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# Underwater Real-Time Oil Pipeline Monitoring Using Underwater Wireless Sensor Networks (Uwsns): Case Study Of Niger Delta Region

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***Abstract*—this paper explores the recent applications of wireless sensor networks (WSNs), especially Underwater WSNs (UWSN), by International Oil Companies (IOCs) in monitoring underwater oil pipelines in Nigerian oil rich Niger Delta region. It examined the different architectures for monitoring underwater pipelines, their challenges and how to overcome them. The paper also looked at how underwater WSNs can be used together with their measurement and communication devices such as GSM modem and Global Positioning System (GPS) to transfer sensed data from underwater network to control station far away from the pipeline.**

***Keywords—Underwater; Wireless Sensor Network (WSN) ; IOCs, Underwater Wireless Sensor Network (UWSNs); RF; Acoustic; GPS; modem; Niger Delta Region***

## I. INTRODUCTION

The majority of the pipelines transporting crude oil and other refined petroleum products such as DPK, AGO and premium motor spirit (PMS) go through underwater in Niger Delta oil region of Nigeria. This is because most of the terrain in Niger Delta region is riverine – ocean, seas and river and mangrove swamps. Fig.1 is the map of Nigerian Niger Delta region showing the distribution of its oilfields and oil pipelines scattering in the mangrove swamp and riverine areas.

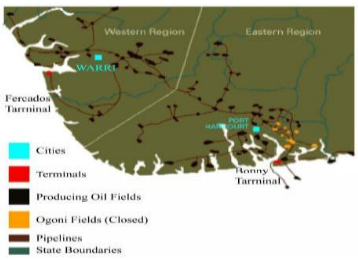


Fig.1. Map of Nigerian Niger Delta showing some oil fields and pipelines [1]

Vandalism of pipelines including the ones that transport crude oil and other refined petroleum products have become increasingly rampant in recent times in Nigeria Niger Delta region which bears majority of Nigeria's oil fields and oil pipelines. Most of the vandalism of pipelines that took place occurred either in underground or underwater pipelines in Niger Delta region but wireless sensor networks have now been adopted by most of the International Oil Companies (IOCs) operating in Nigeria Niger Delta region to checkmate this spate of pipeline vandalism.

Wireless sensor networks (WSNs) are IEEE 802.15.4 enabled devices capable of robust and reliable multi-hop communications [2, 3]. Wireless sensors can be deployed in unattended environments including underwater locations and can enable collection of data from there to distant base stations and then to control room [4, 5].

Wireless sensors have found useful applications in varying number of civilian and military applications because of their low-cost and ease of deployment [3,6,7]. Because of these and other advantages, wireless sensor networks have found useful applications in environmental monitoring applications especially in oil and gas fields.

Prior to January 2005, International Oil and Gas Companies (IOCs) operating in Nigeria Niger Delta region made extensive use of conventional wired network technologies such as fiber optics and wireless technologies such as satellite and radio communications for monitoring of vast oil wells and facilities. These conventional wired and wireless monitoring technologies have disadvantages such as high cost of deployment and maintenance, delayed detection of pipeline problems and leakages, ineffective reservoir management and optimization due to the need to obtain data primarily from conventional and non-timely well tests as well as frequent stealing and vandalisation of the system components.

In January 2005, Shell became the first IOC to shift from these conventional technologies to wireless sensors to monitor her vast oil facilities scattered all over Niger Delta region. Shell shifted to microwireless sensors because of these following inherent advantages:

•Wireless sensor is small enough so that it attracts less attention,

•It demands or consumes low power and it is battery operated, without solar panels required by the conventional satellite communication,

•It has long-range wireless communication capabilities, greater than 4-5 miles in a dense jungle, though limited underwater,

•It is low-cost, almost at a price that would make it disposable. It is maintenance free unlike the conventional technologies wired and wireless technologies, above all, it is easy to deploy and install [7].

Fig.2 depicts the model of vMBusX-SP microwireless sensor installed by Shell in most of her oil wells in Niger Delta [7].

