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Thème :

Application based on mobile wireless sensor network to establish field monitoring of a specific area and protect forest from fire

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At the end of this work, we would like to address our lively Thanks to our dear parents and for their sacrifices, help, support and encouragement during our study course.

AND I WANT TO THANCK ME TO BELIVE IN ME AND SUPPORT ME.

Dedication

I dedicate this modest work to my dearest mother, my dearest father who supported me in our studies may ALLAH protect them and keep them for me.

To my grandmother "Khadija" and that god will keep her for me.

To my dear sister "Roumaissa"who adviced and helped me during my path

To the whole Aliouat and Remache family

To my friends: -Zaki-Iyes²-Haroun-Fares-Riyad-Badrou-Zidane-Haitem-Soufiane-Khaled-Nour-Ismahane-Meryem-Asma

To all the Master 2 2022 promotion

To all the promotions that I have met

To all those who love me and all those whom I love AND ALSO THOSE HATE ME.

ALIOUAT NADER

Dedication

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I still remember the way he encouraged me and pushed me toward success

The light of my days, the source of my efforts, the flame of my heart, my life and my happiness my mother whom I adore. My God grant her good health and long life.

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All family members: Remache, Zouidi and Aliouat.

To all those who are dear to me.

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Abstract:

This work presented in this thesis relates to simulation in the framework of the OMNET program to control the spread of fires in forests or in any area we want, by deploying a mobile wireless sensor network, first, reference was made in this work to the definition and explanation of the sensor, its components, types, and also the way the wireless sensor network works and its types were description of the network simulation program Mobile wireless sensor OMNET and its use to clarify the method of fire detection, information exchange between drones and transfer to the main station to be processed

Key words:

Sensor, base station, wireless sensor network, fire detection method, simulation, UAV

Résumé:

Ce travail présenté dans cette thèse concerne la simulation dans le cadre du programme OMNET pour contrôler la propagation des incendies dans les forêts ou dans n'importe quelle zone que nous voulons, en déployant un réseau de capteurs mobiles sans fil, tout d'abord, il a été fait référence dans ce travail à la définition et à l'explication du capteur, de ses composants, de ses types, ainsi que du fonctionnement du réseau de capteurs sans fil et de ses types. Description du programme de simulation de réseau Capteur mobile sans fil OMNET et son utilisation pour clarifier la méthode de détection des incendies, l'échange d'informations entre drones et le transfert vers la station principale à traiter

Mots clés :

Capteur, station de base, réseau de capteurs sans fil, méthode de détection d'incendie, simulation, UAV

الملخص:

يتعلق هذا العمل المقدم في هذه الأطروحة بالمحاكاة في إطار برنامج ++OMNET للسيطرة على انتشار الحرائق في الغابات او في أي منطقة نريدها وذلك عن طريق نشر شبكة الاستشعار اللاسلكية المتنقلة تمت الاشارة اولا في هذا العمل إلى تعريف وشرح المستشعر, مكوناته, أنواعه وأيضا تم التطرق الى طريقة عمل شبكة الاستشعار اللاسلكية وبيان أنواعها ثانيا تم التطرق الى وصف استراتيجية التنقل في شبكة الاستشعار اللاسلكية وبيان طريقه التحكم فيها وذلك من حيث طريقة تنقل المحطة الرئيسية وتبيان التحديات والقيود الخاصة بها ثالثا تم شرح دور الطائرات بدون طيار في هذه الدراسة وطريقة التواصل بينها رابعا تم وصف برنامج محاكاة شبكة الاستشعار اللاسلكية المتنقلة ++ OMNET واستخدامه لتوضيح طريقة الكشف عن الحريق وتبادل المعلومات بين الطائرات بدون طيار ونقلها الى المحطة الرئيسية لكي تتم معالجتها

الكلمات المفتاحية:

المستشعر، المحطة الرئيسية، شبكة الاستشعار اللاسلكية، طريقة الكشف عن الحريق، المحاكاة، الطائرات بدون طيار

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Abbreviations List:

ADCs: Analog-Digital Converter

GPS: Global Positioning System

WSN: Wireless Sensor Network

SMTP: Simple Mail Transmission Protocol

HTTP: Hypertext Transfer Protocol

RF: Radio frequency

FTP: File Transfer Protocol

MWSN: Wireless Mobile Sensor Network

WPAN: Wireless Personal Area Network

WLAN: Wireless Local Area Network

WMAN: Wireless Metropolitan Area Network

BLR: Radio Local Loop

WWAN: Wireless Wide Area Network

GSM: Global System for Mobile Communication

GPRS: General Packet Radio Service

UMTS: Universal Mobile Telecommunications System

QOS: Quality of Service

BNEP: Bluetooth Network Encapsulation Protocol

SIDS: Sudden Infant Death Syndrome

ESNs: Environmental Sensor Networks

SRI: Stanford Research Institute

ADC: Analog to Digital Converter

RPGM: Reference Point Group Mobility

RVGM: Reference Velocity Group Mobility

RWP: Random Way Point

KDS: Kinetic Data Structures

KDM: knowledge-driven mobility

HCBM: Home-cell Community-Based Mobility

CBM: community-Based Mobility

TVC: Time-Variant Community

UAV: Unmanned Aerial Vehicle

VTOL: Vertical Takeoff and Landing

UAS: Unmanned Aerial System

GCS: Ground Control Station

FANET: Flying Ad-Hoc Networks

PRP: Proactive Routing Protocols

OLSR: Optimized Link State Routing

DSDV: Destination- Sequenced Distance Vector

HRP: Hybrid Routing Protocol

GPR: Geographic routing protocols

MAC: Medium access control

WiMAX: Worldwide Interoperability for Microware Access

GPRS: Radio Packet Radio Service

PPMAC: Position-Prediction-based directional MAC protocol

CR: Cognitive Radio

UNII: Unlicensed National Information Infrastructure

SUMMARY

Chapter 2: Mobile Wireless Sensors Network

Chapter 3: FANET

Chapter 4: Simulation

General introduction

General introduction :

Algeria and many countries around the world have witnessed in recent years a series of forest fires that have become a source of great concern, so that whenever summer approaches, both human resources and forest ecosystems are devastated. Some repercussions of this damage include climate changes and greenhouse effects. As a result, it is necessary to detect forest fires early to minimize the amount of damage they cause by using a mobile wireless sensor network.

Developments in wireless communications, microelectronics and the manufacture of small batteries for storing electrical energy have enabled the development of multifunctional sensors at low costs paved the way for wireless sensor networks to be today a basic technology in many fields, especially the field of pre-service environmental water leak detection, forest fire detection, and air quality measurement. Etc...

The implementation of a wireless sensor network involves the cooperation of many disciplines such as embedded systems, communications department, computer networks, and signal processing and distributed systems.

In the era of the Internet of things, MWSN is an essential infrastructure in the implementation of Smart Homes, Smart Mobility, Smart Cities, etc.…

Data collection is the main function of the MWSN aggregator

- Sensors are miniature independent devices that provide usable output in response to a specific size that the sensor acquires a physical quantity and converts it into a signal suitable for processing (e.g. optical, electrical, mechanical). The sensor node consists of a data processing and storage unit, a wireless transmission unit and a battery.
- WSN wireless sensor network is a dedicated network of base station base and sensor nodes to monitor physical and environmental parameters in several locations. The setups in WSN are limited in terms of processing speed, storage capacity and connection bandwidth.
- To prevent sensor nodes close to the base station from depleting their batteries quickly, mobility can be used as a method that allows improving network performance, is used for mobility, helps in data collection, and also ensures the conservation of resources, especially energy.

Mobility means the use of a mobile base station to solve the problem of data loss and communication resulting from the exhaustion of sensor nodes. This is called a mobile wireless sensor network, which will be the focus of our study in this research.

Our application model is based on a distributed algorithm of drones embedded in a network called FANET, which differs from existing Ad-Hoc networks. This network also has special characteristics, namely node mobility and localization models.

Proceeding from the above, we can raise the following problematic:

- ***The problematic:***

What are the methods used to develop a wireless sensor network when it detects a certain physical or natural phenomenon and is the use of drones useful to support the network

Proceeding from these problems, we can ask the following sub-questions:
What is the effective element of a wireless sensor network
Using a mobile base station is a network developer or not useful
How is UAV integrated into the MWSN network and how effective is it in covering areas isolated from the network.

- ***Importance of study:***

To clarify the relationship between the mobile wireless sensor network and indicate its role in many applications, especially in fire and environmental conservation.

- ***Purpose of the study:***

To show the importance of sensors in our time and to indicate their role and importance in many of the applications that we have discussed previously.

Shed light on the concept of WSN and indicate its role in covering places that are not reached by the network or what is known as static places

Chapter 1:

The sensors and networks

1.1. Introduction:

We live in a sensor world. You can find different types of sensors in our homes, offices, cars, etc. by turning on the lights, detecting our presence, adjusting the room temperature, detecting smoke or fire, tasting us making coffee, turning on as soon as our car is in front of the door Garage doors and many other tasks. From this point of view, it is very important to understand what a sensor is.

1.2 Definition of the Sensor:

According to American National Standards Institute:

- A device which provides a usable output in response to a specified measured

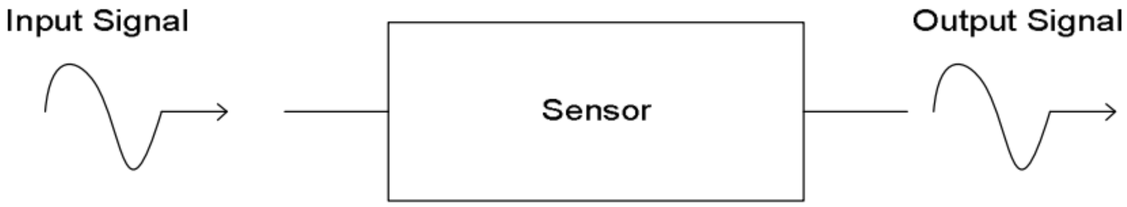


Figure 1.1: Definition of the sensor

• A sensor acquires a physical quantity and converts it into a signal suitable for processing (e.g. optical, electrical, mechanical)

• Nowadays common sensors convert measurement of physical phenomena into an electrical signal

• Active element of a sensor is called a transduce

A wireless sensor is a small, inexpensive electronic device with limited sources of energy (battery), computing power and storage capacity. A sensor has the ability to measure an environmental physical value such as temperature, light, pressure, etc. and transmit it using wireless communications to a control center called a base station. The sensor nodes can be deployed in any application whose objective is to monitor environment.

A sensor is composed essentially of:

- **The acquisition unit:** generally composed of two subunits which are the sensors and the analog-to-digital converters ADCs (Analog-Digital Converter). The sensors collect the physical quantities and provide analog signals. ADCs convert these analog signals into digital signals
- **The processing unit**: composed of two interfaces, one interface with the acquisition unit and another with the transmission module. This unit controls the collaboration of a node with the other nodes in order to collect and store given.
- **A communication module (Transceiver):** Composed of a transmitter and a receiver allowing communication between the various nodes of the network via a radio communication medium.

- **Battery:** used to power the units mentioned above, generally it is neither rechargeable nor replaceable. The limited energy capacity at the sensor level represents the main constraint when designing routing protocols for sensor networks.

There are sensors that include additional units: power generator, mobile unit to move the sensor and a location system.

- **The node location system:** In several applications, it is necessary for a sensor node to be able to determine its geographical position. In this case, the sensor must be equipped with a GPS (Global Positioning System) geographical location system or a software module which implements location algorithms that provide information about the position of the node by distributed calculations.
- **The mobile unit:** A sensor node can be equipped with a mobility system responsible for moving it to accomplish its tasks. The mobility support requires extensive energy resources that should be provided efficiently. The mobile unit can also operate in close collaboration with the detection and the processor to control the movements of the node.

1.3. Classification of the Sensors

Sensors are divided into two categories: proprietors and receptors, with active and passive receptors. Something inside the robot is measured by proprioceptive sensors. The most famous example is a car's speedometer, which counts the number of wheel spins to determine the vehicle's speed. External perception sensors measure the distance between the robot and an object. Active sensors output energy into the environment, such as sonar rangefinders aboard submarines, which use reflected sound to estimate distance. The environment is unaffected by passive sensors; the camera just records the light reflected by objects. External receptors are always used by robots to remedy faults caused by proprietors or to account for changes in the environment. **[1]**

1.4. Sensor's characteristics

The sensor creates output after receiving input stimuli, which is gained through numerous conversion steps before producing an electric signal. The relationship between input and output is used to describe sensor performance.

Types	Properties
Thermal sensor	Temperature, heat, flow of heat Resistance.
Electrical sensor	Current, voltage, inductance.
Magnetic sensor	Magnetic flux density, magnetic moment.
Optical sensor	Intensity of light, wavelength, polarization.
Chemical sensor	Composition, pH, concentration.
Pressure sensor	Pressure, force.
Vibration sensor	Displacement, acceleration, velocity.
Rain/moisture sensor	Water, moisture.
Tilt sensors	Angle of inclination.
Speed sensor	Velocity, distance.

Table 1.1: Based on their detection properties Sensors.

Signals. Sensors are characterized depending on the values of some important parameters. The characteristics of sensors are described here in this section.

1.5. Wireless Sensors network

1.5.1. Wireless Sensor Networks: An Overview

A wireless sensor network (WSN) is an ad hoc network of geographically distributed devices (mote) that use sensor nodes to monitor physical or environmental parameters in several locations. The devices in a WSN are limited in terms of processing speed, storage capacity, and communication bandwidth. In most situations, the network must run for a long time, but because the nodes are powered by batteries, their entire operation is limited. Most components of the gadget, including the radio, should be switched off the majority of the time to save energy. Another noteworthy aspect is that the sensor nodes collectively, but not individually, have tremendous processing power. Nodes must band together to operate and maintain the network, which is far more challenging than handling individual devices. Furthermore, changes in the physical environment in which a network is implemented cause vast differences in connectivity among nodes, which has an impact on networking protocols. **[2]**

1.5.2. Communications

For the Physical (PHY) and Medium Access Control layers, WSNs follow the 802.15.4 specifications. The Network (NWK) and Application (APP) layers of the communication stack are either proprietary or mandated by exclusive alliances such as Digi Mesh or ZigBee. However, because these protocols are not open source and are not supported by all sensor devices, interoperability concerns arise between different hardware vendors. Using IP to link WSNs is an alternative method. The Internet layer is made up of a number of protocols that are in charge of transporting packets from a source site to a specific destination based merely on the address. TCP/IP is, of course, the most widely used protocol in global communications; most online activities, such as web browsing (Hypertext Transfer Protocol-HTTP), email transmission (SMTP-Simple Mail Transmission Protocol), file transfer (FTP-File Transfer Protocol), and remote access (all use TCP/IP protocols) (Telnet). Our research seeks to integrate TCP/IP with WSNs to offer Internet access to online services such as e-mailing, long-distance remote capabilities, live data streaming, and Over the Air Programming (OTAP) on sensor nodes. **[3]**

1.5.3. Networking

Data transmission is a two-step procedure that includes an outgoing transmitter and an incoming receiver. Radio frequency (RF) is the communication channel used in wireless networks to connect network devices and exchange information. Wired networks, on the other hand, use technologies like Ethernet over twisted pair to communicate between networked systems. WSNs are made up of a large number of sensor nodes connected by low-power radio modules that, unlike standard wireless devices found in our computers, spend the majority of their time sleeping or inactive. Our research intends to create a wireless mesh sensor network (WMSN). This sort of network maintains long-distance communications homogeneity by breaking connecting links into a series of smaller hops, allowing intermediary nodes to make cooperative forwarding decisions depending on the network topology. We also want to link the WMSN to an IP network to boost application capabilities including live sensor data access, web server support, Secure Shell (SSH) connections, and cloud storage.

