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Exploring novel architectural elements and design concepts for wireless sensor nodes: A case study

Abstract. Wireless Sensor Networks (WSNs) play a crucial role in modern communication systems, enabling efficient data collection and transmission across various domains. These networks are pivotal in applications such as environmental monitoring, industrial automation, smart cities, and healthcare systems, where real-time and accurate data is essential. The purpose of this study was to develop and validate a novel wireless sensor node architecture for gas sensing applications, with a focus on improving energy efficiency, communication reliability, modularity, and adaptability to diverse environments. The proposed design integrated multiple radio chips, a stack-based architecture, and directional antennas to improve communication robustness and adaptability. A current driver circuit was introduced to mitigate sensor saturation, ensuring accurate gas concentration measurements. The stack-based architecture enhanced modularity and scalability, facilitating seamless upgrades and compatibility with emerging technologies. Additionally, directional antennas and a dedicated medium access control protocol optimised communication efficiency and localisation accuracy. Experimental evaluations, conducted within advanced research facilities, validated the effectiveness of the proposed design under diverse environmental conditions. The hardware design approach presented in this paper focused on using low-cost, off-the-shelf components strategically integrated to deliver high functionality without increasing complexity or cost. The modular design also allows additional sensing features – such as temperature, humidity, or particulate matter detection – to be incorporated easily and economically. The results demonstrated significant improvements in data transmission reliability, power consumption optimisation, and sensor longevity. The system achieved a favourable balance between performance

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and affordability, making it highly suitable for scalable deployment in resource-constrained settings. This work contributes to the advancement of WSN-based gas monitoring by addressing critical challenges in hardware selection, communication efficiency, and adaptive sensor operation. The architecture presents a promising solution for deployment in dynamic and harsh environments where traditional systems may fail

Keywords: hardware platforms; node design; patch directional antenna; transceiver; microcontroller; wireless sensor network

INTRODUCTION

In the era of ubiquitous connectivity and data-driven decision-making, wireless sensor networks (WSNs) have emerged as a transformative technology with diverse applications, ranging from environmental monitoring and precision to healthcare and industrial automation. By enabling efficient data collection and processing from the physical world, WSNs have fundamentally reshaped numerous domains. Their ability to operate in remote, hazardous, or inaccessible environments has expanded the scope of real-time monitoring and intelligent control in both civil and industrial contexts (Divyansh *et al.*, 2019).

As shown by A. Bhat & A. Passi (2022) and L. Gong *et al.* (2021), at the core of these networks are wireless sensor nodes, commonly referred to as "motes", which function as the essential building blocks of WSNs. These motes typically comprise sensing units, microcontrollers, radio transceivers, and power sources, all designed to function cohesively under constrained energy and processing conditions. Their modularity and scalability enable flexible network topologies and dynamic data routing mechanisms, making them suitable for a wide variety of deployment scenarios. Innovations in low-power electronics, adaptive protocols, and integrated sensing technologies have further enhanced the performance and reliability of these systems. WSNs have become integral to modern communication systems, facilitating efficient data collection and transmission across various domains, and serving as a backbone for emerging technologies such as the Internet of Things (IoT) and cyber-physical systems.

Y. Singh & T. Walingo (2024) developed an IoT-based wireless sensor network for real-time water quality monitoring, highlighting its effectiveness in detecting key parameters such as pH, turbidity, and dissolved oxygen. Their study demonstrated that integrating low-power sensors with cloud platforms ensures scalable and efficient environmental monitoring. Researches Y. Luo *et al.* (2024) proposed a novel system enabling simultaneous wireless power and data transmission in full-duplex mode for underwater sensor networks. The research confirmed that this approach significantly improves communication reliability and extends operational lifetime in challenging aquatic environments.

