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Exploring the role of the internet of things (IoT) in enhancing the efficiency of wireless sensor network (WSN) technologies

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Abstract
The integration of the Internet of Things (IoT) with Wireless Sensor Networks (WSN) has revolutionized various industries by enabling more effective monitoring, data collection, and decision-making processes. This study explores the synergies between IoT and WSN, focusing on how IoT enhances the functionality, scalability, and efficiency of WSN techniques. IoT, WSNs can extend their applications across diverse domains, including smart cities, healthcare, environmental monitoring, and industrial automation. The research delves into key IoT-driven advancements such as improved data aggregation, real-time analytics, and seamless communication protocols that optimize WSN performance. Additionally, the study examines the challenges and potential solutions related to security, energy consumption, and network reliability in IoT-enabled WSN environments. The integration of IoT significantly elevates the capabilities of WSNs, leading to more robust, adaptive, and intelligent networks that cater to the growing demands of modern applications.

Keywords: IoT, WSN, networks, clustering, techniques, application, challenges

Introduction

Network performance is crucial to IoT service performance. IoT has found use in a wide range of applications, including "smart" homes, networks, gardens, cities, and more. Different standards & developments are being embraced by the exponentially growing number of IoT devices. The second big problem with IoT devices is that they can't communicate with each other or with administrators' systems. For data transmission with minimal human intervention, specialized equipment should be flexible enough to adapt to different situations [1]. Two types of inevitable human-centered worldviews are the human-driven & human-free.

Energy efficiency in the Internet of Things has attracted a lot of attention from researchers over the past decade. Consequently, this presents new obstacles for energy-efficient routing methods in IoT applications [2]. The most important requirement for WSNs enabled by the IoT is that they should operate continuously & inexpensively for longer periods of time without requiring human intervention. Because most of the devices in these IoT systems will run on batteries, energy efficiency is typically a top priority for device managers. Both of these sources. Energy productivity for battery-operated sensor hubs or lifetime upgrade have been long-standing research topics in the WSN area [5, 6]. Conventions at the Medium Access Control (MAC) layer focus on altering the sensor hubs' obligation cycle, while conventions at the steering layer aim to gather information and facilitate many-to-one transmission. It is important to keep battery consumption in mind while planning an IoT network, as many of the devices that make up the IoT arrange are also powered by batteries. The research aims to acknowledge cost decreases in order to achieve green systems administration. A lot of energy-efficient WSN designs have been floated recently, including cautious [7, 8] designs & chain-of-command [6] designs, however there are still a lot of holes in terms of efficient data total and distribution tactics.

Internet of things

IoT is a mechanical upset that has risen up out of past advancements including Mobile Ad hoc Networks (MANETs) and Wireless Sensor Networks (WSN). A sensor is a gadget contained inside an individual territory organize (PAN) containing detecting (estimating), figuring, and correspondence components that offers the onlooker the chance to watch and react to occasions and events inside an area. MANET is an accumulation of portable sensor gadgets (called hubs) that speak with one another without the utilization of framework, for example, passageways or base stations. These systems are self-arranging, fit for self-coordinated tasks and are effectively deployable henceforth, they are alluded to as a Self-Organizing Networks (SONs). Hubs coordinate to give availability and work without incorporated organization. MANET hubs require no fixed framework in this way, they impart in a shared way with straightforwardly associated neighbors. Because of their portability and restricted battery life, they are constrained in their transmission power & data transfer capacity accessibility. Portable hubs in specially appointed systems frequently participate to transmit information and course data to different hubs that they are not legitimately associated with, subsequently they go about as switches where they register courses and make course tables of goal to different hubs.

A WSN comprises of thickly dispersed sensor hubs which bolster detecting, signal preparing, installed processing, and availability; they are interconnected and self-sorting out. Sensors are conveyed in a short-bounce point-to-point and in an ace slave pair request. They transmit data to observing hubs (sink hub) which total information gathered to a focal station for further examination. WSNs simply like MANETs have impossible to miss highlights, including restricted battery control, repetitive information procurement, and low obligation cycle. They could impart in a multipoint-to-point design (for example sensor hubs transmit their information to a focal hub alluded to as the sink hub). It is critical that, at an early stage in the advancement of MANETs and WSNs their potential advantages were immediately perceived and this prompted their sending in many key application regions like farming, fabricating, social insurance framework. Today the Internet of Things has risen up out of the fiery debris of these two innovation columns.

