[1]Husam K. Salih

[2]Ayad A. Al-Ani

Enabling The E-NOSE: Evaluating Network Technologies for Optimized Odor Data Transmission in IoT and Edge Computing Applications

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Abstract: - Electronic Noses (e-noses) are advanced sensors that are being increasingly used in the Internet of Things (IoT) field. They have various applications in environmental monitoring and medical diagnostics. Optimal transmission of odor-related data is essential for fully harnessing the capabilities of these electronic noses in various network environments. This research paper examines the issue of transmitting odor data in Internet of Things (IoT) applications by assessing recent progress in communication and network technologies. A thorough analysis of various network alternatives, such as Ethernet, cellular (4G/5G), Wi-Fi, Bluetooth, Zigbee, and LoRa, is provided, accompanied by an elaborate table displaying precise technical specifications. The analysis of LoRa, a Low-Power Wide-Area Network (LPWAN) technology, encompasses an investigation into its architecture, modulation method, device classifications, and protocols such as LoRaWAN. The analysis of Edge Computing and cloud-based approaches for managing odor data in IoT culminates in a tabular presentation that succinctly outlines their advantages and disadvantages. This study provides valuable information to enhance the efficiency of transmitting odor data and effectively utilize electronic nose technology in different emerging applications in the Internet of Things (IoT) field.

Keywords: e-nose, IoT, network technologies, LoRa, LoRaWAN, Edge Computing, odor data transmission, LPWAN, Chirp Spread Spectrum.

I. INTRODUCTION

In the rapidly expanding field of the Internet of Things (IoT), the use of modern sensing technologies has become essential, resulting in the development of revolutionary innovations that go beyond conventional constraints. The Electronic Nose, also known as e-nose, has emerged as a revolutionary technology with versatile applications in different industries. This introduction seeks to provide insight into the developing field of e-nose technology, with a focus on its definition, purpose, applications, and the significant obstacle of transmitting odor data efficiently within the Internet of Things (IoT) framework[1].

A. Definition and Purpose of E-Nose

An electronic nose is a sensory device that imitates the human olfactory system, allowing it to detect and analyze odors in its surroundings. E-noses, unlike conventional gas sensors, have a broader range of capabilities as they utilize multiple sensors to capture the complete odor profile rather than detecting specific chemical compounds. This technology is employed in many industries, such as the food & beverage, environmental, and medical fields[2], [3].

An e-nose is primarily designed to augment our capacity to detect and analyze odors beyond the limitations of human capabilities. E-noses utilize sophisticated sensors and machine learning algorithms to detect intricate odor patterns, thereby enhancing quality control procedures, environmental monitoring, and even medical diagnosis. As industries more and more adopt the potential of e-nose technology, the requirement for smooth communication and effective data transmission becomes crucial.

B. Applications and Importance in Sensing Odor

The applications of electronic nose technology are as varied as the spectrum of odors it can detect. E-noses are utilized in the food and beverage sector to maintain quality control by verifying the uniformity and freshness of products. E-noses enhance environmental monitoring by detecting pollutants and noxious gases, thereby aiding in the reduction of air pollution. E-noses have a significant role in healthcare by aiding in disease diagnostics, as they have the capability to detect specific biomarkers that are linked to particular medical conditions.

The significance of e-nose technology in detecting odors resides not only in its adaptability but also in its capacity to deliver prompt and precise outcomes. Conventional approaches to odor detection typically entail laborious and subjective procedures, relying on the human sense of smell. In contrast, electronic noses provide a more impartial

[1] Department of Information & Communication Engineering Al-Nahrain University, Baghdad, Iraq, Department of Computer EngineeringTechniques, Ibn Khaldun University College, Baghdad, Iraq [0000-0002-4267-1465]

husam01salih@gmail.com

2Department of Information & Communication Engineering Al-Nahrain University, Baghdad, Iraq [0000-0002-2932-8670]

ayad.a@nahrainuniv.edu.iq

and effective method, allowing for immediate monitoring and analysis. Nevertheless, in order to fully exploit the capabilities of e-nose technology, it is crucial to have uninterrupted connectivity and reliable data transmission[4], [5]

C. Challenges in Efficient Data Transmission

Despite the increasing capabilities of e-nose technology, there are still challenges in efficiently transmitting data, especially in the context of Internet of Things (IoT) applications. The large amount and intricate nature of scent data produced by electronic noses necessitate an advanced infrastructure to enable smooth communication between devices and central processing systems. The integration of e-nose technology with advanced communications and network protocols is crucial in this context.

