International Journal of Autonomous and Adaptive Communications Systems

ISSN online: 1754-8640 - ISSN print: 1754-8632
https://www.inderscience.com/ijaacs

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DOI: 10.1504/IJAACS.2024.10055464

Article History:

Received:	16 August 2021
Last revised:	25 November 2021
Accepted:	05 January 2022
Published online:	10 January 2024

Applications, merits and demerits of WSN with IoT: a detailed review

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Abstract: This paper provides an in-depth survey of wireless sensor networks (WSNs) and the Internet of Things (IoT). It explores the diverse applications of IoT and WSN in healthcare, agriculture, transportation, automation, etc. The paper provides the various merits and demerits of IoT and WSN technologies. It also investigates the research work exploiting both IoT and WSN technologies for distinct applications and describes the various advantages of integrating these technologies. The paper provides a comparative study of explored applications based on common performance metrics, publication year, technologies used and results achieved. Through exploring the diverse applications, strengths and weaknesses of IoT and WSN systems, this paper offers thorough knowledge on IoT and WSN technologies to readers, encouraging better and more applications exploiting WSN with IoT.

Keywords: IoT; Internet of Things; WSNs; wireless sensor networks; applications; smart devices; monitoring systems.

Reference to this paper should be made as follows: Murthy, M.Y.B. and Koteswararao, A. (2024) ‘Applications, merits and demerits of WSN with IoT: a detailed review’, *Int. J. Autonomous and Adaptive Communications Systems*, Vol. 17, No. 1, pp.68–88.

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1 Introduction

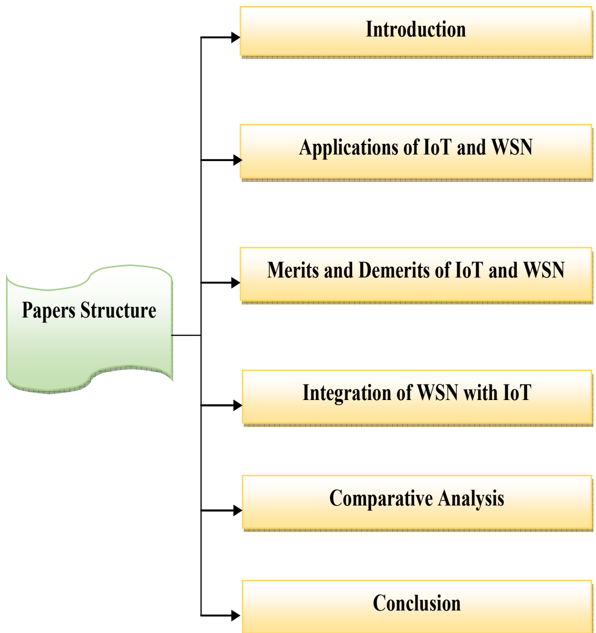
In the present scenarios, vast technical breakthroughs have been ascertained in the modern applications. Various technologies have been used in the development of these applications. Among the heterogeneous technologies, wireless sensor networks (WSNs) and Internet of Things (IoT) have acquired profound attention at both industrial and academic levels. IoT and WSNs have been broadly used in monitoring, sensing, detection, automation and control operations (Ali et al., 2017; Balaji et al., 2019; Li and Kara, 2017). Through incorporating and connecting numerous components or devices like sensors, actuators, microcontrollers, data storage units, processing units, data analysis devices and output display units these technologies have made the highly complicated tasks to be executed in simpler ways. Moreover, they have broadened the boundaries of operations limited to only certain environments through exploiting improved gadgets possessing high features which can be adaptable to dynamic situations and complex environments including unreachable areas like dense forests, deep water bodies, space environments, underground, places with no human habitation, etc. They have not just simplified the complex processes but also have improved the living standard through automating the regular house-hold, industrial and other routine appliances employed for performing daily jobs or everyday activities. The IoT and WSNs have been supportive in bringing a lot of automation in almost every discipline like agriculture, healthcare, transport, security, environment monitoring, water and air quality management and so on. Moreover, they have played a big role in transforming the existing domains into praiseworthy paradigms such as smart farming, smart transportation, smart healthcare, smart vehicles, smart homes and other smart monitoring systems through their innovative features thus making the present generation lead a more comfortable, convenient and a better life. In this paper, the concepts, scope, strengths and limitations of both the IoT and WSN are explored.

The key contributions of this study include:

- To review the diverse applications of IoT and WSN technologies in distinct domains.
- To investigate the strengths and limitations of IoT and WSN.
- To explore the integration of IoT and WSN technologies in different applications and determine the various merits of integrating these technologies.

The paper organisation is depicted in Figure 1. The rest of this paper is arranged as follows: Section 2 discusses the various applications of IoT and WSN. Section 3 discusses the various benefits and limitations of IoT and WSN technologies. Section 4 reviews the integration of IoT and WSN technologies for different applications. Section 5 provides a comparative analysis. Section 6 concludes the review paper.

