

# **TRANSFORMING MOBILE DEVICES INTO SMART IOT GATEWAYS**

M. A.V. Nanayakkara

(158228P)

Degree of Master of Science in Computer Science

Department of Computer Science and Engineering

University of Moratuwa

Sri Lanka

April 2019

# **TRANSFORMING MOBILE DEVICES INTO SMART IOT GATEWAYS**

M. A.V. Nanayakkara

(158228P)

Thesis submitted in partial fulfillment of the requirements for the degree  
Master of Science in Computer Science

Department of Computer Science and Engineering

University of Moratuwa

Sri Lanka

**April 2019**

## DECLARATION

I declare that this is my own work and this dissertation does not incorporate without acknowledgment any material previously submitted for a Degree or Diploma in any other University or institute of higher learning and to the best of my knowledge and belief it does not contain any material previously published or written by another person except where the acknowledgement is made in the text.

Also, I hereby grant to University of Moratuwa the non-exclusive right to reproduce and distribute my dissertation, in whole or in part in print, electronic or other medium. I retain the right to use this content in whole or part in future works (such as articles or books).

Signature: .....

Date: .....

Name: M. A. V. Nanayakkara

The supervisor/s should certify the dissertation with the following declaration.

The above candidate has carried out research for the Masters Dissertation under my supervision.

Signature of the supervisor: .....

Date: .....

Name: Dr. Indika Perera

## ACKNOWLEDGMENTS

First and foremost, I am grateful to my supervisor Dr. Indika Perera for the guidance and support provided to complete the research successfully. His continuous guidance and support contributed a lot in completing this research.

There is no doubt that the elite academic staff of University of Moratuwa successfully managed to improve our character and competencies which refined our professionalism and made us achievers in our career professions.

My sincere appreciation goes to all the faculty members and academic/non-academic staff members of University of Moratuwa who have assisted me in various ways.

The course materials & other relevant facilities provided by the University of Moratuwa also helped me throughout the journey of MSc Programme.

Last but not the least, special gratitude goes to my family for giving me the unconditional support & strength to make this journey a great success.

## ABSTRACT

Internet of Things (IOT) which is considered as the ‘Next Industrial Revolution’ is a heavily discussed topic across the globe which is all about inter-connection of *things* for the betterment of the human beings. Apart from the end nodes which are either sensors or actuators, a reliable and robust connection is the most significant component of any IOT deployment. Therefore, different concepts of IOT gateways have been introduced by many IOT vendors to the industry to cater various types of connectivity options. However, still there are major challenges and weaknesses prevailing in the industry, often in the connectivity component unanswered which have limited the full potential of IOT deployments.

This research is focused on prototyping a smarter IOT gateway using an Android based mobile device which can overcome some of these limitations identified. nRF51822 Bluetooth based sensor tag which gives five different sensor readings and a cloud instance of Splunk IOT Data Analytics platform were used along with the Prototype gateway to demonstrate an actual IOT deployment in this research.

The prototype successfully managed to push processed and filtered sensor data into the Splunk cloud which significantly reduced the data load which saved cloud storage. A python-based application was used to process the raw sensor data to meaningful information. In addition to that this prototype added value to the IOT gateways, by having features such as real-time alerting leveraging on Google Cloud Messaging services.

However, using Android based mobile devices as IOT gateways created new set of limitations where few recommendations such as developing hardware-addons to accept other wireless IOT connectivity technologies and customizing the Android OS etc. were proposed towards the end of this research.

