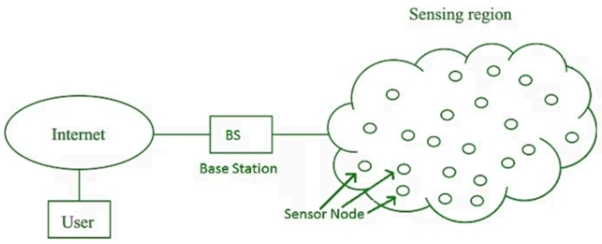
- **Environmental monitoring:** Sensor networks can be used to monitor various environmental parameters, such as temperature, humidity, air quality, and soil moisture. This data can be used to track changes in the environment over time, identify pollution sources, and predict weather patterns.
- **Industrial process control:** Sensor networks can be used to monitor industrial processes and control machinery in real-time. This can help improve efficiency, reduce waste, and prevent accidents.
- **Traffic monitoring:** Sensor networks can be used to monitor traffic patterns and flow in real-time, which can be used to optimize traffic routes and reduce congestion.
- **Agriculture:** Sensor networks can be used to monitor soil moisture and temperature, which can help farmers optimize irrigation and fertilization practices.

Wireless Sensor Network (WSN)

Wireless Sensor Network (WSN) is an infrastructure-less wireless network that is deployed in a large number of wireless sensors in an ad-hoc manner that is used to monitor the system, physical or environmental conditions.

Sensor nodes are used in WSN with the onboard processor that manages and monitors the environment in a particular area. They are connected to the Base Station which acts as a processing unit in the WSN System.
Base Station in a WSN System is connected through the Internet to share data.



WSN can be used for processing, analysis, storage, and mining of the data.

Applications of WSN:

1. Internet of Things (IoT)
2. Surveillance and Monitoring for security, threat detection
3. Environmental temperature, humidity, and air pressure
4. Noise Level of the surrounding
5. Medical applications like patient monitoring
6. Agriculture
7. Landslide Detection

Challenges of WSN:

1. Quality of Service
2. Security Issue
3. Energy Efficiency
4. Network Throughput
5. Performance
6. Ability to cope with node failure
7. Cross layer optimisation
8. Scalability to large scale of deployment

A modern Wireless Sensor Network (WSN) faces several challenges, including:

- **Limited power and energy:** WSNs are typically composed of battery-powered sensors that have limited energy resources. This makes it challenging to ensure that the network can function for long periods of time without the need for frequent battery replacements.
- **Limited processing and storage capabilities:** Sensor nodes in a WSN are typically small and have limited processing and storage capabilities. This makes it difficult to perform complex tasks or store large amounts of data.
- **Heterogeneity:** WSNs often consist of a variety of different sensor types and nodes with different capabilities. This makes it challenging to ensure that the network can function effectively and efficiently.
- **Security:** WSNs are vulnerable to various types of attacks, such as eavesdropping, jamming, and spoofing. Ensuring the security of the network and the data it collects is a major challenge.
- **Scalability:** WSNs often need to be able to support a large number of sensor nodes and handle large amounts of data. Ensuring that the network can scale to meet these demands is a significant challenge.
- **Interference:** WSNs are often deployed in environments where there is a lot of interference

- **Heterogeneity:** WSNs often consist of a variety of different sensor types and nodes with different capabilities. This makes it challenging to ensure that the network can function effectively and efficiently.
- **Security:** WSNs are vulnerable to various types of attacks, such as eavesdropping, jamming, and spoofing. Ensuring the security of the network and the data it collects is a major challenge.
- **Scalability:** WSNs often need to be able to support a large number of sensor nodes and handle large amounts of data. Ensuring that the network can scale to meet these demands is a significant challenge.
- **Interference:** WSNs are often deployed in environments where there is a lot of interference from other wireless devices. This can make it difficult to ensure reliable communication between sensor nodes.
- **Reliability:** WSNs are often used in critical applications, such as monitoring the environment or controlling industrial processes. Ensuring that the network is reliable and able to function correctly in all conditions is a major challenge.

Components of WSN:

1. **Sensors:**
   Sensors in WSN are used to capture the environmental variables and which is used for data acquisition. Sensor signals are converted into electrical signals.
2. **Radio Nodes:**
   It is used to receive the data produced by the Sensors and sends it to the WLAN access point. It consists of a microcontroller, transceiver, external memory, and power source.
3. **WLAN Access Point:**
   It receives the data which is sent by the Radio nodes wirelessly, generally through the internet.
4. **Evaluation Software:**
   The data received by the WLAN Access Point is processed by a software called as Evaluation Software for presenting the report to the users for further processing of the data which can be used for processing, analysis, storage, and mining of the data.

Advantages of Wireless Sensor Networks (WSN):

Low cost: WSNs consist of small, low-cost sensors that are easy to deploy, making them a cost-effective solution for many applications.

Wireless communication: WSNs eliminate the need for wired connections, which can be costly and difficult to install. Wireless communication also enables flexible deployment and reconfiguration of the network.

Energy efficiency: WSNs use low-power devices and protocols to conserve energy, enabling long-term operation without the need for frequent battery replacements.

Scalability: WSNs can be scaled up or down easily by adding or removing sensors, making them suitable for a range of applications and **environments.**

Real-time monitoring: WSNs enable real-time monitoring of physical phenomena in the environment, providing timely information for decision making and control.

Disadvantages of Wireless Sensor Networks (WSN):

Limited range: The range of wireless communication in WSNs is limited, which can be a challenge for large-scale deployments or in environments with obstacles that obstruct radio signals.

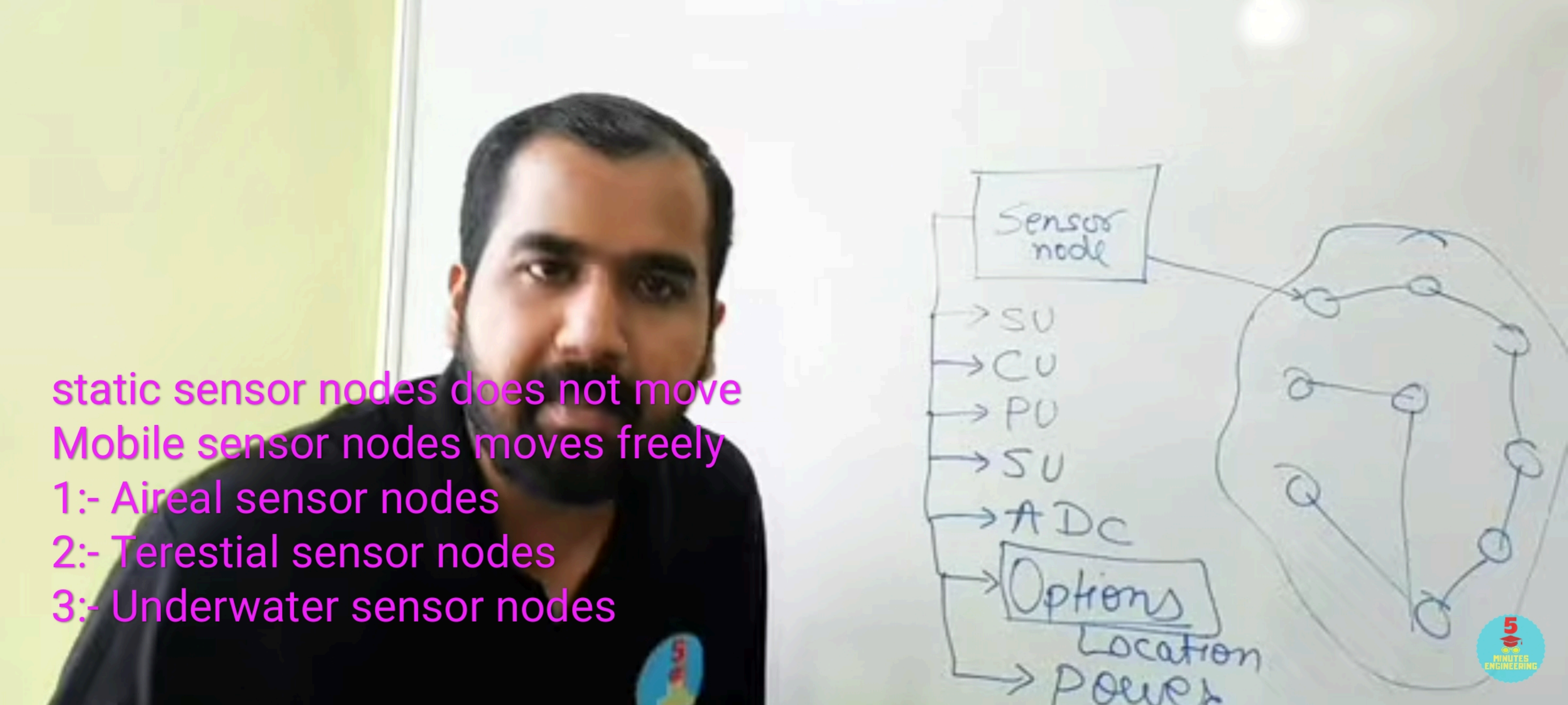
Limited processing power: WSNs use low-power devices, which may have limited processing power and memory, making it difficult to perform complex computations or support advanced applications.

