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Integrating Intelligent Reflecting Surface (IRS) Into Mobile Networks to Bridge the Digital Divide in Rural Areas While Improving User Connectivity

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Abstract
This paper focuses on connectivity in rural areas of Cameroon. While communication technologies such as 4G and 5G are beginning to become widespread in Cameroon, it is clear that there are still parts of the country that are not covered by radio access: "white zones". This lack of coverage is mainly due to the lack of interest of mobile network operators to invest in areas where they cannot obtain a return on investment. One solution would be to deploy low-cost communication networks that are able to adapt skillfully to the environmental conditions of rural areas: this is the objective of this work. This is how the dimensioning of an intelligent communication environment using IRSs as relays for base stations is included. This involves planning the densification of the networks to be deployed, dimensioning the performance of the intelligence attributed to the radio environments to be installed, as well as optimizing the investment costs of site implementation. Four key innovations emerge from our work: improved signal coverage, reduced infrastructure costs, flexibility and scalability, and reduced interference.

Keywords: white zone, return on investment, rural area, IRS, radio coverage.

1. Introduction

In this digital age, the concept of connectivity plays a crucial role in bridging urban and rural areas in terms of access to telecommunications technology. With the rapid development of communication technologies, a significant portion of the population in rural areas still does not have access to a reliable radio network, resulting in what are commonly called “white zones”. This lack of coverage is often attributed to the reluctance of mobile network operators to invest in areas with limited profitability. In response to this challenge, our work explores innovative solutions to deploy cost-effective communication networks that can adapt to the environmental conditions of rural areas. One such solution would be to design and implement Smart Reflective Surfaces as relays for base stations in rural areas. This approach involves planning for network densification, optimizing the performance of smart radio environments, and cost-effective site deployment. The ultimate goal is to improve radio signal coverage, reduce infrastructure costs, provide flexibility and scalability, and minimize interference in rural communication networks.

2. Basic concepts

2.1. Smart Reflective Surface

An IRS is a system composed of a reconfigurable meta-surface that contains a large number of scattering elements and a controller that is responsible for manipulating the signal phase shift.

As shown in Figure 1, the IRS panel consists of several meta-atoms that can passively reflect radio signals to the desired users. Each meta-atom is a low-cost antenna (between a few dollars and a dozen dollars) [1] that can act as a reflector and connect to an IRS controller.

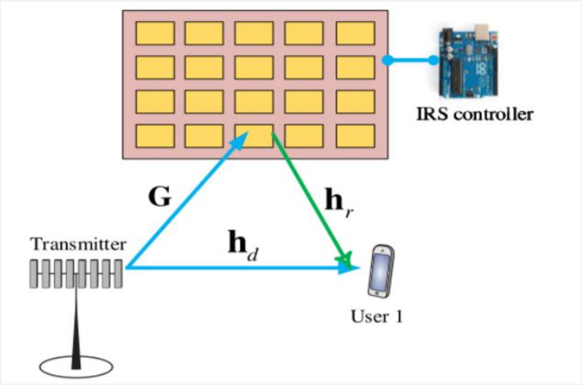


Figure 1: An IRS-enhanced multiple antenna system [1]

2.2. Intelligent Reflective Surfaces Assisted Communication

In general, the IRS-assisted communication system consists of an antenna panel and an IRS controller that has to manipulate the signal phase shifts. It can be verified through Figure 2 that it is an easy-to-install system that can be integrated into an interior wall or any other exterior surface [2].

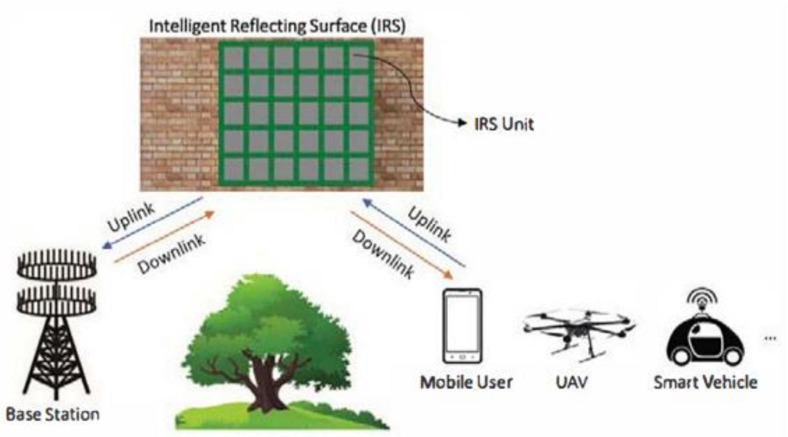


Figure 2: IRS Assisted Communication System [2]

[3] Identifies and describes use cases, deployment scenarios related to IRS, specifies derived requirements, and identifies technology challenges in several areas. Including fixed and mobile wireless access, sensing and positioning, and energy exposure limits, security, and privacy.

A illustrative example of this emerging wireless future is shown in Figure 12. Four application scenarios are identified: signal engineering; interference engineering; security engineering; and broadcast engineering:

which negatively affects the achievable data rate. To avoid this problem, small cell 2 directs the signal intended for the antenna of mobile terminal 3 to IRS 4, which shapes it appropriately to create a rich broadcast environment (high-rank channel) for high-speed data transmission.

The analysis of these four scenarios in Figure 3 shows that with the help of IRS, radio wave propagation in wireless networks can be studied and optimized, with low complexity, in a way that benefits the network.

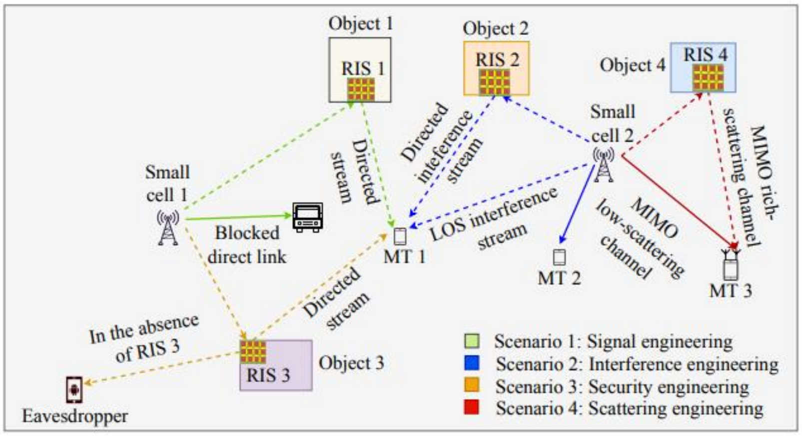


Figure 3: Example of a smart radio environment [3].

2.3. Intelligent radio environment

An intelligent radio environment is a communication network where the environment is transformed into an intelligent reconfigurable space that plays an active role in the transfer and processing of information. Thus, each part of the network will be able to adapt to changes in the environment [4]. Intelligent radio environments largely extend the notion of software networks with software and reconfigurable platforms.

Intelligent radio environments equipped with IRS, shown in Figure 4, are environments that exploit the implicit randomness of the propagation environment to improve coverage and signal quality [5].