Figure 1 Organisation of the paper (see online version for colours)



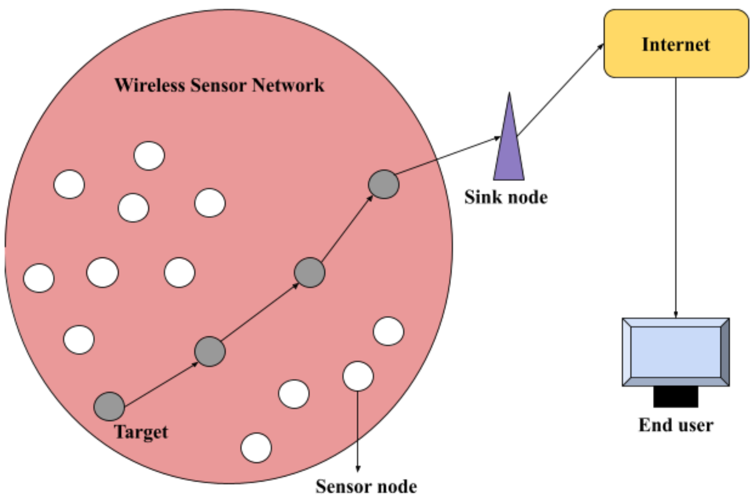
1.1 IoT

IoT is a network which conflates the virtual and physical domains through using the internet as the channel for transmission and communication of information between them (Khodadadi et al., 2016). It interconnects numerous devices and systems are enabling device-to-device and device-to-object communication. The virtual and physical worlds are blended into a single profound network through the utilisation of communication protocols within the IoT infrastructure. It is the internetworking or interoperating of physical tools, vehicles and other objects embedded with software, electronics, sensors, actuators and controllers for exchanging and gathering information. IoT aims at operating devices autonomously without human interference while creating device-to-device communication (Farhan and Kharel, 2019). It allows things to be remotely controlled and/or sensed across existing infrastructure, establishing opportunities for more straightforward coalescence of the physical environment into computer-dependent systems, thereby leading to improved efficacy, accuracy and commercial gain along with minimised human intervention.

1.2 WSN

WSN is a networked system comprising sensors and nodes employed for monitoring, sensing, recording information and interacting with the real environment (Rawat et al., 2014). The nodes include computational power, embedded processing unit, and few smart sensors. Information from the sensor is collected by every node and is communicated to the other nodes. Sensor nodes are usually positioned in the network as per linear, mesh and star topology. WSN comprises multiple sensor nodes, a user and sink node as represented in Figure 2. The sensor node basically comprises a transceiver, microcontroller, power source, external memory and one or more sensors. Sensor nodes communicate mutually and transmit the processed information to the sink node. The other nodes involved in the process as well send information to the sink node which is further conveyed to users via the internet. Conceptually WSN involves a sensing unit, processing unit and a radio unit. Sensing unit is employed for monitoring surrounding premises and its parameters like humidity, pressure and temperature. Processing unit is used for executing necessary computations after completing sensing and monitoring processes. Radio unit is employed for transferring the computed information via wireless mediums. Finally, the information is transmitted to the gateway.

Figure 2 WSN architecture (see online version for colours)



Source: Ali et al. (2017)

2 Applications of IOT and WSN

This section reviews the different applications of IoT and WSN technologies.

2.1 Applications of IoT

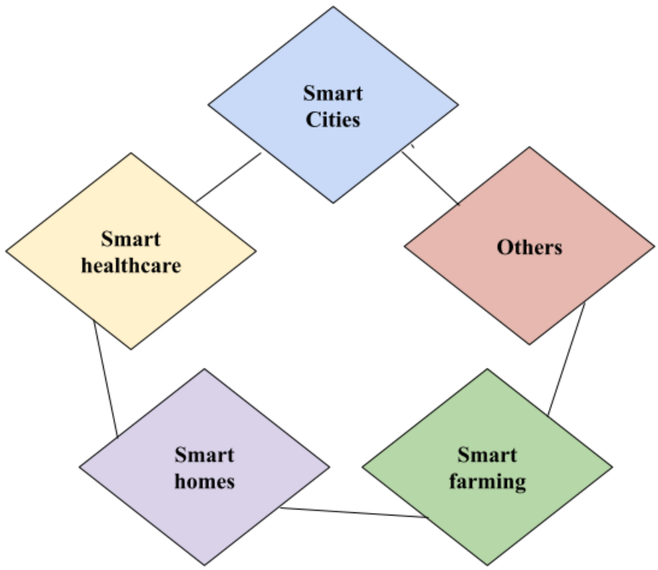
IoT technology has found its applications in smart farming, smart healthcare, environmental monitoring, smart cities, smart homes and so on. Few of them are discussed in this section. The flowchart for the applications of IoT is shown in Figure 3.

2.1.1 Smart farming

Agriculture is the major source of income for rural regions and supplying food and essential eatable items to the expanding population is one of the major demands.

Satisfying the food needs of the entire population worldwide is possible through increasing the agricultural yield. However, this is tedious with the classical farming techniques. The use of IoT technology in farming applications has transformed conventional agriculture to smart agriculture or smart farming wherein every farming activity including crop growth, irrigation supply, pest control, nutrient supply, fertiliser control, soil fertility testing, etc. is consistently and intelligently monitored by IoT tools and systems. These tools not just monitor farm activities but also notify farmers regarding farm conditions through sending messages via SMS or internet thus reducing their time and efforts.

Figure 3 Applications of IoT (see online version for colours)



In Lavanya et al. (2020), IoT technology was exploited for agricultural application. A cost-effective, automated IoT-dependent fertiliser system was developed for determining the fertiliser requirement in smart farming. The information sensed from agricultural fields by nitrogen-phosphorous-potassium sensors was transmitted to cloud database for supporting rapid retrieval of information. The proposed IoT system provided a better approach for informing the farmer regarding the fertiliser usage at the right time intelligently via SMS and served as a good platform for fertiliser management in smart farming.