D. Incorporation of E-Nose with Communications and Network Technologies

1) The significance of connectivity in E-Nose applications.

The crux of e-nose applications lies in both the capacity to capture and analyze odor data, as well as the prompt and dependable transmission of this data for significant interpretation and decision-making. Connectivity is essential for e-nose applications as it provides the foundation for real-time monitoring and quick reactions to dynamic environmental conditions[6].

The demand for reliable connectivity solutions has experienced significant growth as industries increasingly depend on e-nose technology for crucial operations. Connectivity is of utmost importance, whether it is in industrial settings where continuous odor monitoring is essential for quality control, or in healthcare applications where timely detection of specific odors is critical for diagnostics.

2) Improving Efficiency with IoT and Edge Computing

E-nose technology in relation to Edge Computing and the Internet of Things (IoT) has proven to be an essential tool for the effective transmission of odor data. The IoT paradigm, characterized by the interconnectedness of devices and the smooth exchange of data, perfectly aligns with the requirements of e-nose applications.

IoT enables the establishment of a network of interconnected sensors in e-nose technology, which can transmit odor data instantaneously. The interconnection between different components allows for a comprehensive and integrated approach to monitoring odors. This enables thorough analysis and quick response to environmental changes. In addition, the incorporation of Edge Computing brings computational capabilities in close proximity to the origin of data generation, reducing latency and improving the overall efficiency of odor data processing.

3) Edge Computing and IoT Technologies: A Concise Overview

Edge Computing, a paradigm that entails the processing of data in close proximity to its point of origin, has emerged as a prominent technology that complements the Internet of Things (IoT). Edge Computing alleviates the workload on centralized servers and improves data processing speed by distributing computational tasks. Within the realm of e-nose applications, Edge Computing guarantees that the evaluation of odor data takes place in close proximity to the sensors, thereby optimizing the utilization of network resources and reducing delays in decision-making.

The integration of e-nose technology with IoT and Edge Computing has the potential to completely transform odor monitoring in different fields. Nevertheless, in order to fully exploit this capacity, it is imperative to possess a comprehensive comprehension of the disparities between Edge Computing and IoT.

E. Purpose of the Research Paper

1) Filling the Knowledge Gap

The amalgamation of e-nose technology with sophisticated communications and network technologies is a dynamic and progressive domain. Nevertheless, there is a clear deficiency in the comprehensive comprehension of how these technologies collaborate to enhance the transmission of odor data in IoT applications. This research paper seeks to address the lack of understanding by conducting a comprehensive investigation into the combination of e-nose technology with Edge Computing, IoT, and different network and communication technologies.

2) Furnishing exhaustive information for researchers and practitioners.

Researchers and practitioners in the field of e-nose applications frequently struggle with the intricacies of selecting the most appropriate communication and network protocols for their particular requirements. This paper aims to provide them with extensive knowledge regarding the intricacies of Edge Computing, IoT, The purpose of this study is to give them a thorough understanding of the nuances of Edge Computing, IoT, and a comparative analysis of different network and communication technologies. The aim of this is to offer a useful tool that facilitates decision-making and enhances the application of e-nose technology in many fields.

3) Guiding the process of selecting the most suitable technologies for E-Nose applications.

The main aim of this research paper is to offer guidance to researchers, engineers, and industry professionals in choosing the most suitable technologies for e-nose applications. The paper aims to provide readers with the necessary knowledge to make informed decisions by conducting a thorough analysis of Edge Computing, IoT, and different network and communication technologies. The primary objective is to enhance the integration of e-nose technology with advanced communications and network protocols, thereby optimizing its potential across various industries.

