Embedded System Based Internet of Things for Smart Home/Office Appliances Control using Wi-Fi Technology

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ABSTRACT

The positioned and the integration of embedded system ability, wireless sensor and network technology in the ubiquitous architecture has enhance the 6LowPAN communication platform. Such as compatibility, internetworking, energy savings and real-time data acquisition that are the shortcoming of the existing devices like X10, network time protocol (NTP) without feedback system incorporated for the network connectivity and message guarantee constraint. This paper review several works in the area of newly emerge smart technologies which based on IoT architecture and their protocols. It also illustrates an innovative embedded system based internet of thing architecture for remote system control in a smart home and office appliances (SHOA) using android based web apps and Wi-Fi technology. The internet protocol (IP) addresses are assigning to things for easy control and operation of domestic home appliances at a remote network, which aid interoperability and end-to-end communication between multiple appliances connected over the 6LowPAN network. HTTPPOST and HTTPGET command that support RESTful services used for ensuring packet transmission and receiver between the IoT gateway and the cloud database.

Index terms: *Embedded system, Home appliances, Internet of Things, IP Addresses, RESTful services.*

1 INTRODUCTION

The arrival of Internet of Thing (IoT) paradigm has transformed the world nature like nothing before in the locale of information and communication technology, which support the communication between human-to-things and machine-to-machine existence with a standard protocol. The global network known as the Internet has revolutionized the Information and Communication Technology (ICT) with the application of smart device like PDA, mobile phones, laptop computer, tablets and others like nothing ever in practices (Aliyu, et al., 2017). The (IoTs) has proved to be self-motivated network infrastructure that interconnect physical and virtual things together (Sundmaeker, et al., 2010). Therefore, IoT was developed from the convergence of wireless technology, micro-electromechanical systems (MEMS), embedded micro-chip and the Internet facilities for the standard configuration and to achieve the interoperable communication by employing intelligent interface system called (embedded system) to perfectly integrate things into a network (Ajao, et al., 2017).

The general improvement on the development of embedded micro-chip devices with interconnectivity facilities has led to the concept of the “Internet of Things” which requires a flourishing set of wireless connectivity options (such as Bluetooth, ZigBee, Z-wave, Wi-Fi etc) and wireless application protocols includes HTTP, MQTT, CoAP, 6LowPAN and others for the interoperability and better end-to-end communication between smart devices like wrist wearable health care devices, smart home applications, intelligent agriculture precisions and so on (Vance, A 2010).

All these smart embedded and intelligence devices in the IoT platform require scalability for constrain resources, efficient power management, security for data storage and packet transmission with support of RESTful architecture for the integration of cloud services. The complexities and emerging standards for embedded system developers required to understand the designed for its IoT device for the successful connectivity and interoperable among things and the smart appliances in the network.

Embedded systems (ES) are electronic devices that incorporate microcontroller chip within their implementations to simplify the system design and provide flexibility to perform tasks of removing the bugs, which allowing user modifications by adding new features or encoding the software that will control the devices.

Development of an IoTs architecture with embedded wireless system for multiple device monitoring purposes has advanced significantly in the last couple of years, since it added a new dimension to the world of ICT (Hilton, 2012). According to (Chike, 2014), projected that by the year 2020, the number of connected smart appliances are expected to grow exponentially and increases to 50 billion populations all over the world, and by the year 2019, the available IoTs based wearable devices will up to 780 million, while the accessible smartphones will be 2.2 billion devices.

Smart home automation is described as an intelligence device or Single-on Chip (SoC) embedded technology located within the residence to provide comfortable living, amenities, security and power efficiency to the people in the environment. The implementation of an intelligence devices for home/office environment will improved lifestyle of disable humans and elder one’s that needed convenience and comfort. Therefore, the development of an embedded system based IoTs for home automation, control and monitoring is getting more attentions in the recent time. Different wireless technologies have been used for the proposed architecture and implementation of embedded system based home automation system like

Bluetooth, RFID tags and Wi-Fi technology for embedded intelligence system into the Smart Home Environment (SME).