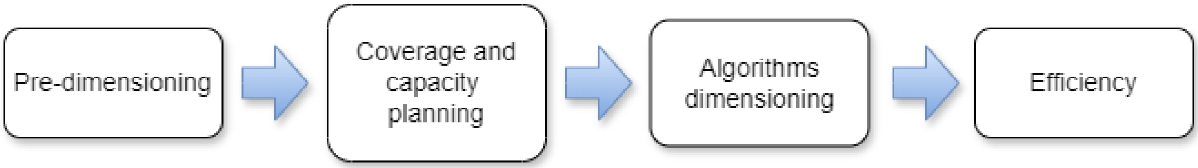


Figure 1: Emerging applications and use cases of IRS for intelligent radio environment [6]

2.4. The intelligence of reflective surfaces

Reflective surfaces are said to be “intelligent” only by means of two (02) categories of algorithms: DDA estimation algorithms and beamforming algorithms [6] summarized respectively in Figures 5 and 6.

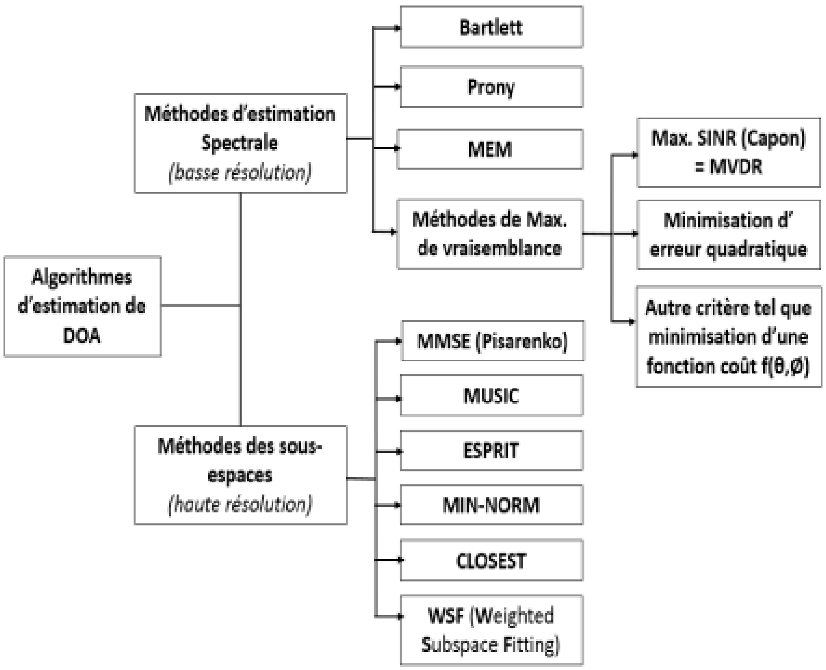


Figure 5: DDA estimation algorithms[6]

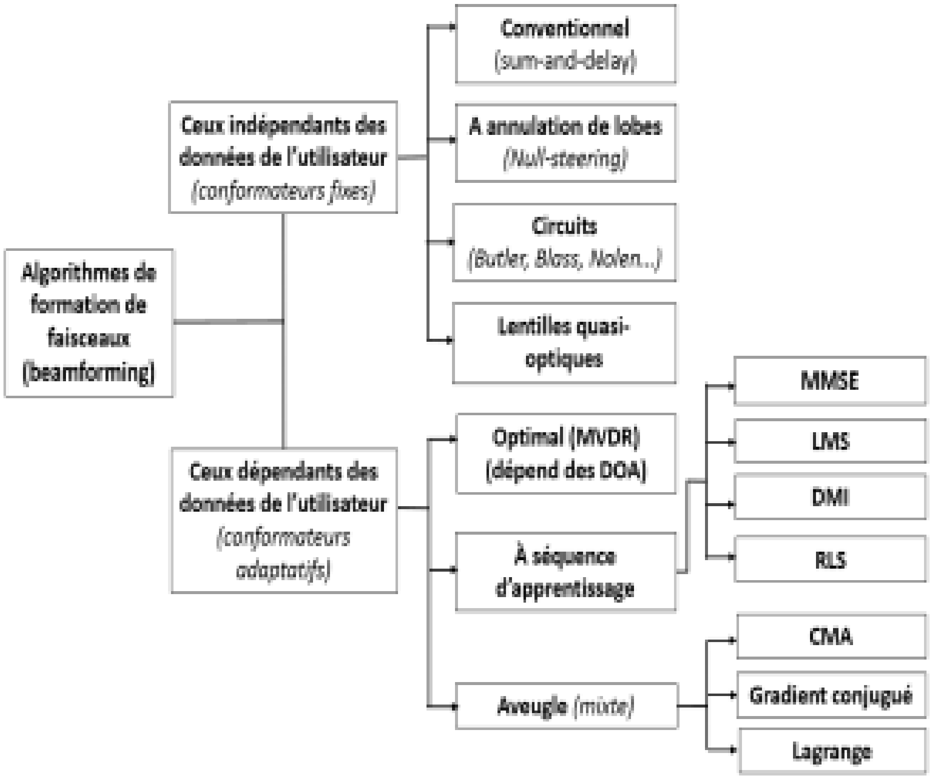


Figure 6: Beamforming Algorithms [6]

3. Method and Tools

3.1. Method for dimensioning a smart reflective surface

Cellular network dimensioning is a complex task, containing a number of consecutive steps, whose output of a certain step provides the input of the next step. The dimensioning tool must be able to provide results with an excellent level of accuracy, when parameterized with all the necessary data. The dimensioning process is directly linked to the quality and efficiency of the network which, in case of poor design, can deeply affect its development. The entire process materialized in Figure 7, can be summarized in five major phases:

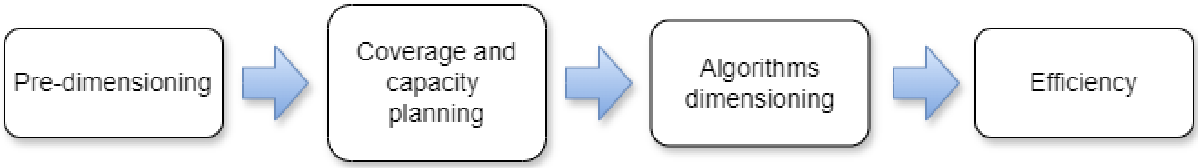


Figure 7: IRS sizing method

3.2. Planification

3.2.1. Coverage Planning

Performance requirements under propagation conditions lead us to determine the maximum distance between the transmitter and the receiver. First we must determine the path loss. Figure 8 gives us the steps to follow to determine this maximum distance and consequently the number of sites to deploy:

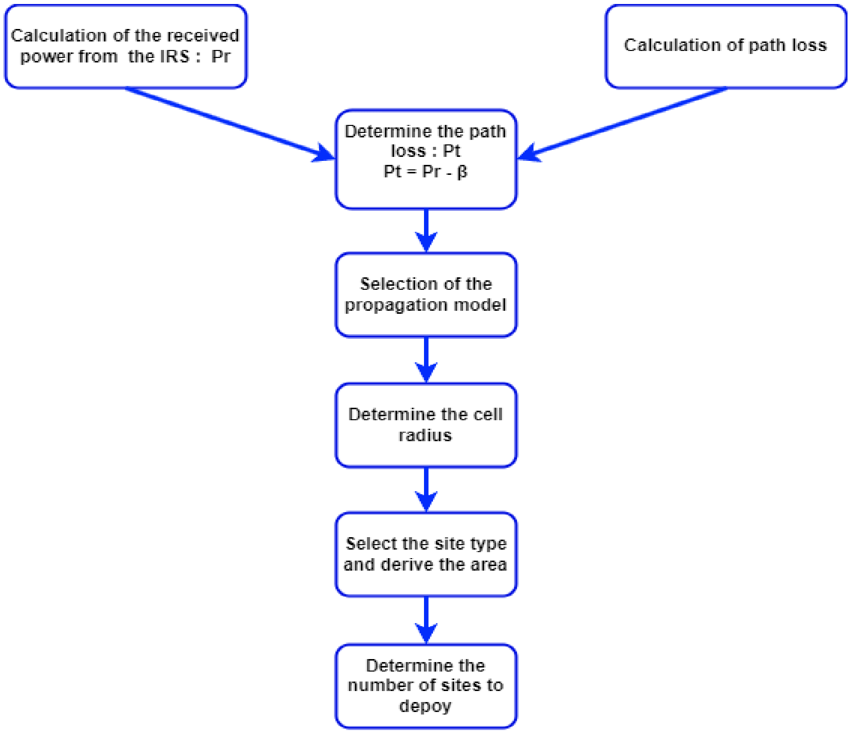


Figure 8: Coverage planning flowchart.

3.2.1.1. Calculation of the link budget (RLB)

From the IRS radio link budget, the minimum power for acceptable communication and depending on the chosen propagation model, it is possible to calculate the maximum distance at which the transmitter can be separated from the receiver.
The RLB of an IRS is given by:

$$PL = Pr - \beta \ [20] \qquad (1)$$

With:

- PL: the power transmitted by the IRS
- Pr: the power received by the IRS
- β: the path loss

Figure 9 gives us an illustration of an incident wave scattered by a metal plate.

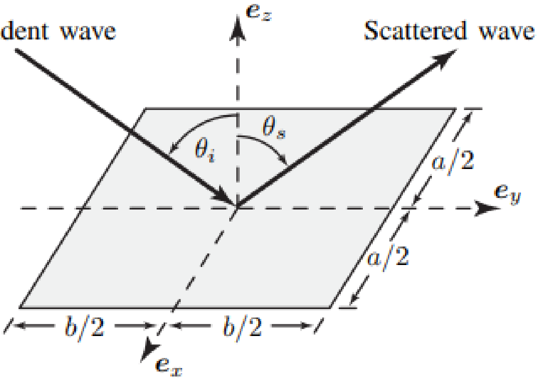


Figure 9: An incident wave is scattered by a metal plate a × b.

$$\mathrm{P_r} = \frac{1}{2\eta} S_{IRS} \left(\frac{\lambda^2}{4\pi} G_r \right) = (\mathrm{ab})^2 \frac{P G_t G_r}{16\pi^2 d_i} \frac{\cos^2(\theta_i)}{r^2} \left(\frac{\sin(\frac{\pi b}{\lambda}(\sin(\theta_s) - \sin(\theta_r)))}{\frac{\pi b}{\lambda} \sin(\theta_s) - \sin(\theta_r))} \right)^2 \quad [7] \qquad (2)$$

$$S_{IRS} = \left(\frac{ab}{\lambda} \right)^2 \frac{2\eta P G_t}{4\pi d_i} \frac{\cos^2(\theta_i)}{r^2} \left(\frac{\sin(\frac{\pi b}{\lambda}(\sin(\theta_s) - \sin(\theta_r)))}{\frac{\pi b}{\lambda} \sin(\theta_s) - \sin(\theta_r))} \right)^2 \quad [7] \qquad (3)$$

With:

- a: the length of the IRS
- b: the width of the IRS
- P: the Power transmitted by the source
- Gt: the gain of the receiver
- di: distance between the base station and the IRS
- r: distance between the IRS and the receiver
- Gr: the gain of the antenna
- λ: the wavelength of the incident signal

- $$\beta = \frac{G_r G_t}{(4\pi)^2} \left(\frac{ab}{d_i r} \right)^2 \cos^2(\theta_i) \left(\frac{\sin(\frac{\pi b}{\lambda}(\sin(\theta_s) - \sin(\theta_r)))}{\frac{\pi b}{\lambda} \sin(\theta_s) - \sin(\theta_r))} \right)^2 \quad [7] \qquad (4)$$
- $$\mathrm{P_L} = \frac{1}{r} \left(1 - \frac{1}{d_i}\right) \frac{G_r G_t}{d_i (4\pi)^2} (\mathrm{ab})^2 \cos^2(\theta_i) \left(\frac{\sin(\frac{\pi b}{\lambda}(\sin(\theta_s) - \sin(\theta_r)))}{\frac{\pi b}{\lambda} \sin(\theta_s) - \sin(\theta_r))} \right)^2 \qquad (5)$$

3.2.1.2. Choice of propagation model

The radio wave propagation model is a mathematical model, given by a certain number of parameters (technical characteristics, type of geographical environment) which allows to simulate the losses between a transmitter and a receiver. The equations of this part are taken from [8]

As part of the design of our application whose goal is the dimensioning of IRS for base stations in rural areas, the choice will be made on the propagation model adapted for small cells and applicable in rural areas: this is the Hata model.

- In an urban environment, the attenuation in dB called here PL is given by:

P$(urbain) = 69.55 + 26.16 \log(f_c) - 13.82 \log(h_{te}) - a(h_{re}) + (44.9 - 6.55 \log(h_{te}))\log(d)$ (6)

With:

h_{te}: 30m to 200m (base station antenna height).

h_{re}: 1m to 10m (mobile antenna height).

d: distance between transmitting antenna and receiving antenna T-R [km].

f_c: frequency in [MHz].

The parameter (h_{re}) is a correction factor depending on the height of the mobile station antenna and the environment whose value is:

A small to medium-sized town:

$(h_{re}) = (1.1 \log(f_c) - 0.7)h_{re} - (1.56\log(f_c) - 0.8)$ in dB (7)

- Big city (f_c< 300 MHz) : $(h_{re}) = 8.29(log 1.54 h_{re})\ 2 - 1.1$ in dB (8)
- Big city (f_c> 300 MHz) : $(h_{re}) = 3.2(log 11.75 h_{re})\ 2 - 4.97$ in dB To obtain the path loss (9)

- Suburban area Hata's standard formula is modified as follows:

P$_L$ $(suburbain)(dB) = L50(urbain) - 2\ (\log\ (f_c\ 28))\ 2 - 5.4$ (10)

- In rural areas :
- Clear environment :

  P$_L$ $(rural)$ = P$_L$ $(urbain) - 4.78(\log\ (f_c))^2 - 18.33 \log(f_c) - 40.94$ (11)
- Semi-clear environment :

  P$_L$ $(rural)$ = P$_L$ $(urbain) - 4.78(\log\ (f_c))^2 - 18.33 \log(f_c) - 35.94$ (12)

For a smart reflective surface, the attenuation is given by:

-Clear environment:

$$PL\ (rural) = \frac{1}{r}(1 - \frac{1}{d_i})\frac{G_r G_t}{d_i(4\pi)^2}(ab)^2 \cos^2(\theta_i)\left(\frac{\sin\ (\frac{\pi b}{\lambda}(\sin(\theta_s) - \sin(\theta_r)))}{\frac{\pi b}{\lambda}\ \sin(\theta_s) - \sin(\theta_r))}\right)^2 - 4.78(\log(fc))^2 - 18.33 \log(fc) - 40.94 \quad (13)$$

- Semi-clear environment:

$$P_L\ (rural) = \frac{1}{r}(1-\frac{1}{d_i})\frac{G_r G_t}{d_i(4\pi)^2}(ab)^2 cos^2(\theta_i)\left(\frac{sin\ (\frac{\pi b}{\lambda}(sin(\theta_s)-sin(\theta_r)))}{\frac{\pi b}{\lambda}\ sin(\theta_s)-sin(\theta_r))}\right)^2 - 4.78(\log(f_c))^2 - 18.33\log(f_c) - 35.94 \qquad (14)$$

Table 2 shows the coverage level in the GSM framework. This measurement ranges from -110 dBm (weak signal) to -46 dBm (good signal) [9].