Fig.2. A model of vMBusX-SP battery-powered Smart Wireless Sensor installed by SPDC in her over 1000 oil wells and other oil facilities in the fields of Niger Delta [7]

This shift by Shell to wireless sensors helped her to reduce the operational difficulties and cost hitherto encountered in the deployment and maintenance of monitoring devices of the previous conventional technologies. Apart from this, Shell was able to increase her production, maintain safety, and increased reservoir life [8]. Since then, WSN has been helping other International oil and gas companies (IOC) and other local firms operating in the Niger Delta region such as NNPC, Chevron Texaco, Exxon Mobil, Total and so on in other oil and gas regions elsewhere by offering great opportunities for production optimization in the areas of remote monitoring of pipelines, oil wells, oil rigs, flow stations, natural gas leaks, corrosion, equipment condition, and real-time reservoir status. Data gathered from wireless sensor nodes enables new insights into plant operation and innovative solutions that improve platform safety, optimize operations, prevent problems, tolerate errors, and reduce operating expenses (OPEX). Fig.3 shows the aerial photograph of one of Shell's over 1000 oil wells in Niger Delta field where these micro wireless sensor units were installed. According to [9], the applications of wireless sensor networks (WSNs) and other wireless technologies in oil and gas industries include process monitoring, asset management, plant

Fig.3. A vMBusX-SP wireless sensor units installed in an oil well in the Niger Delta by Shell to help prevent theft and sabotage [7]

management, productivity enhancements, Health, Safety and Environmental (HSE) monitoring and applications for meeting regulatory requirements.

Special sensors are needed to track crude oil pipelines that are located underwater and the acquired data are sent to remote control station for analysis so that action will be taken to curb or stop the vandalisation. These special sensors differ from application-to-application but the recent type of sensors that are deployed especially in Niger Delta region are known as underwater wireless sensor networks (UWSNs). Normally a usual wireless sensor node is made up of four basic components as shown in Fig. 4: a sensing unit, a processing unit, a transceiver unit and a power unit [10]. Sensing Unit consists of basically two subunits: Sensors which senses the surroundings or produces the analog signal based on observed phenomenon and analog to digital converters (ADCs) which converts these analog signals into digital one then further these signals fed into the processing unit. The Processing unit consists of processor (CPU) and a small storage unit (External storage) and primary memory (Volatile and program memory). It reads out the sensor and processes the locally sensed information and implements the various network protocols. The Transceiver or Radio unit connects the sensor node to the network while the Power unit supplies power to the node and supports by a power scavenging unit such as solar cells.

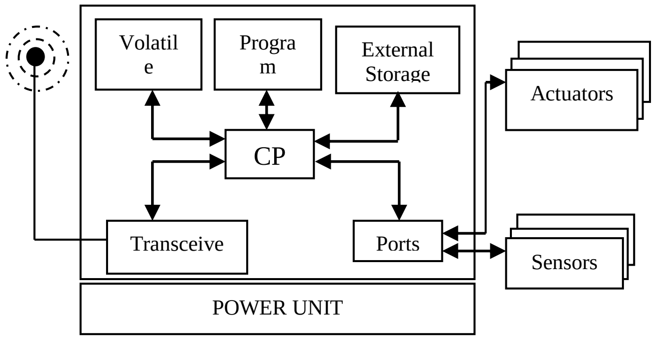


Fig.4. Components of a basic wireless sensor node [10]

Underwater pipelines have several challenges of being monitored because of several factors which include – low data communications, exhaustible power (battery), poor strength of signal, susceptibility to physical damage of sensor equipment, scalability issue, etc. Different technologies have been deployed already to monitor underwater pipelines especially in Niger Delta region.

## II. THE ARCHITECTURES OR TECHNOLOGIES FOR MONITORING UNDERWATER PIPELINES

There are different sensor network architectures that can be used to monitor or carry out surveillance of underwater pipelines. Such architectures include the following:

- Underwater Wired Sensor Networks,
- Underwater Acoustic Sensor Networks,
- RF Wireless Sensor Networks,

In this section, we present and review these architectures and show their advantages, disadvantages and challenges.