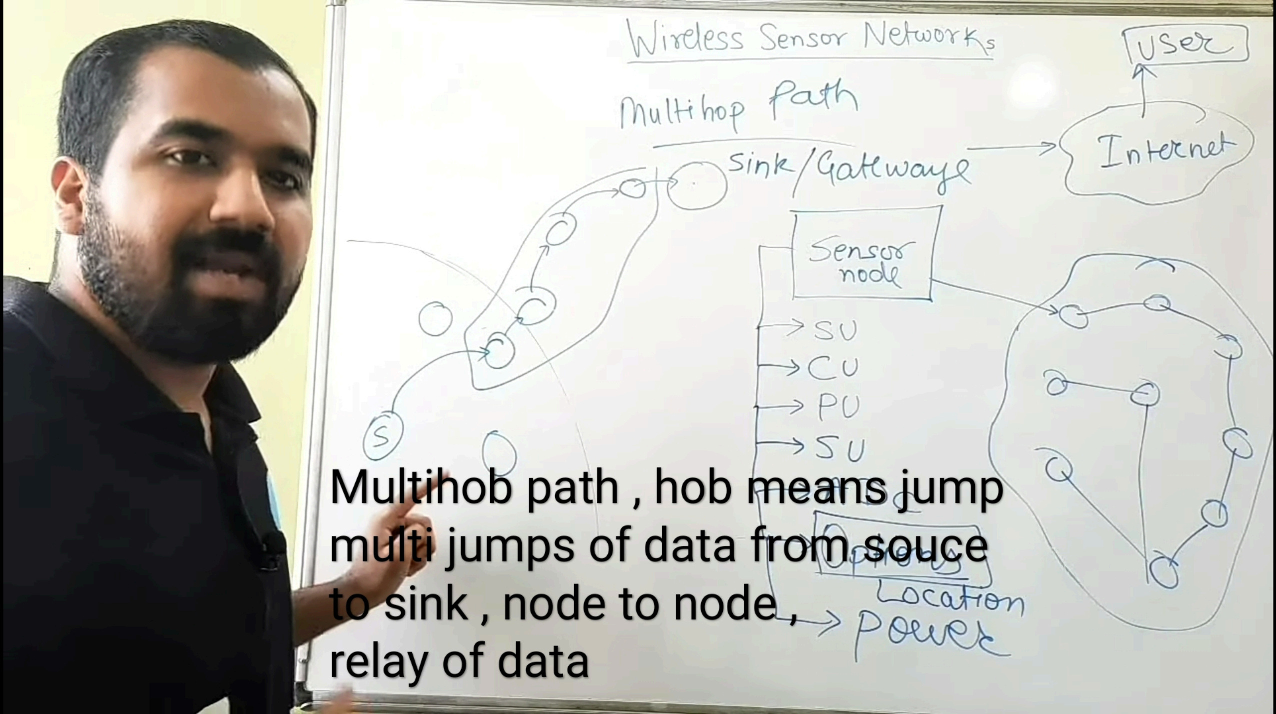
Data security: WSNs are vulnerable to security threats, such as eavesdropping, tampering, and denial of service attacks, which can compromise the confidentiality, integrity, and availability of data.

Interference: Wireless communication in WSNs can be susceptible to interference from other wireless devices or radio signals, which can degrade the quality of data transmission.

Deployment challenges: Deploying WSNs can be challenging due to the need for proper sensor placement, power management, and network configuration, which can require significant time and resources.

while WSNs offer many benefits, they also have limitations and challenges that must be considered when deploying and using them in real-world applications.


static sensor nodes does not move
Mobile sensor nodes moves freely
1:- Aireal sensor nodes
2:- Terestial sensor nodes
3:- Underwater sensor nodes
Sensor node
SU
CU
PU
SU
ADC
Options
Location


Wireless Sensor Networks
User
Multihop Path
sink/Gateway
Internet
Sensor node
SU
CU
PU
SU
S
Location
Power
Multihob path , hob means jump
multi jumps of data from souce
to sink , node to node ,
relay of data

Applications of Wireless Sensor Networks

This entry is adapted from 10.3390/asi3010014

A Wireless Sensor Network (WSN) is a group of spatially dispersed sensor nodes, which are interconnected by using wireless communication. The purpose of this entry is to provide an up-to-date presentation of both traditional and most recent applications of WSNs and hopefully not only enable the comprehension of this scientific area but also facilitate the perception of novel applications.

wireless sensors wireless sensor networks

1. Introduction

A Wireless Sensor Network (WSN) is a group of spatially dispersed sensor nodes, which are interconnected by using wireless communication [1]. As seen in **Figure 1**, a sensor node, also called mote, is an electronic device which consists of a processor along with a storage unit, a transceiver module, a single sensor or multiple sensors, along with an analog-to-digital converter (ADC), and a power source, which normally is a battery. It may optionally include a positioning unit and/or a mobilization unit.

Figure 1. The typical architecture of a sensor node used in Wireless Sensor Networks (WSNs).

A sensor node uses its sensor(s) in order to measure the fluctuation of current conditions in its adjacent environment. These measurements are converted, via the ADC unit, into relative electric signals which are processed via the node's processor. Via its transceiver, the node can wirelessly transmit the data produced by its processor to other nodes or/and to a selected sink point, referred to as the Base Station.

As illustrated in **Figure 2**, the Base Station, by using the data transmitted to itself, is able to both perform supervisory control over the WSN it belongs to and transmit the related information to human users or/and other networks [2].

Figure 2. The typical architecture of a WSN.

The collaborative use of a sufficient quantity of such sensor nodes, enables a WSN to perform simultaneous data acquirement of ambient information at several points of interest positioned over wide areas. The inexpensive production of sensor nodes of this kind, which despite their relatively small size, have exceptionally advanced sensing, processing, and communication abilities has become feasible due to continuous technological advances. For this reason, although WSNs were initially used mainly for military purposes, nowadays they support an ever-growing range of applications of different types [3].

2. Main WSN Applications

Various applications of WSNs are currently either already in mature use or still in infant stages of development. In this paper, WSN applications are classified according to the nature of their use into six main categories which, as illustrated in **Figure 3**, namely are: military, health, environmental, flora and fauna, industrial, and urban.

Figure 3. Overview of the most popular categories of applications of WSNs.

In each category, various subcategories are considered. In what follows in this section, the nature of each one of these categories and subcategories is explained. Additionally, through the indicative examination of characteristic examples of them, their particular features are explained, while their benefits and problems are denoted.

Moreover, various methodologies and technical means that are used in these applications either for sensing or for processing purposes are discussed, while similarities and dissimilarities existing among them are identified.

2.1. Military Applications

The military domain is not only the first field of human activity that used WSNs but it is also considere[d to h]ave motivated the initiation of sensor network research. Smart Dust [4] is a typical example of these initial research efforts, which were performed in the late 90 s in order to develop sensor nodes which despite their very small size would be capable of accomplishing spying activities.

2.1. Military Applications

The military domain is not only the first field of human activity that used WSNs but it is also considered to have motivated the initiation of sensor network research. Smart Dust [4] is a typical example of these initial research efforts, which were performed in the late 90 s in order to develop sensor nodes which despite their very small size would be capable of accomplishing spying activities.

The technological advances achieved since then made WSNs capable of supporting various operations [5]. In **Figure 4**, the main subcategories of the military applications of WSNs which namely are battlefield surveillance, combat monitoring, and intruder detection, are illustrated along with the types of sensors that are most commonly used in them.

Figure 4. The subcategories of the military applications of WSNs and the types of sensors they use.

Specifically, Chemical, Biological, Radiological, Nuclear and Explosive (CBRNE), and Toxic Industrial Material (TIM) sensors may be used to detect the presence of such substances. To detect intrusion, WSNs may use infrared, photoelectric, laser, acoustic, and vibration sensors. Similarly, RAdio Detection And Ranging (RADAR), LIght Detection And Ranging (LIDAR), LAser Detection And Ranging (LADAR) and ultrasonic sensors are used by nodes in WSNs in order to detect the distance from objects of interest. Likewise, LADAR and infrared sensors are used for imaging purposes. Additionally, the flexibility that WSNs have in their structure enables them to adapt to various requirements. For instance, in battlefield operations large-scale WSNs consisting of many thousands of nodes, which are non-manually deployed, are used. In urban warfare and force protection operations, WSNs used consist of hundreds of manually deployed nodes. In other-than-war operations all scales of WSNs and deployment methods are used [5].

2.1.1. Battlefield Surveillance

In applications of this type, the sensor nodes of the WSN may be deployed on a battlefield nearby of the paths that enemy forces may use. The main advantage provided is that the WSN not only can be spontaneously positioned but also can function, without need for continuous attendance and maintenance. The terrain of the battlefield in most cases is absolutely variable. This plays an important role for both the coverage and the energy consumption of the sensor nodes. Some of these applications are presented below.

In [6], the use of WSN technology for ground surveillance is studied. Specifically, the authors propose a system that consists of low-cost common nodes which are capable of sensing magnetic and acoustic signals produced by various moving target objects. The system aims to detect and categorize various targets, such as vehicles and troop movements, based on the spatial differences of the signal strength detected by the sensors. **Figure 5** illustrates the architecture of this system.

Figure 5. Illustration of the system architecture proposed in [6] for target tracking.

In [7] a submarine detection system for Anti-Submarine Warfare (ASW) is presented. The system consists of inexpensive multi-sensing units that combine both active and passive sonars. The system can be scaled to a large number of sensors, which are deployed in littoral waters according to a specific pattern and ocean depth. These sensing units utilize their passive sonar to detect a diesel-electric submarine and their active sonar to confirm their target. The unit that has confirmed a target, notifies its neighboring sensing units by using an alarm signal that contains its ID code. Whenever the units send multiple alarm signals within a predefined period of time, an alert is triggered. Furthermore, the system can acquire low False Alarm Rate (FAR) due to the very low range of the active sonar (50 m) that solves the acoustic multipath problem of the conventional sonobuoys.

2.2. Health Applications

In the health domain, WSNs utilize advanced medical sensors to monitor patients within a healthcare facility, as a hospital or within their home, as well as to provide real time monitoring of patient's vitals by utilizing wearable hardware. In **Figure 6**, the main subcategories of health applications of WSNs namely patient wearable monitoring, home assisting systems, and hospital patient monitoring are illustrated along with the types of sensors that are most commonly used in them. WSNs that have been developed for these types [of he]alth applications are examined in the following subsection.

Figure 6. The subcategories of the health applications of WSNs and the sensors used in them.

2.2.1. Patient Wearable Monitoring

Health monitoring applications can be combined with wearable hardware with embedded biomedical sensors that

1. Introduction

A Wireless Sensor Network (WSN) is a group of spatially dispersed sensor nodes, which are interconnected by using wireless communication [1]. As seen in **Figure 1**, a sensor node, also called mote, is an electronic device which consists of a processor along with a storage unit, a transceiver module, a single sensor or multiple sensors, along with an analog-to-digital converter (ADC), and a power source, which normally is a battery. It may optionally include a positioning unit and/or a mobilization unit.

