KPI DEPLOYMENT FOR ENHANCED RICE PRODUCTION IN A GEO-LOCATION ENVIRONMENT USING A WIRELESS SENSOR NETWORK

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ABSTRACT

Rice production plays a significant role in food security in the globe. The automation of rice production remains the paradigm shift to meet up with the consumer demand considering the tremendous increase in consumption rate. The paper aimed at implementing some selected key performance indicators (KPIs) for enhanced rice production by addressing five major challenges that face rice farmers, especially in Nigeria. The Non-availability of water/rain for year-round cultivation, disproportionate application of fertilizer, weed control/prevention, pest/disease control, and rodents and bird's invasion are outlined as observed constraints. A Zigbee-based Enhanced Wireless Sensor Network (eWSN) was used to model various network scenarios to demonstrate data sensing of different environmental variables in a given farm land. This was achieved by varying network devices at different scenarios using OPNET simulator and understudying the network performances. Each new set of network devices was integrated to a Zigbee Coordinator (ZC) which assigns an address to its members and forms a personal area network (PAN), thus representing data sensing of a particular environmental variable. Three different scenarios were designed and simulated in the study. Each of the temperature and humidity, motion and soil nutrient sensors generated about 29bps of traffic. At the Coordinators, steady stream of traffic was received. The temperature and humidity Coordinators, received a traffic of 64bps each, while the soil nutrient Coordinator received data traffic of 96bps. The outcome of the design demonstrates effective communication between different network components and provides insight on how WSN could be used simultaneously to monitor a number of different environmental variables on a farm field. By implementing the KPIs, the simulation result provided an estimated yield increase from 2.2 to 8.7 metric ton per hectare of a rice farm.

Keywords

Enhanced Wireless Sensor Network(eWSN), Zigbee, Key Performance Indicators(KPI), OPNET Simulator.

1. INTRODUCTION

Food remains one of the basic necessities of life sustenance and which at all times require the need for improved production strategy [1]. The country Nigeria has been a mono-economic country, with revenue from oil accounting for over 90% of her foreign exchange earnings [2]. Due to the failure of her successive governments to properly explore and develop other sectors of the economy especially agriculture, the need for improved system of agricultural sector development cannot be over emphasized considering the exploding population in the face of dwindling oil revenue.

Rice has become a highly strategic and priority commodity for food security in Africa [3]. Consumption is growing faster than that of any other major staple food on the continent because

of high population growth, rapid urbanization and changes in eating habits [4]. Rice is one of the most consumed staples in Nigeria, with a consumption per capita of 32 kg, it is proven to be the single most important source of dietary energy in West Africa and the third most important for Africa as a whole [3].

The importance of rice in Nigeria is no longer the question but rather how the growing demand can be met to reduce its importation and be self-sufficient [5]. Many theories and hypotheses were tried in the past for the rice production systems yet the self-sufficiency level has not been achieved [6]. Recently, it was realized that rice production in Nigeria has significantly improved and has recorded a peak of 4.9 million Metric Tonnes (MT) produced by farmers in Nigeria, despite the production growth, it has not been able to meet the national demand on rice consumption which stands an all-time high of 7 million Metric Tonnes (MT) [7]. This means that there is a gap of 2.1 million MT to be cushioned, which is realizable if the observed limited factors are improved. The limited capacity of the Nigerian rice sector to meet the domestic demand has been attributed to several factors; notable among them is the declining productivity due to low adoption of improved production practices [8].

In-lieu of the rice supply shortage in Nigeria occasioned by poor production output by Nigerian farmers, the author looks at developing an environmental monitoring system using some selected key performance indicators (KPIs) that utilize wireless sensor network technology, capable of alleviating the production deficit of the country and engendering for export. The proposed solution is a multi-functional and integrated system. It is an enhanced Wireless Sensor Network (eWSN) technology solution that can do more than just irrigation work as has been widely reported by many researchers on the subject matter. Consequently, the researcher designed an eWSN system that is capable of:

- i. Ensuring automated irrigation of a rice field for year-round production.
- ii. Adaptable for disease control/prevention via automated application of pesticides.
- iii. Adaptable for weed control/prevention via automated application of herbicides.
- iv. Adaptable for rodents and birds' control/prevention via automated buzzer activation mechanism for scaring animals.
- v. Adaptable for even and right proportion of fertilizer application.

