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IOT TESTBED SYSTEM FOR RESEARCH AND EDUCATION: IMPROVEMENT AND DEPLOYMENT

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This report, written by **Sami Aldahlawi** (342116538). This project report has been prepared and written under my direct supervision and guidance.

Dr.Ibrahim Al-Sukayti

Sincerely

ACKNOWLEDGMENTS

I would like to say thanks for everyone has helped me in this project. The project couldn't be done without Dr.Ibrahim's help. Finally I would like to thanks god, for all the good he provided us.

TABLE OF CONTENTS

ABSTRACT

There has been growing interest in contributing to the development of the IoT technology and its applications. This project contributes towards having an a real-life IoT platform in the College of Computer at Qassim University. The system would not only provide CoC members with a smart campus facility, but also motivate more practical research works on the different IoT aspects. The aim is to deploy an IoT testbed system inside the building of the college using a collection of

hardware and software components. The focus is on integrating the system with short and long-range wireless communication, in addition to different types of sensor modules. The system provides a web-based user interface and enables remote multi-user access to the system resources in a secure and manageable manner. To maintain the complexity and cost at low level, the system will be deployed in certain part of the CoC building at this stage. This report at this stage describe the current phase of the project, phase one, focusing on literature review and requirement analysis. It also provides a detailed description of the testbed design. In the next phase we will implement the software, and carry out the evaluation process. As the project is now at phase one, this report provides an analysis of the current system and improvement the system with some requirements and a description of the design of the new system.

CHAPTER 1

INTRODUCTION

Nowadays we witnesses noticeable advancements in the technology worlds. As a result, there have been growing interest in different technologies and real-life applications. Among of these is Internet of Things (IoT) which extends Internet connectivity to every part of our life. It enables variety of solutions to a number of daily use cases.

Today, Integrated Circuits become inexpensive enough to have low cost and feasible IoT solutions. Small devices can be cheaply and easily integrated with sensing, processing, and communication modules. This allows them to be smart enough for sensing the surrounding, sensor data-processing, automated control, and wireless communication. IoT becomes a reality as it has found its way to our daily life and its applications can be seen in homes, campuses, hospital and the cities around the world.

The IOT technology becomes attractive to the industry. There are now many companies provides IoT products and solutions in different domains. These include smart home, smart cities, smart campus, precise precision, smart parking, smart agriculture.

IOT related principles and topics become of interest to many researchers. IoT becomes a trend research topic and a number of researches has been conducted and implemented considering different topics on the IOT. However, IoT experimentation has been mostly conducted using specialised simulators. While this can help in limiting cost and complexity, experiments over real-life testbed can deliver better and credible results.

Therefore, this project proposes the design and implementation of a hardware and software IoT testbed facility for the College of Computer (COC) in Qassim University (QU). It facilitates realistic experimentation of different IoT solutions, considering different potential application. The work in this project continue the next stage of previous project with deployment the project across the building of College of Computer (COC). The current design and implementation of the testbed will be optimised to make it

deployable in real-life environment. Different functionalities will be reconsidered to provide support for general-purpose experimentation, multi-user access, and multi-tasking.
We think that this project provides a time-saving and cost-saving solution providing different users with a ready to use experimental platform and interactive learning environment. There are a web-based and corolled access allowing remote and managed the experimentations. The testbed also facilitates data collection and management for real-time and off-line processing and analysis data. Scalability is also another feature of the testbed design enabling further expansion of the different parts of the testbed architecture.

1.1 Project Scope

The project scope will focus on deployment the system in the building of College of Computer (COC) and improvement the current system. However, we will particular attention to improve the design and implementing the testbed at both hardware and software levels. This will involve building the testbed physically with carefully selected hardware components such as microprocessors, sensors, communication modules. The project also include the development of different software components including web-technology as front-end and back-end, also there is database and remote testbed control system. However, most of the security aspect will be out of the scope for this project, but the testbed is going to be more flexible for security-oriented extensions and implementations. These could include some kinds of attacks like DDOS attack, brute forcing. The sensitive data will be encrypted. While the purpose of this testbed is to help pushing the IOT research to the experimental level by allowing open and remote access to a real-life IoT testbed.

1.2 Aim

The Aim of this project is to deploy an IoT testbed system inside the building of the College of Computer using a collection of hardware and software components. The focus is on integrating the system with short and long-range wireless communication, in addition to different types of sensor modules. The system provides a web-based user interface and enables remote multi-user access to the system resources in a secure and manageable manner. To maintain the complexity and cost at low level, the system will be deployed in certain part of the CoC building at this stage.

