A schedule-based algorithm for low energy consumption in smart agriculture precision and monitoring system

L. A. Ajao[1*], J. Agajo[1], M. B. Mua'zu[2], J. K. Schueller[3]

(1.Department of Computer Engineering, Federal University of Technology, Minna, 92011, Nigeria;
2.Department of Computer Engineering, Ahamadu Bello University, Zaria, 810253, Nigeria;
3.Department of Mechanical and Aerospace Engineering, University of Florida, Gainesville, FL 32611, USA.)

Abstract: The worldwide connectivity design of embedded wireless sensor-based Internet of Things (IoT) using the 6LoWPAN platform has significantly increased in the industry. However, the development of smart technology in agriculture precision for remote control, monitoring and sensing usually encounter some challenges. These include high power consumption, interoperability, security, and end-to-end communication. In this paper, we developed a smart agriculture precision and monitoring system using schedule-based algorithm techniques to accomplish low energy consumption during the system operations. The Wi-Fi technology (ESP8266) was used as an IoT gateway, ATMega 2560 development chip, with other wireless sensor nodes (such as soil pH meter, soil moisture, and DHT 11 for temperature and humidity). The experimental system simulation results in Cooja Contiki showed the level at which packet generation, packet loss and throughput decline due to large data packet transmission during end-to-end communication. Also, the laboratory experimentation results of the proposed schedule algorithm implementation showed that more than 58% of energy was saved within 600 seconds of packet transmission from the user end to the cloud database.

Keywords: agricultural precision, connectivity, Internet of Things, smart technology, wireless sensor network

Citation: Ajao, L. A. J. Agajo, M. B. Mua'zu, and J. K. Schueller. 2020. A schedule-based algorithm for low energy consumption in smart agriculture precision and monitoring system. Agricultural Engineering International: CIGR Journal, 22(3): 103-117.

1 Introduction

Agriculture practices play an important role in Nigeria economy development with at least 40% contributions, while crude oil is the second notable economy driven for the nation growth with 36.5% impacts (Pivoto et al., 2018). But as a result of the inadequacy of technology development to enhance this occupation as caused a setback in techno-agronomy management. Other influences are lack of infrastructure development, bad road networks, and international marketing barriers. Also, the effect of climatic changes on the physiological environment and agricultural farm crops require regular monitoring with adequate smart embedded wireless system as in (Ajao et al. (2017a) and Popovic et al. (2017). Other methods adopted to improve this smart system technology included the machine learning approach (Rossi et al. 2014), mechatronics system (robotics), and optimization techniques as in Goap et al. (2018), and Partel et al. (2019).

The rapid development of embedded wireless sensors with universal connectivity strategy for remote control is widely manufactured and distributed across the globe for human satisfactions and domestic applications. They are found in agriculture precision systems, home automation systems, in-vehicle trackers and many others. The unprecedented integration stage of smart embedded

Received date: 2019-11-12 **Accepted date:** 2020-04-21
*** Corresponding author: L. A. Ajao,** Engr., Department of Computer Engineering, Federal University of Technology, Minna, 92011, Nigeria. Tel: +234703739128. Email: ajao.wale @ futm inna.edu.ng.

wireless systems with internet connectivity contributes to the improvement of real-time environmental monitoring systems and data acquisition. Others include broadcasting of global information technology, mechanism for multimedia and data transmission, supporting platform for social collaboration, and interaction between individuals and their things (Ajao et al. 2017b; Hassan et al., 2017). Also, these smart devices are widely designed to render services of remote sensing, monitoring, and surveillance in the military battlefield, agriculture, buildings, bridge, environments, and many others (Aliyu et al., 2017).

Internet of Things (IoT) is defined as a self-motivated network infrastructure that connects physical and virtual things using wireless technologies, micro-electromechanical system (MEMS), micro-services, embedded microchip, and the Internet (Ajao et al., 2017a). This possibility network is achieved through universal architecture with self-configuring ability to ensure low power consumption, quality of services, and interconnectivity that seamlessly integrate things into a network (Aazam et al., 2014). The communication between things-to-things, human-to-things, and others are achieved through radio waves and some protocols. These protocols are used to guide the communication from the physical layer to the application layer in the IoTs stack model such as included Constrained Application Protocol (CoAP), Message Queuing Telemetry Transport (MQTT), and Hyper-Text Transfer Protocol (HTTP).

The universal connectivity like IoT makes it possible for the connected trillions of objects, machine-to-machine (M2M), human-to-things (H2M), and thing-to-thing (T2T) over the global network. This advancement increases the production of embedded wireless devices in the various area of smart technology such as smart agriculture precision (Khanna and Kaur, 2019) for remote monitoring, control, and surveillance using cameras, sensors, and quadruplet drones.

1.1 Motivation of the research

The global changes in climate and weather conditions, as a result of diminishing in ozone (O_3) layer, affect the rapid growth of the farm crops, cause deficient in plant nutrients and reduce the quantity of food productions. Therefore, a smart agro-climatic and precision monitoring system is required and significant for this problem. However, energy consumption is the major challenge that threatens the system performance and operation of this smart embedded device during data packet transmission and end-to-end communication. Hence, we developed a schedule-based algorithm for minimizing power consumption during data acquisition and packet transmission (routing) between the perception layer and the cloud database.

1.2 Contributions to the research

This research contributes to knowledge by developing a smart agriculture-precision and monitoring system based IoT prototype to acquire agro-climatic field parameters and transmit to the cloud database for storage in real-time. The research study also focuses on the management of energy consumption during packet routing in the smart agriculture precision system using a schedule-based algorithm with little computation.

The other parts of the research are related works in section 2. The embedded wireless system is introduced in sub-section 2.1, 2.2 discusses smart agriculture-precision in IoT, 2.3 presents related works to the efficient-energy management in wireless sensor networks (WSN). Section 3 present materials and method, 3.1 contains embedded system design, 3.2 discusses wireless sensor nodes application, Section 3.3 introduces schedule-base algorithm for low energy consumption, 3.4 discusses algorithmic state machine (ASM) technique for low energy consumption, 3.5 highlights sensor nodes deployment into the field and 3.6 shows detail implementation of smart agro-climatic precision prototype. Section 4 is results and discussion and section 5 concludes the research with recommendations for the future works.

2 Related works

2.1 Embedded wireless system

The integration of different components in IoT architecture plays a significant role in the smart embedded system design such as interoperability, interconnectivity, and Representational State Transfer (REST) application (Peniak and Franekova, 2016;

Muangprathuba et al., 2019). Other components involved in the design are sensor nodes and actuators that functioning at the perception layer (physical and data link). The network layer utilizes a router as a gateway for packet routing and network service connectivity. The information technology services support the communication between the application layer and cloud database using an appropriate protocol. The integration of several components in embedded wireless system based smart technology is expressed as in (1).

$$\sum_{k=1}^{b} f(\psi) = \sum_{k=1}^{b}\sum_{i=1}^{k}(\alpha_{bk}) + \sum_{k=1}^{b}\sum_{i=1}^{k}(\beta_{bk}) + \sum_{k=1}^{b}\sum_{i=1}^{k}(\gamma_{bk}) \quad (1)$$

where ψ denote IoT architecture, α denote embedded system technology (includes mobile phone, personal digital assistance, and development board, etc), β denote network technology (like Ethernet and Wi-Fi module), γ represent information technology (such as Web apps, TinyOS, software programs, and application protocols), and b is the numbers of additional technology services.

2.2 Smart agriculture precision-based IoT

The recent development of smart agriculture precision systems in IoT has improved the conventional way of practicing agronomy and other branches of agriculture management (such as horticulture, aquaculture, sericulture, animal science, agriculture engineering, and economics). Some of this recent IoT-based technology (Khanna and Kaur, 2019) uses machine learning, artificial intelligence, optimization techniques, and embedded wireless sensors that are automated (Adeghoye et al., 2017) for monitoring environmental factors, climatic changes and fertilizer-irrigation applications.

Apart from the above-highlighted techniques for agriculture precision monitoring in IoT, drone application as a recent invention in IoT-based agriculture precision proofs efficient, accurate, precise, and robust (Popovic et al., 2017). This system takes advantage of several proposed methods in agriculture precision systems using machine learning, optimization techniques, and embedded smart wireless technologies for farm management and agricultural processes.