**Keywords:** IOT Gateways, Data Analytics and Visualizations, Data Translation, Real-time alerting, Bluetooth Sensor Tags

## TABLE OF CONTENTS

|  |      |
|--|------|
| DECLARATION .....  | III  |
| ACKNOWLEDGMENTS .....  | IV   |
| ABSTRACT.....  | V    |
| LIST OF ABBREVIATIONS.....                                       | IX   |
| LIST OF FIGURES .....  | XI   |
| LIST OF TABLES.....  | XIII |
| Chapter 1.....   | 1    |
| 1. INTRODUCTION .....  | 1    |
| 1.1 Background.....  | 1    |
| 1.2 Motivation.....  | 2    |
| 1.3 Objectives of the research.....                              | 3    |
| 1.4 Thesis Organization .....                                    | 4    |
| Chapter 2.....   | 6    |
| 2. LITERATURE REVIEW .....                                       | 6    |
| 2.1 Introduction.....  | 6    |
| 2.2 Internet of Things (IOT) .....                               | 7    |
| 2.3 Sensors .....  | 9    |
| 2.4 Gateways.....  | 10   |
| 2.4.1 Interface protocols .....                                  | 11   |
| 2.4.2 Device Abstraction (DA).....                               | 11   |
| 2.4.3 Central control, Context detection & Management (CCM)..... | 11   |
| 2.4.4 Application Abstraction.....                               | 12   |
| 2.4.5 Data Security.....   | 12   |
| 2.5 Real-world IOT Systems.....                                  | 12   |
| 2.5.1 Libelium.....  | 12   |
| 2.5.2 Libelium Sensor Nodes.....                                 | 15   |
| 2.5.3 Cloud Integrations.....                                    | 16   |
| 2.5.4 Meshlium Gateway .....                                     | 16   |
| 2.5.5 Advantech .....  | 18   |
| 2.5.6 Advantech Sensor Nodes .....                               | 18   |
| 2.5.7 SmartSwarm Gateways.....                                   | 19   |
| 2.6 Cloud Platforms .....  | 20   |

|           |   |    |
|-----------|---|----|
| 2.6.1     | Benefits of cloud computing .....                         | 20 |
| 2.6.2     | Types of cloud services: IaaS, PaaS, SaaS .....           | 21 |
| 2.6.3     | Types of cloud deployments: public, private, hybrid ..... | 22 |
| 2.6.4     | IOT / Cloud Convergence .....                             | 22 |
| Chapter 3 | .....   | 24 |
| 3.        | RESEARCH METHODOLOGY .....                                | 24 |
| 3.1       | Introduction .....  | 24 |
| 3.2       | Solution Architecture .....                               | 24 |
| 3.3       | Real-world IOT Solution deployments .....                 | 25 |
| 3.4       | Prototype Selection .....                                 | 27 |
| 3.4.1     | nRF51822 Sensor Tag .....                                 | 27 |
| 3.4.2     | 3-axis accelerometer MPU6050 .....                        | 27 |
| 3.4.3     | Bosch temperature and pressure sensor BMP180 .....        | 28 |
| 3.4.4     | Ambient light sensor/PIR/Motion detection AP3216 .....    | 28 |
| 3.5       | Prototype Development .....                               | 29 |
| 3.5.1     | Blue-tooth Low Energy .....                               | 29 |
| 3.5.2     | Generic Attribute Profile (GATT) .....                    | 30 |
| 3.5.3     | Services and Characteristics .....                        | 30 |
| 3.5.4     | Roles and Responsibilities .....                          | 30 |
| 3.5.5     | GATT Characteristics and Attributes .....                 | 31 |
| 3.5.6     | GATT Transactions .....                                   | 32 |
| 3.5.7     | nRF51 profile log .....                                   | 33 |
| 3.5.8     | nRF Log File Explanation .....                            | 34 |
| 3.6       | Multi-Device, Multi-Vendor Integrations .....             | 34 |
| 3.6.1     | Smart Environment PRO .....                               | 35 |
| 3.6.2     | Smart Cities PRO .....                                    | 36 |
| 3.6.3     | Smart Agriculture .....                                   | 37 |
| 3.6.4     | Sensors in Sensor Data Log .....                          | 39 |
| 3.6.5     | Waspframes .....  | 40 |
| 3.6.6     | Sample Sensor Data .....                                  | 41 |
| 3.7       | Splunk IOT Cloud Platform .....                           | 42 |
| 3.8       | Alerts and Notifications .....                            | 43 |
| 3.8.1     | SMS Alerts .....  | 44 |
| 3.8.2     | Email Alerts .....  | 44 |
| 3.8.3     | App Notifications .....                                   | 45 |