In the following sections of this paper, we will conduct a detailed comparison between Edge Computing and IoT. We will also examine the distinctions between various network and communication technologies, with a specific focus on LoRa communications. Additionally, we will analyze the protocols, particularly LORAWAN, that are essential for optimizing the transmission of odor data in e-nose applications. By conducting a thorough investigation, our objective is to facilitate progress in the field of odor detection technologies and their effortless incorporation into the wider framework of the Internet of Things.

II. Literature Review

Low-Power Wide-Area Networks (LPWANs) such as LoRaWAN are essential for connecting remote sensors and devices in the Internet of Things (IoT), which is transforming all aspects of our lives[7]. The appeal of LoRaWAN stems from its capacity to provide long-distance communication, minimal energy usage, and strong penetration through barriers, rendering it well-suited for a wide range of IoT applications[8], [9]. This systematic review explores the recent progress and difficulties in LoRaWAN technology, assessing its ability to support the continuously growing IoT environment.

Studies have investigated alternative chirp spread spectrum techniques to improve the efficiency of channel usage and increase data transmission rates in LoRaWAN[10][11]. Both in-phase and quadrature chirp spread spectrum techniques have emerged as promising options for enhancing efficiency and resilience to interference[12]. In addition, multi-hop LoRaWAN uplink extensions utilize intermediate nodes to expand the communication range beyond the direct reach of gateways, thereby overcoming coverage limitations in remote areas[13].

LoRaWAN's performance has been assessed in different scenarios, such as the monitoring of water quality[8], livestock health[14], and indoor remote health monitoring[9]. The evaluations demonstrate the effectiveness of LoRaWAN in various industries, including environmental monitoring, precision agriculture, and healthcare.

The issue of energy consumption remains a crucial concern in IoT devices that rely on batteries. Scientists are investigating clustering methods to enhance data forwarding in LoRa networks, achieving a balance between energy efficiency and dependable communication[15]. In addition, there has been a development of comprehensive sensor energy analysis and modeling techniques to assist developers in optimizing LoRaWAN deployments that are tailored to specific applications[16].

LoRaWAN encounters obstacles such as scalability issues, limitations in latency, and potential vulnerabilities in security, despite its promising capabilities. Subsequent research should prioritize the resolution of these concerns by employing network optimization techniques, implementing hybrid network deployments, and enhancing security protocols[17], [18]. LoRaWAN is a prominent technology in the LPWAN (Low Power Wide Area Network) field, providing long-distance and energy-efficient connectivity for the growing Internet of Things (IoT) industry. Continuous research and development are consistently improving the capabilities and addressing the limitations of LoRaWAN, making it an increasingly influential force in transforming how we connect and interact with the world.

III. Exploring Edge Computing and IoT for E-Nose Applications

Edge Computing is a decentralized computing model that entails processing data in close proximity to its origin, rather than depending on a centralized server located in the cloud. It enables the transfer of computational abilities to the "edge" of the network, where devices and sensors are usually situated. The close proximity enables expedited data processing and minimized latency, as data does not have to traverse long distances to reach a central server[19].

Edge Computing involves the execution of computational tasks on devices or local servers that are located in close proximity to the point where data is generated. This can involve data analysis, processing, and even storage, all happening in close proximity to where the data is created. This approach is particularly beneficial in scenarios where real-time or near-real-time processing is crucial, as it minimizes the delays associated with transmitting data to a remote data center.

Edge Computing is crucial in improving the efficiency of odor data processing in the field of Electronic Noses (e-nose). E-noses are equipped with sensors that capture intricate odor profiles, resulting in significant volumes of data. Through the implementation of Edge Computing, the data can be processed locally at the outset, enabling swift analysis and decision-making. This is particularly vital in applications where rapid reactions to variations in odor patterns are necessary, such as in industrial environments where immediate quality control is of utmost importance.

Edge computing in e-nose applications guarantees prompt and proximate interpretation of odor data in proximity to the sensors. This not only decreases the time delay but also reduces the necessity for ongoing high-capacity communication with centralized servers. Edge Computing enhances the utilization of network resources, thereby improving the responsiveness, scalability, and adaptability of e-nose applications to changing environmental conditions.