The Internet of Things (IoT) alludes to the far reaching utilization of frameworks, heterogeneous innovations and the advancing worldview of the interconnectedness of gadgets, utilizing TCP/IP conventions, around physical situations. From an underlying point of view, IoT resembles a M2M correspondence (the correspondence between framework substances in a wired or remote framework that does not really require direct human intercession) nonetheless, IoT envelops M2M as well as people, home apparatuses, vehicles, hardware, pets, dairy cattle in the field, creatures in the wild, natural surroundings, living space tenants, even corporate associations and how they connect with each other. IoT has turned into a trendy expression today and guarantees to change the manner in which web is seen and utilized. In an ongoing study report by the McKinsey Global Institute, IoT could have a US$ 11 trillion worldwide market sway by 2025. The Internet of Things isn't only an advanced innovation rather it is here with us. IoT incorporates the new influx of sensor gadgets and it works with the developing cloud arrange framework.

Wireless sensor networks

A rapidly expanding area of study, Wireless Sensor Networks (WSN) play an increasingly important role in the everyday data recording world. WSNs work together to transmit detected data from the delivered zone back to the main station. WSNs were first introduced for use in heavy-duty military applications & then expanded to more delicate uses, such as consumer WSNs. Since WSN devices (hubs) rely on batteries, energy conservation is their top priority. The sensor hub's battery life is a significant constraint of the downsizing process, which necessitates the adoption of low-power technology. Similarly, improvements in code (calculation complexity), the operating system, and apps that aid the hub's mobility can extend the lifetime of the sensor hubs. Coordinating and aggregating data responses to the Base Station (BS) is necessary due to the limitations of these sensor hubs' computational, transmission, or battery control capabilities [1]. Research into remote sensor organization for location or following involves handling abnormal state data extensively. The study examined the network's performance with regards to accurately detecting tasks, compensating for missed or false alarms, mistakes in categorization, or track quality. Various sensor modalities, applications, deployment techniques, power supplies, and heterogeneity have been used to categorize sensor networks by the authors. When compared to wired sensors, which make up around 90% of today's WSN, wireless sensors offer significant advantages in terms of deployment time and cost. Budget for wire and insulation is the primary component of deployment cost. Construction, repair, and setting up all add time to the deployment process. It is not practical to set up the wired sensors for some uses. For example, in situations requiring quick deployment & mobility, such as on the battlefield, in sealed regions (for radioactive monitoring), or in automobile systems. Wireless sensor deployment eliminates these problems by cutting down on installation costs & deployment times. The manufacture of affordable wireless sensors will rise in response to rising demand and new functionalities being studied.

A WSN is formed by a network of just a few thousand interconnected sensor nodes. Low participation rates among sensor nodes are a result of high hardware complexity and high link maintenance costs. Identifying node development according to particular applications became possible due to limited resources in WSN nodes. The onboard integrated circuit elements are changed during application-based node deployment according to the requirement. With this approach based on TCP/IP, the usual stack idea to integrate nodes by establishing a standard transport layer protocol on the network layer is obviously not feasible. Based on their exhaustive study, researchers recommended a generic network stack with disabled functionality & cross-layer optimization.

IOT based WSN applications

This section we present the study of different applications in which the IoT enabled WSNs are used [9].

- **Industry Object Tracking:** In a networked environment without regular infrastructure, sensors are utilized to monitor & track objects carried in vehicles or the dislocation of vehicles.
- **Vehicular Networking with Sensors:** Additional features to driver aided systems integrated into modern vehicle designs are brought about by the introduction of "sensor on wheels" (DSRC, 2005) in cars.
- **Home Automation:** The widespread use of WSN, with its cheap cost, portability in design, and easy interface to other networks, has resulted in a tremendous demand for home automation & monitoring.
- **Environmental Monitoring:** The use of sensors allows for the monitoring of wildlife & related environmental actions with minimal impact on local inhabitants.
- **Medical Industry:** Regular health monitoring and the provision of medically-related information are two functions of the healthcare system as a whole.
- **Industrial Process Control:** The industrial & process industries make extensive use of WSN. Their job is to keep an eye on all the interdependent processes and pieces of machinery by conducting random and routine tests.
- **Defense Applications:** When designing new devices or nodes for defense monitoring in real time, the C3I systems—command, control, communication, & intelligence—are crucial.
- **Security and Surveillance:** By preserving & safeguarding user data, the extensive WSN network provides an even surveillance mechanism.

