LIGHTWEIGHT IoT PLATFORM FOR RAPID APPLICATION DEVELOPMENT AND DEPLOYMEN

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DEDICATION

To family and friends....

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ABSTRACT

Sensors connected to the cloud services equipped with data analytics has created a plethora of new type of applications from personal to industrial levels. In other words, the smart devices, the network, and the data come together to form Internet-of-Things (IoT). In this context, IoT provides an opportunity to increase efficiency in how things are done. IoT-based system normally follows a pattern of data collection, data analytics, automation, and system improvement recommendations. However, most application would have its own unique requirements in terms of smart devices, communication technologies as well as its application provisioning service. Although various services are commercially available that provide services such as Backend-as-a-service (BaaS) and Software-as-a-service (SaaS) hosted on the cloud, this, in turn, raises the issues of security and privacy. Individuals and organizations alike would like to protect their sensitive information for various reasons. Therefore, in this project, a lightweight and secure IoT platform is proposed. The platform consists of Raspberry Pi as an IoT device with a pre-configured image that contains hotspot module, user login, PHP, Apache server, MySQL database, Node.js, and Domain Name Server (DNS). The platform also contains a middleware that provides Application Programming Interfaces (API) for both the sensor layer and the application layer. Moreover, the platform has a Graphical User Interface (GUI) designed using Angular to provide management tools and to enable data display sent by the IoT device for the end-user. The middleware is designed using JavaScript programming language in Node.js development framework to provide a lightweight and scalable features which is proven to save up to 45% of memory. The middleware is connected to NoSQL database that allows the platform to be distributed and thus, enhance security and privacy. The performance analysis of the system shows the developed platform has a Hypertext Transfer Protocol (HTTP) operation which is around 600 Bytes, with the system processor not exceeding 6% of usage. It also demonstrates a reduction by 53% and 41% of byte size and time consumed, respectively, for GET operation over a Local Area Network in UTM campus.

ABSTRAK

Sensor yang disambungkan ke perkhidmatan awan yang dilengkapi dengan analisis data telah mencipta banyak jenis aplikasi baru dari tahap peribadi ke tahap industri. Dalam kata lain, peranti pintar, rangkaian, dan data bersama-sama membentuk Internet-of-Things (IoT). Dalam konteks ini, IoT memberi peluang meningkatkan kecekapan perlaksanaan kerja. Sistem berasaskan IoT kebiasaannya mengikuti corak pengumpulan data, analisis data, automasi, dan cadangan pembaikan sistem. Walau bagaimanapun, kebanyakan aplikasi mempunyai keperluan uniknya sendiri dari segi peranti pintar, teknologi komunikasi serta perkhidmatan peruntukan aplikasi. Walaupun pelbagai perkhidmatan sudah tersedia secara komersial yang menyediakan perkhidmatan seperti Backend-as-a-service (BaaS) dan Software-as-a-service (SaaS) yang dihoskan di awan, ini, sebaliknya, menimbulkan isu keselamatan dan privasi. Individu dan organisasi sama-sama ingin melindungi maklumat sensitif mereka atas pelbagai sebab. Oleh itu, dalam projek ini, platform IoT ringan dan selamat dicadangkan. Platform ini terdiri daripada Raspberry Pi sebagai peranti IoT dengan imej pra-konfigurasi yang mengandungi modul hotspot, login pengguna, PHP, server Apache, pangkalan data MySQL, Node.js, dan Server Nama Domain (DNS). Platform ini juga mengandungi middleware yang menyediakan Antara muka Pengaturcaraan Aplikasi (API) untuk kedua-dua lapisan peranti dan lapisan aplikasi. Selain itu, platform ini mempunyai Antara muka Pengguna Grafik (GUI) yang direka menggunakan Angular untuk menyediakan alat pengurusan dan membenarkan paparan data yang dihantar dari peranti kepada pengguna akhir, middleware direka menggunakan bahasa pengaturcaraan JavaScript dalam rangka kerja pembangunan Node.js untuk menyediakan ciri-ciri yang ringan dan berskala yang terbukti dapat menjimatkan memori sehingga 45%. Middleware ini disambungkan ke pangkalan data NoSQL yang membolehkan platform ini diagihkan dan justeru, mempertinghat keselamatan dan privasi. Analisis prestasi sistem menunjukkan platform yang dibangunkan mempunyai operasi Hiperteks Pindahan Protokol (HTTP) sekitar 600 Byte dengan penggunaan pemprosesan sistem tidak melebihi 6%. Ia juga menunjukkan pengurangan dalam saiz byte dan masa yang diambil masing-masing sebanyak 53% dan 43% untuk operasi GET melalui Rangkaian Kawasan Tempatan di kampus UTM.