1.3 Project Goals and Objectives

- Improving different functionalities of the current IoT system
  - Making it deployable for real-life experimentation and applications
  - Improving communication between the different components of the system
  - Enhancing the accessibility of the system
  - Enabling multi-user and multi-tasking functionalities

- Deploying the platform into certain part of the CoC building:
  - Low cost implementation
  - Scalable hardware and software components

- Evaluating the IoT platform considering a smart-campus scenario

1.4 Student Outcome

This project help me as student to:

- Work on real project.
- Improve our knowledge on different topics.
- Use and learn different libraries and API concept.
- Learn more about different network protocol.
- Design and implement a complete system

1.5 Project Plan and Schedule

The plan and schedule of the project is presented in Figure 1.1 and Figure 1.2 detailing the project tasks and deadline

Task name	Start date	End date	Duration (week)
	06/01/2019	15/12/2019	49
Phase1	06/01/2019	14/04/2019	14
Literature Review	06/01/2019	27/01/2019	3
Understand the current System	27/01/2019	17/02/2019	3
Requirement	17/02/2019	03/03/2019	2
Testbed Design	03/03/2019	24/03/2019	3
Start-up Implementation	24/03/2019	07/04/2019	2
Writing Up	07/04/2019	14/04/2019	1
Add a task | Add a milestone			
Phase2	08/09/2019	15/12/2019	14
Software Implementation	08/09/2019	29/09/2019	3
Testbed Setup: Nodes inside building	29/09/2019	13/10/2019	2
Web-Technological	13/10/2019	03/11/2019	3
Re-design Database	03/11/2019	24/11/2019	3
Result Collection and Analysis	24/11/2019	15/12/2019	3
Writing Up	03/10/2019	17/10/2019	2
Add a task | Add a milestone			
Add a new subproject			

Figure 1.1 Project Development Schedule

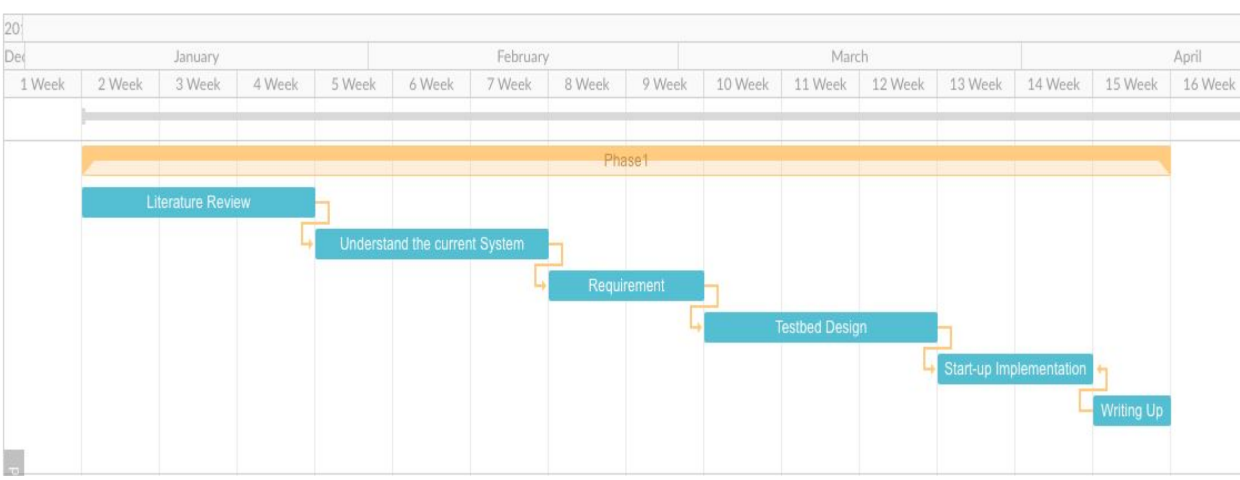

Figure 1.2 Gantt Chart Phase 1

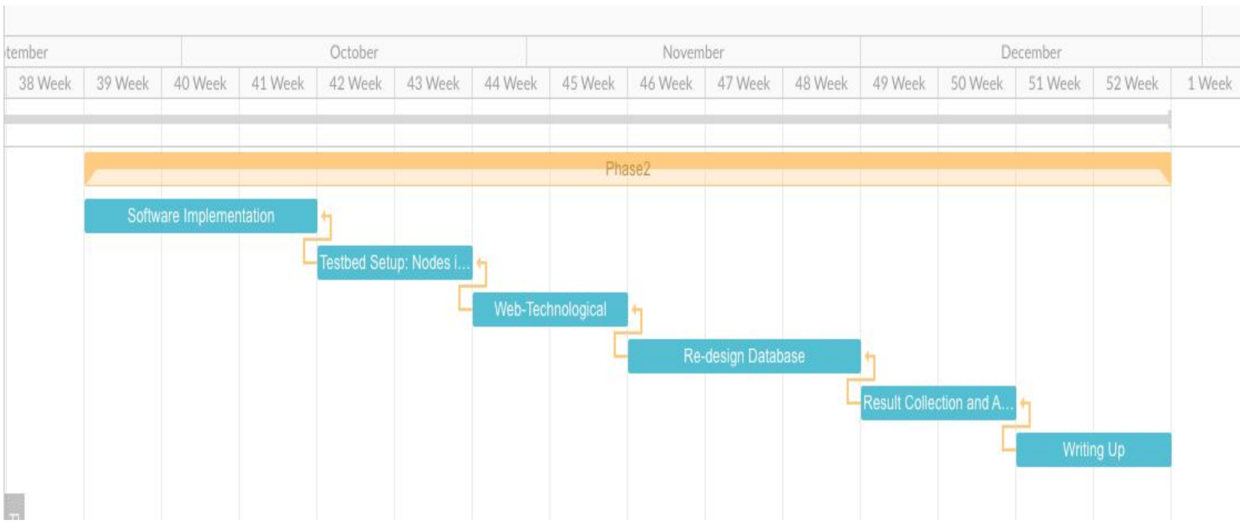

Figure 1.2 Gantt Chart Phase 2

1.6 Report Outline

- ## Chapter 2

  Chapter 2 is about an IOT and its technologies and related topics including the common communication protocols. In addition, it discusses various related IoT solutions in the literature.