As F. Busacca *et al.* (2024) suggested the choice of microcontroller plays a crucial role in WSN design, directly impacting performance and energy efficiency. Microcontrollers like the ATmega128L and MSP430F1611 offer enhanced node capabilities, especially when paired with larger EEPROM sizes to accommodate growing storage demands. In addition, transceivers such as the Chipcon CC1000 and CC2420 enable high-data-rate applications, including audio and video transmission. Furthermore, integrating the TinyOS operating system, widely recognised in the literature, enhances compatibility and flexibility, ensuring seamless deployment in diverse WSN applications.

A. Thakkar *et al.* (2020) provided a broad classification of power management strategies in WSNs, emphasising dynamic voltage scaling, duty cycling, and cross-layer optimisation techniques as key drivers of energy efficiency. T. Mekonnen *et al.* (2017) explored energy consumption in multimedia sensor networks, underscoring the challenges posed by high data rates and suggesting architectural adaptations for multi-tiered node structures. Meanwhile, M. Amjad *et al.* (2016) reviewed the evolution of the TinyOS platform, highlighting its modularity, low overhead, and support for diverse sensing tasks, which makes it a favourable OS for constrained WSN environments.

In light of these findings, the current research builds upon a solid body of work in energy-aware design and system reconfigurability, proposing a wireless sensor node architecture optimised for gas detection. By synthesising advancements in operating systems, hardware modularity, and adaptive energy management, the proposed system is positioned to overcome existing limitations in scalability, environmental adaptability, and long-term deployment sustainability. The aim of this study was to design a wireless sensor network tailored for gas sensing applications, specifically intended to monitor and manage concentrations of hazardous gases. Through a thorough analysis of a specific case study, this paper highlights the innovative approach of selecting optimal hardware platforms, a critical factor in building robust and efficient WSNs.

MATERIALS AND METHODS

This study developed a comprehensive test setup to evaluate the performance and reliability of the wireless sensor node design incorporating methane (MQ4) and carbon monoxide (MQ7) gas sensors. The MQ4 and MQ7 sensors used in this setup were sourced from Winsen Electronics India Pvt. Ltd., a leading supplier and distributor of semiconductor-based gas sensors in India during 2012-13. These sensors are known for their affordability, easy interfacing, and widespread use in academic and industrial research. The MQ4 sensor is capable of detecting methane concentrations ranging from 200 to 10,000 ppm, with a typical sensitivity ratio (Rs/Ro) in clean air of ~4.4, and operates effectively within a temperature range of -10°C to

50°C. The MQ7 sensor, designed for carbon monoxide detection, operates in a range of 20 to 2,000 ppm, with an Rs/Ro ratio of ~1.5 in clean air, and features dual heater voltage operation (high and low cycles) to improve selectivity. The experiments were conducted within the advanced research facilities at the Indian Institute of Technology Bombay (IIT Bombay). The key objective was to assess the system's response to environmental factors and evaluate the effectiveness of innovative design modifications, such as the current driver circuit and stack-based architecture. The testbed ensured controlled gas exposure, precise timing of sensor activation, and real-time data logging to comprehensively analyse sensor behaviour and node-level performance under dynamic conditions. Figure 1 shows the experimental sensor node testbed, which includes sensor nodes integrated with gas sensors, a microcontroller ATmega128L (manufactured by Microchip Technology), and a Radio Frequency (RF) transceiver, providing real-time data for analysis.

Figure 1. Experimental sensor node testbed at IITB Lab, Mumbai
Source: photo by the authors