This innovation of drone applications in the agricultural field plays important roles like taken pictures and survey areas of farm crops, collecting data about the environmental factors (climatic change). Other is surveillance of the environment in cases of weeds growth and pest infection (Stokes, 2018). Other application of drone in the field of agronomy includes automatic spraying of insecticide, irrigation, planting, and study of crops health state. Conclusively, it saves time, energy, cost, and improves work activities.

Popovic et al. (2017) proposed agriculture precision and ecological monitoring system using the internet of things-enable platforms. It is deployed for grapevine management and monitoring infection of plasmopara viticola on the weeds. The smart drone was used for the surveillance with sensors distributed for the infection of grapevine detection and stored information in the cloud database

Partel et al., (2019) proposed a low-cost smart technology for precision of weed management using artificial intelligence for weed spraying. It helps to identify a target weeds from the vegetable crops, and precisely spray on the targeted weeds. Image processing techniques that programmed on the embedded graphic processor unit were used to identify the targeted weeds from the vegetable crops. This smart precision sprayer was using real-time kinematic positioning system (RTKPS) for the enhancement in visualizing and precise position of data generated from weed mapping and vegetable crops. This artificial intelligence (AI) based smart agriculture precision sprayer renders some other advantage over the conventional sprayers, by preventing chemical wastage, reducing the quantity of agrochemicals required, cost, and risk of crop damages.

A smart irrigation control and management system based IoT was proposed in (Goap et al., 2018) using an open-source technology and machine learning algorithm technique. This system assists in managing water resources during irrigation processes to predicts fertilizer-irrigation requirements. The smart sensors were used for field data collection and send the processed information to the cloud database for decision support system.

2.3 Efficient energy management in WSN

In modern trends, the IoTs technology is rapidly bridging the gap between the physical world and the cyber one. But the focus challenge in this research context is to minimize the energy consumption by a smart embedded wireless system. Mahmoud and Mohamad (2016) discussed a comparative analysis for various low power techniques in wireless sensor networks. The size of the sensed data and the sensor duty cycle were mentioned as the major considerations for high power consumption (Casilari et al., 2010).

Several efficient-energy algorithms are proposed for the media access control (MAC) layer and network layer, which are classified into contention-based and scheduled based (Kaur and Mahaj, 2011; Li et al., 2015). The contention-based protocols are designed to achieve Multiple Access with Collision Avoidance (MACA), examples include: Sensor MAC (S-MAC), Berkeley Media Access Control (B-MAC), Predictive Wake-UP MAC (PW-MAC) and Time Out MAC (T-MAC). While on the other hand, the scheduled-based operates on Time Division Multiple Access (TDMA) protocols such as Low-Energy Adaptive Clustering Hierarchy (LEACH), Power-Efficient and Delay-Aware Medium Access Protocol (PEDAMACS) and Priority-Based MAC (PMAC) Protocol for energy consumption and delay (Kabara and Calle, 2012; Yazdi et al., 2019).

The objective of this various MAC protocols presented is energy improvement and scalability. S-MAC was proposed as an energy-efficient protocol and self-configuring for the ad-hoc network using sleep, virtual clustering, and message passing to control energy consumption (Ye et al., 2002; Khatarkar and Kamble, 2013). In the performance evaluation, the result of S-MAC showed 2-6 times better energy efficiency as compared to T-MAC protocols.

B-MAC techniques were used for carrier sensing media access (CSMA) using a radio sampling with reduced duty cycle to eliminate synchronization, overhead, and minimizing idle listening (Polastre et al., 2004). The B-MAC technique has a unique ability to reconfigure the MAC protocols to meet the dynamic demands across several wireless network conditions and low power consumption demand is achieved. The compressed handshake MAC (CH-MAC) protocol is developed to offer an implicit sleep mechanism with improvement in both packet latency and energy consumption (Li and Peng, 2009).

El-Hoiydi and Decotignie, (2005) proposed Wise-MAC protocol for minimized packet size based on the knowledge and information received from neighbors node using non-persistent carrier sense multiple accesses collision detection (CSMA/CD). The Wise-MAC protocol was simulated and compared with S-MAC, T-MAC, and CSMA/CA. The main credit of this protocol is low energy wastages achieved as a result of overhearing. Other proposed efficient energy managements and low power consumptions are experimented in (Ajao et al, 2017b; Casilari et al., 2010; Bencini, et al., 2010),

Therefore, we developed and implemented a smart agriculture precision and monitoring system using a scheduled-based algorithm method to achieve low energy consumption in the IoT architecture.

3 Materials and methods

3.1 Embedded system design

The system consists of an intelligent microchip (ATmega2560 development board), wireless module (802.11b/n/g), and wireless sensor nodes (pH sensor, soil moisture, and DHT11 sensor). All these components were integrated into the IoT architecture using internet protocol (IP) and HTTP for the effective remote communication, monitoring, and data acquisition model as shown in Figure 1.

Also, a cross-platform application that its function written in the C-language of Arduino integrated development environment (IDE) was used in coding the intelligence chip with support of the Arduino board and other supportive components. The proposed schedule-algorithm is developed and configured with the gateway router (wireless module) to idle listening, deep sleep mode, and off status.

To manage the most expensive power expended (radio or IoTG) during packet transmission using synchronous and asynchronous queries. The selection of WiFi as a gateway router in this work has been the bases of argument that is experimented as a low power consumption wireless connectivity and covered a wide range of distance as analyzed in Table 1. The flowchart operation for the agro-climatic parameters acquisition is illustrated in Figure 2.

Table 1 Low power wireless connectivity comparisons

Characteristics	BLE	ZigBee	Z-Wave	LoRAWAN	ZigFox	Dash-7	Wi-Fi
Frequency	2.4 GHz	2.4 GHz	2.4 GHz	433-915 MHz	868-902 MHz	433-915 MHz	2.4 GHz
Range	10m	10-100m	10-100m	2 – 15 km	30-50 km	0-5 km	>100m
Data Rate	750 Kbs^{-1}	250 Kbs^{-1}	250 Kbs^{-1}	300bits^{-1}-50 Kbs^{-1}	100 -600 bit^{-1}s	50 – 100 Kbs^{-1}	10 Mbs^{-1}
Max Current Consumption	30 mA	≥30 mA	≥30 mA	32 mA	<20 mA	20 mA	100 mA
Power transmission	Low	Low	Low	Low (14 dBm)	Low 10μW – 100 mW	Low (10 dBm)	High