Therefore, wireless technology has advanced to the age of connecting things to things for sharing resources and communicate over the internet with the help of several manufacturer automated products and suitable protocols for the embedded system based internet of things. An embedded system can be designed for control and monitoring devices in the area like smart home, smart city, smart car, smart devices, smart factory, smart healthcare, smart agriculture and so on. All these has been focusing, researches and several proposals and development has emanated by the academician and industrial. The universal system with embedded IoT technology has greatly demanded for their needs in the world of connectivity to provide convenience, comfort, security and quality of life. Figure 1 depict the attribute of Internet of Thing connectivity.

Figure 1: Attribute of Internet of Things.

1.1 WIRELESS NETWORK TECHNOLOGY

The implementation of intelligence embedded system based IoTs for multiple devices control and monitoring integrated with android web apps has been proposed by several numbers of researcher in the field of academic and industries. Which they depends on wireless technologies and protocols for their realization (including Bluetooth low energy (BLE), Cellular network, RFID, Wi-Fi, ZigBee and Z-waves), that provide network services for a remote data transfer, sensing, monitoring and control system (Kortuem et al., 2010).

The sharing of information and communication, between things-to-things, human-to-things and others over distance using radio waves for the transmission and receiver were attributed to wireless technology. While the protocols that guiding the communication on the internet from the physical layers to the application layer in the IoTs stack layers are studied like CoAP, MQTT, and HTTP. The performance of these technologies are compared to each other and details are contained in Table 1.

The qualitative comparison was carried out between CoAP and MQTT as reported by (Niccolo et al., 2013). The results shows that in most applications and functionalities for sophisticated requirements like message tenacity, frequent message occurrences, congestion control, multicast security and Quality of Service (QoS) level. MQTT has a better performance, but the overall analysis confirmed that CoAP performances achieved better results than the MQTT counterpart when consider the bandwidth, reliability and round trip time (RTT).

Also, CoAP and HTTP were compared for about 10,000 smart device on the testbed using total cost of ownership (TCO) as a benchmark and others technical parameters such as data generated during transmission over an application's life cycle, energy consumption are included (Tapio et al., 2014). Therefore, the result show that CoAP has better performance compare to HTTP in the energy consumption rate which is six times less when compared to the HTTP PUSH mode, and CoAP-based system generate about 62GB data while its counterpart HTTP-based system generate about 434GB data per month. Details are contained in Table 2. The IoTs network stack layers is depict in Figure 2.

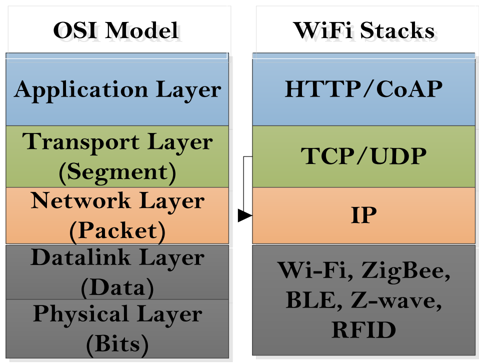

Figure 2: IoT network stack layers/protocols

TABLE 1: COMPARISONS BETWEEN THE WIRELESS NETWORK TECHNOLOGY AND PROTOCOLS

Wireless protocol	Distance (m)	Data Rate (kb/s)	Frequency Band (Hz)
BLE	10	1 Mb/s	2.4GHz
Z-wave	100	9.6/40kb/s	908.42
ZigBee	10-100	250kb/s	2.4GHz
Wi-Fi	100-above	54-600Mb/s	2.4GHz
RFID	5	640Kb/s	3-30MHz

TABLE 2: COMPARISONS BETWEEN THE WIRELESS APPLICATION PROTOCOLS

S/N	Protocols	QoS	Message Quality	Bandwidth	Round trip time (RTT)	Reliability
1.	MQQT & CoAP	Better	Better	Good	Better	Good
		Good	Good	Better	Good	Better
	Protocol	Energy Consumption	Generated Data			
2.	CoAP & HTTP	Better	Lower	Lower	Good	Better
		Good	Higher	Higher	Good	Good

Many of this technology has been used to accomplish various levels of intelligence in the embedded system based internet of things for control and monitoring activities, among the communication that exist between humans and things, human to machine and within things themselves.