Challenges of IOT enabled wsns

Scientists have been concentrating on WSN problems such energy management, efficient routing, data aggregation, security, self-organizing networks, cluster based networks, and more in recent years [2]. Problems with WSN architecture can be categorized according to the data centric approach's following services:

- **Energy Management:** There is a direct correlation between the radio design & quality of the energy optimization protocol suite. Battery power, either by depleting one's supply or from energy harvesting, is what keeps nodes running [2]. Implementing resting sessions, minimizing the number of sensors integrated into a single node, adding forwarding nodes as intermittent nodes, and simplifying processing algorithms are all ways to save energy.

- **Routing:** In order to send the detected data to the sink, a routing mechanism is employed. Over the past ten years, numerous routing protocols have been created with the aim of enhancing routing performance in different contexts. The networking layer is responsible for routing, which can be either single-hop or multi-hop. When routing data from a cluster of nodes that are similar to one another or from nodes that are detecting the same event with different parameters, clustering becomes a challenge.

- **Data Aggregation:** The numerous data points collected by sensor nodes in a given region will have a common format, beginning with the most fundamental data aggregation service [4]. In order to prevent the reuse of data, a local node gathers data from a cluster of nodes that measure the same parameter, and then makes that data available to the sink.

- **Security:** There are dangers and hazards that can affect networks. Data integrity issues, eavesdropping, fake message inserting, man-in-the-middle attacks, Distributed Denial of Service (DDoS), and wasted network resources are some of the threats that WSNs face [5]. It is possible to spoof or eavesdrop on data transmitted by wireless nodes since their messages are broadcast to the medium. One way to improve clustering's security is to reduce the amount of cryptographic keys used.

- **Self-Organizing:** Network operation throughout startup, steady state, & failure is made possible by self-organization [6]. The WSN nodes run autonomously, although this service is necessary for network management. Therefore, clustering is the only way to secure the nodes in self-organization, which includes synchronization of time, distribution of node identifiers, or reconstruction for failure recovery.

- **Clustering:** Researcher consensus has been that clustering WSN is an essential service. More sensor nodes are placed in the network. More than 10 nodes are typically deployed in a group for an identical measurable parameter [7].

WSN clustering

Need of clustering

Developing cluster groups is inevitable in most WSN works. As a result, several writers have sought to increase the operational lifetime of networks by suggesting ways to decrease the energy consumption of sensor nodes.

1. Decreasing the number of packets sent and received between nodes
2. Arranging when the nodes will sleep

When it comes to combining the two, the authors are in agreement that WSN of cluster-based association have the potential to be irreplaceable. Scalability, energy efficiency, & network lifetime are all enhanced by hierarchical-based clustering in WSN, as we've already established. Hierarchical routing decreases cluster energy consumption by lowering data packet transmission to BS through data fusion/aggregation. More congestion at the gateway node causes data gathering to fail in the widely deployed single tier network. Delays, collisions, and data loss are all results of the gateway being overloaded. Not to mention that big networks with a high density of sensors are impractical for this single-tier network, which also fails to generate communication nodes. The ability to govern the network by forming appropriate subsets of nodes under the leadership of a CH makes hierarchical clustering a viable option for many applications. The scalability-created subgroups enhance load balancing & resource utilization. It is more effective to use data aggregation in conjunction with clustering for applications that need removal of duplicated data and multi hop connections.

Clustering not only aggregates data, makes it more efficient for utilizing energy, and improves scalability, but it also generates a smaller-than-any-other WSN routing table—a local table with routes to deliver data packets to the base station. By dividing the channels used for communication between nodes into those that go within each cluster and those that go outside, the clustering process also reduces the amount of bandwidth needed for communication. A CH can communicate with another forwarding CH or even a BS directly for inter-cluster communication. The group's member nodes & CH control the intra-cluster communication. Nodes or BS exchange data packets with little redundant data and message overhead, and the routes remain stable till re-clustering is started. To ensure that no node in the environment gets unchecked throughout the CH selection method, the clustering process encompasses all of the nodes. So, once clustering is complete, the nodes that took part in it either join a nearby cluster or choose to be the cluster leader (CH). By starting the re-clustering process at the correct time & allocating resources to its members based on scheduling, the CH improves the stability of the network operations and puts optimum management rules into place.