1.5.4 Management

Our work focuses on two management techniques:

a) Node management

b) Network management.

A) Node management:

We aim to implement management strategies which improve performance, reliability and stability of sensor nodes. These strategies include:

1. Low-Power alarm utilization: This first technique is used to monitor battery levels in sensor nodes in general, but we want to implement the concept of dynamic threshold configurability, which means that tasks will only be completed when battery levels are above a particular threshold. This strategy is used to promote task independence from one another, preventing nodes from becoming trapped in infinite loops when tasks fail to complete owing to a lack of available energy.

2. Normal, deep, and hibernation are the three sleep types available. The quantity of power consumed while in an active state is the difference between them. Because node components are fully separated from the power supply in deep sleep and hibernation

modes, they have superior power efficiency than standard sleep. These modes will be used to improve battery efficiency and extend the life of each node.

3. Algorithm integration: We want to use algorithms to help with the execution of various activities and functions in the program. We intend to create algorithms that will help generate warning signals in emergency situations, enable radio communication during OTAP operations, and regulate the sensing architecture required by the application.

4. Prioritization of events: We want to put in place a task management system based on priority and importance levels. This strategy will allow nodes to respond more quickly to events in their immediate environment. For example, if a node detects fire at the same time it has to access the SD module, it must decide whether triggering an alarm or saving data is more important. We need to tell the node that if a fire is detected, it should send an alarm message first before saving data to the SD card. We also want to use event management approaches to manage all elements of node functionality and tasks administration.

B) Network management:

We aim to provide a modern approach on WSN management by using various techniques for:

a) accessing/storing sensor data

b) Using secure transmission between networked devices

c) Synchronization of tasks in real time. The methods we use for implementing these techniques are:

- Cloud storage: We want to use a cloud-based network to store data from many WSNs.
- Encrypted data transmission: In a WSN, unsecure data transfer results in unpredictable and unreliable operations. Attacks against the WSN can take several forms, including: a) data manipulation to fool the network into doing something else (e.g., false alarms), b) overwhelming the network with packets, resulting in network failure, or c) stealing data and using it for personal advantage. Security solutions that allow networks to distinguish between actual and foreign nodes can help to mitigate these difficulties. In order to strengthen the security of WSNs, we want to introduce application and link level features. Application-level security refers to communication between nodes within an application, not across a network, whereas link security refers to the encryption of data-payload prior to transmission, and the only way a networked device can make sense of the data is if the encryption key is known beforehand.
- Real-time system: Every networked device, including all node components, sensors, and radio transmission, is synchronized in real time in a real-system. This means that WSNs only respond to specific commands and do not interfere with normal network operations. These commands could include things like retrieving sensor data, changing operating channels, transferring data to a website, or performing device maintenance. We want to build a system that can do a variety of real-time tasks, such

as alarm production, over-the-air programming, database and web server support, e-mail messaging, and online publication (twitter, word-press, etc.).

1.6. Types of wireless networks:

There are several categories of wireless networks that differ in the geographical scope they cover, as well as in the types of applications supported. The following diagram illustrates the categories of wireless networks :

1.6.1 The wireless personal network (WPAN):

It concerns wireless networks with a short range: on the order of a few tens of meters. This type of network is usually used to connect peripherals (printer, mobile phone, home devices, PDA...). There are several technologies used for WPAN such as:

- **Bluetooth technology:** Is also known as the IEEE 802.15.1 standard, it was launched by Ericsson in 1994, offering a theoretical rate of 1 Mbps allowing it to transmit. **[4]**
  Bluetooth is a low-cost technology, thanks to its strong integration on a single 9 mm by 9 mm chip **[6]**; it also has the advantage of working on low-power devices, resulting in low power consumption **[4].**
  Voice, data and images , **[5]** with a maximum range of about thirty meters **[4].**
  Bluetooth is a low-cost technology, thanks to its strong integration on a single 9 mm by 9 mm chip ; **[6]** it also has the advantage of working on low-power devices, resulting in low power consumption **[4].**
- **ZigBee technology:** It is also known as the IEEE 802.15.4 standard, makes it possible to obtain low-cost wireless links with very low energy consumption, which makes it particularly suitable for being directly integrated into small electronic devices (sensors,household,appliances...)**[4]**
  ZigBee networks make it possible to offer data rates up to 250 KBS in the classic 2.4GHz band. RCSF is one of the applications that this standard can cover.**[4]** Allow to create wireless links.
- **The infrared links:** Of a few meters, with data rates that can rise to a few megabits per second. This technology is widely used in home automation (remote controls), and however suffers from disturbances due to light interference.

1.6.2 The wireless local area network (WLAN):

It is a network that allows you to cover a range of about a hundred meters. It makes it possible to connect the terminals present in the coverage area to each other. There are two competing technologies:

- **Wi-Fi networks (Wireless-Fidelity)**: Come from the IEEE 802.11 standard, which defines a cellular architecture. There are mainly two types of wireless networks: Those that work at the speed of 11 Mbps at 2.4 GHz (IEEE 802.11b) and those that go up to 54 Mbps at 5 GHz (IEEE 802.11 a/g).

- **HiperLAN 2 networks (High Performance LAN 2.0):** It are derived from the European standard developed by the ETSI (European Telecommunications Standards Institute). HiperLAN 2 makes it possible to obtain a theoretical data rate of 54 Mbps over an area of one hundred meters in the frequency range between 5,150 and 5,300 MHz **[4].** This type of network has not received as much success as Wi-fi technology.

1.6.3 The wireless metropolitan area network (WMAN):

Also known as Radio Local Loop (BLR). It should be remembered that the BLR allows, by placing a satellite dish on the roof of a building, to transmit voice and high-speed data over the air for Internet access and telephony. There are several types of WMAN networks, the best known of which is:

The WMAN network (Worldwide interoperability for Microwave Access):

They emanate from the IEEE 802.16 standard and are intended to develop microwave links competing with terrestrial xDSL techniques and offer a useful throughput of 1 to 10 Mbit / s in the 10-66 GHz band for a range of 4 to 10 kilometers, which is mainly intended for telecommunications operators.

1.6.4 The wireless wide area network (WWAN):

The cellular mobile network is the most widely used, because all mobile phones are connected to a wireless wide area network. The following are the most important technologies: GSM (Global System for Mobile Communication), GPRS (General Packet Radio Service), and UMTS (Universal Mobile Telecommunications System) are acronyms for Global System for Mobile Communication, GPRS (General Packet Radio Service (Universal Mobile Telecommunication System).

1.7. Communication Protocols Wireless Sensor Network for Network Layer

1.7.1 Direct Transmission Protocols

Each sensor communicates directly with the base station via a direct coordinate communication protocol. If the sensor node is far away, coordinate communication will necessitate a substantial amount of transmit control from each bridge, which will quickly deplete the sensor's battery and reduce or eliminate the system's lifetime. However, while the gatherings in this protocol occur because the base station is close to the node and receiving information is costly, it may be a good mode of communication.

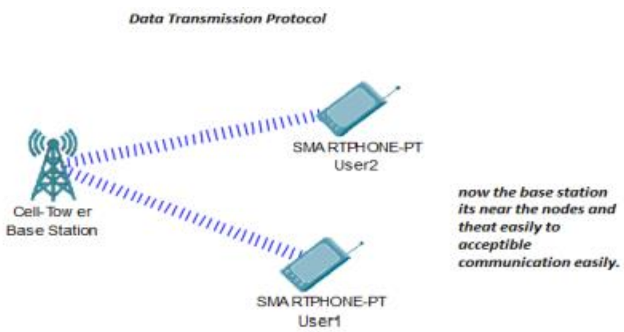


Figure 1.2: Data Transmission Protocol [Near Base Station].

As you can see, the nodes are extremely close to the base station, thus if the base station is close to the nodes or the energy required to receive data is high, this could be a viable communication mechanism.

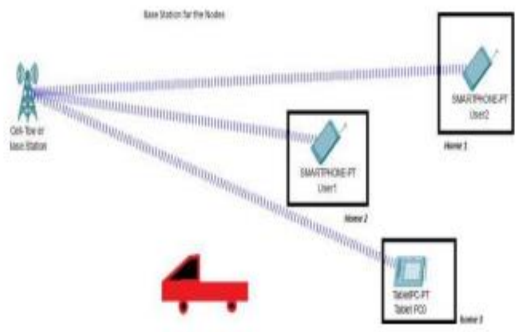


Figure 1.3: *Data Transmission Protocol [Near Base Station]*

If the base station is far away from the nodes, direct communication will require a large amount of transmit power from each node. This will quickly drain the battery of the nodes and reduce the system lifetime.

1.7.2 Clustering Protocol

Aggregation is the most recent wireless sensor network protocol for cable networks, in which nodes are arranged into groups or clusters that communicate with local base stations, which broadcast data to international bases where it is accessible to end users. As a rule, the local base is close to all cluster nodes, reducing node distance and the requirement to transfer data. As a result, concentrations appear to represent a communication mechanism for energy efficiency. Cluster Head in WSN for Lifetime Efficiency: A steering convention oversees the information transit from one sensor hub to the next. WSN supports a variety of routing protocols. Furthermore, these guiding conventions have a wide range of objectives. A handful of these conventions deal with the Quality of Service (QoS) in information exchange between hubs. The Cluster-Tree structure is made up of several single clusters.

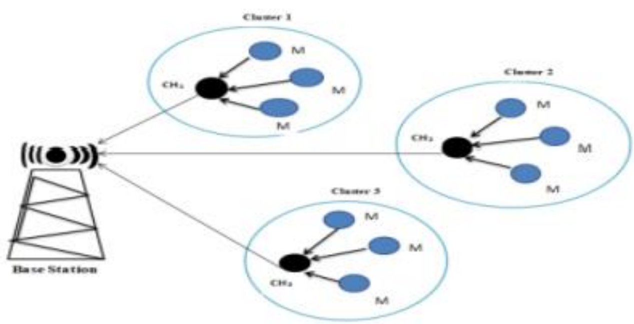


Figure 1.4: Cluster Head for Lifetime Efficiency in WSN

The Cluster-Tree organize has a unique hub called Assigned Gadget (DD), which is connected to these specific clusters and serves as the organize coordinator. Each cluster has a cluster-head, which is responsible for assembling the cluster and contacting the remote sensor hubs to connect it. As a result, this cluster-head executes more activities than any other traditional hub inside the cluster, perhaps causing it to spend more vitality than the other traditional hubs. As a result, moving a portion of the cluster-head from one hub to another will diffuse cluster-head activities and save more energy, perhaps increasing the hubs' and the arrangement's lifetimes Within WSNs, there are several regulating conventions connected to clustering directing conventions. One of the most often used clustering methods is Low Energy Adaptive of Clustering Hierarchy (Leach). A few hubs in Filter accept the role of cluster-heads. These sensor center points will choose a subjective number between zero and one; if this number is less than the center's limit esteem, the center will act as a cluster-head. In any event, there are two disadvantages to following this convention. To begin, Channel assumes that the imperativeness levels of the inaccessible sensor center locations within the organization are the same for each center, allowing any center to operate as a cluster-head. Based on the transmission schedule, assume that each hub has information to communicate to the base station at all times. Control Productive Gathering in Sensor Data Frameworks is another clustering convention (PEGASIS). As an update to LEACH, PEGASIS is recommended. Clusters are the designs that are influenced by the distant sensor hubs. In PEGASIS, each hub can communicate with its neighbors as if it were converted to them. This convention, on the other hand, assumes that each hub has the ability to connect directly to the base station, which isn't always possible. PEGASIS also believes that each hub will have a database to store data on its neighbors' areas, which will lead to more frequent requests for them. In a Cluster Tree: The Cluster-Tree topology, which is built-in the ZigBee standard, is one of the most notable big clustering traditions. The Cluster Tree tradition is a self-organized tradition that supports arrange repetition to arrange the fault strength within the arrange. Bundle transactions are used in the Cluster-Tree convention to create either a single cluster orchestrate or a multi-cluster network. The cluster course of action is divided into two stages: determining the cluster-head and expanding connections to the other hubs in the system. In any event, because there was one fixed hub operating as a cluster-head over the whole arrange lifetime, there is one in each cluster.

1.7.3 Leach Protocol

The Filter computation is a well-known steering calculation for WSN. Filter computation is an extension of the Low Energy Versatile Clustering Chain of command, which is a TDMA-based MAC protocol at WSN that coordinates with clustering and simple steering rules. The purpose of the LEACH computation is to lower the amount of energy necessary to create and maintain clusters in order to increase the lifetime of WSN. Much research is currently being done to generate steering computations in order to extend the lifetime of sensors from the Remote Sensor Arrangement (WSN). Level conventions and progressive conventions are the two types of steering procedures based on the arrange structure. The Moo Vitality Versatile Clustering Progression (Filter) computation is one of the most often used leveling standards. The cave layer low energy adaptive clustering hierarchy is proposed in this study as a Two Layer Filter based on range Parcel (TLLEACH-P) directing calculation based on the Filter directing calculation. Leach is a self-organizing, flexible clustering algorithm that employs sorting to distribute the energy load evenly across the sensors in an orderly fashion. In filter, the nodes form a close cluster, with one node acting as the cluster head or neighborhood base station. Leach is made up of a high-energy nonlinear cycle that changes the position of the head cluster, for example, by combining a rain sensor with a battery sensor.