2.1.2 Smart cities

The innovative developments in IoT have supported in transforming the existing facilities in an automated manner thus giving rise to new applications like smart cities. Smart cities utilise several physical gadgets connected to the IoT for optimising the efficacy of city operations and services. Energy management, surveillance, automated transportation, intelligent vehicle parking, vehicle monitoring, automated highway lighting are few examples of smart cities.

In Ke et al. (2020), IoT technology was used for smart parking surveillance application. The proposed system exhibited high reliability and efficiency in distinct scenarios including outdoor, indoor, rainy, cloudy, nighttime, daytime, occlusion, and foggy situations. In Rahman et al. (2020), an IoT-directed system was exploited for smart lighting application. It allowed light intensity to be controlled on highways as per the traffic demand. It facilitated sensing-exchanging of traffic data on highways and automated switching on/off the lights along with detection of defective lampposts. In Ismail et al. (2019), an IoT-based intelligent parking system was developed. In this system an IoT module was deployed on-site for monitoring and indicating the availability status of parking space. This system was useful in providing the real-time information to users about the parking slot availability in a specific parking region. In Luo et al. (2019), IoT-based system was used for smart public transport management. This system assisted the decision makers in enhancing the usage rate of transport resources and in decreasing the passengers' travelling duration. In Mallidi and Vineela (2018), IoT technology was employed for intelligent vehicle monitoring application. The proposed IoT-based system assisted in monitoring the vehicle consistently and in accessing and controlling it remotely. It also helped in keeping track of vehicles location in the event of emergencies (i.e., theft or accidents). This system was promising in terms of determining the vehicle location, detecting the accidents and its severity. In Li et al. (2015), smart visual IoT technology was used for monitoring the road vehicles. It was capable of detecting the vehicle's colour, type, license plate number, passing moment and passing spot easily. It extracted the visual tag of the vehicle for detecting and tracking the vehicle. This vehicle monitoring system showed 85.80% of tracking accuracy in real-time under distinct traffic flow and weather conditions.

2.1.3 Smart healthcare

Smart healthcare is another significant application of IoT. Utilisation of IoT in healthcare has assisted in real-time health monitoring of patients for examining the individual health through wearable devices and providing necessary solutions for sickness.

In Paul et al. (2018), an IoT-based system was used for monitoring patient's health condition. This system was developed for monitoring the patients suffering with chronic diseases. It showed promising outputs in detecting the health state.

2.1.4 Smart homes

IoT technology is making human life more comfortable and convenient day by day through making the people experience a new digital age never before. Smart homes is one such application of IoT that has automated the usage of home appliances e.g., switching off fans/lights when no one is present at home, door opening when owner enters, etc. Recently, health smart-home applications have also been introduced for monitoring health status and daily activities of patients and elderly people in-home.

In Yuen et al. (2018), IoT was used for home automation. It focussed on humidity and temperature monitoring, health monitoring, home life security and disabled/elderly/pet monitoring functions. The proposed IoT-based home automation worked satisfactorily in controlling the home appliances effectively. In Mano et al. (2016), IoT technology was employed for health smart-home application. It utilised emotions and images for supporting medicare in smart home scenarios in an automated manner via an IoT infrastructure. The proposed system aimed at assisting elderly people and patients in an in-home medicare context.

2.1.5 Others

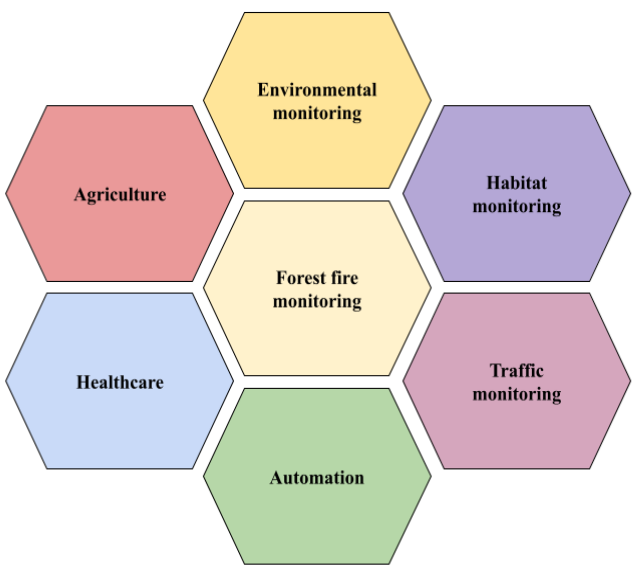
IoT has also been exploited in surveillance and detection of wildfires, energy monitoring and environmental monitoring applications.

In Kaur and Sood (2019), surveillance and early prediction of wildfire was performed using an IoT system. Using this system, the forest region which could possibly be burnt due to wildfire outbreak was also predicted. Moreover, it generated real-time alerts in case of high wildfire vulnerability level. This system offered effective and efficient operation without sacrificing the wildfire predicting capabilities. In Mudaliar and Sivakumar (2020), an IoT-based mechanism was used for energy monitoring in real-time. The proposed system could be useful in determining the switchgear industry's daily energy pattern and in implementing the energy saving measures for operating the industry with efficient power consumption and less cost. In Dhingra et al. (2019), an IoT-based mechanism was used for monitoring the air pollution. The data gathered from gas sensors was forwarded to the microcontroller which transmitted it to the cloud through the WiFi system for allowing the users to access the air quality information. This system assisted the users in forecasting the pollution extent of their travelling route.

