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# A Multi-Input Power System deployment for Enhanced Rice Production

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***Keywords*— Coordinator, Multi-input Power, Router, Sensor Node, Wireless Sensor Network, Zigbee.**

***Abstract*— *Owing to the energy supply challenges observed when Wireless Sensor Networks (WSNs) are implemented for effective coordination and transmission of packets for enhanced rice production, the study focused on actualizing an effective and coordinated power system configuration for enhanced rice production, where a multi-input power model is designed to complement the power of the coordinator (sink node) and the actuator systems. The amount of power required for effective energy distribution is evaluated in the study. The farmland implementation involves coordinated application of fertilizer, weed control/prevention, pest/disease control, rodents and bird's invasion using a Zigbee-based Wireless Sensor Network (WSN). Modelling of various networks to demonstrate data sensing of different environmental variables and energy consumption in a given farm land was demonstrated.***

## I. INTRODUCTION

Food production is generally energy intensive when modern technology is deployed for irrigation and other technology driven devices such as in smart monitoring, coordination and control using wireless-based sensor applications. Energy supply shortage or unavailability in modern farming systems in Nigeria has adverse implications for agricultural yields. The acute energy supply shortage has to a greater extent impacted negatively on the country's economy and more especially in agricultural sector. It has adversely paralysed the country's industrial sector by compelling them to adopt to old self-energy generation using fossil fuel generators, leading to increase in the production cost [1].

Rice is undisputedly considered a universal food crop, being a staple food for well over half the world population, particularly of India, China, and a number of other countries in Africa and Asia [2]. Rice remains an essential commodity in Nigeria and is required to be made readily available to meet up with the consumption rate and as well the population growth. The underlining principal remains on how the growing demands could be met without need for importation. Recently, there was a tremendous improvement in rice production in Nigeria, which has recorded a peak production of 4.9 million Metric Tonnes (MT) by farmers in Nigeria. Notwithstanding 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) [3][4]. This means that a gap of about 2.1 million MT needs to be cushioned. From recent studies, the limited capacity of the Nigerian rice sector to meet the domestic demand has been attributed to several factors, notable among them are the declining productivity due to low adoption of improved production practice and poor implementation of adequate power supply structure on existing modern instruments.

Enhanced productivity is realizable if the observed limited factors could be improved. One of the factors attributable to the limited rice productivity in Nigeria even with the implementation of modern farm facilities is the inadequacy in power supply to drive the electronic and wireless devices.

Since modern farming is anchored on technology such as Wireless Sensor Networks (WSN), such technological devices would require efficient energy sources for its operations and also in driving some basic units such as the sensing unit, control unit and water source unit. Unfortunately, as stated earlier, most Nigerian improved production farmlands are so poorly energy structured which has been a limiting factor for productivity. For instance, a World Bank report says that businesses in Nigeria loss about $29 billion yearly due to poor electricity [5]. The situation is far more critical in semi-urban and rural areas where agricultural activities actually take place. It is estimated that about 85 million Nigerians don't have access to grid electricity, hence making the country largest energy deficit in the world with consequential impart of about 2% of GDP [6]. Another consequential effect of non-availability of power in farm areas apart from poor productivity is that rural farmers would resort and rely solely on the crude method of agricultural practices, whose productivity will be limited relative to the consumption demand. On the other hand, it makes the profession unattractive to the younger generation to practice.

To increase agricultural production in such a manner and size that would cater for the ever-increasing population in Nigeria, requires hybrid off-grid power generation solutions where energy would be readily available to power the devices used at the farmland. The best option would be to have multiple energy sources at farm level devoid of grid power. The study tends to address the problem associated with limited power supply on modern farming vis-à-vis in rice production. A typical modern farm structure considered in the study uses wireless sensor network technology capable of carrying out the following functions: (a) automated irrigation of a rice farmland for year-round production, (b) disease control/prevention via automated application of pesticides, (c) weed control/prevention via automated application of herbicides and fertilizer and (d) rodents, birds' and animal control/prevention via automated buzzer activation mechanism. For efficient implementation of a control system would require reliable energy source distribution to power the devices, hence the proposed study on deployment of a multi-input power model for efficient and dynamic energy distribution in an integrated rice farmland.

