Intelligent Noise Mapping for Smart Cities: Solutions, Trends, and Research Opportunities

Ye Liu, Xiaoyuan Ma, and Carlo Alberto Boano

The authors provide a critical review of recent advances in intelligent noise mapping, analyzing their technical principles, fundamental research topics, advantages, and limitations.

Abstract

Noise pollution is an often-overlooked environmental threat that poses a concealed but severe risk to public health and urban ecological environment. Despite being invisible, noise has become the second-largest environmental factor contributing to public health issues. Furthermore, noise pollution hinders the sustainable development of cities. To manage noise pollution in urban areas, intelligent noise mapping is expected to be an essential tool that can transform invisible noise problems into visible ones and provide an efficient governance basis. However, this technological approach is still in its infancy, and there is a significant gap in implementing large-scale dynamic urban noise mapping. In this article, we provide a critical review of recent advances in intelligent noise mapping, analyzing their technical principles, fundamental research topics, advantages, and limitations. We also present our insights on the development trends of intelligent noise mapping for smart cities. Finally, we identify four critical open issues and discuss our insights to address these gaps for future research. This study's findings can contribute to the development of more effective solutions to address noise pollution and promote sustainable smart cities.

Introduction

Urbanization drives global city growth, with over 50% of the world's population now residing in cities, a figure projected to reach 68% by 2050. It brings economic opportunities, better infrastructure, and enhanced lives. However, it also brings ecological challenges, notably pollution. High population density and human activities increase emissions, causing air, water, and often overlooked noise pollution. Noise, ranked second by World Health Organization after air pollution, poses significant health risks, including cardiovascular issues, sleep disturbances, and cognitive impairment. Moreover, noise pollution harms ecosystems, impeding urban sustainability [1].

China's rapid urbanization has led to a concerning surge in noise pollution, evidenced by its spread from urban to rural areas, new noise sources like high-speed rail, increased indoor and outdoor activity noise, and a rise in complaints to environmental hotlines. Table 1 summarizes the past decade's situation, showing noise ranking as the second-highest pollution factor until 2021, then becoming the primary concern since 2022 [2]. Complaints primarily stem from social life noise, driven by commercial activities, entertainment venues, and household activities, with construction, industrial, and transportation noise also significant. The rise in social life noise complaints is attributed to factors like urban migration, higher population density, reduced noise tolerance, growing environmental awareness, and improved complaint channels. Similarly, developed regions like Europe and North America face substantial noise pollution issues, as highlighted by reports from the United Nations Environment Programme and the European Environment Agency [1].

Noise mapping, crucial for urban noise pollution management [3], enables precise measurement and visualization of noise levels, pinpointing hotspots and assessing noise reduction measures. It also highlights health risks, guiding policymakers in implementing regulations. Additionally, it underpins smart city initiatives by providing data for noise control and informing analyses on social life and public safety. However, implementing noise mapping poses challenges [4], especially with traditional manual methods using sound level meters. To address this, recent research focuses on developing intelligent noise mapping technologies.

Table 2 summarizes key literature surveys and reviews on intelligent noise mapping techniques. Asdrubali *et al.* [5] discussed dynamic noise mapping, mobile noise crowdsensing, and soundscape approaches in urban settings. Alías *et al.* [6] and Picaut *et al.* [10] reviewed wireless acoustic sensor networks for environmental noise monitoring in smart cities. Additionally, a collaborative industrial Internet of Things (IoT) was proposed for noise mapping in industrial parks [11].

These intelligent noise mapping solutions have broad implications for urban planning, public health, and environmental sustainability. In urban planning, optimized zoning decisions can strategically position residential, commercial, and industrial areas to mitigate noise pollution, enhancing residents' quality of life and promoting sustainable development. From a public health standpoint, identifying noise hotspots enables targeted interventions to address health risks associated with prolonged exposure, integrating noise considerations into healthcare

