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THEME

Optimized 3d deployment of wireless sensors network in consideration of the characteristics of the environment

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بسم الله الرحمن الرحيم
السلام عليكم ورحمة الله وبركاته

Dedication

With enormous pleasure, an open heart and immense joy,

I dedicate my work to my dear, respectful and wonderful ***parents****,* ***my mother Houria*** *and* ***my father Yakoub****, for their support. This work is the fruit of your sacrifices that you have made for my education and training.*

To the who supported me, encouraged, the who appreciates my effort, my brothers ***Youcef, Abdellah, Sabah****.*

To ***Imane****, the person who helped and supported me overcome all the hard times.*

To ***Benaissa Khireddin,*** *the person who helped and give me a push and guided me to complete this project.*

And especially to all my friends who have never left me alone.

Special dedication for ***Oussama Khelifi , Imad Ouitis****, and my Binomial* ***Sihem****.*

And to those who contributed to my success.

« Benabderrahmane abdelghani »

Dedication

*First and foremost, I have to thank my parents « **wahiba** » and « **saad** » for their love and support throughout my life, thank you both for giving me strength to reach for the stars and chase my dreams, My brothers « mohamed », « **mahdi** », « **mahfoudh** » deserve my wholehearted thanks as well.that's why i will dedicate this work for all them.*

*this work also dedicated to my friends **karima**(dbr), **soumia**(sof), **anissa**(grb), **nawel, abla.** And my Sisters « **fouzia** » and « **zahra** » who have always been a constante source of support and encouragement during the challenges of my whole collegelife. And for my binomial « **Ghano** »*

*And special dedication for « **Tarek** » who always try to break me.*

And to those who contributed to my success.

« Hocine bey Sihem »

Thanks

First of all, we thank God Almighty for giving us the health
And
The will to begin and finish this memoir.

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Abbreviations:

WSN : Wireless sensor network

PoI : Points of Interest

DT : Delaunay triangulation

PER: packet error rate

Transceiver: sender receiver

Pr : received power

Ps : the sensitivity

Pt : transmit power

dBm：Decibel-mmilliwatts

Abstract:

Wireless sensor networks are deployed to monitor physical phenomena. The accuracy of the information collected depends on the position of sensor nodes. These positions must meet the application requirements in terms of coverage and connectivity, which therefore requires the use of deployment algorithms.

a Good deployment needs also to adapt its operation and save more energy and resources when temperature decreases.

This thesis focuses on the deployment of wireless sensor nodes to monitor 3D areas and study the global effect of temperature as the major factor.

We integrated two models the first one is to save energy by putting some nodes in hibernate mode as in the SO (Stop-Operate) algorithm, and the second one is Delaunay triangulation algorithm to create communication links.

Key words:

Wireless sensor networks, temperature variations, communication links, 3D-deployment, 2D-deployment, Stop-Operate, Delaunay triangulation, lifetime of the network, Hibernate Mode, Energy saving, Energy consumption.

Résumé :

Les réseaux de capteurs sans fil sont déployés pour surveiller les phénomènes physiques. La précision des informations collectées dépend de la position des noeuds capteurs. Ces positions doivent répondre aux exigences de l'application en termes de couverture et de connectivité, ce qui nécessite donc l'utilisation d'algorithmes de déploiement.
Un bon déploiement doit également adapter son fonctionnement et économiser plus d'énergie et de ressources lorsque la température diminue.
Cette thèse porte sur le déploiement de nœuds de capteurs sans fil pour surveiller des zones 3D et étudier l'effet global de la température comme facteur majeur.

Nous avons intégré deux modèles le premier est d'économiser de l'énergie en mettant certains nœuds en mode hibernation comme dans l'algorithme SO (Stop-Operate), et le second est un algorithme de triangulation de Delaunay pour créer des liens de communication.

Mots-clés :

RCSF, Consommation d'énergie, Durée de vie du réseau, variations de température, Économie d'énergie, Veille prolongée, Stop-Operate, liaisons de communication, déploiement 3D, déploiement 2D, triangulation Delaunay.

ملخص:

يتم نشر شبكات الاستشعار اللاسلكية لمراقبة الظواهر الفيزيائية. تعتمد دقة المعلومات التي يتم جمعها على موضع نقاط جهاز الاستشعار. يجب أن تستوفي هذه المواضع متطلبات التطبيق من حيث التغطية والاتصال، مما يتطلب استخدام خوارزميات النشر.

يحتاج النشر الجيد أيضًا إلى تكييف تشغيله وتوفير المزيد من الطاقة والموارد عند انخفاض درجة الحرارة.

تركز هذه المذكرة على نشر نقاط الاستشعار اللاسلكية لمراقبة المناطق ثلاثية الأبعاد ودراسة التأثير العالمي لدرجة الحرارة كعامل رئيسي.

قمنا بدمج نموذجين من اجل الخروج بحل يساهم في تفادي تأثير الحرارة على الشبكة، النموذج الأول هو توفير الطاقة عن طريق وضع بعض العقد في وضع السبات كما في الخوارزمية إيقاف التشغيل بحيث يدخل المستشعر في وضع سبات إذا خارج المنطقة التي يعمل فيها، والثاني هو خوارزمية ديلوناي التي تعتمد التثليث والتي تحدد الجيران لكل مستشعر من اجل إنشاء وصلات وتحسين الاتصال.

الكلمات المفتاحية:

شبكات الاستشعار اللاسلكية ، تغيرات درجة الحرارة ، وصلات الاتصالات ، النشر ثلاثي الأبعاد ، النشر ثنائي الأبعاد ، إيقاف التشغيل ، تثليث ديلوناي ، عمر الشبكة ، وضع الإسبات ، توفير الطاقة ، استهلاك الطاقة.

General introduction:

In the last few years, the technological development of community networks has wireless technology, has grown significantly as a result of technological advances in various areas, such as microelectronics and miniaturization. This is how new investigation channels were opened, with the emergence of wireless sensor networks. In this network, the deployment varies from one application to another, but generally the nodes are unattended and must operate in long periods of time without intervention. Therefore, the nodes must consume the least energy while ensuring that the network continues to function properly. In its basic form, the proper functioning of the network can be achieved only if coverage and connectivity are preserved. The coverage ensures that the entire deployment area is monitored so that no event is not captured, and connectivity means the network is not fragmented so that the transmitted data can reach all the nodes in the network. But the most existing wireless sensor systems and protocols are based on two-dimensional (2D) design, where all wireless sensor nodes are distributed in a two-dimensional plane. This assumption is somewhat justified for applications where sensor nodes are deployed on earth surface and where the height of the network is smaller than transmission radius of a node. However, 2D assumption may no longer be valid if a wireless sensor network is deployed in space, atmosphere, or ocean, where nodes of a network are distributed over a 3D space and the difference in the third dimension is too large to be ignored. In fact, recent interest in under-water sensor networks [47] or space sensor networks [48] hints at the strong need to design 3D wireless networks.

The right 3D deployment must take into account the most adverse conditions. However, these conditions can't occur in a limited number of time other. In the rest of the time, the conditions are more favorable and the network must adapt its mode of operation to save more energy and resources.

Temperature is one of those conditions that affect transmission power and reception sensitivity of the WSN significantly, in particular the quality of the links wirelessly between the sensor nodes. In fact, the sensor nodes are equipped with low-cost, low-power receivers whose performance depends on temperature in which they operate. As, when the temperature increases, both the power of transmission and reception sensitivity decrease which leads to degradation of links wireless communication, and thus the overall connectivity of the network. In this thesis, we propose to study the global effect of temperature in 3D-deployment on the correct operation of the network in mobility radio environments by using algorithms based on famous functions as Delaunay triangulation in communication part and stop-operate in deployment part.

Thesis organization:

chapter 1: deployment methods of WSN this Chapter presents an introduction to the field of WSN, we retrace the basic concepts of sensor networks, also we introduce deployment methods in 3D and 2D environment.

Chapter 2: mathematical optimization methods this chapter present a classification of an optimization problems.

Chapter 3: conception this chapter presents energy conservation methods (stop operate) also we introduce DT

Chapter 4: Implementation and Experimentation this chapter is dedicated to the presentation of DT and triangulation deployment, also we present the evaluation metrics and simulation results.

and we finished by a general conclusion contain the research prospects of the works carried out.

I. Introduction

In few years, new technologies have shaped numerous military and commercial strategies in an unprecedented way. The wireless sensor network (WSN) technology is one such technology and has been attracting significant attention. Most studies focused about that in deploying on 2D environments, but some application need a third dimension for example home automation, precision agriculture (fruit tree plantation). In the scope of this chapter, we ‘ll present a general information about WSN, type of coverages and connectivity algorithm and finally a model for 3D and 2D deployment.

II. General information about wireless sensor network

In this section we have presented the characteristics, the architecture and the structure of the wireless sensor network.

II.1 The sensor:

II.1.1 Definition of the sensor: A sensor is a device that detects and responds to some type of input from the physical environment [10]. Moreover, A sensor is an electronic component, module, or subsystem whose purpose is to detect events or changes in its environment and send the information to other electronics. Sensors are used in everyday objects such as touch-sensitive elevator buttons and lamps [11]. Sensor nodes are often called motes [12]

II.1.2 Types of the sensor: Here are a few examples of many different types of sensors:

- **oxygen sensor** in a car's emission control system detects the gasoline/oxygen ratio, usually through a chemical reaction that generates a voltage. A computer in the engine reads the voltage and, if the mixture is not optimal, readjusts the balance.
- **Motion sensors** in various systems including home security lights, automatic doors and bathroom fixtures typically send out some type of energy, such as microwaves, ultrasonic waves or light beams and detect when the flow of energy is interrupted by something entering its path.[13] .

II.1.3 Architecture of the sensor:

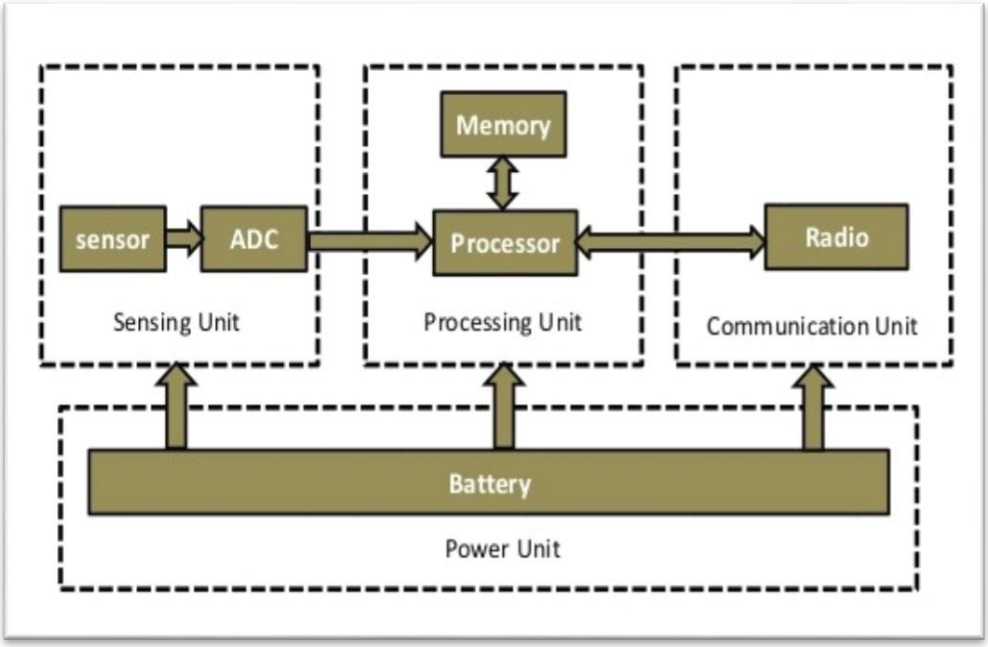


Figure.I.1 : The sensor architecture.

II.2 Wireless sensor network

II.2.1 Definition: Wireless sensor network (WSN) a new technology for collecting data with autonomous task-oriented sensors. this technology became more popular because of its application and cost. The application of WSN includes battlefield surveillance, border monitoring, habitat monitoring. According to the applications the deployment strategy is decided [14].