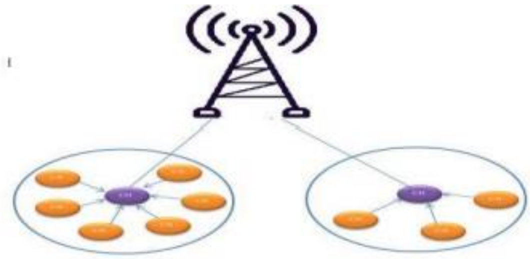


Figure 1.5: A base station's communication cluster Head and Node It indicates that the calculation provided in this study has a better fit, reduces unnecessary vitality loss, and improves vitality consumption.

1.8 Communication Protocols Wireless Sensor Network for Data Link Layer

1.8.1 Medium access control

The OSI model presents medium access control (MAC) as a sublayer of the data link layer. Frame delimitation and recognition, addressing, data transmission from upper layers, error protection (usually utilizing frame check sequences), and arbitration of access to a single channel shared by all nodes are the key responsibilities of the MAC layer. To enhance longevity, WSN MAC layer methods must be energy efficient. Protocols must also be scalable to the network's size and respond to network changes such as the addition of new nodes, the death of existing nodes, and transient noise on the wireless channel. Because the sensor nodes will eventually expire when the battery dies, one frequent goal of WSN research is to extend the network's life. Collision, eavesdropper, controller packet overload, idle eavesdropping, and excessive broadcast are all examples of MAC strategies proposed in the literature to reduce the main sources of power consumption in WSNs. **[6]**

1.8.2 Bluetooth a suitable protocol for WSNs

Bluetooth was originally designed as a short-range connection replacement option for 802.11b, with differences in inclusion, data rate, power consumption, and calculating assets. Bluetooth has recently progressed to a standard capable of enabling more complex impromptu groups with specific requirements, particularly WSNs. The benefits and drawbacks of using Bluetooth in sensor networks are studied, with the conclusion that it is a good choice for applications with rare information travelling at high rates. They conclude that Bluetooth is a capable convention suitable for WSNs after evaluating power usage in impedance strong situations and going from baseband to BNEP (Bluetooth Network Encapsulation Protocol). The synchronization reference for each node in the BSB technique is a snapshot of the gathering of a Bluetooth broadcast message (independent of the contents in it). It is located in the small difference found in the postponements of the advising messages that warn the Bluetooth have (hub) about the transmission collection. Each useful packet delivers information. A vulnerability window is also observed while commencing each space to overcome misalignments between resynchronizations. **[7]**

1.9. Communication Protocols Wireless Sensor Network for Application:

1.9.1 Medical/Health Applications

WSNs have health/medical benefits in the areas of diagnostics, analysis, and drug organization, as well as supporting interfaces for the weakened, incorporated patient monitoring and the board, tele-checking of human physiological data, and following and observing clinical professionals or patients inside the clinical office. According to Nwankwo et al., biosensors are currently being used in clinical applications to advance Nano informatics and Nano medicine. Using WSN, five model designs were produced for applications such as darling observing, alarming the hard of hearing, circulatory strain checking and following, and firefighter sign checking. Because a small percentage of newborns die from sudden infant death syndrome (SIDS), Sleep Safe is designed to keep an eye on them as they sleep. It recognizes an angel's napping position and warns parents when their newborn infant is laying on its tummy. Rest assured. **[8]**

1.9.2 Environmental Applications

The name "Environmental Sensor Networks (ESNs)" was coined to describe a few of the benefits of WSNs in nature and geology research. This includes finding seas, oceans, glacier masses, temperature, volcanoes, and forests, among other things. In any event, certain biosensors have already been developed for use in rural and environmental sustainability. Air tainting observation and the executives, timberland fires revelation/identification, nursery (GH) checking and the board, and Landslide disclosure/location are some additional significant perspectives. Natural observation has long been a key component of Wireless Sensor Network applications. It evolves in general in tandem with the advancement of continual innovation. Climate boundaries such as temperature, moisture, light, and tension are typically controlled and screened by ecological checking frameworks. There are a few studies that focus on natural observational applications. A few analysts approach the problem with an open mind, examining the tradeoff between apparatus cost and sensor organization lifetime to ensure non-critical failure adaption in three-dimensional situations. Developed multi hop correspondence applications, implying that temperature and moisture information would be sent to a neighbor hub and then sent to the end client PC. **[9-10]**

1.9.3 Agricultural-Applications

WSNs have been used to assist ranchers in a variety of ways, including wiring maintenance in a hazardous climate, water system automation, which allows for more creative water use and waste reduction. Wireless sensor networks (WSN) are now widely used in horticulture observation to improve the quality and utility of growing. In this application, sensors collect several types of data (such as stickiness, carbon dioxide level, and temperature) over time. As a result, to avoid poisonous adversaries, information social occasion, transmission, and rapid adaptation to new conditions necessitate a tightly bound information component. The constructed model considers valuable viewpoints, sensor hub design, as well as the necessity to conserve energy while maintaining data security, and advances the model through the use of authoritative and specialized methods. In terms of energy usage, the model assessment is guided by recreation. **[11]**

1.9.4 Traffic Monitoring

A magneto-resistive sensor integrated into the sensor node analyzes changes in the Earth's magnetic field induced by the presence or passage of a vehicle near the node.

1.10. Conclusion

Wireless sensor networks are a new and innovative technology which is of great interest due to its usefulness in various fields. However, there are still many problems that need to be solved in this area In order to be able to use them in optimal conditions. One of the problems that we may encounter in this type of network is the energy consumption at the sensor level when transferring data to a mobile terminal that may be remote of the latter. As a result, many works have been interested, first, in the problem of energy saving at the sensor level and improving the service life of the network. In the next chapter, we will explore mobility-based techniques to save energy in WSNs.

Chapter 2:

Mobile Wireless Sensors Network

2.1 Introduction:

The sensor nodes in the area of a permanent base station become exhausted due to the concentration of data flow around it. The usage of mobile base stations is recommended to solve the problem of data loss and connectivity caused by the exhaustion of sensor nodes that route the acquired data to the stationary base station. Mobile base stations provide implicit load balancing, which helps the network consume energy more efficiently. A vehicle fitted with an instrument to collect data from sensor nodes or a remote guiding drone that moves from one bridge to another to gather data can be used in such a network. The mobility of rocks is the subject of this chapter. We'll also discuss the fuck station's mobility models in WSNs.

2.2. Evolution of Networking:

The US Department of Defense's Advanced Research Projects Agency Network (ARPANET) commissioned a research project in the 1960s to connect academic and research institutions across the country for scientific partnerships. The University of California, Los Angeles (UCLA) and Stanford Research Institute exchanged the first message (SRI). Slowly but steadily, more organizations joined the ARPANET, and numerous smaller independent networks sprang up. The timeline depicts a few of the significant milestones in the amazing voyage of computer network evolution:

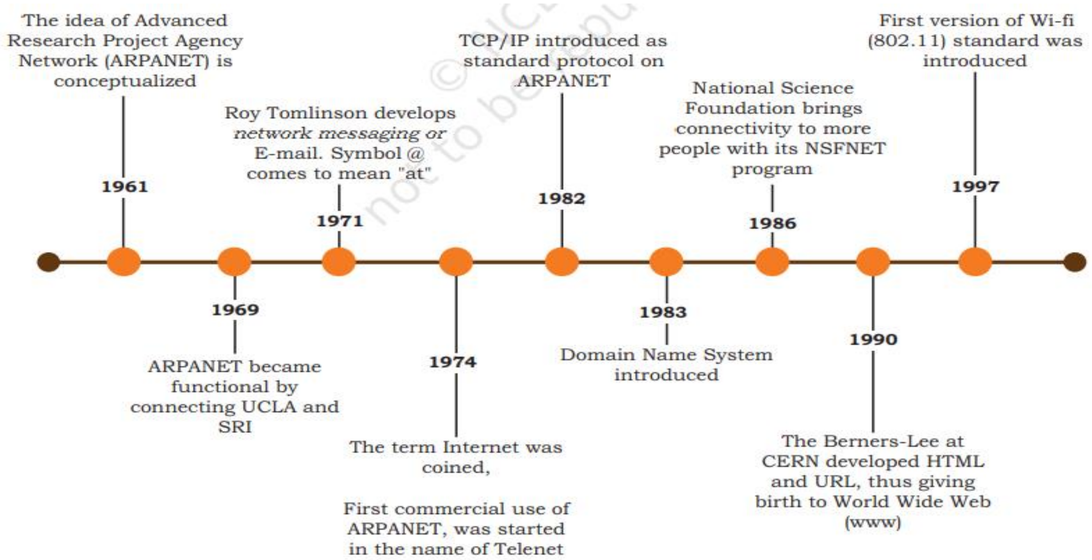


***Figure 2.1*:** the timeline of computer network evolution

2.3 Design challenges of MWSNs:

Hardware cost, system architecture, deployment, memory and battery size, processing speed, dynamic topology, sensor node/sink mobility, coverage, energy consumption, protocol design, scalability, localization, data/node centric, network heterogeneity, node failure, QoS, data fusion/redundancy, self-configuration, cross layer design, balanced traffic, fault tolerance, wireless connectivity, programmability, and security are some of the major design challenges for MWSNs **[12-14].**

2.4 Mobile sensor node architecture

Sensor nodes typically include one or more sensors (temperature, light, humidity, moisture, pressure, luminosity, proximity, and so on), as well as a microcontroller, external memory, radio transceiver, analog to digital converter (ADC), antenna, and battery. Because of their compact size, the nodes have restricted on-board storage, battery power, computation, and radio capacity **[15]** The mobile sensor node architecture, on the other hand, is essentially identical to that of a traditional sensor node. However, for mobile sensor nodes, additional devices such as localization/position finders, mobilizers, and power generators are considered. Figure 2.2 depicts the mobile sensor node's architecture. The sensor node's position is determined by the location or position finder unit, and the sensor node's mobility is provided by the mobilizer. The power generator unit is in charge of generating power to meet the sensor node's additional energy requirements using various ways such as solar cells.

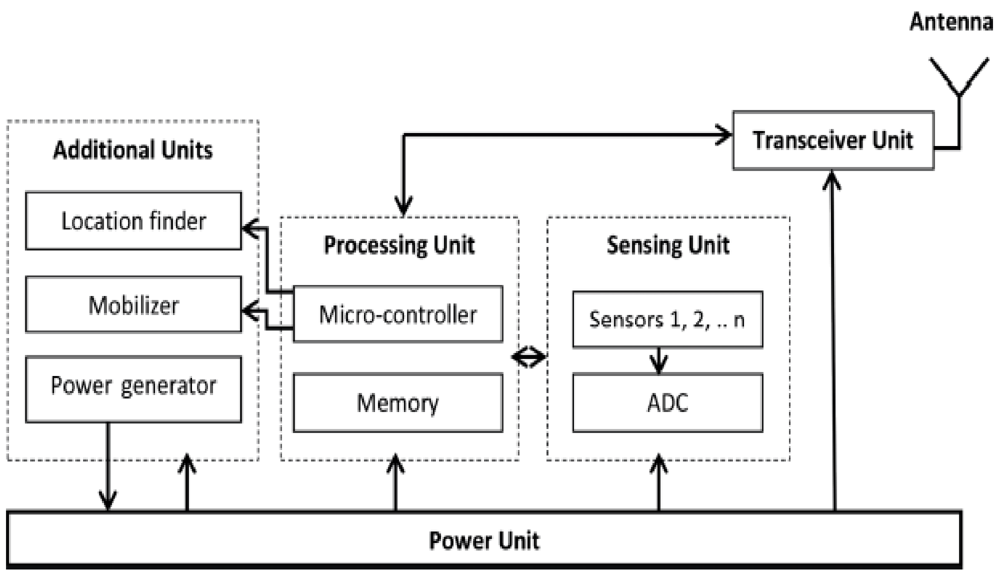


Figure 2.2: Architecture of the mobile sensor node

2.5. General characterization of mobility in WSNs

We can classify mobility in WSNs according to:

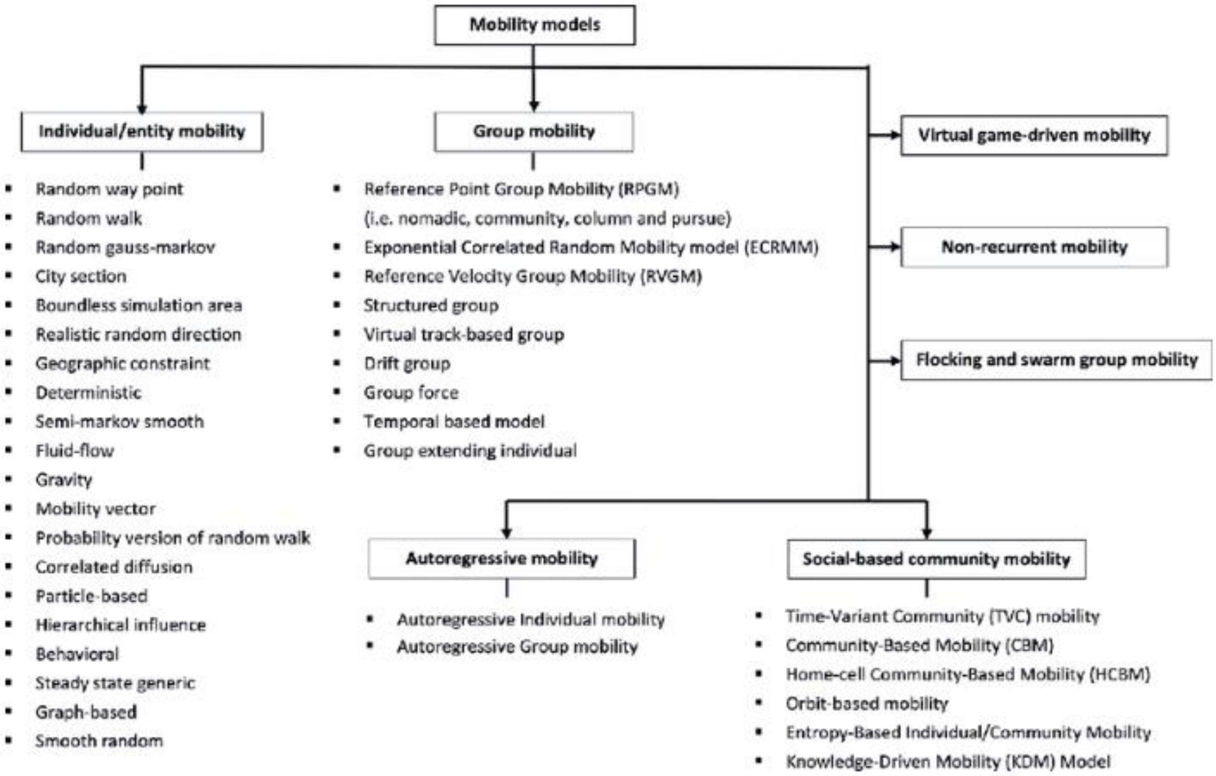


Figure 2.3: Classification of mobility models based on their areas.