For instance, development of physiological parameter monitoring system based wireless sensor network was deployed to the vineyard to prevent creeping plant diseases by (Shinde & Pravin 2014). Since the water retention of different soil moisture are varying to each other for the irrigation like sandy that has high content of water retention than clay or loamy soil. Therefore, the soil moisture in the same fields can decide amount of water that will be irrigated in that field, which helps in the controlling of irrigation system and save water volume. Also, the soil temperature and humidity is measure in another part of vine to prevent plant diseases and reduced numbers of pesticides. All data collected from the sensors are stored in a cloud database which can be accessed by users anywhere, or everywhere in world using available web app on the laptop or a Personal Digital Assistance (PDA).

1.2 Related works

Ramlee et al., (2013) & Sharon et al., (2014), proposed a Bluetooth-based home automation systems using android phones and web application for controlled home appliances. These devices are actually linked to a Bluetooth sub-controller, which is linked and controlled by the Smart android phone using embed Bluetooth connectivity. But, due to limited distance range of Bluetooth operation (up to 10m), the system can only function within the range of services in the home environment.

Thinagaran et al, (2008) attempt to provide network interoperability and remote access to control home appliances through the home gateways using Wi-Fi technology. Also, the Wi-Fi based home control system using PC based web server that will manages the connected home devices through a dedicated web server database and a web page by (Suryanvanshi et al., 2014). The weakness of these systems is that a high end personal computer was used which increase the cost of installation and the energy consumption. Also the system can only be controlled through a web apps located in the home vicinity.

An embedded smart home automation system with web application to control house appliance using Global System for Mobile communication (GSM) technology was developed by (Neha et al., 2014). An interface is created between the users and smart home equipment using GSM wireless technology and web server for control and monitoring the devices. Therefore, the home appliances and other devices are directly connected and controlled by this embedded system module. The GSM module is built with IoT agent and embedded system module. The challenges of the system are the data transmission, authentication security, and also the used of GSM/ Short message Services (SMS) techniques not video streaming.

The proposed system by (Rajeev, 2013) have presented internet of things, ubiquitous home control and monitoring system using android based smart phone micro-web app. The device is set up to provide novel communication protocol and the architecture to monitor and control home switching functionality in the environment using sensors with relays. However, the system could not use voice command over the wireless technology to control domestic home appliances.

In this paper, several authors' idea on the IoTs based smart devices and home automation for remote control and monitoring system have been reviewed using different techniques for IoT smart device development and implementation. Therefore, an embedded system based IoT architecture for multiple device control in the smart home and offices using Wi-Fi technology and android web apps has been proposed and implemented. This IoT architecture developed will provides end-to-end communication, scalability, interoperability, security and others functions among the smart devices in the network.

2 METHODOLOGY

With advance and fast growing of technology in the recent lifetime of IoT, many automated home devices has been manufactured with IoT facilities and integrated wireless services functions in their features to ease the control and better performance of the home or office appliances. The method adopted in the accomplishment of the architectural design is divided into the hardware system and software program development. The communication technology of the proposed embedded system developed in the platform of internet of things is based on the IP address configuration on Wi-Fi technology (IEEE 802. 11 b/g/n) protocol.

The system architecture comprises of automated home appliances, embedded system (ES) such as Atmega 328 embedded on Arduino board with Wi-Fi module

EPS8266, the external power supply unit, wireless router with firewall, and wireless smart home/office appliances like printer, refrigerator, plasma TV, and switch control light. Also includes cloud database and the android web apps based developed in the java script object notion (JSON) as depicted in Figure 3.