A network called the Internet of Things (IoT) links different physical devices, vehicles, appliances, and objects that are equipped with sensors, actuators, and software. These devices utilize internet connectivity to establish communication and exchange data, allowing them to autonomously gather and disseminate information without the need for human involvement. The Internet of Things (IoT) includes a diverse array of applications, spanning from intelligent residential dwellings and industrial mechanization to medical care and ecological surveillance[20].

In the Internet of Things (IoT), devices are outfitted with sensors that collect data. This data is subsequently transmitted across a network to a central server or cloud-based platform for the purpose of processing and analysis. The interconnected devices are capable of receiving commands or updates, enabling remote control and monitoringIoT makes it possible to build "smart systems," in which objects can exchange data, interact with one another, and adapt to changes in their surroundings.

In the field of electronic nose technology, the Internet of Things (IoT) provides a framework to construct sensor networks. E-noses are capable of communicating not just with cloud platforms or central servers, but also with each other as Internet of Things (IoT) devices. This makes it possible for them to work together to advance our understanding of odor patterns. It is especially useful in situations like these since it allows for broad odor monitoring on a larger scale due to the connectivity of multiple e-noses installed in different areas.

The Internet of Things (IoT) facilitates the instantaneous transmission of olfactory data from electronic noses (e-noses) to centralized systems, enabling uninterrupted monitoring and analysis. Moreover, it simplifies the incorporation of electronic noses into broader Internet of Things (IoT) ecosystems, allowing for the use of these devices in various fields. For instance, in an industrial environment, Internet of Things (IoT)-enabled electronic noses can be integrated into a comprehensive system that incorporates additional sensors to monitor environmental conditions. This integrated approach enhances quality control and process optimization. The combination of electronic nose (e-nose) technology and the Internet of Things (IoT) increases the ability to adapt and effectiveness of odor detection in a variety of industries. Table-1 discuss the empirical comparison between Edge computing and IoT[21].

Table 1 Comparison table - IoT and Edge computing

Context	**IoT**	**Edge Computing**
Concept	A network of interconnected devices and objects that collect and exchange data over the internet.	A computing paradigm that moves data storage and processing capacity closer to the data source, or the network's edge.
Data Collection	Devices gather massive amounts of data from sensors and send it to the cloud for processing.	Data is processed locally at the edge devices, reducing the need for cloud transmission.
Data Processing	Data processing primarily occurs in centralized cloud	Data processing occurs at the edge devices or nearby

	servers.	edge servers.
Latency	Latency can be higher due to data transmission over long distances to the cloud.	Lower latency due to local processing and reduced data transmission.
Bandwidth	Requires significant bandwidth for continuous data transmission to the cloud.	Conserves bandwidth by processing data locally and sending only essential insights to the cloud.
Security	Data security concerns due to centralized storage and transmission over the internet.	Enhanced security as sensitive data remains closer to the source and is less vulnerable to breaches.
Response Time	Response time can be slower due to cloud-based processing and decision-making.	Faster response times due to local processing and decision-making capabilities.
Scalability	Can be challenging to scale due to centralized cloud infrastructure and limited bandwidth.	More scalable as edge devices can handle data processing independently and don't rely solely on cloud resources.
Applications	Smart homes, Wearables, smart cities, industrial IoT, connected vehicles, healthcare, etc.	Real-time analytics, autonomous vehicles, augmented reality, smart manufacturing, healthcare monitoring, predictive maintenance, etc.

This section concludes the following

- IoT focuses on connecting devices and collecting data, while Edge Computing emphasizes processing data closer to the source.
- Edge Computing addresses latency, bandwidth, security, and response time challenges associated with cloud-based IoT architectures.
- The choice between IoT and Edge Computing depends on application requirements, data sensitivity, and infrastructure constraints.

- Edge Computing is increasingly becoming a vital component of IoT systems, enabling more efficient, secure, and real-time applications.

