# The Role of Machine Learning in Advancing IoT and WSNs

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**Abstract.** Artificial intelligence (AI) and machine learning (ML) approaches can effectively manage the automated operations of IoT nodes in intelligent cities. Key IoT applications in smart cities include intellectual buildings, waste management, traffic monitoring, and healthcare. However, the design of WSN-based IoT (WSN-IoT) faces several challenges, including Web range and connectivity problems, power consumption, bandwidth requirements, maximizing network lifetime, transmission protocols, and advanced infrastructure development. One of the most significant challenges for wireless sensor networks (WSNs) is extending their lifespan. Over the past few years, considerable research has been focused on improving network longevity and quality of service (QoS). A WSN's sensor nodes are independent, distributed devices that use wireless connections to collect and route data to a central hub, also known as a "Base Station," without the need for a central supervisor. These networks' range and battery life are constrained by their lower processor, memory, power supply, and other capabilities. To overcome such situations, machine learning (ML) methods can be applied to react correctly. The practice of functioning without human intervention or reprogramming to learn from experiences is known as machine learning. The proliferation of Internet of Things (IoT) based Wireless Sensor Networks (WSNs) has triggered a paradigm shift in the business, necessitating the use of dependable and efficient routing techniques. Preliminaries in Machine Learning for WSN-IoT, IOT protocols, and several ML-based methods are reviewed in this study.

**Keywords:**IoT, WSN-IoT,Sensor nodes,AI, Routing,ML, Unsupervised learning, Reinforcement learning, Supervised learning, smart city.

## 1 Introduction of Machine Learning

Enabling computers to "learn" without explicit programming is the general goal of the computer science field of machine learning [1]. It was first introduced in the 1950s artificial intelligence movement and focusses on useful goals and uses, especially optimisation and prediction. By gaining "experience" on tasks, computers "learn" machine learning [2]. The line between machine learning and statistical methods is blurred because in reality, "experience" typically refers to fitting to data [3]. Individuals have employed an expansive assortment of devices to complete different jobs more easily since the beginning of time. Various machines were created as a result of the human brain's inventiveness. By allowing individuals to meet a combination of prerequisites, such as computing, travel, and industry, these machines made life easier

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for humans. One of these is machine learning [4].The require for ML is growing asthe big numbers of datasets that are available.

The main objective of machine learning (ML), a subfield of computer science, is to allow computers to "learn" without explicit programming [5]. Machine-learning is utilized in numerous industries to recover pertinent data. Knowing from the data is the purpose of machine-learning. The subject of multiple studies has been on how to teach robots to learn without explicit programming. Multiple mathematicians and programmers utilize a combination of methods to solve this problem, which involves large data sets.Various algorithms are used in machine learning to address data issues. By determining causal correlations from observational data and obtaining fresh scientific insights, machine learning (ML) advances scientific knowledge in the natural sciences [6]. Machine learning is capable of processing and analysing scientific data from observations, experiments, and other sources in the humanities. ML is now a vital tool in a number of industries, including healthcare, banking, transportation, and more, thanks to its capacity to learn from and get better with experience [7-8]. Fundamentally, machine learning (ML) is the method by which computer systems operate statistical models and algorithms to find patterns in data and arrive at well-informed conclusions or forecasts.

The major contribution of this work lies in exploring how MLmodels can optimize the performance of IoT and wireless sensor networks. It highlights advancements in real-time data processing, energy efficiency, security, and scalability, showcasing the potential of ML to enhance the functionality and reliability of these networks.

## 1.1 Applications of Machine Learning

The use of statistical models and algorithms to allow computers to carry out certain activities without direct suggestion is known as machine-learning. Rather, these algorithms get better over time by learning from data. Applications of machine-learning displayed in Fig.1 ML algorithms in IoT enable real-time data analysis, energy optimization, predictive maintenance, and security enhancement. ML is widely applied across different domains. In social media, it personalizes user experiences, recommends content, and analyzes interactions. Face recognition enhances security in mobile devices and social platforms, while speech recognition powers virtual assistants and voice-activated devices. Navigation benefits from traffic prediction and optimal route suggestions. Spam filters identify and block unwanted messages, and fraud detection prevents financial fraud by analyzing anomalies.