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Year	Total Complaints (Thousand)	Noise in National Ecological Environment Complaints		Breakdown of Various Noise Complaints			
		Proportion	Rank	Social Life Noise	Construction Noise	Industrial Noise	Transportation Noise
2022	4503	59.9%	1	67.5%	25.1%	3.1%	4.3%
2021	4010	45.0%	2	57.9%	33.4%	4.5%	4.2%
2020	2010[1]	41.2%	2	53.7%	34.2%	8.4%	3.7%
2019	200	38.1%	2	24.0%	45.4%	26.5%	4.1%
2018	236	35.3%	2	15.6%	43.0%	30.1%	3.8%
2017	550	42.9%	N/A	39.7%	46.1%	10.0%	4.2%
2016	522	43.9%	N/A	36.6%	50.1%	10.3%	3.0%
2015	354	35.3%	N/A	21.0%	50.1%	16.9%	12.0%
2014	457	56.4%	N/A	60.0%	29.0%	9.0%	2.0%
2013	284	39.2%	N/A	31.9%	36.4%	20.3%	11.3%
2012	N/A[2]	42.1%	N/A	65.4%	25.0%	7.4%	2.2%

[1]: The statistical scope has progressively expanded from a single source to multiple sources, resulting in a sharp increase in the number of complaints. This expansion enables a more accurate reflection of the real situation. [2]: N/A means that the related data was not presented in the official reports.

TABLE 1. The statistical results of noise complaints in China over the past decade from 2012 to 2022 [2].

Unfortunately, the development of intelligent noise mapping technologies is still in its early stages, and there are significant gaps in dynamic noise visualization at a large scale.

Reference	Year	Review of Current Solutions			Development Trends	Research Opportunites
		Simulation Computation	Mobile Crowdsensing	Wireless Sensor Networks		
Asdrubali *et al.* [5]	2018		✓			
Alías *et al.* [6]	2019			✓		✓
Murphy *et al.* [7]	2020	✓				✓
Alam *et al.* [8]	2020	✓				
Liu *et al.* [9]	2020		✓	✓		✓
Picaüt *et al.* [10]	2020			✓		✓
Liu *et al.* [11]	2021	✓			✓	✓
Dove *et al.* [12]	2022				✓	✓
Padilla *et al.* [13]	2023		✓			✓
This Article	2023	✓	✓	✓	✓	✓

TABLE 2. A summary and comparison of related surveys/reviews on intelligent noise mapping.

facility and residential area planning for improved physical and mental well-being. Furthermore, intelligent noise mapping aids environmental sustainability by identifying areas for noise reduction measures to protect wildlife and maintain ecological balance. Enhanced community engagement is also fostered as residents access noise environment information, empowering them to participate in urban planning and advocate for noise-sensitive policies.

Unfortunately, the development of intelligent noise mapping technologies is still in its early stages, and there are significant gaps in dynamic noise visualization at a large scale. The primary objective of this article is to provide a critical review of recent developments in intelligent noise mapping for smart cities. In contrast to the existing state-of-the-art papers, this article makes the following contributions:

- We provide a comprehensive systematic review of current solutions for intelligent noise mapping, analyzing their technical principles, fundamental research topics, advantages, and limitations.
- We present our own insights on the development trends of intelligent noise mapping, focusing on technology routes, application requirements, and system evolution.
- We identify four critical open issues in the field of intelligent noise mapping and shed light on potential research directions to address these gaps.

The remainder of this article is structured as follows. The next section provides a review of current solutions for intelligent noise mapping. After that, the development trends are discussed in detail. Building on these insights, the research

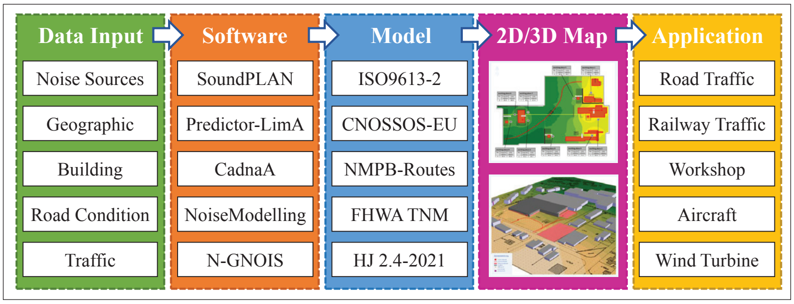

FIGURE 1. The technical principle of simulation models-based noise computation.

opportunities are highlighted. Finally, conclusions are drawn.