- Chapter 3
  Will starts with a discussion about problems domain and problems of current system. In addition, the problems of support power for nodes and the deployment the system across the building of COC.The challenges that needs to be tackled when improvement system of an IOT testbed. Then presents the different design requirement set for the current stage of the project.

- Chapter 4
  Present the new design for the system and testbed. It also provides a summary of the implementation. In addition, it discusses the different options for deployment the system inside the building of College of Computer.

CHAPTER 2

LITERATURE REVIEW

2.1 Internet Of Things (IOT)

Over the past two decades, most of us have had two lives: life on the ground and life on the Internet. With the proliferation of smartphones, tablets and social networking, virtual life has expanded to become a mirror of everyday life. The next step will undoubtedly be what has happened in the concrete world of the digital system that governs us. Many Internet-connected devices already exist, but most are still specifically designed for this purpose and rely on the human user as a key actor. Analysts expect a new revolution in the telecommunications world where users are rigid objects communicating with one another. The concept of IoT is to live in a world of inanimate objects with an awareness and logic. When you wake up, he can alert you to watch it and report it to other things such as a curtain, coffee machine, and car. When you look in the mirror, it may alert you to the fact that the shirt is outdated and the refrigerator automatically orders the products that you are missing. That is, all that surrounds you is interacting with you and with what you need everywhere. All of this is technically feasible and should not be limited to science fiction, but the economic aspect that makes the dissemination of such technologies possible is still in development. It is important to understand the Internet in general as a step towards comprehending IoT. Internet is a universe system which use internet protocol to globally and locally interconnect computer networks. It involves human interaction, Internet access, device connectivity, and most importantly data management. IoT give us new idea expanding the Internet with any things can connect to the Internet with/without human intervention. In another word, any physical object will be able to communicate over the Internet to share data. These could include objects interconnected in different IoT applications such as smart home, smart class, and so on. For an example of an IoT-enabled coffee machine, it could be communicated through the Internet to prepare a cup of a coffee at certain time. This is usually enabled based on some sensor and communication chips attached to physical objects for environment sensing and Internet connectivity. To understand Internet of Things, we also have to imagine that we want to communicate with what is around. The first stage of this new informational adventure is to provide the virtual object with a virtual personality to become a user in turn, just as any person needs a name at birth or a way to define himself electronically. RFID is a radio-based identifier that can be captured by devices designed for short-range communication (NFC). This weak transmission allows the thing to shout to its nearby environment: ”I am here, and my name is such, and I want this.” We find this technology in the metro tickets in Dubai, for example, or use it to enter buildings. Although it is a very practical technique and saves a lot of time in some situations, it does not allow the creation of real IoT, but a way to identify itself and perform simple operations between a thing and a station to monitor it within a few centimeters. By contrast, technologies such as GPRS and LTE can transmit large amounts of information over ethers for long distance. These technologies have already changed our lives by allowing us to use the mobile information network. However, several factors prevent us to transfer this technology to the IoT. The first factor that the technology sector has ignored for many years is that the radio waves on which all these systems depend have limitations. It is a particular spectrum that cannot go beyond it when it is occupied. With the proliferation of private radio stations and the explosion of the use of wireless information thanks to successive mobile Internet generations, the ether oversees the fullness. The second reason why these techniques are not suitable for carrying Internet of things is their economic futility. These high-quality and rare waves come at a high price that does not allow the delivery of ordinary things we use in our daily lives in general. [1]

2.2 Wireless Sensor Network (WSN)

The world of WSN is communication among the sensor nodes within a WSN is performed wirelessly without using any physical link and using different low power communication protocols . WSN is a communication network having wireless communication infrastructure to enable interconnectivity among number of dedicated devices with certain functionalities to measure and collect specific parameters and conditions. These functionalities include sensing using sensor components, processing with computation capabilities, and communicating via networking modules. WSN systems are based on the combination of different technological domains such as sensor technologies, networking protocols, embedded systems, network management, distributed processing, and communication technologies. WSN is one kind of a wireless network that has a set of characteristics distinguishing it from other types of traditional wireless networks such as ad hoc networking. These include the deployment of low power network nodes with the use of batteries as the energy source. The nodes are usually implemented with small-sized devices limited in hardware resources in terms of computation, memory, and energy. This would impose some challenges regarding power management and energy efficiency. WSN is considered one of the features of new technology in the computer world as it is an open domain to create new generation of applications in different domains [2].
These include:

- Environment monitoring

- Sensing and monitoring certain environment parameters such as temperature, humidity, or even motion and sounds.

