Washington University in St. Louis
Washington University Open Scholarship

All Computer Science and Engineering Research | Computer Science and Engineering

Report Number:

2019-04-09

Challenges in Integrating IoT in Smart Home

Leiquan Pan and Chenyang Lu

Wireless devices have become a major part in Smart Home industry. Almost every smart home company has its own wireless solutions and cloud services. Normally, customers can only monitor and control smart devices through applications or platforms companies provided. It causes inconveniences and problems when we have lots of smart devices. In my master project, I did two projects to implement smart home IoT applications. From a single functionality IoT application to a more complicated smart home system, there are lots of challenges and problems appeared. This article will mainly focus on challenges in integrating IoT in a smart...
Read complete abstract on page 2.

Follow this and additional works at: https://openscholarship.wustl.edu/cse_research

 Part of the Computer Engineering Commons, and the Computer Sciences Commons

Recommended Citation

Pan, Leiquan and Lu, Chenyang, "Challenges in Integrating IoT in Smart Home" Report Number: (2019). *All Computer Science and Engineering Research.*
https://openscholarship.wustl.edu/cse_research/1170

Department of Computer Science & Engineering - Washington University in St. Louis
Campus Box 1045 - St. Louis, MO - 63130 - ph: (314) 935-6160.

This ms project report is available at Washington University Open Scholarship: https://openscholarship.wustl.edu/cse_research/1170

Challenges in Integrating IoT in Smart Home

Leiquan Pan and Chenyang Lu

Complete Abstract:

Wireless devices have become a major part in Smart Home industry. Almost every smart home company has its own wireless solutions and cloud services. Normally, customers can only monitor and control smart devices through applications or platforms companies provided. It causes inconveniences and problems when we have lots of smart devices. In my master project, I did two projects to implement smart home IoT applications. From a single functionality IoT application to a more complicated smart home system, there are lots of challenges and problems appeared. This article will mainly focus on challenges in integrating IoT in a smart home.

Challenges in Integrating IoT in Smart Home

Leiquan Pan[1]

[1]Cyber-Physical Systems Lab, Washington University in St. Louis, St. Louis, MO
[2]Department of Computer Science & Engineer, Washington University in St. Louis, St. Louis, MO
[3]https://github.com/leiquanpan/Lotus-House-Android-APP
[4]https://github.com/leiquanpan/WSNW$_{CTP}$

Wireless devices have became an major part in Smart Home industry. Almost every smart home company has its own wireless solutions and cloud services. Normally, customers can only monitor and control smart devices through applications or platforms companies provided. It causes inconveniences and problems when we have lots of smart devices. In my master project, I did two projects to implement smart home IoT applications. From single functionality IoT application to more complicated smart home system, there are lots of challenges and problems appeared. This article will mainly focus on challenges in integrating IoT in smart home.

Smart home | Integration | Wireless | Philips Hue | Nest | Android Application

Introduction. Wireless devices are widely used in smart home industry based on the fact that wired devices are hard to maintain. There are various commercial wireless devices. For example, Nest has a family of Wi-Fi smart devices, Philip has both Wi-Fi and Zigbee smart lights, apple provides wireless earphone etc. Every wireless device is designed for specific functionality. Nest thermostat is designed for T-H sensing and HVAC control. Velux smart window is designed for window control. Google home is designed for voice control and music. Companies provide specific applications or platforms to monitor and control their devices. We can control Nest thermostat by Nest App. We can control lights by Hue App. We can view house status by Growatt platform. They are fascinating while working on their systems. But things become difficult while we have lots of devices need to manage. The cooperation and connection between devices from different vendors are so bad that customers have to uses lots of application at that same time. Thus, we chose to designed from a single functionality application to sophisticated smart home system to discover the possibility and difficulties in integrating various IoT devices.