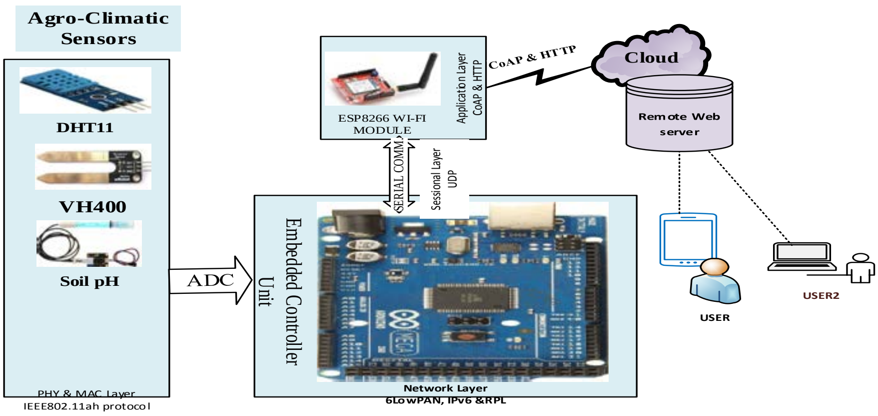


Figure 1 Smart agriculture precision and monitoring for IoT architecture

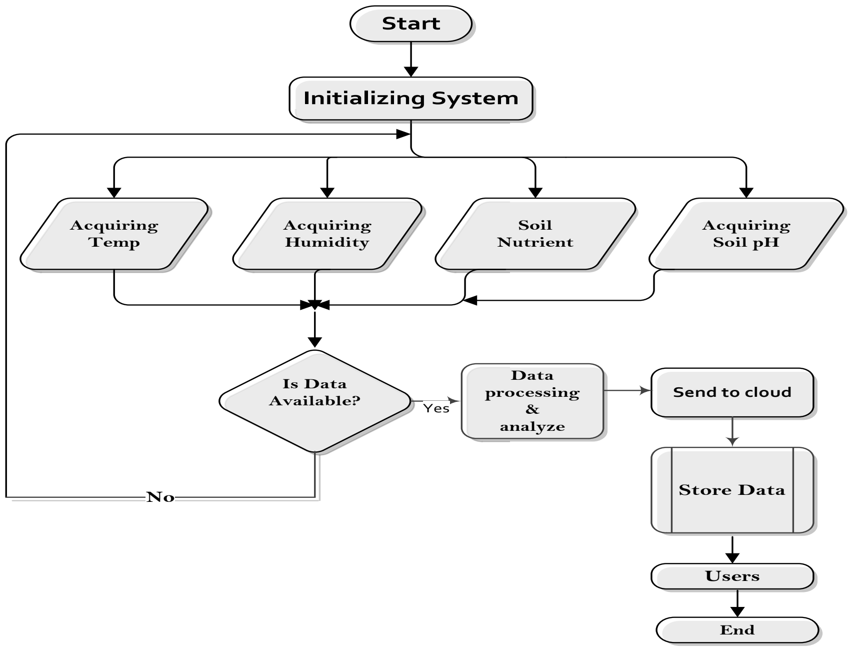


Figure 2 System operation flowchart

3.2 Wireless sensor nodes application

The wireless sensor has undoubtedly become a benchmark for the data acquisition in smart agriculture and climatic precision monitoring which includes DHT 11 sensors, soil moisture sensors and pH meter sensors.

3.2.1 DHT 11 sensor (temperature and humidity)

The DHT 11 sensor was used to determine the environmental temperature and humidity conditions in a real-time, and it sends a data of 40bit maximum. This analog data transmission consists of integral and decimal value as given here. Table 2 shows the characteristics of the DHT 11 sensor.

$$DHT_{11} = 8\int_{n}^{40} RH + 8RH_d + 8\int_{n}^{40} T + 8T_d + 8CS \tag{2}$$

where DHT_{11} is a data format for the temperature and humidity, $8\int_{n}^{40} RH$ is 8bits integral relative humidity (RH) value, $8RH_d$ is 8bits decimal relative humidity (RH) value, $8\int_{n}^{40} T$ = 8bit integral temperature (T) data, $8T_d$ is 8bits decimal temperature (T) value and $8CS$ is 8bits checksum.

Table 2 DHT 11 characteristics

S/N	Characteristics	Parameters
1.	Humidity Range	20%-80% with /±5% accuracy
2.	Temp. Range	0-50^{0}C/±2^{0}C
3.	Body Size	15.5mm x 12 x 5.5mm
4.	Sampling Rate	1 Hz reading per seconds
5.	Max. Current	2.5 mA
6.	Operating Volt.	3-5 V
7.	Advantage	Ultra-low-cost and accurate

3.2.2 The soil moisture (M413)

The soil moisture (M413) is used to determine the amount of moisture content in percentage by subtracting the amount of dry soil (weight) in gram from the moist soil (weight) divided by the weight of dry soil as expressed in (Adegboye et al., 2017; Ajao et al., 2017a). This sensor is considered as important in the growth of the plant. It helps in determining the irrigation period as a result of changes in climate and precipitation. This M413 moisture sensor uses a digital potentiometer for adjustable sensitivity, LM393 comparator chips for stability, red and green light indicator for power, and digital switch output.

The content of dry soil (weight) from zero to infinity, wet soil content from zero to one (0-100%) and volumetric of soil humidity at a range of (0 – 100%) in gram can be expressed as follows:

$$Wd = \frac{Wg}{Sg} \tag{3}$$

$$Ww = \frac{Wg}{Wg+Sg}$$

$$Wv = Wd * \frac{\rho b}{\rho w} \tag{4}$$

where W_d is the weight of dry soil in gram, W_g is grams of water, S_g is grams of soil, **ρ**b is the density of soil (gram of dry soil/cm^3), **ρ**w is the density of water (gram of water/cm^3).

Then, the output parameters of the moisture sensor is in analog reading, the linear function of moisture content of the soil is ($\beth_m$) and the calibration for the sensor is expressed as;

$$\beth_m(\%) = \boldsymbol{\sigma_s} * \boldsymbol{v} \tag{5}$$

where $\boldsymbol{\sigma_s}$ is the calibration coefficient of the sensor and $\boldsymbol{v}$ is the output voltage of moisture content in the soil.

3.2.3 The pH sensor

The pH sensor plays a significant role in the prediction of soil acidity, alkalinity, and basicity measurements. That is, measuring the amount of hydrogen ion present in the soil. The more concentration of positive charges in hydrogen atoms determined the level of soil acidic, and the less concentration of charges present in the soil, the more basicity of the sample. Therefore, the acidity or basicity of soil pH level can be determined using the colorimetric method or electrometric techniques as expressed here, and Table 3 illustrates the details of acidic level ranges and alkalinity (Ajao et al., 2017a).

Table 3. The soil pH parameters range (acidity and alkalinity)

Soil pH condition	pH value and range
Purely acidic	<3.5
Extremely acidic	3.5-4.4
Very strong acidic	4.5-5.0
Strong acidic	5.1-5.5
Moderate acidic	5.6-6.0
Low acidic	6.1-6.5
Neutral	6.6-7.3
Slight alkalinity	7.4-7.8
Moderate alkalinity	7.9-8.4
Strong alkalinity	8.5-9.0
Very strong alkalinity	>9.0

$$E = E^o - \left(\frac{RT}{nF}\right)\log\left[H^+\right] \tag{6}$$

where E is an electromotive force produced by the electrode, E^o is dependent constant on the electrodes, R is a gas constant, T is absolute temperature, n is the number of electrodes, F is Faraday constant.

3.3 Schedule-based algorithm for low energy consumption

In this research, a schedule-based algorithm for low energy adaptive techniques was designed and implemented between the perception layer and the network layer of IoT architecture using stored and forwarding data model techniques. The data is acquired from the field environment, processed, and stored. The IoT gateway transmits all the processed data to the cloud database for the user's application. Thus, this technique is verified to be adequate and improves the WSN performance by maintaining less power consumption and less bandwidth, instead of transmitting data at every sampling acquired as illustrated in Figure 3.

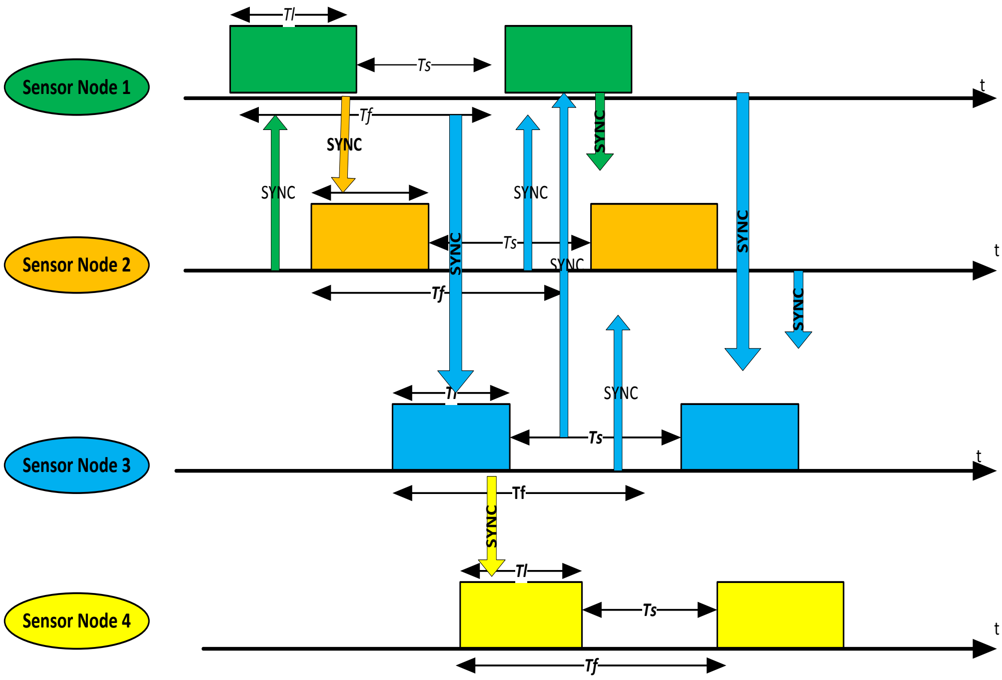


Figure 3 Synchronization of message exchange using scheduling-based algorithm

The cost of energy in the process of received acquire data, packet transmission and sleep mode from internet of thing gateway (IoTG) to the cloud database can be categorized into three and expressed as;

$$E_1 = {}_{Crx} dT_f \tag{7}$$

$$E_2 = c_{sleep}[T_f(1-d) - NT_{pkt}] \tag{8}$$

$$E_3 = NC_{tx} \tag{9}$$

$$E_{\cos t} = E_1 + E_2 + E_3 \tag{10}$$

Therefore, the summary of energy expended in the process of three stages highlighted above (cost of energy for receiving packet Crx, cost of energy sleep mode Csleep, and expended energy for transmitting packet Ctx) is given.