The mobility models can also be classified into the following areas **[16]**:

- **Individual/entity mobility models:** Indicates the particular mobile node's mobility pattern. Random waypoint, random walk, random Gauss-Markov, city section, boundless simulation area, realistic random direction, probability version of the random walk, geographic constraint, deterministic, semi-Markov smooth, widow, gravity, mobility vector, correlated division, particle-based, hierarchical influence, behavioral, steady state generic, graph-based, and smooth random mobility models are just a few examples.
- **Group mobility models:** Cooperative groupings behave in unison to move towards or away from mobile nodes. The mobile nodes' movements are not independent of one another in this case. In addition, the function specifies whether the mobile nodes are linked to a target or a group leader. Reference point group mobility (RPGM) (i.e., nomadic community, column, and pursue), exponential correlated random mobility model (EC RMM), reference velocity group mobility (RVGM), structured group, virtual track-based group, drift group, group force, temporal based model, and group extending individual mobility models are among the many group mobility models available.

- **Autoregressive mobility models:** The mobility pattern of a single sensor node/group of sensor nodes that correlates mobility status and includes position, velocity, and acceleration at several time instants. Autoregressive individual mobility model and autoregressive group mobility model are two examples of such models.
- **Flocking and swarm group mobility models:** A coordinated action by many cooperating mobile agents to achieve a common goal. Ants, bees, fish, birds, penguins, and crowds are examples of agents. A coordinated movement task done by dynamic mobile nodes or mobile agents over self-organized networks of nature in a flocking mobility model. The flocks/groups/schools' self-organizing features provide more insight into MWSN design. Because the random walk (RAW) and random way point (RWP) models are unsuitable for realistic surroundings, the swarm group mobility model is presented to generate realistic motions of live beings or objects guided by psychology behaviors, physics, and perception mimicking.
- **Virtual game-driven mobility models:** Individual/groups of mobile sensor nodes are characterized from real time to virtual agents cooperating with other groups of mobile users based on user requirements. It simulates the user's, group's, communication, and environment's real-world qualities. For the simulation of mobility, a virtual world is employed, which encompasses all elements of mobility models.
- **Non-recurrent mobility models:** Mobility of nodes on an unknown path of previously unrepeatable patterns. Let's say the mobile nodes are moving data objects that are constantly changing their topology. When the mobility of the data object can be denoted as a polynomial of time to gather the non-recurrent mobility pattern of the object, kinetic data structures (KDS) are proposed to capture a continuous moving data object in an information database. KDS can be imagined completely or partially. Soft kinetic data structures also capture random mobility (SKDS). Property testing and reformation keep KDS and SKDS' approximate geometric structure up to date.
- **Social-based community mobility model:** Each mobile sensor node is regarded a member of a community cluster, with different communities making up an overarching society. The model must be able to capture non-homogeneous actions in both space and time that are ordinarily known with confidence. Time-variant community (TVC) mobility, community-based mobility (CBM), home-cell community-based mobility (HCBM), orbit-based mobility, entropy-based individual/community mobility, and the knowledge-driven mobility (KDM) model are only a few examples.

2.6. Mobility of the base station

In wireless sensor networks, many nodes of sensors transmit the collected data to the base station via multi-hop communications. The sensor nodes that are close to the base station exhaust their energies much faster than the remote sensor nodes because they have a very large traffic load. This phenomenon is called the funnel phenomenon (hotspot or funneling problem). This is due to the fact that they transmit their own data as well as the data of remote sensor nodes, thus causing the depletion of the network lifetime.

According to the data transmission model named multi-hop represented in Fig. 2.4, the data packets are sent to the base station thanks to the different node's intermediate sensors. The sensor nodes closest to the base station deplete their energy faster than the remote nodes, while the most distant, their energies can last longer. The reason is simple, compared with the sensors far from the base station, the nearest sensors, involved in several paths (sensor-base station), have a high load of message relays, and thus they consume more energy. If the sensors around the base station exhaust their energy, a large amount of data cannot reach the base station. The latter remains isolated from the network because the replacement or replacement of the sensor battery is often difficult or even impossible in some cases. This leads to a severe degradation of network performance. Thus, the single-hop sensor nodes of the base station will need more computing and communication resources to ensure this relay function for the other sensor nodes that are far from the base station. **[17].**

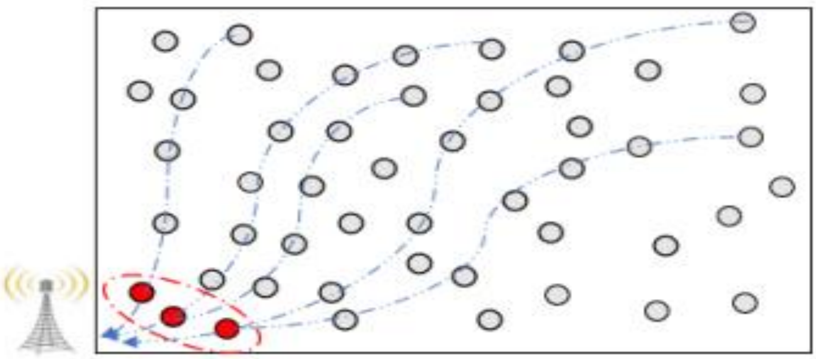


Figure 2.4: Multi-hop communication and the funnel phenomenon (hotspot).

In Fig.2.4, the circled sensor nodes are denoted as heavily loaded nodes. According to the data transmission paths, which are designated by discontinuous lines in this figure, the circled sensor nodes are responsible for retransmitting the data of the other sensor nodes. As a result, the dissipation energy consumption of these nodes is faster. However, the periodic displacement of the base station makes it possible to solve this problem by distributing the load of the traffic between sensor nodes and significantly extend the service life of the network.

2.6.1 Advantages of using a mobile base station

- In terms of energy, processing, and bandwidth, wireless sensor networks face various challenges. The primary goal of such networks is to ensure connection between wireless sensors and the base station while avoiding data loss, which can negatively impact network performance. The station o base is an electrical device that has no resource limits (energy, computing and processing power and communication capacity). In comparison to networks with a static base station, using a mobile base station in a network allows us to greatly improve network performance. The benefits of employing mobile base stations are detailed below.

- **Power consumption:** One of the most significant restrictions in wireless sensor networks is energy. Routing protocols must take this element into account in order to enhance the network's longevity. However, various research has **[18-19-20]** demonstrated the limits of static base station techniques. The base station acts as a gateway between the wireless sensor network and the end user in e and.
  Therefore, all the work generated in the network converges to this hotspot, this increases the load that the nodes closest to the station must bear. And thus limits the lifetime of the neighborhood and the entire network. Thus, the energy consumption at the level of the immediate vicinity of the static base station gradually increases over time until the base station finds itself disconnected from the network because of the disappearance of all its nodes immediate neighboring sensors. The implementation of a mobile base station makes it possible to avoid this problem by distributing the load of the network as well as the energy consumption more uniformly at all the sensor nodes, which makes it possible to increase the lifetime of the network and to minimize data loss.

- **Network connectivity**: Wireless sensor networks are characterized by a dense deployment of sensor nodes on a specific area of interest, ensuring network connectivity. However, the sensor nodes' high energy stress can lead some of them to disappear. As a result, the network has been divided into multiple distinct sections. The installation of a mobile base station allows the network's connectivity to be improved by gathering data from many disconnected areas of the network.
- **Network reliability:** Since density and multi-hop communication are among the characteristics most demanded by wireless sensor network applications, the reliability of a network is compromised by interference and collisions and data loss. The use of a mobile base station makes it possible to visit the nodes of the network and collect data directly via single-hop transmissions. This not only reduces interference and collisions, but also reduces data loss.
- **Scaling up:** The number of wireless sensors deployed in the catchment area can reach thousands of nodes. The communication protocols must therefore be capable of operating with such a number of sensor nodes. Traditional flood-type data dissemination protocols generally do not allow scaling due to the large number of messages generated **[21-22].** As a result, the use of a static base station would be completely unsuitable, since all the traffic generated in the network would be condensed at the base station, limiting the lifetime of the network and increasing collisions at the level of the immediate vicinity from the base station. The use of mobile base stations that move around network regions allows for better scaling by distributing network traffic and energy consumption across all deployed sensor nodes.

- **Nature of the application:** Some applications of wireless sensor networks may require the use of mobile base stations and/or mobile sensors. Examples are: intelligent sensor networks (the base station picks up the sensors), monitoring of animals or people, etc. In these cases, the base station is attached to the level of vehicles, animals or people moving around a geographical area.

- **Security:** The use of a mobile base station makes it possible to reduce the probability of listening to the information exchanged in the network by a third party, which makes the network less exposed to security threats. In e and, in a wireless sensor network with a static base station, attacks can target this easily localizable hotspot. This makes mobility a technique to strengthen network security. Another one an essential point for any communications security system is cryptographic key management and which can take advantage of the mobility of the base station to reduce threats in a WSNs. For example, to refresh the cryptographic keys of a sensor node, the base station moves to the position of the node in question to transmit its new keys to it with a single-hop communication.

2.7. Constraints and challenges

The use of a mobile base station for data collection in a WSNs has several advantages but is not without consequences. In addition, mobility raises several challenges for a successful design and implementation of a collection scheme. Here are some specific challenges to the introduction of mobile base stations in:

- **Mobility management:** The mobility of the base station generates a problem related to the management of communications between the fixed sensor nodes and the mobile base station. To better understand this problem, consider the following scenario: in order to collect the data produced by the neighboring sensor nodes, the mobile base station circulates in a geographical area while issuing a request. We call resolver the sensor node receiving the request from the base station and whose task is to route this request to the sensor nodes having the corresponding data. When the resolver receives the data and the base station is no longer within the communication range of the latter, communication will not be able to take place.
  To remedy this problem, new communication techniques must be implemented to ensure communication between the mobile base stations and the rest of the network.
- **Location of the base station:** In a wireless sensor network, the information collected by the sensor nodes is transmitted to the base station. In the case of a network with a static base station, the information is directly transmitted to this base station base. On the other hand, when the base station is mobile, the sensor nodes a priori have no knowledge of its current position within the network. The location of the base station must be known by the sensor nodes that are within its communication range and updated throughout the network to ensure connectivity. Regularly updating the location of the base station in the network could reduce transmission delays since the paths to the base station are adjusted accordingly. In addition, the location of the base station is very influenced by its speed and by the periods of activity of the nodes, since a node in standby mode will not be able to detect the presence of the base station.
- **Management of the period of activity according to mobility:** To propagate the updates of the location of the base station, the sensor nodes need to be in listening mode. If the movement of the base station is predicted or calculated, it could help the nodes to optimize the detection of the base station. In situations where the visiting times are known a priori or can be calculated with a certain precision, the service cycles of the nodes can be adjusted to put them in active mode at the expected arrival

time of the base station. However, this is achievable in situations where the base station follows a determined trajectory while maintaining a constant speed.

- **Latency:** The latency directly depends on the mobility model of the base station, namely the speed and direction. However, the latency is strongly influenced by the pause period of the mobile base station. In some applications, the base station goes to each node to collect the data. In such scenarios, if the data is too large to be transmitted to the base station during the contact time, the nodes will have to wait for the next turn of the mobile base station, which causes an increase in latency. There is always a trade-off between power consumption and latency in an WSNs. Latency directly depends on the mobility model of the base station. If the latest information about the location of the base station as well as information about its mobility is quickly
propagated throughout the network, the latency end-to-end delay can be reduced by allowing the nodes to adjust their paths to the base station. In doing so, it would cause a huge energy consumption and thus decrease the service life of the network.
- **Packet loss:** Due to the unavailability of the fixed paths to the base station, the data are transmitted by each sensor node to the last known position of the mobile base station. On the other hand, if the latest mobility information does not spread
not in the entire network, the transmission of messages would be compromised. This problem is further complicated when the mobile base station has moved significantly away from its last position, ultimately resulting in the loss of data due to a long travel time.

2.8. The movement of the base station

The use of a mobile base station makes it possible to optimize the energy consumption at the level of the node's sensors, but the control of the movement of the base station for a better data collection is essential. The term base station movement refers to the physical path that the mobile base station follows while moving in the network. We distinguish three main models of base station mobility studied in the literature: random mobility, predictable or fixed mobility and controlled or optimized mobility.

2.8.1 Random Mobility Model

As the name suggests, the random mobility model (Figure 2.5) of a mobile base station comprises a sequence of paths of any length and direction. The residence time of the base station between the different displacements can also be random. The base station is autonomous in its movement.

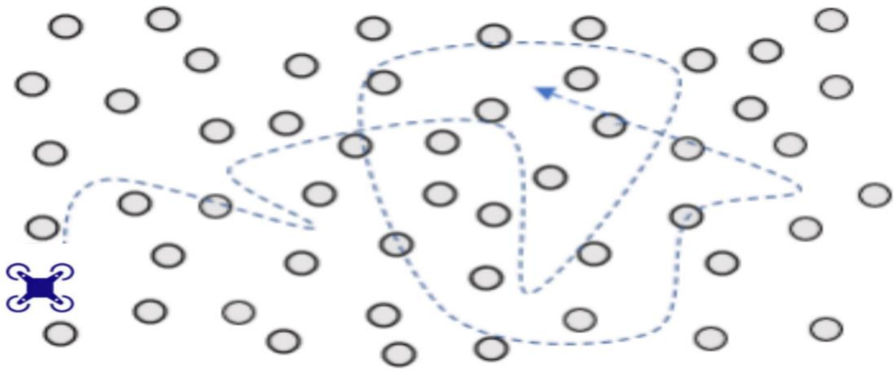


Figure 2.5: Random Mobility Model.

- **Benefit:** In multi-hop sensor networks, the model of random mobility is usually very effective with respect to the hotspot phenomenon, the random change of the location of the base station implies the distribution randomness of traffic and the load of routing through the network, which minimizes the probability that one of the nodes of the network will exhaust its energy and die much earlier than the other nodes.
- **Disadvantage:** In one-hop sensor networks, the mobility model this may involve long delays between the time when a sensory reading is taken and the time when the respective sensor is visited (the reading is retrieved) by the base station. The feasibility of random mobility of the base station is very doubtful. Namely, most real-world environments of sensor networks contain obstacles (walls, furniture, machines in the indoor environment and rocks, mountains, trees in outdoor environments). Therefore, in such environments, it seems very unlikely, if not impossible, that a base station can randomly move in the area of interest of the network in any direction, at any distance, following a straight line.