Table 1: network coverage based on RxLev [9].

RxLev (dBm)	**Coverage level**
-110 à -95	No coverage
-95 à -85	bad coverage
-85 à -75	Pretty good coverage
-75 à -65	Good coverage
-65 à -46	Very good coverage

From the previous table, the receiving power of a mobile device must be greater than -85 dBm. Therefore, the coverage radius (R) can be expressed as Pr – β = -85 dBm. In this case, r = R in equation (15)

- Unobstructed environment:

$$\frac{1}{r}(1-\frac{1}{d_i})\frac{G_r G_t}{d_i(4\pi)^2}(ab)^2 cos^2(\theta_i)\left(\frac{sin\ (\frac{\pi b}{\lambda}(sin(\theta_s)-sin(\theta_r)))}{\frac{\pi b}{\lambda}\ sin(\theta_s)-sin(\theta_r))}\right)^2 - 4.78(\log(fc))^2 - 18.33\ \log(fc) - 40.94 = -85 \qquad (15)$$

So:

$$R = r$$

$$= \frac{(1-\frac{1}{d_i})\frac{G_r G_t}{d_i(4\pi)^2}(ab)^2 cos^2(\theta_i)\left(\frac{sin\ (\frac{\pi b}{\lambda}(sin(\theta_s)-sin(\theta_r)))}{\frac{\pi b}{\lambda}\ sin(\theta_s)-sin(\theta_r))}\right)^2 - 4.78(log(fc))2 - 18.33\,log(fc) - 40.94}{-85}$$

- Semi-clear environment : (16)

$$P_L\ (rural) = \frac{1}{r}(1-\frac{1}{d_i})\frac{G_r G_t}{d_i(4\pi)^2}(ab)^2 cos^2(\theta_i)\left(\frac{sin\ (\frac{\pi b}{\lambda}(sin(\theta_s)-sin(\theta_r)))}{\frac{\pi b}{\lambda}\ sin(\theta_s)-sin(\theta_r))}\right)^2 - 4.78(\log(f_c))^2 - 18.33\log(f_c) - 35.94 = -85 \qquad (17)$$

Therefore:

$$R = r = \frac{\frac{1}{r}(1-\frac{1}{d_i})\frac{G_r G_t}{d_i(4\pi)^2}(ab)^2\cos^2(\theta_i)\left(\frac{\sin\left(\frac{\pi b}{\lambda}(\sin(\theta_s)-\sin(\theta_r))\right)}{\frac{\pi b}{\lambda}\sin(\theta_s)-\sin(\theta_r))}\right)^2 - 4.78(\log(fc))\,2 - 18.33\log(fc) - 35.94}{-85} \quad (18)$$

- **Cell surface**

$$Scell = \frac{3\sqrt{3}}{2}r^2 \quad (19)$$

Where :
r is the radius obtained in the link budget
Scell the surface of a cell.

The surface area per cell is given in Table 1 :

Table 1: Cell surface area as a function of the number of sectors [10]

Type of site	Number of sectors per site	Footprint
Omni directional	1	$Scell = 2.6 \times r^2$
Bi sectorial	2	$Scell = 1.3 \times 2.6 \times r^2$
Tri sectorial	3	$Scell = 1.95 \times 2.6 \times r^2$

- Inter-site distance

The inter-site distance is given by Table 2:

Tableau 2: Inter-site distance[10]

Type of site	Number of sectors per site	Inter-site distance
Omni directional	1	$d = \sqrt{3} * r$
Tri sectorial	3	$d = \frac{3}{2}r$

2.2.1.4. Number of IRS

- The number of sites in coverage

$$Nsite_{DL} = \frac{Szone}{Scell\_DL} \quad (20)$$

3.2.2. Capacity planning

The approach used for capacity planning is illustrated in Figure 10.

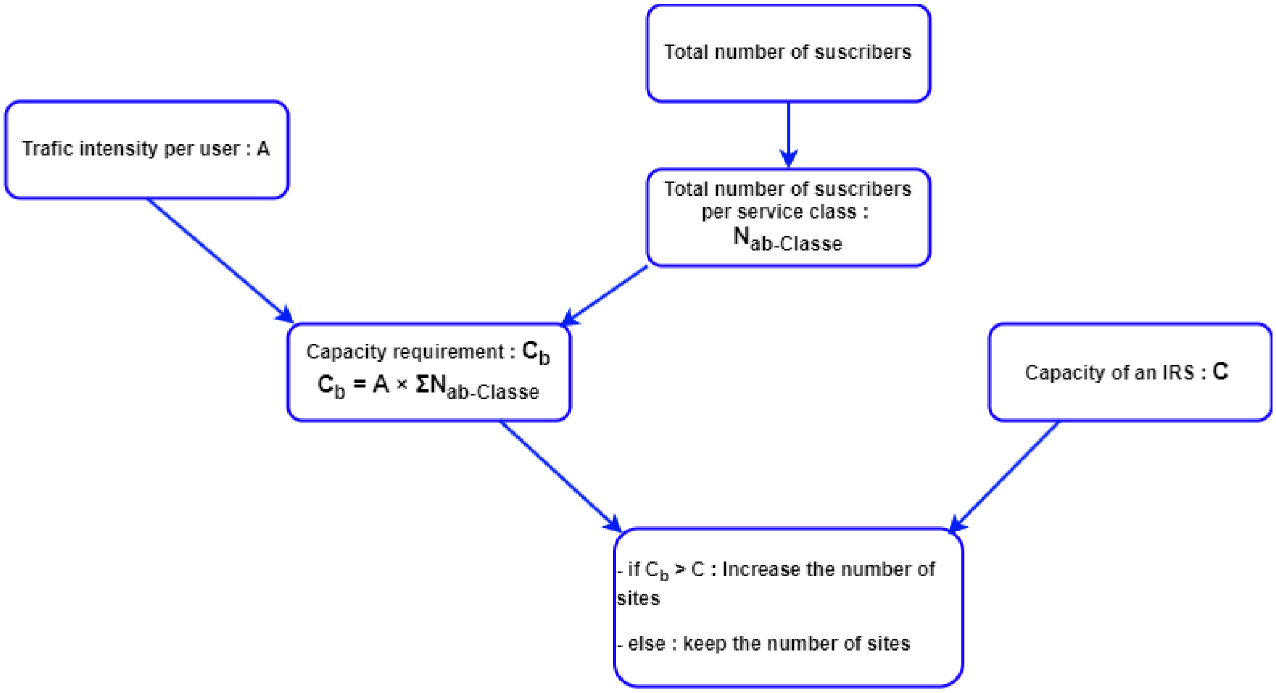


Figure 10: Capacity Planning Flowchart

3.2.2.1. Traffic intensity per user

Traffic is determined from the population density and the type of activity associated with each region. Erlang's laws are used to characterize the rate of telephone calls. This law has as parameters: the call rate and the average call duration. The traffic intensity per user is expressed by:

$$A_u = \mu . H \text{ erlang} \quad (21)$$

With :