$$Ec = C_{rx} dT_f + C_{sleep}[T_f(1-d) - NT_{pkt}] + NC_{tx}$$

(mAh) (11)

3.4 Algorithmic state machine (ASM) for low energy consumption

The algorithmic state machine (ASM) process is an efficient method of realizing low energy consumption in smart agriculture precision nursing and other smart technology as derived here for different events of sensor deployment. The energy expended in the smart technology depends on various metrics involved such as packet size, duty cycle, delay time, listening time during packet transmission. Therefore, this technique is flexible and supports REST application services for the development of low energy consumption in IoT-based smart technology. The ASM expressions illustrate different routes for the packet transmission from beginning y_b to the end y_e. as in Figure 4.

where x' represent logical vertex decision "NO", and x represent logical vertex decision "YES".

The low power propagation model of signal to interference ratio analysis (SIRA) among the sensor nodes link are considered, due to the distance that existed between the transmitter and receiver (d_{tr}), transmission signal power (T_p) and receiver signal power (R_p) are expressed as given in Equation (12).

$$S_{powerRatio} = P_{t.hij} * [D_{tr}]^{\wedge}(-\alpha) \qquad (12)$$

where $S_{powerRatio}$ is the transmitting signal power ratio, P_t is transmitting power, D_{tr} is the distance between transmitter and receiver, $_{hij}$ is the exponential signal distributed coefficient for standard path loss subject to constraint $\alpha = 2$.

3.5 Sensor node deployments in the field

The energy-aware based cluster head routing techniques were adopted at the routing protocol layer to improve the battery lifetime of the WSN and operate in real-time during remote monitoring. Figure 5 (a) and (b) depicts the sensor nodes distributed into the field for agro-climatic parameter sensing and remote monitoring (using DHT11 sensor, soil moisture, and soil pH).

The dispersed sensor nodes for the agro-climatic parameters/data acquisition of an event can be expressed as given in matrix form.

$$\begin{bmatrix} S_{11} & S_{12} & S_{13} & S_{14} & \cdots & S_{1n} \\ S_{21} & S_{22} & S_{23} & S_{24} & \cdots & S_{2n} \\ S_{31} & S_{32} & S_{33} & S_{34} & \cdots & S_{3n} \\ S_{41} & S_{42} & S_{43} & S_{44} & \cdots & S_{4n} \\ . & & & & & \\ . & & & & & \\ . & & & & & \\ S_{41} & S_{42} & S_{43} & S_{44} & \cdots & S_{4n} \end{bmatrix} \begin{bmatrix} Co_1 \\ Co_2 \\ Co_3 \\ Co_4 \\ . \\ . \\ . \\ Co_m \end{bmatrix} = \begin{bmatrix} Net_1 \\ Net_2 \\ Net_3 \\ Net_4 \\ . \\ . \\ . \\ Net_m \end{bmatrix} \qquad (13)$$

Event 1 ($y_b \approx y_e$) = $y_b + Y_1 + Y_2 + Y_3 + Y_4 + Y_5 + Y_6 + Y_7 + Y_8 + x_1 + Y_9 + x_2 + y_e$ (14)

Event 2 ($y_b \approx y_8$) = $y_b + Y_1 + Y_2 + Y_3 + Y_4 + Y_5 + Y_6 + Y_7 + Y_8 + x_1' + Y_9$ (15)

Event 3 ($y_b \approx y_9$) = $y_b + Y_1 + Y_2 + Y_3 + Y_4 + Y_5 + Y_6 + Y_7 + Y_8 + x_1 + Y_9 + x_2$ (16)

Event 4 ($y_b \approx y_9$) = $y_b + Y_1 + Y_2 + Y_3 + Y_4 + Y_5 + Y_6 + Y_7 + Y_8 + x_1' + Y_9 + x_2'$ (17)

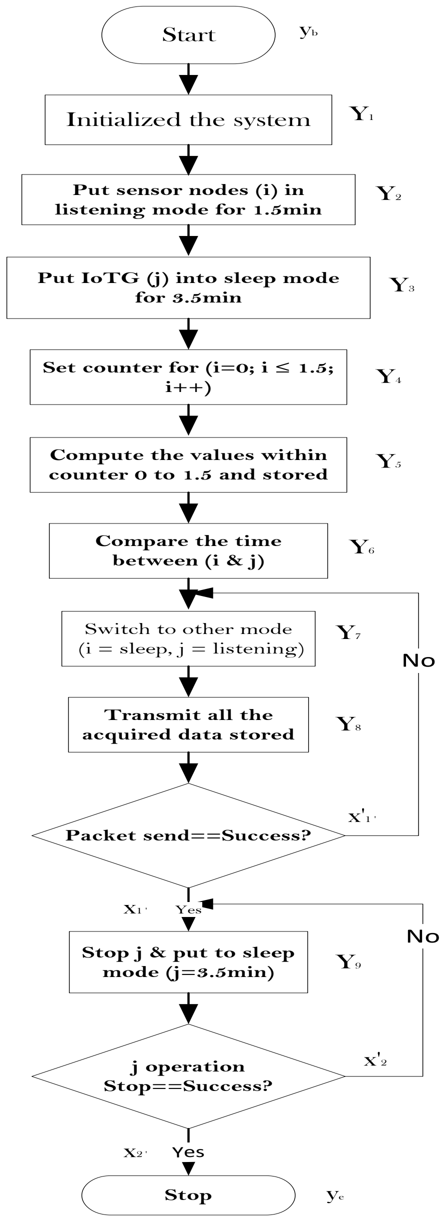
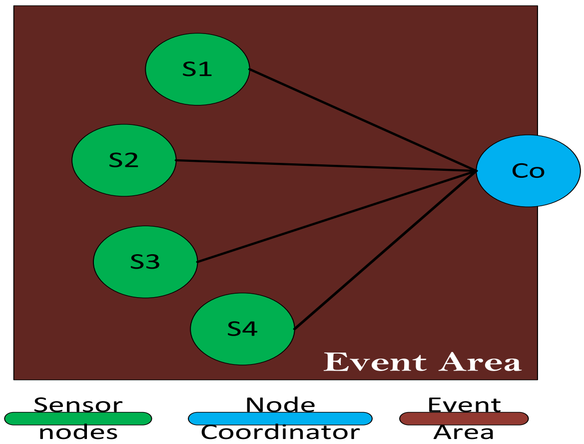
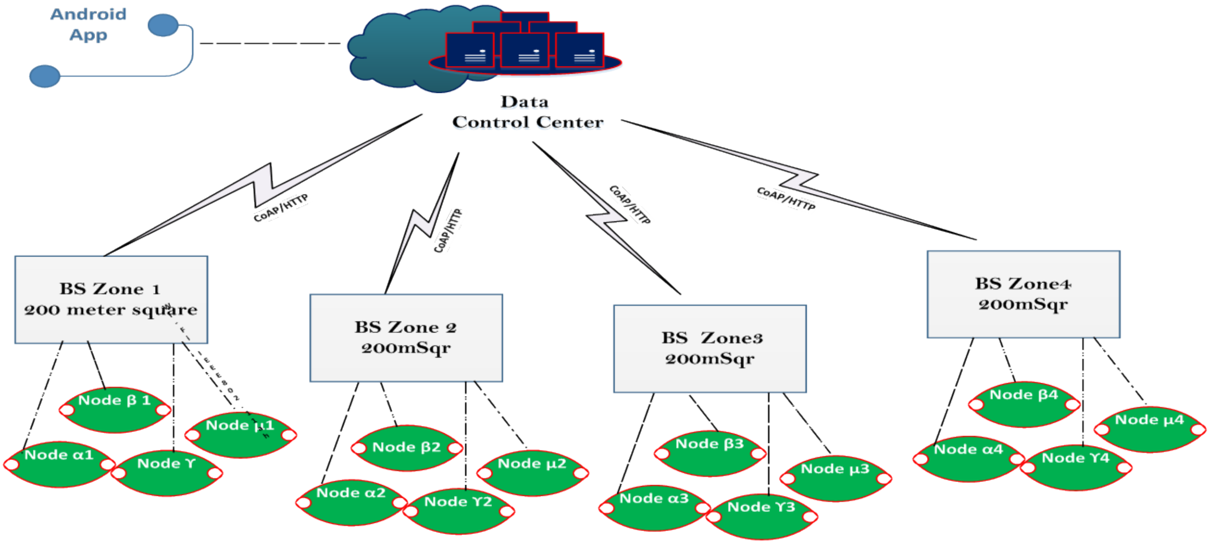