Stock and weather forecasting rely on historical data for predictions. In healthcare, machine learning aids in disease diagnosis, treatment personalization, and patient data management. Chatbots and virtual assistants provide automated support, and autopilot cars use sensor data for self-driving decisions. Additionally, product suggestions are refined based on user preferences and past behavior.

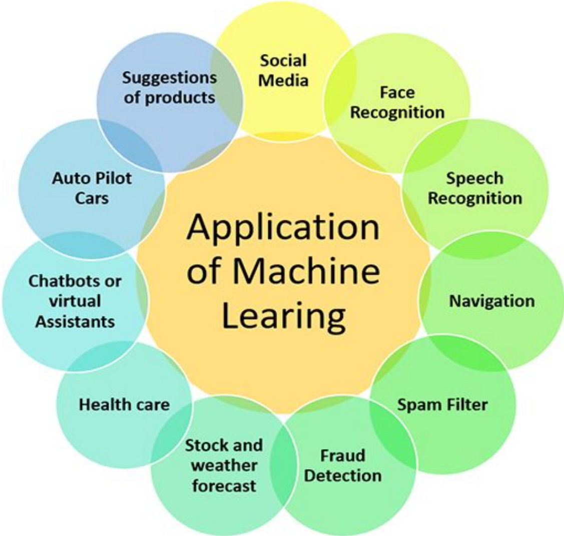



**Fig.1.** Applications of Machine-Learning

## 1.2 Types of Machine Learning

Three popularML learning modelssupervised, unsupervised, and reinforcement learningare each helpful for addressing distinct problems. Fig. 2 shows the different Machine learning types include supervised, unsupervised, reinforcement,semi-supervised, and deep learning for varied tasks.
Here, Supervised learning uses labeled data, unsupervised identifies patterns in unlabeled data, semi-supervised combines both, & reinforcement learning involves learning through rewards and consequences for actions.

### Supervised Learning

In supervised machine learning, a model is trained to map input data to output utilizing example input-output pairs. This process relies on labelled training data, which contains of a set of training samples. Supervised learning algorithms require external guidance, with the input data split into training testing sets. The models usethe training data to predict or classify the output variable, and then identifies patterns to apply to the test dataset for forecast/classification. Fig. 3 illustrates the workflow of supervised machine learning algorithms. Here, we discuss the most widely used supervised learning techniques.

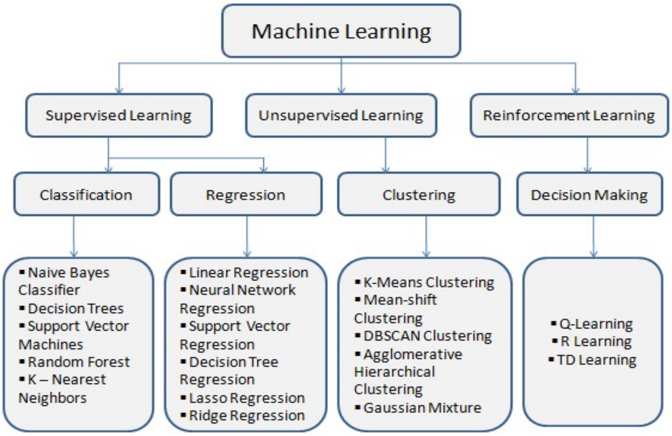



**Fig2.** Types of Machine Learning

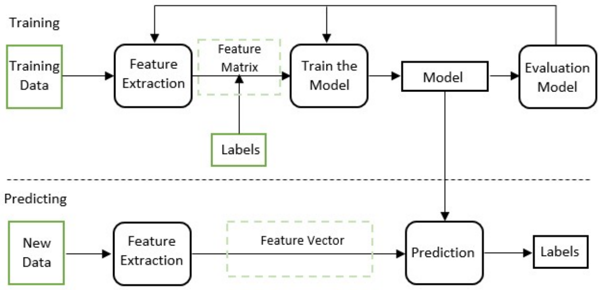



**Fig.3:** workflow of supervised Learning

After identifying training dataset type, the labelled training data is gathered. The dataset is categorised or divided into three groups: training, testing, and validation. After choosing an appropriate algorithm for the technique, it is applied to the training dataset, and the correctness of the model is assessed by providing the test set. If it forecasts the right result, the model is deemed accurate.