## II. LITERATURE

### 2.1 Wireless Sensor Network

A Wireless Sensor Network (WSN) consists of spatially distributed autonomous sensors to monitor physical or environmental conditions (i.e., temperature, sound, vibration, pressure, humidity etc.) and to cooperatively pass their data through the network to a main location [7]. WSN is configured to house a few to several hundreds or even thousands of sensors or nodes, where each node is connected to one (or sometimes several) sensors. Each sensor network node has typically several parts: a radio transceiver with an internal antenna or connection to an external antenna, a microcontroller, an electronic circuit for interfacing with the sensors and an energy source (i.e., battery or an embedded form of energy harvesting).

A wireless sensor network is made up of three components: Sensor Nodes, Task Manager Node (User) and Interconnect Backbone as shown in figure 1[7].

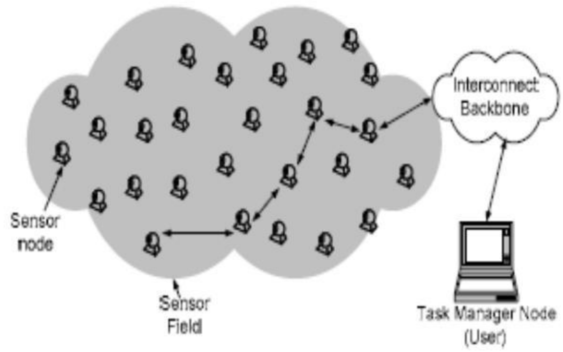


*Fig 1: Wireless Sensor Network (WSN) [7].*

The basic hardware components of a sensor node include a radio transceiver, an embedded processor, internal and external memories, a power source and one or more sensors [8]. In a sensor node, power is consumed by sensing, communication and data processing. More energy is required for data communication than for sensing and data processing. Power can be stored in batteries or capacitors; batteries remain the main source of power supply for sensor nodes.

### Wireless Sensor Network Testbeds

WSN testbeds are deployed in a controlled environment. It serves as an intermediate tool between a real deployment and a simulator or emulator. It provides researchers a way to test their protocols, algorithms, network issues and applications. Preferred standards deployed in this study is Zigbee technology compared with other standards such as Bluetooth and Wireless Local Area Network (WLAN). The choice was because Bluetooth and

WLAN are not well suited for low-power sensor applications. There are three different types of ZigBee devices as shown in figure 2.


*Fig. 2: Types of Zigbee devices in OPNET [9]*

### (a) ZigBee Coordinator (ZC)

The coordinator in every network is responsible for the creation of a network, selection of a channel, and permission to other nodes to connect to the network. All the data transferred from the connected node will be stored in a coordinator. It works like a router or a bridge between different networks [10].

### (b) ZigBee Router (ZR)

A router may act as an intermediate device between the end device and Coordinator or between routers for passing data from other End Devices to the Coordinator. In some networks, End Devices may transfer data directly to the coordinator or from End Devices to other routers. A router can act as an end device and during time, its routing functionality will be inactive. Routers use less memory than ZigBee Coordinators, and cost less, and have the ability to work with all types of topologies [11].

### (c) ZigBee End Devices (ZED)

The end devices are the end point of any network connected to routers and a Coordinator. It does not have the routing functionality. End devices may have contact with only parent node (either Coordinator or Router). End devices go to sleep mode to save battery power and do not have many duties compared to the Coordinator and Routers, which makes them less costly [11].

### ZigBee Specifications

Table 1 presents the basic specifications of the Zigbee standard

*Table 1: Specifications of the Zigbee standard [12]*

| **Parameters** | **Zigbee Value** |
|---|---|
| Transmission Range (meters) | 1-100 |
| Battery life (days) | 100 – 1000 |
| Network Size(No. of nodes) | >64000 |
| Throughput(kb/s) | 20-250 |
| Transmission Band | 868MHz,915Mhz, 2459MHz |
| Complexity | Low |
| Wake up Delay | 15mSec |
| Maximum Power | 1mW |
| Maximum Child | 254 |

## III. METHODS

To demonstrate data sensing of different environmental variables in a given farm land, network devices were varied 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 to demonstrate integration of different sensor types, monitoring different environmental variables simultaneously, yet constituting a single unit of WSN working cooperatively [3]. 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

The modeling of the WSN 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) [3]. 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

### 3.1 System Block Diagram

Figure 3 shows the block diagram of a WSN model, representing a typical farmland of 100m x 100m dimension used as a baseline for the study. Sensors are assumed to be sparsely distributed across the farmland consisting of Zigbee end devices (ZED), Zigbee routers (ZR), Zigbee coordinator (ZC) and actuators. The WSN is connected to a monitoring point via access point gateway, with a wireless database server and a PC for on-the-premise monitoring while a host computer is connected via an internet protocol (IP) cloud for remote monitoring. 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 [3]. 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. A multi-input uninterrupted energy source is connected to power the sensing unit and the control/actuator units. The system is designed to ensure adequate power supply for proper control and coordination.