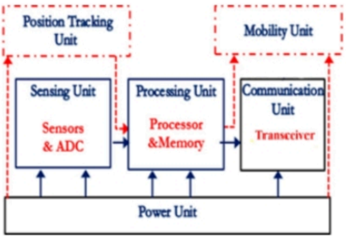


Figure 1. The typical architecture of a sensor node used in Wireless Sensor Networks (WSNs).

A sensor node uses its sensor(s) in order to measure the fluctuation of current conditions in its adjacent environment. These measurements are converted, via the ADC unit, into relative electric signals which are processed via the node's processor. Via its transceiver, the node can wirelessly transmit the data produced by its processor to other nodes or/and to a selected sink point, referred to as the Base Station.

illustrated in **Figure 2**, the Base Station, by using the data transmitted to itself, is able to both perform pervisory control over the WSN it belongs to and transmit the related information to human users or/and other tworks [2].

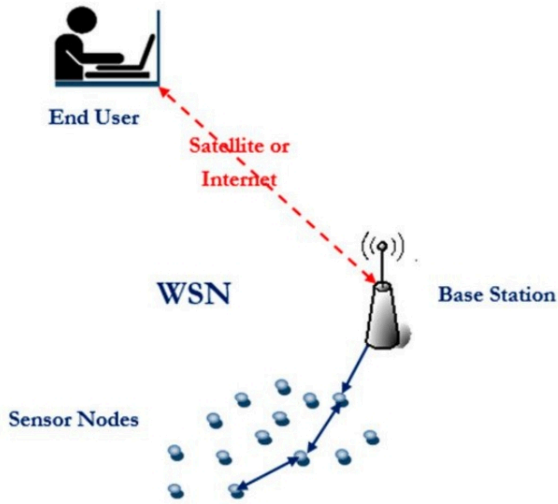


Figure 2. The typical architecture of a WSN.

The collaborative use of a sufficient quantity of such sensor nodes, enables a WSN to perform simultan data acquirement of ambient information at several points of interest positioned over wide areas. The inexpensive production of sensor nodes of this kind, which despite their relatively small size, have exceptionally nced sensing, processing, and communication abilities has become feasible due to continuous technological advances. For this reason, although WSNs were initially used mainly for military purposes, nowadays they support an ever-growing range of applications of different types [3].

2. Main WSN Applications

Various applications of WSNs are currently either already in mature use or still in infant stages of development. In this paper, WSN applications are classified according to the nature of their use into six main categories which, as illustrated in **Figure 3**, namely are: military, health, environmental, flora and fauna, industrial, and urban.

Figure 3. Overview of the most popular categories of applications of WSNs.

In each category, various subcategories are considered. In what follows in this section, the nature of each one of these categories and subcategories is explained. Additionally, through the indicative examination of characteristic examples of them, their particular features are explained, while their benefits and problems are denoted.

Moreover, various methodologies and technical means that are used in these applications either for sensing or for processing purposes are discussed, while similarities and dissimilarities existing among them are identified.

2.1. Military Applications

The military domain is not only the first field of human activity that used WSNs but it is also considered to have motivated the initiation of sensor network research. Smart Dust [4] is a typical example of these initial research efforts, which were performed in the late 90 s in order to develop sensor nodes which despite their very small size ·uld be capable of accomplishing spying activities.

·e technological advances achieved since then made WSNs capable of supporting various operations [5]. ·Figure 4**, the main subcategories of the military applications of WSNs which namely are battlefield surveillance, combat monitoring, and intruder detection, are illustrated along with the types of sensors that are most commonly used in them.

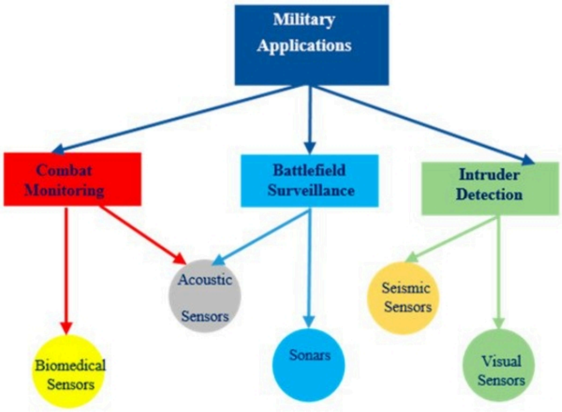


Figure 4. The subcategories of the military applications of WSNs and the types of sensors they use.

Specifically, Chemical, Biological, Radiological, Nuclear and Explosive (CBRNE), and Toxic Industrial Material (TIM) sensors may be used to detect the presence of such substances. To detect intrusion, WSNs may use ·red, photoelectric, laser, acoustic, and vibration sensors. Similarly, RAdio Detection And Ranging (RADAR), LIght Detection And Ranging (LIDAR), LAser Detection And Ranging (LADAR) and ultrasonic sensors are used ·odes in WSNs in order to detect the distance from objects of interest. Likewise, LADAR and infrared sensors are used for imaging purposes. Additionally, the flexibility that WSNs have in their structure enables them to adapt to various requirements. For instance, in battlefield operations large-scale WSNs consisting of many thousands of nodes, which are non-manually deployed, are used. In urban warfare and force protection operations, WSNs used

1. Introduction

A Wireless Sensor Network (WSN) is a group of spatially dispersed sensor nodes, which are interconnected by using wireless communication [1]. As seen in **Figure 1**, a sensor node, also called mote, is an electronic device which consists of a processor along with a storage unit, a transceiver module, a single sensor or multiple sensors, along with an analog-to-digital converter (ADC), and a power source, which normally is a battery. It may optionally include a positioning unit and/or a mobilization unit.

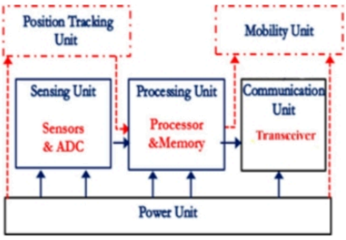


Figure 1. The typical architecture of a sensor node used in Wireless Sensor Networks (WSNs).

A sensor node uses its sensor(s) in order to measure the fluctuation of current conditions in its adjacent environment. These measurements are converted, via the ADC unit, into relative electric signals which are processed via the node's processor. Via its transceiver, the node can wirelessly transmit the data produced by its processor to other nodes or/and to a selected sink point, referred to as the Base Station.

As illustrated in **Figure 2**, the Base Station, by using the data transmitted to itself, is able to both perform supervisory control over the WSN it belongs to and transmit the related information to human users or/and other networks [2].

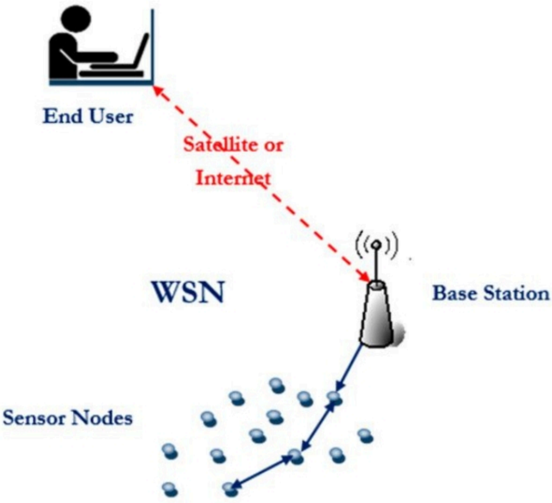


Figure 2. The typical architecture of a WSN.

The collaborative use of a sufficient quantity of such sensor nodes, enables a WSN to perform simultaneous data acquirement of ambient information at several points of interest positioned over wide areas. The intensive production of sensor nodes of this kind, which despite their relatively small size, have exceptionally advanced sensing, processing, and communication abilities has become feasible due to continuous technological advances. For this reason, although WSNs were initially used mainly for military purposes, nowadays they support an ever-growing range of applications of different types [3].

2. Main WSN Applications

Various applications of WSNs are currently either already in mature use or still in infant stages of development. In this paper, WSN applications are classified according to the nature of their use into six main categories which, as illustrated in **Figure 3**, namely are: military, health, environmental, flora and fauna, industrial, and urban.

Figure 3. Overview of the most popular categories of applications of WSNs.

In each category, various subcategories are considered. In what follows in this section, the nature of each one of these categories and subcategories is explained. Additionally, through the indicative examination of characteristic examples of them, their particular features are explained, while their benefits and problems are denoted.

Moreover, various methodologies and technical means that are used in these applications either for sensing or for processing purposes are discussed, while similarities and dissimilarities existing among them are identified.

2.1. Military Applications

The military domain is not only the first field of human activity that used WSNs but it is also considered to have motivated the initiation of sensor network research. Smart Dust [4] is a typical example of these initial research efforts, which were performed in the late 90 s in order to develop sensor nodes which despite their very small size would be capable of accomplishing spying activities.

e technological advances achieved since then made WSNs capable of supporting various operations [5]. **Figure 4**, the main subcategories of the military applications of WSNs which namely are battlefield surveillance, mbat monitoring, and intruder detection, are illustrated along with the types of sensors that are most commonly used in them.

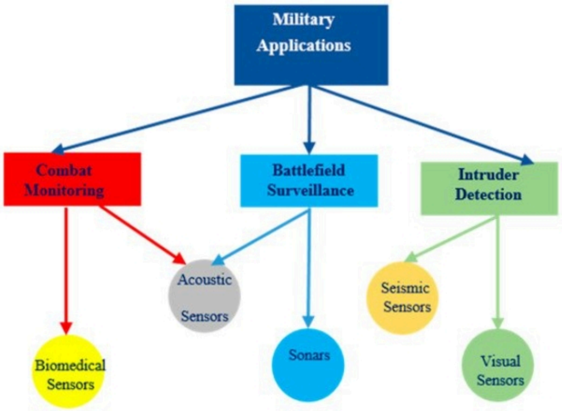


Figure 4. The subcategories of the military applications of WSNs and the types of sensors they use.

