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Li-Fi Electro-Technology Wireless Communication for Revolutionizing Information Transmission in Oil and Gas Field Operations among International Oil Companies

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Abstract **Original Research Article**

The increasing complexity of digital communication infrastructures within the oil and gas industry has created a growing demand for high-speed, secure, and interference-free communication systems capable of supporting industrial monitoring and operational control. This study investigated the potential application of Light Fidelity (Li-Fi) electro-technology as an alternative wireless communication platform for improving information transmission in oil and gas field operations among International Oil Companies. The study adopted a mixed-method research design involving Supervisory Control and Data Acquisition (SCADA) personnel from oil-producing regions of Nigeria. From a population of 432 SCADA personnel, a sample of 56 respondents was selected using a multi-stage random sampling technique. Data were collected through semi-structured online focused group interviews and analyzed using thematic coding and descriptive statistical techniques. Reliability of thematic coding was ensured through inter-coder agreement analysis. Findings reveal that Li-Fi communication systems rely on integrated transceiver architectures consisting of LED transmitters, photodiode receivers, signal amplifiers, and modulation units to enable high-speed data transmission among others. The study concludes that Li-Fi technology presents a viable communication alternative for oil and gas operations due to its large bandwidth capacity, immunity to electromagnetic interference, and operational safety in hazardous environments. The study recommends the development of hybrid Li-Fi/Wi-Fi industrial communication systems and advanced multi-modulation Li-Fi circuits to support real-time monitoring of oil and gas infrastructure.

Keywords: Li-Fi communication, optical wireless communication, SCADA networks, oil and gas operations.

Introduction

Communication systems have become an essential component of modern industrial operations. In the oil and gas sector in particular, the ability to transmit operational data reliably and in real time plays a critical role in ensuring efficiency, safety, and environmental protection. Oil and gas production activities are typically carried out across geographically dispersed facilities, including offshore platforms, pipelines, refineries, and storage terminals. As a result, communication infrastructures are required to support continuous monitoring and coordination between field equipment and central control systems.

In recent years, industrial operations have increasingly relied on Supervisory Control and Data Acquisition (SCADA) systems and wireless sensor networks to monitor operational parameters such as pressure, temperature, flow rate, and equipment condition. These systems form part of the broader Industrial Internet of Things (IIoT) framework that enables intelligent monitoring and automated control of industrial processes (Sisinni et al., 2020; Al-Fuqaha et al., 2020). Despite these technological advancements, communication challenges still persist in complex industrial environments.

Wireless communication technologies such as Wi-Fi have been widely adopted in industrial monitoring networks because of their flexibility and relatively low deployment cost. However, these radio-frequency-based communication systems are often affected by bandwidth congestion and electromagnetic interference, particularly in environments that contain large volumes of electronic equipment and heavy machinery (Willig, 2020; Luvisotto et al., 2020). These limitations can lead to unstable network performance and delayed transmission of critical operational data.

In the oil and gas industry, communication delays or failures may have serious consequences. For instance, the inability to transmit sensor information from remote pipelines or drilling installations in a timely manner can delay responses to abnormal operating conditions such as pressure surges, gas leaks, or equipment malfunction (Mohammed et al., 2020; Ahmed et al., 2021). Consequently, there is a growing need for alternative communication technologies capable of providing higher bandwidth, improved reliability, and greater resistance to industrial interference.

One emerging technology that has attracted considerable attention in recent years is Light Fidelity (Li-Fi). Li-Fi is a form of optical wireless communication that uses light emitted from light-emitting diodes (LEDs) to transmit digital data. The technology operates by rapidly modulating the intensity of LED light in a way that is not perceptible to the human eye, thereby enabling the transmission of information through visible light signals (Haas et al., 2020; Pathak et al., 2020).

Unlike conventional radio-frequency communication systems, Li-Fi operates within the visible light spectrum, which offers a significantly larger bandwidth and is less susceptible to electromagnetic interference. Because of these characteristics, Li-Fi has been considered a promising solution for high-density wireless environments and industrial applications where reliable communication is essential (Tsonev et al., 2021).

Although Li-Fi technology has been widely studied in areas such as indoor networking, smart cities, and intelligent transportation systems, its potential application in oil and gas industrial communication systems has received comparatively limited attention. This study therefore investigates the role of Li-Fi electro-technology in improving information transmission within oil and gas field operations among International Oil Companies.

Research on visible light communication has expanded rapidly over the past decade as interest in alternative wireless communication technologies continues to grow. Li-Fi communication systems operate by transmitting digital data through modulated light signals emitted from LED light sources. These systems typically consist of a transmitter unit, an optical communication channel, and a photodiode receiver that converts optical signals back into electrical signals (Pathak et al., 2020).