The WSN is built of "nodes" from a few to several hundreds or even thousands, where each node is connected to one (or sometimes several) sensors. The topology of the WSNs can vary from a simple star network to an advanced multi-hop

wireless mesh network. The propagation technique between the hops of the network can be routing or flooding [15].

II.2.2. CHARACTERISTICS of WSN: The significant characteristics of WSN are described as follows [10]:

- **Low cost:** in the WSN normally hundreds or thousands of sensor nodes are deployed to measure any physical environment. In order to reduce the overall cost of the whole network the cost of the sensor node must be kept as low as possible.
- **Energy efficient:** the energy in WSN is used for computation, communication and storage. Sensor node consumes more energy. So, the protocols and algorithm development should consider the power consumption in the design phase.
- **Computational power:** normally the node has limited computational capabilities as the cost and energy need to be considered.
- **Communication Capabilities:** WSN typically communicate using radio waves over a wireless channel. It has the property of communicating in short range, with narrow and dynamic bandwidth. The communication channel can be either bidirectional or unidirectional. So, the hardware and software for communication must have to consider the robustness, security and resiliency.
- **Security and Privacy:** Each sensor node should have sufficient security mechanisms in order to prevent unauthorized access, attacks, and unintentional damage of the information inside of the sensor node.
- **Distributed sensing and processing:** the large number of sensor node is distributed uniformly or randomly.

II.2.3 WSN ARCHITECTURE

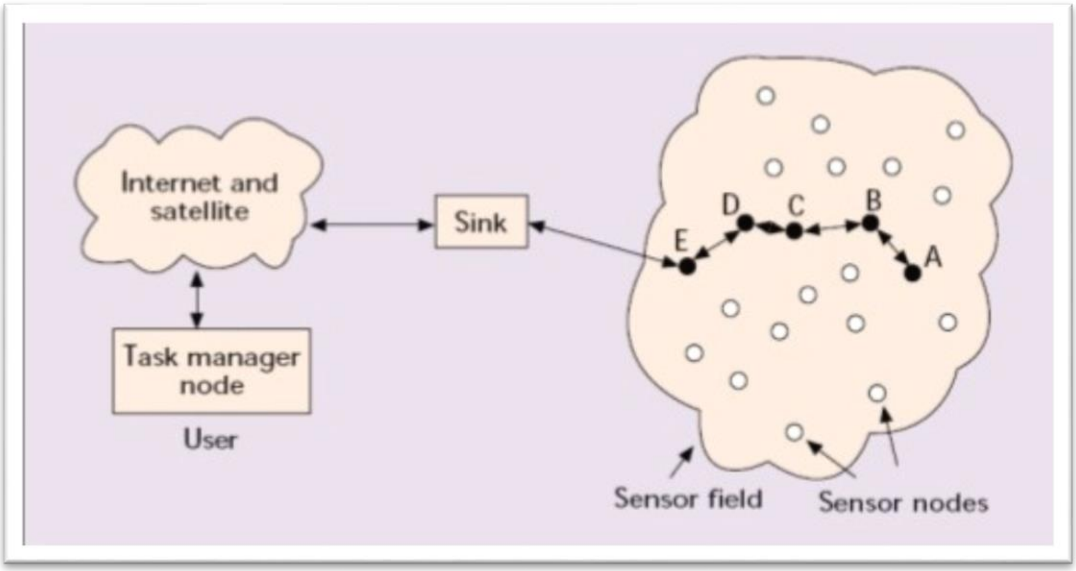


Figure.I.2: WSN architecture.

II.2.4 factors and constraints of a WSN: the main factors and constraints influencing the architecture of sensor networks can be summarized as follows [17]:

a) **network lifetime:** the power supply of each node is ensured by a limited source of energy. the lifetime of a WSN dependent on the energy conservation at each node.

b) **Coverage:** The coverage area is often considered a disk of radius Rs called sensing range.

c) **Connectivity:** is a major problem in sensor networks. A sensor array is connected if there is at least one route between each pair of nodes.so the connectivity depends mainly on the existence of roads.

d) **Deployment:** Deploying Nodes It is factor dependent on the application that affects routing protocols in a static WSN. Deployment can be determined or random.

e) **No fixed addressing of nodes:** nodes use addressing based on the attribute of the captured phenomenon, the requests of the users are not generally intended for a single node, but rather for a set of nodes identified by an attribute.

f) **Dynamic Topology:** The topology of a sensor network may change over time. This dynamicity of the network results from node failures due to physical damage or the expiration of its energy.

II.2.5 WSN parameter

i. **Node parameters**: Some parameters that influence the probability of intrusion detection are:

i.1 Node density: It is defined as the total number of nodes present in the network.

i.2 Transmission range: The maximum distance up to which a node can transmit

i.3 Sensing range: The distance up to which a sensor can detect the presence of intruder. [7].

ii. **WSN types:**

ii.1 Homogeneous WSN: In homogeneous WSN all the sensors have same capabilities. They all have same battery energy, hardware complexity sensing range, and transmission range [18].

ii.2 Heterogeneous WSN: heterogeneous WSN consists different sensor nodes. Moreover, some sensors have larger capabilities than other sensors. In this

network some sensors have larger sensing range, transmission range and have more

battery power. Heterogeneous WSNs are most suitable for real life applications as compared to homogeneous [19].

II.2.6 Structure of a wireless sensor network:

Structure of a Wireless Sensor Network includes different topologies for radio communications networks [20]

1-Star network (single point-to-multipoint): this topology Its where a single base station can send and/or receive a message to a number of remote nodes. The remote nodes are not permitted to send messages to each other. The advantage of this type of network for wireless sensor networks includes simplicity, ability to keep the remote node's power consumption to a minimum (see figure.I.3).

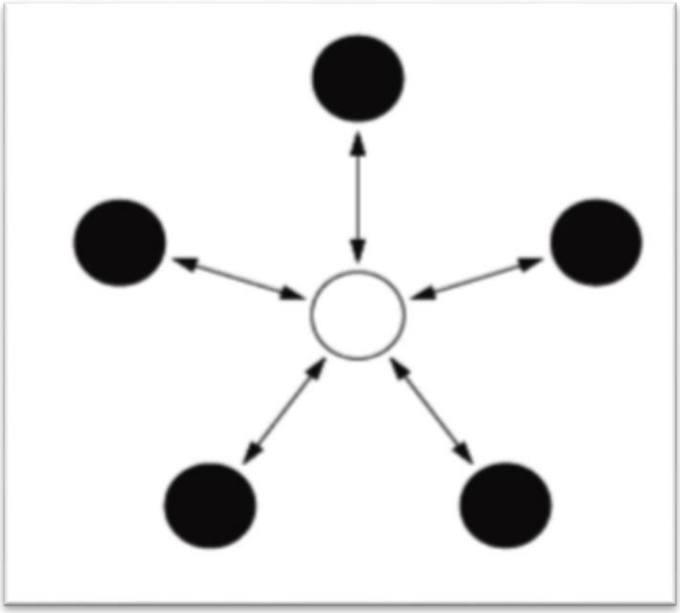


Figure.I.3: star network

2-Mesh network: It allows transmitting data to one node to other node in the network that is within its radio transmission range. This allows for what is known as multi-hop communications (see figure.I.4).

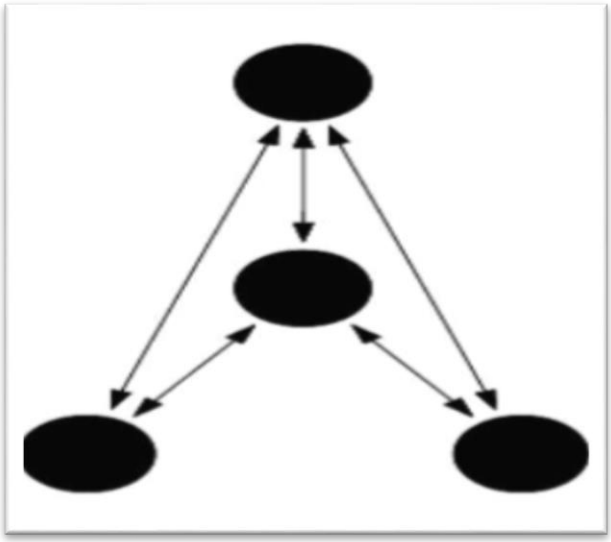


Figure.I.4: mesh network

3-Hybrid star: A hybrid between the star and mesh network provides a robust and versatile communications network. while maintaining the ability to keep the wireless sensor nodes power consumption to a minimum. [11]

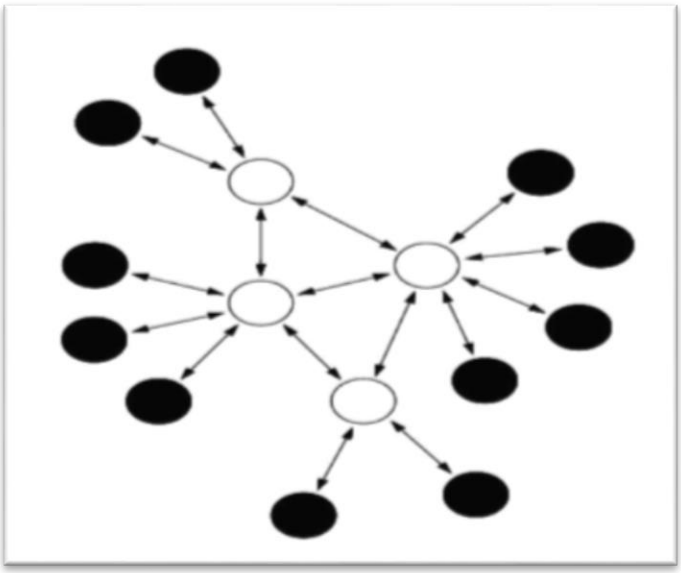


Figure.I.5: hybrid network

III. Analysis of the criteria of deployment algorithms

In this section, we analyze the various factors that have a positive or negative impact on sensor deployment.

1.Factors impacting the deployment:

Several factors impact the deployment and determine how satisfactory the application is. They concern:

- ✓ The assumptions and models used concerning r the sensing range and R the communication range.
- ✓ The number of sensor nodes available for the deployment and the dimensions of the entity monitored will determine whether this number is sufficient to fully cover the entity.
- ✓ The sensor nodes' ability to move is a determining factor.
- ✓ The initial topology may require some extensions to the deployment algorithm.

- ✓ The energy of sensor nodes is di-cult or impossible to renew, and this fact is of great importance. In the deployment phase, the main reason for energy consumption is the movement of the nodes. [8]
- ✓ The presence of obstacles makes the deployment more complex: no sensor node should be placed such that an obstacle prevents its being located
- ✓ The presence of obstacles makes the deployment more complex: no sensor node should be placed such that an obstacle prevents its being located.
- ✓ The positioning system may introduce some inaccuracy in the position of the nodes; such a positioning error is very common with GPS.
- ✓ The quality of the data gathering required by the application may lead to a uniform and regular deployment. Such a deployment provides smaller data gathering delays [9]

2. Criteria for performance evaluation

Different evaluation criteria have been introduced to evaluate and select the best application:

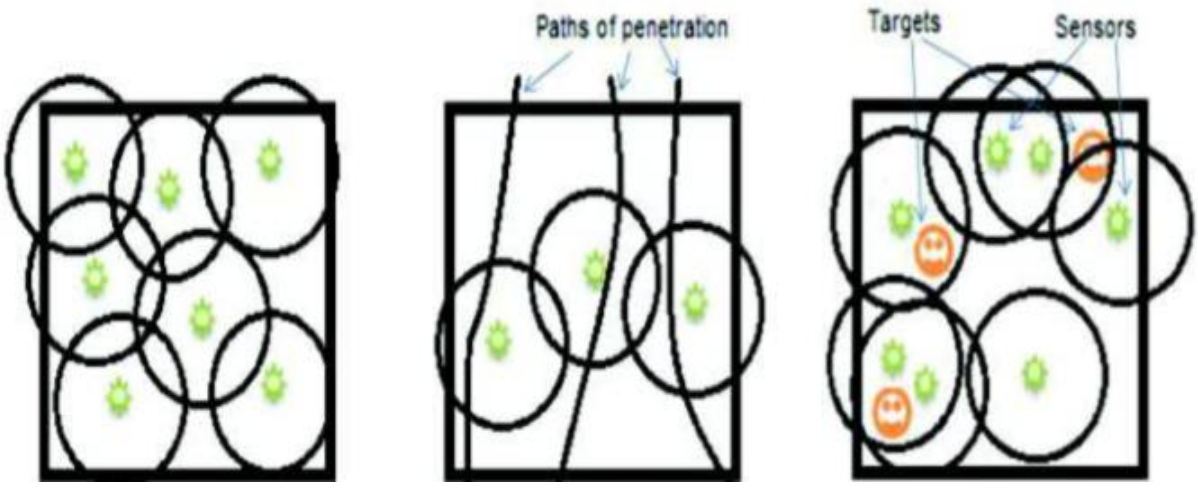
- **coverage:** area, barrier, point of interest, Usually the area to cover is divided virtually into **L x W** grid units, where L is the length and W the width of the area considered.
- **connectivity:** The type of connectivity **full** or **intermittent.**
- **convergence and stability**: the convergence evaluated by the convergence time defined as the time needed to achieve the required coverage and connectivity. And for the stability, it may be used to detect the completion of the deployment.