The wireless sensor node's block diagram (Fig. 2) represents the core components used in the experimentation, including gas sensors, microcontroller, battery, RF transceiver, and actuator. The sensors used in the test setup were calibrated and subjected to various environmental conditions to ensure their accuracy and reliability. To simulate real-world deployment scenarios, the test environment was carefully controlled and included variations in temperature (ranging from 10°C to 45°C) and relative humidity (ranging from 30% to 85%). The gas concentrations introduced in the test chamber included methane levels between 200 ppm and 5,000 ppm for the MQ4 sensor and carbon monoxide levels between 50 ppm and 1,000 ppm for the MQ7 sensor. These ranges were selected to reflect both typical indoor air quality levels and potential industrial leakage scenarios. Environmental chambers equipped with humidity and temperature controls were used to evaluate the sensor node's performance under fluctuating and extreme conditions. The calibration process involved exposing the sensors to known gas concentrations and recording sensor response curves to ensure linearity and repeatability. Additionally, the impact of cross-sensitivity and sensor saturation was assessed under high concentration conditions. These rigorous environmental tests enabled a thorough validation of the sensor node's robustness, response time, and accuracy in detecting target gases, thereby supporting the system's viability for real-world deployment in diverse and dynamic conditions (Yokoyama *et al.*, 2024).

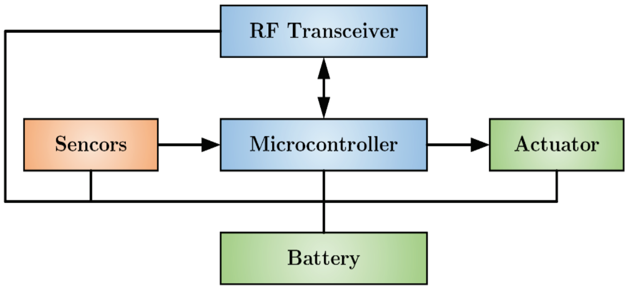

Figure 2. Typical block diagram of a mote
Source: compiled by the authors

Special focus was placed on using a current driver circuit to prevent sensor saturation, where the operating current of the sensors was dynamically adjusted, ensuring optimal performance. The heating elements integrated into the circuit enabled periodic recovery of the sensors to ensure their longevity and prevent damage from high gas concentrations. The wireless sensor node's stack-based architecture formed a critical aspect of the study, allowing for the integration of multiple radio chips for redundancy and improved communication capabilities. The node was designed with multiple radio chips to enable parallel data transmission, improving throughput and system reliability. The system was tested under various interference and environmental conditions to evaluate its adaptability and robustness. A total of 40 test iterations were performed, encompassing both hardware-level functionality and sensor communication reliability across a range of deployment scenarios. Modifying layers and radio chips assessed the modularity and scalability of the stack architecture to accommodate emerging technologies and future communication standards. During the testing process, the sensors were subjected to controlled gas exposure at multiple concentrations – methane (MQ4) at 200, 500, 1000, 3000, and 5000 ppm, and carbon monoxide (MQ7) at 50, 200, 500, and 1000 ppm. These tests were conducted under regulated environmental conditions, with temperature varying from 10°C to 45°C and humidity from 30% to 85%, to ensure comprehensive performance evaluation under both nominal and extreme conditions. These test iterations helped validate the effectiveness of the stack-based design in maintaining communication integrity and sensing accuracy under real-world challenges such as RF interference, fluctuating environmental factors, and variable sensor loads.

Additionally, the sensor nodes were equipped with directional antennas, optimised for energy-efficient communication and localisation. The antennas were tested for transmission range, signal quality, and interference reduction. The results were compared under different directional configurations to determine the most efficient setup for varying operational environments. The integration of the directional MAC layer played a crucial role in enhancing the communication efficiency of the system. The system's overall performance, including power consumption, data throughput, and communication reliability, was analysed to provide a comprehensive understanding of the sensor node's capabilities.

RESULTS AND DISCUSSION

Developing a wireless sensor node incorporating multiple radio chips, directional antennas, a dedicated MAC protocol, and on-air programming represents a promising and innovative direction for future research and development. Table 1 summarises the gaps in existing hardware and commercially available nodes (Maia *et al.,* 2009).