2. LITERATURE REVIEW

The authors of [9] conducted a study to demonstrate the practical ways of using mobile phones in conjunction with WSNs to enable farmers in Nigeria monitor and control their farm and hence increase their productivity. Wireless sensor network was applied in conjunction with GSM technology and was used to monitor and control various environmental factors. The model monitored temperature, humidity, soil moisture and water level which were evaluated to activate or deactivate the designed irrigation system with set threshold values [9]. In [10], demonstrated the implementation of embedded system for automatic irrigation which has a wireless sensor network placed in the root zone of the plant for real time in-field sensing and control of an irrigation system. Data was received, identified, saved and displayed at the base station and if it exceeds the desired limit. the control will be enabled by an android smart phone via GSM network. In the works of [11], [12] analyzed the simulation on wireless sensor network for lowcost wireless controlled and monitored irrigation solution using Zigbee/IEEE802.15.4. The authors implemented a simulation model approach for monitoring and controlling of water and irrigation systems. A Beacon Cluster-based mesh topology was introduced in their study which significantly lowered power consumption with a higher battery life and a good delivery ratio. The authors of [13] designed and implemented an Automatic Irrigation System Based on Monitoring Soil Moisture. The method employed was to continuously monitor the soil moisture

level to decide whether irrigation was needed, and how much water was needed in the soil. A pumping mechanism was used to deliver the needed amount of water to the soil. The work was grouped into four subsystems namely; power supply, sensing unit, control unit and pumping subsystems which made up the automatic irrigation control system [14]. The authors of [15], designed a farmland environment information collection and monitoring system based on NB-IoT to solve the problems associated with waste water resources. Their research study was aimed at reducing the high labour intensity and unscientific irrigation challenges during farmland irrigation and the shortcoming of conventional technologies in the water saving irrigation system network.

The reviewed works has shown the extent of some research work on the subject matter. Scholars have done a great deal of extensive work including implementation of automatic irrigation system using WSN application. However, lack of water resource is not the basic challenge that limits crop production especially rice. Such other challenges like pest and disease invasion, problem with method of fertilizer application, birds/rodent's invasion, and weed control could be among major factors to contend with. On that premise, the study takes a step further to suggest the design of a single multi-functional and integrated WSN application in agriculture adaptable to irrigate, control pests and weeds, apply fertilizer and deter birds and rodents in a rice farm at the same time. Selected key performance indicators for enhanced production, using OPNET Modeler 14.5A to design and simulate a model of the farm on Zigbee based Wireless Sensor Network was introduced.

3. MATERIAL AND METHODS

3.1. Materials

The basic materials implemented for the realization of the research study are the Optimized Network Engineering Tools (OPNET) and Circuit Wizard. The various sensor types were represented as Zigbee End Devices (ZED) and the following were proposed based on their comparative advantages:

- i. Motion sensors for sensing the presence of birds and rodents. Passive InfraRed (PIR) sensor has been adjudged to be best suitable for motion sensing. Panasonic's AMN41121 PIR sensor was proposed because of its comparative advantages of extremely compact with built-in amplifier, adjustable sensitivity, and noise withstanding capability.
- ii. Temperature and Humidity sensors to detect change in temperature and to measure the amount of water vapour within the farmstead. Sensirion Inc. SHT75 was proposed because of its ability to measure temperature and humidity to the highest precision; and it is relatively inexpensive with impeccable continuity and minimal size.
- iii. Biological sensors: Biological sensor has the ability to sense the presence of weed, pests, insects, eg. Weed Seeker.
- iv. Soil moisture sensor to measure the amount of moisture on the farmstead. VG400 (a frequency domain reflectometry sensor) from Vegetronix Inc. is proposed because it is less expensive and uses less power.
- v. Soil nutrient sensor to measure soil micronutrients such as nitrogen (N), phosphorus (P) and potassium (K). Teralytic^(R) sensors are proposed. They can measure Soil electrical conductivity, moisture, pH, Nitrates, Phosphates, Potassium, and temperature at 3 different depths and sample every 15 minutes.

3.2. Method

The method employed in the research study involves computer-based simulation design approach, it provides varied conditions and investigation on the resultant outcome.

3.2.1. Conceptual Model for Selected Key performance Indicators (KPIs)

Stochastic model was adopted to determine the effect of the additional technology input to the overall yield of a rice farm. The Stochastic frontier for crop yield response is viewed as a good approximation and is widely used in crop yield response analysis [16].

Let a farmer's amount of produce (yield) per a hectare of rice farm be a function of his adoption of best technology practice.

This can be represented as:

$$Y_{eft} = f(X_{eft}) + \alpha \tag{1}$$

Where Y_{efit} = yield per hectare (ton) on farm *e* for farmer *f* in season (time) *t*, X_{eft}= technology input variables, And α = unforeseen natural/environmental factors (other agronomic conditions).

For a multi-technology input farm, yield for a given farming season can be given as: $Y_{eft} = X_{0eft} + X_{1eft}(Irr.) + X_{2eft}(Irr. + Fer) + X_{3eft}(Irr. + Fer. + Pst.) + X_{4eft}(Irr. + Fer. +$

 X_{5eft} (Irr.+Fer.+Pst.+Herb.+Bird & Rdnt Ctrl) + α

where

 $X_{0eft} = Rainfed variable$ X_{1eft} (Irr.) = Irrigation variable X_{2eft} (Irr.+ Fer) = Irrigation and Fertilizer application variable. X_{3eft} (Irr. + Fer. + Pst.) = Irrigation, Fertilizer and Pesticide application variable. X_{4eft} (Irr.+Fer.+Pst. +Herb) = Irrigation, Fertilizer, Pesticide and Herbicide application variable. X_{5eft} (Irr.+Fer.+Pst.+Herb.+Bird & Rdnt Ctrl) = Irrigation, Fertilizer, Pesticide, Herbicide application and Birds/Rodents Control variable.