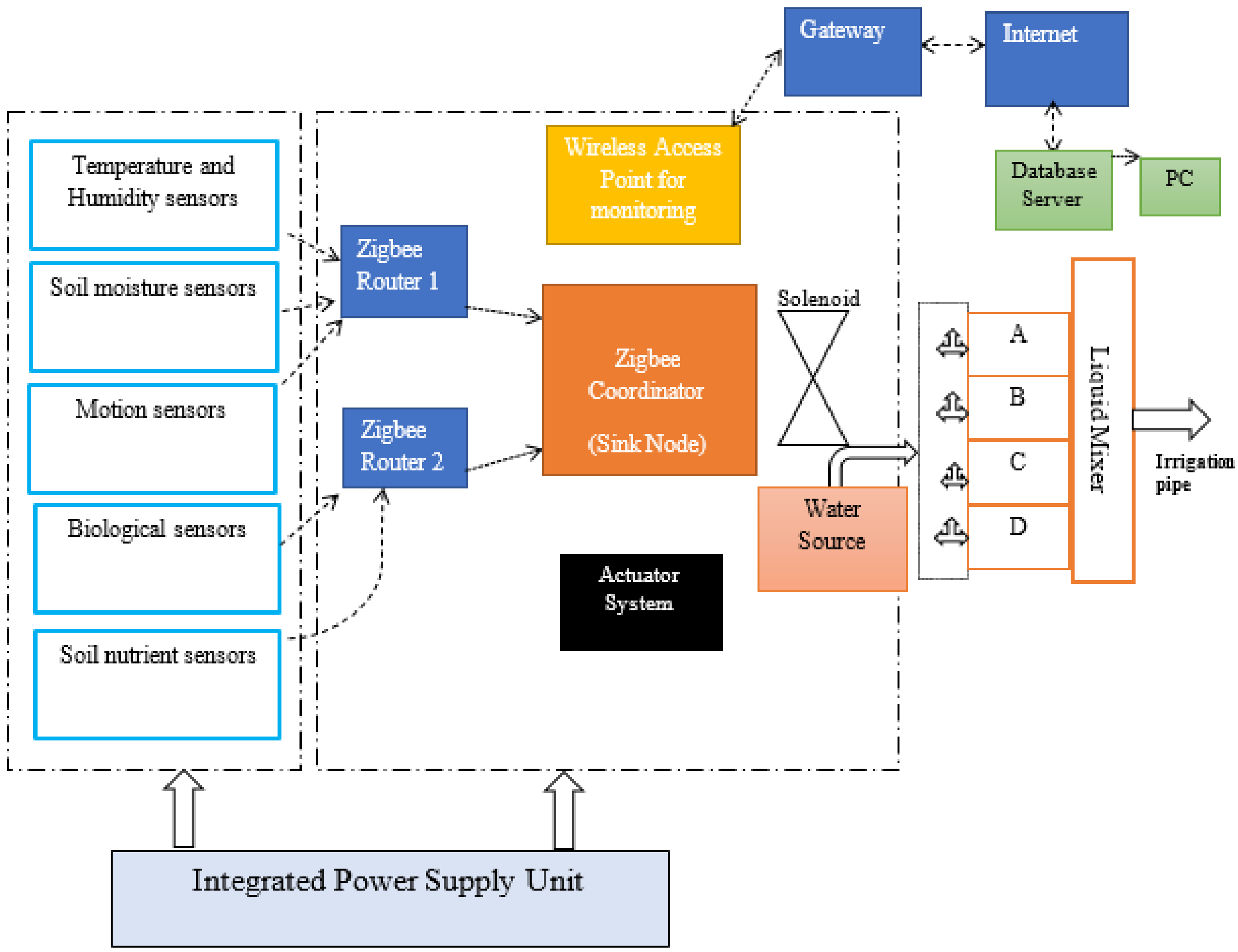


*Fig. 3: Block diagram of a Model Farm network with integrated energy supply*

### 3.2 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.

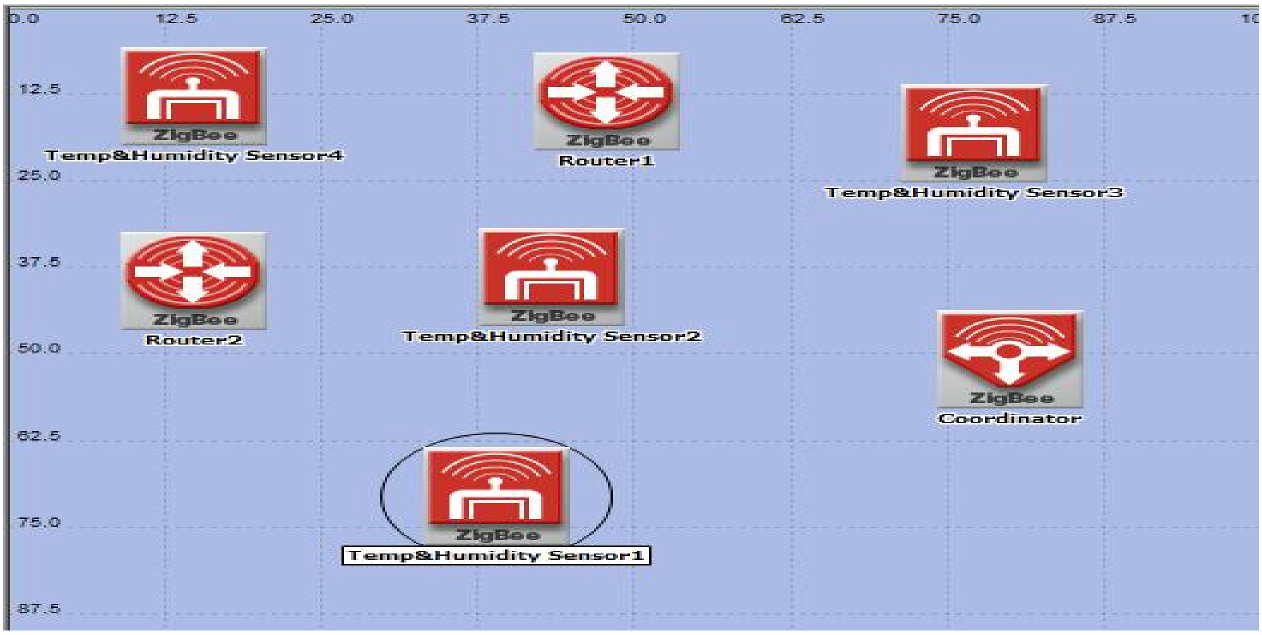


*Fig. 4: Simulation Setup of Scenario 1*

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.