|  |    |
|--|----|
| Chapter 4.....   | 47 |
| 4 RESEARCH IMPLEMENTATION.....                           | 47 |
| 4.1 Introduction.....                                    | 47 |
| 4.2 Step 1: Collecting Data.....                         | 47 |
| 4.2.1 BLE Scanner Android Application.....               | 48 |
| 4.3 Step 2: Processing and filtering data.....           | 49 |
| 4.3.1 nRF51 Sensor data log.....                         | 49 |
| 4.3.2 Libelium Sensor data log.....                      | 50 |
| 4.4 Step 3: Logging filtered data.....                   | 52 |
| 4.5 Step 4: Alerting and Sending notifications.....      | 53 |
| 4.6 Step 5: Analyzing and Visualizing data.....          | 56 |
| Chapter 5.....   | 60 |
| 5 RESEARCH EVALUATION.....                               | 60 |
| 5.1 Introduction.....                                    | 60 |
| 5.2 Data Filtering.....                                  | 60 |
| 5.2.1 Cost.....  | 60 |
| 5.2.2 Latency.....                                       | 61 |
| 5.3 Real-time Alerting.....                              | 62 |
| 5.3.1 Latency.....                                       | 62 |
| 5.3.2 Uninterrupted, Internet-Independent Operation..... | 63 |
| Chapter 6.....   | 64 |
| 6 DISCUSSION.....  | 64 |
| 6.1 Introduction.....                                    | 64 |
| 6.2 Closing the Research Gap.....                        | 64 |
| 6.3 Improving the Prototype.....                         | 64 |
| Chapter 7.....   | 66 |
| 7 CONCLUSION.....  | 66 |
| 7.1 Introduction.....                                    | 66 |
| 7.2 Conclusion.....                                      | 66 |
| 7.3 Recommendations.....                                 | 66 |
| REFERENCES.....  | 68 |
| APPENDIX A: Real-time Application Source Code.....       | 71 |



## LIST OF ABBREVIATIONS

|       |   |
|-------|---|
| ALS   | Ambient Light Sensor                            |
| AMQP  | Advanced Message Queuing Protocol               |
| API   | Application Programming Interface               |
| BLE   | Bluetooth Low Energy                            |
| CCM   | Central control, Context detection & Management |
| COAP  | Constrained Application Protocol                |
| DA    | Device Abstraction                              |
| GATT  | Generic Attribute Profile                       |
| GCM   | Google Cloud Messaging                          |
| HTTP  | Hyper Text Transfer Protocol                    |
| IaaS  | Infrastructure as a Service                     |
| IIOT  | Industrial Internet of Things                   |
| IOT   | Internet of Things                              |
| IR    | Infra-Red                                       |
| IT    | Information Technology                          |
| JMS   | Java Message Service                            |
| LAN   | Local Area Network                              |
| LoRa  | Long Range                                      |
| MQTT  | MQ Telemetry Transport                          |
| NFC   | Near Field Communication                        |
| PaaS  | Platform as a Service                           |
| PS    | Proximity Sensor                                |
| REST  | Representational State Transfer                 |
| RFID  | Radio-Frequency IDentification                  |
| SaaS  | Software as a Service                           |
| TCP   | Transmission Control Protocol                   |
| UUID  | Universally Unique Identifier                   |
| Wi-Fi | Wireless Fidelity                               |

