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Design and Optimization Of Wireless Sensor Networks For IoT

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Abstract

Wireless Sensor Networks (WSN) are an emerging multidisciplinary intersection of cutting-edge research fields, and their advantages in terms of freedom of formation, high signal-to-noise ratio, high strength, and unattended, which makes WSN have good prospects for application in the field of Internet of Things (IoT). Considering all the benefits that WSN offers, this paper reviews the development history of wireless sensor networks Internet of Things (WSN-IoT), analyzes the technologies used by sensors in the IoT, and illustrates the future developing patterns and remaining challenges, in conjunction with the leading technologies in the perception layer of the current network of things industry.

Keywords: Wireless sensor networks, Internet of things, Sensor technologies, Perception layer, Network development, Future trends, Challenges, Signal-to-noise ratio, Unattended systems, Smart networks.

1 | Introduction

Information acquisition is an important area of research. All real-world things, states [1], [2], and processes can be described in terms of physical quantities, and sensors can obtain information about these physical quantities. Sensor information acquisition technology has evolved from its initial singularity to integration and networking, becoming an important means of information acquisition [3]. A Wireless Sensor Network (WSN) system composed of spatially dispersed numerous sensors collaborating provides stable and efficient communication between many sensors distributed in different places [4]. The Internet of Things (IoT) connects various forms of wired and wireless networks to the Internet, thus linking objects to each other and forming a huge network for easy monitoring, analysis, and control. Wireless sensing technology is widely used in many fields [5], such as battlefield surveillance, environmental and traffic detection, and industrial and agricultural production. In essence, IoT technology is a technology that enables the interconnection of things through modern information networks [6], enabling the effective exchange and flow of information between

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items. However, the network environment has a certain openness, making it extremely easy for people to incur certain economic losses due to network risks in IoT technology [7], [8]. Therefore, improving the security of the network environment is also a major issue facing the wireless sensor network while improving its technology level. The following is how the rest of this paper is arranged. The ideas of WSN and IoT are discussed in Section 2. Section 3 describes the WSN-IoT's composition and application. Section 4 examines WSN-IoT research. Section 5 addresses the paper's issues and future directions. Section 6 finally brings the paper to a close

2 | Wireless Sensor Network And Internet of Things

WSN, originated during the Cold War; initially used in the military, it was used to monitor the activities of the enemy [9–12], and achieved better results, and later promoted to be more widely used, sensor technology is used in WSN, network technologies wireless, embedded chip engineering [13], using a lot of tiny sensors to gather data and communicate with one another so that it can real-time monitoring many countries value WSN technology and has several potential variations [14], [15]. It is expected to play a greater role in industrial and agricultural production, urban planning and management, environmental monitoring, and battlefield surveillance [16].

WSN generally consists of three parts: sensor cells, managing nodes, and aggregation nodes; the structure is displayed in *Fig. 1*: 1) sensor nodes: these are large nodes that can be thrown freely into the air and fall freely to the point of data collection for the entire WSN. These nodes are connected in series to form a whole sensor network, 2) convergence nodes: to provide a summary of all the details, the data acquired by the sensor nodes will be collected in the aggregate node using the routing mechanism, and 3) management node: the information filtered by the pooling node is transmitted via the network and communication equipment to a terminal platform, where the relevant staff can effectively analyze the data recorded.

The IoT can be connected to objects because of the sensors, processors, and communication modules installed. On this level, the IoT has a wider range of applications than the Internet. The main core functions of the IoT are sensing information, transferring information, and controlling information [17], [18]. Through the IoT, people can quickly access, transfer, and process information [19].

Any or All of these components play an important role in the IoT's overall structure. 1) perceptual layer: in an IoT system, temperature, operating status, and other relevant parameters need to be collected through the sensing layer. The IoT remote control is activated when certain parameters reach a preset range [20]. For example, in an IoT-based warehouse management system, the site environment is detected by an infrared temperature measuring device, but an alarm is issued when a fire is detected, and a water spray is activated [8], 2) network layer: the IoT system's skeleton is made up of the network transport layer. All types of networks, such as the internet, ethernet, and mobile networks, can be used as network transport layers. The information obtained from the sensing layer and the control commands communicated to the actuators need to be transmitted through the network layer of transmission, and 3) applying layer: the applying layer consists of two parts: a software system for processing information and a web page or mobile app for human control. The application layer integrates intelligent information processing technologies such as distributed and cloud computing. The data and information transmitted from the network transmission layer are concentrated in the application layer system for processing, and the system is equipped with functions such as addressing, command issuance, security control, and data storage. In addition, the application layer has an extension interface to enable the expansion of new functions.