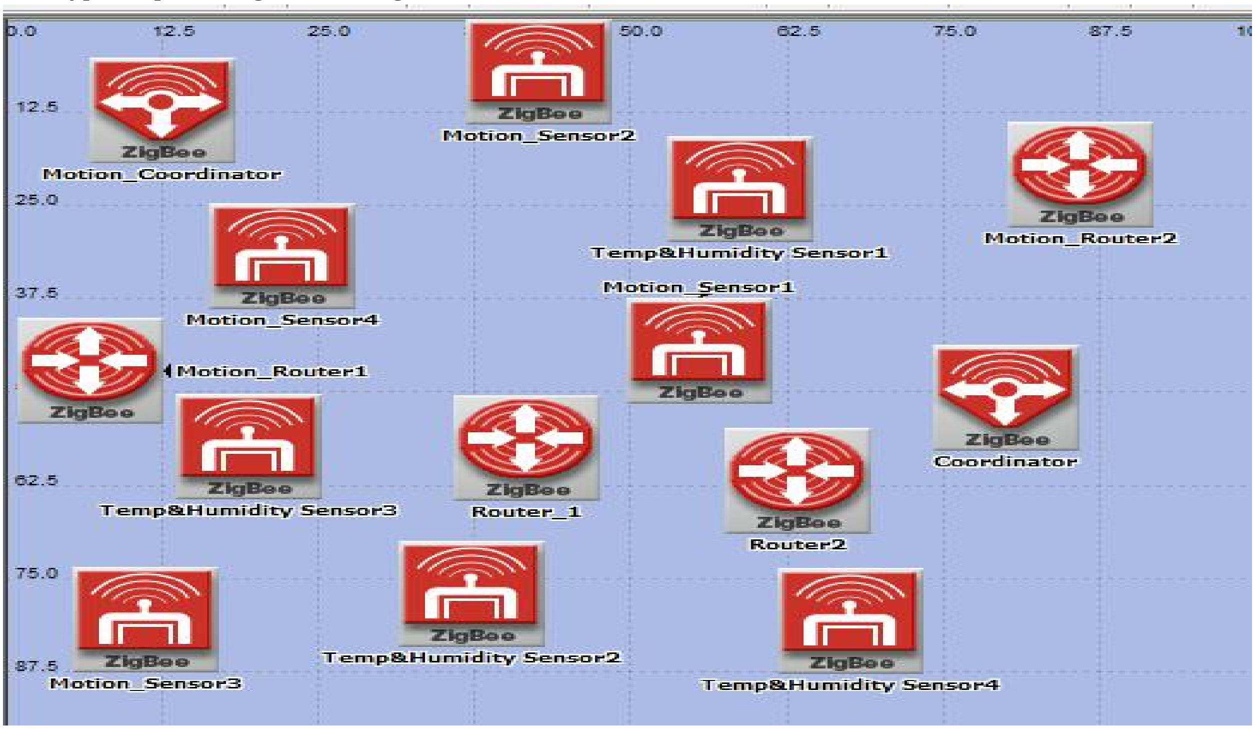


*Fig. 5: Simulation Setup of Scenario 2*

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.

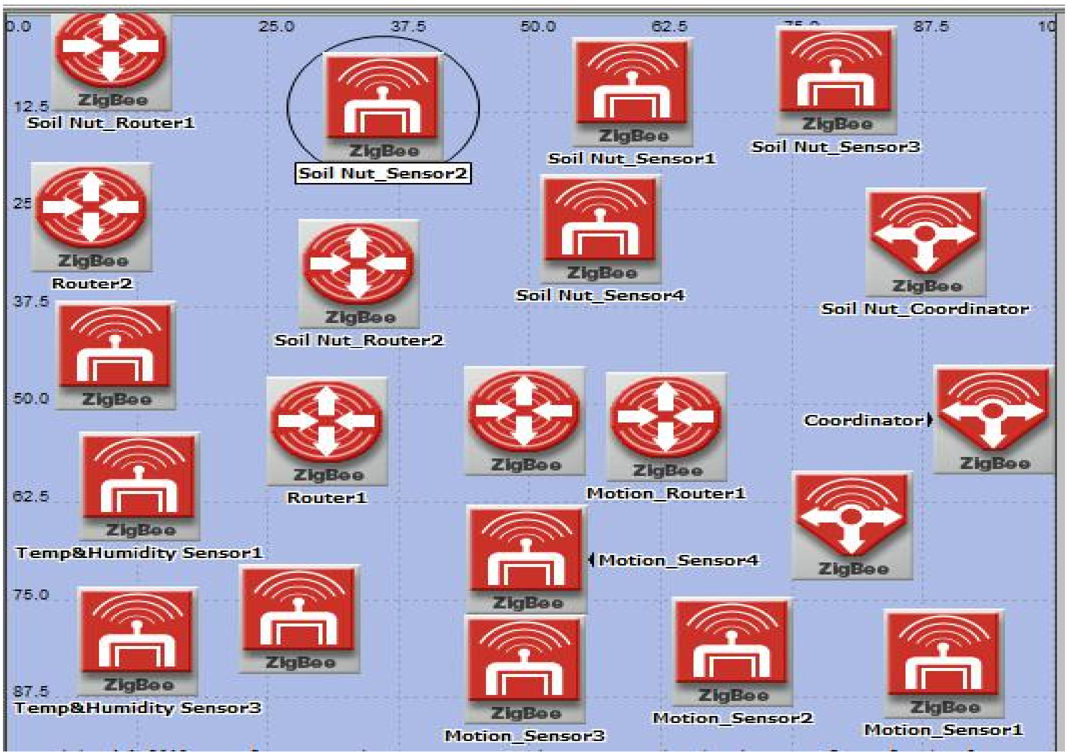


*Fig. 6: Simulation Setup of Scenario 3*

### 3.3 Design Process for Multi-input Power System

To mitigate the problem of limited power capability associated with WSN, a multi-input power model was designed to supplement the power of the coordinator (sink node) and the actuator systems while the end devices would utilize battery energy since more processing occur at the coordinator level.

To achieve this, solar energy is coupled and delivered to the power circuitry of the coordinator through a charging circuit and can also be powered by the wireless powered (Wp) source wirelessly in the event that the solar energy is not available. Figure 7 shows the block diagram of the multi-input power model of the network.