Figure 4 Scheduling-based algorithm using ASM



(a)



(b)

Figure 5 Deployment of distributed sensor node in the field environment

3.6 Implementation of smart agro-climatic precision system prototype

The design and implementation of an embedded system based IoT for agro-parameters monitoring are divided into two major components which are hardware architecture and software development. Both components are integrated as an intelligence, decision making, a scalable and ubiquitous system for the agriculture environmental condition monitoring and parameter measurement. This system was developed using CoAP RESTful based Web services with HTTP as an interoperable and interconnectivity application layer. The embedded system based IoT consists of a micro web server application based on Arduino, Arduino Wi-Fi shield (ESP8266), hardware interface modules like liquid crystal display (LCD), sensors, and the android compatible smartphone app.

The smart agriculture precision monitoring presented can be modified in different ways depending on the user interest and areas of smart applications by interfacing more sensors to the micro web-server, and automatically created a new thread dedicated to the device in the mobile app. Therefore, the purpose of this model in the IoT paradigm is to ensure real-time data acquisition from a remote network, interoperability, interconnectivity, scalable, and security. Figure 6 illustrates the system implementation into the field environment for data acquisition.

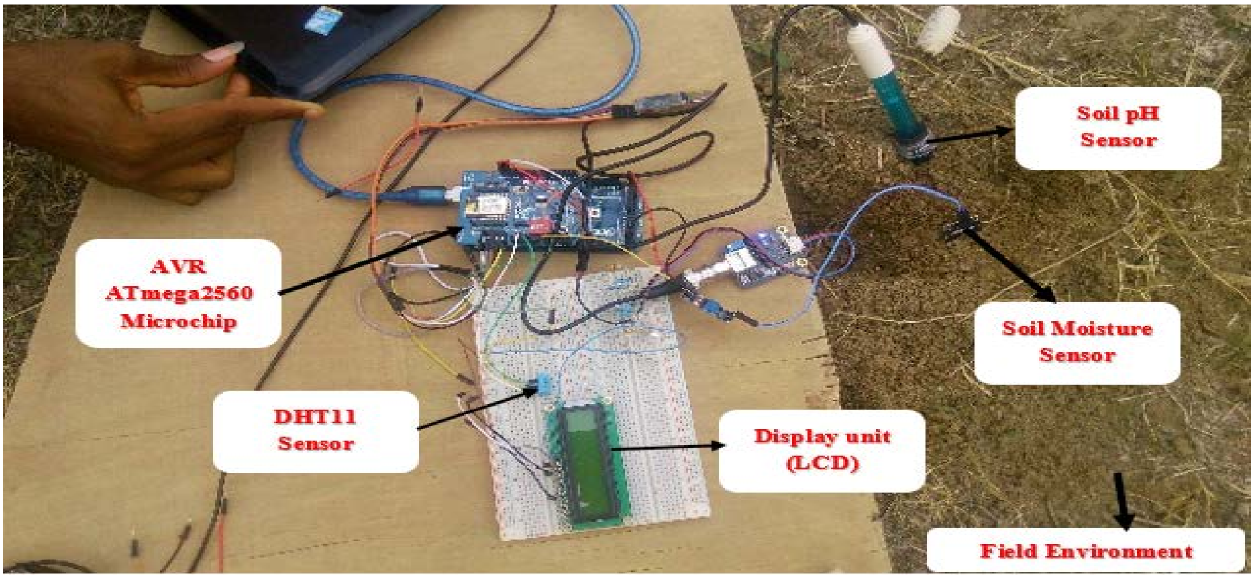


Figure 6 Smart agriculture precision monitoring system based IoT

4 Results and discussions

The result obtained from smart agriculture precision monitoring system that was deployed to the field environment for data acquisition based on pH meter sensor, soil moisture, temperature and humidity parameters in real-time are presented in Table 4, Figure 7 shows the dynamic composite graphical plotting of result acquired in NetBeans API environment using JavaScript language for coding.

Table 4 Agro-climatic parameters acquisition

Time (Min)	Temp (^{0}C)	Humid (%)	Soil Moist (cm^2/ cm^2)	Soil pH
12.00	29.00	55.00	3.00	1.0
12.10	29.00	57.00	101.00	3.5
12.20	30.00	65.00	102.00	4.0
12.30	30.00	66.00	102.00	5.0
12.40	30.00	69.00	89.00	5.5
12.50	31.00	73.00	102.00	5.5
13.00	32.00	75.00	102.00	5.5

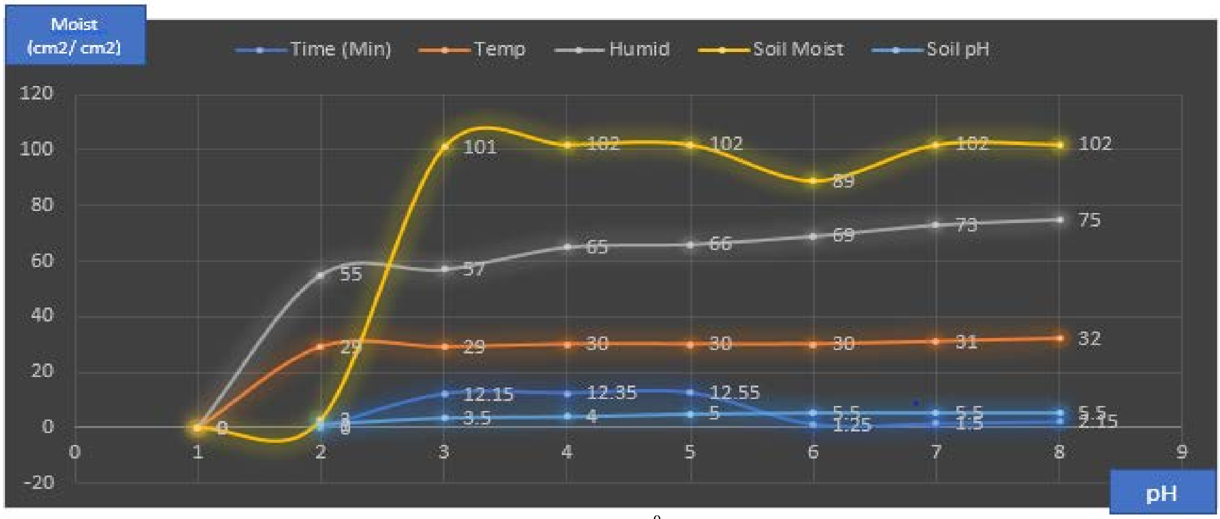


Figure 7 Dynamic composite graph of Temperature (^{0}C), Humidity (%), Moisture, and pH values

4.1 Low energy expended experimentation

The power consumption in a wireless sensor module is dependent on different factors: the network topology, packet routing size, transmission power, standby power efficiency, neighboring sensor nodes, and hardware components. The mathematical model to calculate the battery lifetime of the system is given.

$$Battery_{lifetime} = \frac{Battery_{capacity}(mA/h)}{Load\quad Current\ (mA)} * 0.70 \tag{18}$$