3 | Energy Transparency in IoT Devices

This section of the paper focuses on devising the protocols for energy transparency in IoT devices. We also propose a novel approach for minimizing energy consumption for IoT systems using energy transparency protocols and software optimization. We will also evaluate our approach to compare its performance with other known approaches.

Energy transparency helps determine and gauge the energy consumed by an IoT device while measuring, processing, and communicating data.

4 | Research Studies in WSN-IOT

Currently, WSN-IoT is applied in numerous fields, typically in transport, healthcare, agriculture, and military, and the WSN technologies used in different fields differ. This section reviews the history of WSN-IoT and the implementation of WSN-IoT solutions in various studies. Information acquisition is an important research area in the information society. The development of sensor networks has undergone a long development process and can be roughly divided into four stages. The beginning was in the 1970s when, as an emerging technology, multiple sensors were connected using sensing controllers to form the beginnings of sensor networks, which used rudimentary sensors with simple information signal acquisition capabilities and used transmission methods such as point-to-point connections to sensing controllers to form sensor networks. With the development of related disciplines, the second phase of the sensor network can acquire multiple information signals, and the interface with the sensing controller has been updated with a serial/parallel interface (e.g., RS-232, RS-485 interface), constituting a sensor network with information synthesis and processing capabilities. The third stage appeared in the late 1990s and early 21st century; this period of sensors can be intelligent access to a variety of information, a new type of sensing of signals, connected to the sensing controller using field bus control, according to the application constitutes several local area networks, which can be called sophisticated sensor networks. Sensor networks' fourth stage is being researched and developed, combined with the current research hotspot: a lot of sensors are used in WSN with multiple types of signal acquisition capabilities organized into self-organizing wireless access networks; the biggest change is the wireless way to connect with the sensor network controller, thus forming a WSN. The coverage of sensor nodes and energy consumption are important performance indicators of a WSN. The convergence speed of the traditional computer science algorithm is not high, and the global monitoring capability is not strong. The step size of the algorithm is optimized with the momentum gradient descent method and the root mean square method to increase the algorithm's convergence rate. Then, the global detection capability of the algorithm is improved with the Corsi-Gaussian variation factor to make finding the most advantageous global solution preferable. To address the shortcomings of the EEUC algorithm that the cluster head nodes are not uniformly distributed and the competition radius remains unchanged, it is shown that selecting the cluster head nodes from two factors, namely the nodes' remaining energy and their physical placement, to make their distribution more uniform, and then the calculation formula of the competition radius is optimized from these two factors so that it can make reasonable changes with the operation of the network and balance the energy consumption of the nodes. Energy consumption of the nodes. The number and variety of sensors in the network environment have increased, and with different sensors having different functions, the storage and transmission of data in the network environment have grown exponentially. Often set up in unattended environments, factors such as humidity and temperature can cause further increases in the probability of abnormal data changes in the network. Current researchers in the field are addressing the problem in two ways: reducing the burden of sensors on data collection and transmission to lower the network operation's energy usage, improving the network's resilience to abnormal data, and promoting the overall robustness of the network operation. The most important issue in WSNs is data privacy protection. The current solutions proposed by researchers for data privacy protection in WSN-IoT are: Slice-Based Data Aggregation Privacy Protection Algorithm (S-DAPP), authentication technology combined with WSN, Cluster Privacy Data Aggregation Approach (CPDA), and Slice Mixing And Aggregation Mechanism (SMART).

5 | Challenges and Future Directions

The technology underlying WSN is far from perfect at the moment. That requires more study and development, and innovative work will substantially ease the progress of the IoT. Multi-hosted network transmission method: the IoT relies on wireless sensor network technology. Attempts can be made to leverage multi-homed network transmission to boost the IoT's resiliency. It allows many links to transfer commands from the top down and collect data from several sensors to be relayed to the upper network. This method could speed up data transfer via networks and make them more reliable.