- Smart City and Civil applications
  - Smart Home, office, room and building
  - Manage and control traffic by placing sensor devices at intersections of
  - main streets to reduce traffic violations and facilitate traffic

2.3 WSN Communication and IOT Technologies

Network connectivity is a fundamental requirement in the world of IoT & WSN. Today, we have a number of wireless communication technologies and standards that can meet the different requirements of varying IoT & WSN applications. The IEEE has a number of wireless communication standards that are applicable to support connectivity in IoT & WSN. These include the IEEE 802.15.4 standard which supports low-cost, low-power, and low-rate wireless communication. It defines the Physical and MAC layers and enables different protocol stacks, such as Zigbee and 6LowPAN, to be built on top of it. Zigbee is a widely adopted IoT & WSN protocol to establish mesh networking, while 6LowPAN supports building an IP-based IoT & WSN systems. Built on 6LowPAN with the support of IPv6 networking, Thread protocol provides another simple and secure IP-enabled option designed for home automation applications. Another standard with the support of IP-based solutions is the recently developed

IEEE 802.11ah, that is based on the original WiFi standard and called WiFi HaLow. IEEE 802.15.1 is the standard for the Bluetooth technology with its special version, Bluetooth version 4 (known as Bluetooth Low Energy (BLE)), that supports low-power Bluetooth communication applicable for different IoT & WSN applications. There is also other technologies such Z-Wave standardized by the Z-Wave Alliance to provide less complex and reliable IoT & WSN communication protocol. Other protocols such as LoRa and SigFox provides Low Power Wide Area Network (LPWAN) solutions to support long-distance and scalable IoT & WSN deployment. The remaining part of this section sheds a light on these wireless communication technologies with the focus on Zigbee, 6LowPAN, BLE, Z-Wave [3].

2.4 Zigbee

The Zigbee enhances reliability through mesh networking technology developed by the Zigbee Alliance and also Zigbee is acknowledgments and use of the robust IEEE 802.15.4 to define the network and application layers of the OSI model. standard. In addition to mesh networking, Zigbee provides reliable broadcasting, a technique for distributing a message to many nodes in the network. ZigBee also provides multicasting, which ca send a message to any given group of nodes. Zigbee is a short-rang, low bit-rate, low delay, and low energy communication technology, supporting long battery life with years of operation and large-scale deployment of more than 65000 Zigbee nodes. Zigbee extends the peer-to-peer topology supported by the underlying IEEE 802.15.4 standard into three topology models. It also provides security support enabling key management, device authorization, and frame protection. Every Zigbee node is assigned two addresses, extended and short addresses. The extended address is 64-bit long which is usually the IEEE MAC address of the device while the short address is 16-bit node ID in the PAN network [4].

2.5 Existing related solutions

The following table shows and compare a number of real-life IoT testbeds.

System	University	Location	Number of Nodes	Node Type
MoteLab [5]	Harvard University	3 floors Building	190	TMote Sky Motes
TowNet [6]	University	4 floors Building	20 100	Raspberry Pi Opal sensors
SRMSenseNet [7]	SRM University	-	-	TelosB devices
Supersensors [8]	Glasgow University	campus	-	Raspberry Pis
RTLab [9]	University	Lab	150	Memsic Micaz
SmartCampus [10]	University of Surrey	3 floors Building	200	TelosB devices

CHAPTER 3

PROBLEM DOMAIN AND REQUIREMENTS ANALYSIS

3.1 Problem Domain

The most common methodologies for IoT testing and experimentation are analytical modeling, simulation, and experimental testbed. In analytical modeling, the researchers use mathematical and statistical methods to proof certain concepts. Simulation is a common approach to conduct low-cost and flexible IoT experiments. However, real-life experimination using realistic components over experimental testbed would enable collecting credible results.

On the other hand, researchers usually have to build own experimental testbed setup for carrying out certain testing procedures. This would result in additional cost and complexity. Therefore, having a general-purpose IoT testbed system can help accelerating the IoT development process.

For the College of Computer in Qassim University, there is growing interest in the IoT technologies and different related topics. Helping the college to advance the IoT research and education process would open the doors for huge opportunities. Therefore, it is feasible and important to deploy a real-life IoT testbed system and provide an experimental IoT facility for the faculty members. With such an IoT infrastructure, more time can be invested on the research and experimentation activities, instead of the equipments and low level details.

In fact this has been addressed previously in limited and small-scale manner. In a previous FYP project, in-lab IoT testbed system has been developed. The system incorporate a collection of hardware and software components. However, it only support in lab emulated experiments and provides no large-scale deployment. It also has certain functionalities that makes it limited to single-user access and single-task management. The communication among the different components of the system was based

on basic inter-process communication whereas advance options such as incorporating APIs interaction can improve its flexibility and functionality.
The existing system has been built for in-lab experimentation and requires further improvement to make it widely deployable over the CoC building. There are also certain challenges the need to be addressed to achieve effective deployment in the CoC building. These include location selection, node power supply, maintenance, connectivity, and so on. These will be discussed in the next subsection.

3.2 Challenges

Building and implementing an IoT testbed using collection of hardware and software components requires the considerations of different challenges. These include:

3.2.1 Space:

To deployment tcahe testbed nodes across the building needs logistical arrangement. The way of deployment required wall-hands so we hope the COC allows us to make testbed nodes across the building and give us space to do that.