2.8.2 Predictable mobility model

Unlike random mobility, predictable (or fixed) mobility is completely deterministic. With this type of mobility, the base station constantly follows the same path through the network (see Figure 2.6). Predictable mobility is generally imposed on the mobile base station by the nature of the physical terrain and/or the presence of obstacles in the environment. An example of a research study that deals with this type of mobility is presented in **[23]**. The study focuses on the use of a wireless sensor network to track free parking spaces and provide this information to cars at the entrance to the parking lot. In this study, cars are modeled as mobile base stations (i.e.d. final recipients and users of the collected data) which, by the nature of the parking design, should follow a well-defined deterministic trajectory.

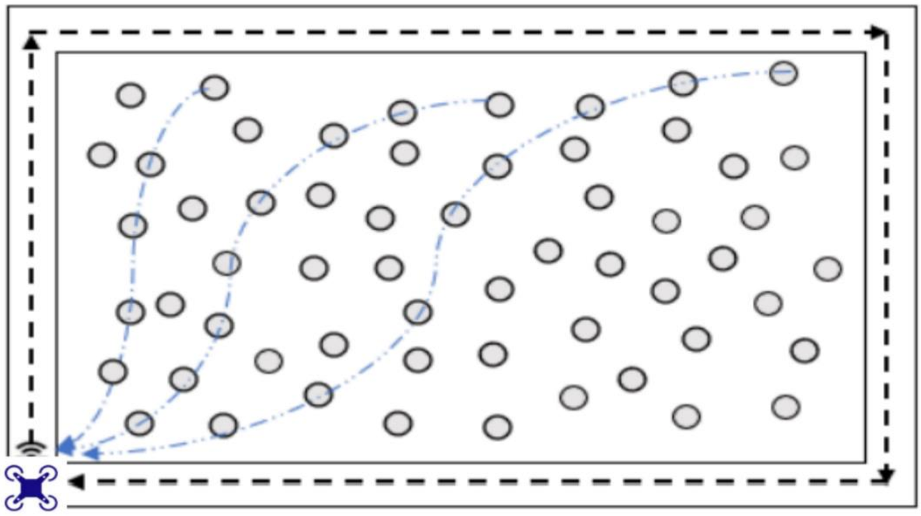


Figure 2.6: Predictable mobility model.

- **Benefit:** The environments of real-world wireless sensor networks, especially those found in urban and industrial environments, are known by the presence of small and large obstacles. In these environments, a trajectory limited to a limited number of paths seems to be the most likely, which makes predictable mobility a much more realistic model for the movement of the base station than the other two types of mobility.
- **Disadvantage:** In multi-hop sensor networks, predictable mobility is generally less effective against the hotspot phenomenon than the other two mobility models. Specifically, by moving along a seemingly limited (and possibly predefined) number of paths, the station's capacity to distribute the work and the routing load is also limited. In addition, in single-hop sensor networks, the inability of the base station to reach all areas of the network field can degrade the performance of the latter.

2.8.3 Controlled mobility model

In the case of controlled (or optimized) mobility, the path of the base station is a function of a particular network variable (for example, the current state of the nodes' energy, the range of nodes, the density of nodes, the direction of traffic flows, etc.). The path is continuously adjusted to ensure optimal network performance with respect to one or more performance metrics. In **[24],** the authors present a multi-hop WSNs in which the mobile base station receives regular updates on the current energy status of the nodes. Based on these updates, the base station maintains the adjustment of its position to minimize the routing load on nodes with critical energy levels. The authors of **[25]**, studied a network of sensors for pollution monitoring, in which the nodes deployed in different areas of the network operate at different sampling frequencies. The path of the base station through the network is controlled by these frequency rates, with the aim of minimizing the probability that one of the buffers of the nodes sensors overflows. In **[26],** the authors proposed another approach for the mobility of the base station, in which the mobile base station moves to the node having the highest residual energy.

- **Benefit:** The above analysis shows that the nature and physical form of the random and predictable trajectories are in no way related to the state and/or events occurring inside the corresponding sensor network. On the other hand, the fitness of the optimal trajectory is intended to be fully controlled within the network, with the aim of optimizing one or more aspects of network performance. Therefore, the controlled (optimized) trajectory brings more improvement in network performance than the two more mobility models of the base station.
- **Disadvantage:** In most of the proposed approaches using mobility optimized, the shape of the trajectory is assumed to be controlled inside the network. Nevertheless, as already mentioned, the existence of obstacles in the real-world environment of wireless sensor networks is likely to constrain the movement of the base station (prevent it from following the theoretically optimal trajectory).

2.9 Sink mobility and node mobility:

For data collecting, a number of strategies take advantage of node mobility. Sink mobility and node mobility are the two types of mobility that these approaches are primarily focused on. Sink mobility occurs when the sink, the final destination of sensed data in wireless sensor networks, moves and routes itself through the network to gather data from static nodes. However, node mobility, in which individual sensor nodes actively move from one location to another while attempting to maintain an end-to-end communication link, is a more difficult and challenging instance.

2.9.1 Sink mobility:

When it comes to determining the mobility pattern that the mobile sink should follow, there are numerous options. Various approaches may give different outcomes and have a significant impact on the resulting network performance depending on the application situation, network size, and conditions. Entity and group mobility models are the two most common types of mobility models. The entity mobility model depicts the movement of a single node without taking into account the movement of other nodes. The group mobility model, on the other hand, coordinates the movement of the nodes as a whole. The sink node in our approach moves at random according to two different mobility patterns: the Random Walk Mobility Model and the Random Way Point Mobility Model.

- **Random Walk Mobility Model:** It's a straightforward mobility model with random directions and speeds. A node in this mobility model travels from its current location to a new place by selecting a direction and speed at random. Both the new speed and direction are set in stone. In the Random Walk Mobility Model, movement happens over a fixed time period t or a fixed distance traveled d, after which a new direction and speed are determined. When a node moving according to this model comes to a simulation barrier, it "bounces" off it at an angle given by the incoming direction. After that, the MN continues on its new path. This property assures that the random walk is a mobility model that examines the movements of entities around their beginning positions without the risk of them wandering off and never returning.
- **Random Waypoint Mobility Model:** There are stop durations between changes in destination and speed in this model. A sink node starts by staying in one place for a set

amount of time (i.e., a pause time). When the timer runs out, the sink node selects a random destination in the simulation area and a uniformly distributed speed. The sink node then travels at the given speed toward the newly selected destination. When it arrives, it stops for a set amount of time before resuming the operation.

2.9.2 Node mobility:

Individual nodes can be mobile instead of the sink, either continuously or sporadically, and either intentionally or unintentionally, depending on the nature of the application. Apart from the benefits outlined in Section I, node mobility can improve coverage in circumstances when nodes become disconnected due to initial uneven or random deployments, as well as unforeseen failures, or when they run out of power.

Mobility can be regarded either a macroscopic or microscopic characteristic if the mobile subjects to which the nodes are coupled are human beings. It reflects the mobility habit based on everyday activities on a macro level (for example, going back and forth from home to office; taking a break; going to a meeting or working with colleagues). It reflects how humans interact with their surrounding environment (for example, indoor, outdoor, road, or network) on a microscopic level. Because only the motions observed at the radio range of wireless interfaces are of interest, microscopic mobility has a greater influence on them.

2.10 Conclusion

In this chapter, we have presented the mobility in wireless sensor networks, which makes it possible to ensure a good load balancing between sensor nodes and significantly extend the service life of the network. More precisely, we have detailed the mobility of the base station which is the most referenced case in the literature and to which the most applications correspond. The following chapter presents a synthesis of the different data collection approaches that exploit the mobility of the base station in order to improve the performance of wireless sensor networks.

Chapter 3 :

FANET

3.1 Introduction:

Unmanned Aerial Vehicle (UAV) are increasingly used as data collectors for Wireless Sensors Networks (WSN) on the ground. Most of current research proposes optimizations for itinerary creation for a single UAV. Contrary to this, our work proposes a distributed algorithm for collecting WSN data using a dynamic set of UAVs, that takes into account that UAVs leave or join the group due to recharging or malfunctions. In our work, we consider that the UAVs only have medium-range communication capability (a few meters) to deliver collected data, similar to the assumptions in related work. Compared to the costly and non-real-time Traveling Salesman Problem (TSP).

3.2 Overview on UAV, UAS and FANET:

3.2.1. Unmanned Aerial Vehicle (UAV):

UAVs are split into two types: fixed wing and rotary wing, each with its own set of characteristics. Fixed-wing UAVs, as seen in Fig. 3.1(a), have a high speed and payload, but they must sustain a constant forward motion to stay aloft, making them unsuitable for stationary applications like inspection work. Rotary-wing UAVs, on the other hand, despite their limited mobility and payload, can travel in any direction and remain motionless in the air (Fig. 3.1(b)). As a result, the application determines which UAVs to use.

***Figure 3.1*:** Fixed wing and rotary wing UAVs.

UAVs are also classified by range (close-range, short-range, and mid-range), endurance in the air (small and large), and purpose (racing drones, trick drones, helicopter drones, delivery drones, photography drones, GPS drones, and VTOL (Vertical Takeoff and Landing)). The utilization of a single large UAV for a mission was common in the early days of UAV use. The UAV-based communication network in these systems consists of simply one aerial vehicle and one or more ground stations. Most civil applications may now be carried out more efficiently with the use of many small UAV systems. The UAVs in a multi-small UAV system are small, inexpensive, and cooperative. Using a network of tiny UAVs has various advantages:

- Low cost: acquiring and maintaining a small UAV is less expensive than acquiring and maintaining a large UAV.
- Short mission completion time: operations such as surveillance and search and rescue can be completed faster with a large number of small UAVs (when multiple UAVs receive a request, it is ready faster than one UAV).
- Scalability: In the operation area, new UAVs can be easily added. The network structure of the system was dynamically rearranged by the system.
- Survivability: Multi-UAV systems are resistant to sensor and UAV failures. The mission can proceed normally with any remaining UAVs if some sensors fail or some UAVs lose control.

Small UAVs, on the other hand, have a restricted capacity. Because of its small size, the UAV's capabilities are limited depending on its use. Small UAVs have very little weights, which limits their load carrying capacity and any add-ons that can be attached to them. Because of its small size, we are unable to add any accessories, such as a camera if one is missing, or any other item that would improve its functioning.

3.2.2. Unmanned Aerial System (UAS):

A typical UAS consists of five main components, as shown in figure 3.2:

Figure 3.2 : A typical UAS consists of five main components

1) Unmanned aerial vehicles (UAVs): The UAV is the most important component. As a result, the payload, altitude, range, endurance, and other capabilities of the UAS are directly determined by its capacity, performance, and Operation Theater.
2) Payloads: the equipment installed on the UAV to carry out various operational duties (sensors, nonlethal weapons, lethal weapons, and so on).
3) Human-UAV interaction is facilitated by command-and-control systems such as static/portable ground control stations, air traffic control stations, or ground data terminals, among others.
4) Support equipment: a launcher that allows a UAV to fly over a small distance in a short amount of time.
5) Control and data transmission links: These links specify how data is transferred and received from and to UAVs and GCS.

UAVs require increased autonomy to expand their use in new application areas by reducing manpower requirements. UAVs must also be able to fly autonomously in the sky and execute various missions without the assistance of a centralized controller.

The authors of **[28]** categorize UAS depending on the connectivity between the several UAVs:

- Physically linked: Physical links connect the UAVs.
- Formations: the vehicles are not physically attached, but their relative motions are limited in order to maintain the formation.
- Swarms: by their interactions, they are homogeneous teams of UAVs.
- Forme a group mentality.
- Intentional cooperation: the team's vehicles follow trajectories defined by individual tasks that must be assigned to complete a common mission.

3.2.3. Flying Ad-Hoc Networks (FANET):

FANET is an ad hoc network structure made up of a group of unmanned aerial vehicles (UAVs), at least one of which must be connected to the Global Positioning System (GPS) or a satellite. FANET is not the same as existing Ad-Hoc networks, although it can be thought of as a variant of MANET or VANET. However, there are certain distinctions in terms of design considerations between them. The UAV network has its own set of characteristics, which are outlined in the following paragraphs:

- Network topology: Because of the enhanced mobility of UAVs, the network topology in FANET changes often.
- Mobility models: the flight path is predetermined in some mobility models, and the map is recalculated at each change.
- Other models are haphazard (i.e. using random speed and directions).
- Node mobility: In comparison to MANET and VANET, the mobility of UAVs is critical. UAVs may change locations in a considerably shorter time span, which can lead to communication issues between them.
- Node density: due to the nature of flight, nodes in FANET networks must be sparsely spaced in the sky with significant distances between them. As a result, FANET has a substantially lower node density than MANET and VANET.
- MANET's radio propagation model: There is no radio transmission between nodes in MANET. The UAVs in FANETs, on the other hand, use a LoS (Line-of-Sight) between them and the GCS.
- Localization: Due to their great mobility, it is difficult to detect the precise position of UAVs in FANET. In smaller time intervals, localization data should be current.

3.3 Communication in FANET:

Communication is one of the most important design concerns for FANET, so defining a reliable communication protocol for UAV networks is critical. The UAV communication architectures, routing protocols, MAC protocols, FANET mission-oriented communication, and the frequency and technology chosen for this network are all presented in this part.

3.3.1. UAV communication architectures:

3.3.1.1. UAV direct communication:

The communication architecture lays out the rules and processes that govern how data is sent between GCS and many UAVs, or between UAVs. As shown in Fig.3.3, UAV networks include four main communication architectures: UAV direct communication, UAV communication via satellite networks, UAV communication via cellular networks, and UAV communication via ad-hoc networks.

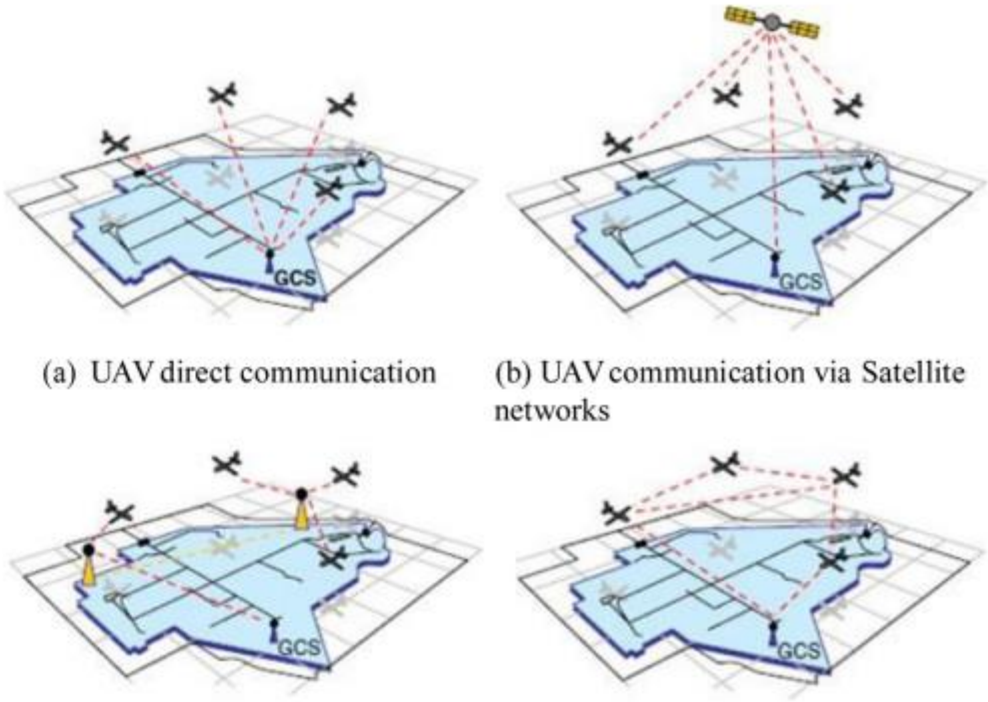


Figure 3.3 : UAV communication architectures.