Wireless Sensor Network. To start with, we need to figured out what an IoT application looks like? We designed and implemented an temperature sensing system, which focused on sensing temperature data from environment and store them in the Internet. The goal of our project was to create a high-quality wireless sensor network with a AWS dataset that we could analyze as well as make available for future usage and calculation. This was accomplished by creating an indoor/outdoor wireless sensor network that was continuously monitoring several pieces of environmental data. The data collected by wireless network was sent via a Raspberry Pi TelosB basestation to a AWS database server, where measured temperature stored. We also build a monitoring

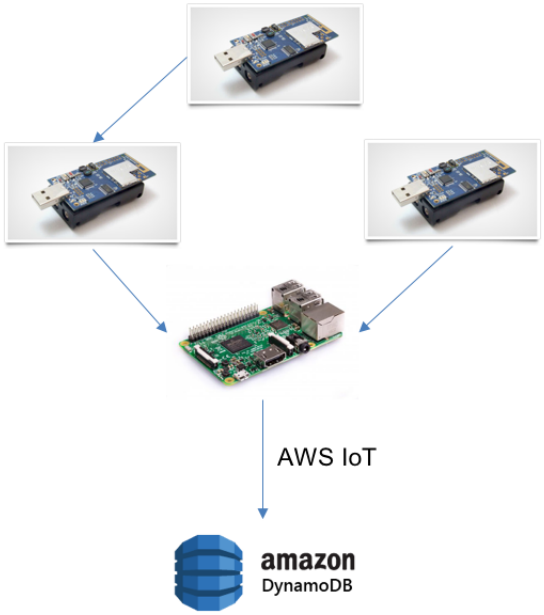

Fig. 1. Temperature Sensing System Topology. a) All the building blocks including telosb mote modules, CTP wireless protocol and AWS cloud services.

user interface that various data calculated and shown. Although WSN is a single functionality IoT application, it has all the required building blocks for a successful IoT application including resource constraint embedded devices, wireless protocol, cloud services, front-end application.

Wireless Network Setup. Our wireless network consists of resource constraint devices and wireless protocol. The embedded devices we use is telosb mote module. It's a robust devices with tinyOS installed and lots of wireless protocol implemented. From 1, There are one receiver and lots of relays in our network. The receiver was responsible for collecting all temperature data, and send them to the Raspberry Pi3 through serial port. The relays were responsible for measuring data send their measured data wireless through a multi-hopping network called Collection Tree Protocol based on TinyOS.

Cloud services Setup. Our cloud services used AWS to enable cloud services including AWS IoT and AWS DynamoDB. AWS IoT registered our basestation as a "thing". The "thing"(Raspberry Pi3) then sent temperature events to AWS cloud periodically. AWS DynamoDB is then being applied to store all those temperature data for future use. We connected our WSN database with the "thing". Whenever

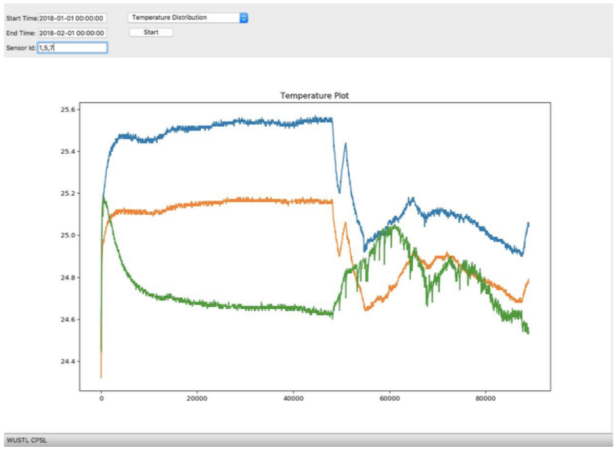

Fig. 2. Experimental Result a) Three telosb motes were installed in different rooms. Measured for a month

there is a new data coming from the basestation, it will be immediately updated to the database.

Experimental Results. We tested our temperature sensing system in our lab for a month. We installed three relays in three different rooms to make sure they are using Collection Tree Protocol instead of broadcast protocol. One receiver connected with a Raspberry Pi, but without sensing any data because it will be heated by the Raspberry Pi. From 2, blue mote and orange more were put in two different room but was connected, so they followed the same pattern. All those data was calibrated before storage.