2.2 Applications of WSN

WSN technology has found its applications in agriculture, healthcare, environmental monitoring, traffic monitoring, wildfire monitoring, habitat monitoring, automation, and so on. Few of them are discussed in this section. The flowchart for the applications of WSN is shown in Figure 4.

Figure 4 Applications of WSN (see online version for colours)



2.2.1 Agriculture

WSN technology has largely contributed to agricultural productivity improvement through monitoring the agricultural activities and notifying farm authorities or farmers in a timely manner for taking desired actions. Utilisation of sensor networks for sensing the moisture level, soil fertility, pH content, water requirement, illumination, temperature and humidity and other factors essential for plant growth including pest control, appropriate nutrient and fertiliser delivery have helped in enhancing the agricultural yield. The real-time monitoring feature of WSNs in farming applications has minimised the efforts of farmers and has led to time and energy conservation.

In Jiber et al. (2011), a WSN based framework was employed for monitoring precision agriculture. The proposed WSN framework provided numerous services including disease and pest control, water and irrigation management, resource optimisation, crop yield planning and prediction.

2.2.2 Healthcare

Healthcare domains have shown tremendous improvements in their services and facilities through the exploitation of WSN technologies. Deployment of real-time sensors and improved medical sensors have helped in monitoring patients' health states in a more easier and quicker manner. Moreover, the introduction and use of wireless body area networks (WBANs) in medicare have reduced the physician's efforts in determining the patients health condition. WBAN systems are instrumental in detecting the real-time health profile and sending critical feedback to the physicians or end-users through the connectivity. These systems aid in monitoring physiological parameters like oxygen level, stress level, temperature, blood pressure, pulse rate or heartbeat and so on. Apart from monitoring these conditions, they also analyse and monitor the routine of workout and other health maintaining activities.

In Desai et al. (2017), WSN platform was used for monitoring human health. It could detect the human heartbeat, pulse rate and temperature easily for determining one's health state. In Ali et al. (2018), heart pulse monitoring was performed using WSN technology for measuring the patients' heart pulse in real-time environments. The proposed system was user-friendly and cheaper. Moreover, it delivered rapid and accurate results. In Suryadevara and Mukhopadhyay (2012), WSN based home monitoring mechanism was used for determining the wellness of elderly people. The elderly well-being status was estimated based on utilisation of house-hold appliances linked through multiple sensing units. This system also helped in recognising the activity behaviour of elderly and assisted the care providers in evaluating the performance of the elderly activities being carried out independently.

2.2.3 Traffic monitoring

In urban regions and big cities, traffic management has also been a key concern. Severe challenges in traffic management like monitoring the heavy traffic, individual vehicle monitoring and detecting vehicles violating traffic rules that are faced by traffic authorities and government have been simplified to a vast extent by exploitation of WSN technologies. Using WSNs, real-time and complete traffic flow status, vehicle speed, number of vehicles and other details of vehicles could be easily determined.

In Barbagli et al. (2011), WSN technology was exploited for traffic monitoring. This system provided an immediate and complete status of traffic flow in real-time and at an unaccustomed range. The plug and play feature of this system provided robustness and high communication reliability. This system could be used as an effective means for providing traffic regulatory authorities with appropriate information regarding traffic parameters. In Du et al. (2014), vehicular sensor networks were utilised for monitoring the urban traffic. The vehicle traffic was accurately detected and monitored using these WSNs. In Balid et al. (2016), another WSN-based mechanism was used for traffic monitoring in real-time. The speed estimation and vehicle counting was performed using computationally efficient and reliable WSN protocols. The proposed WSN system provided 96.11% accuracy in speed estimation and 99.95% accuracy in vehicle counting.

2.2.4 Habitat monitoring

WSNs have also been used for monitoring the habitat of living creatures. Habitat monitoring is crucial in determining the trespassers' activity in the habitat region who may create disturbance in the plant breeding or animal husbandry sites.

In Naumowicz et al. (2010), WSN technology was exploited for monitoring the habitat. Real-time sensors were deployed for visualising and monitoring seabird nesting on Skomer island in UK. In Boulmaiz et al. (2016), acoustic bird detection and their habitat monitoring was achieved using WSNs. The proposed WSN-based habitat monitoring system effectively performed acoustic bird detection in complex scenarios and improved energy consumption, noise immunity and recognition performance.

2.2.5 Automation

The role of WSNs in the automation realm is inexpressible. WSNs these days are extensively exploited for automating the routine operations in diverse commercial and domestic sectors. Some of the examples include smart manufacturing, smart transactions, smart energy management, smart homes, etc.

In Nandury and Begum (2015), a smart-WSN dependent model was presented for smart transactions which provided an ubiquitous environment for uninterruptible interaction of diverse smart objects, systems and devices. It offered reliability, scalability, versatility, pervasiveness and flexibility. In Sharma et al. (2018), WSN technology was employed for automation applications such as smart homes/industries. It provided interoperability of multiple devices/users with high data throughput and offered an efficient and robust way for multi-user/multi-access in industry and smart home environments.