3.2.2 node power supply:

Powering the system devices that are distributed over the CoC building is very challenging. It is not always the case that power sockets can be located around the building where the nodes should be located. If this requires longer power cabling, the case becomes more challenging. While this can be addressed using batteries, this option can results in additional maintenance challenges.

3.2.3 Time:

The deployment of an IoT testbed system would involve the integration of a different hardware and software components. Compared to other research methodologies, this is a time-consuming task and the larger the testbed size the the more it becomes challenging. As this project is limited in time, time management becomes critical to successfully meet the objectives of this project.

3.2.4 Cost

Building the IoT testbed is a costly project and deploying it in the building of the CoC would incur higher cost. The system needs to be managed in a way that insure the use of inexpensive but credible components and devices.

3.3 Requirement

3.3.1 Security:

Security is one of the main requirements in order to provide the system with more confidentiality and reliability. It is important to protect the system against potential misuses and maintain user data and the data of user will encrypted via AES-256.

3.3.2 Scalability:

The testbed should be scalable. The scalability is one of the main requirements for the system design. If the system requires additional hardware devices or software components in future, the system should be scalable enough to incorporate such functionalities. It is also important to implement only scalable hardware and software modules.

3.3.3 Accessibility:

The testbed have to enable easy and open access while making it accessible in some use cases from different platforms such as tablets, laptops,desktops and smartphones. The users maybe needs to access the testbed from outside the building. Multi-user access should be supported by the system.

3.3.4 Flexibility:

The flexibility is so important and a main requirement for the testbed design. There are many additional features will add to the current testbed and should be enabling to support the other features like the wireless communication protocols, and any other related topics.

CHAPTER 4

SYSTEM DESIGN

4.1 The improvement of testbed design

In this subsection, the improvement to the current design of the testbed is described. We will discuss about the difference between previous design and the new design. Firstly, we show the current design and discuss its drawbacks. Then, we describe how it can be improved. Overall, the testbed design should be matched with the requirements discussed in chapter 3.

Figure 4.1 show the main components of the IoT testbed system. It shows the following hardware components:

- Server
- Node devices: each node has:
    - Sensor board
    - Sensor devices
    - Zigbee devices
- Switch connecting Nodes to the server

It also contains the following software components:

- At the server:
    - Controller
    - Database
    - Web User Interface
- At the nodes:
    - Sensor Node Manager (SNM)
    - Zigbee modules

- Sensor modules

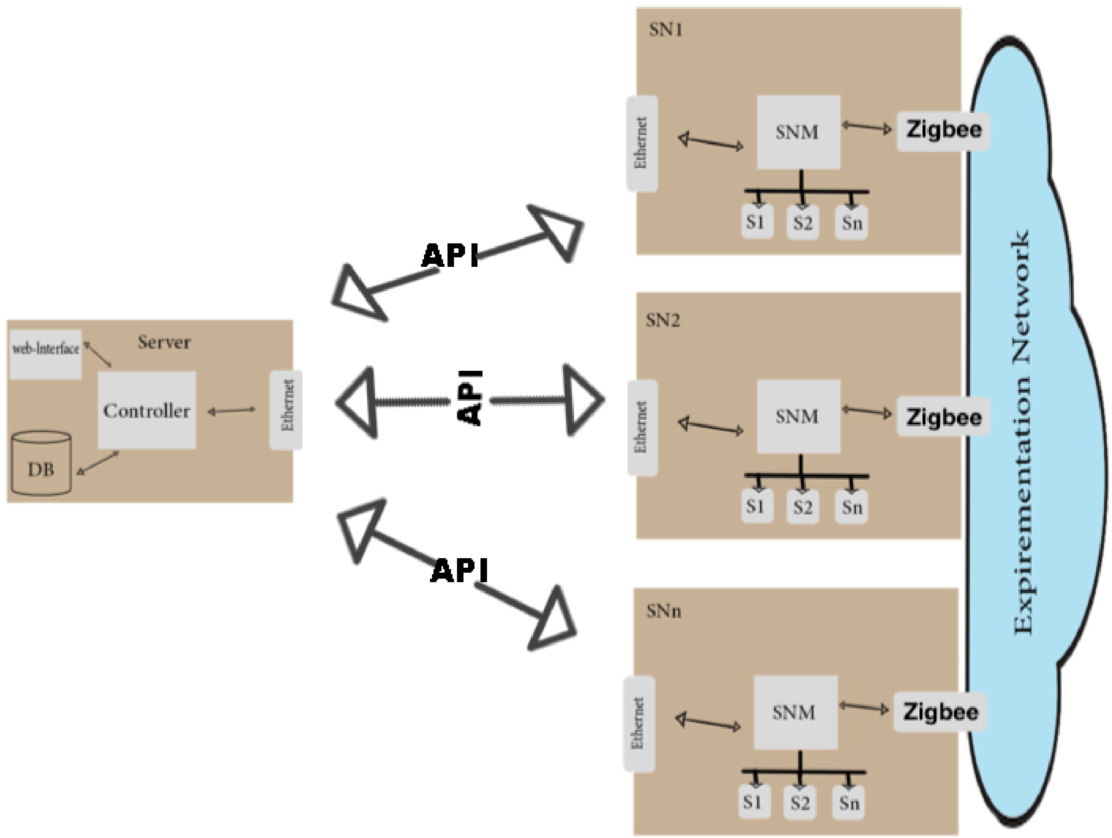

Figure 4.3 Main design of the project

As discussed earlier in the previous chapter, the current design targeted in-lab implementation allowing only emulated experiments to be carried out. It is also limited to only single-user access and single-task management. The flexibility and functionality were also limited to basic inter-process communication.