The general form of equation 2 can be written as:

$$Y_{eft} = \sum_{i}^{n} X_{eft} + \alpha \tag{3}$$

3.2.2. Data Evaluation from Technological Input variable

Data from comparative study of yield for rainfed (Lowland) and irrigated rice farm by [17] and Potential Yield from [18] for some selected Nigerian states was used. The average yield (ton/ha) for rainfed rice farm stood at 2.2, while average yield (ton/ha) for irrigated rice farm was 3.5. This shows a percentage difference of 37.14%.

Drawing from the model equation and using the data above as basis, the computation of the effect of additional technology-input variable results are represented in table 1.

(2)

| Production System | Maj | Major Nig. State Covered | | | | Yield % Change |
|---|-----------------|--------------------------|-------|--------|-----|-------------------|
| Rainfed (Lowland) | Benue, Niger | Ebonyi, | Cross | River, | 2.2 | 0 |
| Irrigated | Benue, Niger | Ebonyi, | Cross | River, | 3.5 | 37.14 |
| Irrigated + Fertilized | Benue, Niger | Ebonyi, | Cross | River, | 4.8 | 64.22 |
| Irrigated +Fert. +Pest. Appl. | Benue, Niger | Ebonyi, | Cross | River, | 6.1 | 85.53 |
| Irrigated +Fert. +Pest. + Herb. | Benue, Niger | Ebonyi, | Cross | River, | 7.4 | 103.09 |
| Irrigated +Fert. +Pest. + Herb. + Birds/Rodent Control | Benue, Niger | Ebonyi, | Cross | River, | 8.7 | 118.03 |

Table 1. Estimated Average Rice yield(ton/ha) by additional technology-input variable

3.2.3. Wireless Sensor Network Modeling

Modeling of various network scenarios were deployed to demonstrate data sensing of different environmental variables in a given farm land. This was achieved by varying network devices at different scenarios using OPNET simulator and understudying the network performances such as traffic sent (bits/sec), traffic received (bits/sec), end-to-end delay(second), throughput (bits/sec) and media access control (MAC) load (bits/sec). The idea of varying network devices is a design approach adopted in the study to demonstrate integration of different sensor types, monitoring different environmental variables simultaneously, yet constituting a single unit of WSN working cooperatively. Each new set of network devices are integrated to a Zigbee Coordinator (ZC) which assigns an address to its members and forms a personal area network (PAN), thus representing data sensing of a particular environmental variable. Mesh topology was adopted for the design because of its ability to cover limitless area with the power to route data across different paths[19].

The modeling of the eWSN was based on Zigbee standard (IEEE 802.5.4) using OPNET Modeler 14.5A. The Zigbee wireless sensor network consists of three types of nodes: the end device nodes, the router nodes, and the gateway node (coordinator). The end device and router nodes were used to manage the data collection of various environmental variables (temperature & humidity, soil nutrients level, soil moisture level, presence of pests and rodents) and then the collected data were sent to the coordinator for processing, and control.

Design Assumption: it is assumed that OPNET has the capability to be configured to allow for received data analysis of packets sent from different sensor types – packet containing temperature, humidity, soil nutrient level, soil moisture, etc.

3.2.4. System Block Diagram

Figure 1 shows the block diagram of the WSN model. Sensed data from individual sensor types are routed through the router to the coordinator (Sink node) for further processing and control. The monitoring sub-network is equally connected to the coordinator for both on-the-premise and remote monitoring as maybe deemed necessary. Irrigation, pesticide application, herbicide application, and soluble fertilizer application could be done from any of the 4 compartments (Liquid A - D) connected to a water source through the irrigation pipe by the activation of the

solenoid depending on the type of instruction received from the controller (coordinator). The other actuator systems could be for the alarming system to deter birds and rodents from the farm.



Fig. 1. The System Block Diagram

3.2.5. System Flow Chart

Figure 2 is the sensor designed flow chart showing sequence of events for system realization.



Fig 2. Sensor Design Flowchart

3.2.6. Model Farm Network Design

A farmland of 100m x 100m was used as a baseline for the study. Sensors were sparsely distributed across the farmland consisting of Zigbee end devices (ZED), Zigbee routers (ZR), Zigbee coordinator (ZC) and actuators. The WSN was connected to a monitoring point via an access point gateway, with a wireless database server and a PC for on-the-premise monitoring while a host computer was connected via an internet protocol (IP) cloud for remote monitoring. Figure 3 shows the block diagram of the model farm network.



Fig.3. Block Diagram of the Model Farm Network

3.2.7. Configured Network Scenarios

Three network scenarios were created to demonstrate data sensing of different environmental parameters by varying number of network devices while watching out for network performance. New set of Zigbee devices were added to the ideal network (network of one sensor type) and configured to form a personal area network with an identifier for its members.