2.2.6 Environmental monitoring

Environmental monitoring is essential for leading a peaceful, healthy and better life. Various natural and human-introduced activities have polluted and damaged the living environment. Therefore to protect and stop the environment from further degradation, it is necessary to constantly monitor environmental activities and regulate strict measures. Through technologies like WSN, diverse environmental conditions can be easily monitored. WSNs have assisted in real-time monitoring of air, soil, water and other environmental parameters.

In Yang and Li (2010), WSN technology was exploited for autonomous, near-real-time and long-term environmental monitoring applications. Networking protocols were developed for reliable information gathering with low power consumption. A network of sensor nodes were deployed for monitoring soil moisture and other environmental parameters. In Jeličić et al. (2011)1, a WSN-dependent environmental monitoring system was presented. It supported several sensors like temperature, illumination, air pressure, humidity and soil moisture for monitoring environmental conditions and provided better energy saving through low power consumption. In Yu et al. (2013), WSN technology was exploited for monitoring the indoor air quality. The proposed system performed firmware update and remote parameter adjustment of sensors for enhancing the system convenience and flexibility. In Patil et al. (2019), WSN based system was exploited for monitoring air pollution. The air pollution data was gathered in real-time from distinct locations using sensors and this data was transferred to cloud for further analysis and estimation of air quality index. This system helped in monitoring air pollution at low concentration levels with high energy efficacy. In Pavani and Rao (2016), a WSN system was exploited for monitoring pollution in real-time. Through this system, concentration of significant pollutant gases like oxygen, carbon monoxide, carbon dioxide and nitrogen dioxide contained in air were sensed through gas sensors. These sensors were then incorporated with WSNs via multi-hop information aggregation method. The proposed WSN-dependent system was capable of gathering the air pollutant related data continuously under the diverse timings and conditions. In Kadri et al. (2013), another WSN-based system was presented for real-time monitoring of air pollution. The system comprised several dispersed monitoring stations which wirelessly communicated with a backend server through machine-to-machine communication. Every station was equipped with meteorological and gaseous sensors along with wireless communication and data logging capabilities. This system provided an effective approach for better air quality monitoring. In Lazarescu (2013), environmental monitoring was accomplished using WSN platform. The application requirements like low cost, fast deployment, high service quality, long lifetime and low-maintenance were satisfied by this system. In Jamil et al. (2015), WSNs were exploited for environment monitoring application. Using WSN nodes, the air pollution in the city and the movement of public transport was constantly monitored. This system enabled direct communication of sensor nodes with moving nodes, and reduced the necessity for special connectivity.

2.2.7 Forest fire monitoring

Forest plays a prominent part in maintaining the atmosphere's biogeochemical cycle and in influencing the plant, animal, human and other living creatures lives. However, urbanisation has led to afforestation causing severe imbalance in the ecosystem. For forest surveillance, monitoring has become indispensable. Recently, WSNs are largely exploited for maintaining forest safety including early wildfire prediction and recognition.

In Kadri et al. (2018), WSN technology was employed for early fire recognition. This system exploited the advantages of WSN facility such as extensibility, flexibility and deployment for facilitating early fire detection. In Molina-Pico et al. (2016), a hierarchical WSN technology was used for identification of forest fires. The proposed WSN system could be deployed easily at regions of special risk. In Jadhav and Deshmukh (2012), WSN system was exploited for monitoring the forest fire. This system detected temperature, smoke and humidity using WSN for preventing forest fires which could result in loss of numerous natural resources. This system served as a promising tool in informing and alerting the concerned authorities in-advance regarding the forest fires.

3 Merits and demerits of IOT and WSN

With tremendous advances in technology, numerous applications based on IoT and WSN technologies have been developed. Each of these technologies have their own strengths and weaknesses which encourage/discourage their application in different domains.

3.1 Merits of IoT

The crucial merits of IoT include:

- *Real-time monitoring*: IoT is an interlinked network comprising multiple devices which facilitate real-time monitoring. The features embedded in diverse IoT components aid in performing real-time monitoring as per application's requirements.
- *Automation and control*: Owing to the centrally and digitally controlled and connected physical objects with wireless infrastructure, IoT offers a vast amount of automation and control in real-life settings. Without human interference, the machines or devices in IoT are able to interact with one another leading to timely and faster output.
- *Effective communication*: IoT promotes the communication between multiple devices, also termed as machine-to-machine (M2M) communication. Due to this feature, the devices are able to stay connected and thus the transparency is available with greater quality and lesser inefficiencies.
- *Cost and energy saving*: IoT basically proves to be highly useful for people/individuals in their regular routines, as the appliances involved in daily activities are made to communicate with one another in an appropriate way, thus conserving and saving cost and energy. Through adopting IoT technology and maintaining the devices under surveillance, energy and resources can be optimally utilised. Moreover, alerts can be provided in conditions of possible damages, bottlenecks and breakdowns to the system thus saving costs.
- *Better efficiency and time saving*: In IoT, the M2M interaction offers better efficiency. The improved monitoring devices employed in IoT networks aid in achieving accurate results rapidly thereby leading to valuable time saving.
- *Better living standard*: IoT technology helps in improving convenience, comfort and makes life simple thus resulting in better quality of life.