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LIST OF ABBREVIATIONS

IoT	-	Internet of thing
BaaS	-	Backend-as-a-Service
SaaS	-	Software-as-a-Service
PaaS	-	Platforms-as-a-Service
UI	-	User Interface
API	-	Application Programming Interface
RFID	-	Radio-Frequency Identification
WSN	-	Wireless Sensor Networks
M2M	-	Machine to Machine
DBMS	-	Database Management Systems
SOA	-	Service Oriented Architecture
HTML		Hypertext Markup Language
XML		Extensible Markup Language
HTTP		Hyper Text Transfer
QoS		Quality of Service
JSON		Java Script Object Notations
RPI		Raspberry Pi
LAN		Local Area Network
SSH		Secure Shell
MQTT		Message Queuing Telemetry Transport

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CHAPTER 1

INTRODUCTION

1.1 Overview

The transition from 1G to 2G in Wireless communications was said to be revolutionary and has since witnessed some significant paradigm shift till date as it is expected that 5G will be the next revolution in communication. This is due to promising technology concepts like the Internet of Things (IoT) which is considered as one of the key enabling technologies of Future Internet (FI) and consists of things connected to a gateway and then to a Cloud as shown in figure 1.1.

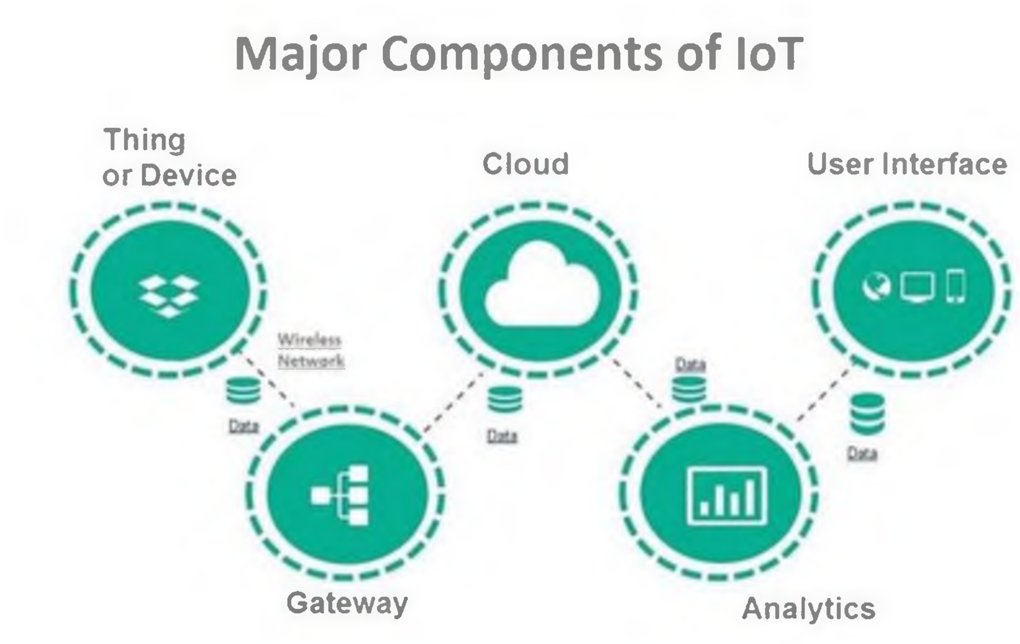

Figure 1. 1 IoT Components.