Specifically, Chemical, Biological, Radiological, Nuclear and Explosive (CBRNE), and Toxic Industrial Material (TIM) sensors may be used to detect the presence of such substances. To detect intrusion, WSNs may use ared, photoelectric, laser, acoustic, and vibration sensors. Similarly, RAdio Detection And Ranging (RAD light Detection And Ranging (LIDAR), LAser Detection And Ranging (LADAR) and ultrasonic sensors are used odes in WSNs in order to detect the distance from objects of interest. Likewise, LADAR and infrared sensors used for imaging purposes. Additionally, the flexibility that WSNs have in their structure enables them to adapt to various requirements. For instance, in battlefield operations large-scale WSNs consisting of many thousands of nodes, which are non-manually deployed, are used. In urban warfare and force protection operations, WSNs used

Specifically, Chemical, Biological, Radiological, Nuclear and Explosive (CBRNE), and Toxic Industrial Material (TIM) sensors may be used to detect the presence of such substances. To detect intrusion, WSNs may use infrared, photoelectric, laser, acoustic, and vibration sensors. Similarly, RAdio Detection And Ranging (RADAR), LIght Detection And Ranging (LIDAR), LAser Detection And Ranging (LADAR) and ultrasonic sensors are used by nodes in WSNs in order to detect the distance from objects of interest. Likewise, LADAR and infrared sensors are used for imaging purposes. Additionally, the flexibility that WSNs have in their structure enables them to adapt to various requirements. For instance, in battlefield operations large-scale WSNs consisting of many thousands of nodes, which are non-manually deployed, are used. In urban warfare and force protection operations, WSNs used consist of hundreds of manually deployed nodes. In other-than-war operations all scales of WSNs and deployment methods are used [5].

2.1.1. Battlefield Surveillance

In applications of this type, the sensor nodes of the WSN may be deployed on a battlefield nearby of the paths that enemy forces may use. The main advantage provided is that the WSN not only can be spontaneously positioned but also can function, without need for continuous attendance and maintenance. The terrain of the battlefield in most cases is absolutely variable. This plays an important role for both the coverage and the energy consumption of the sensor nodes. Some of these applications are presented below.

In [6], the use of WSN technology for ground surveillance is studied. Specifically, the authors propose a system that consists of low-cost common nodes which are capable of sensing magnetic and acoustic signals produced by various moving target objects. The system aims to detect and categorize various targets, such as vehicles and troop movements, based on the spatial differences of the signal strength detected by the sensors. **Figure 5** illustrates the architecture of this system.

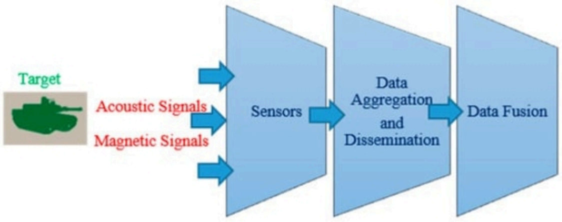


Figure 5. Illustration of the system architecture proposed in [6] for target tracking.

In [7] a submarine detection system for Anti-Submarine Warfare (ASW) is presented. The system consists of expensive multi-sensing units that combine both active and passive sonars. The system can be scaled to a large mber of sensors, which are deployed in littoral waters according to a specific pattern and ocean depth. These nsing units utilize their passive sonar to detect a diesel-electric submarine and their active sonar to confirm their target. The unit that has confirmed a target, notifies its neighboring sensing units by using an alarm signal that contains its ID code. Whenever the units send multiple alarm signals within a predefined period of time, an alert is triggered. Furthermore, the system can acquire low False Alarm Rate (FAR) due to the very low range of the active sonar (50 m) that solves the acoustic multipath problem of the conventional sonobuoys.

2.2. Health Applications

In the health domain, WSNs utilize advanced medical sensors to monitor patients within a healthcare facility, as a hospital or within their home, as well as to provide real time monitoring of patient's vitals by utilizing wearable hardware. In **Figure 6**, the main subcategories of health applications of WSNs namely patient wearable monitoring, home assisting systems, and hospital patient monitoring are illustrated along with the types of sensors that are most commonly used in them. WSNs that have been developed for these types of health applications are examined in the following subsection.

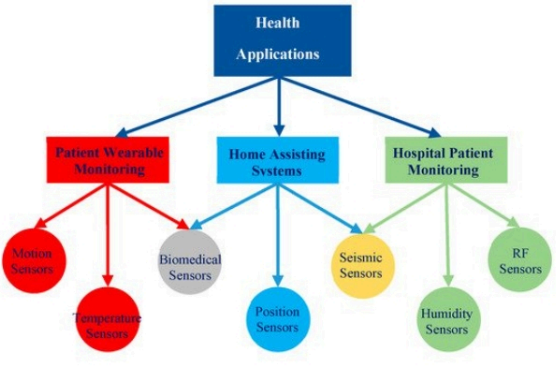


Figure 6. The subcategories of the health applications of WSNs and the sensors used in them.

2.2.1. Patient Wearable Monitoring

Health monitoring applications can be combined with wearable hardware with embedded biomedical sensors that provide the patient's health status in a remote environment or within a healthcare facility.

A healthcare solution of this type, is examined in [8]. It uses real-time sensors incorporated in smartphones along with a barcode system to provide personalized medicine care assistance. The mechanism developed, performs Electrocardiogram (ECG) monitoring in real time. Also, the monitoring of the blood glucose level, blood pressure, and several kinds of diagnostics could be possible too, by using real-time sensors. This system developed is illustrated in **Figure 7**.

Figure 7. An illustration of the real time electrocardiogram (ECG) monitoring environment [8].

An alert portable tele-medical monitor system (AMON) is proposed in [9], aiming to provide continuous monitoring for high-risk cardiac/respiratory patients. The system collects multiple vital signs, detects multi-parameter medical emergencies and is connected to a cellular telemedicine center (TMC). This system uses a wrist worn device, to monitor vital parameters of patients in order to provide an integrated picture of their health condition.

2.3. Environmental Applications

Environmental applications that demand continuous monitoring of ambient conditions at hostile and remote areas can be improved with the utilization of WSNs. In **Figure 8**, the main subcategories of environmental applications of WSNs, namely water monitoring, air monitoring, and emergency alerting, are depicted along with the types of sensors that are typically used in them. WSNs that have been developed for these types of environmental applications are studied in the following subsection.

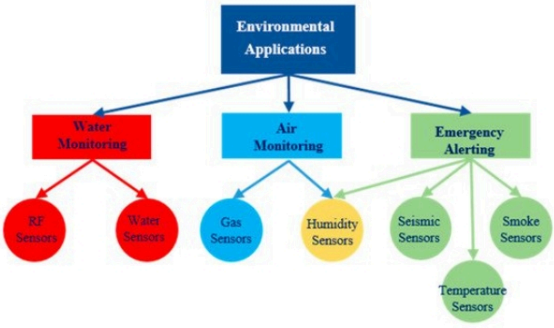


Figure 8. The subcategories of the environmental WSN applications and the types of the sensors used in them.

2.3.1. Water Monitoring

Water, either for drinking or oceanic is an important factor in human lives, therefore the monitoring of water has a great academic interest for researchers as described below.

The researchers in [10] designed a WSN application to evaluate the quality of fresh drinkable water. They designed a Cyber physical system (CPS) called PipeSense, which is an in-pipe system for water monitoring that utilizes RFID (Radio Frequency Identification) based WSN. The network can provide information about water demand or water quality and various repair information such as weak spots or pipe leakage. The in-pipe RFID sensors collect information from the system and send them to the data servers, where algorithms provide decision support.

A WSN application for marine environment monitoring is presented in [11]. In order to prevent damage to the flora and fauna of a fish farm from feed and fecal waste, the authors designed an Underwater WSN (UW with ground based wireless sensor nodes capable of monitoring the pollution of the farm. The sensor are mobile in a limited space in order to measure a greater area.

2.3.2. Air Monitoring

Air is a vital element for human lives and nowadays the air pollution of the atmosphere is a result of many modern human activities. WSNs can be utilized for air quality monitoring in occupied regions in order to prevent

2.3.2. Air Monitoring

Air is a vital element for human lives and nowadays the air pollution of the atmosphere is a result of many modern human activities. WSNs can be utilized for air quality monitoring in occupied regions in order to prevent dangerous diseases and contaminations or risk the health of people.

A characteristic example of an application of this kind is presented in [12], where an air quality monitoring application assisted by WSNs, called WSN-AQMS, is proposed. The specific system combines gas sensors along with Libelium waspmotes [13] to measure air quality parameters of gases such as ozone, CO, and NO_2. The waspmotes monitor in real time the air quality and utilize the Zigbee protocol for data communication. The authors further introduced the Clustering Protocol for Air Sensor network (CPAS) in order to support the operation of this system

2.3.3. Emergency Alerting

Proactive monitoring of the causes of natural disasters, can help to avoid these disasters or/and lower their cost. WSNs can be utilized for monitoring common disastrous causes in real time to provide proactive alerts in order to lower damage or even prevent disaster. Typical examples described in the rest of this subsection, are related to the monitoring of seismic activity, volcanic activity, forest fires, and tsunamis.

Seismic Activity Monitoring

Earthquakes can cause enormous damage to an occupied region where they take place. WSNs can be utilized to monitor seismic activity in real time in order to take precautionary measures and enable the authorities to act in advance. A real time seismic activity monitoring system is presented.

In [14], the authors designed a warning system for earthquakes in order to increase the time before an earthquake so as to take precaution measures. The authors deployed a WSN in the island of Mauritius, which has high seismic activity. The system monitors seismic activity by utilizing primary waves (P-waves) and estimates local velocity and the hypocenter's location according to time delays in the arrival of the P-waves at the sensors.