## Decision Tree

A decision tree is a graphical representation that options and their results as a tree. The graph's edges denote the judgment rules or needs, while the nodes in the diagram stand for an affair or choice. Each tree has branches and nodes. Each branch represents a importance that the node may accept, and each node indicates characteristics in a group that need to be categorised.

## Support Vector Machine

SVM are a popular and advanced ML technique. As a supervised learning model, SVM applies related methods to process data for both regression and classification tasks. A key feature of SVM is the "kernel trick," which enables it to achieve non-linear category by mapping information into higher-dimensional areas. This technique allows SVM to separate data points by drawing hyperplanes that divide different classes. The goal is to maximize the margin between the classes, reducing classification errors and improving model accuracy.

**Navie Bayes**

Is the classification method predicated on independence of predictors and based on the Bayes Theorem. To place it just, a NB classifier constructs the premise that a component's presence if a class have nothing to do with the existence of any other features. The text categorisation industry is the primary aim of Naïve Bayes. It is mostly used for classification & clustering, depending on the conditional likelihood of occurrence.

$$P\,(c/x) = \frac{P(x/c)P(c)}{P(x)} \quad (1)$$

Here, $P = (x/c)$ is Probability,$P(c)$ is the class Previous Possibility, $P\,(c/x)$ is the Posterior chances&$P(x)$ is Predictor Prior Probability.

**Unsupervised Learning**

In Unsupervised Learning (UL), unlabelled datasets are analysed and clustered using CML methods. Without human assistance, they are able to uncover hidden patterns/ data clusters. UL has been used in practical applications such as Suggestion machines, abnormality detection, and medical imaging, to mention an in-frequent. Fig.4 represents the workflow diagram of Unsupervised learning involves data clustering, pattern detection, dimensionality reduction, and model evaluation without labeled data.

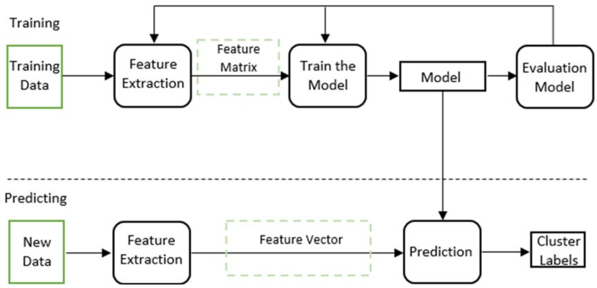



**Fig. 4:**Workflow of unsupervised Learning

The standard procedure for unsupervised learning, which includes dimensionality reduction or clustering, is depicted in this workflow diagram. Training and Predicting are the two primary stages of the diagram. For projects where the objective is to uncover hidden patterns or groupings in data without established labels, this method is crucial.

**Reinforcement Learning**

RL is a branch of ML that examines how the software agents should act in a certain atmosphere in order to maximizes the concept of cumulative reward. Reinforcement learning is one of the three core machine learning paradigms, along with supervised and unsupervised learning.Through trial & error, reinforcement learning teaches systems to become proficient at a task over time [9]. By receiving +ve or -ve feedback based on how well a task is performed on data (whether it be classification, prediction, or another activity), reinforcement learning methodsemploy an iterative learning method. The learner then self-adapts& tries the tasksimilarly on recent data, though previous data may be encountered again. This method can be semi supervised (as in generative adversarial neural networks) or similar to supervised learning, depending on how it is applied.