Current Solutions

Extensive research has focused on intelligent noise mapping technologies, broadly categorized into simulation models-based noise computation, mobile noise crowdsensing, and wireless acoustic sensor networks. This section reviews their technical principles, advantages, and limitations. Furthermore, global real-world examples are demonstrated.

Noise Computation Based on Simulation Models

Technical Principle: This approach [7, 8] employs computer software to simulate sound propagation in a given environment, as depicted in Fig. 1 Acoustic models within the software calculate noise values based on input data collected from various sources, such as field inspections, surveys, remote sensing, and government agencies. These data are then imported into the software to initiate calculations. Commercial software offers diverse noise calculation models, while open-source options are tailored for specific research applications with limited models. Mathematical models simulate sound wave propagation, considering factors like reflection, diffraction, and absorption, resulting in noise level predictions at different locations. This facilitates the creation of 2D or 3D maps and assessment of noise sources' environmental impacts. Currently, this approach enables noise calculations for various sources like road traffic, railway traffic, industrial workshops, aviation aircraft, and wind turbines.

Fundamental Research Topics: Implementing simulation models-based noise computation entails fundamental challenges across several aspects:

- **Data Acquisition and Integration:** Gathering and integrating data from diverse sources for noise simulation involves challenges in collection, processing, standardization, and quality control. Solutions utilizing Geographic Information Systems (GIS) facilitate efficient multi-source data handling.
- **Software Development:** It is crucial to import information about noise sources and environmental attributes into noise simulation software for calculation and graphical representation. Commercial software like SoundPLAN, Predictor-LimA, and CadnaA offer robust functionality, while academic open-source options such as NoiseModelling and OpeNoise, provide specific applications.
- **Accuracy of Models:** The accuracy and applicability of noise calculation rely on sound source and propagation models, which may vary between countries and regions. Despite standardized models like ISO9613-2 and CNOSSOS-EU, differences in environmental conditions can affect predictions. Furthermore, the quality of input data is a crucial factor in achieving accurate calculation results, given the highly complex sound source parameters and environmental parameters.
- **Dynamic Noise Map Generation:** Generating large-scale dynamic noise maps for urban areas demands significant computational and data processing capabilities. Commercial software employs distributed computing and parallel computing methods, while supercomputers support efficient map generation. Additionally, traffic-noise relationship models and spatiotemporal noise distribution analysis aid in quick map generation.

Advantages and Limitations: Simulation models-based noise computation offers advantages such as low labor costs and the ability to predict and evaluate noise compared to manual professional instruments. However, it has limitations. Firstly, the noise prediction model is restricted to specific areas like road traffic, railway traffic, industrial workshops, and aviation, necessitating further study for broader applicability to massive noise sources and environments. Secondly, model universality is limited, often requiring calibration with actual measurement results. Thirdly, generating dynamic noise maps is challenging due to online data acquisition and extensive computation requirements.

Mobile Noise Crowdsensing

Technical Principle: With the rise of mobile devices, mobile crowdsensing has become a method for monitoring environmental noise using built-in sensors [6, 9, 13]. As shown in Fig. 2, smart devices equipped with microphones and positioning systems enable easy environmental noise monitoring. Users can install noise monitoring apps to collect data, which is uploaded to a cloud platform for monitoring and visualization. Integration with map services allows users to observe noise levels in areas of interest via the web.

Fundamental Research Topics: Mobile noise crowdsensing encompasses four critical areas, detailed below:

- **Mobile System Development:** Numerous mobile noise crowdsensing systems have been developed worldwide, offering real-time noise monitoring and analysis. Examples include NoiseTube, Ear-Phone, SoundOfTheCity, NoiseSense, and GRC-Sensing system. A detailed review of these works can be found in [9] and [13].
- **Noise Measurement Calibration:** Calibrating data collected via mobile crowdsensing ensures accuracy. Deviations between smartphone microphone measurements and professional sound level meters exist, and variations between smartphone brands and models further complicate measurements. Calibration is essential for result consistency, with phone age also impacting measurements.
- **User Incentives:** Encouraging user participation in crowdsensing is crucial. Battery and data consumption may deter participation, necessitating incentive mechanisms such as

FIGURE 2. The technical principle of mobile noise crowdsensing.

rewards, entertainment, social relationships, and virtual points to motivate users at scale.