Volcanic Activity Monitoring

Volcanoes can cause enormous damage to nearby towns or cities when they are activated. Before a volcano erupts, there are many signs that a WSN system can measure, proactively, in order to inform nearby citizens about the eruption. When such a system is applied, citizens can protect their families and belongings by transporting them outside of the area of the eruption, preventing further damage. Below is an example of such a system.

[15], a WSN based system to monitor volcanic activity components is proposed. The system is low cost, flexible, d easy to deploy and to maintain for remote locations. The users of the system can choose GPS data nchronization when the sensor nodes have signal reception, or a specific algorithm when they have not, to llect accurate timestamps of each sample. Pieces of the equipment used, are shown in **Figure 9**.

Figure 9. A depiction of a geophone sensor with a wireless antenna deployed in the field [15].

2.4. Flora and Fauna Applications

Both flora and fauna domains are vital for every country. In **Figure 10**, the main subcategories of flora and fauna applications of WSNs which namely are greenhouse monitoring, crop monitoring, and livestock farming, are illustrated along with the types of sensors that are most commonly used in them.

2.4. Flora and Fauna Applications

Both flora and fauna domains are vital for every country. In **Figure 10**, the main subcategories of flora and fauna applications of WSNs which namely are greenhouse monitoring, crop monitoring, and livestock farming, are illustrated along with the types of sensors that are most commonly used in them.

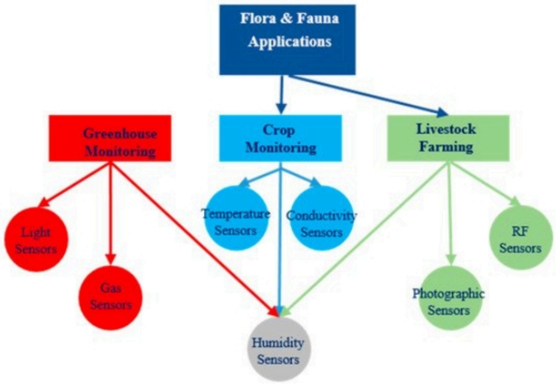


Figure 10. The subcategories of flora and fauna applications of WSNs and the types of the sensors used in them.

WSNs that have been developed for these types of flora and fauna applications are examined in the following subsection.

2.4.1. Greenhouse Monitoring

An important sector of the agriculture domain involves greenhouses. Within them many crops can be grown to provide sustainable food while climate crops can be harvested all year round if certain conditions are applied within the greenhouse. Therefore, WSNs can be applied in greenhouse monitoring and control to improve their operation. Below are some examples of these applications

In [16], a system of this type, called the Agricultural Environment Monitoring System (AEMS), is presented. It is an inexpensive and easy to apply system that can collect and monitor data related to crop growth, inside or outside a greenhouse via WSN sensors and CCTV cameras. The system gathers vital environmental parameters such as temperature, light intensity, humidity, air pressure, rainfall level, pH, and electrical conductivity (EC).

A relevant system developed for greenhouses which has energy management and indoor climate control capabilities, is introduced in [17]. The system monitors vital greenhouse parameters such as indoor luminance, temperature, and relative humidity, via sensor nodes. The indoor climate control is possible by the utilization of two fuzzy logic controllers, P (Proportional) and PD (Proportional-Derivative) that use the desired indoor climatic set-points. Furthermore, the system utilizes output actuations of heating units, motor-controlled windows and shading curtains, artificial lighting, etc. in order to achieve more precise greenhouse control.

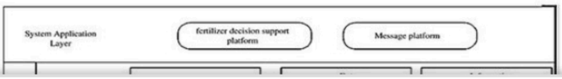
2.4.2. Crop Monitoring

Within the agriculture domain, the preservation of the crops plays a vital role. In order to provide a better environment for the crops, various WSNs applications can be implemented. Crop irrigation and fertilization are some examples of the applications that have been designed as described below.

Hidro Bus is a system described in [18]. It is a remote controlled, automatic irrigation system for large areas of land applied at Jumilla (Murcia, Spain). The system divides the deployment area into seven sub-regions, where each has a control sector for monitoring and controlling. The control sectors communicate with each other and the central controller via WLAN network.

An automated fertilizer applicator system is built in [19], which consists of three modules, the input, the decision support, and the output modules. The input module can provide to the Decision Support System (DSS) module, GPS and real time sensor data by utilizing bluetooth technology. With these data the DSS is able to calculate quantity, application rate, and the spread pattern of the fertilizer that the output module will provide to the crops.

The authors of [20] developed and integrated an optimal fertilization decision support system using a wireless sensor LAN, IEEE 802.11 protocol (Wi-Fi) and a GIS analysis server. Sensor nodes were used to acquire vital data in real time such as soil moisture, conductivity, temperature, etc. Also, the system used B/S a (brows ver) structure mode to provide high interactivity. Also, a GIS analysis server was used to interpolate the rom small experimental plots to larger plots to exploit data reduction for energy conservation. An overvi the overall system architecture is illustrated in **Figure 11**.



2.5. Industrial Applications

WSNs can be applied in various industrial applications to solve many related problems. In **Figure 12**, the main subcategories of industrial applications of WSNs namely logistics, robotics, and machinery health monitoring are illustrated. These specific categories of applications are studied in the rest of this subsection.

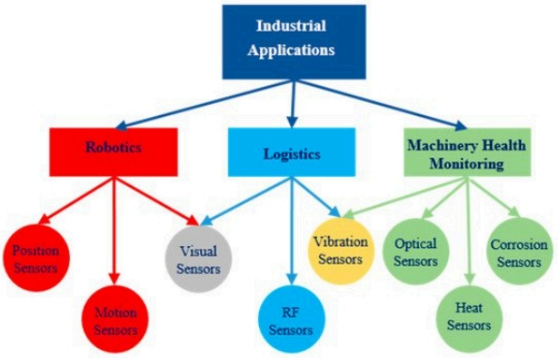


Figure 12. The subcategories of the industrial applications of WSNs and the types of the sensors used in them.

2.5.1. Logistics

The domain of logistics is an area of interest where WSNs can be applied, because many logistics systems need real time monitoring of various environmental parameters and better handling of packages. These requirements can be fulfilled by combining the logistics systems with WSNs. Some types of these applications are described below.

The transport logistics sector requires low cost and high-quality during deliveries. In [22], the development and deployment of a WSN based system for monitoring transportation conditions, such as temperature and humidity, within a cargo container travelling via both a trans-Atlantic cargo vessel and a lorry is described. The main idea for the deployment of the monitoring system is depicted in **Figure 13**. It is shown that the use of a system of this kind, can increase quality by providing better supervision and lower the cost by reducing losses during transportation.

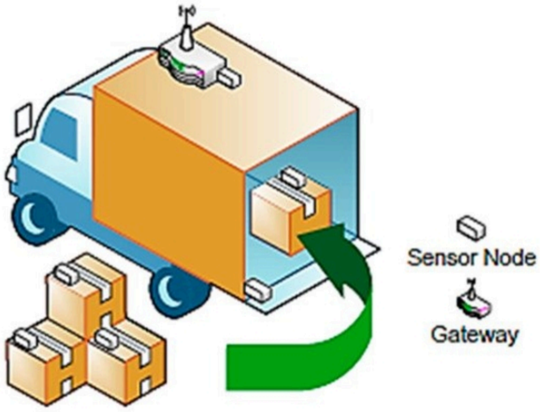


Figure 13. Depiction of the basic configuration of a WSN based system for transport logistics applications [22].

The application of WSNs in Cold Chain Logistics (a continuous temperature-controlled supply chain) can greatly improve the monitoring and management of these chains [23]. WSNs are suitable for real time monitoring of many environmental parameters and provide accurate data collection that meets the demand of Cold Chain Logistics. The researchers used a Zigbee ad hoc network model to build the system's framework. By using fuzzy control decision, the environmental parameters are maintained in a stable range and with Maximum Similarities Multiple Characteristic Recognition (MSMCR) the safety of cold-chain food is ensured.

Another application of WSNs developed for Cold Chain Logistics is studied in [24]. This system focuses only on aquatic products and their transportation. In order to develop such a system, the authors proposed a WSN integrated with Compressed Sending (CS), in order to combat heavy data traffic from the real time se[illegible] data transmission. Also, CS provides a low complexity approximation which assists storage, transmission, processing, and meets the recourse constraints of WSNs.

A WSN application in logistics that utilizes GPS technology is described in [25]. This system monitors in real-time the status of the goods and has embedded a terminal, which is used to locate the goods and a cloud services platform, which is used to identify the recipient.

2.5.2. Robotics

Nowadays there are many applications that combine WSNs and robots. Robots can cooperate and combat some of the major problems of WSNs, such as sensor node mobility, node redeployment, travelling salesman, etc. Typical WSN applications of this kind are presented below.

A robotic navigation method proposed in [26] provides road maps for the robot to traverse. It uses a WSN with sensors, designed to provide sophisticated maps of their sensing areas. Specifically, each sensor constructs a map, based on the traversable area sensed. Then, all sensor maps are combined to create one large map. Once the road maps are generated, the sensors are used to sense areas of interest for the robot to travel to. The robot then considers all possible roads to take and selects the most efficient path available in the network. If an area becomes hazardous for the robot, the network can reconfigure the road map, and remove this hazardous area from the list of available paths.

One of the most difficult tasks concerning WSNs is the maintenance of a projected network. A combination of WSNs and robotics was researched in [27], where a robotic network servicing system, named Randomized Robot assisted Relocation of Static Sensors (R3S2) was developed. In R3S2, robots move around a network which is contained within a virtual grid. The robot moves to the least recently visited grid point, searching for sensing holes in the network. When an area that is not being covered by a sensor is detected, the robot will find a node which has overlapping coverage with other nodes and move it to the uncovered area. In addition, if the robot discovers redundant sensors, it will move the nodes to cover a greater area.

A different approach is proposed in [28], where a mobile robot is used to transfer data from a widespread network between nodes that are out of reach from one another for various reasons. This is the so-called travelling salesman problem (TSP)—within a WSN. By having a robot traveling among nodes which are out of each other's wireless communication range, it allows the network to be widespread while also saving power by using the robot for data muling.

