Remote Real-Time Monitoring System for Oil and Gas Gathering Station based on Wireless Sensor Networks on Cloud Platform in the Niger Delta

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***Abstract*-Various activity monitoring applications have been implemented using Wireless Sensor Network (WSN). WSN provides a platform to utilize information from connected sensors. This paper presents a real-time monitoring system for a gathering station based on a wireless sensor network on the ZigBee network to monitor sensor output, where sensors are used to measure temperature, pressure, and other data. The received data is transmitted to the cloud data center for analysis in real-time and accessed from websites and mobile phones. When the sensor data reaches the threshold limit, the user receives an alarm notification on the cell phone for timely action.**

***Keywords*: Real-Time Monitoring, WSN, GPRS, ZigBee, User Interface, Gathering Station.**

I. INTRODUCTION

The real oilfield consists of the Reservoirs, Wells, the Production gathering system, the Distribution Network, and the Injection Network. The Production gathering system receives the fluid from the functional producing wells and delivers it to the flow station or gathering station for the separation of fluids/ processing into its constituent components of Oil, Water, and Gas. The Injection network injects fluid (water or gas) into the reservoir to enhance further recovery. Figure 1 shows a typical station.

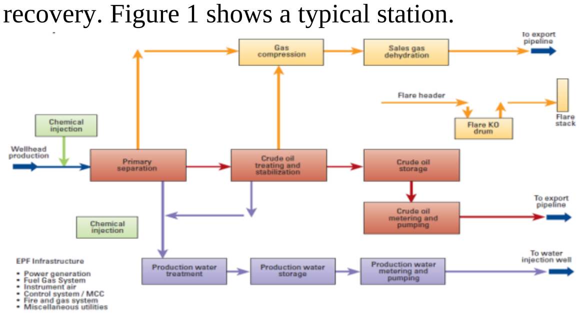


Figure 1: Typical Oil and Gas Gathering Station

Nigeria is geographically located at 10^0N, 8^0E within the Sub-Sahara African region with a total land area of 923,768sqkm (land-910768sqkm, water-13000sqkm, and coastline-853km) with a population of 206,139,589(2020) and shares borders with Benin(773km) in the west, Cameroon(1960km) in the East, Chad(87km) and Niger (1497km) in the North and the Gulf of Guinea to the South [1], [2]. The current gas reserve of Nigeria stands at 202trn cubic feet and production is now at 8.5billion standard cubic per day (bscfd). The gas export is 3.7bscf which represents 4.3% of global gas produced while 2.7bscf representing 32% is used for reinjection and gas lift at the upstream sector and Nigeria's domestic gas consumption stands at 1.5bscf representing 18% of the total gas produced. The amount of gas flared is 0.6bscf representing 7% in the Niger Delta [3]. The oil reserve of Nigeria is 36.972billion barrels, which is the equivalent of 207.6bscf of natural gas, which implies that the gas reserve of Nigeria is about 900times the country's proven oil reserve representing the largest producers of Natural gas in Africa and ninth in the world [4]. Nigeria joined the league of oil-producing nations in 1956 with the discovery of oil in commercial quantity in Oloibiri in the Niger Delta region of Bayelsa state. The actual production started in 1958 with a recorded production of 51,000bbl/d. The Nigeria oil and gas industry is continuing to be the mainstay of Nigeria's economy contributing 10% to GDP, 65% to Government revenue, and 88% of foreign earnings in 2019. However, it accounted for 95% foreign earnings, 40% or more of its GDP, and 75% of federal government total revenue in 2016 [5]. A site map of Nigeria is shown in figure 2.