- **energy and distance traveled**: the movement of the nodes is the main cause of energy consumption, that is why the total distance traveled by the nodes must be measured, Obviously, minimizing the total distance traveled leads to savings in energy. [6]
- **communication overhead:** it comes from the control messages exchanged between the nodes to organize the deployment and the data gathering. [7]

IV. Coverage types and connectivity algorithms

Many deployment algorithms may vary according to the strategy used, the coverage problem, the connectivity problem, the number of sensor nodes needed, etc. however

we discuss a various deployment algorithms which cope with area coverage (figure.I.6.a), barrier coverage(figure.I.6.b) and Points of Interest (PoIs) coverage (figure.I.6.c).which may be helpful to choose the most suitable deployment algorithm[6].



a-Area coverage b-barrier coverage c-point coverage

figure.I.6 : coverage types[5]

1. Area coverage and connectivity algorithms

In this section, we study area coverage and connectivity algorithms

1. Full coverage

Many deployment algorithms aim to ensure full coverage of the area to be monitored.

These algorithms are classified into three strategies. the forces-based strategy, the grid-based strategy and the computational geometry-based strategy.

1.1. The forces-based strategy:

based on virtual forces that can be attractive, repulsive or null. In this strategy, a sensor node should maintain a fixed threshold distance called Dth from its 1-hop neighbors (see figure.I.7). [17]

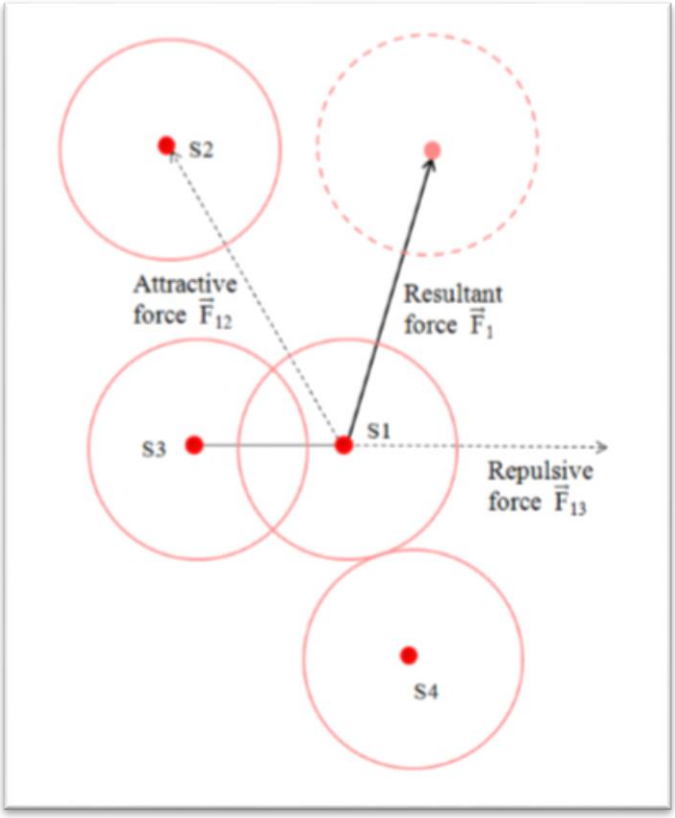
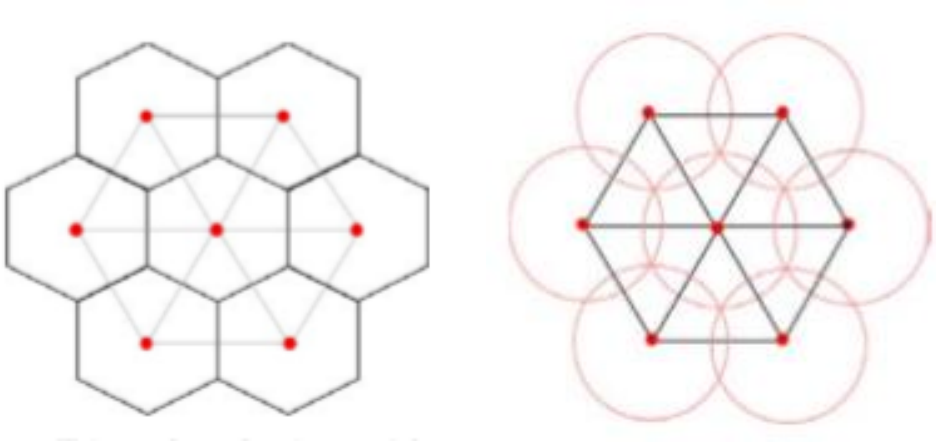


Figure.I.7: forces-based strategy

1.2.The grid-based strategy

This strategy provides a deterministic deployment where the positions of the sensor nodes are fixed according to a special grid pattern such as a triangular lattice (see figure.I.8), square grid or a hexagonal grid. the area is divided into virtual cells and depending on the deployment algorithm used, sensor nodes are located either in cell vertices or at the cell center [20].



a- with hexagonal cells b-simple

Figure.I.8: Triangular lattice [4]

1.3.The computational geometry strategy

is used to solve problems based on geometrical objects: points, polygons, line segments, etc. The Voronoi diagram and Delaunay triangulation are two computational geometry methods used in WSNs to solve static problems.

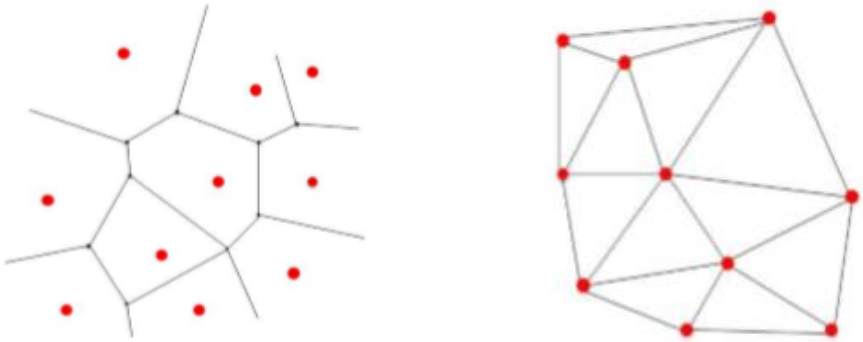
1.3.1. Deployment algorithms based on the Voronoi diagram:

Some schemes proposed to detect coverage holes. Sensor nodes are able to construct their Voronoi polygons based on location information received from their neighbors. Due to these Voronoi polygons, nodes can detect coverage holes. Then, they move in

order to reduce or eliminate these holes while maximizing the coverage rate of the area (see figure.I.9. a). [3]

1.3.2. Deployment algorithms based on Delaunay Triangulation: Delaunay triangulation is used to partition coverage holes into

triangles of edges less than r and then, a sensor node is placed in one of the triangle vertices to cover it. (see figure.I.9. b). [2]



a-Voronoi diagram b- Delaunay Triangulation

figure.I.9: The computational geometry strategy

2. Partial coverage

Generally, partial coverage is one solution to prolong network lifetime when full coverage is not required. However, only a few studies have focused on partial area coverage. [1]

2 Barrier coverage and connectivity algorithms

Barrier coverage is a model for some applications. A deployment of sensor nodes along a barrier is necessary to detect an intruder crossing, this deployment can ensure either full barrier coverage or partial barrier coverage.

1. Full barrier coverage: It can be simple or multiple. If there is just one barrier it's simple if there are k successive barriers of sensor nodes it's multiple. To ensure full barrier coverage, two types of deployment algorithms can be used, depending on whether the sensor nodes are static or mobile. [21].

Static sensor nodes: generally, nodes deployed uniformly over the whole area based on a Poisson Point Process model. Using this kind of deployment, barrier coverage can be provided by selecting a chain of overlapping sensor nodes. [22].

Mobile sensor nodes: it should execute two phases to reach their final positions. firstly, each sensor node moves vertically to reach a line. Then, secondly it moves horizontally along the line to a predetermined grid point position. When each grid point is occupied by a sensor node, full barrier coverage is provided. [23]

2.Partial barrier coverage: In the barrier coverage problem, the optimal number of nodes (denoted m points) required to fully cover the barrier, can be determined based on the sensors' sensing range and the barrier length, if the number of available nodes is less than optimal, the barrier coverage problem will be formulated as how to move n mobile sensor nodes to monitor n points among the m points so as to maximize the average intruder detection while minimizing the average sensor movement distance. To solve this problem, two algorithms, PMS and CSP, are proposed [24].Sensor nodes may be dropped randomly, trying to follow a barrier line [22]. In this case, coverage can be improved by a centralized algorithm [23].

3.Point coverage and connectivity algorithms

The last type of coverage is the coverage of Points of Interest (PoI). Examples of applications include the detection of some static or moving target. And there's two types of Pols static and dynamic.

3.1 Static Pol: The strategy of this deployment algorithm minimizes the number of sensors used to maintain connectivity by using the Relative Neighborhood Graph (RNG) [25].

If multiple PoIs exist in the area, two approaches can be adopted:

- ✓ **Random PoI deployment:** the sensor chooses one of the PoIs at random.
- ✓ **Barycenter PoI deployment:** Every sensor calculates the barycenter of all the PoIs and the sink to cover it. Then each sensor chooses a PoI at random and covers it. [26]

Temporary coverage of Multiple PoIs is called the sweep coverage problem as sensor nodes sweep between PoIs and cover them periodically [27].

3.2Mobile PoI: there's three strategies to reach the mobile PoI:

- ✓ **the first strategy:** sensor nodes move back to the sink before deploying toward the new location of the PoI. it provides a high coverage quality but increases the deployment duration and the amount of energy consumed.
- ✓ **the second strategy,** sensors try to move directly toward the new location of the PoI without going back to the sink. It reduces the covering time and the coverage quality as it requires a greater number of sensors to maintain connectivity.

- ✓ the third strategy, a sensor moves to the straight line between the sink and the new location of PoI, then it follows the line toward the PoI. It provides a higher coverage quality and reduces the covering time of the PoI. [28].
- ✓ Any PoI needs only one sensor to be covered. If permanent connectivity is required, a sufficient number of sensor nodes are deployed to ensure connectivity with the sink.

V. Models for 2D and 3D deployment

1. Models for 2D deployment

1.1. Sensing range and communication range in 2D: In a 2D area, the wireless sensors are all assumed to have the same sensing range denoted r and the same radio range R. we also assume that the condition $R \geq \sqrt{3}r$ is met. This condition guarantees that any deployment of wireless sensor nodes ensuring full coverage and full connectivity. [29]

1.2. The area considered and obstacles in 2D: The area to fully cover is considered as a polygon which may or may not be convex, this polygon is defined by its edges. These edges constitute the borders of the area. We distinguish two types of borders:

1.2.1. Transparent border: it doesn't prevent the sensing activity of sensor node.

1.2.2. Opaque border: it prevents nodes from sensing the area located behind the border.

The area considered usually have obstacle no sensor node must be located within an obstacle there's two types of obstacle .an obstacle is defined by the edges of its polygon which may be irregular in shape and not convex.

1.2.3. Transparent obstacle: have no impact on either the sensing range or the communication range of the node, they only prohibit nodes from crossing them.