Scenario 1: consists of 4 Sensor Nodes, 2 Routers, and 1 Coordinator; to represent data sensing of temperature and humidity variables.

Scenario 2: consists of 8 Sensor nodes, 4 Routers, and 2 Coordinators. The second Coordinator is for the new set of sensor types; representing data sensing of soil nutrients, it is configured to route its traffic to the central Coordinator.

Scenario 3: consists of 12 Sensor nodes, 6 Routers, and 3 Coordinators. Again, the third Coordinator is for the next new set of sensor types; representing data sensing of motion variable, while the first Coordinator remains the central Coordinator while traffic from Nut_Coordinator is equally configured to be routed to it.

Parameter Description for the Simulation of Scenario 1

The global frequency and maximum bit rate of the network parameter of the coordinator is set at 2.4GH and 250kbps respectively (Zigbee standards).

Media Access Control (MAC) Parameters

Figure 4 shows the MAC configuration of the network. The maximum back-off exponent of the MAC parameter is assigned to 4 and the minimum back-off exponent is assigned to 3. The value of the maximum back-off exponent executes Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) algorithm for 4 times, while the minimum back-off exponent ensures 3 attempts of executing before declaring the channel access failure. Both values were chosen for convenience's sake. Channel sensing duration which is the duration each channel will be scanned for beacons after the beacon request has been sent is assigned to 0.1 seconds.

| Attri | oute | Value |
|-------|-------------------------------|-----------------------|
| 2)n | ame | Temp&Humidity Sensor3 |
| e z | JoBee Parameters | |
| 6 | MAC Parameters | |
| 3 | ACK Mechanism | () |
| 2 | - Status | Disabled |
| 2 | - ACK Wait Duration (seconds) | 0.05 |
| ? | - Number of Retransmissions | 5 |
| 2 | CSMA-CA Parameters | Default Settings |
| 2 | - Channel Sensing Duration | 0.1 |
| | Physical Layer Parameters | |
| 2 | - Device Type | End Device |
| 2 | - PAN ID | 0 |
| Ē 🖻 🖊 | oplication Traffic | |
| | | |
| | | |

Fig. 4. MAC parameters configuration

Network Parameters of the Coordinator

The network configuration parameters for the coordinator is shown in figure 5. The maximum children number specifies the number of sensor nodes, routers and actuators that can be supported by a coordinator or a router. Maximum depth means the number of network trees the coordinator could have while router discovery timeout is the length of time allowable for the network to keep route discovery entries. In scenario 1, the coordinator established its network with personal area network identifier (PAN ID) of 0; representing data sensing of a single environmental variable (temperature and humidity sensing).

| * (C | oordinator) Attributes | | - | | \times |
|--------------|--|----------------|----------|----------------|---------------------------|
| Att | ribute | Value | | | ^ |
| ? r | name | Coordinator | | | |
| 8 | ZigBee Parameters | | | | |
| | MAC Parameters | | | | |
| | Physical Layer Parameters | | | | |
| ? | Network Parameters | () | | | |
| ? | - Beacon Order | 6 | | | |
| 2 | - Superframe Order | 0 | | | |
| ? | Maximum Children | 7 | | | |
| ? | Maximum Routers | 5 | | | |
| 2 | - Maximum Depth | 5 | | | |
| 2 | Beacon Enabled Network | Disabled | | | |
| 2 | - Mesh Routing | Enabled | | | |
| 2 | Route Discovery Timeout | 10 | | | |
| 2 | PAN ID | 0 | | | |
| Ŧ | Application Traffic | | | | |
| | | | | | |
| ?[| | <u>F</u> ilter | Apply to | Ac selected | l <u>v</u> ance object |

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Fig. 5. Network parameter of the coordinator

Physical Layer Parameters

The physical layer parameters is shown in figure 6. In order to determine whether a node is dead or alive, a packet reception-power threshold is set to -76 dBm (considered optimal).

| | Attribute | Value | - |
|----|----------------------------------|-----------------------|---|
| 3 | iname | Temp&Humidity Sensor2 | |
| | ZigBee Parameters | | |
| | MAC Parameters | | |
| | Physical Layer Parameters | | |
| 3 | - Data Rate | Auto Calculate | |
| 3 | Packet Reception-Power Threshold | -76 | |
| 3 | Transmission Bands | () | |
| 3 | Transmit Power | 0.06 | |
| 3 | - Device Type | End Device | |
| ٢ | - PAN ID | 0 | |
| | Application Traffic | | |
| | | | |
| | | | |
| | | - Advan | |
| () | | Eiter | |

Fig. 6. Physical Layer Parameters

Application Traffic Attributes

The application traffic parameters used as shown in figure 7. The packet size of the sensed environmental variables is set to 32 bits; however, they could be an overhead added by each layer of the open system interconnection (OSI) model. The sensed nodes select a random destination within its own PAN. All traffic is started, followed by a distribution of uniform (60, 61) seconds after the simulation starts and traffic generation stops at the end of the simulation.

