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Wireless Sensor Network Technology: Conceptualization & Trends

Avneesh Kumar

GIBM Institute, India

Abstract

WSNs were first developed for military missions, substituting for large, expensive and energy-hungry systems. They enable the transmission of data from remote locations, often without physical access. WSNs are deployed in small, distributed systems of sensor nodes that communicate wirelessly with one another, eliminating the need for long-range communication and data transmission cables, while providing real-time on-site data.The paper explores the structure, classification, networks topologies, core and application layers, communication protocols, and communication models of WSNs. Finally, this paper provides an outlook by introducing some potential future developments of WSNs.

Keywords: WSN, Network Topologies

Introduction

Wireless Sensor Networks (WSNs) are networks of tiny devices, usually consisting of nodes that work together to sense/monitor environmental conditions, such as temperature, pressure, sound, light, etc [1]. These devices are often placed in remote or inhospitable places for long-term surveillance or observation.

WSNs are becoming increasingly popular in a variety of civilian applications, such as smart homes, utility networks, traffic flow management, agricultural production monitoring and natural resource management [2]. They are also being used for health monitoring, disaster management, environmental monitoring, military operations and many more.

The military application of sensor networks is mainly attributed to the need to track a wide range of military activities such as surveillance, battle management, and intelligence gathering [3]. These applications require rapid deployment and the ability to detect, measure, and transmit data from a wide variety of wireless sensors. This can be done using wireless sensor nodes with various sensors built in performing specialized tasks such as temperature, humidity, and motion detection [4]. Additionally, military applications also require the sensor nodes to be small, low-power, and ultra-reliable and also integrate communication, sensing, and computing capabilities. Furthermore, the data gleaned from the sensors must be effectively connected and transmitted to the end user for analysis, decision-making, and communication. Sensor networks provide a cost-effective way to fulfill these needs and provide the much-needed real-time data for efficient battle management [5].

Congestion impacts negatively the lifetime of the sensor nodes and affects critical decisions, such as target tracking schemes, logical or physical topology management, etc [6]. Therefore, nodes need to communicate efficiently and rapidly in order to reduce congestion and achieve a much better performance with regard to energy usage and data management. Additionally, the sensor networks need to deal with external and environmental interference due to changes in the environment, terrain, weather conditions, etc., and mitigate the effects of these instabilities [7].

In order to meet these requirements, sensor networks are designed to incorporate resilient and efficient routing protocols such as multi-hop routing and geographic-based forwarding [8]. These routing techniques also provide better reliability and fault-tolerance by leveraging a wide range of nodes through dense deployment, failure detection, and fault recovery techniques such as node redundancy and path diversity [9]. Moreover, sensor networks need to adopt a distributed architecture in order to enable distributed processing, scalability, and gain the ability to monitor large spaces that cannot be monitored efficiently by one single device. Additionally, sensor networks need to incorporate a secure data transmission protocol, such as end-to-end encryption, in order to protect the data from malicious attacks [10].

Sensor networks are an extremely useful tool for military applications due to their capabilities to detect, measure, and transmit data from a wide variety of wireless sensors [11]. However, these networks need to adopt various routing protocols, distributed architectures, and secure data transmission protocols in order to ensure efficient data transmission, scalability, and to mitigate external or environmental interferences [12].
Radio signals can be subject to interference from other wireless devices in the area, such as other Wi-Fi networks or Bluetooth devices. Data transmission

will also suffer from the same sources of interference [13]. Therefore, when multiple devices are attempting to transmit data concurrently, congestion can occur as data from certain devices may be delayed or lost due to interference from other devices [14,15]. Furthermore, the transmission rate of a device may be impacted by the number of other devices transmitting simultaneously [16]. As more devices attempt to transmit data in the same area, the likelihood of interference increases and this may lead to decreased network performance due to congestion [17].

Sensor Network Concept

Sensor networks are a type of wireless communication system that relies on a variety of sensors to collect, analyze, and transmit data [18]. Sensor networks have been used in a variety of applications since the 1950s and have enabled advancements in climate change research, medical diagnostics, and automated manufacturing [19,20].

This data was then analyzed to observe changes in the environment, such as changes in climate, water, and vegetation patterns. Since then, the capabilities of sensor networks have grown and expanded to include real-time applications in the military, civilian, and industrial sectors [21].

In recent years, advances in the internet of things (IoT) and the development of low-cost, low-power sensors have led to the widespread adoption of sensor networks. These networks are now being used for a variety of applications such as traffic management, manufacturing processes, smart homes, emergency response systems, and security monitoring [22,23]. In addition, the use of sensor networks has been essential in the development of driverless cars and other autonomous technologies.Sensor networks are likely to continue to be an important tool for data collection and analysis in the coming decades and will help shape the technologies of tomorrow [24].

Sensor Network Practices in Traffic Management

Sensor networks are used extensively in the field of traffic management for improving mobility and safety [25]. They enable the collection and analysis of traffic data from various sources such as surveillance cameras, radar and other sensors, and provide real-time insights on the traffic flow, allowing dynamic re-routing, adapting traffic signals and changing speed limits[26].

Sensor Network Practices in Emergency Response System

Sensor networks provide vital information for emergency response systems such as air quality monitoring, search and rescue, and fire and disaster management [27]. By using embedded sensors and radio communication devices, these systems can detect changes in an environment and send alerts in case of possible dangers or disasters. This can help first responders arrive in the right area with the right resources in the quickest possible time [28,29].

Sensor Network Application in Precision Agriculture. Precision agriculture is a farming management concept that uses sensors to measure soil quality, water levels, plant growth and temperature, allowing farmers to make decisions in real-time [30]. Sensor networks can be used to provide up to date information about crop production and soil moisture, helping farmers optimize their crop cultivation, maximize yield and reduce energy use. This has the potential to increase crop yield and reduce wastage, leading to more efficient and sustainable agricultural production [31,32].

Sensor Network Practices in Security Monitoring

Sensor networks are essential in providing effective security monitoring. By combining motion sensors, cameras and infrared sensors, these networks can detect the presence of intruders and alert the relevant authorities if necessary [33,34]. By using intelligent sensing mechanisms, security systems can effectively monitor difficult terrain and critical infrastructure, increasing awareness levels and providing comprehensive security [35].

Sensor Network Practices in Autonomous Technologies

Sensor networks are also essential components of autonomous technologies in areas such as automated engineering, robotics and unmanned aerial vehicles [36,37]. For example, they are used to provide real-time tracking and positioning information of an object, environment or scene [38,39]. This is commonly used to control and coordinate the motion of autonomous vehicles and machines, helping them to navigate their surroundings with greater accuracy and safely complete their mission [40]. Sensors in these networks are also used to gain insights about the environment and improve decision-making [41,42]. Advanced sensor networks may also be used to provide enhanced surveillance and intelligence-gathering capabilities for military or police forces [43].

Conclusion

In conclusion, Wireless Sensor Networks (WSNs) have the potential to bridge sensing and communication technologies to enable various applications. While WSNs have enormous practical implications, Prior to deployment on a mass scale, there are still numerous obstacles that need to be addressed.. The key challenges for WSNs include communication protocols and energy consumption, as well as developing efficient algorithms for data processing. With continuous advancements in these areas, WSNs can revolutionize the way we interact with our environment, as well as increase efficiency in many industries.

Furthermore, development and deployment of sensor networks is not an easy task and the process has its own challenges, such as communication protocols and energy consumption. Therefore, at present, sensor networks are still in the research and development phase and it's not yet adopted in any large scale application.

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