The current system does not support multi-experiments and not allow multi-user access the testbed at the same time. So we are going to redesign the system. In figure 4.2 shows an architectural overview of the previous testbed design using sockets and ports. And figure 4.2 shows an architectural overview of new design using API instead of sockets and ports.

As we can see in figure 4.2, the controller of the testbed needs to maintain many connections with the different nodes. These are socket connections which require low level maintenance by the developer. Moreover, the design focus on the controller and all tasks should be processed in the controller. the controller more busily also need to care and listening for socket and port for each testbed node. As a result, the controller here cares about everything! The testbed node is sometimes become impossible to be multitasked because it can only manage one socket connection at a time.

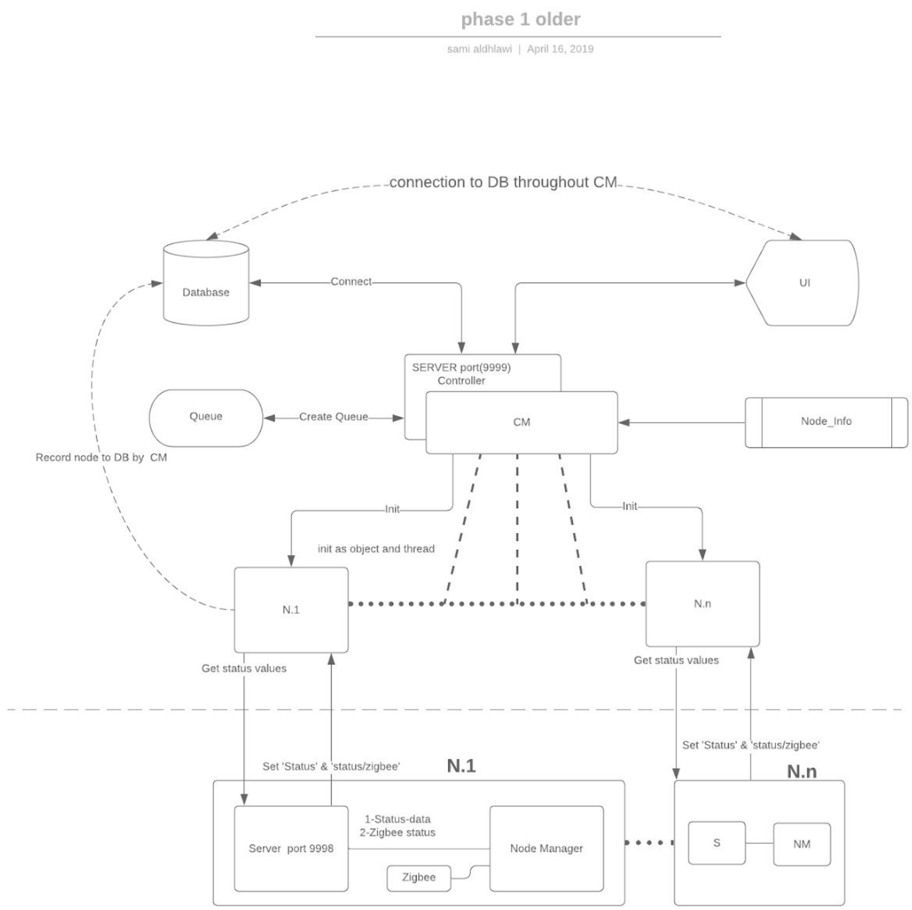

Figure 4.2 Previous design of the testbed

On other hand, Figure 4.3 shows an architectural overview of the new testbed design with API. One of the main core addition feature to the system is going to use API (application programming Interface) between the controller and testbed nodes over the control network. The system shall be flexible to add new components in the system without requiring to change the back-end of the server as update automatically not manually.

It is a best practice that the controller sends the tasks or the experiment details to the nodes using APIs requests. Each testbed node will become as a server to response to the request of controller. To carry out the required experiment, the main node communicate with other nodes by ‘experimentation network’ via ‘Zigbee’. When the nodes are done the experiment return the result of experiment to the server via APIs response.

The controller would then just care about send and receive of the experiment and store it in database then display it to User interface. This will add more flexibility to the system as the user can interface with it using the web interface or the system’s APIs. This would allow easy integration of the system with external modules. For example, data processing modules can be integrated with the nodes directly using the APIs to provide better functionality.