Several obstacles arise during the design and deployment of WSN. Since WSN is an element of MANETS, some of these characteristics are inherited from their parent network. There are extra considerations for processing power, battery life, transmission distance, and hardware requirements when designing a WSN for a mobile environment compared to a fixed network. However, MANET nodes have unique battery needs due to their direct power source and the ability to swap out their batteries. Conventional approaches to clustering design in WSN take into account network throughput, battery life, load balancing, and coverage. As a result of developments in VLSI design, modern times take into account factors such as low power CPU alternatives, secure data transfer, link reliability, & application robustness of the applied algorithms and protocols. However, owing to application specific limitations, it is not immediately possible to deploy several applications.

Parameters of clustering

- **Multi hop communication:** Data sent by CH nodes must reach BS via direct transmission or multihop transmission; this is something that clustering must guarantee. Nearby BS nodes send data directly to one another, while CHs farther away employ multihop communication to send data to the next CH in the chain, which is either closer to the BS or, depending on the deployment situation, to a gateway node. Generally speaking, multihop communication channels are better for larger network sizes.

- **Cluster size & number of clusters:** In order to accommodate all service requesters, the cluster size in the simulation environment is kept as big as feasible. In some real-world deployments, TDMA-based communication channels are used to distribute resources to all member nodes. As we'll see in the next section, the setup phase's cluster formation count is dependent on the clustering model. Both iterative clustering techniques with a fixed number of cluster heads or probabilistic-based computing clustering algorithms with a naturally random number of clusters can adapt to different work environments.

- **Mobile support:** The chosen CH nodes must take into consideration both their own mobility & dynamic position changes of the member nodes. Due to the presence of stable clusters and linked links, this does not pose a problem in stationary network environments. Therefore, in order to keep up with the ever-changing mobile environment, it is necessary to re-cluster nodes at the appropriate times and continuously manage them during cluster activity.

- **Node type:** If the proposed models are to contain nodes with higher capabilities in terms of computing, battery life, and transmission ranges (heterogeneous), then choosing them as CH will be more advantageous. Homogeneous nodes, with identical capabilities for both the CH & subset of member nodes, are typically employed in large-scale node deployments.

- **Methodology to form clusters:** As standard sensor nodes in the network, CHs are often chosen in a decentralized fashion by other nodes in a WSN, with little to no coordination between them. As a centralized solution, a master controller collects the clustering parameters from a gateway or trigger node in the environment and uses them to govern the membership of the nodes in the network. In a distributed setting, the CH selection procedure uses a random assignment of nodes from the senior node group.

- **Computational complexity:** Recent techniques have considered the computational complexity & time required to construct stable networks in clustering. Consequently, as the number of nodes in the network increases, so does the rate of convergence. Consequently, the main goal of the design is to end the cluster formation period as soon as possible.

- **Multilevel communication:** The data distribution process in network scaling involves communication at a level between member nodes, CH, and BS, with either a single hop or multiple hops between them. A subset of the CH is designated to have efficient load balancing & energy management, however in bigger networks, data is collected at multiple levels inside the cluster before being forwarded directly to CH from member nodes.

- **Intersecting Cluster regions:** When it comes to cluster formation, a number of algorithms have ignored the overlapping cluster transmission range. After connecting to a CH, nodes in the neighboring cluster may also receive signals from that CH. The ability for nodes to dynamically switch clusters according to the resources assigned to each group by CH is a great asset.

When clustering, it is necessary to take into account the parameters mentioned above, which are examples of several generalized decision-making aspects.