- **Privacy Protection:** Crowdsensing involves uploading sensitive data, raising privacy concerns and reducing participation. Addressing this issue involves techniques like differential privacy, fuzzy anonymization, and homomorphic encryption to safeguard privacy.

Advantages and Limitations: This approach offers advantages such as low-cost, large-scale sensing, and realistic measurement. However, it also has limitations. First, the degree of public participation cannot be actively controlled, leading to either insufficient or redundant data, hindering the formation of efficient noise maps. Second, ensuring data quality is challenging due to device measurement accuracy and the risk of malicious reporting. Users may upload fabricated data, compromising the accuracy of noise maps. Third, uploading noise data often includes users' time and location information, increasing privacy risks and potential leakage.

Wireless Acoustic Sensor Networks

Technical Principle: Wireless sensor networks (WSNs) are widely studied for noise pollution monitoring [9, 10]. As illustrated in Fig. 3, acoustic sensor nodes are deployed to collect noise data. This data is wirelessly transmitted to edge nodes for processing before being uploaded to the cloud for storage, computation, and data mining. Visualization services provide multi-dimensional and multi-source information display in spatial and temporal domains.

Fundamental Research Topics: The related work on this solution can be categorized into four aspects:

- **Network System Architecture:** Various architectures for wireless acoustic sensor networks have been developed to facilitate efficient data collection and processing. Examples include cluster-based architectures, human-in-the-loop architectures, and integrated systems [3].
- **Mobile Acoustic Sensor Networks:** Mobile networks offer low-cost, large-scale noise monitoring without extensive fixed sensor deployment. Solutions include using vehicles (e.g., bicycles, public buses, and electric scooters) for data collection, although filtering out vehicle noise poses challenges.
- **Acoustic Sensor Nodes Design:** Design considerations for acoustic sensor nodes include accuracy, communication and computational capabilities, energy consumption, and deployment costs. Optimization is crucial to meet application requirements.

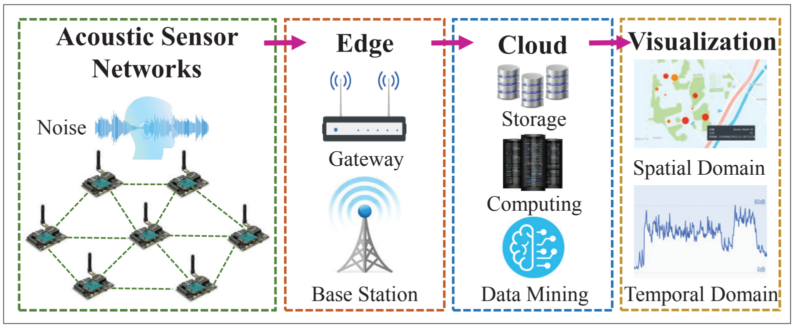

FIGURE 3. The technical principle of wireless acoustic sensor networks.

- **Environmental Noise Recognition:** Beyond recording decibel values, recognizing noise types is crucial for effective noise pollution control. Open-source datasets like URBANSOUND and URBANSOUND8K have been established for noise recognition using machine learning on local sensor nodes or cloud-based processing.

Advantages and Limitations: Wireless acoustic sensor networks offer advantages over on-site manual measurement, including long-term real-time monitoring. Compared to simulation models-based noise computation, they provide wider applicability and more realistic measurement. Additionally, they offer stable and reliable data sources without privacy risks compared to mobile noise crowdsensing. However, there are limitations. Firstly, achieving large-scale and fine-grained noise sensing incurs high deployment and maintenance costs. Secondly, network capacity becomes an issue with increasing node numbers. Lastly, as smart cities adopt IoT systems, ensuring the dependability and trustworthiness of wireless acoustic sensor networks becomes a challenge.

Real-World Examples

Lastly, some instances where intelligent noise mapping solutions have been successfully applied worldwide are showcased.