XMPP      Extensible Messaging and Presence Protocol

## LIST OF FIGURES

|  |    |
|--|----|
| Figure 2.1: Components of IOT Deployment .....                 | 07 |
| Figure 2.2: IOT Layered Architecture .....                     | 09 |
| Figure 2.3: Smartphone Sensors .....                           | 10 |
| Figure 2.4: Functional Components of IOT Middleware .....      | 11 |
| Figure 2.5: Libelium IOT Products.....                         | 13 |
| Figure 2.6: Libelium IOT Products.....                         | 13 |
| Figure 2.7: Libelium Sensor Node.....                          | 14 |
| Figure 2.8: Libelium Sensor Sockets .....                      | 14 |
| Figure 2.9: Libelium Cloud Integrations .....                  | 15 |
| Figure 2.10: Meshlium Gateway.....                             | 16 |
| Figure 2.11: Advantech Sensors .....                           | 17 |
| Figure 2.12: SmartSwarm Gateway .....                          | 18 |
| Figure 3.1: Solution Architecture .....                        | 23 |
| Figure 3.2: Deployment Option 1 .....                          | 24 |
| Figure 3.3: Advantech IOT Products .....                       | 25 |
| Figure 3.4: Development Option 2 .....                         | 25 |
| Figure 3.5: nRF51822 Sensor Tag .....                          | 26 |
| Figure 3.6: 3-axis accelerometer MPU6050 .....                 | 26 |
| Figure 3.7: Bosch temperature and pressure sensor BMP180 ..... | 27 |
| Figure 3.8: AP3216 Sensor .....                                | 27 |
| Figure 3.9: Prototype Key Components.....                      | 28 |
| Figure 3.10: GATT Services and Characteristics .....           | 29 |
| Figure 3.11: GATT Data Exchange Process.....                   | 31 |
| Figure 3.12: nRF51 Profile Log.....                            | 32 |
| Figure 3.13: nRF Log File Explanation .....                    | 33 |
| Figure 3.14: Smart Environment PRO Sensor Node .....           | 35 |
| Figure 3.15: Smart Cities PRO Sensor Node.....                 | 36 |
| Figure 3.16: Smart Agriculture Sensor Node .....               | 37 |
| Figure 3.17: Libelium Sensor Data Logs.....                    | 41 |
| Figure 3.18: Splunk Visualizations.....                        | 42 |
| Figure 3.19: Alert and Notifications .....                     | 43 |
| Figure 3.20: SmsManager Method .....                           | 43 |

|  |    |
|--|----|
| Figure 3.21: Email Method .....                          | 44 |
| Figure 3.22: GCM Architecture .....                      | 45 |
| Figure 4.1: Implementation Setup.....                    | 46 |
| Figure 4.2: nRF Connect Android App .....                | 47 |
| Figure 4.3: Python Code .....                            | 49 |
| Figure 4.4: ASCII Logs.....                              | 50 |
| Figure 4.5: Sensor Data Processing App .....             | 52 |
| Figure 4.6: Android App - Optional Actions .....         | 53 |
| Figure 4.7: Android App – Alerts and Notifications ..... | 54 |
| Figure 4.8: Android App - Alerts and Notifications ..... | 55 |
| Figure 4.9: Splunk Data Upload .....                     | 56 |
| Figure 4.10: Splunk Data Upload .....                    | 56 |
| Figure 4.11: Sensor data on Splunk .....                 | 57 |
| Figure 4.12: Splunk Visualizations.....                  | 57 |
| Figure 4.13: Splunk Visualizations.....                  | 58 |
| Figure 5.1: Splunk with Raw Data.....                    | 61 |

## LIST OF TABLES

|   |    |
|---|----|
| Table 3.1: Log Profile Description .....      | 27 |
| Table 3.2: Libelium Nodes and Sensors .....   | 34 |
| Table 3.3: Smart Environment PRO Sensors..... | 34 |
| Table 3.4: Smart Cities PRO Sensors .....     | 35 |
| Table 3.5: Smart Agriculture Sensors .....    | 37 |
| Table 3.6: Libelium Sensors .....             | 38 |
| Table 3.7: Waspframe Structure .....          | 40 |
| Table 3.8: Waspframe Explanation .....        | 41 |
| Table 4.1: Sensor UUIDs.....                  | 48 |
| Table 4.2: Sample Sensor Data.....            | 50 |
| Table 5.1: Storage Space Calculation .....    | 60 |