Table 1. Summarising the gaps in existing hardware and commercially available nodes

No.	Particulars	Motes	Features	Limitations	Remarks	Proposed Note
1.	**Microcontroller**					
1.1	Atmel AT 90LS8535	WeC, Rene 1	Clock 4 MHz RAM/ Flash-512/8k			
1.2	Atmel Atmega 163	Rene 2 Dot	Clock -8 MHz RAM /Flash-1K/16K	8 bit		
1.3	Atmel Atmega128 L	Mica, BT Node, Mica 2 Dot, iBadge CENS Medusa MK2, Nymph, MicaZ, AquisGrain, DSYS 25, Ember RF Module, Module, Fleck	Clock 8 MHz RAM/ Flash-4K/128K		Most popular among motes	Proposed
1.4	Atmel AT91FR40162S	Sunspot	Clock -75 MHz Flash-256K	%	32bit (Suitable for sink)	
1.5	TI MSP430F1611	Telos B/ TmoteSky, eyesIFXv2, SHIMMER	Clock -8 MHz Flash/EEPROM-10 K		16 bit (Lowest power consumption	Proposed
2	**External Memory**					
2.1	EEPROM 32K	WeC, Rene 1, Rene 2, Dot				
2.2	EEPROM 48 K	Telos B/ TmoteSky, eyesIFXv2, SHIMMER				
2.3	EEPROM 512 K	Mica, BT Node, Mica 2 Dot, iBadge CENS Medusa MK2, Nymph, MicaZ, AquisGrain, DSYS 25, Ember RF Module, Module, Fleck				Proposed
2.4	EEPROM 2M	Sunspot				
3	**Radio Transceiver**					
3.1	RFM TR 1000	WeC, Rene 1, Rene 2, Dot Mica	BW (Kbps)-10 Freq (MHz)-900	Low Data Rate		
3.2	Chipcon CC	BT Node, Mica2, Mica2 Dot, Nymph	BW (Kbps)-38.4 Freq (MHz)-900			Proposed
3.3	Chipcon CC 2420	Telos, MicaZ,BSN Node, AquisGrain, Pluto, iMote 2, XYZ Sensor Node, ProSepKz II	BW (Kbps)-250 Freq (MHz)-2400		High Data rate Application audio	Proposed
4	**Operating System**					
4.1	Tiny Os	WeC, Rene 1, Rene 2, Dot Mica, BT Node Spot ON,Telos, Mica 2, Mica2 Dot, iMote. Spec, MicaZ,CIT Sensor Node, BSN Node, AquisGrain, Telos B/ TmoteSky			Most popular among motes	Proposed
4.2	Squawk VM (Java)	Sunspot				
5	**Multiple Radio chip**					
		Not Present				Proposed
6	**Directional Antenna & MAC Protocol**					
		Not Present				Proposed
7	**On Air programming**					
		WeC				Proposed

Source: developed by the authors based on M. Johnson *et al*. (2009)

As shown in Table 1, microcontrollers and transceivers are essential components of any communication system, and their selection must be based on theoretical principles to optimise system performance. For instance, a microcontroller should be selected based on processing speed, power consumption, peripheral support, and application requirements. Key theoretical factors to consider include the microcontroller's clock speed and architecture (e.g., RISC vs. CISC), power consumption analysis, and the availability of integrated peripherals such as analog-to-digital and digital-to-analog converters, and communication interfaces. As described in R. Qi & R. Li (2022) the Transceivers, responsible for transmitting and receiving data, are chosen based on factors such as frequency range, modulation techniques, and sensitivity.

Block diagram of the designed mote. Figure 3 shows a block diagram of the designed mote, highlighting the evolution of the wireless sensor node architecture. This design departs from the traditional actuator by introducing a current driver as an innovative replacement. This modification enhances the node's functionality, enabling the generation of pulsating signals in response to specific contextual conditions.