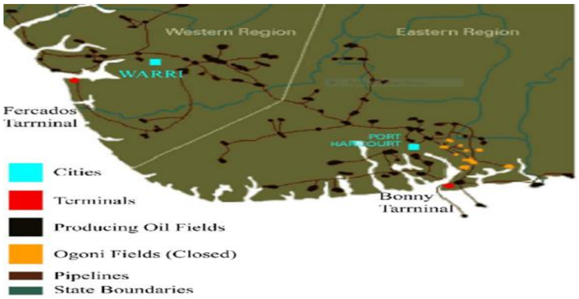


Figure 2: Site Map of Oilfields in the Niger Delta

II. RELATED WORK

Wireless Sensor Network (WSN) Gathering station based on cloud data center provides a platform to visualize and analyze the live sensor data. WSN belongs to the family of embedded devices consisting of a microcontroller, a radio, sensors, and a battery [6]. Several wireless sensor networks are deployed in the oil and gas domain. These include terrestrial WSN which are positioned into either structured or unstructured nodes in specific areas where an ad-hoc network is used to communicate between the sensor nodes [7]. Underground WSN is placed under the ground for collecting information or monitoring underground conditions [8] and Underwater WSNs consist of vehicles and sensors deployed underwater and interact between nodes and ground-based stations [9], whereas Multimedia WSN multimedia nodes collect video, audio, image and transmit to sink [10], and Mobile WSN sensor nodes are mobile and can interact with its environment [6]. Many sensors are connected in nodes to collect real-time information. This collected sensor data is transmitted to the main cloud data centre via the internet. WSN can incorporate real-time monitoring, collect and process the information of the objects in the geographical area and transmit the data to users who are subscribed to the service [11]. A monitoring system requires real-time communication with the sensor node, cloud data center, and database so that it can store all the sensor node data at the cloud platform and generate alerts notification based on the sensed data. Thus, it is necessary to consider a real-time operation while designing a monitoring application. WSN is based on an embedded device and has limited resources like power and memory. Thus, it is necessary to consider power, real-time functionality, and low memory footprint while designing a real-time monitoring system. In this work, the sensor node has been implemented to provide real-time monitoring of temperature and pressure data sensed by sensors via the ZigBee protocol [12], [13]. Instrumentation measures the value of plant parameters, such as pressure, flow rate, fluid level, temperature, and supplies standard signals of 4-20mA electronic signal and 20-100kPa pneumatic signal in proportion to the measured parameter. Pressure is the measurement of force per unit area or surface area and it is mathematically expressed as:

$$\text{Pressure} = \text{Force}/\text{Area}$$

The frequently used unit in the field is pound per square inch(PSI), equivalent to 7000Pa in the metric unit. The purpose of pressure is to indicate a standard(4-20mA) electronic signal to represent the process pressure. Some readily used pressure sensing elements are Diaphragms, Bourdon tube, or bellow. Level measurement on the other hand employs sight glasses to view the level or height of the fluid. Floats connected to the potentiometer vary in proportion motion to the amount of motion of the float. This can be expressed as:

$P_r = WH$

where P_r = Pressure(Pa)

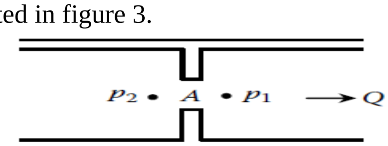
W = Weight of fluid density(N/m^3) = ρg

H=Height of liquid column(m)

ρ=density(kg/m^3)

g=acceleration due to gravity ($9.8m/s^2$)

The liquid level of the tank is determined from the pressure reading at constant density. However, Differential pressure(DP) capsules are used to measure the pressure at the base of the tank. The orifice method which is based on the Bernoulli principle can be used to measure the flow rate. It is a measure of the velocity change of kinetic energy. This shows that velocity depends on the difference of the liquid to the flow through the conduit(meter-run). This is indicated in figure 3.



This shows an inverse relationship, meaning that when pressure increases, velocity decreases. The orifice plate is a thin plate with an orifice or hole in the middle placed in the meter-run(Pipe) through which the fluid flows. The pressure is created by the restriction caused by the orifice plate. The maximum convergence occurs immediately downstream of the orifice plate which is called the vena contracta point. The volume and mass flowrate is stated mathematically as

$$Q = C_d \cdot A_2 \cdot \sqrt{\frac{1}{1-\beta^4}} \cdot \sqrt{2(P_1 - P_2)/\rho}$$

Where:
C_d=Discharge coefficient
A_2=Area of diaphragm bore
β=Ratio of d_2 to d_1
P_1=Pressure at steady flow
P_2=Pressure at vena contracta
ρ=Liquid density

III. METHODOLOGY

A. System Design

The real-time gathering station on cloud platform consists of the following; A) Design for WSN Sensor Node; B) Function Design; C) Wireless Communication Protocol; D) System Node Implementation and E) Cloud Data Centre Interface.

B. Design consideration for WSN Sensor Node

Design for WSN sensor node can be as follows:

- Multitasking: The application should provide each task to run independently without a deadlock.
- Synchronization: All tasks should synchronize with each other to share the resources.
- Low power consumption: The system should provide less power consumption to enhance the sensor node lifetime.
- Small footprint: Program size should be small so lesser memory will be consumed by the system while running the program.

C. Function Design

The function construction as shown in figure 4 is to gather real-time data at the cloud data center and to show value updates on web apps and mobile apps, send and receive data on the cloud platform and also view and analyze data. The system also provides alarm notifications for user management. Wireless sensor technology gathers the data and sends the data to the cloud for hosting on web applications. The GPRS communication module is used to send alarm notifications to the subscribed numbers and also manage the threshold limit for proper action.