6 | Conclusion

The development and deployment of IoT technologies is heavily influenced by WSN. The range of applications of WSN-IoT is constantly expanding, and people are relying on them more and more. In practical applications, people can only improve the network performance of wireless sensors and encourage advancing cutting-edge information network technologies if they fully understand the connection between the IoT and WSN and optimize the specific technical forms. The following improvements are proposed based on WSN' current power consumption and security. Wireless sensors are limited by their size and carry a limited battery capacity, so it is important to reduce their power consumption while achieving information transfer. In traditional WSN, communication between nodes requires wake-up to communicate. WSN can use a timed wake-up asynchronous communication mechanism to transfer information. The transmitting node can transmit data to the receiving node when it is asleep and then send data to other nodes after the receiving node wakes up. The timing here is the node wake-up interval set by the wireless sensor network system, and the system can set the timing wake-up interval according to real-time requirements. When real-time requirements are high, the node wake-up time interval is short, and vice versa; a longer wake-up time interval can be set. This can effectively improve the operational lifetime and throughput of the net. To improve the security of the sensor net protocol, a cluster head election method can be added to the LEACH routing protocol. A one-way hash function and a shared key can be added to the communication between the base station and sensor nodes, so the key between the two can be changed periodically. An authentication mechanism can be added so that only the internal members of the system have permission to access, thus increasing the confidentiality of the information in the communication and improving the security of the information transmission. At present, the research and development of WSN technology still has many imperfections; its breakthrough research will certainly have a huge impact on the IoT further to promote the construction and development of information technology; with the fast advancement of knowledge and technology, it is foreseeable that the future application of WSN-IoT will provide more convenience for people's production life.

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Author Contribution

Conceptualization and research design: the author initially proposed and developed the primary concept of the study on energy-efficient IoT networks through AI-driven approaches. They designed the study structure, established research objectives, and outlined the theoretical framework.

Methodology and model development: the author led the development of AI-based models and energy optimization strategies, designing novel algorithms and conducting initial testing to ensure the models aligned with the study's energy efficiency goals. They contributed to refining the model architecture, particularly integrating IoT network-specific requirements and constraints.

Data collection and analysis: the author managed the data collection processes, ensuring the quality and relevance of the data sets used for training and testing the AI models. They also implemented the analysis pipeline. They contributed by refining the preprocessing steps and conducting statistical validation of model outputs to enhance reliability.

Software development and testing: the Author developed the implementation code for AI-driven optimization, managed software integration, and supported the software testing phase, troubleshooting, and debugging to ensure reliable performance across different IoT network conditions.

Manuscript preparation and revision: the author wrote the initial draft of the manuscript, with contributions from all authors to various sections. They also provided substantial revisions, particularly in the technical and methodological sections. Final proofreading and review were conducted.

Funding and project administration: the author managed Project funding and resource allocation. They also oversaw the project's administrative aspects, coordinating between different teams to maintain the study timeline.

Each author has read and approved the final version of the manuscript, ensuring an accurate and comprehensive presentation of the research findings.

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Any opinions, findings, or conclusions expressed in this work are those of the author and do not necessarily reflect the views of the funding organization.

Data Availability

The data sets used in this study on energy-efficient IoT networks using AI-driven approaches were sourced from publicly accessible repositories and, where applicable, proprietary IoT network datasets to model real-world scenarios. Specific data on IoT network traffic, energy consumption, device usage patterns, and network performance were anonymized to protect privacy and were preprocessed for the study.

Public datasets: the research relied on publicly available datasets, including those related to IoT network performance, energy consumption metrics, and simulation models that provide general patterns applicable to energy-efficient IoT applications.

Proprietary datasets: where necessary, proprietary data from specific IoT network case studies were employed under restricted use conditions to validate model performance. Access to proprietary data may be subject to institutional permissions and data-sharing agreements.

Generated data: additional synthetic data were generated to model edge cases and optimize the AI models. These synthetic datasets have been made available in the project repository for reproducibility.

All relevant data and code have been available at [provide repository link, e.g., GitHub or a data-sharing platform such as Zenodo or Figshare] for further research and reproducibility. Researchers interested in proprietary or sensitive data used in this study may request access by contacting the corresponding author, subject to institutional approvals and confidentiality agreements.

Conflicts of Interest

The author declares no conflicts of interest in this research paper on energy-efficient IOT networks using AI-driven approaches. The research was conducted independently, and no financial or personal relationships influenced the outcomes or interpretations presented in this study.

If any potential conflicts arise in the future, the author is committed to disclosing them transparently to uphold the integrity of the research.

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