Challenges when installed in real house. There are three challenges we need to overcome when I was trying to installed this system in a real house. The first one is long-term usage. Long-term usage means your devices need to be robust enough for months or years, and they are need to be extremely power efficient. Because it's hard to change, repair and maintain devices in real situation. Low-power mode is one of the best solutions for this challenge. Low-power mode means your devices will be automatically changed to sleep mode while there is nothing to do. It's very easy to do in telosb mote configuration file.

The second challenge is sensor's error. IoT application often contains lots of devices with various kinds of sensors to perform better in sensing data. But it's inevitable for those sensors to have their own error. And also IoT devices are resource constraint devices it's not optimized to calibrate on the sensing nodes. Take our temperature and humidity sensor as an example, every sensor has its own error. And we need to figure out a way to reduce their error in the receiver side. Then we come up with the linear regression as the method to reduce the error. We computed an equation applied to all sensors to reduce the global error. It's a big challenge which will easily influence the quality of your IoT services.

The third challenge concerned the range of our wireless sensor network. Wide range is essential for lots of wireless network. Multi-hopping system is widely used today. In our experiment, collection tree protocol supports multi-hopping and fault tolerant, provide us with a reliable wide IoT services.

Fig. 3. Lotus House a) Lotus House built in Dezhou, Shandong, competing in Solar Decatholon China

Lotus House Smart Home. Lotus Hosue Smart home is a smart home application built in a real house - Lotus House, which built by Professor Yin and a group of architecture students. Lotus House is competing in Solar Decatholon China 2018, where 20 university teams together built 20 hosues in a month. From 3, it has a circular structure, curved panels and lots of special windows etc. Cooperated with modern technology like 3D printing, smart home. Lotus House is one of the system built in this house. It requires lots of functionality to be a smart home application. For example, temperature, humidity, air quality, camera, energy inputs, energy outputs, lighting, windows etc. This is a really complicated system that a single company's appliances can not satisfy our needs. We selected lots of smart devices from different company, and came up with an unified platform. The main difficulty is to integrating all devices in application level, where we integrated devices by API provided by companies.

Functionalities and devices. Lotus House smart home is suppose to be a sophisticated system covered every functionality you need. There are mainly three major parts after discussing with Professor Yin, who is the architecture leader of the Lotus House, including Comfort, Energy and Safety. Comfort part in Lotus House covers temperature, humidity, air quality sensing and HVAC, Window control. We selected Nest thermostat, Nest Smoke and Velux windows. Nest devices are Wi-Fi dependent wireless appliances. Energy part including solar panel monitoring. We used Growatt devices to record electricity production and Philip Hue lighting system as our lighting plan. Safety part we picked Nest cam and Nest secure to record video streams. Nest devices are Wi-Fi dependent devices, Philip Hue both supports Wi-Fi and Zigbee lighting link, a specialized Zigbee protocol for lighting plan. Growatt devices are using GPRS to send energy data.

Integration platform. The integration platform was built upon Android platform, an open-source platform well-supported by lots of smart home companies. From the dashboard of Lotus House application in 4, three major functionalities comfort, safety and energy's information included. In this app, we can successfully communicate with our smart devices by API or SDK. We integrating Nest family using Nest Android SDK. Monitorting Growatt devices by Growatt API. Con-

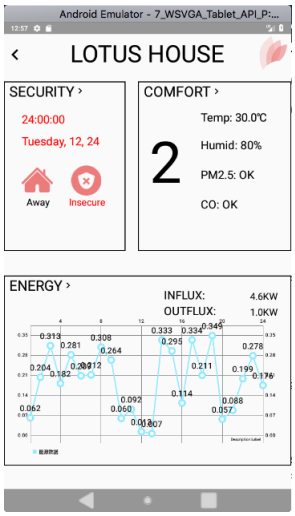

Fig. 4. Lotus House Android App a) Temperature is 30, comfort value is 2, means little bit hot. The daily information of energy production and the house's security status is unsafe

trol lights by Philip Hue SDK. For the communication purpose, we need to get information from devices through Lotus House application. And send control commands to those devices through our platform.