## 2 Introduction of Internet of Things (IoT)

The terminologyIoT depicts a destiny where commonplace objects linked through the Internet can swap data. These items might be anything from refrigerators to watches. The idea behind the Internet of Things is that these gadgets may be remotely controlled and observed by connecting them to the internet. People could, for example, use their phones to control the temperature of their refrigerators or turn on the lights in their homes [10].The IoT is becoming more and more popular very quickly. Various businesses are producing goods that use IoT technologies. There are many potential benefits for IoT. Among the multiple common uses of the Internet of Things are home automation, healthcare, and city administration.

For example, since more people want to operate their houses from a distance, home automation is becoming more and more popular [11]. In actualityIoT is based on the internet and WSN, but with significant enhancements. A network of physical things, including cars, household appliances, &the other items, that implanted by using sensors, software, & electronics and have internet connectivity and the ability to interact with one another is known as the IoT. In contrast to WSN, IoT is utilised for control as well as monitoring and data collecting.

### 2.1 Study of IoT Protocols

Application protocols and communication protocols are the two categories of Internet of Things protocols. Communication protocols control device connections and communication. These protocols can be built on top of a variety of technologies, including as Wi-Fi, Zigbee, Bluetooth, & LoRa. Each protocol has pros and cons of its own, and the best one for a given application will depend on the specific requirements [12].

Wi-Fi widely utilized web access protocols that may be applied to Internet of Things applications. It has better range of data throughput, & devices and infrastructure widely support it. However, it could be power-hungry and not ideal for apps requiring very-low data rates either battery life is long.

## 2.2 Comparison Criteria

IoT technologies vary in range, data rate, power consumption, and application suitability. Short-range options like Bluetooth (up to 100m, low power) are ideal for wearables and personal devices, while BLE (Bluetooth Low Energy) supports fitness and health devices. Zigbee and Z-Wave offer similar ranges (10–100m) and low power for smart homes and industrial applications. For larger areas, Wi-Fi supplies high data rates but destroys more additional power, fitting high-data IoT like video streaming.

Long-range technologies like LoRaWAN (up to 15km) and NB-IoT (up to 10km) operate at low power, making them suitable for rural or low-data IoT like asset tracking and environmental monitoring. Sigfox, also low power, supports basic communication over long distances (up to 50km). Cellular networks (3G, 4G, 5G) offer the highest speeds and longest ranges (up to 35km for 5G), fitting high-speed IoT in smart cities and autonomous driving.

**Table 1.**depicts the comparison of various IoT network technologies based on key criteria such as range, power consumption, frequency,data rate, and typical applications.

**Table 1.** Various technologies used in IoT networks

| Technology | Range (approx.) | Data Rate | Power Cosumption | Frequency | Typical Applications |
|---|---|---|---|---|---|
| **LAN(Local Area-Network)** | Up to 100 meters | Up to 1 Gbps | Moderate | 2.4GHz/5 GHz | Home automation smart office |
| **PAN (Personal Area Network)** | 1–10 meters | Varies (few Mbps) | Low | Various(e.g.,2.4 GHzfor Bluetooth) | Wearables, home devices |
| **Bluetooth** | Up to 100 meters | Up to 3 Mbps | Low | 2.4 GHz | Audiostreaming, wearable devices |
| **Bluetooth Low Energy (BLE)** | Up to 50 meters | Up to 2 Mbps | Very low | 2.4 GHz | Fitness trackers, health devices |

| | | | | | |
|---|---|---|---|---|---|
| **Zigbee** | 10–100 meters | 250 kbps | Very low | 2.4 GHz, 868 MHz | Smart home, industrial IoT |
| **Z-Wave** | 30–100 meters indoors | 100 kbps | Very low | 908.4 MHz (US) | Home automation, security systems |
| **Wi-Fi** | 100–200 meters | Up-to 10 Gbps (Wi-fi-6) | High | 2.4 GHz / 5 GHz | High-dataIoT, video streaming home. |
| **LoRaWAN** | 2–15 km | 0.3–50 kbps | Low | Sub-GHz (e.g.,868 MHz,915 MHz) | Rural IOT asset tracking |
| **NB-IoT (Narrowband IoT)** | Up to 10 km | Up to 250 kbps | Low | Licensed LTE bands | Smart cities, environmental monitoring |
| **Sigfox** | 10–50(km) (rural) | 100 bps | Very low | 868 MHz / 902 MHz | Smart metering, low-data sensors |
| **Cellular (3G, 4G, 5G)** | Up to 35 km (5G urban) | Up to 10 Gbps (5G) | High | Various cellular bands | High-speed IoT, smart cities, autonomous driving |