| ຈ່ | | Value | |
|----|----------------------------|-----------------------|--|
| | - name | Temp&Humidity Sensor2 | |
| | ZigBee Parameters | | |
| T | Application Traffic | | |
| D | - Destination | Random | |
| 6 | - Packet Interarrival Time | constant (1.0) | |
| Ð | - Packet Size | constant (32) | |
| D | - Start Time | uniform (60, 61) | |
| ð | . Stop Time | Infinity | |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |

Fig. 7. Application Traffic Parameters

Transmit Power Configuration

Figure 8 shows the transmit power parameter used. A value of 0.06 mW was chosen because it is considered as optimal transmit power in terms of achieving maximum traffic sent (Shah Nawaz, 2015).

| * | (Temp&Humidity Sensor2) Attributes | | - | | \times |
|----|--|---------------------|----------|---|-----------------|
| | Attribute | Value | | | <u>^</u> |
| 1 | name | Temp&Humidity Sense | or2 | | |
| | ZigBee Parameters | | | | |
| | MAC Parameters | | | | |
| | Physical Layer Parameters | | | | |
| | · Data Rate | Auto Calculate | | | |
| | Packet Reception-Power Threshold | -76 | | | |
| 3 | Transmission Bands | () | | | |
| 2 | Transmit Power | 0.06 | | | |
| | Device Type | End Device | | | |
| | - PAN ID | 0 | | | |
| | Application Traffic | | | | |
| | | | | | ~ |
| (2 | Exact match | <u>Filter</u> | Apply to | ⊢ Ad <u>v</u> selected o <u>C</u> anc | anced bjects |

Fig 8. Transmit Power Parameter

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| Scenari | No. | No | NO | М | MAC Layer | | PHY | APPL Layer | | Transm | ZC |
|---------|-----|------|------|---------|-----------|---------|----------|------------|--------|--------|----|
| 0 | of | . of | . of | | | | Layer | | | it | PA |
| | ZE | ZR | ZC | Max.Bac | Min. | Sensing | Pkt. | Pkt | Distri | Power | Ν |
| | D | | | k-off | Back- | Duratio | Receptio | size | | (mWatt | ID |
| | | | | Expon. | off | n (sec) | n Power | (bits | Time |) | |
| | | | | | Expon | | (dBm) |) | (sec) | | |
| | | | | | | | | | | | |
| Scenari | 4 | 2 | 1 | 4 | 3 | 0.1 | -76 | 32 | 60,61 | 0.06 | 0 |
| o 1 | | | | | | | | | | | |
| Scenari | 8 | 4 | 2 | 4 | 3 | 0.1 | -76 | 32 | 60,61 | 0.06 | 1 |
| o 2 | | | | | | | | | | | |
| Scenari | 12 | 6 | 3 | 4 | 3 | 0.1 | -76 | 32 | 60,61 | 0.06 | 2 |
| o 3 | | | | | | | | | | | |

Table. 2. Summary of Network Parameter Configuration.

Simulation Setup of Scenario 1

Figure 9 shows the device configuration for the simulation of scenario 1. It consists of 4 sensor nodes, 2 routers, and a coordinator. The number of routers is chosen to be 2 to ensure self-healing mechanism of mesh topology should one fail while minimal number of ZED were used for visual simplicity.

| 0.0 | 12.5 | 25.0 | 37.5 | 50.0 | 62.5 | 75.0 | 87.5 | 10 |
|--------|-------------------|------|--------------------------|--------------|------|--------------|---------|----|
| . 12.5 | | | € | ZigBag | | | T | |
| Tem | p&Humidity Sen | sor4 | | Router1 | | ZinBee | | |
| .37.5 | ZigBee Router2 | | Zige emp&Humid | lity Sensor2 | Tem | 8 Humidity 5 | iensor3 | |
| 62.5 | | | | | | Coordina | itor | |
| .75.0 | | | |) | | | | |
| 87.5 | | Temp | &Humidity S | ensor1 | | | | |

Fig. 9. Simulation Setup of Scenario 1

Simulation Setup of Scenario 2

Figure 10 shows the device configuration of Scenario 2. It consists of 8 sensor nodes, 4 routers, and 2 coordinators. The topology of scenario 2 differs from that of scenario 1 in that the number of sensor nodes and routers doubled in size but the second coordinator (Motion Coordinator) is set to establish network with its ZED and with the two new routers (Motion Router 1 & Motion Router 2) with a PAN ID of 1 (PAN ID_1). These new number of network devices added to the network forms a network sensing different environmental variables (motion detection) from the first set of nodes. Data routed through Motion Coordinator from its ZEDs and ZRs are configured to route to the central Coordinator. Sensor nodes and routers have similar parameter configuration as in scenario 1.