- μ : call rate
- H : average call duration

3.2.2.2. Number of subscribers per service

This is the total number of subscribers or users who benefit from a specific service. This number helps to understand the magnitude of subscribers and make strategic decisions regarding network capacity, service expansion and customer satisfaction [11].

$$N_{ab\_classe} = \frac{pourcentage\_classe \times N_{abonnés}}{100} \tag{22}$$

Calculation:

- **Messaging service**

$$N_{ab\_msg} = \frac{pourcentage\_msg \times Nbre_{abonnés}}{100}$$

- **Navigation service**

$$N_{ab\_nav} = \frac{pourcentage\_nav \times N_{abonnés}}{100}$$

- **Data network services**

$$N_{ab\_rd} = \frac{pourcentage\_rd \times N_{abonnés}}{100}$$

- **Voice service**

$$N_{ab\_voix} = \frac{pourcentage\_voix \times N_{abonnés}}{100}$$

3.2.2.3. Capacity requirement

This is about determining the amount of traffic the site will have to handle simultaneously in a given area:

$$C_b = A_u \times (N_{ab\_msg} + N_{ab\_nav} + N_{ab\_rd} + N_{ab\_voix}) \tag{23}$$

3.2.2.4. The capacity of an IRS

The capacity of an IRS is given by:

$$C_{IRS} = \log_2 \left(1+ \frac{p(| h_{sd}| + \alpha\Sigma_{n=1}^{N} | [h_{sr}]_n [h_{rd}]_n |)^2}{\sigma}\right) \quad [12] \qquad (24)$$

With:

- P: The emission power
- α: The reflection coefficient
- hsr: Deterministic channel between the IRS and the source
- hsd: Deterministic channel between the source and the obstacle
- hrd: Deterministic channel between the IRS and the destination
- σ: the SINR experienced by the EM
- N: number of elements of the IRS

3.3. Algorithm Sizing

The source codes related to the implementation of the algorithms as well as the formulas used in this part are taken from [13].

3.3.1. DDA Algorithm

Here we will determine the direction from which a signal is received using the procedure shown in Figure 11:

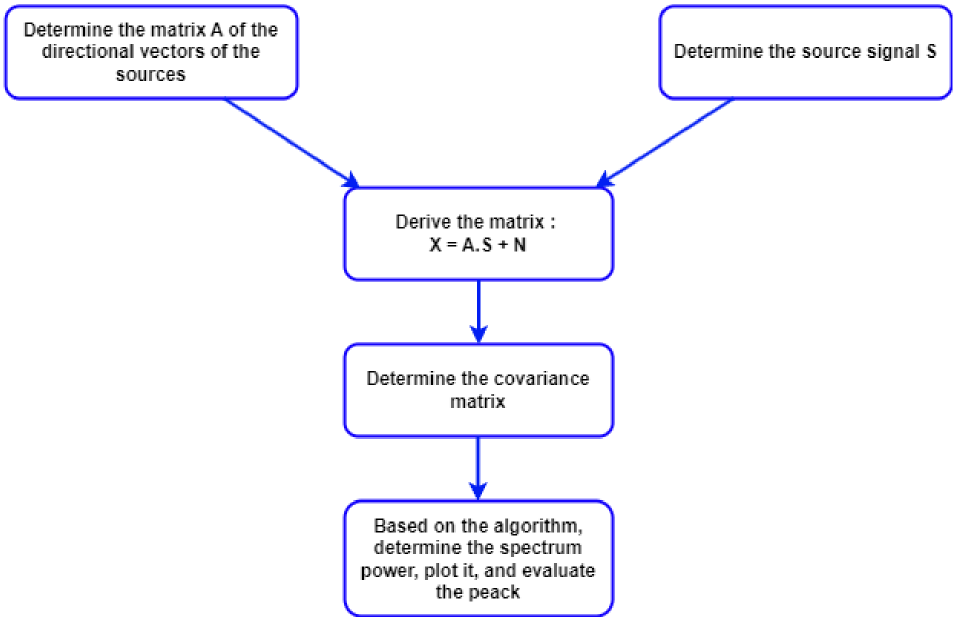


Figure 11: Peak evaluation flowchart for direction of arrival estimation algorithms

= λ/2,

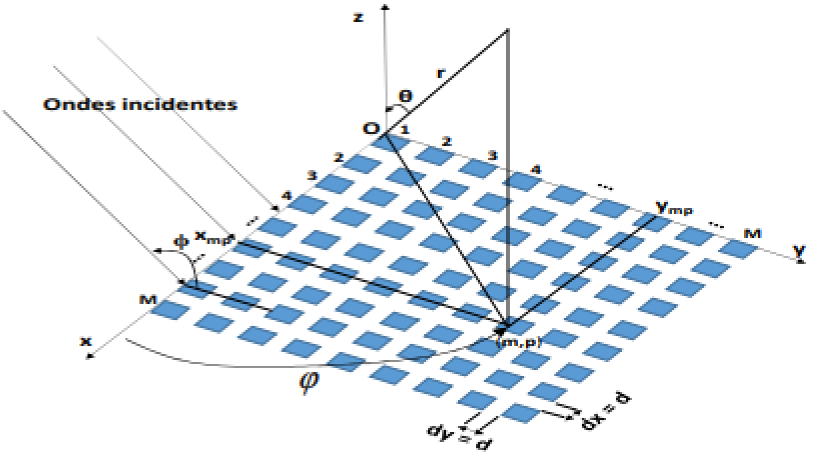


Figure 12**:** Uniform square network of MxM elements

- **The matrix of directional vectors of the sources :**

$(\theta) = [a(\theta 1)\ a(\theta 2)\ \dots\ a(\theta M)]^T$ is the matrix of the directional vectors of the sources; it contains the information on the angles of arrival.

With: $a_n(\theta_k) = \exp(-j(n-1) \times K \times d \times \cos(\theta_k))$ (25)

- **The source signal :**

This is the vector of the complex envelopes of the K sources:

$S = 2 \times \exp(j \times w \times (T-1))$ (26)

- **The X matrix :**

The matrix X corresponds to the reception vector at the output of the radiating element array:

$X = (\theta).\ S + N$ (27)

With N the additive Gaussian noise.

- **The covariance matrix :**

The covariance matrix will allow us to establish the relationships and dependencies between the variables. Its expression is given by:

$R_{xx} = X \times X^T$ (28)

Considering that the weight vector allowing beam formation becomes an M×M matrix: X^T.