EU Strategic Noise Mapping: Established in 2002 through Directive 2002/49/EC, the European Union's Strategic Noise Mapping Initiative addressed environmental noise concerns. Member states use simulation models-based approaches to create urban noise maps, with the fourth round of mapping and action plans nearing completion.

The evolution of intelligent noise mapping began with acoustic models in the early 2000s, followed by advancements in smartphone and wireless sensor networks from 2000 to 2015.

DYNAMAP Project: The DYNamic Acoustic MAPping (DYNAMAP) project aimed to establish affordable WSNs for real-time noise monitoring. It focused on creating two demonstrative systems in Rome and Milan, assessing and validating the feasibility of updating noise maps in real time.

OxAria Project: OxAria is a collaborative effort between the University of Birmingham and the University of Oxford. It aimed to comprehensively understand the air and noise impacts of the COVID-19 pandemic in Oxford City. Strategically deploying 16 audiomoth noise sensors, the project distinguished between anthropogenic and natural sources of noise, contributing valuable insights to environmental research.

SONYC Project: The Sounds of New York City (SONYC) project [3] positioned sensors throughout New York. The collected data serves as a testament to uncovering the complex fabric of urban soundscapes, offering valuable insights into the dynamic nature of city's acoustic environment.

Barcelona Microphone Sensor Network: A methodology [14] using street categorization and a city microphone network facilitated city-wide road traffic noise mapping, even without direct traffic data access. This approach, applied uniquely in Barcelona, involved strategically deploying around 250 sensor nodes over a decade.

Hydra Noise Radar in France: The Hydra noise radar [15] is a cutting-edge solution in noise mapping. Utilizing multiple microphones and integrated cameras, it accurately determines noise levels and origins. Successfully deployed in seven French communities, including Nice and Paris, Hydra also has an educational version in other European countries.

Development Trends

In this section, we present our insights on the development trends of intelligent noise mapping for smart cities.

Development Trends in Methodology

The evolution of intelligent noise mapping began with acoustic models in the early 2000s, followed by advancements in smartphone and wireless sensor networks from 2000 to 2015. This era saw the emergence of crowdsensing and wireless acoustic sensor networks for noise monitoring. Post-2015, with the rise of the Internet of Things (IoT), these monitoring technologies have been further refined, offering complementary advantages. This evolution aims to establish a closed-loop IoT system for noise prevention and control, integrating perception, prediction, analysis, and management seamlessly. Today, the synergy between crowdsensing and wireless acoustic sensor networks provides continuous noise monitoring, while noise simulation calculations utilize real-time data to refine models and predict future noise conditions. The ultimate goal is to integrate these technologies into a cohesive ecosystem for effective noise prevention and control within the IoT.

Development Trends in Application Requirements

Noise monitoring has evolved from simple noise level measurements to encompassing multimedia information, emphasizing the integration of audio signals, scene images, and video clips [15]. This integration promises significant advancements in noise pollution prevention and social governance. Multimedia sources provide visual context for precise identification and localization of noise sources, enhancing the accuracy of noise mitigation strategies and enabling detailed spatial mapping. Moreover, visual data aids in analyzing noise patterns over time, facilitating strategic interventions during peak periods.

However, this integration raises ethical considerations, notably privacy concerns. Deploying microphones and cameras in public spaces may intrude on privacy, necessitating privacy-preserving measures such as automatic blurring of identifiable information. Robust cybersecurity protocols are also crucial to protect multimedia data from misuse or unauthorized access. Furthermore, there is a shift towards larger-scale, fine-grained noise perception, driven by urban development. Sophisticated monitoring systems are needed to address the complexities of expansive urban environments. Regarding monitoring frequency, there is a transition from static visual displays to dynamic noise maps. This trend towards minute-level granularity offers comprehensive insights into noise dynamics, aiding in the detection of short-term noise events and facilitating broader noise management strategies. Access to minute-level data empowers communities to actively participate in noise abatement initiatives and improve living conditions.

Development Trends in System Evolution

Initially, fixed acoustic sensors and mobile nodes operated independently. However, a recent trend emphasizes their integration into a cohesive fusion for collaborative noise perception. This integration ensures a wider spatial reach and offers a more accurate understanding of the acoustic landscape.