### A. *Underwater Wired Sensor Network*

This is not wireless sensor network per say but it is one of the oldest and popular sensor network used to connect and monitor underwater pipelines. Wired networks can either be copper or fibre optic cables []. The wired networks are normally connected to regular sensor devices such as transducers or transmitters that measure specific pipeline parameters such as pressure, temperature, flow rate, vibration, sound, motion etc., that can sense pipeline parameters and transmit signal to other communication devices at the base station and then to the control station.

The wires are not used for communication only but also to transfer electrical power to different parts of the pipeline system to enable the sensors, actors, and communication devices to function. Power for the pipeline resources and networks can be provided by different sources such as pipeline flow energy (generated using turbines embedded in the pipelines), external gas-based power generators or third-party power. These electric power are transferred in wires to different communication and sensor devices along the underwater pipeline. Fig.5 shows a typical process diagram for underwater wired sensor network.

### B. *Underwater Acoustic Sensor Network*

Acoustic sensor nodes can be installed with underwater pipeline infrastructures. Each node has a limited transmission capability in which each node can communicate with few neighboring nodes. Multi-hop communication is used to transfer the sensed information among the underwater pipeline. UnderWater Acoustic Sensor Networks (UW-ASN) can also consist of a variable number of sensor nodes and

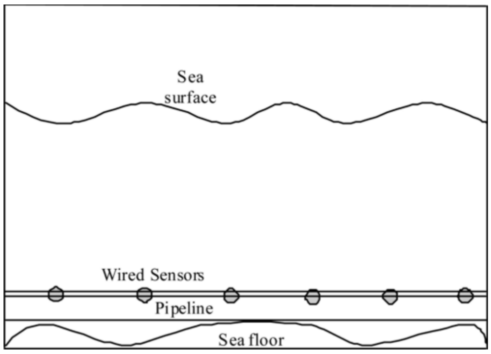


Fig. 5. Underwater wired sensor network [11]

vehicles that are deployed to perform collaborative monitoring tasks over a given area underwater. Here, sensors and vehicles are deployed in self-organizing topology and in an autonomous network which can adapt to the characteristics of the ocean or water environment. Fig. 6 depicts a typically underwater acoustic sensor network as reported in [11].

Each sensor node for monitoring pipelines is usually equipped with an acoustic transceiver, a processor, a battery, memory, and small storage in addition to one or more sensor devices. Power consumption is critical to the life span of pipeline communication systems. Pipeline systems are usually installed to be used for years. Therefore the associated communication systems should also be long lived. This type of wireless sensor network is better suited for underwater real-time monitoring system.

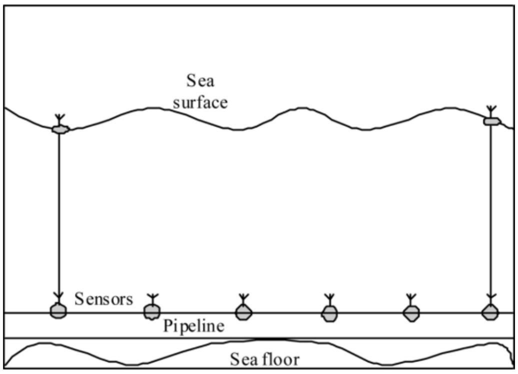


Fig. 6. Underwater acoustic network [11]

Unlike wired networks where the power is not a constraint in building the system, network designers have to consider power as one of the main constraints in the wireless system. Power in a node can be consumed when data is sent through the transceiver, when the transceiver is turned on waiting to receive data from other nodes, when sensor devices are turned on, and when the processor is active. Careful scheduling of these resources is therefore needed to optimize power consumption.

### C. *RF Wireless Sensor Neworks*

Radio Frequency (RF) wireless Sensor Network is another type of wireless sensor network that can be used to monitor underwater pipelines. This type of wireless sensor network uses radio frequency to monitor the environment. Fig.7 depicts the architecture of this type of network.