The concept of Li-Fi was popularized by Haas and colleagues, who demonstrated the potential of LED lighting systems to function simultaneously as illumination devices and high-speed data transmitters (Haas et al., 2020). Since then, researchers have explored a wide range of Li-Fi applications, including indoor broadband communication, smart city infrastructure, and industrial automation networks.

One of the major advantages of Li-Fi technology lies in its ability to utilize the visible light spectrum, which offers significantly greater bandwidth compared with the radio-frequency spectrum used by conventional wireless communication systems. This feature makes Li-Fi particularly attractive for environments where large volumes of data must be transmitted quickly and reliably (Tsonev et al., 2021; Ghassemlooy et al., 2021).

Another important aspect of Li-Fi communication systems involves the modulation techniques used to encode digital information within optical signals. Several modulation schemes have been proposed for visible light communication systems, including On-Off Keying (OOK), Amplitude Shift Keying (ASK), Pulse Position Modulation (PPM), and Orthogonal Frequency Division Multiplexing (OFDM) (Rajagopal et al., 2020).

Among these techniques, OFDM has attracted significant attention because of its ability to support high data transmission rates while maintaining robustness against signal distortion. OFDM divides the data stream into multiple subcarriers, enabling parallel transmission of information across different frequencies and improving spectral efficiency (Darlis et al., 2021).

Beyond indoor communication networks, researchers have also begun exploring the potential of Li-Fi technology in industrial communication systems. Industrial environments often present challenging communication conditions due to electromagnetic interference, signal attenuation, and physical obstructions. In such environments, optical communication technologies may offer advantages over traditional RF systems.

Industrial communication systems play a critical role in enabling automated monitoring and control of industrial processes. Wireless industrial communication networks allow sensors, controllers, and monitoring devices to exchange operational data in real time (Luvisotto et al., 2020). The integration of Li-Fi technology into industrial communication systems could significantly improve communication reliability and data transmission performance in complex industrial environments.

This study is anchored on Visible Light Communication theory and Optical Wireless Communication principles. Visible Light Communication systems operate based on the principle of Intensity Modulation and Direct Detection (IM/DD), where electrical signals modulate the intensity of LED light sources to encode digital information. These modulated optical signals are then transmitted through free space and detected by photodiodes at the receiver (Uysal et al., 2020; Dimitrov & Haas, 2021).

The optical wireless communication model consists of three major components:

Transmitter system (LED and modulation circuit

Optical communication channel

Receiver system (photodiode detector and signal processor)

This architecture enables high-speed data transmission within the visible light spectrum and forms the fundamental operational mechanism for Li-Fi communication systems (Wang et al., 2021).

Statement of the Problem

Effective communication is essential for the smooth operation of oil and gas field activities, particularly in areas such as monitoring, control, and data transmission between remote operational sites and control centers. In most oil and gas facilities, wireless communication technologies such as Wi-Fi and radio-frequency communication systems are commonly used to transmit operational information. However, these technologies often experience challenges such as signal interference, limited bandwidth, and slow data transmission, especially when many devices are connected within complex industrial environments.

These communication challenges are more pronounced in oil-producing regions such as the Niger Delta, where harsh environmental conditions and remote operational locations can disrupt network stability. As a result, delays in transmitting operational data may affect effective monitoring of critical parameters such as pressure, temperature, equipment performance, and pipeline conditions.

Recent technological developments such as Light Fidelity (Li-Fi), which uses Light-Emitting Diodes to transmit data through visible light, present a promising alternative for improving wireless communication performance. However, the application of Li-Fi technology for enhancing information transmission in oil and gas field operations among International Oil Companies has not been sufficiently explored. This situation therefore necessitates an investigation into how Li-Fi electro-tech wireless communication can improve information transmission in oil and gas field operations

Purpose of the study

The main purpose of this study was to examine the potential of Light Fidelity (Li-Fi) electro-technology as an alternative wireless communication system for improving information transmission in oil and gas field operations among International Oil Companies. Specifically, the study examined:

1. Transceiver network behavior in Li-Fi systems for transmitting operational information in oil and gas field operations among International Oil Companies.
2. Modulation techniques that can improve the efficiency of information transmission in Li-Fi electro-technology communication systems for oil and gas operational environments.

Research Question

The following research questions guided the study:

1. How does Transceiver network behave in Li-Fi systems for transmitting operational information in oil and gas field operations among International Oil Companies?
2. What modulation techniques can improve the efficiency of information transmission in Li-Fi electro-technology communication systems for oil and gas operational environments

Methodology

The study adopted a mixed-method research design combining qualitative and quantitative research approaches. The research was conducted in the Niger Delta region of Nigeria, where major oil exploration and production activities are concentrated. The population consisted of 432 Supervisory Control and Data Acquisition (SCADA) personnel working in oil and gas companies operating within oil-producing states in Nigeria. While a multi-stage sampling technique was employed. Oil-producing states were purposively selected; SCADA personnel were randomly sampled from selected companies within each state, having a sample Size of 56 respondents. Data were collected using a semi-structured online focus group interview guide designed to capture expert insights on Li-Fi communication systems. The interview protocol was validated by three experts in communication engineering technology and research methodology. Reliability of thematic coding was ensured through inter-coder agreement analysis. Frequency distributions and percentage were used to summarize participant responses.