2.5.3. Machinery Health Monitoring

The objective of machinery health monitoring is to examine the performance of various types of technical equipment and to either detect or predict the occurrence of faults that are obstructive or even catastrophic for their operation.

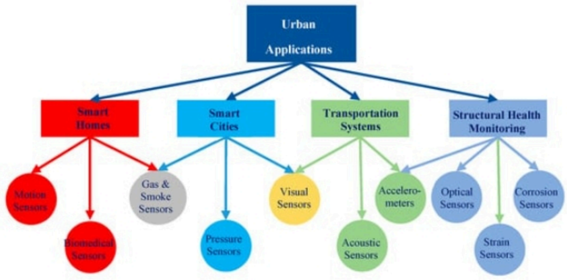
In [29], a WSN is developed in order to perform energy usage evaluation and condition monitoring for electric machines. The motor efficiency and health condition are estimated non- intrusively by using wireless nodes that monitor the motor terminal quantities (i.e., line voltages, line currents, and temperature, with no interference with the operation of the electric machines.

In [30], a WSN based monitoring system of oil and gas pipelines, named REMONG, is proposed. In order to detect the existence of leakages, the system uses wireless sensor nodes which monitor the pressure and temperature of the pipeline fluid at several points of interest on the pipelines which are stretched over large geographical areas.

In [31] a WSN designed to enhance safety in industrial machinery consisting of a main vehicle and an attached trailer is proposed. A 3D accelerometer and a 3D magnetometer, incorporated in a sensor system device, monitor the trailer operating conditions and the corresponding data are wirelessly transmitted to a processing unit which executes a stability control algorithm. A vibrational energy harvesting system developed, converts kinetic energy from trailer natural vibrations to electrical energy for the system power supply.

2.6. Urban Applications

The variety of sensing abilities offered by WSNs also provides an opportunity to gain an unprecedented level of information about a target area, be it a room, a building, or outdoors. WSNs are indeed a tool to measure the spatial and temporal features of any phenomena within an urban environment, providing a limitless number of applications. The most popular applications of WSNs in the urban domain are related to smart homes, smart cities, transportation systems, and structural health monitoring, as depicted in **Figure 14** and further described in the rest of this subsection.



2.6.1. Smart Cities

In large cities monitoring of various parameters is crucial for the optimal life of the citizens. WSNs have a huge amount of applications to provide real time data to the authorities for the optimal function of a city. Specifically, increased transportation of people creates problems and time wastage, when a large number of vehicles is heading towards common destinations. WSNs can be utilized for monitoring in order to reduce traffic, indicate car parking spots, etc. [32].

In [33] a WSN-based intelligent car parking system is proposed. Specifically, within a car park area, each parking lot is equipped with one inexpensive sensor node, which detects the occupation or vacancy of this parking lot. A base station collects data relative to the status of all parking lots and sends periodic reports to a database. This database can be accessed by the upper layer management system in order to execute several tasks, such as vacant parking lots discovery, security supervision, automated toll, or/and statistic report creation.

In [34], a system to measure and classify road traffic based on WSN is proposed. The nodes of this system have integrated magnetic sensors and are deployed along the road in order to provide real time traffic monitoring. This configuration has been proposed as an easy and cheap to implement alternative to inductive coils that are traditionally deployed in roads for basic traffic control tasks. The architecture adopted in the system proposed is graphically presented in **Figure 15**.

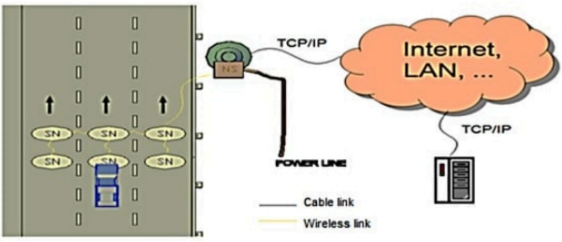


Figure 15. A depiction of the various setups where WSNs can be deployed [34].

In [35], a system for road traffic control near flooded tunnels is proposed. The specific system, consists of a WSN and a centralized control system. The analogue output signals of sensors, located in the interior of two underground tunnels, are converted to digital ones which are next transmitted through serial-to-Ethernet converters to an access point. Following a corresponding procedure the signals reach a programmable logic controller, which monitors the level of water in the interior of two underground tunnels and accordingly not only regulates the water drainage of flooded tunnels by using pumps, but also performs traffic control of vehicles approaching the entrance to the tunnels.

A WSN based system for street lighting monitoring and control is presented in [36]. This system enables the remote control of street lighting lamps, by using Doppler sensors to allow for vehicle detection. The light intensity of the lamps is increased, to a preset level, in the presence of approaching vehicles and reduced in the absence of them.

2.6.2. Smart Homes

In the era of informatics, various systems can improve human lives. Wireless sensor networks can be applied in the indoor environment as in smart homes where machine to machine communications take place. Two typical examples are the indoor localization and motion monitoring and the monitoring of the indoor air quality.

Specifically, the monitoring of indoor air quality (IAQ), which is a term that refers to the air quality of a building, has become, with the rapid urbanization process that is taking place, one of the most important topics of WSN urban applications. Modern people spend a great part of their life within a building, thus the air quality plays a critical role for their health, safety, and comfort. In order to monitor IAQ the authors of [37] developed a WSN application that utilizes wireless nodes equipped with gas sensors for sensing and communicating wirelessly in real time.

Similarly, the WSN based IAQ monitoring system, which is described in [38], uses sensor nodes that measure temperature, relative humidity, and concentration of carbon dioxide in classrooms in order to correlate the level of indoor air quality with the students' level of performance in their studies.

Another popular application of indoor localization and motion monitoring that uses WSNs, is described i... The authors developed a system, which is used to estimate the position of a person within an indoor environ... The system utilizes mobile sensor nodes worn by the moving persons and a network of static sensor nodes ...own locations. To calculate the person's position, the system gathers data from the nodes in a central PC and applies Monte Carlo based estimation algorithms to track the moving persons in real time.

2.6.3. Transportation Systems

2.6.3. Transportation Systems

The transportation of vehicles within the urban environment is an important factor for the safety and proper function of public roads. In the modern era various researchers have proposed many systems in the transportation domain, which by utilizing WSNs can improve the safety of roads and provide information during the use of them by drivers. Below we present some relative WSN applications applied in the transportation domain.

In [40] the authors describe a WSN application for VANETs. This application using Secure Multimedia Broadcast Framework (SMBP) is to monitor a persons' way of driving by utilizing a processing unit on the vehicle, which analyzes data, collected from the sensors in order to calculate the cost of the driver's insurance. The described system is utilized in order to determine how much the driver detects nearby vehicles, drives with caution, follows the traffic law, or uses a mobile device. The sensing system includes a static sensor board that provides the sensed data via cellular network to the control center and a Global Position System/Universal Mobile Telecommunications System (GPS/UMTS) module in order to connect to the Internet. The basic configuration of SMBP is depicted in **Figure 16**.

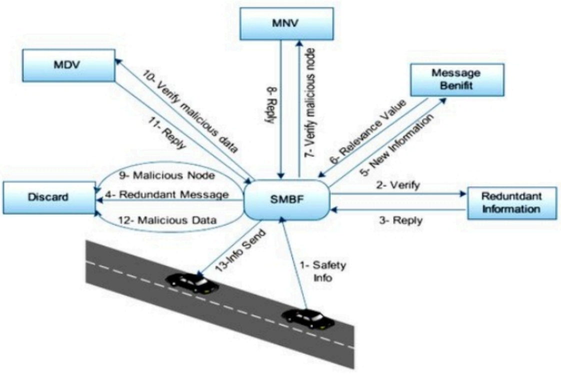


Figure 16. A representation of the Secure Multimedia Broadcast Framework (SMBP) [40].

In [41] a system is proposed, which analyzes the performance of a vehicle on the road by utilizing a telematics WSN. The system utilizes deployed sensor nodes on the road and a sink node on the roadside. The sensors nodes detect the passing vehicles and transmit data to the sink node. Furthermore, when an event occurs a packet is generated, the sink node implements a timestamp to it and forwards it to the com node, which utilizes a level-based static routing protocol. Next, the com node forwards this packet to the user, which analyzes the provided information in order to determine various metrics of the road such as a vehicle's speed, lane vehicle density etc. A depiction of the overall system configuration is shown in **Figure 17**.

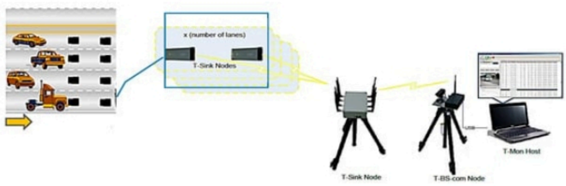


Figure 17. A graphical depiction of the WSN based transportation monitoring system [41].

In recent years, various WSN have been deployed within cities resulting in the formation of small WSN based islands. In [42] the authors describe an integration of these existing islands deployed along the roadside, in order to be utilized for post-accident management and to prevent accidents. Furthermore, the authors utilize two wireless standards i.e., IEEE 802.15.4 and IEEE 802.11p due to the need for separate roadside sensor units. In order to prevent accidents, the WSN islands constantly detect road conditions and transmit information to the vehicles passing by the area, which aggregate these data. Then the vehicle that has this information, transmits warning messages to nearby vehicles in order for the data to be disseminated along the road. The post-accident gathered information is restricted, by the authors, in order to be used only by authorized personnel such as insurance companies, criminological teams, or other authorities. Moreover, according to the authors, the post-accident management can function properly by communicating with the WSN islands on the roadside, without the use of VANETs. The overall system operation is illustrated in **Figure 18**.

Figure 18. An illustration of the WSN deployed for an Intelligent Transport system [42].

The researchers of [43], presented a mechanism that controls the speed of a vehicle by utilizing an infrastructure-to-vehicle communication via WSNs. In the described system the traffic lights utilize long-range RFID tags, which can measure a vehicle's speed and communicate with the vehicle's onboard RFID tags, to avoid collisions. The onboard RFID tags are able to provide feedback to actuators, which can change the longitudinal speed by controlling various parameters of the vehicle such as braking and throttling. Furthermore, the authors created a fuzzy logic algorithm enabling the automatic control of the vehicle. Structural elements of the system developed are shown in **Figure 19**.