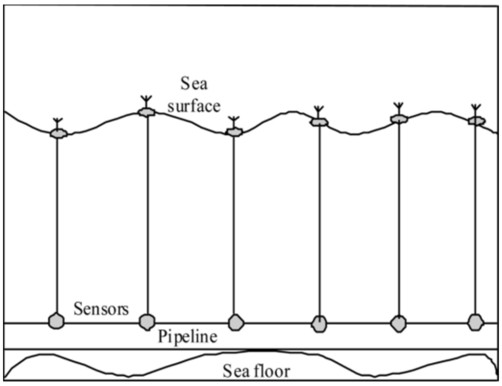


Fig. 7. RF wireless sensor network [11]

According to authors in [11], the major differences between this architecture and other wireless sensor networks used for above ground applications is that each sensor node is connected to a surface buoy through a cable as shown in Fig. 7. Radio transceivers are available on the surface buoys. As a result, the nodes can communicate through radio frequency channels which provide better communication bandwidth, propagation delay, bit error rate and connectivity, as well as less power consumption for processing communication signals compared to the underwater acoustic sensor network. In addition, surface buoys can be equipped with solar cells to provide energy for the sensors and communication devices [11].

## III. THE CHALLENGES IN WSN UNDERWATER PIPELINE MONITORING

Using Underwater WSN (UWSN) monitoring is a new and promising field; it equally presents several challenges especially in oil pipeline monitoring. The following challenges have been identified as the key factors that may make application/deployment of Underwater WSN (UWSN) difficult in underwater oil pipeline monitoring:

- Unpredictable underwater environment,
- Intricate network design and deployment,
- Lack of scalability,
- Unreliable information,
- Requirement of novel protocols for UWSNs
- Low data rates,
- Physical damage to equipment due to vandalism ,
- Problem of recharging underwater sensor battery, and
- High cost of acquisition and deployment.

### *A. Unpredictable underwater environment*

Underwater conditions are extremely unpredictable. The anonymous high water pressure, unpredictable underwater activities and uneven depths of the underwater surface makes is difficult to design and deploy UWSNs.

### *B. Intricate network design and deployment*

Due to the unpredictable underwater environment, it is extremely difficult to deploy the network underwater sensors which work reliably and wirelessly. The current tethered technology allows constrained communication but it incurs significant cost of deployment, maintenance, and device recovery to cope with volatile undersea conditions.

### *C.Lack of Scalability*

Traditional underwater exploration relies on either a single high-cost underwater device or a small-scale underwater network. Neither existing technology is suitable to applications covering a large area. Enabling a scalable underwater sensor network technology is essential for exploring a huge underwater space.

### *D.Unreliable Information*

Underwater sensor nodes are in continuous motion due to the water currents, thus locating nodes underwater becomes much more difficult and challenging.

### *E. Requirement of novel protocols for UWSNs*

The medium of communication in underwater network/communication is water, unlike air as in terrestrial sensor networks. Therefore, terrestrial sensor network communication protocols get void underwater. Mostly, acoustic signals are used for underwater communication over large distances, while radios are considered for short distance, water surface communication.

But radio signals transmits long distances at extra low frequencies, which requires large antennas and high transmission power, which can decrease the overall network lifetime of UWSNs. Moreover, the propagation delay of acoustic communication is very high compared to RF communication; hence many algorithms and protocols for terrestrial WSN cannot be adapted directly to UWSN.

### *F.Low Data Rates*

Radio frequency (RF) communications is not effective in underwater communication due to medium effect on communication. Water absorbs much of the RF energy and hence only very short range communication is allowable using RF. Instead, acoustic communication is being used to transmit pulse signals and low fidelity information underwater due to its low band width. Potential UWSN applications such as measuring the level of pressure variation in pipelines installed at the sea bed require transmitting lots of data. However, with such low frequencies, it requires a lot of time to send such a dynamic data.

Much time *delay to send data can drain the battery energy of the underwater sensors.*

*G.Physical damage to equipment due to vandalism*

In many rivers of Niger Delta region, oil thieves and vandals look for any installed monitoring device underwater or above the ground in order to destroy them so that they can vandalize crude oil pipelines undetected. This case has become rampant, of recent, in Niger Delta oil region [12].