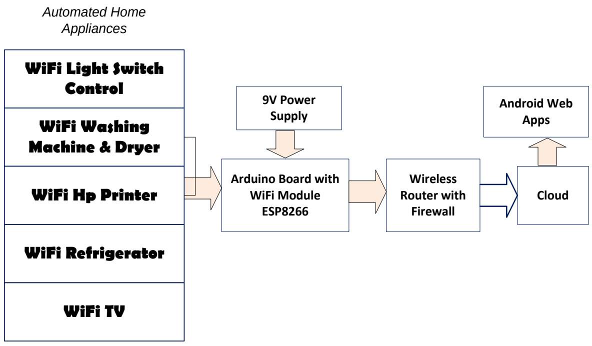

Figure 3: Block diagram of proposed architecture

2.1 SMART HOME/OFFICE APPLIANCE (SHOA)

These refer to the smart building device that design with integration of IoT wireless facilities for the ease control and operation at a remote network. It provide conveniences to assist disable human and elderly one in control home/office appliances easily at a distance range from 10m and above. In the illustration of SHOA includes light switch control, washer and dryer machine, plasma television, mobile phone, refrigerator, printer, security door and so on.

2.1 SMART EMBEDDED SYSTEM (SES)

The (SES) refer to the intelligent micro-chip used for control operation and function involved in the system development, like storage of firmware coding. This unit contain ATmega328 which integrated with many functions on the same board. These are 8-bit analog/digital I/O pins for PWM (3, 5, 6, 9, 10 and 11), onboard +5V AREF pin, USB port, Serial Peripheral Interface (SPI) communication pins 10 (SS), 11 (MOSI), 12 (MISO), and 13 (SCK). While other pins support I2C (TWI) communication such as A4 (SDA) and A5 (SCL) and others features. It also consist of external interrupts pins 2 and 3 which can be configure to change an interrupt from rising edge to falling edge and vice-versa.

2.3 INTERNET OF THING GATEWAY (IOTG)

This module contain ESP8266 Wi-Fi technology that is self-contained, Single-on-Chip (SOC) device with TCP/IP protocol stack integration which linked microcontroller to access Wi-Fi network. The ESP8266 is capable of either hosting an application or depositing all Wi-Fi networking function from another application processor. The Wi-Fi module is designed with pre-programmed advanced technology command set firmware. This is powerful enough for on-board processing and storage capability of several sensors and application specific for their connectivity through General-purpose Input/output (GPIO). Also, to support minimal up-front development and runtime during the program loading process. It provides APSD for VoIP applications and co-existence of Bluetooth interfaces that a self-calibrated radio frequency (RF) that allowing it to function without require of external RF for all operating conditions.

2.4 SOFTWARE SYSTEM DEVELOPMENT

The system software development for this proposed smart home/office control appliances will be in two folds: the mobile phone web application software design in JSON and the ATmega firmware microcode developed in Arduino IDE. The micro web-server application and Wi-Fi library are implemented on Arduino IDE platform. This Wi-Fi module is capable of executing a dual function such as a client and server application for the successful end-to-end communication between a remote user and the gateway. In the configuration process, the Wi-Fi library <wifi.h> used JavaScript Object Notation (JSON) format to create output messages for data transmission and receiver on Arduino platform.

The wireless module and router (Home Gateway) are linked to cloud database through TCP/IP protocol, since Arduino Wi-Fi module supports a TCP/IP stack. Therefore, we focus majorly on the software coding implementation that will support service connection to remote users. When the wireless router is power ON (Home Gateway), it will boots to enters the configuration stage. During this process, the Wi-Fi shield will establish connection with Wireless Local Area Network (WLAN) using a static IP address. In order to optimizing the process of connection, static IP address is required instead of acquiring an IP via Dynamic Host Configuration Protocol (DHCP). After initializing and booting process, the Home Gateway will automatically enter an idle state until a command like string is received from remote user mobile web apps. This will be decoded immediately and respond to the execution of automated home appliances. Figure 4 depict system flowchart of connection establishment between the embedded system control unit and the internet.