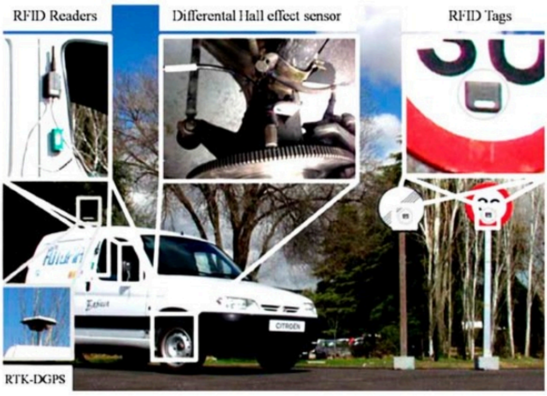


Figure 19. A depiction of the various sensors deployed on a car for experimenting [43].

2.6.4. Structural Health Monitoring

The aim of Structural Health Monitoring (SHM) in buildings and other types of civil engineering substructures, is to monitor their integrity and to detect the existence and the extent of damages in the materials or/and the structure of their bodies. The use of wireless sensors facilitates the accomplishment of tasks of this kind both in a periodic basis and after critical events (e.g., earthquakes).

A WSN application of this kind is presented in [44]. Specifically, a WSN incorporating nodes with appropriate sensors, such as accelerometers and strain gauges, was developed to monitor the restoration works carried out in an old church building located in Italy, which was damaged after an earthquake. The system monitored the on the response of the structure to vibrations and enabled the transmission of alert signals when needed.

[45] the design, development, and deployment of a, WSN based, structural health monitoring platform for a adium located in the USA is described. By using vibration sensing, the system collects real time, data during athletic and other major events to verify the structural behavior of the stadium, in correlation with the behavior of the audience.

Another structural health monitoring system which makes use of a WSN is presented in [46]. This system is designed, implemented, deployed, and tested to monitor the structural performance of a bridge in China by sensing vibration signals that are produced under various conditions in specific points of interest located at the body of the bridge.

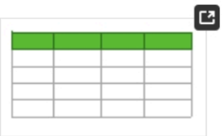
3. Discussion

There is no doubt that WSNs enjoy remarkable capabilities which make them ideal for an ever- extending range of applications. On the other hand, the operation of WSNs comes up with serious problems. Some of them are application dependent.

For instance, in military applications the required physical dimensions and weight of nodes are application dependent. For instance, in some surveillance applications the sensor nodes have to be extremely small in order to be undercover, while in many other military applications, physical dimensions and weight of the nodes are not considered to be important restrictions. On the other hand, nodes in such applications should definitely have an adequately extensive communication range (maybe ≥1 km), while the area to be covered is several square kilometers. Also, communication should attain optimal throughput, reliability, security, and resistance to jamming and intervention. Moreover, nodes should be robust enough to resist severe ambient conditions. Sim the WSN should be tolerant to the loss of a certain quantity of nodes.

In health applications, the physical dimensions and weight of the nodes have to be as small as sible particularly in the cases where they are wearable. Conversely, there is not any need for an extended communication range of nodes or area covered. Communication should be fault tolerant, fast, and reliable while jamming should be definitely avoided because the transmission of data is absolutely vital when time critical alert application, are synoptically presented in **Table 1**.

Table 1. Required specifications of Wireless Sensor Networks (WSNs) per type of application.



Additionally, apart from the aforementioned issues that are application dependent, the operation of WSNs is also obstructed due to general issues, such as difficulties of wireless communication and weaknesses of the nodes.

Specifically, sensor nodes of WSNs suffer from extremely strict energy constraints. This is because their energy is typically supplied by batteries which are usually impractical to be either recharged or replaced, since the locations of sensor nodes are usually difficult or even impossible to reach. Therefore, the attainment of energy conservation is a vital issue for WSNs. For this reason, energy inefficiencies that exist at every one of the five layers of the protocol stack of sensor nodes must be eliminated. Given that data transmission is by far the most energy consuming task of nodes, power control schemes [47], data aggregation schemes that decrease the size of data transferred [48], [49] and energy efficient routing protocols [50] have been proposed. Likewise, in applications in which multimedia data are transmitted, the use of compression and restoration schemes provide a substantial reduction of communication load [51][52]. Additionally, the presence of excessive data traffic in a specific region of a WSN causes network congestion which obstructs data transmission, generates packet losses, and decreases the network throughput. For this reason, methodologies for congestion avoidance [53][54][55], congestion control [56][57], and load balancing [58][59] are used. Furthermore, each time that a node is disconnected from the rest of the network, due to, malfunction, damage, or energy depletion the communication for the remainder becomes more difficult and the communication cost is increased. For this reason, methods for the preservation of network connectivity are essential to be applied [60][61]. Moreover, it is anticipated that the nodes achieve the best exploitation of their sensing range and their communication range in order to cover as much of the network area. This is why coverage maximization methods are considered [62][63]. Moreover, in WSN applications where multimedia data are transmitted, the attainment of high Quality of Service (QoS) is a necessity. Furthermore, the accomplishment of energy efficient routing in WSNs is often influenced by other issues such as the QoS attained [64][65]. Last but not least, in most WSN applications, the data transmitted within the network must be protected from any unauthorized use. For this reason, security preservation schemes are used [66][67].

4. Conclusions

e usage of WSNs already provides remarkable advantages for various domains of human activity. Thanks to the ntinuous evolution of technology both the capabilities of sensor nodes will keep expanding and their anufacturing costs will become lower. This is the reason why the range of WSN applications is expected to carry on growing.

In this article, the utilization of WSNs in specific domains, namely military, environmental, flora and fauna, health, industrial, and urban, was examined via the investigation of corresponding typical examples, both novel and well-known ones. From this examination, it became evident that the usage of WSNs not only provides numerous advantages in specific domains when compared against the relative means and methods that were traditionally used, but it also introduces novel applications. Additionally, for various applications both the problems and solutions developed, were identified and discussed.

The combinational utilization of relative methodologies and tools will assist both the enhancement of existing applications and the development of novel ones. On the other hand, certain problems that obstruct the usage of WSNs, such as energy limitations, congestion, connectivity loss, inadequate coverage, low QoS, and susceptible security, will remain at the center of scientific research.

References

1. Akyildiz, I.F.; Su, W.; Sankarasubramaniam, Y.; Cayirci, E. Wireless Sensor Networks: A Survey. Comput. Netw. 2002, 38, 399–422.
2. Yick, J.; Mukherjee, B.; Ghosal, D. Wireless sensor network survey. Comput. Netw. 2008, 52, 2292–2330.
3. Arampatzis, T.; Lygeros, J.; Manesis, S. A Survey of Applications of Wireless Sensors and Wireless Sensor Networks. In Proceedings of the 2005 IEEE International Symposium on, Mediterrean Conference on Contro Automation Intelligent Control, Limassol, Cyprus, 27–29 June 2005; p. 719.
4. Warneke, B.; Last, M.; Liebowitz, B.; Pister, K.S. Smart dust: Communicating with a cubic-millimeter co r. Computer 2001, 34, 44–51.
5. Đurišić, M.P.; Tafa, Z.; Dimić, G.; Milutinović, V. A Survey of Military Applications of Wireless Sensor Networks. In Proceedings of the 2012 Mediterranean Conference on Embedded Computing (MECO), Bar, Montenegro, 19–21 June 2012.

Top Applications of IoT in the World

The most important characteristic of humans is that we can work with each other as a team and gain knowledge from each other. What if this was true for machines as well? What if they could interact with each other and share information and data. That would lead to a truly connected world! And that is the central concept of the Internet of Things. This concept just means a connected network of various devices that can collect data and share it with each other to obtain meaningful insights from the data. There are various applications of IoT in the modern world and these are so diverse that you cannot imagine.

There are endless possibilities for having an interconnected web of "things" that can interact with each other over the internet. IoT can be used for all types of applications ranging from connecting all the devices in your house to create a smart home or even connecting all the government and civic services in a city to create a smart city! Who knows, we may even have a smart world one day!

So let's see all these applications of IoT in different facets and industries of the world.

1. Smart Agriculture

Food is an integral part of life without which we cannot survive. However, it is an unfortunate fact that a lot of food is wasted in developed countries like America while people starve in poorer countries like Chad, Sudan, etc. One way to feed everyone is better agricultural practices which can be enhanced using IoT. This can be done by first collecting data for a farm such as soil quality, sunlight levels, seed type, rainfall density from various sources like farm sensors, satellites, local weather stations, etc. and then using this data with Machine Learning and IoT to create custom recommendations for each farm that will optimize the planting procedure, irrigation levels required, fertilizer amount, etc. All this will result in better yield or crops with a focus on reducing world hunger in the future. This is done very efficiently by SunCulture, which is an initiative by Microsoft AI for Earth.

2. Smart Vehicles

Smart vehicles or self-driving cars as they can be called are pretty dependent on IoT. These cars have a lot of features that are integrated with each other and need to communicate such as the sensors that handle navigation, various antennas, controls for speeding or slowing down, etc. Here the Internet of Things technology is critical especially in the sense that self-driving cars need to be extremely accurate and all the parts need to communicate with each other in milliseconds on the road. Tesla Cars are quite popular and working on their self-driving cars. Tesla Motors' cars use the latest advancements in Artificial Intelligence and the Internet of Things. And they are quite popular as well!!! Tesla Model 3 was the most sold plug-in electric car in the U.S. in 2018 with a total yearly sales of around 140,000 cars.