The performance of the system design is evaluated based on the network metrics like bandwidth, throughput, transmission power, packet generation, packet loss, delay/latency, and bit error rate (BER) to support deep sleep and standby listening modes for low energy adaptive and consumption. Bandwidth is defined as the maximum rate of data transfer in a network. It is the measured amount of data transfers over a specific connection in a given period as expressed in Equation (19). That is, bit rate (τb) divided by the number of bits per modulation (M).

$$\beta_{width} = \frac{\tau b}{log2(M)} \tag{19}$$

Packet/data transmission delay (δ) is the time taken packet/data to be transmitted from the source (physical layer) to the destination over the link. The efficiency of this factor depends on context switch MAC delay, number of active sessions, and transmission capacity of the link. The delay factor is expressed by (Xiao, 2008) as given in Equation (20).

$$\delta = (\aleph_{ip} * D_{ip}) + (\aleph_{dd} * D_{dd}) + (\aleph_{cd} * D_{cd}) + (\aleph_{id} * D_{id}) + 1.25 * R_{km} * \frac{5}{1000} + 80 \tag{20}$$

where, $\aleph_{ip}$, $\aleph_{dd}$, $\aleph_{cd}$ and $\aleph_{id}$ are the number of IP access, distribution device, core device, and internetwork device respectively. While, D_{ip}, D_{dd}, D_{cd} and D_{id} are delay of the devices, R_{km} is the distance through the path and 80 is end-point delay.

Bit error rate is a technique for measuring the quality of the transmitting device, the receiver, the pathway transmission, and its environment. It can be expressed as given in Equation (21).

$$BER = \frac{total\ number\ of\ bit\ errors\ occur}{Total\ number\ of\ bits\ received} \tag{28}$$

In the laboratory experimentation, the maximum current transmission is approximately 116 mA when in full power mode, and the average current of packet transmission from IoT gateway is 98.7 mA when using 3.0 V, 400-600 mAh^{-1} for the algorithm implementation. The transmission time (s), standby current mA, and power consumption during packet transmission are analyzed in Table 5. In this case, both layer two and layer three are not considered for MAC protocol configuration to either sleep or standby listening mode for low power consumption. The transmission packet rate is 40 Mbs^{-1} with 0.0074 MJs^{-1} of energy expended. Figure 8 and Figure 9 depicts the cumulative current and energy consumed for 10 sampling intervals (1 s to 600 s). The cumulative analysis of the energy consumption during packet transmission when it was configured with synchronous transmission asynchronous receiver (STAR) MAC protocol using scheduling algorithm is presented in Table 6 with a sample interval of 1 s to 600 s.

The discrepancy between the energy consumption when the wireless module is configured with STAR MAC protocol using a scheduling algorithm and without configuration were compared and presented in Table 7. The Wi-Fi technology utilized 0.0030 MJs^{-1} of energy to transmit a packet for a sampling interval (s), with a data rate of 40 Mbs^{-1}, using an average current of 98.7 mA, 0.03 mA standby current and 0.1 s for the period of each transmission. Therefore, about 4.444 MJs^{-1} of energy was expended to transmit the packet for 10 minutes at an average current transmission of 98.4 mA. The experiment was also carried out the system configuration using a scheduling algorithm to achieve deep sleep mode and off status listening mode. About 0.0030 MJs^{-1} of energy was used for packet transmission within a period of 1s, and the Wi-Fi module transmit packet at a minimum current of 40.37 mA.

This gave rise to a deep low power consumption for packet transmission at 10 different sampling period intervals. Therefore, more than 58% of energy was saved compared to the non-configuration module of the IoT mechanism. Figure 10 shows the discrepancy of energy expended between the configured module and non-configuring system testing of the smart agriculture precision system.

Table 5 Cumulative current and energy consumption without configuration

Sampling interval (s)	Standby current (mA)	Transmit current (mA)	Transmit time (s)	Energy Consumption (MJs^{-1})
1	0.03	98.7	0.1	0.0074
5	0.03	98.7	0.1	0.037
10	0.03	98.7	0.1	0.074
20	0.03	98.7	0.1	0.148
30	0.03	98.7	0.1	0.222
60	0.03	98.7	0.1	0.444
120	0.03	98.7	0.1	0.888
180	0.03	98.7	0.1	1.332
300	0.03	98.7	0.1	2.220
600	0.03	98.7	0.1	4.440

Table 6 Cumulative current and energy consumed without algorithm implementation

Sampling interval (s)	Standby current (mA)	Transmit current (mA)	Transmit time (s)	Energy Consumption (MJs^{-1})
1	0.03	40.37	0.1	0.0030
5	0.03	40.37	0.1	0.015
10	0.03	40.37	0.1	0.03
20	0.03	40.37	0.1	0.06
30	0.03	40.37	0.1	0.09
60	0.03	40.37	0.1	0.180
120	0.03	40.37	0.1	0.360
180	0.03	40.37	0.1	0.500
300	0.03	40.37	0.1	0.90

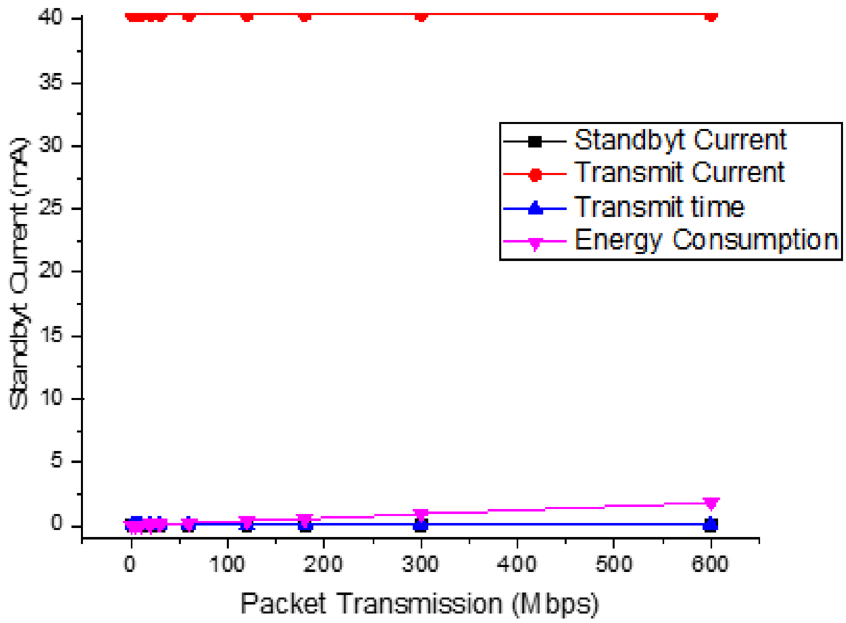


Figure 8 A plotted graph of energy consumption level against packet transmission period without protocol configuration

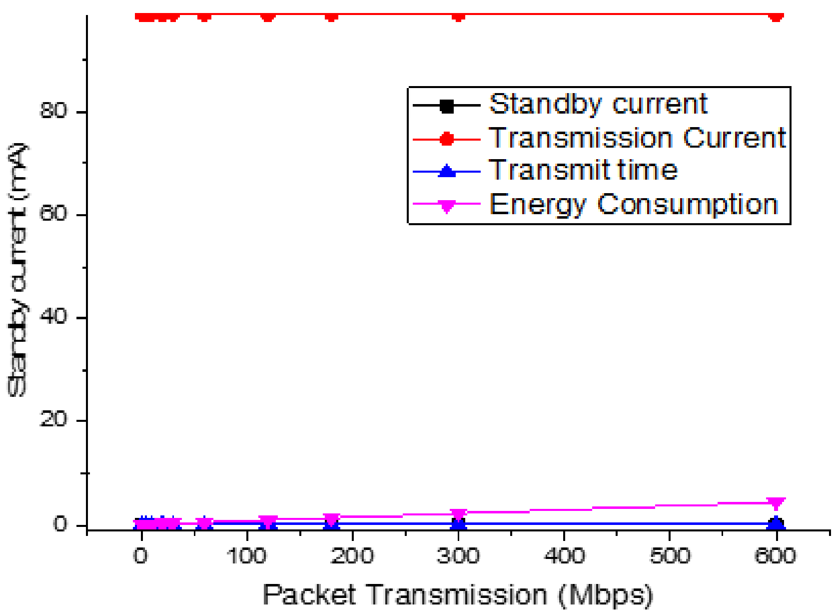


Figure 9 A plotted graph of energy consumption level against the packet transmission period with scheduling algorithm