System topology. From 5, you can see the topology of Lotus House smart home system. In the center, represents our integration platform, Android application whose icon is a pink lotus flower. From the left part, we had a nest family. Nest hello is a door bell with camera installed, it can send video stream wireless to Nest sever. Nest thermostat sends temperature and humidity to Nest server. Nest cam stream video data. After Nest sever has the video stream, graphic algorithm will be applied to determine whether there is a human or sound or motion detected. Nest Smoke is a smoke alarm device, which is able to measure air quality (CO) and set alarms. Nest secure is a microsystem consist of a brain and other security sticks. The connection between Nest sever and our platform is built by Nest Android SDK. Lotus House Application can either retrieve devices' data from Nest sever or send control command to Nest sever, where controls commands will be forwarded to devices through the Internet. Same architecture applies to Growatt devices. Growatt monitoring device can transmit Inverter's data to Growatt's server. And we can retrieve lots of energy related information from their sever including history electricity production of a power plant, daily electricity report etc. But it's different in Philips Hue lighting system. Philips Hue system consist of a gateway, which will connect to the Internet. The gateway, Hue bridge, control all smart lights by Zigbee lighting link. However, our platform directly communicate with Hue lighting system in local network instead of via Philips Hue server. Because Hue bridge behaves like a simple web services. It has specific URI for different functionalities.

Challenges in wireless protocols. Wireless protocol is an essential part in IoT applications. When we are trying to design an unified platform, we cannot ignore effects and defects

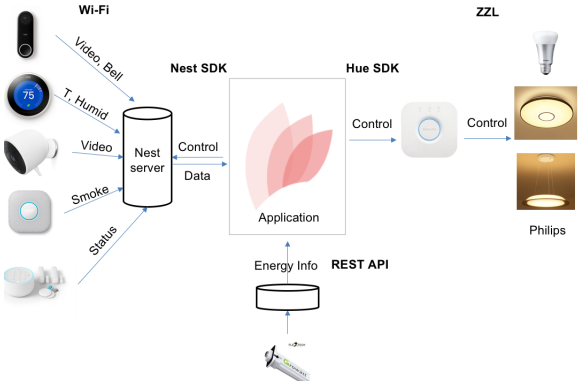

Fig. 5. Lotus House Topology a) An unified platform in the center, we have Nest family, Philips Hue lighting system and Growatt devices

caused by wireless protocols. Challenges introduce by wireless protocols vary from different wireless protocols. In our system, we have Wi-Fi devices, Zigbee devices and GPRS devices. Wi-Fi devices are picky for Wi-Fi signal. Devices in our system like Nest cam has bad performance when Wi-Fi in weak, Hue bridge cannot even work when offline. Same applies to Zigbee lighting link device. It's the biggest challenges when we were implementing the system. From application level, we cannot guarantee the wireless network but it still can be improved by enabling work offline. This idea came from Nest thermostat, it's able to sensing environment and control HVAC system when offline. It can be applied to lots of devices, like Hue bridge. Because lighting control does not require Internet and Hue bridge also support Zigbee protocol. Customers will gain better use experience when devices can work offline. From platform's perspective, it's also an important property needs to be considered when choosing devices to integrate. Other devices like Growatt are using wireless services like GPRS, which is easy to install but expensive to use. Besides working offline, an appropriate distribution plan can be helpful to overcome challenges from wireless protocols. How to come up with an appropriate distribution would be illustrated later.

Challenges in integrating API (SDK). APIs or SDKs are main tools to integrate wireless devices. There are two different kinds of SDKs in our system and one OpenAPI. Nest SDK is built on Nest APIs, both support REST and REST-Streaming architecture, to communicate with Nest sever. While Philips Hue SDK uses REST architecure to direct communicate with Hue bridge. Although SDK is a convenient tool for third-party integration, it also introduce integration challenges. When we were implementing Lotus House smart home system, one situation we faced is we cannot register devices or create an account through SDK or API companies provided, which means our platform can only communicate with devices that has already been registered through official platform. It's a huge limitation for our Lotus House application. The only solution is asking for permissions from companies. Unfortunately, Lotus House application was still not able to register devices. The solutions depends on the requirement of your integration platform and choosing the appropriate devices to integrate. For example, if your platform supports reg-