IoT is the next wave in communication technologies, a paradigm that impacts the IT sector. The term IoT comes from the two words i.e. “Internet” and the second word “Things”. The internet is the most wildly used technology in the world. The internet is a network of networks that is distributed to provide connectivity on a global scale to users by the use of exciting communication technologies and protocols. Most of the countries around the world have access to internet. According to [1], the always on customers spend around 24 hours/week online, which shows an increase of 50% on the usage of smartphones since 2017, in which the always on customers spent 12 hours/week. The main contributors to the increase use of the internet is the availability of 4G networks. On the other hand, the "things" refer to the objects, or people in a real world. The things not just refer to electronic devices it also refers to living things. When combining the two words we gain a 6th sense which is "Sensing", since the things can communicate with each other by the use of internet, as well as sensing and giving feedbacks.

The first time the world witnessed internet application was at 1980s in Carnegie Melon University [2]. Several programmers experimented on how much time it takes to fill a column in coke vending machine, and the vending machine was connected to the internet. In essence, the first time the phrase "Internet of Things" was used was in 1999 by Kevin Auston at the Auto-ID Labs, since then IoT becomes very popular with applications and objects start to connect to the internet [2].

The term IoT is mainly used to refer to the network of smart things connected by internet and the enabling technologies such as machine-to-machine communication, RFID, Wireless sensor Network (WSN), sensors/actuators, as well as the set of applications that embraces the vision of this technology to open up a new business frontier. Following this, the IoT market value is boosted due to the valuable data obtained from the Things and vendors started to adopt the idea of IoT to transform their business process and gain value. IoT ecosystem solutions grow from $1.9 trillion in 2013 to $7.1 trillion in 2020 [3]. Hence, Information and Communications Technology (ICT) sectors have 90% of IoT units installed [4].

IoT is expected to have more than 40 million things connected by 2019 in smart cities, agriculture, industry, healthcare applications and etc [5]. For one to develop an IoT application, there is need for a platform upon which its application solution will be provided. Network operators and internet service providers are investigating platforms and competing to dominate IoT applications. Some of the major companies that have invested in IoT platforms include Amazon, Arm, AT&T, Cisco, Google, Huawei, IBM, Intel, Dell, Microsoft and Samsung to mention a few. These IoT platforms can provide services like Backend-as-a-Service (BaaS), Software- as-a-Service (SaaS) and Platform-as-a-Service (PaaS) which depends on the basic needs of the application. IoT provides an opportunity to increase efficiency of doing things as compared with the conventional approach.

Generally, IoT ecosystem consist of things connected to a platform. In this projects we aim to build a lightweight IoT platform that can be used to enable IoT applications hosted on a cloud server owned by the individuals or organizations while effectively securing the data.

1.2 Problem Background

Beyond the great value of IoT, several challenges are raised such as security, privacy, and scalability. The existing IoT platforms offer great functionality to the end-user, but with much complexity. Moreover, IoT platforms let the customer subscribes to the platform and send all the data and resources to the cloud repository. In the same manner all the customers share the sensitive resources with the service provider, which in turn raise the trust issues knowing that the resources are not with them. Also, most of the IoT platforms focus on a specific domain such as health, smart cities, and real time applications, but most applications have their own requirements. Thus, a generic IoT platform that can be adopted to satisfy a customer needs is lacking. Another issue with IoT platforms is the heavyweight computational footprint and the systems memory. Since the focus of exciting IoT platforms is to cover the customer needs, some of the functions are not required by a specific application which leads to a heavyweight performance that impacts the end-user system. Those IoT platforms lack lightweight features which can enhance the user expectations and more importantly, provide security for the user's resources. Therefore, in this project, a lightweight IoT platform that can be used to enable IoT applications hosted on their premises owned by the individuals or organizations is proposed. It is expected the lightweight platform will effectively secure the user data and provides a trustworthy IoT systems. The system performance will be investigated in terms of Hyper Text Transfer Protocol (HTTP) methods of round trip time and packet size.