1.2.4. Opaque obstacles: like the other one block the node from moving. They may also cause a hidden zone.[29]

2. Models for 3D deployment:

Most studies use a 2D space to model the area considered, in the reality the area is not always flat, also in some application need a third dimension so 2D is not sufficient application requiring 3D monitoring.

2.1 **Sensing range and communication range in 3D:** in 3D sensing range and communication range are modeled by two spheres of radius r and R (Figure.I.10)

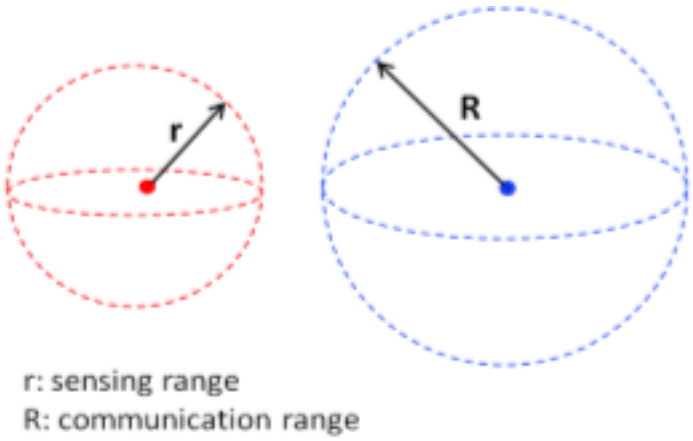


Figure.I.10 sensing and communication range modeled by sphere

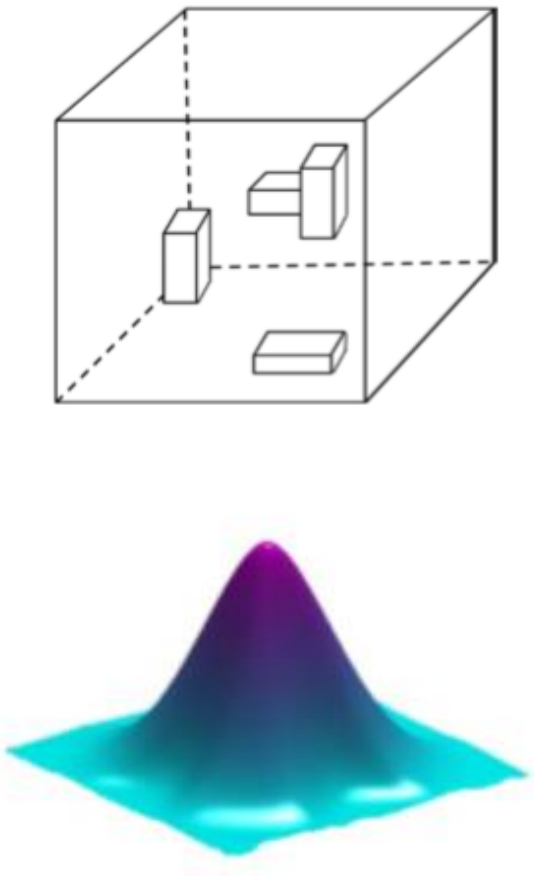
2.2 The area considered and obstacles in 3D:

In 3D space the area to cover can be either a polyhedron or a surface (see figure.I.11).

When the area to cover is a polyhedron, a sensor node can be located at any position inside the polyhedron. When the area is a 3d surface the sensor node

should follow the shape of this surface. This problem called a 3d surface covering.

An obstacle is modeled by a polyhedron .and also present in 3D space and they may be transparent or opaque as in a 2D space.[30]



a- Polyhedron b- surface

Figure.I.11: 3D area

VI. Delaunay triangulation in 3D:

the Delaunay triangulation (shortly DT) is one of the most popular and most often used methods. A lot of the optimal properties of DT are known in 2D.

The properties of DT in 3D or generally in higher dimension are not as good as 2D and different kinds of methods are used mainly to remove the tetrahedra of undesirable shape.

triangulation of a given set P of n points in d-dimensional space E^d is a simplicial decomposition of the convex hull of **P**. for 3D space it means the convex hull of the **P** is decomposed into tetrahedra such that:

- Vertices of tetrahedra belong to **P**
- Intersection of two tetrahedra is either empty or a vertex or an edge or a face.

some properties of DT in E^d are:

- The DT is unique, if the point set is in general position
- The DT includes at most o ($n^{[d/2]}$)simplices
- The DT minimizes the maximum radius of a simplex enclosing sphere.
- The faces of DT hold visibility depth ordering for any viewpoint
- The DT minimizes the maximum radius of circumcircle.
- The DT maximize the minimum angle.

VII. Conclusion:

In this chapter we introduced the basic concept of WSNs, the coverage types and models for 2d and 3d deployment that we'll use it in the following chapters.

I. Introduction:

In this chapter we'll present an overview of optimization problems, optimization problems fall into two categories: problems with variables whose domain is continuous and problems with variables whose domain is discrete and that also called combinatorial problems, also we present some classic problems in combinatorial optimization.

II. Definition of optimization:

an optimization problem is defined as the search for a minimum or maximum of a given function. We can also find optimization problems for which the variables of the function to be optimized are forced to evolve in a certain part of the search space. In this case, there is a particular form of what is called a constrained optimization problem. [31]

For Mathematique an optimization problem explains in the following form:

Minimizer f ($\vec{x}$) optimization function

with g ($\vec{x}$) m inequality constraints

and h ($\vec{x}$) p quality constraints

This set of constraints delimits a small search space for the optimal solution. [32]

III. Formulation of optimization problems:

We can classify the different optimization problems that we encounter in everyday life according to their characteristics: [32]

1. number of decision variables:
   - one =⇒ mono variable.
   - Several =⇒ multivariable.
2. type of decision variable:
   - continuous real number = ⇒ continuous
   - integer = ⇒ integer or discrete.
   - Permutation on a finite set of numbers = ⇒ combinatorial.
3. type of the objective function:
   - Linear function of the decision variables = ⇒ linear.
   - Quadratic function of the decision variables = ⇒ quadratic.
   - Nonlinear function of decision variables = ⇒ nonlinear
4. Problem's formulation:
   - With constraints = ⇒ constraint.
   - Without constraints = ⇒ not constrained.

Here is an example of use of this classification. If we consider the problem of optimizing the plans for reloading nuclear fuel, we see that this problem is:

- nonlinear ⇒ there is no explicit representation of the problem. We have to use a numerical calculation code to calculate as precisely as possible the different values to be optimized.
- constraint ⇒ fuel elements cannot be placed anywhere;
- multivariable ⇒ a reloading plan is composed of several fuel elements
- combinatory ⇒ to switch to another reloading plan, we switch fuel elements of a reloading plan. [33]

IV. classification of an optimization problems

1) problem of the commercial traveler:

representative must visit n cities once and only once, and return to his departure city, minimizing the total cost of the trip, a complete graph G = (V, E) with an application c: E −⟶R the problem is to find the shortest Hamiltonian circuit in graph G. [34]

$$z = \sum_{i=1}\sum_{j=1} c_{ij}x_{ij} \ (\min)$$
$$(1) \ \sum_{j=1} x_{ij} = 1 \ i \in \{1, ..., n\}$$
$$(2) \ \sum_{i=1} x_{ij} = 1 \ j \in \{1, ..., n\}$$
$$(3) \ x_{ij} \in \{0, 1\} \ (i, j) \in \{1, ..., n\}^2$$
$$(4) \ x_{ij} \in \{0, 1\} \ (i, j) \in \{1, ..., n\}^2$$

2) The problem of bipartite coupling:

a complete bipartite graph G = (V1 ∪V2, E) associated with a weight c ∈ N^m associated with the edges of E, A coupling of G is called a set of non-incident two-to-two edges.

The problem of bipartite coupling is to determine a coupling that maximizes the sum of the weights of its edges. There are several efficient polynomial algorithms to solve this classic problem.

Moreover, it has been shown that an assignment is complete as soon as the weight vector c is whole. Consider the next PL: [34]

$$z = \sum_{e \in E} c_e x_e \ (\max)$$
$$(1) \sum_{e \in \delta(u)} x_e \leq 1 \ \forall u \in V_1$$
$$(2) \sum_{e \in \delta(u)} x_e \leq 1 \ \forall u \in V_1$$
$$(3) \ x(e) \geq 0 \ \forall e \in E$$

3) tree problem covering minimum weight:

a graph G = (V, E) connected, with an application c: E −→R the problem is to find in G, a maximal tree. [34]

A = (V, E'), E' ⊂ E of a minimum total weight.

$$z = \sum_{i=1}\sum_{j=1} c_{ij} x_{ij} \ (\min)$$
$$(1) \sum_{i=1}\sum_{j=1} x_{ij} = n - 1$$
$$(2) \sum_{(i,j) \in s^2} x_{ij} \leq \mid S \mid -1 \ , S \subset \{1, .., n\} : 2 \leq \mid S \mid \leq n - 1$$
$$(3) \ x_{ij} \in \{0, 1\} \ (i, j) \in \{1, ..., n\}^2$$

V. Conclusion:

In this chapter we presented a classification of an optimization problems, also the formulation of this problems and we present some of this problem.

I. Introduction

The wireless sensor network uses low-power transceivers to allow nodes to communicate, this transceiver have a temperature sensitivity, which effect on the communication ability of this transceiver.

In this chapter, we will present the design and architecture of our system. We will explain the functionalities of each component and the methods used to find the optimal position of node .and we will exploit the fact of the temperature on the WSN as the supreme factor, we suppose that WSN continues to work properly if both a full coverage and connectivity are guaranteed.

II. The goal:

Our purpose in this project is about creating an optimized WSN in 3D plane (real world), also we'll find a solution for the temperature as the main factor to make the WSN work for a longest time as possible, for the energy we'll create a channel based on DT and using other technique (stop operate) to save energy.

III. WSN deployment:

As we talked before there's three type of deployment hexagonal, square and triangle. For our project we chose triangle due to:

- the common sensing spaces is less than others.
- The triangulation deployment consumes the least number of nodes to cover the same area.

IV. Radio links:

the packet error rate or the PER express the wireless communication link between two transceiver nodes,

the PER depend on the intensity of the signal measured at the receiver, the sensitivity is a PER of less than 1% it's called Ps.

if the received power Pr is equal to or greater than the sensitivity Ps. It is assumed that there is a link, The intensity of this signal depends on the transmit power Pr and the attenuation of the transmitter.

The attenuation A (d) on the distance d is the ratio between Pt and Pr (d) where Expressed A(d)expressed in dB, Pt and Pr (d) are expressed in dBm [35]:

$$A(d)= Pt - Pr(d) \quad \text{(III.1)}$$

The attenuation include: $$A(d)= A0 + A1(d) + A2 \quad \text{(III.2)}$$

Where:

- A0 is the path loss at the distance reference d0.
- A1 (d) is the loss of log-distance path based on function of distance and d0.
- A2 is a random variable reflecting the attenuation caused by fading

We take A0 according to the free space propagation model.

we obtain :

$$A0 = 20\log d0 + 20\log f - 27.55 \quad \text{(III.3)}$$

$$A1(d)= \alpha 10\log(d/d0) \quad \text{(III.4)}$$

$$A2 \sim N(0,\sigma) \quad \text{(III.5)}$$

Where:

- f is the frequency (in MHz).

- α is the exponent of path loss.
- N (0, σ) is a normal random variable (in dB).
- d0 equal 1 meter.

V. Communication range:

the communication range is the distance at which the lost packets less than 1% also the communication range is a random variable R with the cumulative distribution function FR (d) is defined [35]:

$$FR(d)= Pr[R \geq d]= Pr[Pr(d)\geq Ps]$$
$$=Pr[Pt - Pr(d)\leq Pt - Ps]$$
$$= Pr[A(d)\leq Pt - Ps] \quad \text{(III.6)}$$

We replace A (d) by its value eq (III.2) and A2 is a normal random variable we obtain:

$$FR(d)= Pr[A2 \leq Pt - Ps - A0 - A1(d)]$$
$$= FA2(Pt - Ps - A0 - A1(d)) \quad \text{(III.7)}$$

Where:

FA2 is a cumulative distribution function (CDF) of A2, and with eq (III.5) we get:

$$FA2(Pt - Ps - A0 - A1(d))= \frac{1}{2} + \frac{1}{2} \text{erf} \left(\frac{Pt - Ps - A0 - A1(d)}{\sigma\sqrt{2}}\right) \quad \text{(III.8)}$$

Where:

erf is the error function defined as follows

$$\text{erf} = \frac{2}{\sqrt{\pi}} \int_0^z e^{-t^2} dt \quad \text{(III.9)}$$

we used eq(III.7) and eq(III.8) we obtain:

$$Fad = FA2(Pt - Ps - A0 - A1(d))$$

$$= \frac{1}{2} + \frac{1}{2}\,\mathrm{erf}\left(\frac{Pt - Ps - A0 - A1(d)}{\sigma\sqrt{2}}\right) \quad \text{(III.10)}$$

So, eq(III.10) it's not valid to calculate FR(d).

