method for the project is because there were only 2 members in the team anyway, and the problem where there would be people that could not help in any way because of the limit on the work in progress, could barely happen. By using Kanban, it was also possible to focus on where the biggest problems were and solve them as quickly as possible while also avoiding the situations where bottlenecks would keep the progress of the project from moving forward. In comparison with Scrum, there was no need to wait until the end of the sprint to start working on new tasks while tasks in that sprint were already done. The next big issue could already get going if the previous one was done.



The big advantage of being able to visually see how the work-flow of the project is going through the use of the Kanban board, also helped to decide on which tasks there should be

more focus. As shown in the screenshot above, the “In progress” swimlane has a working limit of 5 as it was considered that both group members could handle 2 or 3 tasks at the same time. If the work was going well with the task in progress, then more tasks would be added depending on how much time it was estimated for the tasks to take. Having this kind of flexibility was really important because the group members didn’t have any experience beforehand for developing an IoT system, so a lot of subjects were new to them thus taking a lot of time to comprehend.

5.10 Future work

The plan for the future is to develop a fully featured mobile applications. Right now the server and the SDK support much more features than the ones implemented in the clients. Right now the mobile applications support turning on and off the lights, picking a RGB colour from a colour wheel and changing the brightness. There are functions in the backend like animating the light colours and grouping bulbs together to create different effects that are yet to be implemented by the client. With future development it is possible to make the system even smarted with features like turning the lights on automatically when the user gets home (device connects to Wi-Fi). Google Home Assistant and Alexa integrations are also not far in the future.

6. Conclusion

This was definitely the biggest and most complicated project any of the team members ever developed. There is a huge satisfaction when putting high goals and achieving them. Even though the project used one primarily programming language, it was developed in more than 10 frameworks all of which felt like a new programming language. The final project consists of 3 smaller independent projects - the SDK, the NodeJS server and the React Native applications. When combined the 3 projects make for one complete system that is used on daily basis.

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APPENDIX

Event table: User account CRUD – Story

Event	Actor	Use case	Steps in use case
Create a new user account	User	Create account	Insert the user details into the sign-up form Sign up
Update the user information	User	Update account	Log into the app with the user credentials Go to user's page Update user details accordingly
Delete the user account	User	Delete account	Log into the app with the user credentials Go to user's page Delete account

Event table: Basic system functionality - Story

Event	Actor	Use case	Steps in use case
Turn the lights on/off (Assumption: The user is already registered)	User	Turn lights on/off	Log into the app with the user credentials Select desired device from a list of devices on the home page Turn device on/off
Change the brightness of the lights (Assumption: The user is already registered)	User	Change brightness	Log into the app with the user credentials Select desired device from a list of devices on the home page Adjust the brightness level
Change the color of the lights (Assumption: The user is already registered)	User	Change color	Log into the app with the user credentials Select desired device from a list of devices on the home page Select desired color from a color picker

Event table: Device CRUD - Story

Event	Actor	Use case	Steps in use case
Add a new device to the system	User	Add device	Log into the app with the user credentials Go to the Devices page Select desired device from a list of devices Add device
Delete device from the system	User	Delete device	Log into the app with the user credentials Go to the Devices page Select desired device from a list of devices Delete device