Moving on to communication dimensions, sensor nodes traditionally used ZigBee and WiFi technologies. Yet, recent noise IoT systems favor LoRa for transmission, enabling low-power and wide-area networks for enhanced efficiency and coverage. Moreover, the evolution of cross-technology communication anticipates heterogeneous sensing networks, where diverse smart devices equipped with various communication modules interchange noise data seamlessly. This fosters interoperability and allows devices to leverage multiple technologies for efficient transmission and coverage. In computing, there's a shift towards on-device processing for noise source identification, with a future trajectory aiming for a balanced approach between cloud, edge, and end processing. This strategy envisions a seamless integration of computing resources across infrastructure layers for a comprehensive and efficient noise processing framework.

Research Opportunities

Analyzing development trends reveals a gap in achieving real intelligent noise mapping. To address this, we propose a future IoT system, identifying four key open issues for future research, as summarized in Fig. 4.

Improving Sensing Quality under Periodic Collection Mode

Energy-constrained acoustic sensor nodes are vital for intelligent noise mapping due to their easy deployment, yet managing their power consumption remains a significant concern. Even with the use of solar energy, maintaining dynamic sampling presents a challenge. Consequently, the primary operational mode for noise perception becomes periodic wake-up. However, relying solely on periodic wake-up sampling captures key noise events opportunistically, resulting in suboptimal data quality. Therefore, the pressing challenge is to enhance collection efficiency and ensure the quality of transmitted data within the constraints of low-power periodic wake-up mode. Research opportunities include:

On-Demand Event Noise Monitoring: Environmental noise encompasses both background noise and event noise. Currently, periodic wake-up schedulings effectively collect background noise with low power consumption and high quality. However, their ability to capture event noise is limited. Therefore, addressing the on-demand perception of sudden noise events is crucial. A pioneering hardware architecture called EcoSense was introduced and its circuit implementation for noise mapping was further detailed in [11].

Radio-Frequency Noise Computing: Changes in wireless link status could provide valuable situational awareness, offering an opportunity to improve noise sensing scheduling. One potential research direction is to construct mapping relationship models between wireless link status and noise scenarios.

Adaptive Periodic Noise Sampling: The above insights can be leveraged to refine the performance of sampling algorithms, addressing the intricate interplay between hardware design and software-generated periodic wake-up scheduling to achieve a comprehensive solution.

Multimedia Transmission under LPWANs

Low-power wide-area networks (LPWANs) like LoRa and NB-IoT are increasingly used in noise mapping. While effective for short data exchanges in sparsely deployed IoT environments, their low transmission rates and duty cycle limit the transfer of multimedia data. Enhancing these technologies to better support multimedia applications, such as noise mapping, will broaden their utility. Innovative strategies at both the sensor and network levels can improve transmission efficiency, offering significant research opportunities as follows:

Lightweight On-Device Noise Recognition: Audio signals are processed at sensor node to extract sound pressure values and identify noise types. Based on application needs, a decision is made whether to transmit level and noise type information or to upload raw multimedia data. Therefore, enabling AI capabilities on resource-constrained sensor nodes is crucial. Techniques such as model pruning, quantization, and knowledge distillation can reduce model size and computational load while maintaining recognition accuracy.

Tiny Machine Learning-Based Data Compression: When uploading essential multimedia information based on application needs, data compression is crucial. Prior research suggests that machine learning can efficiently compress multimedia data. Therefore, investigating the performance of model pruning, quantization, and knowledge distillation techniques in terms of accuracy, execution speed, and model size