From (III.7) We have :

$$FR(d)_{\alpha=0} = Pr[0 \leq Pt - Ps - A0 - A1(d)]$$

$$= Pr[A1(d) \leq Pt - Ps - A0] \quad \text{(III.11)}$$

With eq(III.4) and d0 =1 ,eq(III.11) become:

$$FR(d)_{\alpha=0} = Pr[10\alpha \log(d/d0) \leq Pt - Ps - A0]$$

$$= Pr[d \leq 10^{pt-ps-A0/10\alpha}]$$

$$= \begin{cases} 1, & \text{if } d \leq 10^{pt-ps-A0/10\alpha} \\ 0, & elsewhere \end{cases}$$

(III.12)

We put:

$$R = 10^{pt-ps-A0/10\alpha} \quad \text{(III.13)}$$

We combine eq (III.8) With eq (III.12) and using eq(III.13)we obtain:

$$FR(d) = \begin{cases} \frac{1}{2} + \frac{1}{2}\,\mathrm{erf}\left(\frac{Pt - Ps - A0 - A1(d)}{\sigma\sqrt{2}}\right), & \alpha > 0 \\ 1_{(-\infty,R)}(d), & x = 0 \end{cases} \quad \text{(III.14)}$$

Where $1_{(-\infty,R)}(d)$ it's a function equal 1 when d<R and 0 elsewhere, also we note that R represent communication range.

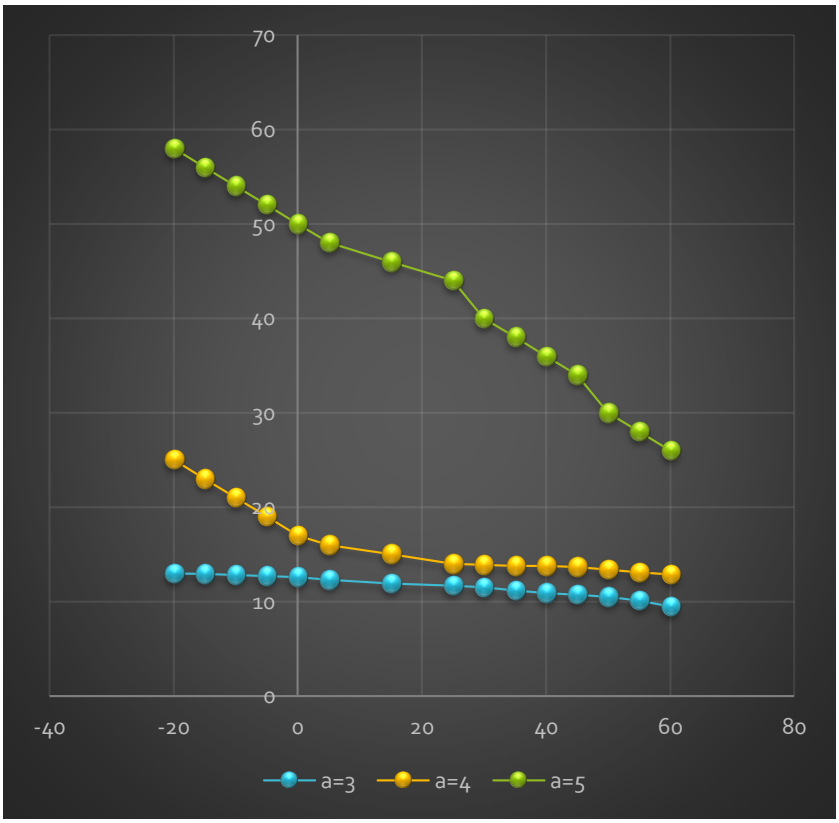


Figure.III.1 the communication range under the variation of temperature

VI. Effect of temperature on the communication power

high temperatures affect communication between the sensor nodes [36], CC2400 [37] and CC2530 [38] show that the temperature affects both the quality of transmission and reception.

The effect of temperature on transmission power and reception sensitivity is studied in the technical documentation, we found that the values of Ps and Pt vary with temperature T ,moreover the real value of R depends on the temperature.

The following equations were obtained from [39] with degree equal 2:

$$Pt(T) = -0{,}0001.T^2 - 0{,}0676.T + 1{,}6112 \text{ (dBm)} \quad \text{(III.15)}$$

$$Ps(T) = 0{,}0005.T^2 + 0{,}0407.T - 89{,}547 \text{ (dBm)} \quad \text{(III.16)}$$

We used Pt(T_t)(resp. Ps(T_r)) to write the transmission power and The reception sensitivity as a function of the temperature T.to make things clear we need to say that the temperature measured by the transmitter and the receiver is the same.

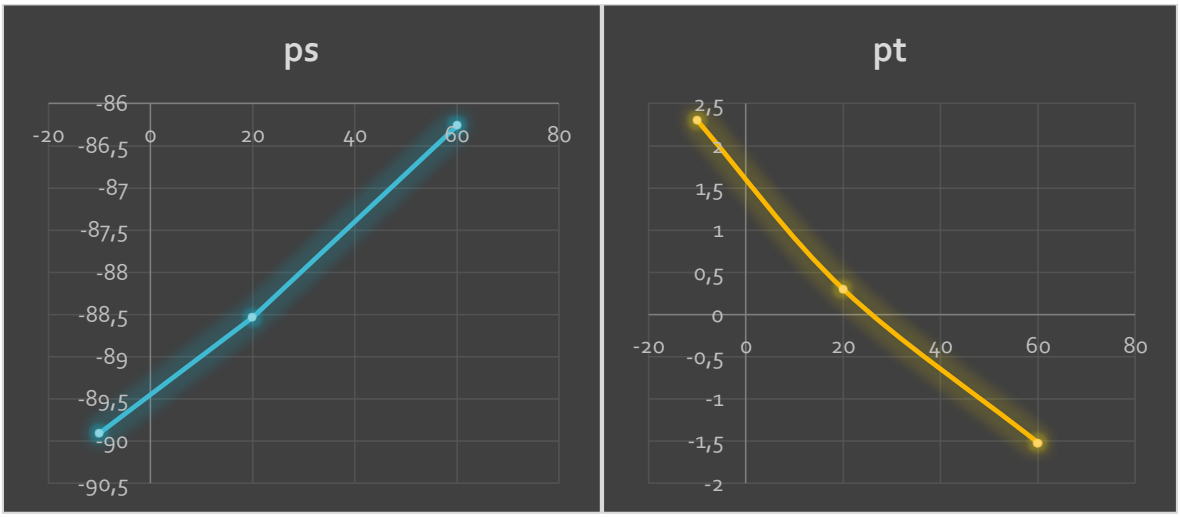


Figure.III.2: the effect of temperature on the pt and ps

VII. Network connectivity

the connectivity of network represent as follows [40]:

$$\mu(R)=\frac{N.\pi.R^2}{A} \quad \text{(III.17)}$$

where:

- R is the communication radius
- A the deployment area.
- N the number of nodes located in Area A.

VIII. Energy conservation techniques

The average power consumed increases when the temperature drops. When temperature decrease, it makes each node spend more energy to receive several packets, then each node will have a large number of neighbors, more connectivity. We propose algorithms designed to operate properly in extreme conditions to conserve energy it's stop operate.

IX. Algorithms and system model

IX.1 Node position:

Each node has three components X and Y and Z as it shown in Figure.III.3, The distance between each two nodes is defined as:

d (N1, N2) =$\sqrt{(N1,X\ -\ N2,X)^2 + (N1,Y\ -N2,Y)^2 + (N1,Z\ -N2,Z)^2}$

To insure connectivity and sensitivity we defined the default distance between two suit nodes equal √3*r

Where: r is the sensing rang.

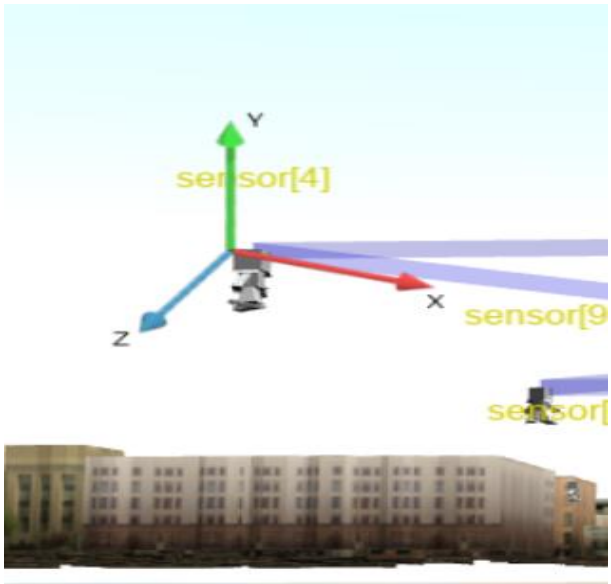


Figure.III.3: node position

IX.2 Stop operate:

In this approach a proportion of the nodes continues to operate normally and the others must be put in hibernation mode to save energy when the temperature drops. the principle of this algorithm is in every iteration, the nodes must change their positions and continue to operate normally if their position does not exceed the coverage area, else they must be hibernated.as shown in Algorithme1:

Algorithm 1: StopOperate (Run by each node)

Data: Temperature ,AreaWidth , AreaLength ,AreaHeight

/* Get the new communication radius NewR. */
1 NewR = CommunicationRange(Temperature) ;

/* Calculate the difference between the new radius and the old DiffR. */
2 DiffR ← NewR −OldeR ;

/* Calculate new coordinates on the map (x,y,z). */
3 Node.GetPosition() ;

4 X ← Node.X +Node.CoefX ×DiffR ;

5 Y ← Node.Y +Node.CoefY ×DiffR ;

6 Z ← Node.Z +Node.CoefZ ×DiffR ;

7 if X ≤ AreaWidth And Y ≤ AreaLength And Z ≤ AreaHeight then

/* Moves according to its coefficients on the X, Y and Z axis and continues to function normally. */

8 Node.SetPosition(X,Y,Z) ;

9 else /* Extended Standby. */

10 Node.SetRadio(off) ;

11 end

IX.3 movement coefficient:

when the temperature decreases the range of communication increase, in this case it is possible to migrate the sensor nodes so that the distance between these nodes may still be equal over the transmission. Next, the Stop-Operator algorithm is applied.

Nodes are migrated with motion coefficients on the X, Y and Z axis in 3D plane, and these coefficients are calculated in the following way, as shown in the algorithm2:

Algorithm 2: NodeCoefficients (Run by each node)

Data: Communication radius R
/* Get his coordinates on the map (x,y,z). */
1 Node.GetPosition() ;

/* calculate his displacement coefficients on the map(x,y,z) (CoefX, CoefY, CoefZ) */

2 $\text{Node.CoefX} \leftarrow \frac{\text{Node.X}}{\text{R}}$;

3 $\text{Node.CoefY} \leftarrow \frac{\text{Node.Y}}{\text{R}}$;

4 $\text{Node.CoefZ} \leftarrow \frac{\text{Node.Z}}{\text{R}}$;

For both algorithms 1 and 2, for each period node must measure the temperature and make decisions on the spot.

IX.4 Delaunay algorithm:

We choose a WSN deployment that minimizes consumption to maximize the life of WSN. The following algorithm illustrates DAULAUNYA TRINGULATION. With an equal ranges R in the case where the temperature is at the maximum, such that, in Tmax=50° and we choose a deployment zone of width and length And height equal to 200m.

- ✓ **The principle steps:**

1. take each possible three nodes (a circle contains this nodes).

2. calculate the center of this sphere.