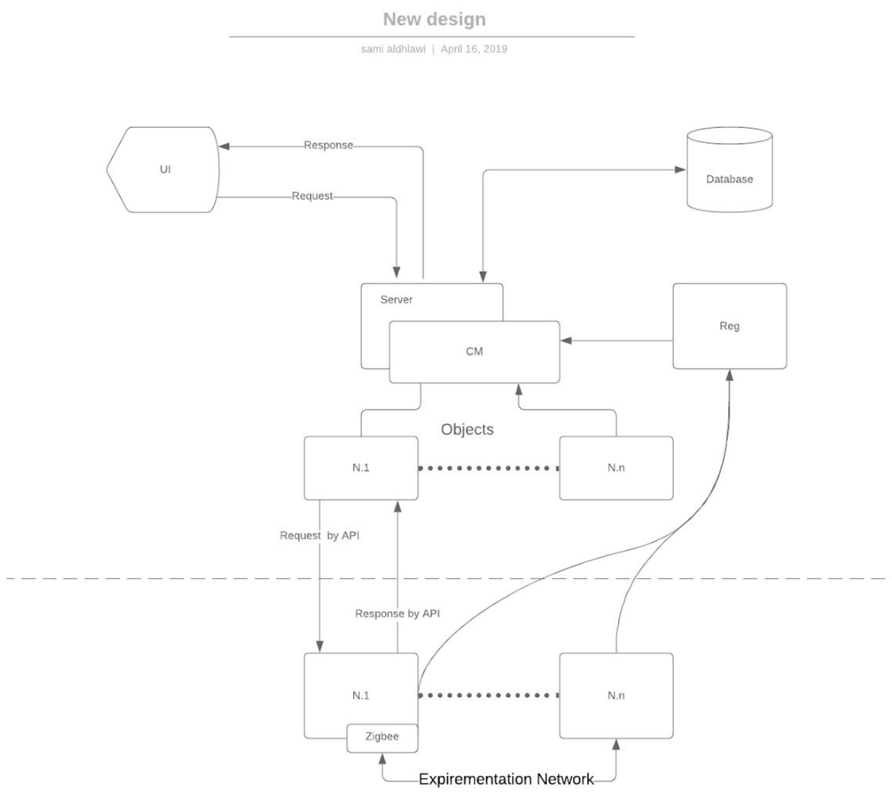

Figure 4.3 The new design of the testbed

4.2 Deployment

The second stage of this project is deploying the system in a specific part of the College of Computer in order to make it ready for evaluating it in a real IOT Application. In this subsection we will discuss our plan for the system deployment. This includes discussing the different options for successful deployment in regards to how to maintain power supply and connectivity. As Seen in figure 4.4, the system will be deployed in certain part of the building. We focus in having it located around the classrooms and facilities' offices. For the current deployment, the system will be deployed using 10 node devices. This is important to maintain the cost and complexity of the system. However, the system can be easily expanded in the future to contain more nodes.

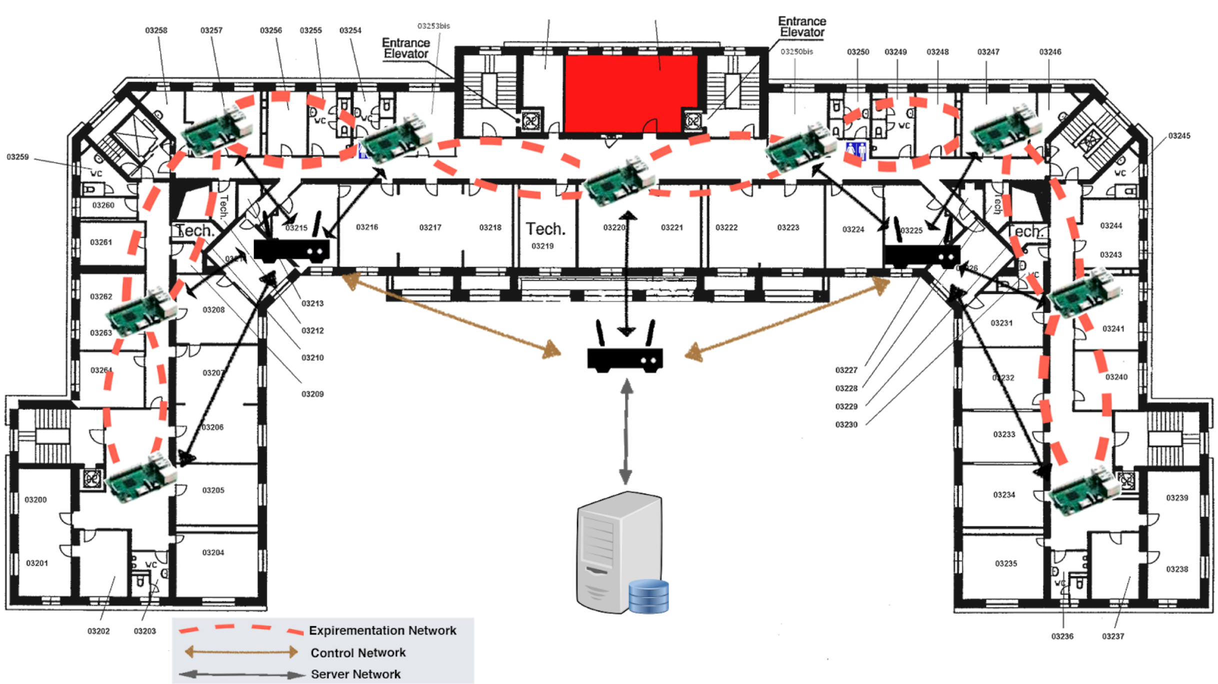

Figure 4.4 The design of the system inside the building

The main challenges in this stage are node power supply and connectivity among the nodes. There are many options as follows:

- Power over Ethernet

This is one of the option to power the testbed nodes and at the same time interconnect them. POE is a good solution because we need only one cable for each node. This option ensure that power always provided to the nodes. However, it is important to notice that the testbed nodes may not so close to each other. In this case, longer cables or multiple switch need to be used. So this will make the deployment more complex with many wires throughout the building. It will also increase the deployment cost.