1.3 Research Objectives

The objectives of this project are:

1. To provide a light-weight IoT platform that can be used to enable IoT applications that interact with Object Relational Mapping (ORM) databases.

2. To test the platform with an IoT application using Raspberry Pi.

3. To assess the lightweight performance of the platform by benchmarking with existing IoT platform.

1.4 Scope of Project

In this project, the platform middleware is designed using the JavaScript programming language in Node.js. The database will be limited to document-oriented model MongoDB and it will keep all the records of activities within the platform. The User Interface (UI) will be a web page that provides resource management and allows users to interact with the database. The web page is developed using HTML 5. The front-end will be developed using Angular version 6 with one template for the endpoint and the test will be limited to one IoT application using Raspberry Pi.

1.5 Contributions

A lightweight IoT platform is developed with its contributions summarized in terms of the main three layers in IoT: the sensory (Physical layer), the middleware, and the application layers, as follows:

Sensory or physical layer (IoT devices). The lightweight IoT platform will provide set of API that will allow IoT devices to have the capability to communicate and send various types of data according to the application. The lightweight platform follows the actor-based architecture discussed in (2.4) which allows it to provide edge computing features, and hence, increases the scalability of the system.

Middleware Layer (The Back-end). The middleware is the pillar of the lightweight IoT platform as it provides an end to end solution by allowing both the application layer and sensory layer to communicate efficiently. The middleware also adds business values by designing an effective API that fulfil the business requirements.

The application layer (The Front-end). The lightweight platform provides a GUI that will allow the user to view the data. Also, the GUI will give full control to the authorized user to manipulate the data to achieve the application requirements. The GUI provides administrative tools for the end-user.

1.6 Thesis Organization

This thesis will present the design, development, and implementation of an IoT Platform. Chapter 1 presents the introduction, research concept, problem statement, project objective, scope of the project, and main contributions of the research. Chapter 2 will discuss about related works which will be divided into related studies and related projects. In addition, it will discuss the difference between middleware and platforms and also the role of lightweight IoT platforms in improving resource security. Chapter 3 highlights the methodology of this project detailing the steps taken to achieve the expected results, and explains the design of the platform with emphasis on the research activity and development of the framework, back-end, API end points and the front-end. Chapter 4 will focus on the performance evaluation of the platform as the results, observations, and findings will be discussed. Chapter 5 summarizes the project and aligns the outcomes of the project with the objectives of the research and provides a plan to contribute for future works

REFERENCES

1. Communication market report, Agust 2017.

2. The little-known story of the first iot device, February 2018.

3. Denise Lund, Carrie MacGillivray, Vernon Turner, and Mario Morales. Worldwide and regional internet of things (iot) 2014–2020 forecast: A virtuous circle of proven value and demand. *International Data Corporation (IDC), Tech. Rep*, 1, 2014.

4. The internet of things (iot) units installed, February 2017.

5. Xiangyu Hu and Songrong Qian. Iot application system with crop growth models in facility agriculture. In *Computer Sciences and Convergence Information Technology (ICCIT), 2011 6th International Conference on*, pages 129–133. IEEE, 2011.

6. ITU-T Study Group et al. New itu standards define the internet of things and provide the blueprints for its development, 2012.

7. D Giusto. A. lera, g. morabito, l. atzori (eds.) the internet of things, 2010.

8. Luigi Atzori, Antonio Iera, and Giacomo Morabito. The internet of things: A survey. *Computer networks*, 54(15):2787–2805, 2010.

9. Debasis Bandyopadhyay and Jaydip Sen. Internet of things: Applications and challenges in technology and standardization. *Wireless Personal Communications*, 58(1):49–69, 2011.

10. Xiaolin Jia, Quanyuan Feng, Taihua Fan, and Quanshui Lei. Rfid technology and its applications in internet of things (iot). In *Consumer Electronics, Communications and Networks (CECNet), 2012 2nd International Conference on*, pages 1282–1285. IEEE, 2012.

11. EWT Ngai, Karen KL Moon, Frederick J Riggins, and Y Yi Candace. Rfid research: An academic literature review (1995–2005) and future research directions. *International Journal of Production Economics*,

112(2):510–520, 2008.