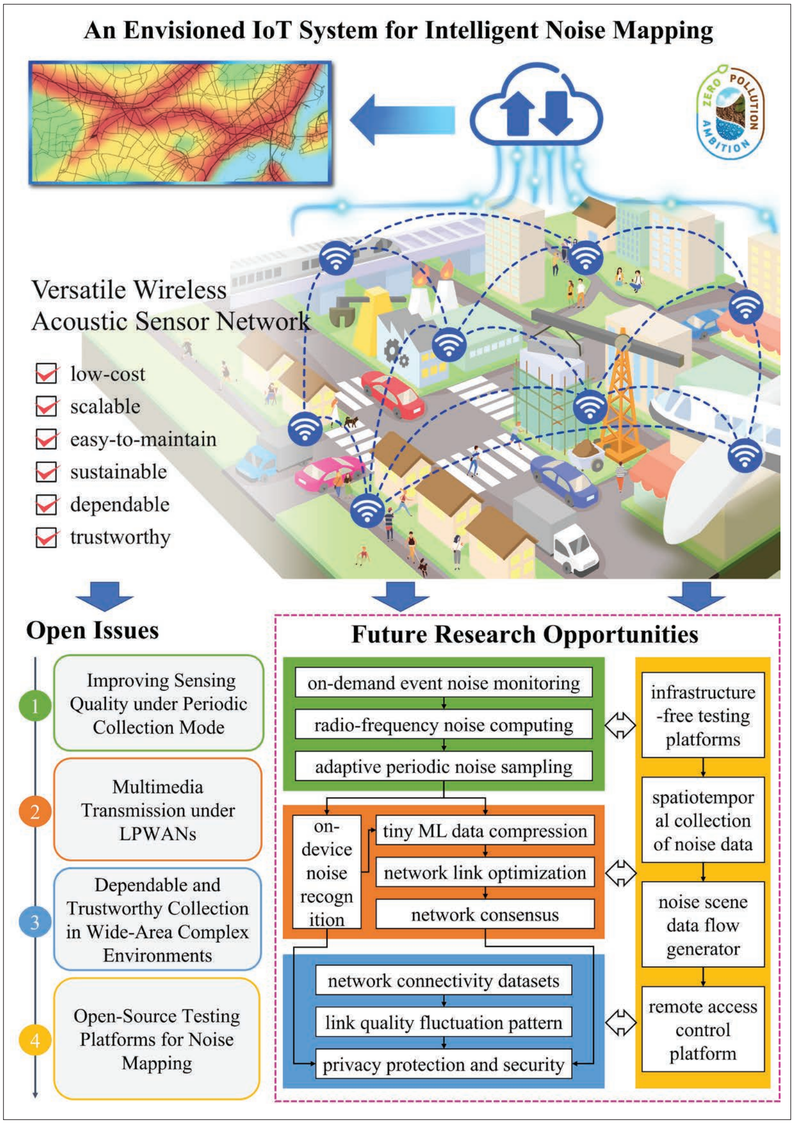

FIGURE 4. Envisioned IoT system, open issues, and future research opportunities for intelligent noise mapping.

is essential. This exploration will aid in developing data compression solutions based on tiny machine learning, ensuring smooth operation on resource-constrained sensor nodes.

Network Link Optimization: Low-power wireless communication has potential for throughput enhancement. For example, multiple LoRa signals could be emulated by controlling a standard FSK radio transmitter, enabling simultaneous transmission of multiple LoRa packets and improving throughput.

Network Consensus: Network scheduling and consensus algorithms can be introduced to further improve the quality of service. For example, sensors can establish a multi-hop network for efficient information exchange, utilizing random linear network coding to enhance consensus and data reliability. Nodes next can assess message similarity by comparing data features, facilitating ordered batch uploads to mitigate network collisions.

Dependable and Trustworthy Collection in Wide-Area Complex Environments

Noise mapping in urban areas like cities and airports faces challenges due to complex environmental conditions, including obstructions and dense

Testing platforms are vital for IoT communication research, offering controlled environments and tools for reproducible experiments.

populations. Long-distance transmission with low power makes the system vulnerable to interference, especially for large data payloads. Additionally, privacy and data security are paramount concerns as noise mapping systems collect and process various data types, raising potential privacy risks. Current research on intelligent noise mapping has inadequately addressed these concerns, highlighting the need for dependable and secure data collection methodologies. Potential solutions include:

Network Connectivity Datasets: Network link dataset entails deploying test nodes in urban areas to monitor wireless link quality at high frequency (e.g., every 5 minutes) and over extended periods (e.g., one year). This dataset encompasses signal strength, signal-to-noise ratio, packet loss rate, and environmental parameters, correlated with geographic locations, antenna types, and obstructions. Furthermore, existing network dataset obtained by assessing packet loss rates could validate patterns in the network link data and assesses the impact of base station capacity on connectivity over time.