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Fig. 10. Simulation Setup of Scenario 2

Simulation Setup of Scenario 2

Figure 11 is the device configuration of scenario 3. The network model of scenario 2 was replicated with 12 sensors, 6 routers, and 3 coordinators. The third Coordinator (Soil Nut_Coordinator) establishes a network with its members (Soil Nut_Sensor 1 - 4 and Soil Nut_Routers 1&2) with a PAN ID of 2 (PAN_2). Sensed data (traffic) from Soil Nut_sensors are routed through the Soil Nut_Routers to the Soil Nut_Coordinator. The Soil Nut_Coordinator is configured to route its traffic to the central Coordinator. By so doing, another set of environmental variables (soil nutrients: NPK, etc.) different from those of scenarios 1 and 2 are sensed.



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Fig. 11. Simulation Setup of Scenario 3

Simulation Run-Time

The simulation run-time information for the investigation of the network performance for the three scenarios simulated for 10 minutes is shown in figure 12.

| | DES Execution Manager: | ZB_lab1 | | | | | | | - | | Х |
|---|------------------------|-----------|------------------|----------|-------------|---------|----------|-----------|-------|-------------|---------------|
| 4 | 🗐 🚎 IdealFarm 🔺 | Status | H | lostname | Du | uration | Sim Time | e Elapsed | Time | Elapsed | Time * |
| | Run 1 | Completed | lo | calhost | 10 | Om OOs. | | 10m 00s. | | Os. | |
| | E- IdealFarm1_Motion | Status | H | lostname | Du | ration | Sim Time | e Elapsed | Time | Elapsed | Time |
| | Run 1 | Completed | lo | calhost | 10 | 0m 00s. | | 10m 00s. | | 1 s. | |
| l | | Status | H | lostname | Du | ration | Sim Time | e Elapsed | Time | Bapsed | Time |
| | Run 1 | Completed | lo | calhost | 10 | Om OOs. | | 10m 00s. | | 1s. | |
| | ۲ ۲ | <u> </u> | | 1 | 1 | | | | | 1 | × |
| | View Details Pause | | <u>S</u> top Run | Stop Set | Stop Sequen | ice | | (| Close | | <u>l</u> elp |

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Fig. 12. Simulation Run-time for the three scenarios

Functional Description of Metrics

In order to collect the statistics for the performance metrics, the simulation was run using OPNET Modeler 14.5A. Table 3 is a description of the global and object metrics collected.

| Table 3. | Performance | Metrics |
|----------|-------------|---------|
|----------|-------------|---------|

| SN | Name | Description | Group | Capture Mode | Draw Style | Filter |
|----|------------|-----------------------------------|-----------|-----------------|---------------|---------|
| | | | | moue | Bijie | |
| 1. | Traffic | Application traffic sent by the | ZigBee | bucket/defau | Linear | time |
| | Sent | layer in bits/sec. | Applicati | lt | | average |
| | (bits/sec) | | on | total/sum_ti | | |
| | | | | me | | |
| 2. | Traffic | Application traffic received by | ZigBee | bucket/defau | Overl | time |
| | Received | the layer in bits/sec. | Applicati | lt | aid | average |
| | (bits/sec) | | on | total/sum_ti | | |
| | | | | me | | |
| 3. | 802.1544_ | Represents the total number of | ZigBee | bucket/defau | Linear | As Is |
| | MAC | bits (in bits/sec) forwarded from | 802.15.4 | lt | | |
| | Throughp | 802.15.4 MAC to higher layers | MAC | total/sum_ti | | |
| | ut | in all WPAN nodes of the | | me | | |
| | (bits/sec) | network. | | | | |
| | | | | | | |

| 4. | 802.15.4_ MAC Load (bits/sec) | Represents the total load (in bits/sec) submitted to 802.15.4 MAC by all higher layers in all WPAN nodes of the network. | ZigBee 802.15.4 MAC | bucket/defau lt total/sum_ti me | Linear | As Is |
|----|--|---|---------------------------|--|--------|-------|
| 5. | End-to- End Delay(bits /sec) | Represents the entire delay between the invention and reception of application packets (bits/sec) | ZigBee 802.15.4 MAC | bucket/defau lt total/sum_ti me | Linear | As Is |

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4. RESULTS AND DISCUSSIONS

The outcome of the Implementation of Conceptual Model of Selected Key performance Indicators (KPIs) is represented in figure 13



Fig. 13. Average Yield (ton/ha)

The intent of this study was to understudy the effect of the introduction of each of the selected KPIs on the overall yield of a rice farm. Rice yield across incremental addition of the KPIs as production inputs followed priori expectation and corroborates the result of previous studies that adoption of improved agricultural production techniques increases yield per hectare of a farmland. For instance, the result showed that with irrigation as an input variable, a yield increase of 1.3 metric ton (MT) per hectare is possible. This representing about 37.14% increase in yield from the rainfed production system. In that order, the combination of the other selected KPIs increased yield per hectare up to 8.7MT as shown in figure 13.