12. Li Da Xu, Wu He, and Shancang Li. Internet of things in industries: A survey. *IEEE Transactions on industrial informatics*, 10(4):2233–2243, 2014.

13. Itu internet reports, 2005.

14. Thiago Teixeira, Sara Hachem, Valérie Issarny, and Nikolaos Georgantas. Service oriented middleware for the internet of things: a perspective. In *European Conference on a Service-Based Internet*, pages 220–229. Springer, 2011.

15. Vedran Galetić, Iva Bojić, Mario Kušek, Gordan Ježić, Saša Dešić, and Darko Huljenić. Basic principles of machine-to-machine communication and its impact on telecommunications industry. In *MIPRO, 2011 Proceedings of the 34th International Convention*, pages 380–385. IEEE, 2011.

16. Final version of nist cloud computing definition, October 2011.

17. Maria Fazio, Antonio Celesti, Fermin Galan Marquez, Alex Glikson, and Massimo Villari. Exploiting the fiware cloud platform to develop a remote patient monitoring system. In *2015 IEEE Symposium on Computers and Communication (ISCC)*, pages 264–270. IEEE, 2015.

18. Sanjay P Ahuja, Sindhu Mani, and Jesus Zambrano. A survey of the state of cloud computing in healthcare. *Network and Communication Technologies*, 1(2):12, 2012.

19. Mohammad Aazam, Imran Khan, Aymen Abdullah Alsaffar, and Eui-Nam Huh. Cloud of things: Integrating internet of things and cloud computing and the issues involved. In *Applied Sciences and Technology (IBCAST), 2014 11th International Bhurban Conference on*, pages 414–419. IEEE, 2014.

20. Bhumi Nakhuva and Tushar Champaneria. Study of various internet of things platforms. *International Journal of Computer Science & Engineering Survey*, 6(6):61–74, 2015.

21. Anne H Ngu, Mario Gutierrez, Vangelis Metsis, Surya Nepal, and Quan

Z Sheng. Iot middleware: A survey on issues and enabling technologies. *IEEE Internet of Things Journal*, 4(1):1–20, 2017.

22. Dimitrios Georgakopoulos and Michael Papazoglou. *Service-oriented computing*. Number Sirsi) i9780262072960. 2009.

23. Nest, 2014.

24. Heiko Desruelle, John Lyle, Simon Isenberg, and Frank Gielen. On the challenges of building a web-based ubiquitous application platform. In *Proceedings of the 2012 ACM conference on ubiquitous computing*, pages 733–736. ACM, 2012.

25. Ramao Tiago Tiburski, Leonardo Albernaz Amaral, Everton De Matos, Dario FG De Azevedo, and Fabiano Hessel. The role of lightweight approaches towards the standardization of a security architecture for iot middleware systems. *IEEE Communications Magazine*, 54(12):56–62, 2016.

26. Soma Bandyopadhyay, Munmun Sengupta, Souvik Maiti, and Subhajit Dutta. Role of middleware for internet of things: A study. *International Journal of Computer Science and Engineering Survey*, 2(3):94–105, 2011.

27. Apostolos Malatras, Abolghasem Asgari, and Timothy Baugé. Web enabled wireless sensor networks for facilities management. *IEEE systems journal*, 2(4):500–512, 2008.

28. Markus Eisenhauer, Peter Rosengren, and Pablo Antolin. A development platform for integrating wireless devices and sensors into ambient intelligence systems. In *Sensor, Mesh and Ad Hoc Communications and Networks Workshops, 2009. SECON Workshops' 09. 6th Annual IEEE Communications Society Conference on*, pages 1–3. IEEE, 2009.

29. Hydra.

30. João Pedro Sousa and David Garlan. Aura: an architectural framework for user mobility in ubiquitous computing environments. In *Software Architecture*, pages 29–43. Springer, 2002.

31. Per Persson and Ola Angelsmark. Calvin–merging cloud and iot. *Procedia Computer Science*, 52:210–217, 2015.

32. Linkdln, October 2018.

33. Node, October 2018