Results

Interview Question 1

Describe the Transceiver network behavior in transmitting information in Li-Fi electro-technology communication systems for oil and gas field operations?

Interview Extracts	Components	Code
Act as a transmitter and receiver at the same time by integration its functions	Transceiver Block	
LED light bulbs at downlink transmitter to convert electrical signals into light signals	LED Bulbs	
Strengthens received optical signals by converting tiny changes in amplitude into an electrical signal-data stream	Amplifier	
Streams data embedded in its beam at ultra high speeds to the photodiodes by detecting incoming light signals.	Photodiodes	
Modem is used to modulate and demodulate the signal	Modem	
Lamp to LED functions to drive current to get flickering for data transmission	Flickering for data transmission	

Interview1. On Transceiver network behavior in transmitting information, participants often described transceiver as acting as a transmitter and receiver at the same time. 7.14% of the participants noted "Transceiver Block" as both a transmitter and a receiver, represented with color code purple. Participants also cited a Lamp attached to LED functions to drive current to get flickering. 30.36% of participants noted "flickering for data transmission" represented with Green color code. LED Bulb at downlink to transmit light, 17.85% participants noted "LED bulbs" which is coded with color Orange, among others where the participants responses on Transceiver network behavior for Revolutionizing Information Transmission in Oil and Gas Field Operation among Iocs

Interview Question 2

What Modulation Techniques can improve the efficiency of transmitting information in Li-Fi electro-technology communication systems for oil and gas field operations?

Interview Extracts	**Code**
Amplitude shift keying ASK Technique: uses a sub-carrier index to transmit information to the receiver.	Sub-carrier index
OFDM Technique: provides multiple dimensions modulations to increase efficiency and performance.	Multiple Dimension
ON-OFF modulation: transmits information at flicking state in an increasing or dimming level.	UsesON-OFF
Pulse-position modulation technique: encodes data using position of light pulse within a time period to support light dimming	Supports Light Dim

Interview2. On Modulation Techniques in transmitting information, participants often described Amplitude Shift Keying technique as a single modulation technique. 12.5% of the participants noted “sub-carrier index” as a source of transmitting information to the receiver, represented with purple color code. Participants also cited ON-OFF modulation to be a place holder in transmitting information at increasing and dimming level. 37.5% of participants noted “ON-OFF flickering state” represented with Green color code, among others where the participants responses on Modulation Techniques for Revolutionizing Information Transmission in Oil and Gas Field Operation among Iocs

Discussion

The findings of this study highlight the potential of Li-Fi communication technology as a viable alternative to conventional wireless communication systems in oil and gas field operations. Participants in the study emphasized the importance of transceiver architectures that combine LED transmitters, photodiode receivers, amplifiers, and signal modulation units to enable reliable optical data transmission.

The use of modulation techniques such as Orthogonal Frequency Division Multiplexing was also identified as an important factor in improving communication performance. OFDM allows multiple data streams to be transmitted simultaneously across different frequency subcarriers, thereby increasing transmission capacity and reducing signal interference. These observations are consistent with previous studies that have demonstrated the advantages of OFDM-based Li-Fi communication systems in high-data-rate wireless networks (Darlis et al., 2021).

Another important implication of the findings relates to the potential integration of Li-Fi technology with existing wireless communication infrastructures. Rather than replacing RF communication systems entirely, Li-Fi may be deployed alongside Wi-Fi networks to create hybrid communication systems that combine the strengths of both technologies. Such hybrid networks have been proposed as part of the emerging architecture for next-generation wireless communication systems (Wu et al., 2021; Rahaim et al., 2023).

In industrial environments such as oil and gas facilities, the use of hybrid Li-Fi/Wi-Fi communication systems could provide improved network reliability, particularly in areas where .

Conclusion

The study highlights the transformative behaviors of Li-Fi electro-technology in improving communication efficiency within oil and gas field operations. The findings indicate that Li-Fi communication systems provide higher bandwidth capacity, enhanced communication security, and improved resistance to electromagnetic interference compared to conventional RF-based communication technologies RF communication performance is limited by interference or environmental conditions.

Recommendations

The study recommends the following:

1. Development of hybrid Li-Fi/Wi-Fi communication systems for industrial operations.
2. Design of high-speed multi-modulation Li-Fi circuits.
3. Integration of Li-Fi technology into SCADA monitoring systems.
4. Further research into underwater Li-Fi communication systems for offshore platforms.

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