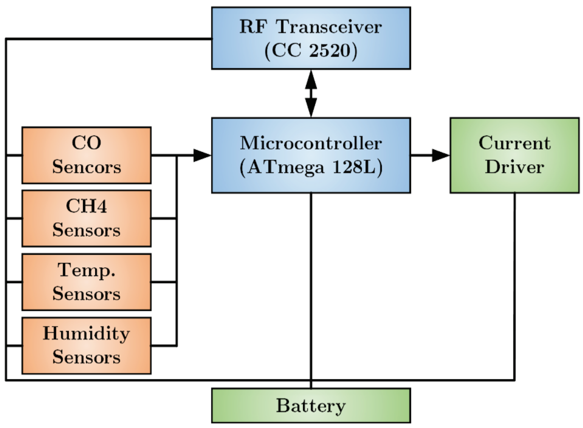

Figure 3. Block diagram of a designed mote
Source: compiled by the authors

To illustrate this concept, consider the operation of a gas sensor within the system. When activated, the gas sensor initiates the heating element, facilitating the detection of gases such as methane. A blade-in-sensor mechanism precisely manages gas deposition, converting it into an electrical signal. However, when exposed to excessive gas concentrations, the sensor risks oversaturation, leading to an increase in output values. This phenomenon not only signals potential saturation but also enriches the dataset with valuable insights.

A key innovation in this architecture is the integration of a current driver. By generating controlled pulsations, the current driver enhances the sensor node's ability to respond dynamically to environmental changes, improving accuracy and adaptability (Fig. 4). The block diagram of the designed mote in Figure 3 visually represents this concept, emphasising the role of the current driver.

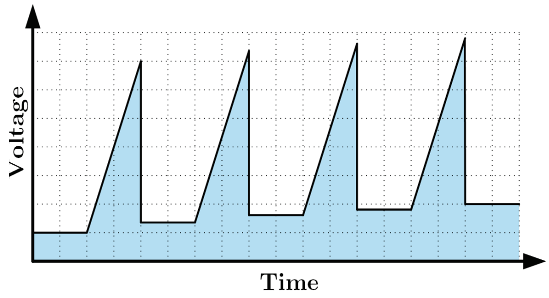

Figure 4. Current driver waveform
Note: gas sensor saturation
Source: compiled by the authors

Gas sensors can become saturated when exposed to high concentrations of the target gas, resulting in inaccurate readings or potential damage to the sensor. To mitigate this issue, various strategies are employed, including gas dilution, the utilisation of alternate sensors, periodic calibration, controlled sampling, physical protection, automatic shutdown, remote control, robust sensor design, data analysis, and regular maintenance. F. Ricciardella *et al.* (2017) proposed a novel strategy to address saturation and recovery delays in CVD (chemical vapor deposition) graphene-based gas sensors by applying pulsed heating and interface engineering. Their results showed enhanced response times and greater stability of the sensors under high gas concentration conditions. Scientists C. Ezeigweneme *et al.* (2024) investigated the role of wireless communication in electro-mechanical systems, focusing on the transition to cordless interfaces. They demonstrated that such technologies improved system modularity, reduced interference, and enhanced the adaptability of hardware configurations.

A highly effective approach to preventing gas sensor saturation is the integration of a current driver circuit. This circuit dynamically adjusts the sensor's operating current, optimising its sensitivity and preventing saturation. Additionally, it incorporates heating elements that can be selectively deactivated, allowing the sensor to recover and maintain accuracy for subsequent readings. This design ensures reliable gas detection, particularly in high-concentration environments, increasing both the sensor's longevity and performance. By integrating these approaches, sensor saturation risks are effectively mitigated, ensuring precise and reliable monitoring of hazardous gas concentrations within the wireless sensor network.

Stack architecture. As B. Aghaei (2011) and S. Petersen *et al.* (2007) have shown in their work without any stack-based approach, the second key feature distinguishing in current study designed wireless sensor node is its stack-based architecture – a transformative approach that significantly enhances the node's capabilities and versatility. Unlike conventional designs, this architecture enables the seamless integration of multiple radio chips within a single node, introducing greater flexibility and adaptability. Even P. Bekal *et al.* (2024) have adopted the stack-based architecture with a layered system design, promoting modularity, ease of debugging, and scalability. By partitioning the system into distinct layers, each responsible for specific functions, it minimises interdependencies, ensuring that modifications in one layer have minimal impact on others. This enhances maintainability and facilitates incremental upgrades. Moreover, incorporating multiple radio chips leverages parallel processing and redundancy, improving both robustness and performance. Backup communication channels enhance reliability, while load balancing optimises throughput. The ability to transmit and receive data simultaneously across different frequencies reduces latency and increases efficiency.