3.2 Demerits of IoT

The crucial demerits of IoT include:

- *Compatibility*: In IoT, interconnection of diverse devices from distinct manufacturers might lead to severe compatibility problems. These issues could be settled through following same standards by all manufacturers or designers.
- *Complexity*: IoT systems are complex in nature. As IoT networks comprise numerous components and gadgets, failure of power supply or hardware, software might result in complete disaster.
- *Privacy and security problems*: As information transfer or communication of devices occur over the network, IoT gadgets are easily susceptible to adversaries. As devices are interlinked, any information leakage from a single device might cause severe privacy problems.
- *Technology is ruling the life*: As IoT is enhancing the comfort zone, people's dependence on IoT devices is growing day by day which can ultimately lead to a condition where the human life will be completely controlled by technology.

3.3 Merits of WSN

The significant merits of WSN include:

- *Compatibility*: WSNs are generally compatible with new plug-ins and external devices. This feature has increased their functionality and usage areas.
- *No necessity of sophisticated infrastructure*: As WSNs utilise wireless communication rather than hard wiring, WSNs do not require any sophisticated infrastructure.
- *Portability and cost-effectiveness*: Owing to their wireless characteristics, WSN devices are portable and cheaper.
- *Energy saving*: These devices utilise less energy as they are designed to enter into sleep mode when not used for conserving energy.
- *Wide deployability*: WSNs can be extensively deployed. These networks can be employed for communicating over non-reachable regions like mountains, underwaters, deep forests, islands, etc.
- *Easily scalable*: The general architecture of WSNs makes them easily scalable. WSNs allow additional sensor nodes to be configured for communicating on the same network without modifying or changing the existing sensors during adding the new ones.

3.4 Demerits of WSN

The significant demerits of WSN include:

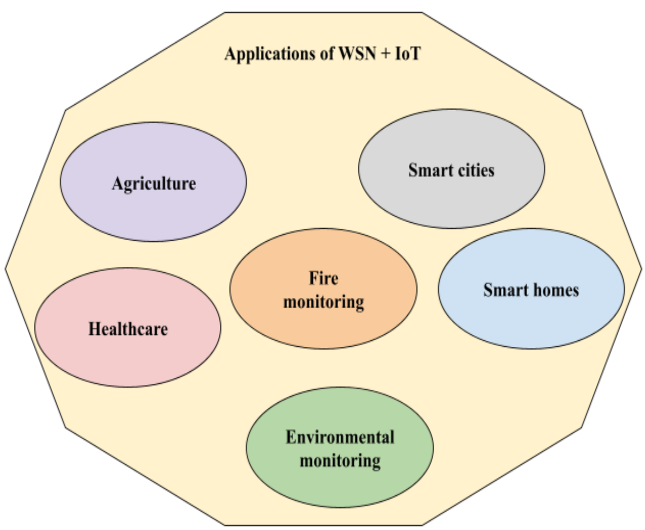
- *Security and privacy issues*: WSNs usually experience security and privacy problems. As WSNs possess constrained power resources, they are devised to utilise less operating energy. However, less energy consumption could lead to avoidance of taking necessary security precautions. In WSNs, certain security leaks occur owing to energy conserving policies. Due to this, WSNs could be prone to malicious attacks.

- *Costly*: The cost of certain sensors implemented in WSNs are extremely high. As numerous sensor nodes are deployed for communication and interaction in these networks, their maintenance and installation expenses are high.
- *More energy/power consumption and maintenance issues*: The sensor nodes in WSNs consume more power for sensing, information processing and communicating. These nodes utilise more energy for communicating the information when compared to other processes. Moreover, sensor nodes are generally battery powered and need maintenance efforts for recharging and replacing the system frequently.
- *Vast data quantity*: Due to utilisation of multiple components in WSNs, data produced is of a vast quantity. Therefore handling such vast data quantities is a very tedious job.

4 Integration of WSN with IoT

The WSN and IoT technologies have provided several benefits in monitoring, detection, and other operations. However, they do suffer certain limitations due to their design structure, maintenance, cost, and other aspects when used alone. Because of this many applications have come up with the idea of integrating both these technologies in a single platform for achieving more productive results. In this section, the applications exploiting both IoT and WSN technologies are reviewed. The flowchart for the applications of WSN with IoT is shown in Figure 5.

Figure 5 Applications of WSN with IoT (see online version for colours)



4.1 Agriculture

In Haseeb et al. (2020), a IoT-based WSN framework was exploited for smart agriculture application. The information related to moisture level, temperature, water level and humidity was captured using IoT-based sensors. This information was transmitted securely to cluster heads which served as storage sources or memory buffers. The system provided up to date data to users within minimum time for effective decision making. Moreover, it offered a reliable and energy-efficient routing for automating farm productions with reduced burden on farmers. In Codeluppi et al. (2020), an integrated WSN-IoT framework was employed for smart farming application. The environmental information regarding the growth of agricultural products was sensed using WSN technology and gathered information was analysed and investigated using the IoT platform. This framework provided an effective method for monitoring the farm parameters and increasing the yield with reduced manual efforts.