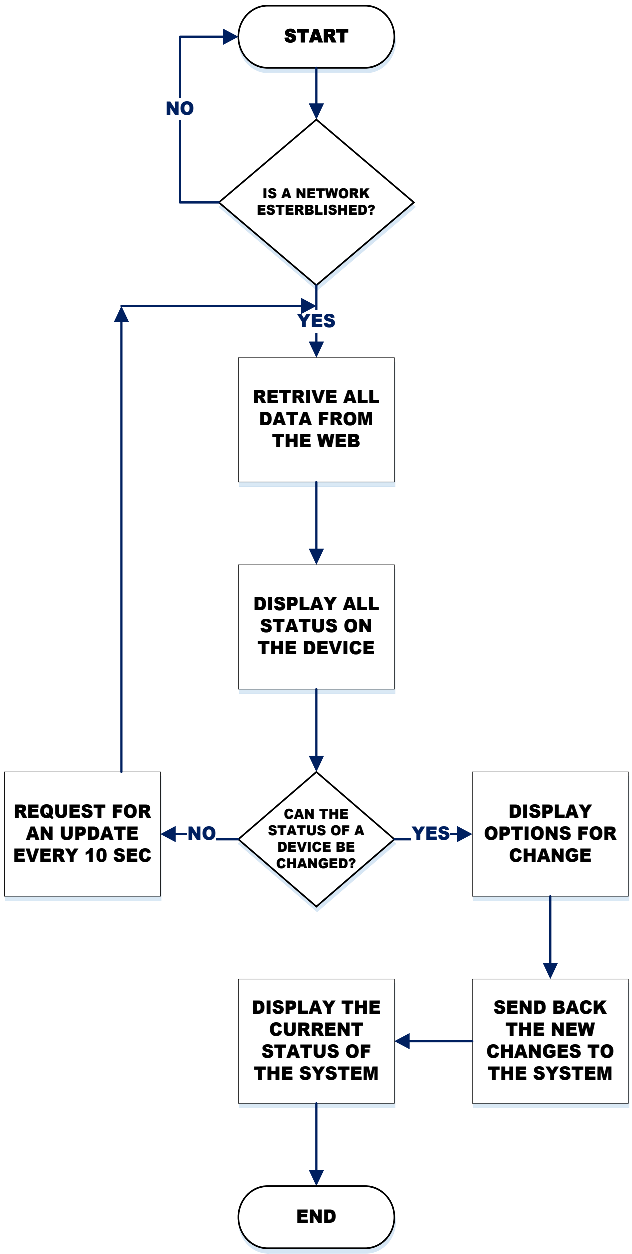

Figure 4: The system flowchart for embedded system based IoT for multiple device monitoring

3 PROPOSED IOT ARCHITECTURE FOR SMART HOME/OFFICE EMBEDDED SYSTEM

The proposed embedded system based IoT for controlling, monitoring and automation of domestic appliances can be classified into three categories in the architecture layers development. These includes smart embedded system layer (physical and data link layer), smart gateway layer (network and transport layer) and cloud database layer (application layer and remote server).

3.1 Smart Embedded System (SES) Layer

This layer is categorized as zone A in the SHOA control and monitoring based IoT architecture. This layer contains an intelligence chip (ATmega328) device that capable of making decision based on the command given at a remote android-based web application. Also the integration of low power consumption Wi-Fi technology (802.11 b/g/n) is function within the PHY and MAC layer. It is configured to transmit IP packet wirelessly to and/or from gateway router to the Wi-Fi enable home/office appliances. The internet protocol (IP) address and graphic user interface (GUI) web app are engaged to identify each devices state (ON/OFF) in the network, instead of deployed numbers of sensor or actuator for this purposes.