3. calculate the distance between every other node and the sphere center.
   a) If the distance for just one point < rayon of circle we can't create DT by this point.
   b) If the distance for all point > rayon of sphere, we can create DT.

```
//calculating delaunay triangelation witch will return table of all possible triangulations
void delaunay_traingle(NodeContainer c,float R){ uint32_t i=0;uint32_t z=0;uint32_t j=0;uint32_t k=0;uint32_t l=0;
    float reyan; Vector center; float dest;
    while ( i < nbr )
      {j=0;
        while ( j <  nbr){
            if(i!=j)
            { z=0;
                while ( z < nbr ){
                    if(z!=j && z!=i){
                        Vector v1 = GetPosition (c.Get(i));
                        Vector v2 = GetPosition (c.Get(j));
                        Vector v3 = GetPosition (c.Get(z));
                        center= sphere_center(v1,v2,v3);
                        reyan = destence(center,v1);

   k=0;  dest=destence(center,GetPosition (c.Get(k)));
                                                    while(k<nbr && dest>=reyan && reyan<50.0){
                                                           dest=destence(center,GetPosition (c.Get(k)));
                                                           k++;
                                                           }
                                                    dest=destence(center,GetPosition (c.Get(41)));
                                                    if(dest<reyan){ k=0; }
                                                                        if(k==nbr){  uint32_t m=0;
                                                                            while(m<=l){
                                                                                Vector v4 = GetPosition (c.Get(triangles[m].A));
                                                                                Vector v5 = GetPosition (c.Get(triangles[m].B));
                                                                                Vector v6 = GetPosition (c.Get(triangles[m].C));
                                                                                Vector center2=sphere_center(v4,v5,v6);
                                                                                Vector center3=sphere_center(v5,v4,v6);
                                                                                Vector center4=sphere_center(v6,v4,v5);
                                                                                if(center2.x==center.x and center2.y==center.y and center2.z==center.z){
                                                                                    m=l+1;
                                                                                }else if(center3.x==center.x and center3.y==center.y and center3.z==center.z){
                                                                                    m=l+1;
                                                                                } else if(center4.x==center.x and center4.y==center.y and center4.z==center.z){
                                                                                    m=l+1;
                                                                                }
                                                                                m++;
                                                                            }

                                                                        if(m==l+1){
                                                                            triangles[l].A=i;
                                                                            triangles[l].B=j;
                                                                            triangles[l].C=z;
                                                                            l++;
                                                                        }
                    }
                }
                z++;
            }
        }
        j++;

      }
       i++;
    }
}
```

Figure.III.4:DT algorithm

X. Network working diagram:

the following diagram illustrate our project simulation steps

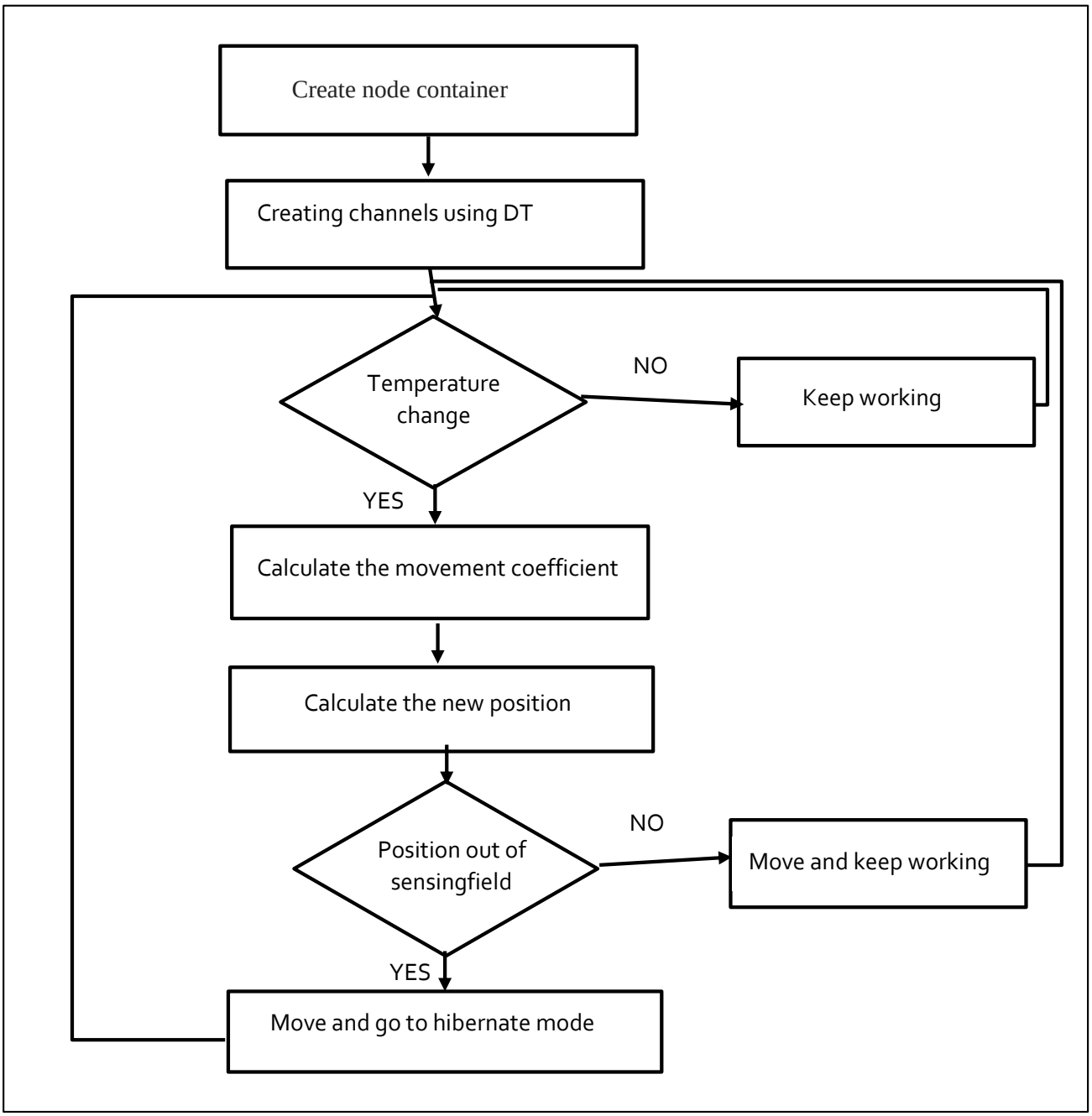


Figure.III.4: diagram of simulation steps

XI. Conclusion:

In the scoop of this chapter we talked about the effect of the temperature on the wireless communication, the transmission power, and the reception sensitivity, and we defined the communication range. In this chapter, we presented the architecture of our system and its components. We also explained the principle of the methods that we aim to implement it in the next chapter. We will present also the technical details for implementing the techniques to save energy and the application of Delaunay triangulation on 3d plane.

I. introduction:

Network simulators provide a lot of savings, time and money for performing simulation tasks. Moreover, Network simulation makes it possible to mimic real-world communications, allowing for a developer to discover potential boundaries, problems, detect and correct errors.

In this chapter, we will explain the technical details of our system. We will give an overview of the environment and language used to build applications in order to find the estimated position of node by DT and optimization, at the end we'll discuss the results of this simulation,

II. choice of simulator:

OMNET++ and **NS-3**, both discrete event simulators, could be good choices, we chose OMNET++ because it works better than NS-3, for many aspects as explained below:

- OMNET++ comes with its own IDE (Eclipse-based).
- OMNET++ is faster in terms of execution compared to NS-3.
- OMNET ++ support 3D environment.
- OMNET ++ more efficient than NS-3 in terms of memory management.
- OMNET++ has very good visualization support.

III. The tools:

III.1 OMNET ++ presentation:

OMNET++ (***O**bjective **M**odular **Net**work **T**estbed in C++*) is a modular, component-based on C++ simulation library and framework, primarily for building network simulators.

OMNET++ has a generic architecture, so it can be used in various problem domains: modeling communication networks, protocol modeling, queueing networks, multiprocessors and other distributed hardware systems [41]

OMNET++ uses C++ to define source code of protocols and applications and its own NED language to combine these implementations into (sub-)modules and networks. [42]

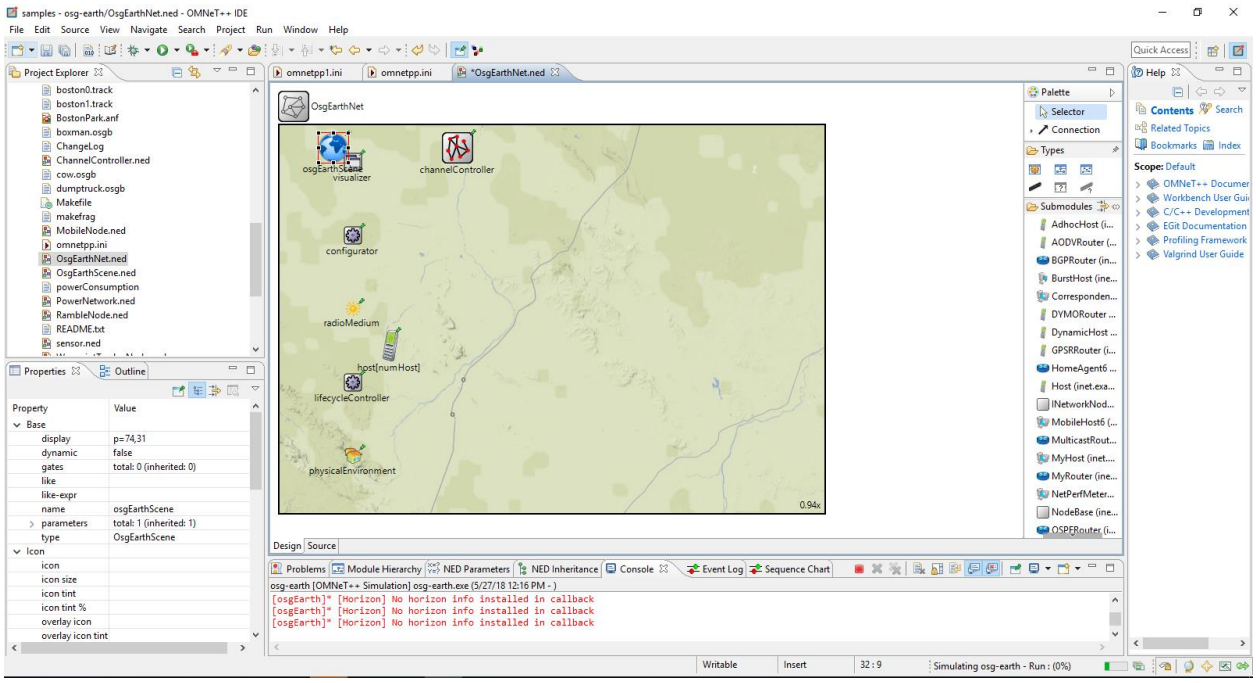


Figure.IV.1: OMNET ++ interface

III.2 NED language

NED *(*Network Description*)* is the topology description language of OMNET++. It has a simple syntax. The NED open a space to declare simple modules and connect and assemble them into compound modules.

NED language topology descriptions (.ned files) that describe the module structure with parameters, gates, etc. NED files can be written using any text editor.

III.3 C++ language:

C++ is a general-purpose object-oriented programming (OOP) language, developed by Bjarne Stroustrup, and is an extension of the C language. The main highlight of C++ is a collection of predefined classes, which are data types that can be instantiated multiple times.

C++ has also been found useful in many other contexts, with key strengths being software infrastructure and resource-constrained applications, [43] including desktop applications, servers (e.g. e-commerce, web search or SQL servers), and performance-critical applications (e.g. telephone switches or space probes). [44]

III.4 INET framework:

INET Framework is an open-source model library for the OMNET++ simulation environment. It provides protocols, agents and other models for researchers. 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 [45].