This architecture aligns with the open systems interconnection model by M. Kaddi *et al.* (2024), which provides a conceptual framework for network interactions across seven layers. Key advantages include: 1) modularity – independent operation of each layer allows targeted upgrades and efficient troubleshooting; 2) interoperability – standardised interfaces ensure compatibility with diverse hardware and software components; 3) scalability – new functionalities can be easily incorporated by adding or modifying layers (Mazin & Onykiienko, 2023). Figure 5 illustrates the stack designed in this study. The stack architecture's contribution extends beyond its immediate functionality, significantly enhancing the node's scalability by accommodating multiple radio chips. The node can quickly adapt to evolving communication standards and emerging technologies. This future-proofing feature safeguards investments and ensures the node remains relevant in the dynamic landscape of technological advancements.

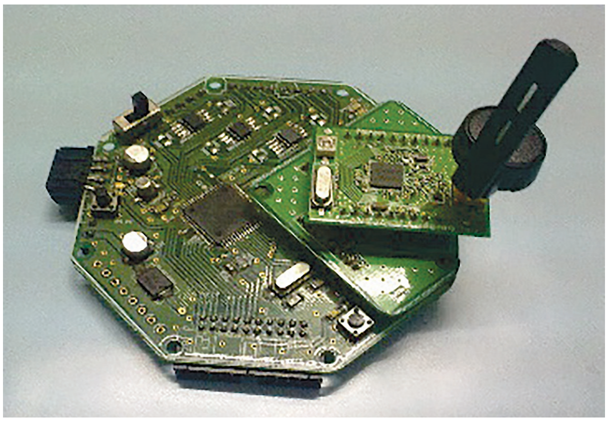

Figure 5. Stack design
Source: photo by the authors

Integrating a stack-based architecture within the wireless sensor node introduces a new dimension of communication capabilities (Fig. 6). This innovation improves the node's ability to interact, collaborate, and contribute within wireless sensor networks. By leveraging the advantages of layered integration, the stack architecture exemplifies adaptability and potential, paving the way for new opportunities in wireless communication technology.

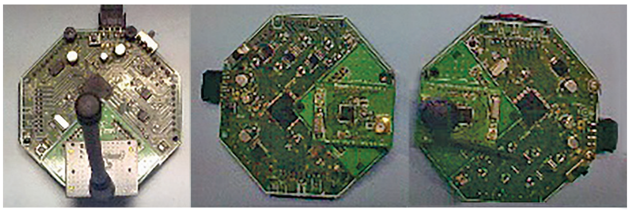

Figure 6. WSN of designed nodes
Note: node design using multiple directional antennas for localisation
Source: compiled by the authors

Another key feature of the wireless sensor node is the directional antenna, which enhances energy efficiency by optimising radiation directivity. As M. Shah & S. Mehta (2013) and S. Kasar *et al*. (2013), review key localisation techniques in wireless sensor networks, categorising them into range-based and range-free methods. It analyses algorithms like RSSI, ToA, AoA, and DV-Hop, discussing their trade-offs in terms of cost, accuracy, and complexity. The authors highlight real-world challenges and suggest directions for improving localisation efficiency and precision in future research. This approach marks a shift in antenna design, focusing on improving signal propagation and reception patterns. While testing is still ongoing, the potential benefits are promising. These antennas are expected to offer enhanced transmission range, reduced interference, and improved signal quality by directing radiation toward specific areas.