IV. Comparison of prominent network Technologies for Odor Data Transmission

A. Importance of Strong Communication in Electronic Nose Systems:

In the field of Electronic Nose (e-nose) technology, the requirement for strong communication systems is of utmost importance because of the type of data produced by these sensory devices. Electronic noses continuously capture and analyze complex odor profiles, producing a significant amount of data that requires efficient transmission. Efficient transmission of this data is crucial for immediate monitoring, prompt reaction to environmental fluctuations, and the overall dependability of the e-nose system. An efficient communication infrastructure guarantees the prompt transmission of data collected by e-noses, enabling precise and rapid decision-making. The selection of communication technology plays a crucial role in fully harnessing the potential of e-noses, which are widely used in various industries for purposes such as quality control in manufacturing and environmental monitoring.

B. Summary of Diverse Network and Communication Technologies:

Within the realm of network and communication technologies relevant to e-nose systems, there is a wide range of choices available, each possessing distinct characteristics and capabilities[22], [23].

Ethernet, a dependable wired technology, demonstrates exceptional performance in terms of data transfer rates and minimal latency, rendering it well-suited for applications that prioritize stability. 4G/5G cellular networks offer wireless connectivity and mobility, making them well-suited for portable e-nose deployments. Wi-Fi provides rapid data transmission, although it may have restricted range and vulnerability to interference. Bluetooth, renowned for its minimal energy consumption, is well-suited for facilitating communication between devices over short distances. Zigbee, a protocol specifically developed for low-power sensor networks, effectively manages energy consumption while maintaining constrained data rates and range. LoRa technology is exceptionally good at covering large areas over long distances with minimal power consumption. It is therefore perfect for using electronic noses in isolated or outdoor settings. Low-power, wide-area Internet of Things (IoT) applications are met by Long-Term Evolution for Machines (LTE-M) and Narrowband Internet of Things (NB-IoT). NB-IoT offers extensive geographical coverage, while LTE-M offers enhanced data transmission rates. UWB offers outstanding data transfer rates and accurate location monitoring. Satellite communication encounters difficulties in terms of latency and the expenses associated with its implementation, despite its worldwide accessibility. The selection of the appropriate network technology for e-nose systems is contingent upon the specific requirements of the application, taking into account factors such as data transmission rates, coverage distance, power consumption, and mobility. Table-2 provides in-depth comparisons that delve into these technologies within the e-nose framework.

Table 2 Comparison of various communication protocols with various evaluation parameters

Feature	**Ethernet**	**4G/5G**	**Wi-Fi**	**Bluetooth**	**Zigbee**	**LoRa**	**NB-IoT**	**LTE-M**	**UWB**	**Satellite**
Technology	Wired	Cellular	Wireless	Wireless	Wireless	Wireless	Cellular	Cellular	Wireless	Satellite
Range	Short (up to 100m)	Wide (regional/global)	Medium (up to 300m)	Short (up to 10m)	Medium (up to 100m)	Long (up to 10km)	Wide (regional)	Wide (regional)	Short (up to 10m)	Global
Bandwidth	High (Gbps)	High (Mbps-Gbps)	High (Mbps-Gbps)	Medium (Mbps)	Low (kbps)	Low (kbps)	Low (kbps)	Medium (kbps-Mbps)	High (Gbps)	Moderate (kbps-Mbps)
Power Consumption	High	Medium	Medium	Low	Low	Very Low	Low	Low	High	Moderate

Latency	Low	Medium	Medium	Low	Low	High	High	High	Low	High
Security	High	Strong	Strong	Good	Weak	Moderate	Moderate	Moderate	Strong	Varies
Scalability	Limited	Large	Medium	Small	Large	Large	Large	Large	Small	Global
Mobility	No	Yes	Yes	Yes	Yes	Limited	Yes	Yes	No	Yes

V. DEEP DIVE INTO LORA COMMUNICATIONS

Long Range (LoRa) technology has become a prominent solution for enabling efficient and long-distance communication in the Internet of Things (IoT) ecosystem, where connectivity is crucial. LoRa, also known as Long Range, is a networking protocol that has become popular due to its capability to offer wide coverage with minimal power consumption[24]. This introduction will elucidate the fundamental elements of LoRa network architecture, providing insight into its key constituents, operational principles, and its role in enabling various IoT applications[25], [26]. Figure-1 represents LoRa communication architecture.