3.2 Smart Home Gateway (SHG) Layer

This layer is categorized as zone B in the IoT-based architecture for SHOA control and monitoring system. The layer contains wireless router and the firewall for the security purposes and authentication, connectivity, end-to-end communication, interoperability and destination identities. The major roles of this zone are logical connection, storing of the static IP address, routing of data and conversions of IP addresses (IPv4-IPv6) using tunneling techniques. It is also responsible for managing the IoT services, securing devices analysis, information analysis and the data management.

3.3 Cloud Database (CD) Layer

Application layer and Cloud database are the topmost layer called zone C in the proposed architecture for the embedded system based IoT architecture for smart home/office device control, monitoring and automation. This layer responsible for the control functions of the automated home/office devices remotely and provides an effective utilization of collected data by illustrating the device status on the graphic user interface of the web application. The architecture proposed for the system implementation is shown in Figure 5.

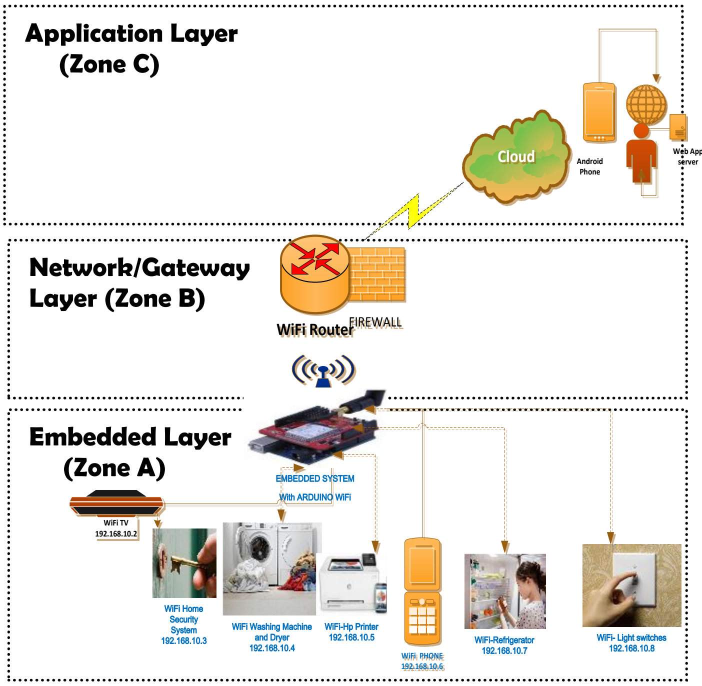

Figure 5: Proposed architecture for embedded system based internet of things for monitoring home/office appliances

3.4 DESIGN MODEL FOR IOTS ARCHITECTURE

The integration of several and different facilities exist in the IoT system architecture development can be mathematically expressed as "(1)' according to (Ajao, et al., 2017), and the application layers protocol implemented for the end-to-end communication between the internet of thing gateway (IoTG) and the cloud database can be expressed as "(2), & (5)".

$$\sum_{k=1}^{n} f(\varphi_s) = \sum_{k=1}^{n}\sum_{i=1}^{k}(\alpha_{ki}) + \sum_{k=1}^{n}\sum_{i=1}^{k}(\beta_{ki}) + \sum_{k=1}^{n}\sum_{i=1}^{k}(\mu_{ki}) \quad (1)$$

where, $\sum_{k=1}^{n} f(\varphi_s)$ denotes the summation and integration of several facilities functioning in the internet of thing system architecture. That is (the smart embedded device, the network services and information system languages), $\sum_{k=1}^{n}\sum_{i=1}^{k}(\alpha_{ki})$ is the summation of different components embedded in smart system of IoT architecture (such as Atmega328, sensor nodes and others), $\sum_{k=1}^{n}\sum_{i=1}^{k}(\beta_{ki})$ is the summation and integration of different network facilities employed in the IoT architecture (includes 802.11 b/g/n, Bluetooth, Wi-Fi or ZigBee) and $\sum_{k=1}^{n}\sum_{i=1}^{k}(\mu_{ki})$ is the summation and integration of different information technology programming used in the IoTs communication (e.g JNL, micro C, MySQL and protocols like CoAP and HTTP etc).