## 2.3 Security of Internet of Things

The security of IoTgadgets has grown to be a significant concern in the 21$^{st}$century. IoT connects the world and makes everything more interconnected, but it also makes it easier for many types of attacks to target individuals. The term "Internet of Things" may be short, but it refers to all of the smart technologies & services those are available on the globe. The term "IoT" was first used by Kevin Ashton in his 1999 research presentation [13]. Since then, a range of smart devices and associated services via different communication protocols have been used to connect the real and virtual worlds through the Internet of Things. What was simply a dream twenty-five years ago is currently a fact because of the Internet of Things. The anticipated proportion of IoT device users by 2020 is displayed in Fig. 5 [14]. The IoT market is expected to be worth between 3.9 and 11.1 trillion USD by 2025 [15].

Nowadays, people cannot think for even a moment without using IoT gadgets and benefits. According to the survey, by 2020, around 50 billion objects will have internet connections, which will grow rapidly. Figure.6displays the projected % of the IoT devices, users by 2020. In 2025, the IoT market is predicted to reach a value of between 3.9 and 11.1 trillion USD. The no. of connected IoT gadgets, the present global market for IoT approach, and industry predictions through 2025 are displayed.

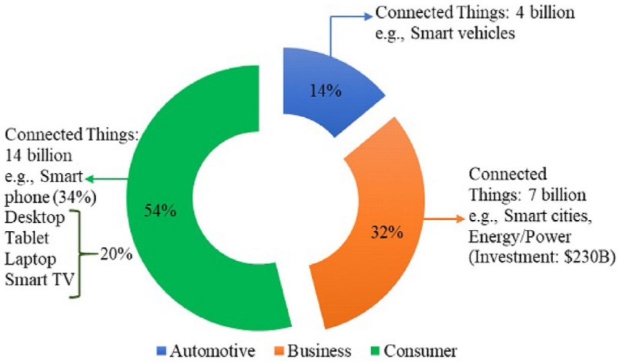



**Fig 5.** IoT device users by 2020

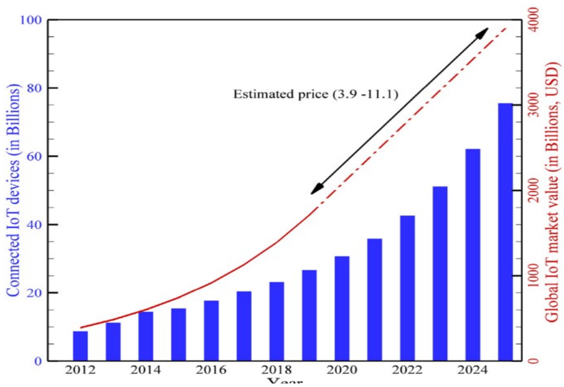



**Fig.6:** Graphical representation of total interconnected IoT gadgets and global IoT demand so far and forthcoming forecast

The IoT is at the core of the smart technology that permeates the advanced world of today. These days, people can't even function without utilizing IoT gadgets and benefits. An estimated 50 billion objects will have internet connections by 2020, and this figure is expected to increase quickly over time [16].

## 2.4 Applications of Internet of Things

IoT applications can be small-scale (like house automation) or large-scale (like cloud based industrial applications). When developing a particular application, the following design constraints need to be properly managed in order to strike a balance between cost and efficiency [17]. IoT has a lot of potential to affect adaptation in the social, environmental, and economic spheres. Among the IoT-based concepts are mobility, smart grid, smart homes and buildings, industry processing, agriculture and breeding, medical and healthcare, public safety and environmental monitoring, and independent living. We are somehow connected to each of these applications. Nowadays, there is a great reliance on these applications' existence, and their use and dramatic benefits are crucial. They are now of utmost importance and their existence and usability have reached a visionary level in recent years [18]. Figure.7 shows a variety ofIoT applications contains smart houses, healthcare monitoring, agriculture, industrial automation, transportation, and environmental monitoring.