3.3.1. Beamforming Algorithm

This part will consist of obtaining the trace of the network factor corresponding to the focused radiation pattern in privileged directions [14]. For this we followed the steps of the flowchart found in figure 13:

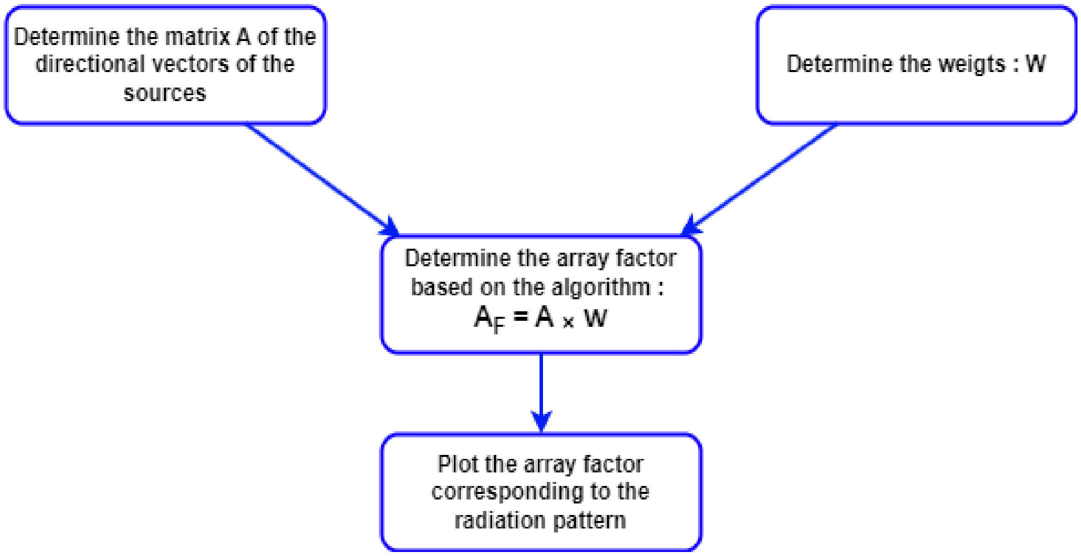


Figure 13: Network Factor Plot Flowchart

- **The matrix of directional vectors of the sources:**

$(\theta) = [a(\theta 1)\ a(\theta 2)\ \ldots\ a(\theta M)]^T$ is the matrix of the directional vectors of the sources; it contains the information on the angles of arrival.

With: $a_n(\theta_k) = \exp(-j(n-1) \times K \times d \times \cos(\theta_k))$ (29)

- **The weights:**

The weights allow the formation of beams and are expressed according to the following relation:

$$W = \frac{1}{N_r} e^{(j2\Pi d(N_r-1)\times \cos\ (\theta_k)} \qquad (30)$$

- **The network factor as a function of the algorithm :**

The choice of the grating factor depends on the beamforming algorithm used and the specific communication objectives. Different algorithms may require different grating factor configurations to achieve the desired performance.

$AF = A \times W$ (31)

From here we can plot the grating factor corresponds to the radiation pattern.

3.4. System modeling

3.4.1. Django

For our sizing tool, we used Django software which is a high-level Python framework, allowing simple and rapid development of secure and maintainable websites.

3.4.2. UML diagram

The Unified Modeling Language (UML) diagram is a pictogram-based graphical modeling language designed as a standardized method of visualization in the fields of software development and object-oriented design.

3.4.2.1 Use case diagram

The use case diagram shown in Figure 14 helps express the needs of users of a system by collecting, analyzing, and organizing user requirements and identifying the major functionalities of the system.

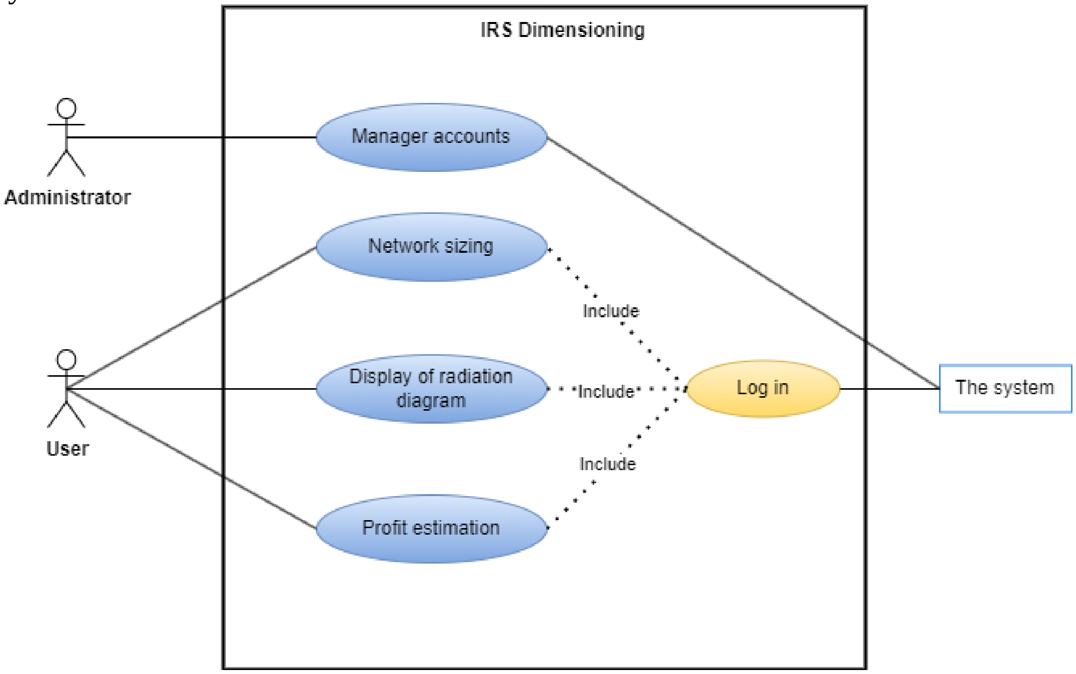


Figure 14**:** Use case diagram

By analyzing the functionalities of the tool we can distinguish the following actors:

- **The user:** internal actor, whose role will be to send and receive information from the system.
- **The administrator**: internal actor responsible for the management (consultation, modification, deletion) of data present in the server.
- **The system:** internal actor, is our application, which will have the role of sending and receiving
information to users.

3.4.2.2. Sequence diagram

The sequence diagram is used to illustrate the exchanges between objects during a scenario described in a use case diagram.