IV. System information:

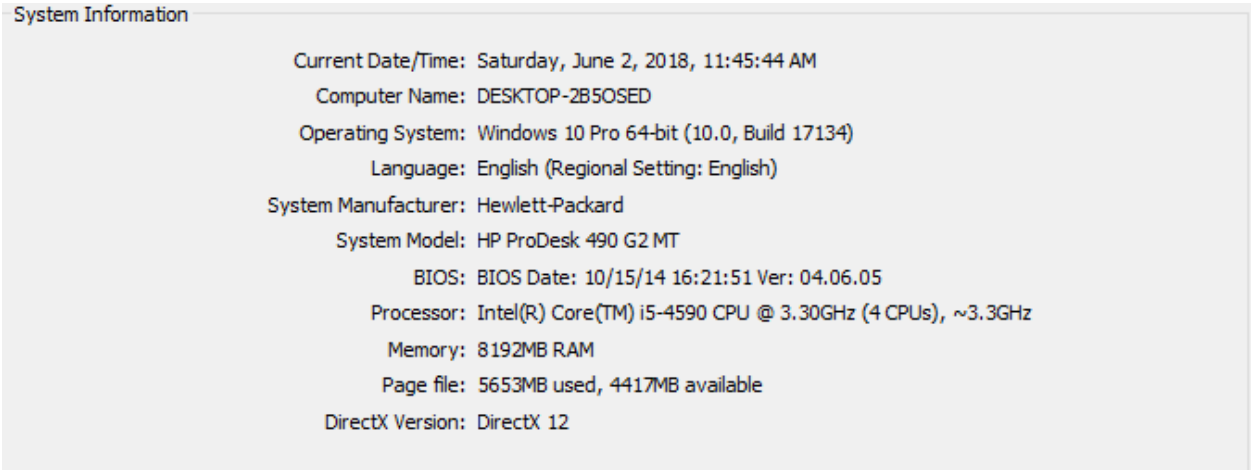


Figure.IV.2: system information

V. Daily temperature:

for model of weather statistics, we chose the one proposes in [46] to make our simulation more real testing we used this function:

$$\tau(Y,m,t) = \tau(Y,m) + A\tau(Y,m)[0.4632\cos(r(t) - 3.805) + 0.0984\cos(2\gamma(t) - 0.360) + 0.0168\cos(3\gamma(t) - 0.822) + 0.0138\cos(4\gamma(t) - 3.513)]$$

Where:

$\gamma(t) = 2\pi(t-1)/24$, t is the time on hour.

$\tau(Y,m)$ is the monthly temperature of the air.

$A\tau(Y,m)$ Is the monthly thermal amplitude in degrees Celsius.

As result we get the monthly temperature of the air equal the monthly thermal amplitude in degrees Celsius .

$A\tau(Y,m) = \tau(Y,m) = 23°$.

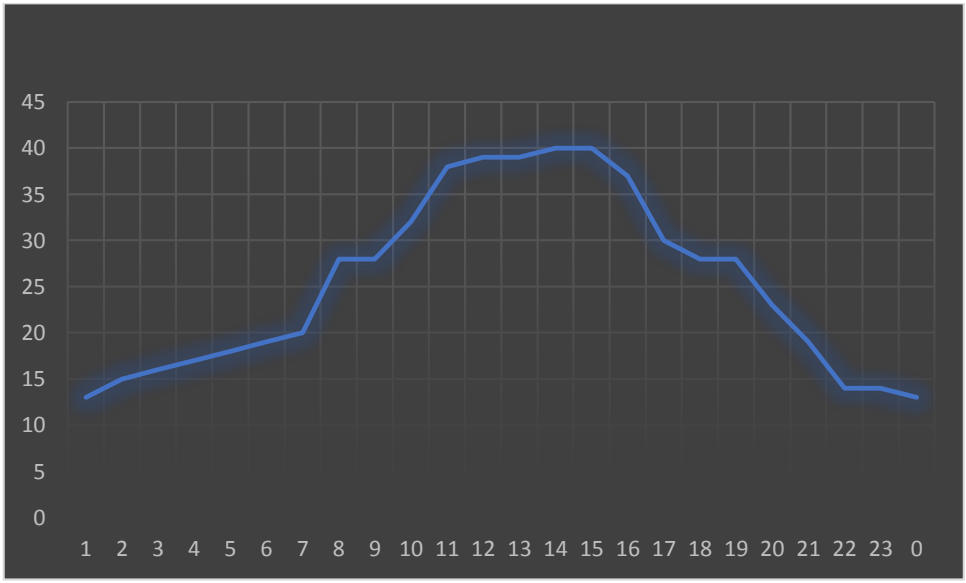


Figure.IV.3: daily temperature

VI. Experimentation:

The deployment of the full coverage area as a function of temperature was studied in 24 hour, the area is about 200m × 200m ×200m , this zone deploys in 50˚C as maximum temperature ,by 40 nodes in triangulation mode.

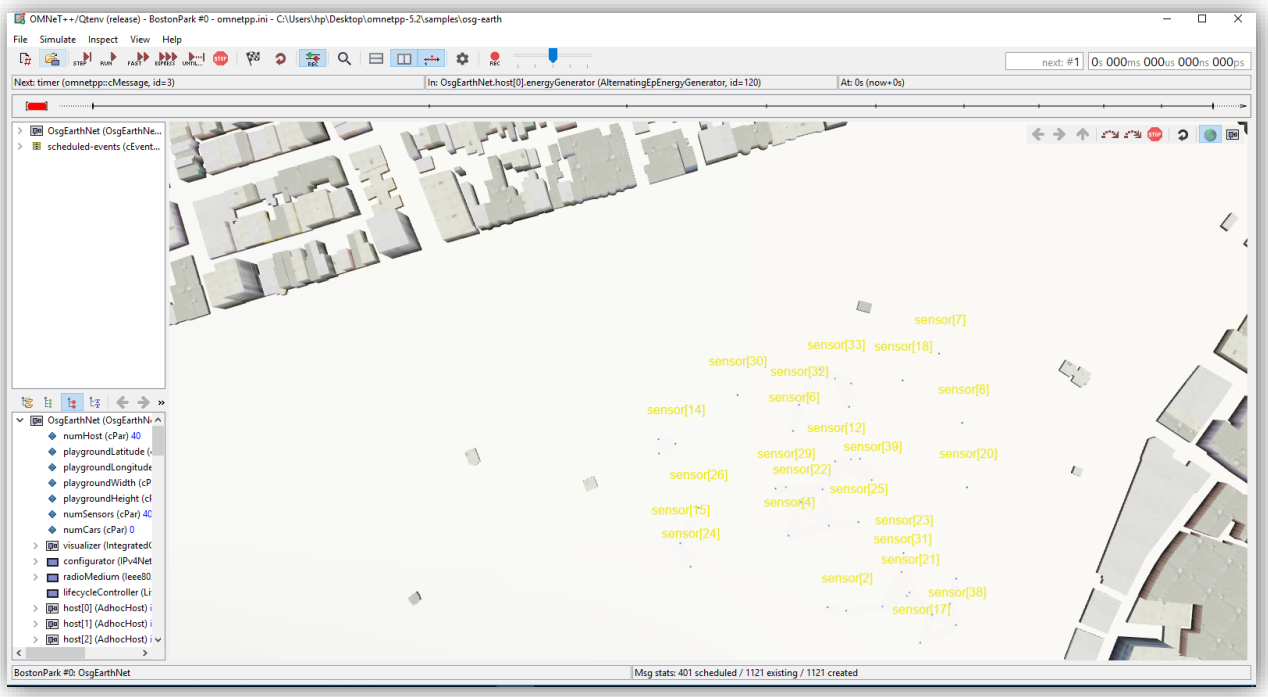


Figure.IV.4: deployment of WSN

Figure.IV.4 shows the initial deployment of WSN, and figure.IV.5 shows the deployment in time of moving of nodes in triangulation mode.

As we explain in previous chapter we used Delaunay triangulation to make channels between nodes to create UDP communication for sending and receiving packets, as it shown in figure.IV.6.

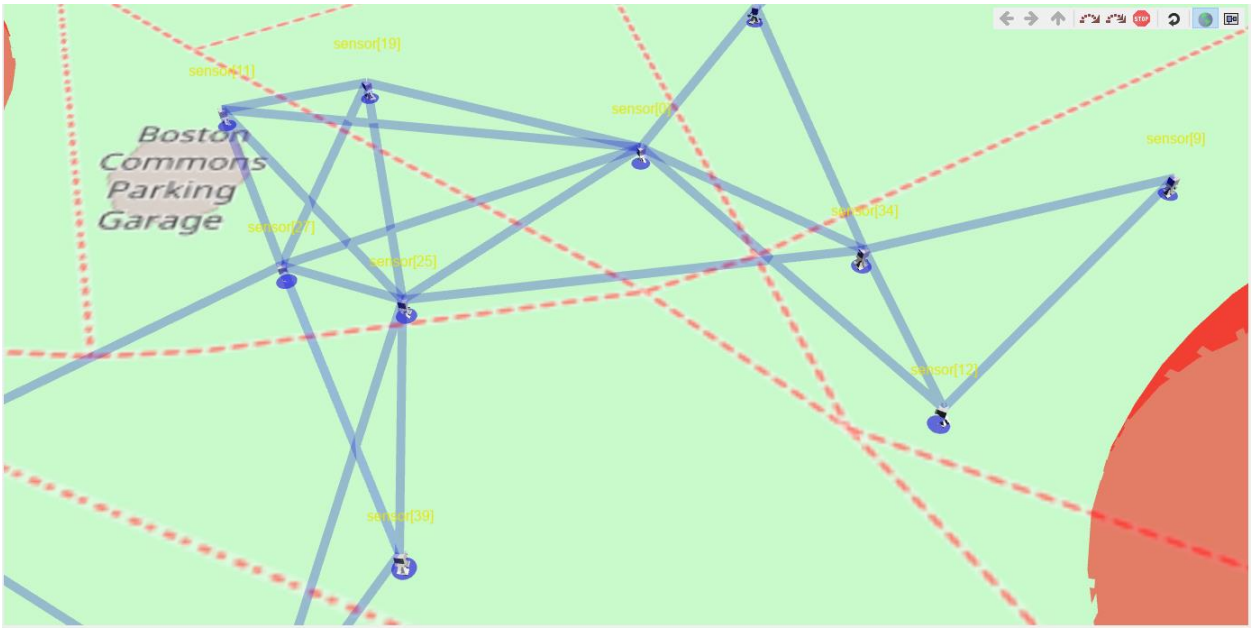


Figure.IV.5: triangulation in time of moving

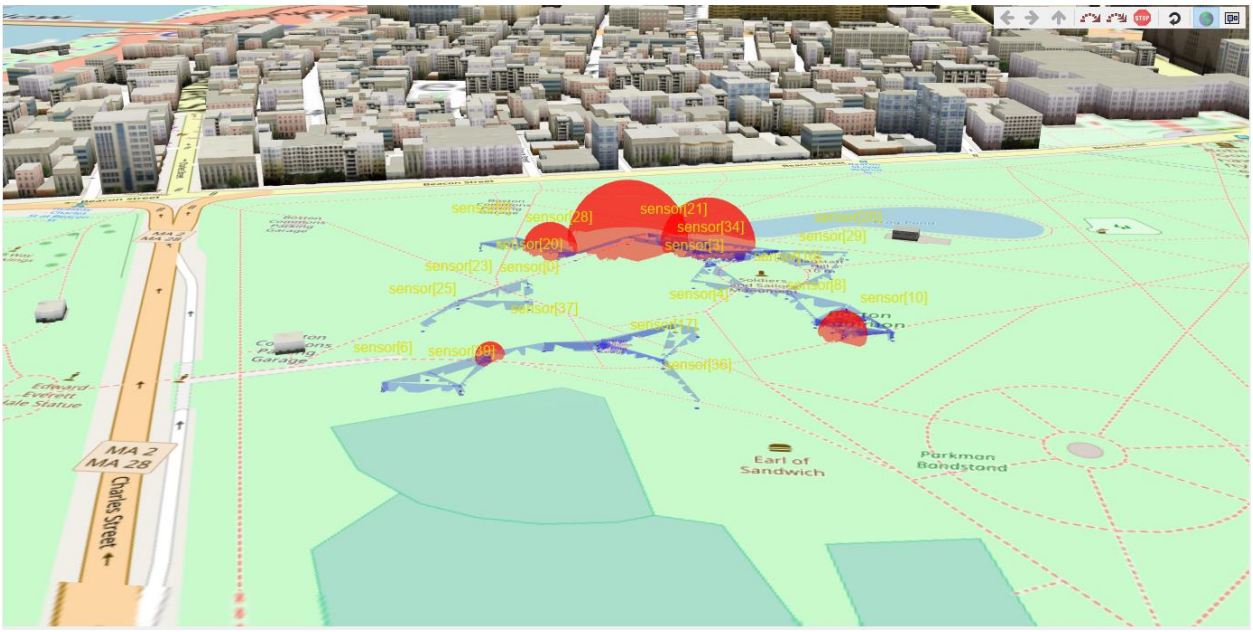


Figure.IV.6: communication between nodes and sensing range

a. Packets:

After the application of DT to create UDP communication we get a packets transmission Figure.IV.7 and Figure.IV.8, show us number of packets transmit per node.