Table 7 Differences between the configured and non-configuring module

	Wi-Fi without configuration		Wi-Fi with scheduling configuration	
Sampling interval (s)	Transmit current (mA)	Energy consumption (mJ/s)	Transmit current (mA)	Energy consumption (MJs^{-1})
1	98.7	0.0074	40.37	0.0030
5	98.7	0.037	40.37	0.015
10	98.7	0.074	40.37	0.03
20	98.7	0.148	40.37	0.06
30	98.7	0.222	40.37	0.09
60	98.7	0.444	40.37	0.180
120	98.7	0.888	40.37	0.360
180	98.7	1.332	40.37	0.500
300	98.7	2.220	40.37	0.90
600	98.7	4.440	40.37	1.800

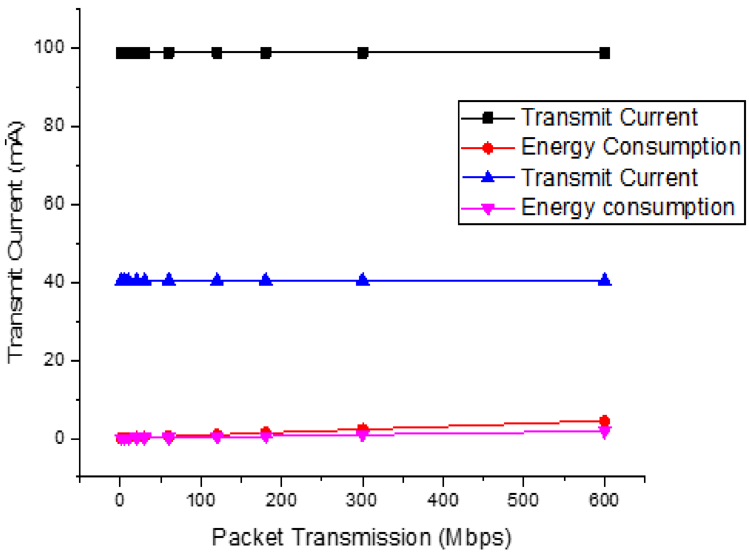


Figure 10 Energy consumption discrepancy between configuring and non-configuration method

4.2 Sensor nodes simulation results

The sensor node is designed and simulated to test the RPL routing as well to evaluate the performance of the stack. The design consists of 5 motes running CoAP servers, providing pH, soil moisture, temperature, and humidity values as resources from the different wireless sensors. These motes are periodically queried by the CoAP client and Californium based Java program, which periodically sends GET requests to the servers in the simulation environment to obtain the agro-climatic parameters through the border router. This connects the nodes to the internet using the TUNSLIP utility to communicate between the external network and border router. The network topology in Cooja is shown in Figure 11.

The throughput and packet loss are considered for the selected motes in the network to determine the routing of packets from source to the destination in Kbps using the 6LoWPAN platform with setup feature of 5 nodes to the router and it was evaluated. The results obtained were presented in Table 8 and Table 9. Figure 12 shows the graphical representation of packet generation rate (packet s^{-1}) to the network throughput in (Kbs^{-1}), and Figure 13 depicts the graphical representation of packet loss (%) against packet generation rate (packet s^{-1}).

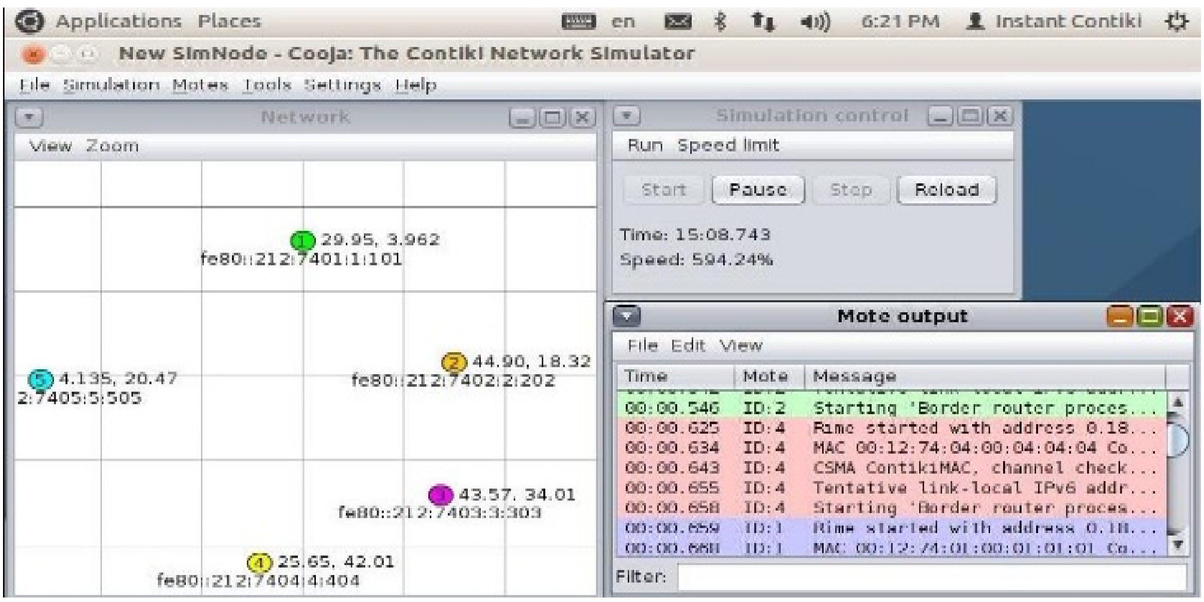


Figure 11 Network topology in Cooja-Contiki environment

Table 8 Table packet generation against throughput

Packet generation rate (packet s^{-1})	Network throughput (Kbs^{-1})			
	Node1	Node2	Node3	Node4
1	0.9050	0.8557	0.7154	0.6305
5	1.1714	0.9732	0.7592	0.6066
10	1.8463	1.2632	1.0626	1.8463
20	2.1739	1.9628	1.2534	0.7582

Table 9 Packet generation against packet loss

Packet generation rate (packet s^{-1})	Packet loss (%)			
	Node1	Node2	Node3	Node4
1	1.00	2.50	4.23	5.50
5	2.80	4.62	8.55	11.61
10	4.15	7.01	12.25	21.77
20	6.01	8.11	14.60	17.05