Taxonomy of clustering

A number of algorithms offer clustering procedures that take into account the aforementioned parameters and various approaches to WSN clustering [8]. There are a number of ways to classify the algorithms that are currently available; these include cluster head capability, node type, methodology (model), & clustering approaches. Figure 1. Shows that this categorization begins with processing and decision making at nodes, whether they are distributed or centralized. Heterogeneous networks consist of nodes with varying degrees of capability and compatibility across various communication technologies; homogeneous networks consist of nodes with identical features. In heterogeneous sensor networks, simple sensor nodes do the sensing while nodes with more processing capacity & transmission range gather, process, and send the data to other nodes. Nodes that possess the aforementioned capabilities are designated as CH nodes, responsible for providing support to the rest of the group. In further rounds of clustering, the nodes with the most power are chosen to be CH if there are more than one. In homogeneous WSN, nodes with similar hardware characteristics choose a central hub (CH) utilizing a clustering algorithm; each node in the network must take part in the clustering process and be elected CH at least once; this ensures that the CH rotation process produces clusters that are both energy efficient & load balanced.

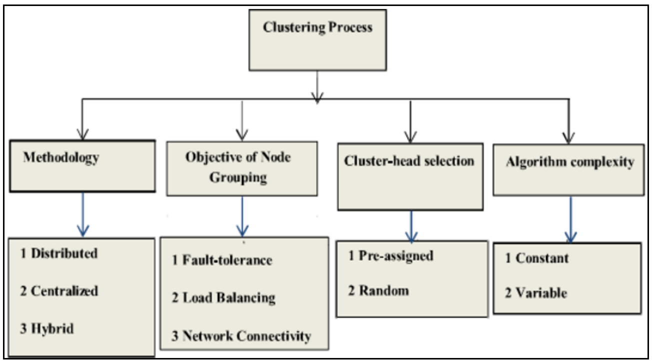

Fig 1: Taxonomy of Clustering Process

The clustering environment forms the basis of the next prevalent classification. To efficiently respond to changes in the network topology, clustering should adhere to a standard clustering technique, which includes a setup phase, steady state phase, & maintenance phase (re-clustering). This approach is called dynamic clustering. In contrast, static clustering's predetermined CHs might not work in networks that aren't monitored. For this reason, WSN are more suited to the dynamic clustering approach, which allows for more efficient load sharing & coverage optimization. In addition, as demonstrated in Figures 2 and 3, clustering algorithms can have their classifications refined based on CH capabilities & cluster features. The cluster property details the process of electing a CH, the network requirements of CHs, connectivity to CHs, and the stability of the established cluster. The kind of node determines which nodes with more power are elected as CH.

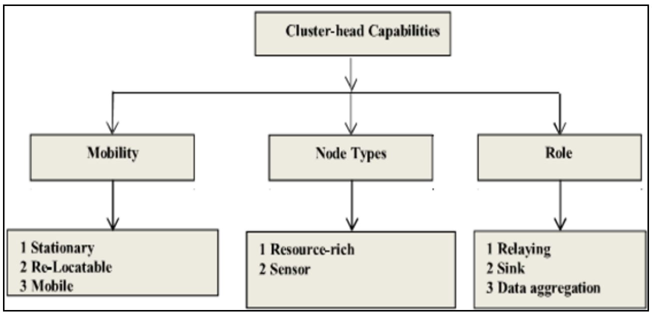

Fig 2: Taxonomy of CH Capabilities

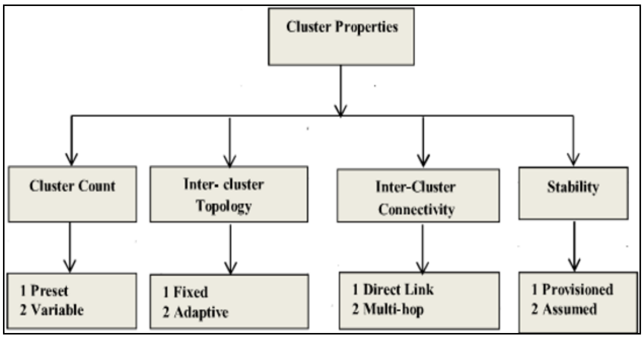

Fig 3: Taxonomy of cluster properties

WSN data forwarding methods

The term WSN refers to a system of interconnected WSN that can detect and record a wide range of environmental variables, including but not limited to: motion, sound, vibration, pressure, & temperature. The initial impetus for the development of WSN came from military needs for battlefield surveillance. Recent technological advancements have made WSNs one of the most talked-about areas of wireless communication, thanks to smaller, cheaper, and more powerful sensor nodes as well as improved wireless interfaces. Any WSN must have these four main parts:

- A group of distributed sensor nodes;
- An interconnecting wireless network;
- A gathering-information base station(Sink);
- The data received from the nodes is interpreted and analyzed by a set of computing equipment at the base station or elsewhere; occasionally, the computation is performed by the network itself.