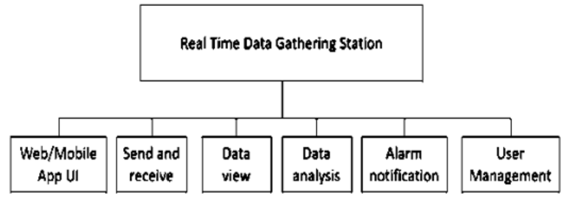


Figure 4: Function Module

D. Wireless Communication Protocol

The ZigBee protocol is used to communicate between wireless sensor nodes and microcontrollers. ZigBee is based on IEEE 802.15.4 standard with powerful networking capabilities. The ZigBee protocol as shown in figure 5 was designed to provide an easy-to-use wireless data solution characterized by secure, reliable wireless network architectures. It provides star, network, and cluster-based networking structures. It has the following characteristics:

1. Low power consumption. A sensor under a standby status can run more than six months;
2. Cheap due to the opening standard;
3. It supports communication in a limited range from 10 to 100 m;
4. A low rate and short latency, typically a response requires 15-30ms;
5. Each node can manage up to 254 child nodes; therefore, the ZigBee can have a maximum of 64,516 nodes;
6. It provides high-security with Advanced Encryption Standard AES-128 symmetric password and Access Control List (ACL).
7. The licensing of the ZigBee network is free for any industry.

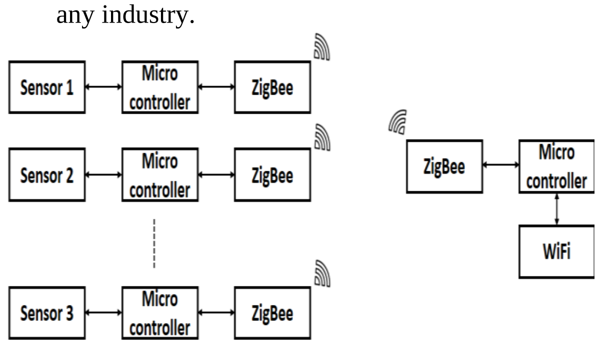


Figure 5: ZigBee Protocol Communication

E. System Node Implementation

The gathering station consists of a microcontroller, sensors, wireless transceiver, cloud datacentre, GPRS as shown in Figure 5. A sensor node uses a microcontroller for data processing and a transceiver to transmit data to the cloud data centre. The wireless sensor node is powered by the battery and the temperature and pressure sensors are used for the data gathering. The wireless sensor node is based on the real-time operating system and the tasks implemented are: Sensor node transmits data to the microcontroller; GPRS send a notification to cell phone; WSN send sensor data reading to cloud data centre to reflect data on the web page and mobile app for monitoring remotely [12].

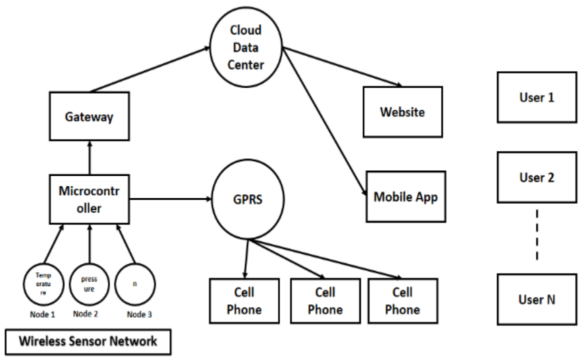


Figure 6: System Node Implementation

The XBee modules have been used to send the data wirelessly to the server. In this system, one XBee is configured as a router and the other as a coordinator. To send messages to the subscribed cell phones GPRS module is used. The memory requirement of the real-time depends on application functionality. RTOS kernel itself requires about 5 to 10 Kbytes of ROM space [14]. In this system, the idle task concept is used to reduce power consumption, which further uses microcontrollers sleep modes by the use of the RTOS kernel. All sensors will continuously send the updated data to the microcontroller and it will be forwarded to the cloud for monitoring and analysis.

IV. CLOUD DATA CENTRE INTERFACE

An XBee module has been configured as a router and connected to the Server to receive wireless sensor data. A web-based application is developed using PHP and a Database system to send live data for monitoring purposes on the web page.

1. At the start, the application will ask for the user to log in with the user name and password.
2. After successful login, received data will reflect on the web page.
3. Cloud data center receives the data from the base station.
4. All sensor data is displayed in the corresponding textbox and stored in a database with date, timestamp, and data.
5. The whole process continues in an infinite loop.

A. Alarm Notification

Alarm notification can be sent via SMS and email notification. The program of sending alarm SMS to cell phone and registered email addresses as soon as the sensed value reaches a threshold value. The text message can be sent via the GPRS module and email notifications can be sent via Cloud Data Centre. The login users can also see the notification on the web and mobile application.