The node's architecture includes provisions to support up to six directional antennas (Fig. 7), offering significant versatility to meet the dynamic needs of various applications. This modularity allows the node to customise its antenna configuration for specific scenarios, optimising communication paths and enabling adaptive responses. Central to this capability is the development of an advanced localisation algorithm, which is essential for providing precise spatial awareness, enabling the node to accurately determine its position relative to neighbouring nodes.

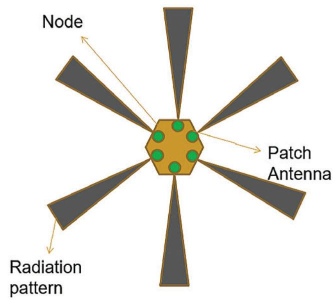

Figure 7. Directional antenna
Source: compiled by the authors

The directional antenna design is closely integrated with the development of a directional MAC layer. This layering strategy facilitates efficient channel access, reducing contention and collisions while enhancing communication efficiency. The synergy between the directional antennas and the MAC layer forms a powerful combination, improving energy conservation and communication reliability. The node's design incorporates a scheme that leverages the collective potential of multiple directional antennas for precise localisation.

M. Shah & S. Mehta (2013) reviewed key hardware platforms for wireless sensor networks, comparing options like MICA, TelosB, and IRIS. It highlights trade-offs in processing power, energy use, memory, and cost, emphasising the need for modular and energy-efficient designs suited to specific applications. This paper highlights the key innovations and features of the mote design. Additionally, the limitations and challenges encountered during experimentation are examined, along with potential solutions and future directions. A comprehensive summary of the research and its implications is provided in Table 2.

Table 2. Summary of the research and its implications

Limitation/Challenge	Description	Potential solutions
Power consumption	High power usage reduces node lifespan.	Low-power components, energy-efficient protocols, energy harvesting (solar, kinetic).
Processing and memory constraints	Limited processing power and memory restrict complex algorithms.	Optimise algorithms, use lightweight data compression, and offload tasks to the central server/edge device.
Communication range and reliability	The range is limited by antenna design, transmission power, and obstacles.	Mesh networking, additional nodes/repeaters, adaptive communication protocols.
Environmental factors	Performance and longevity are affected by temperature, humidity, and obstructions.	Robust materials, calibration routines, and adaptive systems.
Cost constraints	Keeping costs low can compromise performance and reliability.	Careful component selection, economies of scale, and cost-sharing models.
Scalability	Ensuring performance with a large number of nodes.	Hierarchical architectures, efficient routing protocols, dynamic network management.
Data security and privacy	Securing data transmission and ensuring privacy.	Strong encryption, secure key management, and protective protocols against eavesdropping/ data tampering.
Synchronisation	Maintaining time synchronisation across all nodes.	Time synchronisation protocols (IEEE 1588 PTP, NTP), periodic re-synchronisation.
Interference and coexistence	Potential interference from other wireless devices.	Interference mitigation techniques (frequency hopping, adaptive channel selection), coexistence protocols.
Node deployment and maintenance	Difficult deployment in large/inaccessible areas and logistical maintenance challenges.	Autonomous deployment (drones/robots), self-healing/ self-organising networks, remote maintenance and diagnostics tools.

Source: compiled by the authors

Table 2 summarised the key challenges faced in designing and deploying WSNs, including high power consumption, limited processing and memory capabilities, and restricted communication range. Environmental factors like temperature and humidity also impact node reliability and lifespan. To address these, solutions such as low-power components, energy harvesting, and robust calibration mechanisms are suggested. Cost remains a major constraint, often requiring a careful balance between performance and affordability. Scalability and synchronisation become critical as networks grow, necessitating hierarchical designs and time synchronisation protocols. Ensuring data security and privacy is another priority, tackled through encryption and secure key management. Additionally, interference from other wireless devices and the complexity of node deployment in remote areas pose ongoing challenges. Mitigation techniques include adaptive communication, autonomous deployment methods, and self-healing networks.