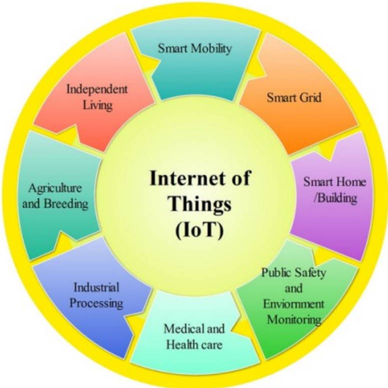



**Fig.7:** Various IoT application

Smart technologies are transforming various sectors. Smart mobility enhances transportation with VANETs and the Internet of Vehicles (IoV) to improve road safety and efficiency. Smart grids use digital communication for real-time electricity management. Smart homes/buildings enable remote control of devices via the Internet. Public safety and environment monitoring utilize sensors to track weather, water quality, and endangered species. Medical and healthcare integrate IoMT for seamless machine-to-machine communication. Industrial processing leverages IoT for optimized operations. Agriculture and breeding adopt Climate-Smart Agriculture (CSA) with smart devices for better farming practices. Independent living supports seniors with technology for a safer and more autonomous lifestyle.

# 3 Wireless Sensor Networks (WSNs)

A WSNs organization of independent sensors that may screen physical/ecological circumstances like temperature & send their information to a focal area. Remote sensor networks are made out of hubs, which are much of the time battery-worked, independent, and independent with sensors, the radio handset, & an installed signal-handling unit. The constant sensors will quickly detect, record, & send criticism to the end client for additional handling of the acquired data. The outside climate can be associated with the PC framework by means of sensors, actuators, and information yield gadgets. Remote sensor networks that empower the organization limited postpone ensure, which is fundamental for the start to finish parcel conveyance, are named as constant WSN [19].

WSN has various sensors which are conveyed through sending information starting with one sensor then onto the next sensor in a wide region by means of parcels. WSN is pervasively utilized in different fields, for example, military observation, the medical care industry, and different ventures.

Today, in all aspects of life, the sensor is utilized to identify the sound, distinguish any pulsations, prevent the moisture level, and recognize the temperature status; in shrewd homes, in advanced mobile phones, and in particular, we utilize some sensors in the human body. A sensor hub comprises a microcontroller, handset, outside memory, power source, and at least one sensor. WSN comprises sensor hubs, a client, and an interconnected spine. Fig. 8 presents the WSN Organization design comprising sensor hubs, which are utilized in natural observing.With regards to remote correspondence, the sensor hubs speak with one another and send the handled information to the sink hub. Every one of the hubs send information to the sink hub, which is additionally shipped off clients through the web [20].

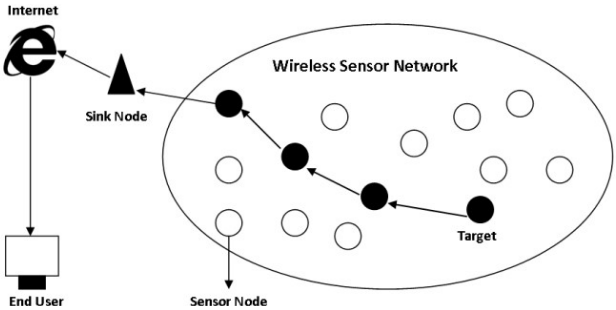



**Fig.8:** WSNs System Architecture

Recent years have seen numerous developments in WSN due to advancements in the sensor area, including as embedded systems, MicroElectroMechanical Systems (MEMS) another isWireless communication, & dispersed processing. Large amounts of data, such as those from an intelligent system can obtain and process traffic control, weather monitoring, and air quality control. The real-time environmental monitoring applications of WSN will be covered in this study. These systems have effectively replaced human labour and may be able to meet functional needs.