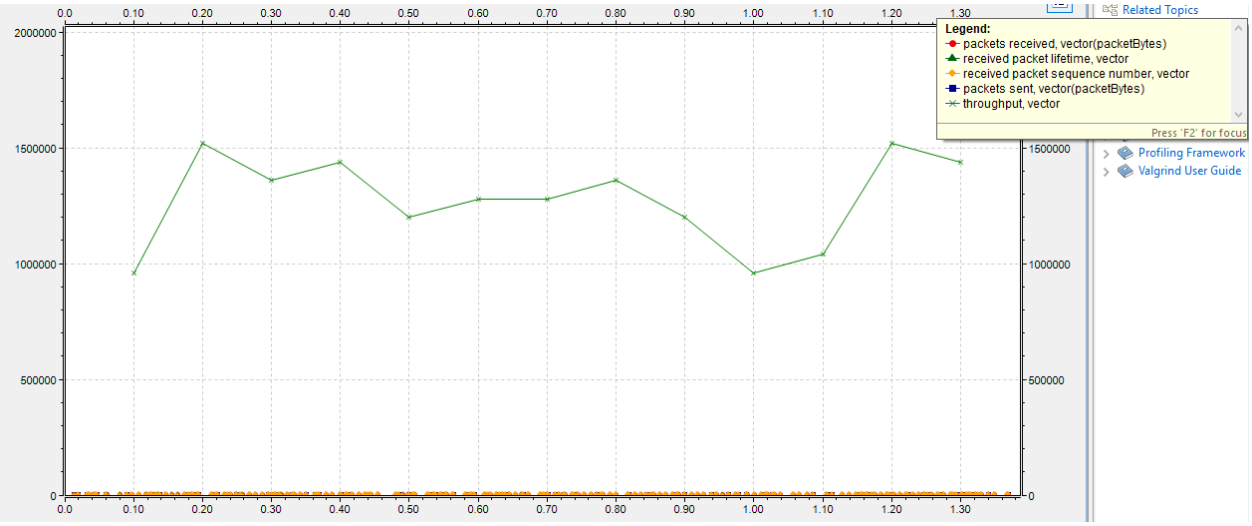


Figure.IV.7 :UDP packets

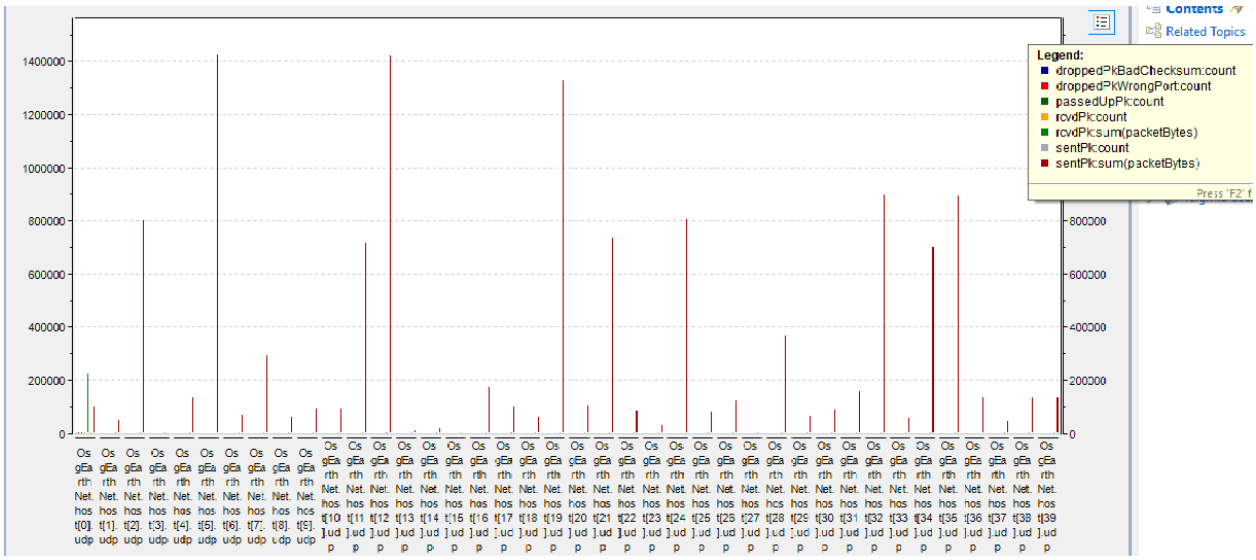


Figure.IV.8: UDP packets send receiver

b. The energy:

The main objective for our simulation is saving energy for a long time as possible, for that reason, we applied stop operate algorithm.

The question is did we obtain our goal? figure.IV.9 and figure.IV.10 can make it clear to give us an answer of our question.

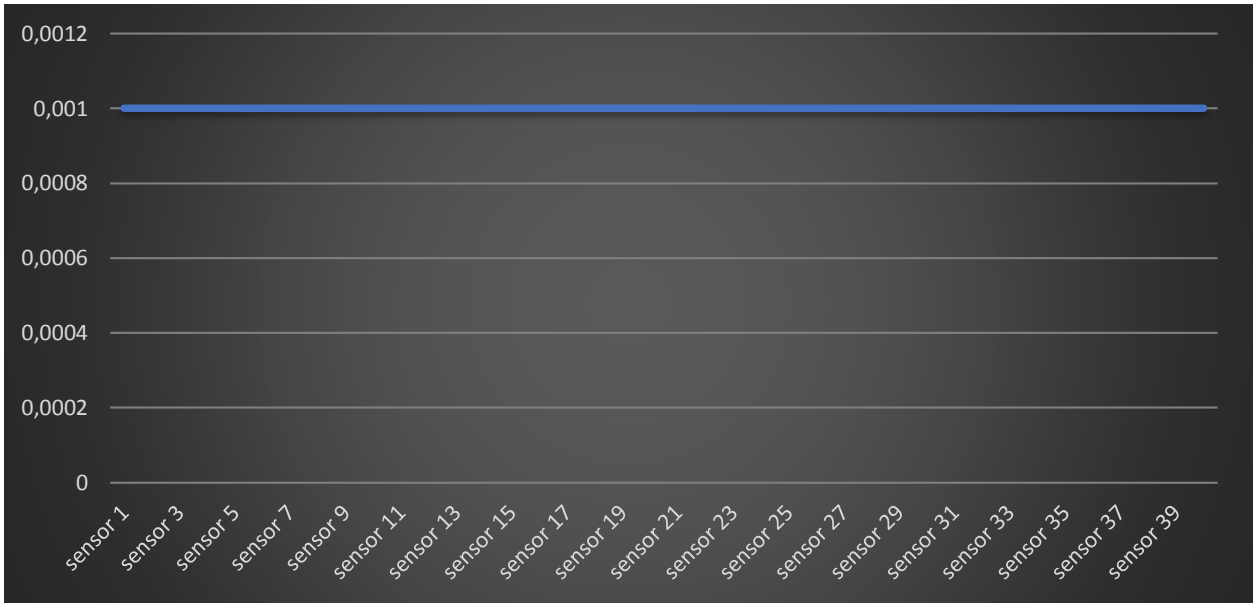


figure.IV.9: normal deployment energy consumption

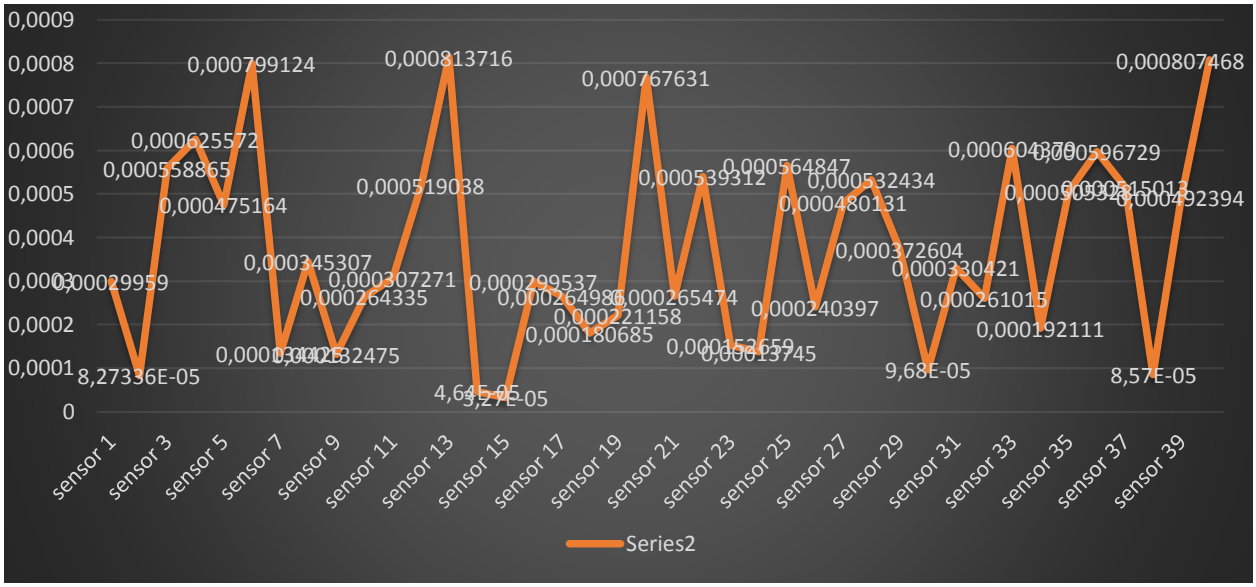


figure.IV.10: triangulation deployment energy consumption

c. The parameters used in simulation:

Time of simulation about 60 s, and for the supreme parameters used in our simulation explained in this table:

Parameters	**Values**
Deployment area	200m×200m×200m
Maximum temperature	Tmax = 50˚C
Exposing attenuation	α = 4
Frequency	F = 2×10^3MHz
Energy source	E = 150J
Hibernate power consumption	Ph=3µW
Power consumed on the move	Pm=30mW
Transmission speed	Data Rate = 1 Mbps
Radio	CC2400
Radio Standard	DLT_IEEE802_11_RADIO
Traffic type	UDP

Table. .IV.1: simulation parameter

VII. Result discussion:

Our results show that for a triangulation deployment of the WSN in 3D environment using a DT with applying stop operate algorithm, saves more energy about 0.0002 comparison to a normal deployment with all of that we a proved that the DT and using deployment in triangulation mode have an effect on the energy consumption and on the transmission of UDP packet.

VIII. Conclusion:

In this chapter we presented a small presentation for the simulator OMNET++ and we evaluated The Delaunay triangulation in 3D environment. In order to minimize the consumption of energy, while maintaining the good functioning of the WSN assuring the connectivity and the coverage at the same time.

General conclution:

The main goal of sensor networks is collection, processing and the transmission of a set of physical quantities of the environment in which they are located, these operations are greedy in terms of energy consumption, which is a crucial factor for the lifespan of the sensors and consequently the network.

Energy is a critical resource and often constitutes a major obstacle to the deployment of sensor networks.

In this thesis, we are interested in optimizing deployment in a 3d environment for mimic a real world on the other hand the conservation of energy consumption with taking into consideration the characteristics of this environment.

In this thesis we have seen that variations in temperature significantly affect energy consumption.

and how network deployment will become better when considering temperature variations as major feature of our environment.

We proposed a triangular deployment, and evaluated both algorithms DT and stop-operate, the targets of these two algorithms improving energy efficiency and ensuring connectivity and coverage are conserved for WSN.

Future work:

All the algorithms proposed in this thesis showed very good performances in simulation.

An interesting perspective would be to implement the algorithms on real robots to validate them in a real environment

in this these we take a temperature as major factor, we could extend to take a pollution as another factor. We were interested to use the metaheuristic to make the node intelligent for a self-deployment.

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