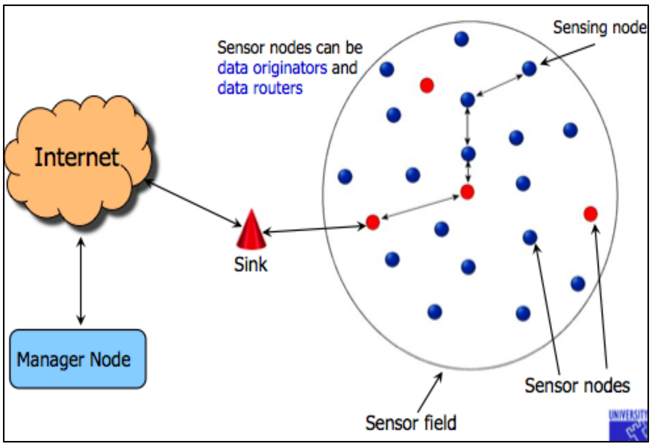

Fig 4: Basic sensor network components

Nodes that collect the necessary data and transmit it to the base station are known as sensor nodes, and they are inexpensive and power-efficient. Figure 5 shows the four main components of a sensor node. These are a sensing unit, a radio transceiver or other wireless communications device, a small microprocessor, and an energy source (often a battery; however, some sensor nodes also incorporate memory components).

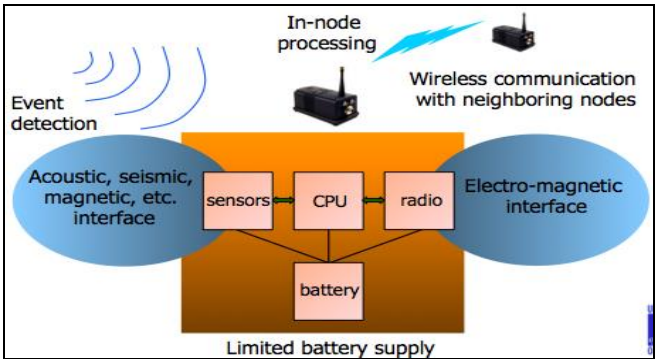

Fig 5: Components of Sensor nodes

A sensor node's functionality is based on its capacity to sense an event and broadcast the data, or it can be a pure transceiver that receives data from various sources and relays it to other nodes until it reaches the base station. The network design is application-specific, which means that this capability is application-dependent as well.

Table 1: List of sensor nodes

Sensor Node Name	Microcontroller	Tranceiver	Program+Data Memory	External Memory
BEAN	MSP430F169	CC1000 (300-1000 MHz) with 78.6 kbit/s		4 Mbit
BTnode	Atmel ATmega 128L (8 MHz 8 MIPS)	Chipcon CC1000 (433-915 MHz) and Bluetooth (2.4 GHz)	64+180 K RAM	128K FLASH ROM, 4K EEPROM
COTS	ATMEL Microcontroller 916 MHz			
Dot	ATMEGA163		1K RAM	8-16K Flash
EPIC Mote	Texas Instruments MSP430 microcontroller	250 kbit/s 2.4 GHz IEEE 802.15.4 Chipcon Wireless Transceiver	10k RAM	48k Flash
Eyes	MSP430F149	TR1001		8 Mbit

Sensor nodes can range in size from tiny dust particles to shoeboxes. In a similar vein, the price of sensor nodes can vary greatly, from a few pennies to hundreds of dollars, all dependent on the complexity & size of the sensor network.

Conclusion

The IoT encompasses a wide variety of uses, some of which operate in static network environments and others in more dynamic, mobile ones. This study highlights how IoT enables WSNs to overcome traditional limitations related to scalability, real-time data processing, and seamless communication. Addressing these challenges is crucial for fully realizing the potential of IoT-enabled WSNs. The convergence of IoT and WSNs represents a significant step forward in the evolution of sensor networks, offering promising opportunities for innovation across various sectors. The ongoing advancements in IoT technology will continue to drive the effectiveness and expansion of WSN techniques, paving the way for more connected, efficient, and intelligent systems.

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