B. System Implementation

The web application is hosted on a cloud data center server for security purposes and a login with a password is provided as shown in Fig 6. The web application receives the stream of sensor data.

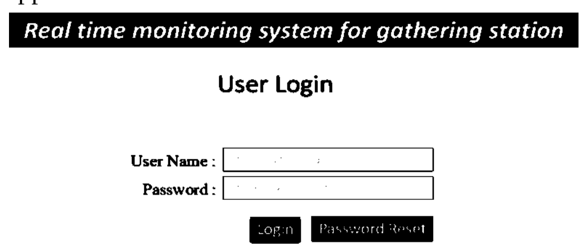


Figure 7: Web page view

This application continuously monitors the received sensor data as shown in Figure 7 and if the output exceeds a certain limit, then it will generate alerts like SMS (Short Message Service) or Emails (Electronic Mail).

V. RESULT AND DISCUSSION

The performance of a system depends on its accuracy therefore the temperature and pressure wireless monitoring network has undergone a series of tests in the laboratory. The wireless monitoring network has continuously operated in the Lab and no abnormal phenomenon has occurred. To test the nodes, the real-time sensing, and remote accessibility, the nodes were set to acquire and send data every 5 minutes and sleep for 5 minutes. The Data packet delivery rate was 100% with no packet error. Mesh network topology was used for multi-hop communication between nodes and coordinators that provided alternative paths to the sink node. Sensor readings were compared with readings from a digital thermometer and accuracy was found to be ±2%. Table 1 and Figure 8 show the oil and gas production data received at the cloud data center with time trends. However other data like temperature, pressure, differential, and static pressure can also be configured to be shown as a trend.

Table 1: Data received at the cloud data center.

Gas Volume MMscf/d	Oil Volume stb/d	Water Volume stb/d	Active Pressure psi(a)
0.145	504.39	718	2064.695943
0.186	564.76	922	1989.695943
0.231	653.51	753	1864.695943
0.268	740.71	700	1814.695943
0.261	678.06	530	1714.695943
0.329	789.29	580	2064.695943
0.303	915.05	700	1284.695943
0.26	797.53	590	1184.695943
0.252	777.06	530	1064.695943
0.236	710.58	429	994.695943
0.223	675.5	380	914.695943
0.21	635.51	343	854.695943
0.237	705.49	360	724.695943
0.208	638.78	332	664.695943
0.247	735.32	392	504.695943
0.204	634.31	338	454.695943
0.281	818.35	455	254.695943
0.233	692.73	406	214.695943
0.22	642.89	340	174.695943
0.211	604.32	302	154.695943
0.178	543.23	245	149.695943
0.185	562.47	232	134.695943
0.175	518.79	205	134.695943
0.162	489.92	180	119.695943
0.17	504.6	167	114.695943
0.116	443.19	140	114.695943
0.14	352.2	127	114.695943
0.142	520.73	123	114.695943
0.122	410.53	105	109.695943
0.13	403.06	100	109.695943
0.126	410.56	98	109.695943
0.126	372.02	87	109.695943
0.128	304.49	85	109.695943
0.124	380.22	105	104.695943
0.114	357.2	81	104.695943
0.117	367.99	70	109.695943
0.108	338.42	64	99.695943
0.11	340.51	63	99.695943
0.114	349.73	62	104.695943
0.068	219.03	32	84.695943
0.014	126.09	25	84.695943
0.177	540.74	92	134.695943
0.174	469.96	60	184.695943
0.11	329.23	51	94.695943
0.098	291.09	52	94.695943
0.109	314.63	55	94.695943
0.102	243.21	48	94.695943
0.088	241.01	43	84.695943

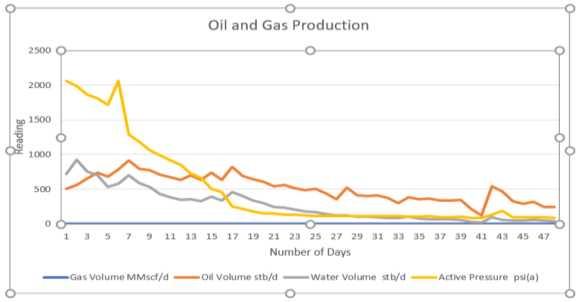


Figure 8: Trend showing Data received at the cloud Datacenter.

VI. CONCLUSION

This paper demonstrates the design and implementation of a real-time monitoring system for a gathering station based on a wireless sensor network on a cloud platform. This system shows that various sensor data can be collected and transmitted synchronously with real-time constraints over wireless media with the help of microcontroller and XBee modules. The data gathered from temperature and pressure sensors can be used for monitoring and further analysis purpose.

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