$$\varphi_G = \{N_1, N_2, N_3,..., N_z\} \quad (2)$$

$$N_1(\varepsilon) = \{N_{11}, N_{12}N_{13}..., N_{1i}\},$$

$$N_2(\varepsilon) = \{N_{21}, N_{22}, N_{23},..., N_{2i}\},$$

$$Cache = \{x_1N_1 + x_2N_2 + x_3N_3..., x_nN_{zm}\} \quad (5)$$

where,

φ_G is the coefficient of internet of thing gateway, ε is the coefficient of the applicable protocols (such as HTTP, CoAP, MQQT, and so on), N is the number of connected systems with specific application protocol selected in the system architecture,
x is the number of request messages protocol like (HTTP GET/POST, subscriber/publisher) that are translated into the equivalent queries in IoTs architecture.

4 SYSTEM IMPLEMENTATION

The scenario of IoT based smart home/office gadget were implemented in the network simulation tools environment to test for the possibility of the proposed system and is confirmed working accordingly as shown in Figure 6.

When the packet transmit through the network layer, it is broken down into smaller pieces which are identified. Each of these pieces is assigned with a specific name protocol data unit (PDU) and associated with a specific layer. The packet transmission processes and the response of the system implementation from the cloud database application layer to the smart embedded layers are outlined as follows:

1. At Layer 7, the HTTP client constructs a discover packet and sends it out using HTTP POST.
2. At Layer 4, the datagram encapsulates the PDU into a TCP/UDP segment.
3. At Layer 3, the destination IP address in the same subnet sets the next-hop to the destination.
4. At layer 2, the next-hop IP address is broadcast using the Wi-Fi technology to sets the frame's destination MAC address to the broadcast MAC address. Then, the device encapsulates the PDU into an Ethernet frame for the concerned devices.

5. At layer 1, the port 3G/4G Cell is sending another frame at this time. The device buffers the frame to be sent later.

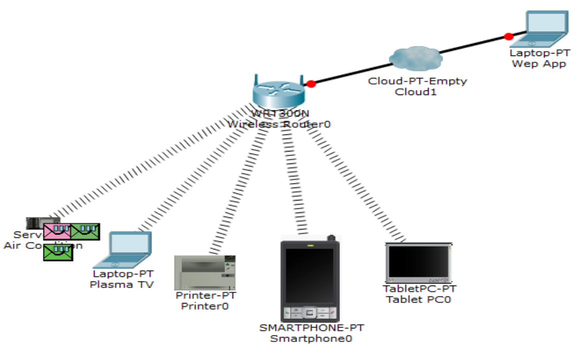

Figure 6: Implementation of IoT based architecture for smart home/offices remote control using wireless technology

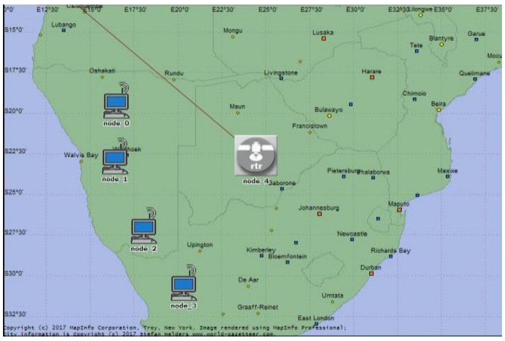

Figure 7: Simulation of SHOA based IoT arcitecture

In the real-life scenario, many component were involved as depicted in Figure 5, and it was simulated with the aid of network tools called packet tracer. This tools support physical representation of each hardware and configuration by assigning the smart device with Internet Protocol (IP) using IP version 4 Addresses. Also, NS-3 network simulator was used since it support simulation of Internet of Things (IoT) system architecture with performance analysis as depicted in Figure 7. This includes Throughput, packet loss rate, bandwidth, latency, and so on. Therefore, RESTful based Web services is utilized as an interoperable protocol with Hypertext Transfer Protocol (HTTP) at application layer for the communication between the remote access users and the home gateway devices. The HTTP is a request and response protocol that used for both client and server based computation model, it helps to establish the connection between the entities, web application browser (client) and web application hosting (server). Then, the transport Control Protocol and Internet Protocol (TCP/IP) is used with HTTP application protocol for the interconnectivities and sending of packet in the IoT architecture platform to the cloud database.