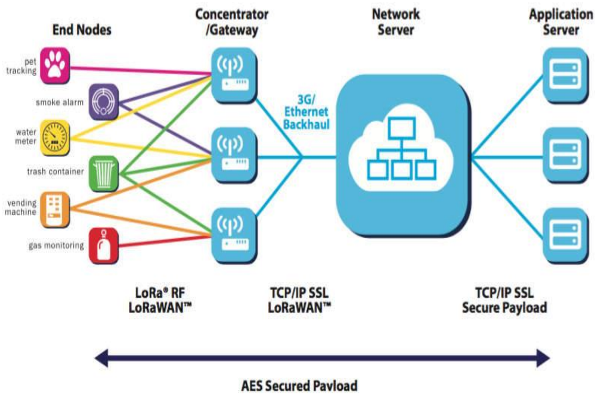

Figure 1 LoRa communication architecture (source-3glteinfo)

A. *Network Components*

- End Nodes: These are powered by battery devices, such as actuators or sensors, that use chirp spread spectrum modulation to gather and send data over the LoRa physical layer.
- Concentrator/Gateway: Between the end nodes and the network server, this serves as a bridge. Through the LoRa airways, it takes data from end nodes, transforms it into IP packets, and then sends those packets to the network server. Although a LoRaWAN network can have many gateways for redundancy and wider coverage, the illustration only shows one.
- Network Server: This is the central intelligence of the network. It manages the entire network, authenticates devices, filters duplicate messages, performs security checks, and routes data to the appropriate application server based on the device's ID and pre-configured settings.
- Application Server: This server processes application-specific data received from the network server. It may perform further analytics, generate reports, trigger actions based on the data, and send downlink commands to the network server for transmission to the end devices.

B. *Data Flow:*

- Uplink: End nodes send their data payloads securely using AES-128 encryption to the nearest gateway over the LoRaWAN protocol.
- Gateway Processing: The gateway receives the data, decrypts it, and converts it into IP packets. It then forwards these packets to the network server over a standard backhaul connection (e.g., cellular, Wi-Fi, Ethernet).
- Network Server Processing: The network server authenticates the device, checks for duplicate messages, and routes the data to the appropriate application server based on the device's ID and pre-configured settings.

- Application Server Processing: The application server processes the data, performs any necessary actions, and may send downlink commands back to the network server.
- Downlink): The network server receives downlink commands from the application server and transmits them to the relevant end node through the gateway.

Using a star-of-stars design, LoRaWAN allows end nodes to communicate with gateways directly while gateways communicate with the network server.

The network is perfect for Internet of Things applications in isolated or difficult-to-reach areas because of its low power consumption and long-range communication capabilities.

With AES-128 encryption and device authentication to safeguard data integrity and privacy, security is a fundamental component of LoRaWAN.

Following tables-3,4,5 represent the detail technical aspect of LoRa in detail.

Table 3 LoRa technical description

Feature	Description
Technology	Long Range Wide Area Network (LPWAN)
Modulation	Chirp Spread Spectrum (CSS)
Frequency Bands	Varies by region (433 MHz, 868 MHz, 915 MHz common)
Range	Up to 10-15 km (rural), 2-5 km (urban)
Bandwidth	Low (500 kHz to 50 kHz)
Data Rate	Up to 50 kbps
Power Consumption	Very low, enabling long battery life
Security	AES-128 encryption
Cost	Low-cost infrastructure and devices
Suitable for	Long-range, low-power IoT applications

Table 4 Comparison of LoRa with other major communications

Feature	LoRa	4G/5G Cellular	NB-IoT
Long Range	Excellent (up to 15km rural)	Good	Good (regional coverage)
Low Power Consumption	Excellent	Moderate	Excellent
Penetration	Good	Limited	Good

Cost	Low (devices & infrastructure)	High (devices & service)	Moderate (devices & service)
Scalability	Large	Very large	Large
Security	AES-128 encryption	Strong network security	Various protocols & encryption

VI. LoRa Protocols: Focus on LoRaWAN

LoRaWAN is a communication protocol specifically created for low-power, wide-area networks. It facilitates long-range communication between low-power devices, like sensors and actuators, and a central network server. LoRaWAN is based on the LoRa modulation technology, which combines long-range capabilities with low power consumption. This makes it ideal for a range of Internet of Things (IoT) applications, including the implementation of Electronic Noses (e-noses).