4.2 Healthcare

In Onasanya and Elshakankiri (2019), WSN was integrated with IoT technology for healthcare application. This WSN-IoT system exploited cloud services/business analytics for actionable insights, information transmission, decision making and reporting. The healthcare solution was accomplished through the utilisation of smart connected gadgets and WSNs. In Li et al. (2020), integrated WSN-IoT mechanism was exploited for health monitoring application. Using sensors embedded in wearable devices, the respiratory frequency, movement cadence and heart rate were monitored. The gathered sensor data was uploaded to the IoT system and authorised people were allowed to access the information via the internet for tracking the health status. This proposed WSN-IoT system displayed high accuracy in forecasting abnormal health conditions. In Adame et al. (2018), a WSN-IoT hybrid monitoring system was employed for smart healthcare. This hybrid system integrated WSN and RFID in a single platform providing the status, location and tracking of patients. It was capable of activating alarms from temperature, movement and the pulse of the patient and determining the patient’s location with greater accuracy.

4.3 Smart cities and smart homes

In Abdulkader et al. (2018), an integrated WSN-IoT system was exploited for smart parking application. The cybersecurity problems in IoT were addressed through adopting a cryptographic method which satisfied the device requirements with regard to energy consumption and cost. This system provided real-time data for identifying parking lots and reservation, parking management optimisation and e-payment solutions for alleviating traffic congestion. In Pirbhulal et al. (2017), a WSN-IoT integrated technology was employed for smart home automation. The proposed WSN-IoT (Jaladi et al., 2017) system was effective, reliable and highly efficient.

4.4 Environmental monitoring and fire monitoring

In Simitha and Raj (2019), WSN and IoT technologies were integrated for monitoring the water quality. This system provided the water authorities with real-time water quality information for conserving and managing the water bodies more effectively. The sensor values were transmitted and received through a wireless LoRa module and the uploaded water quality data was visualised and examined using IoT platform. It provided a long range, low cost, low power and scalable method for monitoring the water quality. In Brito et al. (2020), WSN-IoT system was exploited for fire ignition detection. Using wireless sensors, the temperature, barometric pressure, humidity and flame ignition in the target area were sensed and this sensor data was uploaded to the IoT network for visualisation and examination of received data for detecting fire ignition. In Roque and Padilla (2020), WSN (Shende and Swami, 2017) and IoT (DipaliShende et al., 2018) technologies were integrated together for detecting fire in outdoor scenarios. The real-time estimation of gases and temperature was executed via wireless sensors and the analysis of gathered sensor information was conducted using IoT devices. This system was scalable and suitable for detecting fires in unpredictable weather conditions.

5 Comparative analysis

In this section, the reviewed IoT, WSN, WSN + IoT applications are compared with respect to common performance metrics, technologies employed, publication years, and results as shown in Table 1.

Table 1 Comparison of IoT and WSN applications

References	*Publication year*	*Technologies*	*Application*	*Performance metrics*	*Results*
Lavanya et al. (2020)	2020	IoT	Smart agriculture	Delay, throughput, jitter, Energy consumption	Efficient and Fast
Ke et al. (2020)	2020	IoT	Smart parking	Detection accuracy	Achieved higher detection rate
Rahman et al. (2020)	2020	IoT	Smart lighting	Energy consumption, Delay	Facilitated automated switching on/off the lights
Li et al. (2015)	2015	IoT	Vehicle monitoring	Detection accuracy	Offered better detection accuracy
Paul et al. (2018)	2018	IoT	Health monitoring	Latency, energy consumption	Easily detection the health condition
Yuen et al. (2018)	2018	IoT	Smart home	Detection accuracy	Provided simple access for disabled and elderly people
Mano et al. (2016)	2016	IoT	Smart home, health monitoring	Detection accuracy	Provided an in-home health monitoring system for elderly people and patients
Mudaliar and Sivakumar (2020)	2020	IoT	Energy monitoring	Energy consumption	Detected the everyday energy pattern of the industry effectively
Balid et al. (2016)	2016	WSN	Traffic monitoring	Detection accuracy	Provided higher detection accuracy

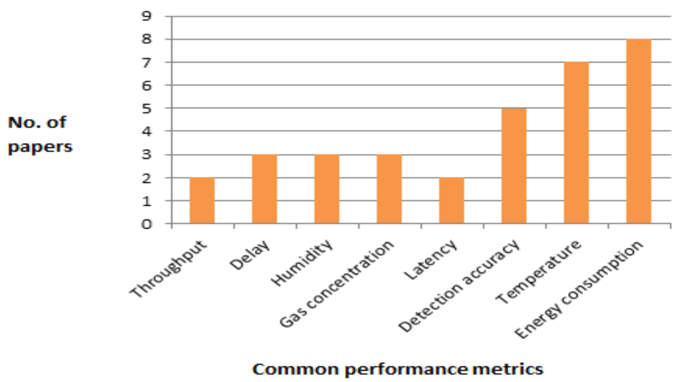
Table 1 Comparison of IoT and WSN applications (continued)