3. Smart Home

Maybe the most famous application of IoT is in Smart Homes. After all, who hasn't heard about connecting all the home applications like lighting, air conditioners, locks, thermostat, etc. into a single system that can be controlled from your smartphone! These IoT devices are becoming more and more popular these days because they allow you complete freedom to personalize your home as you want. In fact, these IoT devices are so popular that every second there are 127 new devices connected to the internet. Some popular ones that you might have heard have, or even have in your home, include Google Home, Amazon Echo Plus, Philips Hue Lighting System, etc. There are also all sorts of other inventions that you can install in your home including Nest Smoke Alarm and Thermostat, Foobot Air Quality Monitor, August Smart Lock, etc.

3. Smart Home

Maybe the most famous application of IoT is in Smart Homes. After all, who hasn't heard about connecting all the home applications like lighting, air conditioners, locks, thermostat, etc. into a single system that can be controlled from your smartphone! These IoT devices are becoming more and more popular these days because they allow you complete freedom to personalize your home as you want. In fact, these IoT devices are so popular that every second there are 127 new devices connected to the internet. Some popular ones that you might have heard have, or even have in your home, include Google Home, Amazon Echo Plus, Philips Hue Lighting System, etc. There are also all sorts of other inventions that you can install in your home including Nest Smoke Alarm and Thermostat, Foobot Air Quality Monitor, August Smart Lock, etc.

4. Smart Pollution Control

Pollution is one of the biggest problems in most of the cities in the world. Sometimes it's not clear if we are inhaling oxygen or smog! In such a situation, IoT can be a big help in controlling the pollution levels to more breathable standards. This can be done by collecting the data related to city pollution like emissions from vehicles, pollen levels, airflow direction, weather, traffic levels, etc using various sensors in combination with IoT. Using this data, Machine Learning algorithms can calculate pollution forecasts in different areas of the city that inform city officials beforehand where the problems are going to occur. Then they can try to control the pollution levels till it's much safer. An example of this is the Green Horizons project created by IBM's China Research Lab.

5. Smart Healthcare

There are many applications of IoT in the Healthcare Industry where doctors can monitor patients remotely through a web of interconnected devices and machines without needing to be in direct contact with them. This is very useful if the patients don't have any serious problems or if they have any infectious diseases like COVID-19 these days. One of the most common uses of IoT in healthcare is using robots. These include surgical robots that can help doctors in performing surgeries more efficiently with higher precision and control. There are also disinfectant robots that can clean surfaces quickly and thoroughly using high-intensity ultraviolet light (which is pretty useful these days!) Other types of robots also include nursing robots that can handle the monotonous tasks that nurses have to perform for many patients day in and day out where there is little risk to the patients.

6. Smart Cities

Cities can be made more efficient so that they require fewer resources and are more energy-efficient. This can be done with a combination of sensors in different capacities all over the city that can be used for various tasks ranging from managing the traffic, controlling handling waste management, creating smart buildings, optimizing streetlights, etc. There are many cities in the world that are working on incorporating IoT and becoming smarter such as Singapore, Geneva, Zurich, Oslo, etc. One example of creating smart cities is the Smart Nation Sensor Platform used by Singapore which is believed to be the smartest city in the world. This platform integrates various facets of transportation, streetlights, public safety, urban planning, etc. using sensors in conjugation with IoT.

7. Smart Retail

There is a way to make shopping even more exciting for customers and that's to use the latest tech like IoT of course! Retail stores can make use of IoT in a wide range of operations to make shopping a much smoother experience for customers and also easier for the employees. IoT can be used to handle the inventory, improve store operations, reduce shoplifting and theft, and prevent long queues at the cashiers. A prime example of this is the Amazon Go stores which provide an IoT enabled shopping experience. These stores monitor all their products using IoT so that customers can pick up any products and just walk out of the store without stopping at the cashier's queue. The total bill amount is automatically deducted from the card associated with the customer's Amazon account after they leave the store.

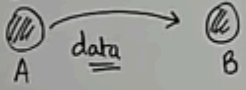
Conclusion

These are only some applications of IoT in the world that are the most popular. Actually, there is no limit to the application of IoT, especially when it is combined with other technologies like Machine Learning and Artificial Intelligence. This is especially true because the declining hardware costs make it feasible to embed sensors in just about any device imaginable thereby creating a connected IoT network. IoT has many applications in smart energy creation, manufacturing, supply chain management, wildlife conservation, etc. And maybe this expanding list of applications for IoT will lead to a smart world after all!

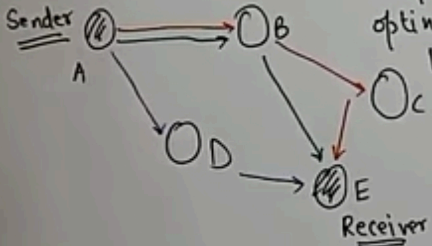
Article Tags : GBlog

ROUTING PROTOCOLS:-

Routing is the process of establishing a path b/w the sender and receiver nodes for transmitting the packet along the path.



Routing Protocol will find best optimum path.
↳ Shortest Path.



Design Constraints:-

(i) Mobility of nodes.
(ii) Dynamic topology.
(iii) No Centralised infrastructure.
(iv) Bandwidth
(v) Energy
(vi) Establishing end-to-end Constraints.

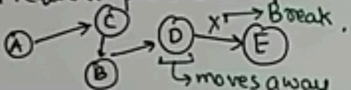
Characteristics:-

↳ i) Fully distributed
ii) Adaptive towards frequent changes → mobility.
iii) Route Computation and maintenance must involve min. no. of nodes.
iv) Packet collision must be minimum.

Issues in Designing Routing Protocols:-

(i) **MOBILITY:-** Nodes are dynamic.

↳ frequent path break

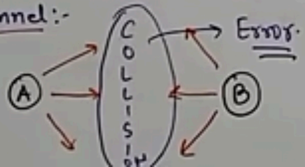


(ii) **Bandwidth Constraint:-**

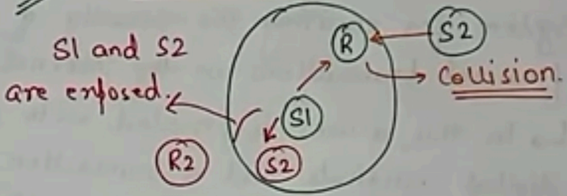
↳ Due to limited Radio Spectrum.

↳ Affects multiple access, interference Cond^n.

(iii) **Error-prone Shared Broadcast channel:-**



IMP (iv) **Hidden and Exposed Terminal Problems:-**

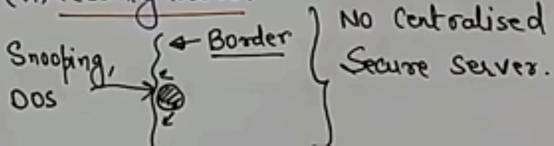


(v) **Resource Constraints:-**

↳ Sensor nodes.

↳ limited Battery, Processing power, memory and energy.

(vi) **Security Issues:-**



Types of AdHoc Routing Protocols:-

Routing Info^n update

obtain necessary path when required.

Conn^n establishment Process.

Proactive Routing

(Table-Driven Routing)

each node maintains a routing table.

↳ DSDV, STAR, CGSR.

Reactive Routing

(On-demand Routing)

no node maintains a routing table.

↳ DSR, AODV

Hybrid Routing

Combination of both (Pro. Rea.) Best features.

N/w is divided into zones.

↳ CEDAR, ZRP.

Types of AdHoc Routing Protocols:-

① Routing Info^n update.

obtain necessary path when required. } Conn^n establishment Process.

Proactive Routing
(Table-Driven Routing)
each node maintains a routing table.
↳ DSDV, STAR, CGSR.

Reactive Routing
(On-demand Routing)
no node maintains a routing table.
↳ DSR, AODV

Hybrid Routing
Best features. Pro. Rea.
Combination of both (Pro. Rea.)
N/w is divided into zones.
↳ CEDAR, ZRP.

② Temporal Info^n for routing.

Past History
↳ DSDV, AODV

Future.
↳ LBR

③ Topology Info^n

Flat
↳ DSR AODV

Hierarchial
↳ CGSR

④ utilization of specific resources

↳ Flooding
Geographical
Power aware.

Proactive Routing Protocols:-

Advantages:-

↳ Minimum time to find route.

Disadvantages:-

↳ Periodically infoⁿ exchange required.
↳ High N/w overload.
↳ High Bandwidth Consumption.
↳ Not suited for Large N/w.

Reactive Routing Protocols:-

Advantages:-

↳ Less broadcast Control msg. required.
↳ Low N/w overload.
↳ Low Bandwidth wastage.
↳ Suitable for Large N/w.

Disadvantages:-

↳ Time to discover route is non-predictable.

Hybrid Routing Protocols:-

→ **Advantages:-**

→ Requires less memory & processing Power.
↳ Adv. of both reactive and proactive Protocols.

→ **Disadvantages:-** → If the border nodes move away, re-establishing path takes long

Proactive Routing Protocols:-

Advantages:-

- Minimum time to find route.

Disadvantages:-

- Periodically infoⁿ exchange required.
- High N/w overload.
- High Bandwidth Consumption.
- Not suited for Large N/w.

Reactive Routing Protocols:-

Advantages:-

- Less broadcast control msg. required.
- Low N/w overload.
- Low Bandwidth wastage.
- Suitable for Large N/w.

Disadvantages:-

- Time to discover route is non-predictable.
- Requires less memory & processing Power.

Hybrid Routing Protocols:-

Advantages:-

- Adv. of both reactive and proactive Protocols.

Disadvantages:-

- If the border nodes move away, re-establishing path takes long time.

Parameter	Proactive	Reactive
Delay level	Small as routes are predetermined	High as routes are computed on demand
Control traffic	Usually higher than reactive	Increases with mobility of active routes.
Periodic updates	Always required	Not required
Route availability	Always available	Computed on-demand
Handling mobility	Updates occur at regular intervals	Localized route discovery is used
Scalability	Nearly up to 150 nodes.	Higher than proactive.
Storage requirement	Higher than reactive.	Depends on the number of required routes.
Communication overhead	High	Low
Route structure	Flat/Hierarchical	Flat, except CBRP
Bandwidth requirement	High	Low
Power requirement	High	Low

Comparison between proactive and reactive routing protocols [4] [10].