## 3.1 Applications of WSN

Applications for WSNs are numerous and span a variety of industries, including retail, industrial control, entertainment, transportation, smart cities, healthcare, security, and the military. Spatial sensors that gather and send data for analysis and decision-making make up these networks. WSNs contribute to technical improvements and an enhanced quality of life by improving efficiency, safety, and convenience in a variety of industries. Different applications of WSN shown in Fig. 9. WSN applications include environmental monitoring, smart cities, agriculture, healthcare, military, and industrial automation systems.

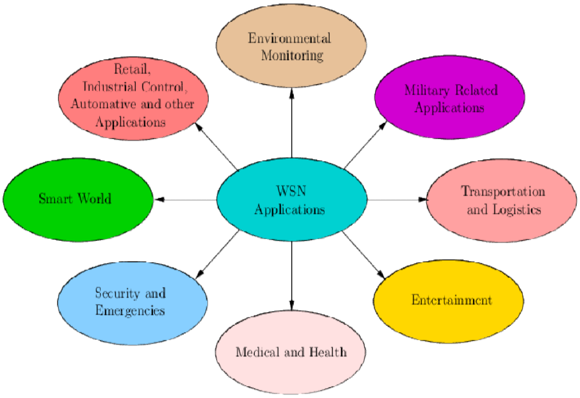



**Fig 9.** Applications of WSN

Wireless Sensor Networks (WSNs) have diverse applications through multiple sectors. Environmental monitoring uses sensors to track pollution, temperature, and natural disasters, aiding climate studies and policy-making. In military applications, WSNs enhance battlefield surveillance, base security, and intelligence gathering. Transportation and logistics benefit from real-time traffic monitoring, shipment tracking, and optimized supply chains. Entertainment applications include VR, AR, and interactive experiences. In medical and health, wearable sensors enable remote patient monitoring and telemedicine. Security and emergencies use WSNs for surveillance and hazard detection. The smart world relies on WSNs for automation in cities, homes, and industries. In retail, industrial control, and automotive sectors, WSNs improve supply chains, production safety, and vehicle diagnostics, enhancing efficiency and reducing costs.

### 3.2 Wireless Sensor Networks BasedInternet of Things (WSN-IoT)

Remote servers, laptops,user phones, phone towers, etc. are all directly connected to the IoT cloud. The tasks related to ML and IoT demand a significant amount of memory and data processing. As the result, the Internet of Things cloud server is constructed as a powerful computer with anenormous amount of storage. Nevertheless,the WSNends node have limited processing capacity, little storage, and the limited nonrechargeablebattery energy source.The IEEE 802.15.4-based WSN-IoT end nodes can only send data at a maximum speed of 250 kbps. Two AA-size batteries like (1.5 volts& 1000 mAh) power the end nodes in WSN-IoT, while the gateway is connected to the main energy source.

Additionally, machine learning methods can be used to forecast the future energy availability in IoT-WSNs if the WSN-IoT nodes are powered by renewable energy collecting power supply [21]. The maximum power point technique (MPPT) algorithms in the battery management system can be tracked using machine learning approaches [22].

Machine Learning techniques used from the cloud to enable independent process at the WSN-IoT node apparatus level. The cloud server receives the sensor/detector data from the IoT device. Information transmission network protocols of an upper, more elevated class are shown individually in Table 2. High-level transmission protocols in WSN-IoT include MQTT, CoAP, XMPP, and HTTP, ensuring efficient data transmission and network management.