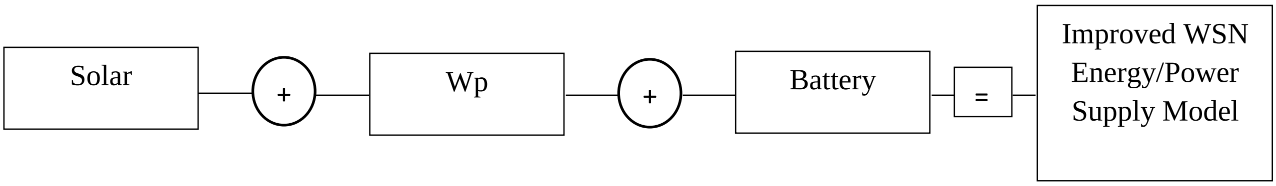


*Fig. 7: A simple block diagram of the WSN power supply system.*

From Fig. 7;

Let S = solar energy from the sun.

$W_p$ = Energy obtained from the wireless power system.

$B^+$ = Energy stored in the battery backup system.

The power supply model can be represented as: [13]

$$\sum_n [(S + Wp + B^+) - \varphi] = P_{supply}\ (j/s) \qquad (1)$$

Where $\psi$ is an error factor (0.1 – 0.01), assumed of the circuit which represents power loss due to circuit imperfection.

### 3.4 Power Model Schematic Diagram and Operation

The system is configured such that energy from the solar system is used for charging the battery and/or powering the coordinator (sink) and the actuator systems. The wireless power system is activated by a dark sensor switch when solar energy is unavailable and it transmits energy to the coordinator if there is a potential/energy difference between the battery terminal and the wireless power sensor terminal coordinated by the relay coil as shown in figure 8.

It can be seen from figure 9 that the solar panel power is fed to a charging circuit, and also to a Single Pole Double Throw (SPDT) relay coil (via a 78L12 voltage regulator). This relay remains activated as long as the solar panel voltage is persistent, and as soon as the voltage falls below threshold, the relay contacts automatically switch the mains Switching Mode Power Supply (SMPS) adapter voltage through the wireless power receiver to the charging circuit which then stores some energy and powers the coordinator electronics through the regulated adjustable 5-volt circuit model of figure 8 designed using electronic circuit wizard. The output voltage can be fine-tuned to the desired value (usually 4.5-5.5V) with the help of potentiometer (variable resistor (VR1)) connected just behind the 5-volt regulator. The regulated 5-volt circuit is to be built into the coordinator power system and the actuator system.