Link Quality Fluctuation Pattern: Utilizing the network link dataset, a micro-level model for wireless network links can be developed, exploring relationships between link quality and environmental factors, deployment locations, obstructions, and antenna types. Concurrently, leveraging the existing network dataset allows for constructing a model for network capacity, studying the link quality-network capacity relationship. Analyzing the datasets helps identify correlations among periodicity, duration, and influencing factors of link quality variations, while integrating these findings with models can reveal key variables causing changes in link quality.

Privacy Protection and Security: In addition to employing data compression to enhance transmission capabilities, privacy protection and security in intelligent noise mapping can be further enhanced. Dissociating identifiable information from multimedia data safeguards individuals' privacy. Additionally, robust secure authentication processes should be incorporated to verify the identities of new devices joining the mesh network, allowing only authorized devices to connect and relay messages. Implementing secure authentication adds an extra layer of protection against unauthorized access, contributing to a more resilient and secure network infrastructure.

Open-Source Testing Platforms for Noise Mapping

Testing platforms are vital for IoT communication research, offering controlled environments and tools for reproducible experiments. However, creating such platforms faces technical and deployment challenges. While some wide-area IoT testing platforms exist, they are often limited or closed. Publicly accessible platforms may be restricted to indoor deployment or have few nodes. Moreover, existing platforms lack support for specific applications like noise mapping. Therefore, an open testing platform for wide-area IoT-based noise monitoring is crucial. This initiative will provide open-source tools for researchers in intelligent noise mapping and the Internet of Sound. The envisioned solutions are outlined as follows:

Infrastructure-Free Network Testing Platforms: Infrastructure has been pivotal in IoT testing platform evolution, particularly indoors, where Ethernet and USB interfaces facilitate functions like power supply and firmware deployment. However, in outdoor applications, power supply and wired connections become significant challenges. While cellular communication serves as an alternative, its communication costs and the unreliability of base station communication quality make it less than ideal. Additionally, for IoT devices powered solely by batteries, the energy efficiency of the testing platform becomes a primary concern, necessitating the avoidance of modules that consume significant power.

Spatiotemporal Collection of Noise Data: The collection of spatiotemporal noise events is vital for constructing a noise scene data flow generator. It injects genuine data sources, ensuring realism and credibility in the generated results. Additionally, it allows for analysis of underlying patterns to optimize algorithms and validate generator performance. By comparing generated data with actual collections, shortcomings can be identified and addressed for enhanced reliability and stability in practical applications.

Noise Scene Data Flow Generator: To ensure realistic traffic generation, two technical approaches can be used: cloud-based deployment and local autonomous generation. In the cloud-based approach, noise data is stored centrally and distributed to testing nodes based on user-defined parameters. Nodes generate traffic collectively in cycles to ensure continuous data distribution. In the local autonomous approach, noise data is used to train machine learning models in the cloud, which are then distributed to nodes for autonomous traffic generation based on learned patterns.

Remote Access Control Platform: To federate multiple front-end networks effectively, a cloud-based remote access control platform is essential. It could streamline management and offers a unified interface for simplified data analysis. Prioritizing user experiments, it facilitates connectivity via user and proxy interfaces, allowing for experiment deployment, device status acquisition, result retrieval, and experiment cancellation. Leveraging established technologies like HTTP, MQTT, and REST services ensures platform stability and efficiency. Remote access also enhances scalability, enabling experiments across regions for deployment-independent results.

Conclusion

The development of intelligent noise mapping approaches for smart cities is still in its early stages. While there have been significant advancements in simulation models-based noise computation, mobile noise crowdsensing, and wireless acoustic sensor networks, there are still significant gaps in dynamic noise visualization at a large scale that need to be addressed to fully realize the potential of smart cities. This article provides a critical review of these technologies by analyzing their technical principles, fundamental research topics, advantages, and limitations. In addition, the development trends of intelligent noise mapping are discussed focusing on technology routes, application requirements, and system evolution. Through these analysis, four critical open issues are identified with potential research directions.

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