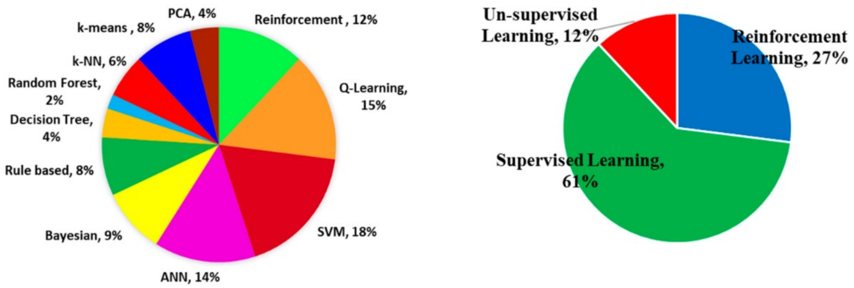
**Table.2:** High-level transmission protocols in WSN-IoT

| S. No. | Transmission Protocols | IEEE Standard | Remarks |
|---|---|---|---|
| **1.** | MQTT [23] | IEEE P1451-99 [27] | Functions with TCP for Data Security and Load Balancing |
| **2.** | AMQP [24] | IEEE P1451-99 [27] | Functions with TCP for Smart Electronics Gadgets and QoS |
| **3.** | CoAP [25] | IEEE P1451-99 [27] | For Cloud Services |
| **4.** | DDS[26] | IEEE P1451-99 [27] | Works with UDP for Data Delivery, Machine to Machine Communication |
| **5.** | STI [28] | IEEE P21451 [29] | Sensor Connectivity, interoperable communication |

Message query telemetry transport (MQTT) protocol [23], advanced message queuing protocol (AMQP) [24], constrained application protocol (CoAP) [25], and data distribution service (DDS) protocol [26] are a few of the most widely used higher-level IoT protocols. The IEEE P1451-99 [27] standard for harmonising internet of things (IoT) systems and devices serves as the foundation for these IoT protocols. Sensor management in WSN is accomplished by a smart transducer interface protocol [28]. The IEEE P21451 interoperability interface standard [29] serves as its foundation.

### 3.3 ML Techniques for WSN-IoT

An overview of all the machine-learning approaches put out an ideal remedy for WSN-IoT issues is given at the end of this section. We will now map each smart city issue with the MLapproacheswidely utilized in WSN-IoT that provide the answer. As a result, SVM techniques for classification or regression model are used to address the node localisation issues in WSN-IoT. In the field of machine-learning, packet routing in WSN-IoT is seen as a classification challenge. Routing optimisation algorithms like genetic algorithms and classification algorithms like Q-learning (QELAR) and random forest have been employed. Fig. 10 (a)Provides a concise and visually clear depiction of key ML algorithms applied in WSN-IoT and Fig. 10(b) offers a quick visual comparison of the dominance of RL, unsupervised, supervised learning approaches in the WSN-IoT domain.




(a) (b)

Fig 10. (a) Visual presentation of ML algorithms applied in WSN-IoT,
(b) Comparative graphical illustration of Unsupervised Learning, Supervised Learning, and Reinforcement Learning in WSN-IoT.

## 4 Conclusions and Future Work

This study explores the features and functionality of differentML algorithms in WSN-IoT, with a focus on smart city applications. Our analysis shows that supervised learning algorithms are the most commonly used 61%, followed by reinforcement learning is 27% and the unsupervised learning is12%. Machine learning's flexibility makes it ideal for diverse WSN-IoT applications. For example, the robust SVM method is effective for regression and classification tasks in WSN-IoT scenarios.IoT has the potential to transform the future and make the world more accessible. Because of the IoT's smart services, anyone can use the network to access, connect, and save that information from any location. Even if the Internet of Things empowers us by connecting our lives to the effective world through the smart gadgets to assemble living comfortable, easy, and seamless, security becomes a major worry in IoT systems to maintain their services. As a result, in order to improve security over time and as IoT becomes more widespread, new research in this area is needed, along with innovative solutions and interesting strategic plans for potential assaults in the years to come. This paper offers a thorough examination of ML methods. An increasingly sophisticated and potent algorithm that reduces the need for human involvement will eventually be developed.

Future research in this field could aim at refining machine learning techniques for real-time data analysis in IoT and WSNs, enhancing energy efficiency, and strengthening security. Furthermore, exploring the integration of edge computing, scalable network designs, and adaptive learning models for evolving environments will propel progress.

**Conflict of Interest:**According to the authors, there are no conflicts of interest to report.

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