3.3.1.2. UAV communication via Ad-Hoc networks:

The FANET network is proposed for a swarm of UAVs, as shown in Fig. 3, to solve the disadvantages of the communication topologies outlined previously (d). This network architecture is part of the MANET, and it allows nodes to connect without the use of a central infrastructure. Each UAV is regarded as a complete system. Because all UAVs must collaborate, they must organize themselves to communicate information. Because of the great mobility of UAVs, the Ad-Hoc architecture copes well with the constantly changing topology of the UAV networks. The GCS also serves as a typical end node in FANET, with a fixed or variable geographic position. It communicates with the UAV closest to it, which serves as a gateway. As a result, in FANET, there are two forms of communication to consider: UAV to UAV and UAV to GCS.

UAV to UAV communication: UAVs communicate with one another to complete a common goal such as cooperative target monitoring or path planning. Direct or multi-hop communication is possible. UAVs can communicate over short or long distances, which helps improve FANET's communication range and data rate efficiency.

UAV to GCS communication: UAVs communicate with fixed infrastructure (e.g., a ground station, a warship, cellular infrastructure, or a satellite) to provide information services to other users in the global network.

3.4 Routing protocols:

At present, the industry does not have a proprietary routing protocol for FANET, and its main routing protocol still uses the routing protocol of MANETs. MANET routing protocols can be divided into different types according to different classification criteria. According to the route discovery strategy:

3.4.1 Static routing protocols:

In static routing protocol, a routing table is computed and loaded to UAV nodes before a mission, and cannot be updated during the operation; therefore, it is static. In this type networking model, UAVs typically have a fixed topology. Each node can communicate with a few numbers of UAVs or ground stations, and it only stores their information. In case of a failure (of a UAV or ground station), for updating the tables, it is necessary to wait the end of the mission. Therefore, they are not fault tolerant and appropriate for dynamic environments.

3.4.2 Reactive routing:

It is known as the on-demand routing protocol which means if there is no any communication between the nodes then there is no need to store the route between the two. There are two different type of messages Route Request message and Route Reply message. Route request messages are produced by source node and route reply messages are produced by destination node.

3.4.3. Proactive routing:

Proactive routing protocols (PRP) use tables to store all the routing information of each other's node or nodes of a specific region in the network. Various table-driven protocols can be used in FANET, and they differ in the way of update mechanism of the routing table when the topology changes. The main advantage of proactive routing is that it contains the latest information of the routes; therefore, it is easy to select a path from the sender to the receiver, and there is no need to wait. However, there are some explicit disadvantages. Firstly, due to the need of a lot of message exchanges between nodes, PRPs cannot efficiently use bandwidth, which is a limited communication resource of FANET; therefore, PRPs are not suitable for highly mobile and/or larger networks. Secondly, it shows a slow reaction, when the topology is changed, or a failure is occurred. Two main protocols are widely used in VANETs: Optimized Link State Routing (OLSR) and Destination- Sequenced Distance Vector (DSDV) protocols.

3.4.4 Hybrid routing:

Hybrid routing protocol (HRP) is a combination of previous protocols, and is presented to overcome their shortcomings. By using HRP, the large latency of the initial route discovery process in reactive routing protocols can be decreased and the overhead of control messages in proactive routing protocols can be reduced.

3.4. Geographic routing protocols:

The GRP routing protocol uses the concept of geographic routing for the exchange the information. Position based routing or geographic routing is used to eliminate the limitations of topology-based routing. It gives the better performance in dynamic topologies because the packets are forwarded to its destination with respect to its position. Each node determines its own position and for determining the position of the network node the different positioning schemes are used such as GPS, GPRS etc .By using the concept of position-based routing, the geographic routing protocols do not need to set up and to maintain the connections. In hybrid routing, the nodes do not require to store the routing tables and not to maintain the routing tables up to date for transmitting the information. It simply detects the location of the target node in the network and simply conveys the information from starting place to target. The way of transmitting the information in this protocol is based on the site information of the target and one hop neighbors. There are two types of forwarding strategies in hybrid routing for conveying the information such as Greedy Forwarding and Face-2 Routing Perimeter

3.5 MAC protocols:

One of the most important properties of FANET networks is mobility, which introduces additional MAC layer obstacles. The high mobility and varied distances between different drones are directly reflected in the FANET MAC layer design. The packet latency that needs to be throttled in real-time FANET applications is also a concern. As a result, a dependable MAC protocol should be proposed to maintain high signal strength by monitoring the channel and forecasting antenna attitude changes to automatically modify the antenna. Drone networks initially used the IEEE 802.11 protocol with omnidirectional antennas, which is one of the most widely used MACS for ad-hoc networks (MANET and VANET). The RTS CTS signaling technique is used by IEEE 802.11 to tackle the hidden node problem **[29]** . Due to omnidirectional antennas, IEEE 802.11 may not be suited for some UAV applications. Later, numerous MAC layer techniques to meet FANET criteria were published in the literature, including full duplex radio circuits with MPR and directional **[30-31]**. The FANET MAC layer is affected by full-duplex and MPR radio circuits. In high-demand contexts like UAV networks, the CSI is one of the most significant characteristics for full-duplex radios, and it's usually to specify the perfect CSI **[32]** describes a FANET MAC layer based on full duplex and MPR technology. The goal is to update the CSI on a regular basis so that the various drones have the most up-to-date information at all times. The results indicated that this method prevents packet collisions. However, authors in **[33]** have stated that MAC protocols over full duplex communication are too difficult to implement. For UAV networks, directional antennas have several advantages over omnidirectional antennas, and they pose a unique design challenge, particularly at the MAC layer. MAC techniques based on directional antennas are examined. Researchers use directional antennas to construct a FANET MAC, similar to MANET and VANET. Alshbatat and Dong proposed an adaptive MAC system for drones in. They devised a method for controlling the directional antenna as well as other aircraft settings. Their plan is to send DATA packets via directional transmission while control packets are sent by Omni transmission. They have demonstrated that their idea can minimize and increase FANET network speed and bit error rate. However, they don't do a good job of dealing with directional antenna issues like asymmetric range and buried terminals.

3.6 Frequency and technology considered for FANET:

The mission-oriented communication feature of FANET requires that for each application domain, we have to consider the quantitative and qualitative demands, as well as the design methodology. Hence, protocols and technologies that can be used for an application domain may not necessarily be suitable to another as shown in Table 3.1.

Application domain	Communication technologies
SAR	**Communication requirements:** • Data type: coordination and sensed data (Images or video (1 Mbps and 2 Mbps)) • Traffic: real-time (50–100 ms) • Coverage: small and medium size areas **Suitable technologies:** Wi-Fi, WAVE, WiMAX, UMTS and LTE
Coverage	**Communication requirements:** differ from one application to another. • Data type: coordination and sensed data (the data can be visual (images and videos) or sensor readings (temperature and humidity) or voice traffic) • Traffic: real-time / periodic / delay- tolerant • Coverage: small and medium areas **Suitable technologies:** LTE and 802.11 standards
Construction	**Communication requirements:** • Data type: coordination • Traffic: real-time • Coverage: small areas **Suitable technologies:** Zigbee, Wi-Fi
Delivery and transportation	**Communication requirements:** • Data type: coordination • Traffic: periodic • Coverage: small, medium and large areas **Suitable technologies:** 802.11 standards and licensed technology WiMAX, LTE etc

Table 3.1 *:*Communication technologies for each application domain.

Table 3.1 shows that depending on throughput and range demands, multi-hop 802.11 or Zigbee technologies may be considered for small and medium range FANET applications. If high payload drones are used, the choices of wireless technologies increase significantly including specific radio transceivers. Likewise, network interfaces with data security support may require to be developed for some applications. It is essential to note that if the coverage area is large and multi-hop 802.11 is inefficient to support the required throughput needs, licensed radio technologies like WiMAX **[34]** , EDGE, UMTS **[35],**LTE **[36-37]**and GPRS **[38]** may be more suitable. But these technologies need an existing infrastructure. Environments where such infrastructure based licensed technologies are not accessible or in disaster-struck zones, networking coverage for medium and large areas may not be feasible until alternative technologies for such situations are designed.

There may be a necessity to adjust the currently existing algorithms, protocols, and technologies to cater to the requirements of recently emerging FANET applications. In **[39]** authors suggest adaptive hybrid communication protocols including a PPMAC (Position-Prediction-based directional MAC protocol) and a self-learning routing protocol based on reinforcement learning (RLSRP). The performance results prove that the suggested PPMAC over comes the directional deafness difficulty with directional antennas, and RLSRP gives an automatically evolving and more powerful routing scheme. These communication protocols have the potential to give an intelligent and highly autonomous communication solution for FANETs and indicate the main research orientation of FANET protocols.

A promising technology that can satisfy the spectrum needs of the emerging FANET applications is CR (Cognitive Radio). Never the less, currently available CR routing protocols cannot fulfill the mobility exigencies of FANET. Therefore, there might be a need for a bottom-up cognitive radio keeping in mind features of UAVs networks.

Commercial UAVs communicate in the various parts of the radio spectrum which are shared with multiple other users. In the air, the radio propagation is like the free space propagation. Accord ingly, UAVs generate further interference to the networks in the up-link, also they encounter more interference in the down-link. This calls for interference management techniques or interference mitigation techniques. These methods need to be developed to preserve the network against unintended radio jamming while allowing intended lawful interception. The concept of interference management raises the question of the frequency intervals possible for UAV transmissions in the radio spectrum. These frequencies are:

- 420-450 MHz: UAV control links, amateurs in emergency communications
- 902-928 MHz: UAV video and telemetry, computer networking, Industrial, Scientific and Medical (ISM) equipment, walkie talkies, cordless phones, repeaters, amateur TV.
- 1.24-1.3 GHz: UAV video links, voice, data, amateur TV, GPS • 2.39-2.485 GHz: UAV control links, Wi-Fi, video and telemetry, microwave ovens, Bluetooth, wireless headphones, cordless phones
- 5.15-5.825 GHz : UAV video, 5 G routers, Unlicensed National Information Infrastructure (UNII) devices.

Each of these frequency bands has its own set of weaknesses. Lower frequencies, such as 430 MHz and 900 experience less multipath distortion, have a range with equal power, have less sensitivity to weather, however, they do not take video quality, 900 MHz is rated for in Europe, and may experience interference in urban areas due to prolonged use of corded telephones. On the other hand, higher frequencies allow video streaming of quality, have more transmitting antennas however, they require line-of-sight operations, their range is influenced by the humidity of the air, need higher power at low frequencies for equivalent range, and they can suffer from interference from wide variety of devices usually used in urban areas.

3.7 Trajectory optimization:

Environmental changes in this scenario could include UAV node failures, GT density, and position changes, among other things. Although relocation capacity has the potential to provide significant performance advantages, such as increased coverage and rate for GTs, it also poses a number of theoretical and practical problems. Path planning is one of the most difficult challenges: the UAV trajectory must be properly planned to meet the applications requirements. A mission trajectory that maintains continuous connection with the GCS, for example, could be important for time-critical emergency missions like SAR. Most commercial UAVs now communicate with their GCSs through point-to- point communication over unlicensed spectrum, which has restricted performance. Obtaining the ideal UAV positions is a non-convex optimization problem whose dimensionality grows with the number of UAVs, even in a static setting where the locations or density of GTs are fixed and known. Optimization of UAV trajectories is also included in dynamic settings, resulting in far more complex infinite-dimensional optimization issues. Critical. As a result, it has been a major research topic in the existing UAV literature. A variety of solutions to the issues of UAV deployment have been offered. Investigate the ideal placement of UAVs to maximize coverage and introduce many techniques in the case of static deployment. These studies presume that a UAV can cover a GT if the distance between them is kept to a minimum. Instead of using the average throughput as the objective function, the authors in use the hover time limits of UAVs to formulate the problem. The use of UAVs as relays to offload cellular traffic and generic multichip communication. Uses stochastic geometry methods to investigate random UAV deployments. The authors of **investigate** the best way to deploy cache-enabled UAVs. To circumvent the issue of limited fronthaul capacity, content caching techniques can be used to proactively download and store content at the UAVs during off- peak hours or when the UAVs are docked. The use of caching allows UAVs to transport content directly to the requested user, decreasing fronthaul traffic burden. There are also a number of studies on the deployment of UAVs in a dynamic manner. The use of UAVs as mobile access points for GTs is a well-studied scenario. In this situation, proposes methods for UAV coverage under varying coverage radii and probable UAV losses optimizes the UAV trajectory for one UAV and one GT to achieve maximum throughput with low UAV energy consumption. The authors of take a look at a single UAV serving a device-to device communication network. **[38]** proposes a genetic method for UAV trajectory optimization with the purpose of restoring network service after natural disasters. The authors of **[39]** use space-division multiple access to improve the trajectory of a single UAV serving many mobile GTs. The UAV trajectory is determined by a Kalman filter that anticipates future GT locations **[40]**. describes the time-varying UAV speed that minimizes data collecting time given several sensors on a one-dimensional space and one UAV. The optimization of UAV trajectories under speed limitations is a comparable challenge.

3.8 Security in FANET:

FANET networks are intrinsically unsafe, necessitating robust security solutions that take into account the network unique properties, as these qualities are the primary sources of its vulnerability to assaults. Active interference, passive eavesdropping, data tampering, leaking secret information, message replay, message misuse, denial of service, and impersonation can all be carried out using a wireless link between the transmitter and receiver. Attacks from the inside and outside can occur in an Ad-Hoc network due to the uncontrolled environment. When an attacker is inside a node's transmission range, for example, it can send and receive data packets. Furthermore, more UAVs are at risk of being captured physically. The dynamic topology is another issue that emerges in FANET. Due to the poor network quality, detecting the misbehaving node is frequently challenging. Also, because there is no guarantee that a route between two UAVs would be free, collaboration between the UAVs nodes, for example in path finding, might be a major source of assaults.