A. Essential elements of LoRaWAN:

1) End Devices (Nodes)

LoRaWAN, like the overall LoRa network architecture, consists of end devices, also referred to as nodes, that are equipped with LoRa communication capabilities. These nodes are commonly sensors or devices that gather data, such as those utilized in e-nose applications for detecting odors.

2) Gateways

Gateways act as bridges between endpoints and the network server. They transfer the data to the network server after receiving the signals that the end devices generate. By using several gateways, the LoRaWAN network's coverage is increased.

3) Server

An essential component in managing the exchange of data between applications and end devices is the network server. It manages operations including network administration, security, and data routing. The network server guarantees that the application server receives and processes the data from the end devices in an effective manner.

4) Application Server

The data gathered from the end devices must be processed, analyzed, and used by the application server. It functions as the intermediary between the unprocessed data and the actions that are specific to the application, such as initiating alerts or storing information for future retrieval.

B. The communication process in LoRaWAN:

In LoRaWAN, communication uses a star-of-stars architecture. A one-to-one connection between end devices and gateways is established, and gateways forward the data to the network server. The network server is responsible for coordinating communication with end devices and managing and controlling several gateways. Adaptive data rate and acknowledgment methods are used in LoRaWAN to enable efficient and dependable data delivery.

1) Key Features and Benefits for E-Nose Applications:

Long Range:

The long-range capabilities of LoRaWAN are essential for e-nose applications, particularly in situations where sensors are spread out over vast geographical regions. This enables the efficient surveillance of odors in expansive industrial facilities, agricultural fields, or urban settings.

2) Minimal energy usage:

E-nose devices frequently rely on battery power, and the low power consumption of LoRaWAN is beneficial for prolonging the battery life of these devices. This is especially crucial in remote or demanding environments where regular maintenance may be unfeasible.

3) Scalability

The ability of a system or process to handle more work or data without reducing its effectiveness or efficiency is referred to as scalability. LoRaWAN enables the connection of numerous end devices to a single network, resulting in exceptional scalability. This scalability is advantageous for e-nose applications in which a large number of sensors can be deployed to achieve extensive odor monitoring across multiple locations.

4) Adaptive Data Rate

LoRaWAN utilizes adaptive data rate mechanisms, enabling the network to dynamically modify the data rate according to the signal quality between the end device and the gateway. This guarantees the effective utilization of the network bandwidth, optimizing communication in diverse environmental circumstances.

5) Security

Security is of utmost importance in IoT applications, and LoRaWAN integrates strong security features. E-nose devices employ end-to-end encryption and authentication mechanisms to ensure the data's integrity and confidentiality during transmission, effectively preventing unauthorized access.

6) Standardization at a global level

LoRaWAN is a globally recognized and open standard that promotes compatibility between different vendors, allowing devices from various manufacturers to communicate effortlessly within a shared network. This standardization facilitates the integration of diverse e-nose devices and sensors.

7) Cost-Effective Deployment

The cost-efficient implementation of LoRaWAN networks is beneficial for e-nose applications, particularly in situations that require extensive deployments. Utilizing unlicensed spectrum and optimizing network resources are key factors in ensuring the economic feasibility of implementing solutions based on LoRaWAN technology.

The LoRaWAN protocol provides a resilient and effective communication framework for e-nose applications. The odor monitoring system is an excellent option for various environments, including industrial facilities and agricultural landscapes, due to its impressive long-range capabilities, low power usage, scalability, and security features. LoRaWAN is a crucial technology for connecting e-nose devices and enhancing the capabilities of odor sensing technology in the evolving IoT landscape. Following tables- 6 to12 represents the detail specifications of LoRaWAN.