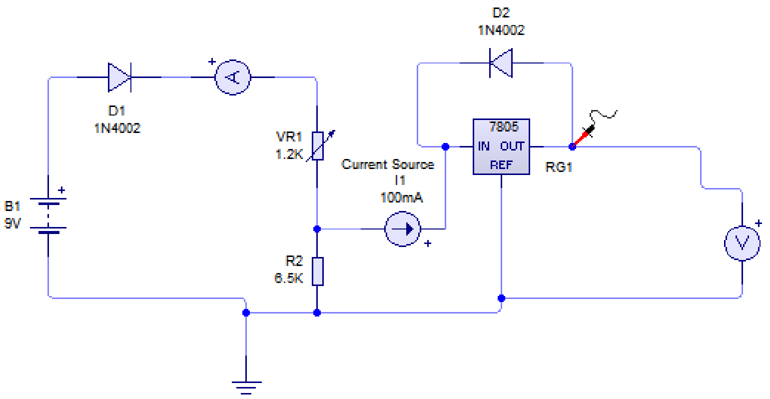


*Fig. 8: Volt regulated power supply model.*

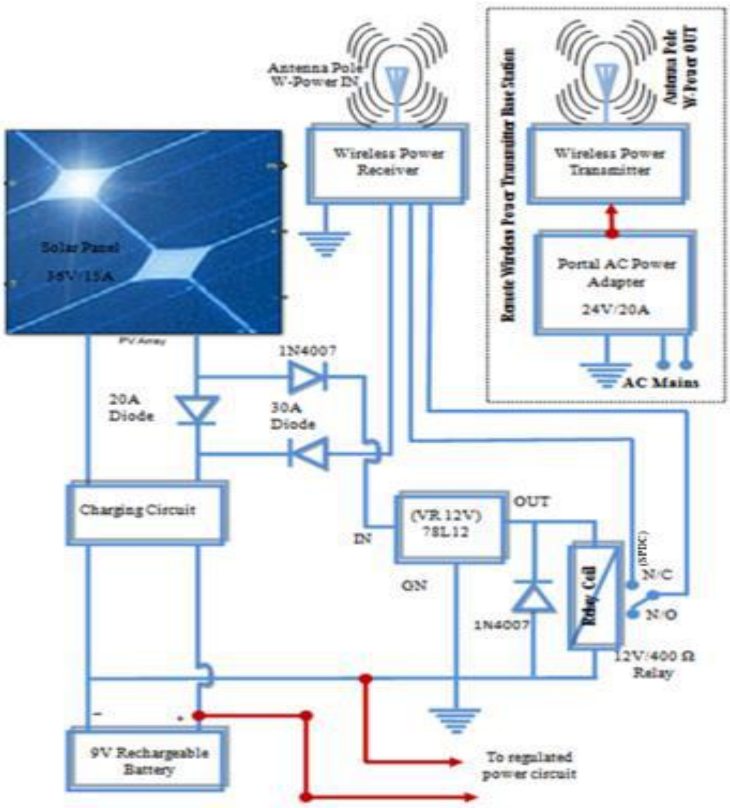


*Fig. 9: Schematic diagram of the WSN power system*

In order to ensure the system performs as expected, it is important to evaluate what the right energy requirement would be.

The energy model of the network is developed based on the following design assumptions:

1. Assume that it takes 1 joule/sec (1 watt) of energy to move one unit charge of electric current containing one packet of sensed data from one sensor node to the router node;

2. Same quantity of energy is expended by the router node to move the data to the coordinator;

3. 1 joule/sec (1 watt) of energy is needed to power ON and activate a sensor node. At standby mode, power consumption is equal to zero; for simplicity's sake;

4. It takes 1 joule/sec (1 watt) of energy for a node to sense and gather measurement signals such as temperature, distance etc.;

5. The water pump is fractional horse power (1/3hp, 250Watt) liquid pump, which does not operate all the time except when actuation signal is received.

Also,

Let $x$ = ON-OFF mode energy in joules (Activation energy);

$y$= energy required to gather measurement data (temperature, proximity, etc.), that is, Sensing Energy

$t$ = Operation time (1 sec)

$k$ = Gain constant (1-1.5; assumed)

$m$ = pump/actuator energy consumption.

λ = Coordinator node energy consumption.

$\beta$ = energy consumption of Router node (Transmit and Reception)

$\alpha$ = energy required to transmit sensed data (propagation energy).

Then;

**Energy consumed by a node during active state**

$$(x+y+\alpha)kt-\psi = P_{Tx} = P_{Rx} \ (j/s) \quad (2)$$

**Energy consumed by a node during inactive state**

$$\sum(x+y+\alpha)\,kt-\Psi = 0(j/s) \quad (3)$$