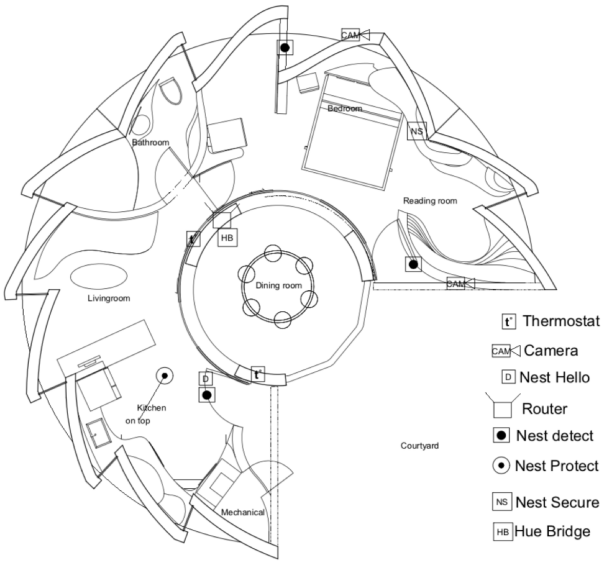

Fig. 6. Lotus House Distribution Plan a) We have router and Hue beidge in the center. Nest smoke on the top of kitchen. Nest cam on the front door. Nest security close to your bed.

istration, you'd better to integrate devices allows third-party integration. However, it's not a general solution for this problem. Considering devices all using a open cloud platform, where it support registration and communication like Google Cloud IoT. It will be an optimal situation for integrating devices.

Challenges in installing devices. Installing a smart home system requires interdisciplinary knowledge such as electrical engineer, mechanical engineer and computer science. For example, in Lotus House smart home, Nest thermostat needs to connect with HVAC. Nest hello needs to connect with doorbell. Growatt needs to connect with inverters. Installation problems can greatly influence the quality of your services. There are two different problem we need to solve. One is the disconnection between wireless devices and other devices. It's often caused by wrong wiring or communicating in different protocols. Wiring can be solved by detailed instructions, communication problem can be solved either by switching devices or adding adapters. By the way, adding adapters is very expensive and unsafe. The other installation problem is weak wireless signals in real house. It's quite common for IoT applications today. In fact, it can be solved by a easy solution, coming up with an appropriate distribution. After some research from famous smart home companies, it's disappointing that we could not find any instruction about distribution plan for their devices. However, from my perspective, a good distribution plan is crucial for IoT applications, which can easily improve the quality of your wireless devices. How to come up with a good distribution plan? There are several factors worth to consider. House material, floor plan, wi-fi location, gateway location etc. In Lotus House we came up with a distribution plan as 6, it positioned the gateway and router in the center.

Difficulties in approaching interoperability and one solution. In Lotus House, we were trying to build a android application that can communicate with lots of different, which was achieved by dealing with API and SDK. By approaching this application level interoperability, we found challenges from wireless protocol, API(SDK) or installation. Moreover, there are three major difficulties when approaching interoperability. First is complexity, dealing with different API largely increase the complexity of the integration process. Second difficulty is security, it's not easy to ensure security in application level. Third one is feasibility, failing to integrate devices are quite common due to technical or business reasons. For those difficulties, I do suggest one solution to improve them, using standard IoT platform like Google cloud IoT would be really helpful from the interoperability's perspective. Google IoT provides creating, registering and managing devices through their platform. Because of using the same architecture in Google cloud IoT, it incredibly reduce the complexity of integration process. And Google cloud IoT also provide security services. Most importantly, even every IoT devices can register at Google cloud IoT platform, it's much easier to build a integration platform based on one cloud service. Take Lotus Hosue for example, if google cloud services was applied to Lotus House's devices, it's much easier to integrate growatt devices. It's also feasible for Philips hue system to enable remotely control. We can easily applies the Nest home structure, which is a concept and data structure created by Nest, to represent Lotus House in a more reasonable back-end structure.

ACKNOWLEDGEMENTS
First, I want to express my thanks to Professor Lu and Professor Yin. Professor Lu provide the basic idea of Lotus House smart home, instructed me while I was working on this project. Professor Yin, as the main architecture professor in Lotus House, provide me the opportunity and detailed supports while I was installing the Lotus House smart home.