- Batteries

We can support the testbed nodes by external rechargeable batteries connected to each node. At the same time, connectivity among the nodes are established using WiFi. We can make use of the existing WiFi network to interconnect the nodes. This option will make the deployment more easy as no wiring is required. However, batteries need to recharged over the time which add to the maintenance cost of the system.

- Normal power support

Another possibility is to power the nodes using the normal electrical sockets. At the same time, WiFi connectivity can be used to interconnected the nodes. The problem in this case is that the cibel of power have to reach out each nodes.

- Hybrid option

We can have some nodes connected over PoE while the others can be battery-powered. In this case, some of the nodes can use the WiFi network in the building. This option can provide more flexibility to the system as battery-power nodes can be made portable and not fixed to specific location.

In our case, we think that using PoE is the best solution. It would enable us to insure the robustness of the system. It also allows the system to avoid WiFi and Batteries related problems.

4.3 System Evaluation

The evaluation of the system is the third stage in this project. This is going to be based on utilizing the system in a real-life IoT scenarios. In this context, there are a number of IoT applications that can be considered. For example, the system can be configured to collect indoor climate data and monitor the changes in air quality. It can also be utilized for activity monitoring and track people motions and activities using sensors and cameras. Another advance possibility is to implement a smart campus facility incorporating all these options and even more.
However, all theses opportunities needs additional functionalities including cloud integration and data processing. Therefore, the evaluation process would involve the following steps:

- System configuration:
  The system is going to be configured to operate for limited smart campus application. It involves environment and activity monitoring using a set of sensors devices. The experiment will be conducted for a duration of one week (during weekdays).
- Cloud integration:
  Collected data gathered by the system needs to be sent to the cloud. There are a number of choices when it come to IoT cloud services. After intensive

search, we found that the ThingSpeak cloud platform provides a powerful and easy to use services. It provides certain APIs to effectively integrate the IoT testbed with the cloud. Moreover, it ensure a good level of security for the IoT data.

- Integration with external data processing modules:
  Currently the system does not provide data processing functionalities. However, it is going to be enhanced to support APIs and easy interfacing with external modules. With that, the collected data will be processed and visualized using external modules.

References

[1] R. Buyya, and A. V. Dastjerdi, eds. *Internet of Things: Principles and paradigms*. Elsevier, 2016.

[2] P. Waher. Learning internet of things. Packt Publishing Ltd; 2015 Jan 27.

[3] R. Gravina, C.E. Palau, M. Manso, A. Liotta and G. Fortino. eds., 2018. *Integration, interconnection, and interoperability of IoT systems*. New York, NY, USA:: Springer International Publishing.

[4] D. Gislason. Zigbee wireless networking. Newnes; 2008 Oct 9.

[5] G. Werner-Allen,P. Swieskowski, and M. Welsh. MoteLab:A wireless sensor Network testbed. Fourth International Symposium on Information Processing in Sensor Networks,USA, April 2005.

[6] Qiang Li,Dong Han, Omprakash Gnawali, Philipp Sommer, and Branislav Kusy, Demo Abstract: Twonet -Large-Scale Wireless Sensor Network Testbed with Dual-Radio Nodes, in Proceedings of the 11th ACM Conference on Embedded Networked Sensor Systems, 2013.

[7] M Pushpalatha, Revathi Venkataraman,K. Sornalakshmi and T. Ramarao, Implementation of Wireless Sensor Network Testbed: SRM SenseNet,International Journal of Computer Applications, February 2013.

[8] K.Hentschel, D. Jacob, J. Singer and M. Chalmers, "Supersensors: Raspberry Pi Devices for Smart Campus Infrastructure,"2016 IEEE 4th International Conference on Future Internet of Things and Cloud (FiCloud), Vienna, 2016.

[9] P.Pradeep,P.Divya,R.D.A.Devi,P.Rekha,K.Sangeeth and M.V. Ramesh, "A remote triggered wireless sensor network testbed, "2015 Wireless telecommunications Symposium (WTS), NewYork, NY, 2015.

[10] M. Nati, A. Gluhak, H. Abangar and W. Headley, "SmartCampus: A User-centric testbed for Internet of Things experimentation,"2013 16th International Symposium on Wireless Personal Multimedia Communications (WPMC), Atlantic City, NJ, 2013.

[11] ZigBee is a standard based on the IEEE 802.15.4 standard for wireless personal networks. The author is Drew Gislason of the book Zigbee Wireless Networking.