- **Availability**: This refers to the fact that all FANET services are always available at any time and in any circumstance.
- **Timeliness:** To avoid delays, updated information should be provided on time.
- **Self-stabilization:** FANET communication protocols must be able to recover from any attacks automatically, without the need for human involvement.

To protect the Ad-Hoc networks resilience and integrity, several security mechanisms have been implemented. For packet exchange, these mechanisms include cryptographic algorithms (symmetrical, asymmetrical, hashing, hash chains, and authentication approaches), intrusion detection methods, and reputation-based systems. These techniques can be employed in UAV networks. The authors of **[41]** examine how these various strategies perform in FANET networks in order to secure FANET routing protocols and the various routing messages exchanged, such as path discovery. Several studies have contributed to the data security of UAV networks. He et al. concentrates on four FANET security requirements: authentication, confidentiality, partial privacy preservation, and denial-of-service attack resistance. The authors of **[42]** propose a mutual authentication approach between UAVs and end devices based on identity-based signcryption to ensure authentication. To determine whether a drone/end de vice is a genuine master/receiver or an imposter, a signature is generated. He et al. use a hierarchical identity-based broadcast encryption solution to meet the confidentiality criterion, in which messages for broadcast are encrypted using a preassigned broadcast key. He et al. **[42]** use a pseudonym and cipher text transition approach to maintain privacy. Finally, a dynamic control of access numbers and the period of time for each login is proposed to resist denial of service attacks.

3.9 Conclusion:

The functions and capacities of UAVs have been seen throughout the last few years. As a result, FANET networks are gaining in importance and playing an increasingly essential part in a variety of operations, applications, and sophisticated missions. As a result, maintaining excellent communication between the UAVs and links to the GCS and other users is a difficult task. Indeed, one of the most critical design concerns for FANET networks is communication (routing protocols, QoS, mission oriented requirement etc.). In addition to communication concerns, FANET must handle a number of other issues, including: Mobility models, in order to give a realistic simulation of the UAV environment, security challenges, in order to ensure data sharing among all FANET members, and a lack of FANET standards. All of the above listed difficulties are explored in this study. First, we went over the differences between UAV, UAS, and FANET networks. A quick review of the current FANET surveys is carried out. The communication requirements and issues are ad-dressed. The models for mobility and trajectory optimization, as well as possible security mechanisms for FANET, are also discussed. Finally, open questions and challenges are presented. The purpose of this publication is to inspire and motivate scholars to suggest answers to FANET network's open difficulties and challenges.

***Chapter* 4:**

Simulation

4.1 Introduction:

Forest fires have become a major concern all across the world, wreaking havoc on human habitats and forest ecosystems alike. Some of the repercussions of such damage include climatic changes and the greenhouse effect. Surprisingly, human-caused forest fires account for a higher percentage of all forest fires. As a result, it is necessary to detect forest fires early on in order to reduce the amount of damage caused by them. Using a mobile wireless sensor network, this research presents a system and approach for detecting forest fires in their early stages. This simulation model is developed to obtain more accurate fire detection. A solution is readily available due to the primary power source given by rechargeable batteries with a secondary solar power supply. Additionally, in order to limit the damage and detrimental impacts produced by wild animals, weather conditions, and other factors on the system, special attention is paid to sensor node design and node location requirements in difficult forest environments.

4.2 The forest fire:

Forest fires are disasters that cause extensive damage to the entire world in economic, ecological, and environmental ways. These fires can be caused by natural reasons, such as high temperatures that can create spontaneous combustion of dry fuel such as sawdust, leaves, lightning, etc., or by human activities, such as unextinguished campfires, arson, inappropriately burned debris. According to research, 90% of the world's forest fire incidents have occurred as a result of the abovementioned human carelessness. The increase in carbon dioxide levels in the atmosphere due to forest fires contributes to the greenhouse effect and climate change. Additionally, ash destroys much of the nutrients in the soil and can cause erosion, which may result in floods and landslides.

At earlier times, forest fires were detected using watchtowers, which were not efficient because they were based on human observations. In recent history and even the present day, several forest fire detection methods have been implemented, such as watchtowers, satellite image processing methods, optical sensors, and digital camera-based methods, although there are many drawbacks, such as inefficiency, power consumption, latency, accuracy and implementation costs. To address these drawbacks, a forest fire detection system using mobile wireless sensor networks is proposed in this paper.

Mobile wireless sensor networks (MWSNs) play a vital role in today's real world applications in which the sensor nodes are mobile. MWSNs are much more versatile than static WSNs as the sensor nodes can be deployed in any scenario and cope with rapid topology changes. Mobile sensor nodes consist of a microcontroller, various sensors (i.e., light, temperature, humidity, pressure, mobility, etc.), a radio transceiver, and that is powered by a battery.

Recent progress in two seemingly disparate research areas namely, distributed robotics and low power embedded systems has led to the creation of mobile sensor networks. Autonomous node mobility not only brings with it its own challenges, but also alleviates some of the traditional problems associated with static sensor networks. It is envisaged that in the near future, very large scale networks consisting of both mobile and static nodes will be deployed for applications ranging from environmental monitoring to military applications.

We consider the problem of monitoring a large area using wireless sensor networks (WSNs) in order to detect and locate a fire. In this context, we assume that the fire emits a signal that is propagated in the environment. The sensors capture attenuated and noisy measurements of the signal and the objective is to reliably detect the presence of the fire and estimate its position. By reliably we mean that we would like to minimize the probability of miss event (an event that remains undetected) subject to a constraint on the probability of false alarms (the sensors report an event due to noise). Note that in many applications false alarms are as bad (if not worse than) as missed events. In addition to the incurred cost for sending response personnel to the area of the event, frequent false alarms may lead the users to ignore all alarms, and as a result even detected events will go unnoticed**.**

4.3 Installation:

In order to run the simulations and use the components in this repository you need to have both OMNeT++ and the INET framework installed.

After installing both OMNeT++ and INET, the repository must be cloned to the active omnet++ workspace.

4.4 What is OMNet++?

OMNeT++ is an extensible, modular, component-based C++ simulation library and framework, primarily for building network simulators**.** "Network" is meant in a broader sense that includes wired and wireless communication networks, on-chip networks, queueing networks, and so on. Domain-specific functionality such as support for sensor networks, wireless ad-hoc networks, Internet protocols, performance modeling, photonic networks, etc., is provided by model frameworks, developed as independent projects. OMNeT++ offers an Eclipse-based IDE, a graphical runtime environment, and a host of other tools. There are extensions for real-time simulation, network emulation, database integration, SystemC integration, and several other functions. OMNeT++ is distributed under the Academic Public License.

Although OMNeT++ is not a network simulator itself, it has gained widespread popularity as a network simulation platform in the scientific community as well as in industrial settings, and building up a large user community.

OMNeT++ provides a component architecture for models. Components *(modules)* are programmed in C++, then assembled into larger components and models using a high-level language *(NED)*. Reusability of models comes for free. OMNeT++ has extensive GUI support, and due to its modular architecture, the simulation kernel (and models) can be embedded easily into your applications.

Check the screenshots or videos gallery if you are interested how the IDE and running simulations look like. **[43]**

4.4.1 Components:

The main ingredients of OMNeT++ are:

- Simulation kernel library (C++)
- The NED topology description language
- Simulation IDE based on the Eclipse platform
- Interactive simulation runtime GUI (Qtenv)
- Command-line interface for simulation execution (Cmdenv)
- Utilities (makefile creation tool, etc.)
- Documentation, sample simulations, etc. **[43]**

4.5 What Is INET Framework?

4.5.1 A Network Simulator

INET Framework is an open-source model library for the OMNeT++ simulation environment. It provides protocols, agents and other models for researchers and students working with communication networks. INET is especially useful when designing and validating new protocols, or exploring new or exotic scenarios.

INET contains models for the Internet stack (TCP, UDP, IPv4, IPv6, OSPF, BGP, etc.), wired and wireless link layer protocols (Ethernet, PPP, IEEE 802.11, etc.), support for mobility, MANET protocols, DiffServ, MPLS with LDP and RSVP-TE signaling, several application models, and many other protocols and components.

Several other simulation frameworks take INET as a base, and extend it into specific directions, such as vehicular networks, overlay/peer-to-peer networks, or LTE.**[44]**

4.5.2 Designed for Experimentation

INET is built around the concept of modules that communicate by message passing. Agents and network protocols are represented by components, which can be freely combined to form hosts, routers, switches, and other networking devices. New components can be programmed by the user, and existing components have been written so that they are easy to understand and modify.

INET benefits from the infrastructure provided by OMNeT++. Beyond making use of the services provided by the OMNeT++ simulation kernel and library (component model, parameterization, result recording, etc.), this also means that models may be developed, assembled, parameterized, run, and their results evaluted from the comfort of the OMNeT++ Simulation IDE, or from the command line**.[44]**

https://inet.omnetpp.org/Introduction

4.6 Working principle:

4.6.1 Usage:

OMNeT++ simulations are initialized by ***.ini*** files**.** The already provided **mobilityDrones-omnetpp.ini** file contains some launch configurations for WIFI only communication and shared WIFI and MAM communication, each with configs for one to four UAVs. Launch configurations are defined in the same ***.ini*** file denoted by the [Config Sim2drone] tag where Sim2drone is the name of the launch configuration. The [Config WIFI] and [Config MAM] configs are base configs for the other ones and should not be ran.

Launch configurations dictate the parameters of your simulation and can change **mobilityDrones-omnetpp.ini** to suit necessities. Here are some of the most important parameters that can be switched yourself:

The number of UAVs and sensors in the simulation:

```
*.numUAVs = 2 // Initializes the *.quad[] array with 2 UAVs

*.numSensors = 8 // Initializes the *.sensors[] array with 8 sensors
```

4.6.2 Some UAV (called quads in this file) parameters:

```
// The protocol the UAV will follow (protocols explained further bellow)
// Change this to test other protocols like "ZigzagProtocol"
*.quads[*].protocol.typename = "DadcaProtocol"

// The UAV's destination addresses (nodes it talks to and recieves messages from)
*.quads[0].app[0].destAddresses = "quads[1] sensors[0] sensors[1] sensors[2] groundStation"

// Start time for the UAV's communication and mobility modules
// Change this to expertiment with different start timings
*.quads[1].app[*].startTime = normal(40s, 1s) // Here the normal function gives a value 1s within 40s
*.quads[1].mobility.startTime = 40s

// The waypoint file the UAV should follow
*.quads[*].mobility.waypointFile = "paths/voo_ar.waypoints"
```

4.6.3 Some sensor parameters:

```
// The sensor's destination addresses
*.sensors[*].app[0].destAddresses = "quads[0] quads[1]"
// The protocol the sensor should follow
*.sensors[0..2].protocol.typename = "DadcaProtocolSensor"
// The sensor's position coordinates
*.sensors[0].mobility.initialLatitude = -15.84245230deg
*.sensors[0].mobility.initialLongitude = -47.92948720deg
```

INET offers a series of modules that control node mobility. Our objective was to create a module that was capable of simulating a very simple UAV mobility model and could react to network events. This setup allows support for a wide array of possible UAV coordination protocols.

The described requirement was achieved with three modules, one resposible for communication between UAVs (communication), one for controlling the node's movement (mobility) and the last to manage the interaction between the last two (protocol). The behaviour and implementation of these modules is detailed further below. They were made in such a way that the messages exchanged between them are sufficiently generic to allow the creation of a new protocol by creating a new protocol module, with no changes to the other ones by levaraging these generic messages to carry out different procedures. The messages exchanged between them are explained further bellow and are contained on *.msg* files like **MobilityCommand.msg**, **Telemetry.msg** and **CommunicationCommand.msg**.

These three modules are loaded in a *.ned* file. In OMNeT++ *.ned* files define modules that can use other modules forming a module tree. These modules can be simple (the leaves of the module tree) or a compound module that connects simple modules or other compound modules with gates. A network is a special kind of compound module that can be run as a simulation.

The compound module that represents our UAVs is **MobileNode.ned** and **MobileSensorNode.ned** represents our sensors. These modules contain Communication and Mobility modules (defined in the extended module AdhocHost) and the Protocol module (defined in the file). The **mobilityDrones.ned** file connects all the UAVs(called quads), sensors and some other modules necessary to the simulation.

4.6.4 Mobility

The mobility module is responsible for controlling UAV movement and responding to requests from the protocol module to change that movement through MobilityCommand messages. It also needs to inform the protocol module about the current state of the UAV's movement through Telemetry messages.

As part of the module initialization the waypoint list is attached to a Telemetry message so the protocol module has access to the tour the mobile node is following.

These are the messages used:

MobilityCommand.msg

```
// Commands that the mobility module should be capable of carrying out
enum MobilityCommandType {
    // Makes the UAV reverse on its course
    // No params
    REVERSE=0;

    // Makes the UAV travel to a specific waypoint, following the tour pack
    // Param 1: Waypoint index
    GOTO_WAYPOINT=1;

    // Makes the UAV go to a specific coordinate and orient itself so it can continue the tour afterwards
    // Param 1: x component of the coord
    // Param 2: y component of the coord
    // Param 3: z component of the coord
    // Param 4: Next waypoint (Waypoint the UAV should go to after reaching the target)
    // Param 5: Last waypoint (Waypoint the UAV used to reach the coords)
    GOTO_COORDS=2;
}

// Message declaration containing the command Id and its parameters
message MobilityCommand {
    MobilityCommandType commandType;
    double param1=-1;
    double param2=-1;
    double param3=-1;
    double param4=-1;
    double param5=-1;
}
```

Telemetry.msg

```
// Activity that the UAV is currently carrying out
enum DroneActivity {
    IDLE=0;
    NAVIGATING=1;
    REACHED_EDGE=2;
    FOLLOWING_COMMAND=3;
}

// Message declaration designed to share necessary UAV information with the communication module
message Telemetry {
    int nextWaypointID=-1;
    int lastWaypointID=-1;
    int currentCommand=-1;
    bool isReversed=false;
    DroneActivity droneActivity;
}
```

The only mobility module currently implemented is **DroneMobility.ned** which simulates the movement of a UAV.

An optional feature of the mobility module is attaching a failure generator module. They connect to the mobility module using the same gates the protocol module does and use that to send commands in order to simulate failures. This can be used to trigger random shutdowns and even to simulate energy consumption. An example of a module that simulates energy consumption is the SimpleEnergyConsumption, a parametrized component to simulate consumption and battery capacity. It sends RETURN_TO_HOME messages to the vehicle when the UAV's battery reaches a certain threshold and shuts it down when the battery is depleted.