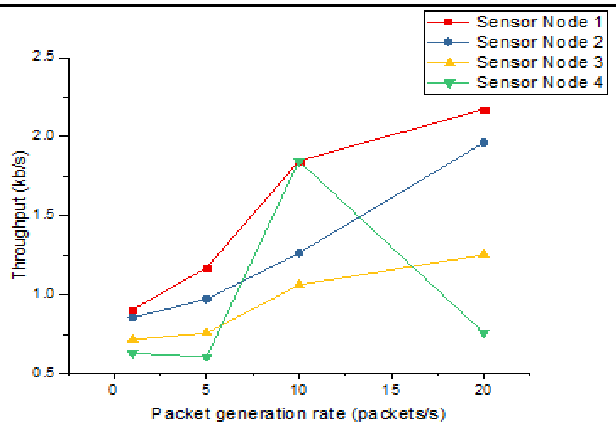


Figure 11 Packet generation versus throughput

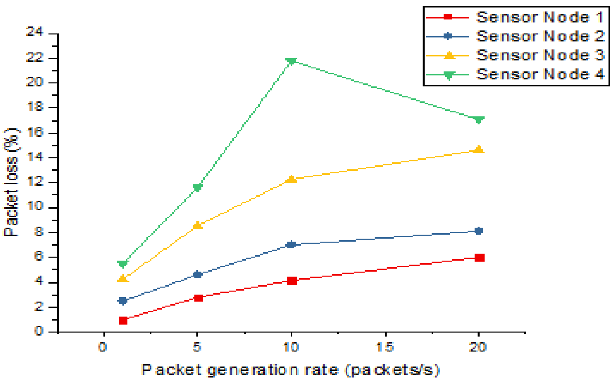


Figure 13 Packet generation versus packet loss

5 Conclusion

In this paper, schedule-based algorithm techniques were proposed and implemented by considering both sensor MAC and wireless sensor MAC that support this topology using STAR. It is observed that the ZigBee wireless module was verified to be 3 $^1/_2$ times less in power consumption compared to enhanced low power consumption Wi-Fi module (802.11 ah, b/g/n) technology. The ZigBee wireless module was verified to be 3$^1/_2$ times less in power consumption as compared to enhanced low power consumption Wi-Fi module (802.11 ah, b/g/n) technology. Since it utilized about 27.5 mA for packet transmission throughout sampling interval and the life expectancy is 17.3 days when using 3V, 240 mAh^{-1} batteries. When the Wi-Fi technology was adopted for packet transmission with the proposed implemented schedule-based algorithm, the result obtained shows that, the current reduces from 98.7 mA to 40.37 mA which is more than 58% power management during a sampling period interval of packet transmission. The performance evaluation table between the two scenarios as presented in Table 5 shows that more than 58% of energy was saved during agro-climatic parameters monitoring. Also, the simulation results in Cooja-Contiki environment show the difference between the throughputs, packet generation rate, and packet loss along the transmission. In summary, sensor node 4 reaches throughput peaks at 10 packets/sec and declines due to an increase in incoming traffics. Future work can be proposed on big data management, heterogeneity, and packet routing in the cloud database based on smart embedded WSN.

Acknowledgments

The authors acknowledge the management of the Federal University of Technology, Minna, for their support towards the achievement of this research.

References

Aazam, M., I. Khan, A. A. Alsaffar, and E. Huh. 2014. Cloud of things: integrating the internet of things and cloud computing and the issues involved. In *Proc. of 2014 11th International Bhurban Conference on Applied Sciences and Technology (IBCAST)*, 414-419. Islamabad, Pakistan, 14-18 January.

Adegboye, M. A., L. A. Ajao, T. A. Folorunso, A. Y. Mamudu, and A. S. Isah. 2017. Automatic fertilized-irrigation control and management system, *FUW Trends in Science and Technology Journal*, 2(2): 801-805.

Ajao, L. A., J. Agajo, J. G. Kolo, D. Maliki, and M. A. Adegboye. 2017a. Wireless sensor network based-internet of thing for agro-climatic parameters monitoring and real-time data acquisition. *Journal of Asian Scientific Research (JASR)*, 7(6): 240-252.

Ajao, L. A., J. Agajo, J. G. Kolo, O. C. Inalegwu, and E. A. Edem.

2017b. Development of a low power consumption smart embedded wireless sensor network for the ubiquitous environmental monitoring using Zigbee module. *Journal of Science, Technology and Education (JOSTE)*, *5*(1), 94–108.

Aliyu, S., A. Yusuf, A. Umar, M. Hafiz, and L. A. Ajao. 2017. Design and development of a low-cost gsm-Bluetooth home automation system. *International Journal of Intelligent System and Application*, *8*(8): 41–50.

Bencini, L., D. D. Palma, G. Collodi, A. Manes, and G. Manes. 2010. Wireless sensor networks for on-field agricultural management process. In *Wireless Sensor Networks: Application-Centric Design*, eds. G. Merrett and Y. K. Tan, ch. 2. 1-17. London, UK: IntechOpen.

Casilari, E., J. M. Cano-García, and G. Campos-Garrido. 2010. Modeling of current consumption in 802.15.4/zigbee sensor motes, *Sensors, 10*(6): 5443–5468.

El-Hoiydi, A., and J. D. Decotignie. 2005. Low power downlink MAC protocols for infrastructure wireless sensor networks. *Mobile Networks and Applications*, *10*(5): 675–690.

Goap, A., D. Sharma, A. K. Shukla and C. R. Krishna, 2018. An IoT based smart irrigation management system using Machine learning and open source technologies, *Computer and Electronics in Agriculture*, 155: 41-49.

Hassan, S. A., S. S. Syed, and F. Hussain. 2017. Communication technologies in IoT networks, *In Internet of Things: Building Blocks and Business Models*, ed. F. Hussain, ch. 2, 13-26. Switzerland: Springer.

Kabara, J., and M. Calle. 2012. MAC protocols used by wireless sensor networks and a general method of performance evaluation. *International Journal of Distributed Sensor Networks*, *8*(1): 834784.

Kaur, S., and L. Mahajan. 2012. Power-saving MAC protocols for WSNs and optimization of S-MAC protocol. *International Journal of Engineering Business Management*, 4(17): 1-8.

Khanna, A., and S. Kaur. 2019. Evolution of Internet of Things (IoT) and its significant impact in the field of precision agriculture, *Computers and Electronics in Agriculture,* 157: 218-231.

Khatarkar, S., and R. Kamble. 2013. Wireless sensor network MAC protocol: SMAC and TMAC. *Indian Journal of Computer Science and Engineering (IJCSE)*, *4*(4): 304–310.

Li, D., F. Peng. 2009. Energy-efficient MAC protocols for Wireless Sensor Networks. *Information and Communications Technologies*, 3(3): 32-36.

Li, Z., Q. Chen, G. Zhu, Y. Choi, and H. Sekiya. 2015. A low latency energy-efficient MAC Protocol for Wireless Sensor Networks. *International Journal of Distributed Sensor Networks*, *11*(8): 946587.

Mahmoud, M. S., and A. A. H. Mohamad. 2016. A study of efficient power consumption wireless communication techniques modules for Internet of Things (IoT) applications. *Advances in Internet of Things*, *6*(2): 19–29.

Muangprathub, J., N. Boonnama, S. Kajornkasirata, N. Lekbangponga, A. Wanichsombata, and P. Nillaor. 2019. IoT and agriculture data analysis for smart farm, *Computers and Electronics in Agriculture,* 156: 467-474.

Partel, V., S. C., Kakarla, and Y. Ampatzidis. 2019. Development and evaluation of a low-cost and smart technology for precision weed management utilizing artificial intelligence, *Computers and Electronics in Agriculture,* 157: 339-350.

Peniak, P., and M. Frannekova. 2016. Model of integration of embedded systems via CoAP protocol of the internet of things. In 2*016 International Conf. on Applied Electronics (AE)*, 201-204. Pilsen, Czech Republic, 6-7 September.

Pivoto, D., P. D. Waquil, E. Talamini, C. P. S. Finocchio, V. F. D. Corte, and G. V. Mores. 2018. Scientific development of smart farming technologies and their application in Brazil, *Information Processing in Agriculture,* 5: 21–32.

Polastre, J., J. Hill, and D. Culler. 2004. Versatile low power media access for wireless sensor networks. In *Proc. of the 2nd international conf. on Embedded Networked Sensor Systems*, 95-107. Baltimore, Maryland, USA, 3-5 November.

Popovic, T., N. Latinovic, A. Pesic, Z. Zecevic, B. O. Krstajic, and S. Djukanovic. 2017. Architecting an IoT-enabled platform for precision agriculture and ecological monitoring: A case study. *Computers and Electronics in Agriculture*, 140: 255-265.

Rossi, V., F. Salinari, S. Poni, T. Caffi, and T. Bettati. 2014. Addressing the implementation problem in agricultural decision support systems: the example of vite.net, *Computers and Electronics in Agriculture,* 100: 88–99.

Stokes, P. 2018. IoT applications in agriculture: the potential of smart farming on the current stage, Available at: https://medium.com/datadriveninvestor/iot-applications-in-agriculture-the-potential-of-smart-farming-on-the-current-stage. Accessed 2 October 2018.

Xiao, X. 2008. *Technical, Commercial and Regulatory Challenges of QoS: An Internet Service Model Perspective*. Francisco, CA, United States: Morgan Kaufmann Publishers Inc.

Yazdi, F. R., M. Hoseinzadeh, and S. Jabbehadri. 2019. A priority-based MAC protocol for energy consumption *and Communications Societies,* 1567–1576. New York, 23-27 June. and delay guaranteed in wireless body area networks. *Wireless Personal Communications,* 108: 1677-1696.Ye, W., J. Heidemann, and D. Estrin. 2002. An energy-efficient MAC protocol for wireless sensor networks. In *Proc. Twenty-First Annual Joint Conf. of the IEEE Computer.*