Table 5 General Parameters

Parameter	**Description**
Technology Type	Long Range Wide Area Network (LPWAN)
Standard	LoRaWAN (open standard maintained by LoRa Alliance)
Frequency Bands	Varies by region (e.g., 433 MHz, 868 MHz, 915 MHz)
Modulation	Chirp Spread Spectrum (CSS)
Network Architecture	Star-of-stars topology
Device Classes	A, B, C (different downlink availability and power consumption)

Table 6 Application Layer

Feature	**Description**
Adaptive Data Rate (ADR)	Automatically adjusts data rate and power for optimal performance
Over-The-Air Activation (OTAA)	Secure device provisioning
Multicast	Efficient group communication
Geolocation	Location tracking using gateways

Table 7 Deployment Models

Model	Description
Public Networks	Operated by network providers, offering coverage in specific areas
Private Networks	Deployed by organizations for control and privacy
Hybrid Networks	Combination of public and private networks

Table 8 Key Advantages

Advantage	Description
Long Range	Wide coverage for remote and rural areas
Low Power Consumption	Enables long battery life for devices
Good Penetration	Signals can penetrate buildings and obstacles
Low Cost	Affordable devices and infrastructure
Scalability	Supports large-scale deployments
Security	Built-in security features for data protection

VII. Conclusion and Future Scope

A. Conclusion

To summarize, the study on network technologies for transmitting e-nose data highlights the importance of strong communication protocols in odor monitoring applications. Seamless and dependable transmission of odor data depends on the integration of Electronic Nose (e-nose) technology with robust network architectures. The ongoing production of complex scent characteristics highlights the necessity for uninterrupted transmission of data, which is essential for real-time monitoring and prompt responses to environmental fluctuations. The choice of network technology, taking into account factors such as speed, coverage, energy consumption, and scalability, is crucial. An examination of technologies such as Ethernet, 4G/5G, Wi-Fi, Bluetooth, Zigbee, LoRa, NB-IoT, LTE-M, UWB, and Satellite demonstrates clear advantages and limitations. Practitioners and researchers should make well-informed decisions by considering their specific requirements for using an electronic nose. The examination of the LoRaWAN protocol underscores its importance, as it provides extensive range capabilities, minimal energy consumption, scalability, and security attributes, rendering it an optimal choice for effective and dependable transmission of odor data.

B. Potential for Future Development:

The future of odor data communication holds great potential for further research and progress. Important focal points encompass the creation of tailored data analysis algorithms for scent data utilizing machine learning, the merging of e-nose technology with emerging technologies such as edge computing and blockchain, interdisciplinary cooperation among researchers, examination of energy harvesting methods for sustainable e-nose deployments, standardization endeavors within the IoT ecosystem, and exploration of human-machine interaction in odor sensing applications. In summary, comprehending network technologies for transmitting e-nose data lays the groundwork for future progress, presenting prospects for innovative solutions and enhanced capacities in perceiving, examining, and responding to odors in our environment.

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BIOGRAPHY

Husam K. Salih, Born in Baghdad/Iraq, in 1989. He gained B.Sc. from department of computer engineering techniques / Al-Mammon University College, Iraq and M.Sc., from department of information technology engineering/ Pune University, India, in 2014 and 2017, respectively. He is preparing for a PhD research in Dept. of Information and Communication Engineering / College of Information Engineering / Al-Nahrain University.

Ayad A. Al-Ani, Born in Baghdad/Iraq, in 1961. He gained the B.Sc., M.Sc., and Ph.D., from Dept. of Physics/College of Science/ Baghdad University., in 1983, 1990, and 1995, respectively. Previously, he was Univ. Vice President for Administrative affairs /Al-Nahrain University., Deputy Dean for Post Graduate Studies and Scientific Research/Baghdad University, and Head of Space and Astronomy Dept./College of Science/Baghdad Univ. Since 2006, he is a Professor of Digital Image Processing in Dept. of Information and Communication Engineering/College of Information Engineering/Al-Nahrain University.