*H.Problem of recharging underwater sensor battery*

Batteries of underwater sensor nodes sometimes need replacement or recharging; replacing or recharging batteries of these underwater sensor nodes can be very challenging because going down to the depth of the river, sea or ocean in order to replace hundreds or thousands of scattered sensor nodes is not an easy task. Efficient energy consumption in underwater sensor networks can be enhanced by developing efficient water communication techniques or protocols which saves critical battery life of the sensor node in order to increase the its longevity.

*H.High cost of acquisition and deployment*

Finally, the energy requirements and cost of underwater wireless sensor networks are higher compared to that of terrestrial wireless sensor networks monitoring pipelines located above the ground or buried undergrounds. Procuring the acoustic wireless sensor nodes and deploying them underwater is cost prohibitive but necessary considering the fact that majority of the oil pipelines are deployed underwater in Niger Delta region.

## IV. Field Components Of Underwater Real-Time Monitoring, Control And Communication System

The essential field components of any underwater monitoring system required for real-time monitoring and control of underwater pipelines comprises the sensors, measurement and control devices [idachaba].

The sensors are required to measure and monitor pipeline parameters such as pressure, vibration, flow, acoustic, level, sound, density, temperature, etc. Sensing devices such as transducers, transmitters, indicators and meters are used to accomplish real-time monitoring and measurement. Sensors and measurement devices (transducers) are related as shown in the block diagram in Fig.8.

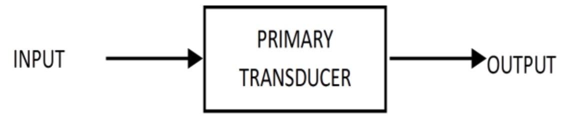


Fig.8. Block diagram of a sensor

The communication systems are either wired or wireless links such as copper or fibre optics cables or RF wireless or hybrid network of wired and wireless used to transmit the data acquired from the underwater pipelines to remote control stations. Global Positioning System (GPS) are nowadays used in dispatching sensed data from underwater sensors to control stations using satellite communication and Global System for Mobile Telecommunication (GSM) General Packet Radio Service (GPRS) to map location of sensed data on Google Map.

The control devices are used to perform remote control of valves and switches from specified remote locations. Emergency shutdown procedures can be implemented from any of the specified offsite locations such that the control of the plant and any vital equipment can be controlled remotely in the event that onsite control becomes impossible [idachaba].

For example, the real-time underwater monitoring system shown in Fig.9 uses a multi-hop (3 sensing/Relay nodes) to monitor a seabed where there is an installed pipeline. This underwater monitoring system uses temperature-based wireless sensor nodes and attached modems along with a GPS receiver to sense, transfer and map the sensed data to the control station via the sink node. The sensed data is mapped using Google Map to locate the exact position on earth where the pipeline burst is detected by the underwater monitoring system.

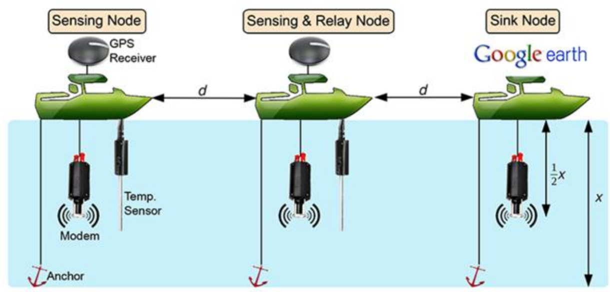


Fig. 9.A real-time underwater wireless temperature-based monitoring system anchored to the seabed

## V. Conclusion

In this paper, we have presented a comprehensive survey of the importance of deploying wireless sensor networks in Niger Delta region by International Oil Companies (IOCs) operating there. We equally presented a survey of the different architectures of underwater monitoring systems for monitoring underwater oil pipelines especially Underwater Wireless Sensor Network (UWSN). Majority of oil pipelines in Niger Delta region are underwater so monitoring them real-time to deliver performance and safety is very crucial and important to the economic growth of Nigeria and that of the IOCs. UWSN has become one of the prime focuses for researchers so if these applications are properly exploited and catered, a lot of improvements can still be achieved in terms of increasing the effectiveness of preventing vandalism and detecting vandalized or damaged pipelines underwater on time to save cost and the environment.

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