CONCLUSIONS

This study presents a novel wireless sensor node architecture specifically designed for gas sensing applications, focusing on key challenges such as energy efficiency, communication reliability, and system adaptability. The proposed design integrates multiple radio chips, a modular stack-based hardware architecture, and directional antennas to significantly enhance performance in dynamic environments. The inclusion of a current driver circuit effectively addresses the issue of sensor saturation, thereby improving the accuracy of gas concentration measurements even under fluctuating environmental conditions. The stack-based design promotes scalability and modularity, allowing for seamless integration of emerging technologies and easier customisation for various application domains.

In addition, the use of directional antennas and a dedicated medium access control layer helps optimise communication efficiency, improve signal strength, and support enhanced node localisation – critical for applications such as hazardous gas leak detection and environmental monitoring. The system was rigorously tested across a range of environmental conditions, including variations in temperature, humidity, and gas concentrations, to evaluate its robustness and reliability. Experimental results confirm improvements in data transmission accuracy, power consumption, and overall system longevity.

The architecture also supports the integration of additional sensors and communication modules at a low cost, making it a viable solution for large-scale deployments. This work contributes to advancing WSN-based gas monitoring systems by addressing fundamental hardware challenges and proposing a cost-effective, energy-conscious, and future-ready solution. Future work will focus on refining real-time data processing, enhancing interference resilience, and enabling broader field deployments in industrial and urban settings.

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CONFLICT OF INTEREST

None.

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Дослідження нових архітектурних елементів і концепцій проєктування для бездротових сенсорних вузлів: приклад з практики

Анотація. Бездротові сенсорні мережі відіграють важливу роль у сучасних системах зв'язку, забезпечуючи ефективне збирання та передавання даних у різних сферах. Такі мережі є ключовими для застосувань, пов'язаних із моніторингом довкілля, промисловою автоматизацією, розумними містами та системами охорони здоров'я, де критично важливими є точні й оперативні дані. Метою цього дослідження було розробити та перевірити нову архітектуру бездротового сенсорного вузла для задач газової детекції з акцентом на підвищення енергоефективності, надійності зв'язку, модульності та адаптивності до різноманітних умов експлуатації. Запропонована конструкція поєднує використання декількох радіочіпів, архітектури на основі стеку та спрямованих антен для підвищення стійкості до зовнішніх впливів і адаптивності мережі. Для запобігання насиченню сенсора було введено схему струмового драйвера, що забезпечує точність вимірювання концентрації газів. Архітектура на основі стеку покращує модульність і масштабованість, спрощуючи оновлення та забезпечуючи сумісність із новітніми технологіями. Крім того, спрямовані антени та спеціалізований протокол доступу до середовища підвищують ефективність зв'язку та точність локалізації. Експериментальна перевірка, проведена в сучасних наукових лабораторіях, підтвердила ефективність запропонованої конструкції в умовах різноманітного середовища. Представлений підхід до розробки апаратної частини базується на використанні недорогих, масово доступних компонентів, інтегрованих таким чином, щоб забезпечити високу функціональність без збільшення складності або вартості. Модульна конструкція також дає змогу легко та економно додавати додаткові сенсорні функції, наприклад, вимірювання температури, вологості або концентрації частинок. Результати показали суттєве покращення надійності передавання даних, оптимізацію енергоспоживання та збільшення довговічності сенсорів. Система досягла оптимального балансу між продуктивністю та доступністю, що робить її придатною для масштабованого розгортання в умовах обмежених ресурсів. Це дослідження робить внесок у розвиток газового моніторингу на основі бездротової сенсорної мережі шляхом вирішення ключових викликів у виборі апаратного забезпечення, ефективності зв'язку та адаптивної роботи сенсорів. Запропонована архітектура є перспективним рішенням для розгортання в динамічних та суворих умовах, де традиційні системи можуть виявитися неефективними

Ключові слова: апаратні платформи; конструкція вузлів; спрямована патч-антена; приймально-передавальний пристрій; мікроконтролер; бездротова сенсорна мережа