Therefore, the application software for micro web server library is running on the Arduino Uno (ATmega128) using Wi-Fi module (ESP8266). This module render a dual logical functions as both server and the client. The ESP8266 module and wireless router was configure for the ease communication and connection establishment between the remote user, gateway and the domestic home/office appliances. The (Wi-Fi library.h) is used to receive any packet transmitted from Arduino development board and create by sending output messages in Java native language (JNL) format. In this design, the RESTful support android web facilities is used for assure end-to-end communication among the things, human and others connected in the network and for the standard operation between the remote user and smart home/office appliances using a java script object notation (JSON) support for HTTP GET and POST request. The login interface of JSON and JNL support android web interface for SHOA system are depicted in Figure 8, while graphic user interface (GUI) for accessing, controlling and automation of domestic home/office wireless based appliances is shown in Figure 9 respectively.

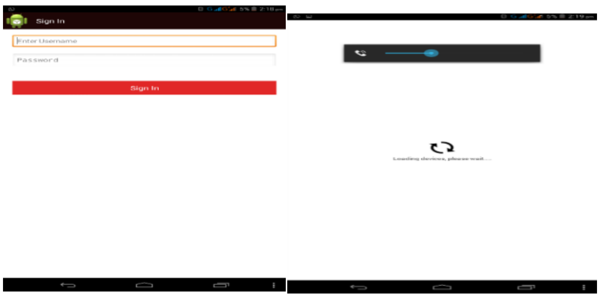

Figure 8. Login interface for android web apps

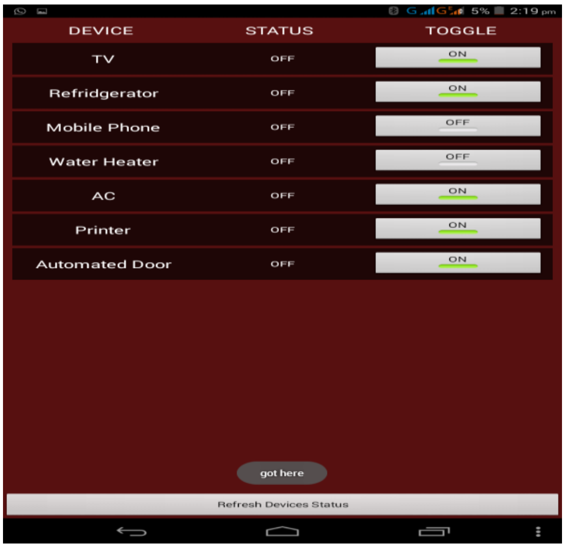

Figure 9. Android web apps control interface

5 CONCLUSION

The mobile phone with Wi-Fi technology support has been proposed, demonstrated and implemented for the monitoring and control of the smart home/office appliances. It includes printer, mobile phone, washing machine, home dryer and washer, air condition, light switches, security doors and so on which all are built with wireless low power consumption Wi-Fi technology. In case of Wi-Fi connectivity failure or set-up, the mobile cellular networks such as 3G or 4G can be used to access the system remotely based on this RESTful architecture development. This technology is most common embedded wireless facility that readily available in the recent domestic home appliances, offices and industrial equipment with IoTs protocol configuration support and application. Also, some of IoTs protocol were study but their performances depend on the area of smart technology. Therefore, HTTP and TCP/IP were adopted to ensure inter-communication, interconnectivity, security and quality of service (QoS) among things connected in the network using HTTPPOST and HTTPGET command for transmission and receiver of packet in IoTs architecture.

Future works will be focused on creating a wireless network between the home server and the home devices using low power consumption wireless technology on the 6lowPAN platform.

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