4.1. WSN Modeling and System Simulation Results

Data sensing and transmission by wireless devices were modeled using OPNET 14.5A. Simulation was run to collect results as follows:

- i. Traffic sent by the 3 sensor types used in the scenarios (bits/sec);
- ii. Traffic received at the individual Coordinators (bits/sec);
- iii. The network End-to-End delay (sec);
- iv. Medium Access Control (MAC) Throughput (bits/sec), and
- v. MAC load per PAN (bits/sec).

Traffic Sent by the 3 Sensor Types Used in the Scenarios (bits/sec)

The focus of this study is to determine if the different sensor types used in the scenarios were able to generate and transmit their traffic (data). Figure 14 shows the traffic sent by motion_sensor1, soil Nut_sensor1 and Temp & Humility sensor1 to their respective routers.



Fig. 14. Traffic Sent by the 3 Sensor Types (bits/sec)

Data traffic sent is defined as the total number of data bits sent by the source to destination per unit time irrespective of the condition whether all the data bit reach the destination or not [20]. It can be seen that each of the sensor type was able to generate and transmit an average traffic of 29kbps to its router destination. In each instance of the sensors, there was a delay of about 54s from when the simulation starts during which the sensor senses its data and determines the best path to route it.

Traffic Received at the Individual Coordinators (bits/sec)

Figure 15 shows the traffic received at the individual Coordinators used in the simulation. Traffic received is defined as the total number of data bit received per unit time.



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Fig. 15. Traffic Received at the Individual Coordinators (bits/sec)

The statistics was collected as object statistics and presented as overlaid. It can be seen that each of the coordinators received steady stream of data without disruption. The amount of data received by Temp & Humidity coordinator (blue) and that of the Motion Coordinator (red) is 64bps for each, hence the overlap while that of the Soil Nut_Coordinator (green) is 96bps.

Network End-to-End (ETE) Delay (seconds)

Figure 16 shows the End-to-End (ETE) delay for the three PANs of the network. End-to-End delay is an OPNET global statistics. It is the entire delay between the invention and reception of application packets.



Fig. 16. Network End-to-End Delay (second)

Global statistics give relevant information concerning the overall system and measures the effect in real time monitoring. As can be seen, the average delay for the 3 PANs shows a consistency in the amount of ETE delay. It shows that the Zigbee end devices (blue line) of PAN 0 connect to

their routers with a delay of 0.01s, PAN 1(red line) with a delay of 0.003s and PAN 2 (green line) with a delay of 0.007s. On the average, the ETE of the network stood at about 0.007s. Significantly, the average ETE of the network is low due to ability of mesh routing process to find more efficient route.

Medium Access Control (MAC) Throughput (bits/sec)

Figure 17 shows the MAC throughput of the 3 scenarios. The MAC throughput was collected as a global statistic. It is the number of bits or packets successfully acquired or transmitted by the receiver or transmitter channel per second. The spike for each of the scenarios at the beginning and at some point, of the simulation are indications of management and control traffic sent and received to determine the presence of devices as well as the optimal route. As can be seen, the throughput for the scenarios showed same pattern with the farm of one sensor type (blue line) having a throughput of 1368bps, 3192bps for the farm of two sensor types (red line) and 3977bps for the farm of three sensor types (green line).



Fig. 17. Medium Access Control of the 3 scenario (bits/sec)

MAC Load per PAN (bits/sec)

Figure 18 is the graph of the global MAC load per PAN of the simulation. MAC load represents the forwarding load for each PAN to transfer the packets to the IEEE 802.15.4 MAC layer, i.e., physical layer, by the upper layers [21]. The MAC load for PAN 0 (blue line) is 1976 bits/sec, while that of PAN 1 (red line) is 304 bits/sec and PAN 2 (green line) is 1849 bits/sec respectively. There is a spike in each of the PAN at about 6 seconds when the simulation started and later at about 60 seconds. This is due to the routing messages being broadcast at those times.



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Fig. 18. MAC Load per PAN (bits/sec)

5. CONCLUSION

The study aimed at implementing the selected Key Performance Indicators (KPIs) for enhanced rice production towards addressing five major challenges that face rice farmers in developing countries like Nigeria. The result of the design and simulation indicated the possibility of integrating different sensor types to work cooperatively to sense different environmental variables simultaneously. The learning experience in the course of the study is that an integrated and enhanced wireless sensor network (eWSN) is realizable and suitable for improved rice production since it has the capability of managing and maintaining the scarce resources at the farmer's disposal.

Future studies should consider developing protocols and standards for ease of interoperability and low-cost efficient energy harvesting mechanisms for energy sustainability of the wireless network communication architecture which is envisaged as a limiting factor on the proposed system.

CONFLICTS OF INTEREST

The Author declares no conflict of interest

References

- [1] Sule Abiodun (2021) "Food Security in Nigeria: Effect on small scale Agribusiness, Aquaculture Challenges". International Journal of Research Publication and Reviews, Vol. 2, issue 9, pp 1159-1165.
- [2] Agbaeze E.K., Udeh S.N., Omwuka I.O. (2015), "Resolving Nigeria's dependency on Oil The Derivation Model", *Journal of African Studies and Development*.
- [3] Langsi D.J., Nukenine E.N., Fokunang C.N., Katamsadam T.H. (2017) "Evaluation of Post-Harvest Maize Treatment Phyto-insecticide use on Maize varieties in Mezam Division". International Network for Natural Sciences, Vol. 10, Issue 3, pp 9-17.