Configuring the use of failures for your mobile nodes is easy. The. failures*[]* array can be used to add as many failure generators as needed and the number of failures can be configured using the *.numFailures* option.

```
# Configuring two types of failures for quads[0]

*.quads[0].numFailures = 2 # Two failures
*.quads[0].failures[0].typename="SimpleConsumptionEnergy" # The first one will use a simple energy consumptio
*.quads[0].failures[0].batteryCapacity = 5000mAh
*.quads[0].failures[0].batteryRTLThreshold = 4500mAh
*.quads[0].failures[0].batteryConsumption = 10A
*.quads[0].failures[0].rechargeDuration = 5s

*.quads[1].failures[1].typename="RanfomFailureGenerator" # The second will use a random failure generator
*.quads[1].failures[1].failureStart = 10s
*.quads[1].failures[1].failureMininumInterval = 40s
*.quads[1].failures[1].failureChance = 0.001
```

4.7 Communication

INET provides built in support for the simulation of real communications protocols and the communication module takes advantage of this to simulate communication between nodes. It also has to inform the protocol module of the messages being recieved by sharing the messages themselves and listen to orders from the protocol module through CommunicationCommands. Here are the messages used:

4.7.1 CommunicationCommand.msg

```
enum CommunicationCommandType {
   // Sets the payload that the communication module sends
   SET_PAYLOAD=0;
   // Sets the target of the communication message (null means broadcast)
   SET_TARGET=1;
}

// Message declaration for the communication command
message CommunicationCommand {
   CommunicationCommandType commandType;

   // Template for the SET_PAYLOAD message type (message that the communication module should send)
   inet::FieldsChunk *payloadTemplate;

   // Target for the set target command
   string target;
}
```

The message module has several implementations. The *base* folder contains several base implementations for possible communication modules, these files contain functions that interface with INET's communication capabilities but don't implement interaction with any other module.

These files were used as base for the implementation of the communication modules. The following files are the implementations used in the simulations:

- **UdpMobileNodeCommunicationApp.ned**

  Manages the communication between mobile nodes and between mobile nodes and sensors.

- **UdpSensorCommunicationApp.ned**

  Manages communication between sensors and mobile nodes.

4.8 Protocol

The protocol module manages the interaction between the movement and communication of the mobile nodes. It makes use of the messages provided by its two sibling modules to create node interaction strategies. It mostly reacts to messages it receives from those modules and determines which orders to give them to achieve the desired result.

It gathers information about the current state of the simulation by analyzing Telemetry messages received from the Mobility module and Packets forwarded to it by the Communication module. An important task it performs is the definition of the message sent by the Communication module. These messages will be sent to other nodes that will themselves handle them. The messages are inserted into IP Packages as payload. They can have different formats depending on the protocol being implemented. Here is the **DadcaMessage.msg** used by the Dadca protocol, for example.

DadcaMessage.msg

```
enum DadcaMessageType
{
  HEARTBEAT = 0;
  PAIR_REQUEST = 1;
  PAIR_CONFIRM = 2;
  BEARER = 3;
}

class DadcaMessage extends FieldsChunk
{
  chunkLength = B(34); // Fixed chunk length
  int sourceID = -1;  // ID of the message's source
  int destinationID = -1; // ID of the message's destination
  int nextWaypointID = -1; // ID of the next waypoint
  int lastWaypointID = -1; // ID of the last waypoint
  int dataLength = 5; // Length of the imaginary data being carried in the message
  int leftNeighbours = 0; // Neighbours to the left of the UAV
  int rightNeighbours = 0; // Neighbours to the right of the UAV
  bool reversed = false; // Reverse flag which indicates the current direction the UAV is travelling in
  DadcaMessageType messageType = HEARTBEAT; // Type of message
}
```

Protocools implement an IProtocol interface and extend **CommunicationProtocolBase.ned** which provides useful stub functions to use when implementing protocols. These functions are as follows:

```
// Redirects message to the proper function
virtual void handleMessage(cMessage *msg);

// Handles package received from communication
// This packet is a message that was sent to the UAV
virtual void handlePacket(Packet *pk) {};

// Handles telemetry received from mobility
// The mobility module exchanges mobility information in the form of telemetry
virtual void handleTelemetry(Telemetry *telemetry) {};

// Sends command to mobility
virtual void sendCommand(MobilityCommand *order);
// Sends command to communication
virtual void sendCommand(CommunicationCommand *order);

// Sets a timeout
virtual void initiateTimeout(simtime_t duration);
// Checks if the module is timed out
virtual bool isTimedout();
```

These are the currently implemented protocols:

- **ZigZagProtocol.ned** and **ZigZagProtocolSensor.ned**

  These files implement the mobile node and the sensor side of the ZigZag protocol. This prococol manages a group of UAVs folowwing a set path passing above several sensors from where they pick up imaginary data from those sensors. The UAVs also interact with each other sending several messages to coordinate their movement.

  Heartbeat messages are sent on a multicast address, if these are picked up by sensors they respond with data. If they are picked up by other UAVs they initiate a communication pair by sending a Pair Request message which is them confirmed by the other UAV with a Pair Confirmation message. The UAV furthest away from the starting point of the path sends its data to the other UAV in the pair and they both reverse their movement. The objective is that over time the UAVs will each occupy an equally sized section of the course, picking up data on the way and sharing it at their section's extremities.

- **DadcaProtocol.ned** and **DadcaProtocolSensor.ned**

  This protocol is similar to the ZigZagProtocol. It also manages data collection by mobile nodes in a set path. The difference is that this method aims to speed up the process of equally spacing the UAVs in the course by implementing a more advanced movement protocol.

When the Pair Confirmation message is recieved by both UAVs, confirming the pair, both UAVs take note of the number of neighours on their left (closer to the start) and their right (further from the start) and share this information with their pair. Both update their neighbour count and use it to calculate a point in the course that would represent the extremity of both their sections if their current count of neighbours is accurate. Them they both travel together to this point and revert. This behaviour is implemented with a sequence of commands that get queued on the mobility module.

4.9 Operation

The nature of the operation of a OMNeT++ simulation is dictated by the messages exchanged between modules and how they react to them. In the case of the GrADyS project the focus of our simulations is the use of quad copters to collect data from static sensors spread in a field. The UAVs and sensors are the network nodes of the simulation and are the main focus for development efforts. Each of these nodes are composed of three main modules, illustrated in the previous sections that interact with each other to form the node’s behavior. Since all our nodes are composed of the same types of modules development is fast and simple and the implemented coordination protocols focus on creating complex behavior emerging from individual actions taken by the nodes. In the protocols that we have developed every node of the same type is functionally identical and there is no coordinator but there still needs to be coordination to ensure efficient data collection. In the Dadca protocol this is achieved by the collection of information by each of the UAVs to gather a basic understanding of the layout and the distribution of other UAVs in the formation, namely by the counting and sharing of other neighbor UAVs they have encountered. The Zigzag protocol more primitively has the UAVs reverse every they encounter another one, with the vehicle farthest away from the ground station passing on the data to the one closest, ensuring it will eventually reach it. The way that these nodes act is mainly determined by the implementation of their protocol module. It uses the other two modules as both sensors and actuators, gathering information about the network’s state through information about the node’s movement and messages received from other nodes and using this information to command the other two modules to perform the desired behavior. An example of this is how in the previously described Zigzag coordination protocol the protocol module, on receiving communication from another UAV, compares the location visible in their message with its own location by analyzing telemetry received from the mobility module and uses all this information to decide if it should collect or send data to the other vehicle and commands the mobility module to invert the UAV’s movement.

4.10 Fire detection:

A new technology known as a wireless sensor network (WSN) can be used in a variety of systems, including forest fire detection. The wireless transceiver, sensors, and data processing are all housed on the same printed circuit board. Pressure, temperature, gases, radiations, humidity, and a variety of other physical factors can all be influenced by sensors. Sensor networks are typically implemented in a large-scale random distribution in remote or inaccessible locations and in harsh environments for a limited time. To reach the sink, this system relied on low data rates and short communication ranges in a multi-hop method.

4.10.1 Sensor node design:

The sensor node is designed with a spherical shape to withstand external forces and with characteristics to prevent damage due to the harsh conditions prevailing in tropical forests (Fig. 4.1). The sensor node is used to detect the temperature, humidity, light intensity level, and CO level, which are detected from the lower side of the node facing downwards (Fig. 4.2). The interior of the node is designed in three layers to place the sensors and modules (Fig. 4.3). The topmost layer is designed to place a lithium-ion battery, while the middle layer is designed to place the microcontroller, voltage regulator, and connecting board. The lowest layer, which is also the base of the node, is used to fix the sensors that are used to monitor the environmental conditions mentioned above.

All the sensors are fixed facing downwards to protect them from harmful effects of environmental conditions such as rain, strong winds, and objects such as leaves. From the side of the node, a hole is designed to take the antenna of the transceiver outside. The mounting brackets of the node on the tree trunk and supporters are connected on the rear side of the sensor node (Fig.4.4).

Figure 4.1: Spherical external design.

***Figure 4.2*:** Sensor place at the base.

***Figure 4.3*:** Inertial component placing.

Figure 4.4: Mounting supporters.

4.11 How the simulation work:

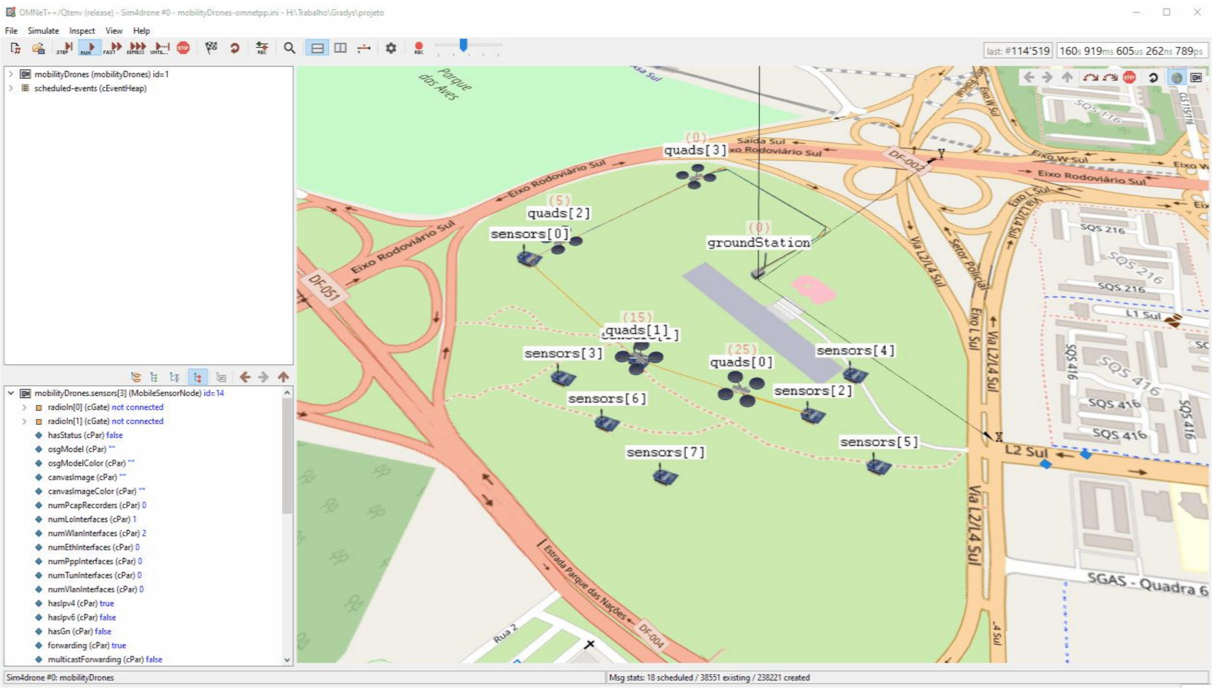
This simulation works to detect fires in any area we want or in forests through the following work methodology:

Initially, we plant seven fire sensors so that the space to be monitored contains the space to be monitored so that the distance between the sensors covers the space we want to work on, then we create the base station and its place is in the center of the workspace so that it is surrounded by sensors and there are four drones inside this station. These drones work to bring the information stored in the sensors to the main station in order to process and take the necessary actions about it, and in order to transfer information faster and use the least energy to work the system for as long as possible there the communication system between drones works to exchange information and transfer it to the main station to take advantage of it and coordinate between them there the protocol module controls the interaction between the mobile nodes' movement and communication. It creates node interaction strategies using the messages provided by its two sibling modules. It generally reacts to messages from those modules and decides which instructions to issue in order to achieve the desired result.

It analyzes Telemetry messages received from the Mobility module and Packets forwarded to it by the Communication module to acquire information about the current status of the simulation. The definition of the message conveyed by the Communication module is an important task it performs. These messages will be transmitted to other nodes, who will deal with them on their own. As payload, the messages are placed into IP packets. Depending on the protocol in use, they might have a variety of formats.

Thus this simulation is made to minimize the risk of fires in forest areas and in any other regions of the world.

4.13 Simulation:



4.14 Conclusion:

We suggested system for forest fire detection based on mobile wireless sensor networks and was found to be a reliable way for detecting fires in forests. The analysis takes done at both the sensor node and the base station to achieve a more accurate result with the least amount of latency. A threshold ratio is introduced for analysis within the sensor node to fit any weather state, climatic condition, or place. Because the transceiver module is based on dedicated built-in network infrastructure, it can be mounted anywhere in the forest, even if there is no preexisting network connectivity. Because rechargeable batteries provide the major power source.

General Conclusion

General conclusion:

Security is a very important issue for MWSN coils due to the nature of deployment and limited resources of sensor nodes, where the main challenge of MWSN core management lies in the limitations of sources. MWSN has become increasingly used in large system monitoring applications in various fields: military, environment, health, due to its increasingly reduced size and increasingly low prices, as well as their means of communication without gravity and space-saving, there are still some major drawbacks in managing the mobility of the base station and nodes. In fact, mobility can be used as a technique to improve network performance, especially improving the battery power of sensor nodes, which is an important resource throughout the life of the network. From our research, we were able to come to the following conclusions: - the use of drones leads to faster data transfer and coverage of areas where the WSN network is isolated. - Allows simulation application detection of physical and environmental phenomena of reducing the magnitude of the risk to the environment and human resources. And at the end of the work, we can say that the goal of the study has been achieved.-There are many problems that we encountered during our research, the most prominent of which is the difficulty of applying the model on the ground and the lack of sources in some research titles. In conclusion, we hope that our work will not stop there, but will make us strive to develop MWSN networks and increase educational attainment in the field of wireless communications.

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