**Energy consumed by the router node during active state**

$$n(\beta+x)kt-\psi\,(j/s) \quad (4)$$

Where $n$ is the number of simultaneous operations/quantity of packets arriving at the router at any given time, *t*.

**Total Node Energy consumption at any point in time**

$$\sum_{i,j}^{i} n(x+y+\alpha)\,kt-\Psi(j/s) \quad (5)$$

**Coordinator Energy Consumption**

$$n(\lambda)kt-\psi\,(j/s) \quad (6)$$

**Gross Farm Field Energy Consumption**

Sensor node energy + Router node energy + Coordinator energy + Pump/Actuator energy, that is;

$$\sum_{j,j\to 0}^{i}([(x+y+\alpha)kt-\psi]+[n(\beta+x)kt-\psi]+[n(\lambda)kt-\psi]+(m)) = Pconsumed \ \text{(j/s)} \quad (7)$$

**3.5 Parameter Computation**

From the power consumption model and basic assumptions presented in section 3.4, the average energy requirement of each unit and the entire network can be estimated as follows:

**(i) Energy Consumption at the Node level**

Citing from equations 2 and 3;

From our design assumptions we have;

$$x=y=\alpha=1 \quad (8)$$

With $k=1.3$ (mid-range value considered optimal), and $t(s)=1$;

Eqn. 5 now becomes

$$(1+1+1)*1.3(1)-\psi = P_{TxRx} \ \text{(j/s)} \quad (9)$$

Applying mid-range value of energy loss, $\psi$ of 0.055;

$$P_{Tx/Rx} = 3.845(j/s) \quad (10)$$

For $n$ number of nodes, total average energy is

$$n(P_{Tx/Rx}) = n(3.845)(j/s) \quad (11)$$

**(ii) Energy Consumption at the Router/Repeater level**

$$n(\beta+x)kt-\psi\,(j/s) \quad (12)$$

Where $n$ is the number of packets from end devices arriving at the router at a given time, $t$.

$$n(2)1.3(1)-0.055 = 2.6n-0.055(j/s) \quad (13)$$

**(iii)Energy Consumption at the Coordinator level**

$$n(\lambda)kt-\psi\,(j/s) \quad (14)$$

Where $n$ is the number of packets arriving at the coordinator at a given time, $t$.