References	*Publication year*	*Technologies*	*Application*	*Performance metrics*	*Results*
Yang and Li (2010)	2010	WSN	Environmental monitoring	Delay	Effectively performed environmental monitoring
Yu et al. (2013)	2013	WSN	Air quality monitoring	Energy consumption, network lifetime, dissemination time	Improved transmission speed and reduced power consumption
Pavani and Rao (2016)	2016	WSN	Pollution monitoring	Gas concentration, temperature	Effectively determined air pollution under distinct timings and conditions
Kadri et al. (2013)	2013	WSN	Pollution monitoring	Gas concentration	Performed air pollution monitoring in real-time
Jadhav and Deshmukh (2012)	2012	WSN	Forestfire detection	Temperature, humidity	Detected wildfire rapidly and easily
Haseeb et al. (2020)	2020	WSN, IoT	Smart agriculture	Throughput, latency, energy consumption	Reduced energy consumption and provided better throughput
Codeluppi et al. (2020)	2020	WSN, IoT	Smart farming	Humidity, temperature	Monitored farming conditions precisely and speedily
Adame et al. (2018)	2018	WSN, IoT	Smart healthcare	Energy consumption	Provided fast and precise results
Pirbhulal et al. (2017)	2017	WSN, IoT	Smart home	Temperature, energy consumption	Provided better data security, network security and lowered energy consumption
Simitha and Raj (2019)	2020	WSN, IoT	Water quality monitoring	Temperature, turbidity, pH, dissolved oxygen	Efficiently monitored the water quality
Brito et al. (2020)	2020	WSN, IoT	Ignition detection	Temperature, humidity	Provided rapid and precise results
Roque and Padilla (2020)	2020	WSN, IoT	Wildfire detection	Temperature, gas concentration	Detected wildfires accurately and speedily

5.1 Results and discussion

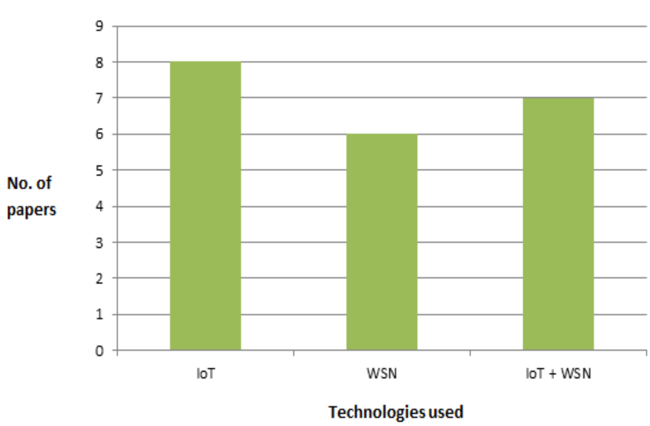
Among diverse performance metrics in Table 1 that are employed by existing studies, the common ones are found to be throughput, delay, humidity, latency, detection accuracy, temperature, energy consumption, and gas concentration as depicted in Figure 6. These performance metrics show that the throughput and latency are used only for two papers and the performance metrics like delay, humidity, and gas concentration are used in four papers and the detection accuracy employed in five papers and the temperature used in seven papers and the energy consumption is used in eight papers. For the performance analysis, energy consumption is employed for most of the existing applications.

Figure 6 Analysis of common performance metrics (see online version for colours)



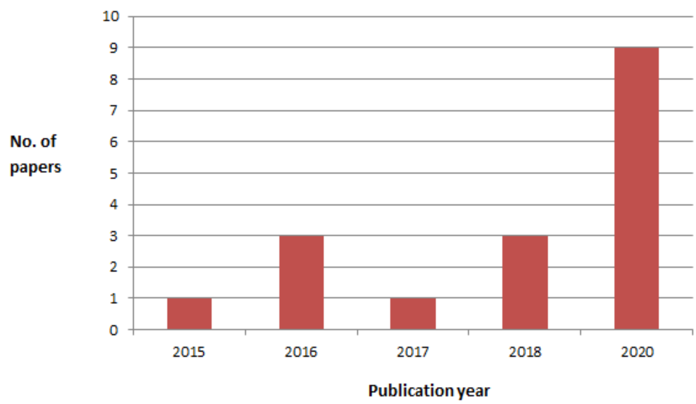
Comparison of different technologies in Table 1 such as IoT, WSN and WSN with IoT (IoT + WSN) that are exploited in diverse applications are depicted in Figure 7. It shows that the IoT is used for the eight papers and the IoT + WSN is used for the seven papers and also the WSN can be utilised for the seven papers. From the given analysis, IoT is used for most of the existing applications and the WSN is utilised for only a few existing applications. IoT and IoT + WSN technologies are exploited in several existing applications.

Figure 7 Technologies employed for various applications (see online version for colours)



Comparison of IoT, WSN and IoT + WSN applications in Table 1 based on publication year-wise analysis are depicted in Figure 8. Among the recent publications (i.e., from 2015 to 2020) considered in Table 1, it is found that these technologies are largely exploited in papers published in the year 2020. From the analysis based on publication year, it shows that most of the papers are reviewed in the year 2020 and also only a few of papers taken in recent years.

Figure 8 Analysis of studies based on publication year (see online version for colours)



6 Conclusion

This review paper presented the scope of IoT and WSN technologies. It discussed the diverse applications of IoT and WSN in agriculture, healthcare, transportation and automation. It presented the merits and limitations of IoT and WSN technologies. This paper reviewed the integration of WSN with IoT technologies for distinct applications. The integration of WSN with IoT has shown more promising and improved outcomes than the exploitation of only IoT or only WSN technology. As each of this technology experiences challenges in terms of cost, design architecture, deployment, maintenance, and resource constraints, they are inefficient in delivering the anticipated results. Therefore, instead of standalone exploitation of these frameworks, hybridising the two technologies in a single platform would support in achieving more productive, desired, and rapid outcomes for performing the diverse tasks in heterogeneous domains.

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