- [4] Seck, P.A., Toure, A. A., Coulibaly, J. Y., Diagne. A. and Wopereis, M. C. S. (2013) "Impact of rice research on income, poverty and food security in Africa: an ex-ante analysis", *CABInternational*, *Wallingford*, UK. pp. 24-33.
- [5] Zarmai J.U., Okwu O.J., Dawang C.N., Nankat J.D. (2014) "A Review of Information needs of Rice farmers: A Panacea for Food Security and Poverty Alleviation". Journal of Economics and Sustenable Development, Vol. 5, No.2.
- [6] Fashola O.O, Oladele O.I, Alabi M O Tologbonse D and Wakatsuk T (2007), "Socio-economic factors influencing the adoption of Sawah rice production technology in Nigeria", *Journal of Agriculture and Environment* 5(1): 239-242
- [7] Libby George (2020) "A growing problem: Nigerian rice farmers fall short after borders close" https://www.reuters.com/article/us-nigeria-economy-rice-idUSKBN1ZM109.
- [8] Shaibu U.M., and Shaibu Y.A. (2017) "Adoption Determinants of Improved Farming Technologies: An Assessment of Rural Rice Farmers in Kogi State, Nigeria". Journal of Agriculture and Rural Research, Vol. 1, Issue 1, pp 5-10.
- [9] Nwabueze C.A, Akaneme S.A & Nwabueze R.I (2019) "Enhancing Agricultural Production Using Wireless Sensor Network" Iconic Research and Engineering Journals, Volume 2 Issue 11 | ISSN: 2456-8880, pp 274-284.
- [10] Nilesh Kuchekar & Rajendraprasad Pagare (2021), "Design & Implementation Of Automatic Irrigation System Using Wireless Sensor Network & Zigbee Module", *International Journal Of Innovation In Engineering, Research And Technology (IJIERT).*
- [11] Mehamed Ahmed Abdurrahman & Md. Asdaque Hussain (2015), "Simulation Studies on Wireless Monitoring and Control of Water and Irrigation System using IEEE 802.15.4 MAC", International Journal of Computer and Information Technology (ISSN: 2279 – 0764) Volume 04 – Issue 04.
- [12] Sultana Parween, Manjhi P.K., and Somnath Sinha (2018) "Design of automated irrigation system using Zigbee". International Journal of Engineering Research and Advanced Development. Vol 4, issue 4, pp 46-50.
- [13] Agbetuyi Ayoade Felix, Orovwode Hope. E, AwelewA Ayokunle. A, Wara Samuel.T and Oyediran Tobiloba (2016), "Design and Implementation of an Automatic Irrigation System Based on Monitoring Soil Moisture", *Journal of Electrical Engineering*.
- [14] Bouketir O., (2019) "An Automatic Irrigation system for water optimization in the Algerian Agricultural Sector". Agricultural Science and Technology journal, Vol II, No. 2, pp 133-137.
- [15] Lou Xiaokang, Zhang Lixin, Zhang Xueyuan, Fan Jinkie, Hu Xue, Li Chunzhi (2020) "Design of Intelligent farmland environment monitoring system based on wireless sensor network". Journal of Physics: Conference series IOP Publishers, pp 1-8.
- [16] Lenis Saweda O. Liverpool-Tasie2, Christopher B. Barrett and Megan B. Sheahan(2013),"Understanding fertilizer use and profitability for rice production across Nigeria's diverse agro ecological conditions;" Selected Paper prepared for presentation at the Annual Bank Conference on Africa, June 23- 24th.
- [17] Ezedinma, C. I. (2008). "Impact of Trade on Domestic Rice Production and the challenge of Selfsufficiency in Nigeria. Ibadan, Nigeria".
- [18] Grant W, CharetteD, Field M (2009), "Global Food Security Response West Africa Rice Value Chain Analysis: A Nigeria Rice Study". *A report prepared for the USAID, Micro Report* p: 159.
- [19] Iftekharul Hoque (2013), "Modelling and Performance study of large scale Zigbee Based green House monitoring and control network". A thesis (master of Engineering) in Electronic and Communication Engineering, Massey University, Albany, New Zealand pp 12-96.
- [20] Sukhvinder S.B. and Ajay K.S. (2010), "Comparative performance investigation of different scenarios for 802.15.4 WPAN". International Journal of Computer Science Issues, Vol. 7, Issue 2, pp 16-20.
- [21] Sercan V., Ebubekir E., (2015) "Design and Simulation of Wireless Sensor Network Topologies using the Zigbee standard". International Journal of Computer Networks and Application, Vol.2, Issue 3 pp 135-143.