The $n$ factor at the coordinator expectedly should be higher than at router since packets from various routers arrive at the coordinator for processing.

Following from eqn. 14;

$n(1)1.3(1) - 0.055\ (j/s)$

$$\therefore\ P_{Cordinator} = 1.3n - 0.055\ (j/s) \qquad (15)$$

**Gross/average power consumption of the farm field**

$$\sum_{j,j\to 0}^{i}(P_{node} + P_{router} + P_{Cordinator} + P_{Actuators/pump} + P_{others}) = P_{gross}\ \ (j/s) \qquad (16)$$

Where $P_{others}$ are powers consumed by lighting system, etc. Assuming $P_{others} = 10\%$ of Coordinator Power $= 0.13n - 0.0055$ and

$$P_{pump/actuator} = \frac{1}{3}\ of\ 1hp = \frac{1}{3} * 750 = 250\ j/s$$

then,

$$P_{av} = (3.84 + 2.6n - 0.055 + 1.3n - 0.055 + 0.13n - 0.0055 + 250)\ (j/s) \qquad (17)$$

$$= 4.03n + 253.73\ (j/s) \qquad (18)$$

The proposed power model for enhanced WSN is expected to supply this amount of power to the farm, with expansion factor taken into consideration. This means that the computed power can be varied either upward or downward to meet the energy requirement of the proposed farm.

## IV. RESULTS AND DISCUSSION

The 3-power sources designed for the farm were modeled and represented mathematically as a combination of the various sources as represented in equation 1. Expectedly, the equation of the power combination is suggestive of the fact that the system will be sustained for a longer period of time than it would have been for a single source of power. This is true since any of the sources, say, the battery can independently power the system but can get drained up much faster.

### 4.1. Result of Power System Evaluation for the WSN and the Actuator System

The energy requirement for each component unit of the WSN and actuator system was evaluated and presented. For Zigbee end devices (ZEDs), the amount of energy required to sense its data and transmit same is given by

$(x + y + \alpha)kt - \psi = P_{Tx} = P_{Rx}\ (j/s)$.

While the amount of energy required by Zigbee Router (ZR) during active state is given by $n(\beta + x)kt - \psi\ (j/s)$.

And the amount of energy required by a Zigbee Coordinator (ZC) during active state is given by

$n(\lambda)kt - \psi\ (j/s)$.

The result of the computation indicated that about $3.845$ (j/s) will be required by a Zigbee end device for its operation during active state.

For Zigbee router, the computed energy is $2.6n - 0.055$ (j/s) while for Zigbee coordinator, the value is $1.3n - 0.055$ (j/s). The n factor is the amount of data packets arriving from Zigbee end devices for the router, and from Zigbee routers for the coordinator. It is expected that the value of n is higher at the coordinator than at the router. This is so since all the routers route their data to the coordinator.

Energy requirement of the pump/actuator is a fractional horse power (1/3hp), i.e., 1/3*750 = 250 (j/s).

Although the computed energy values for Zigbee end device, Zigbee router and the coordinator are low, they can be seen to be high in comparison with standard energy definition for Zigbee devices. This is understandable since parametric values were assumed for simplicity of computation.

Since energy is a scarce commodity in most rural areas in Nigeria and to ensure network longevity, an improved multi-input power system comprising an integration of solar energy, wireless power and battery source could serve as an enhanced energy power supply for improved rice production.

## V. CONCLUSION

Adoption of new and modern agricultural practices is said to be driven by access to affordable and uninterrupted sources of energy. The implementation of a dynamic multi-input power system for enhanced rice production is proposed in the study to address the predominant issue affecting modern farming especially in rice production in Nigeria. Energy-harvesting deployment was introduced which converts ambient energy from solar and wireless energy from wireless transmitted network to electrical energy with the aim to revolutionize the power supply on sensor nodes. The study was able to actualize an effective and coordinated power system configuration for improved rice production to address the classical limitation of inadequate energy supply and distribution on the deployed WSN. The amount of power required for effective energy distribution in a specified rice farmland was evaluated in the study. The study context could be implemented in other farm sectors as an enhanced approach for efficient energy supply.

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