Sequence diagram of the use case "network dimensioning"

Figure 15 illustrates the sequence diagram of the "network dimensioning" use case:

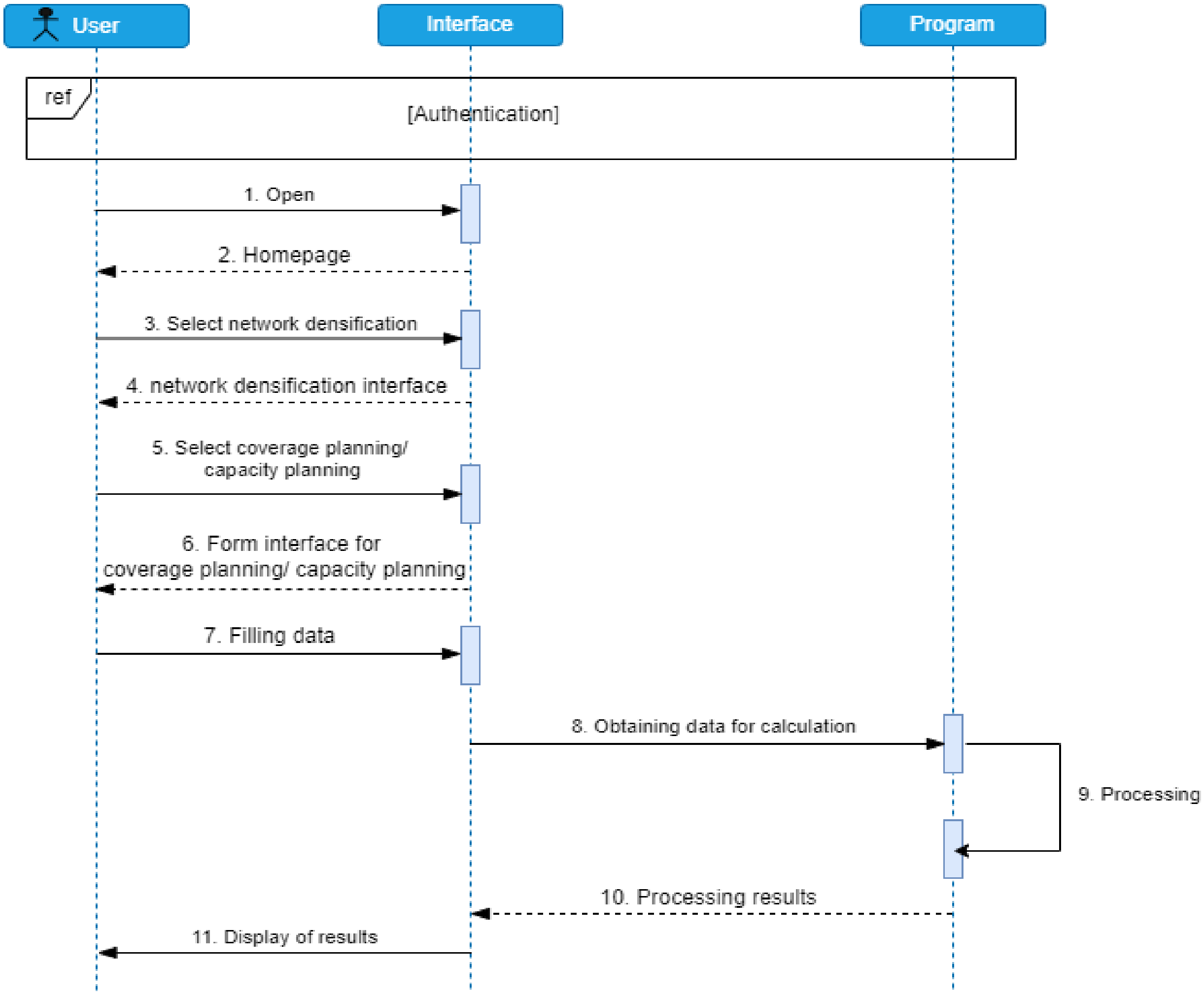


Figure 15: Sequence diagram of the "network dimensioning" use case

- **Sequence diagram of the use case "how embedded algorithms work"**

Figure 16 illustrates the sequence diagram of the "integrated algorithms operation" use case:

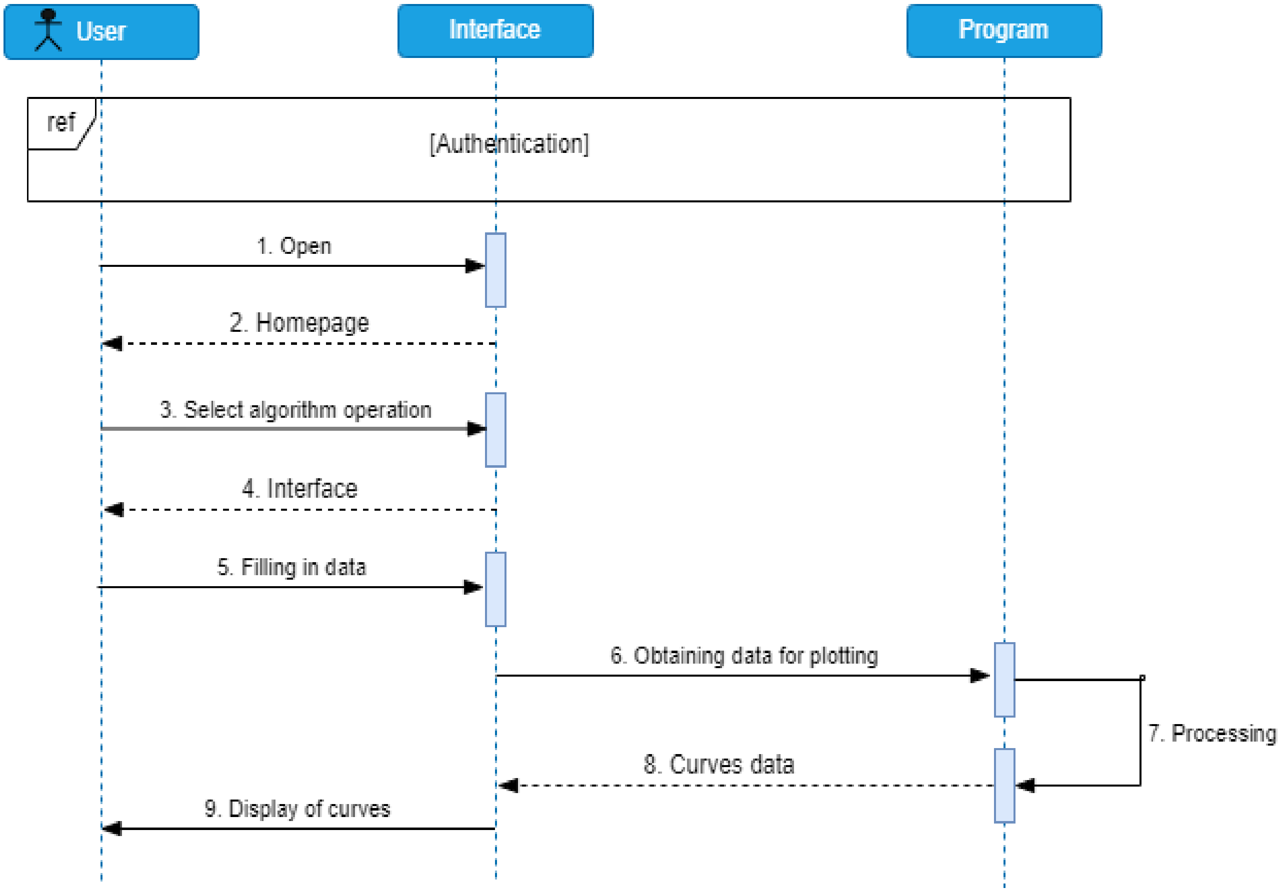


Figure 16: Sequence diagram of the use case "operation of integrated algorithms"

- **Sequence diagram of the "profitability planning" use case**

Figure 17 illustrates the sequence diagram of the "profitability planning" use case:

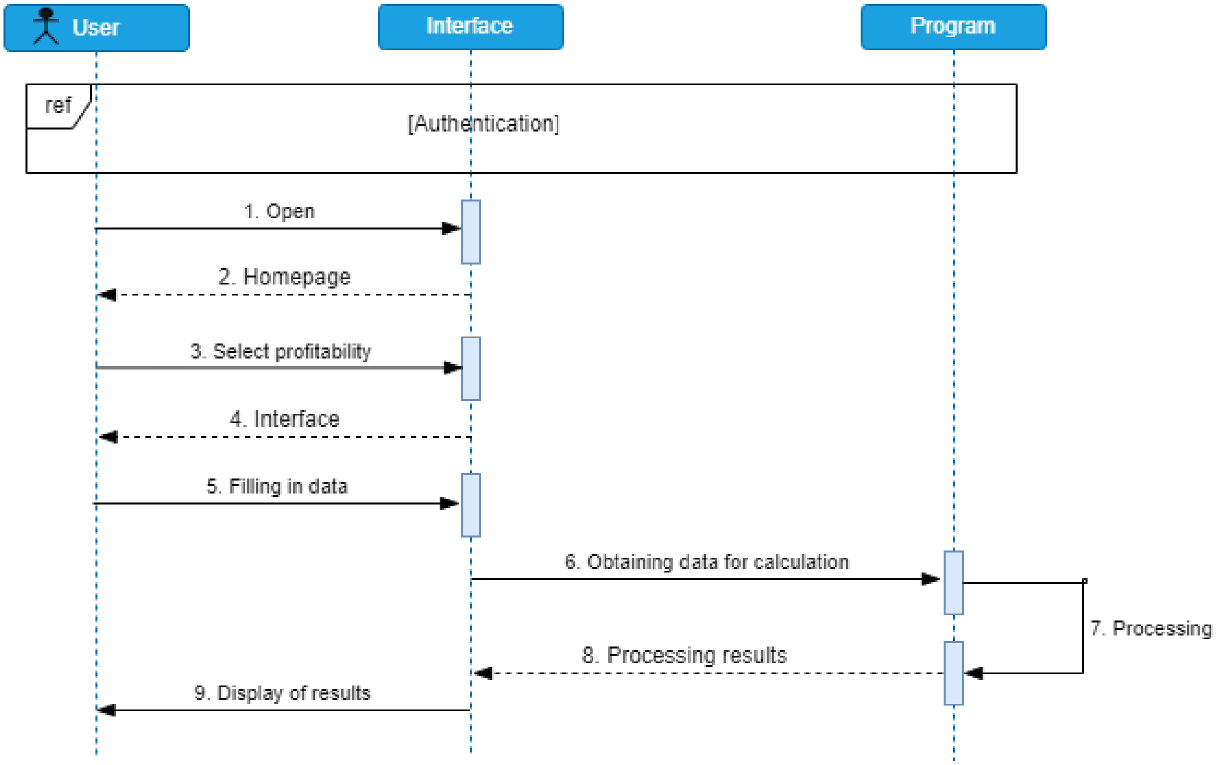


Figure 17: Sequence diagram of the use case "operation of integrated algorithms"

4. Results and Comments

4.1. Structural architecture of the tool

Our results will be presented according to the three main aspects of our application whose architecture is illustrated in Figure 18:

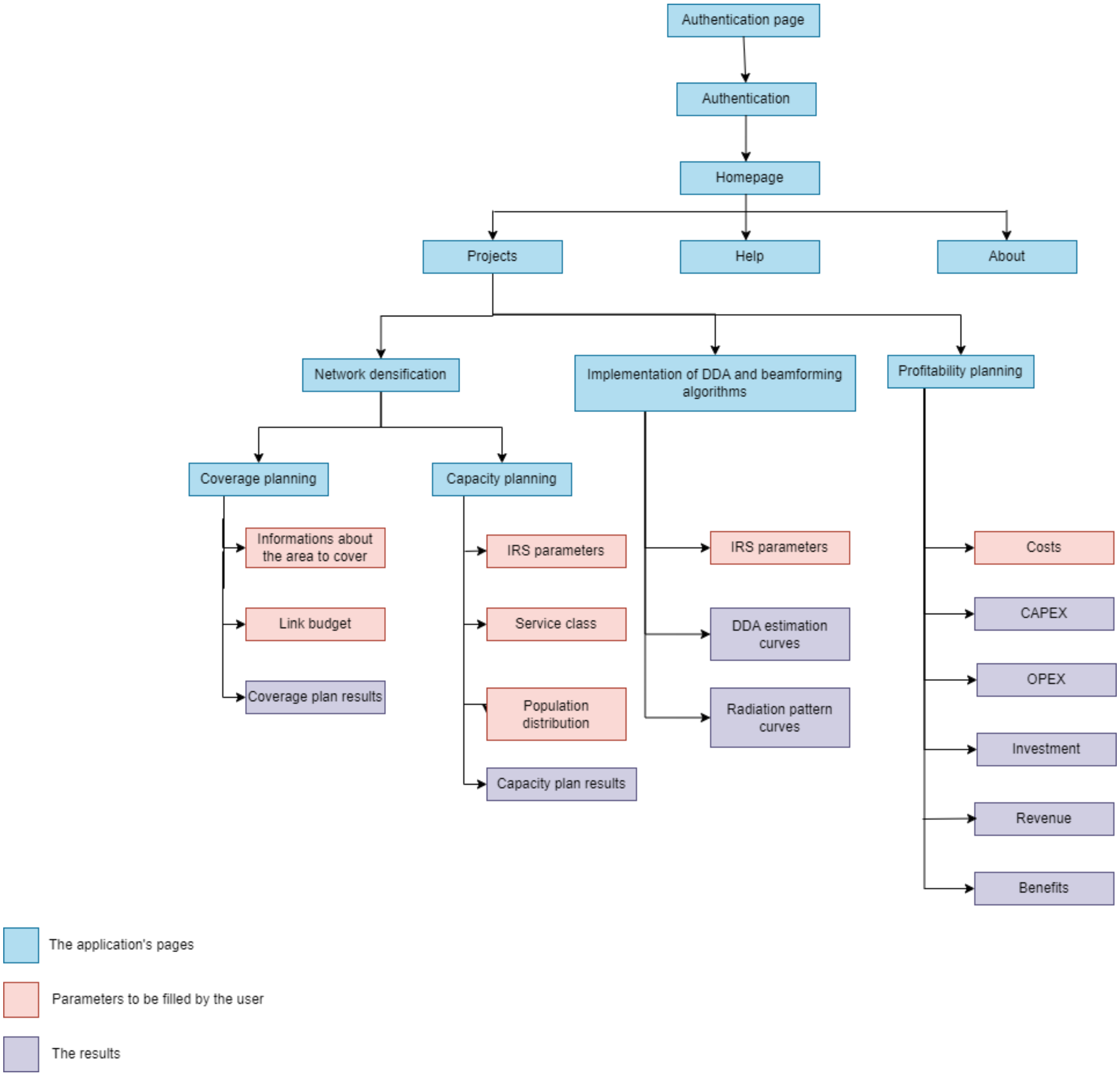


Figure 18: Application architecture

4.2. Presentation of the tool

4.2.1. Home page

Once the user has entered his data, the home page is displayed as in Figure 19:

APPLICATION IRS

BIENVENUE SUR L'APPLICATION DE DIMENSIONNEMENT ET DE PLANIFICATION DES IRS DES STATIONS DE BASES EN ZONES RURALES

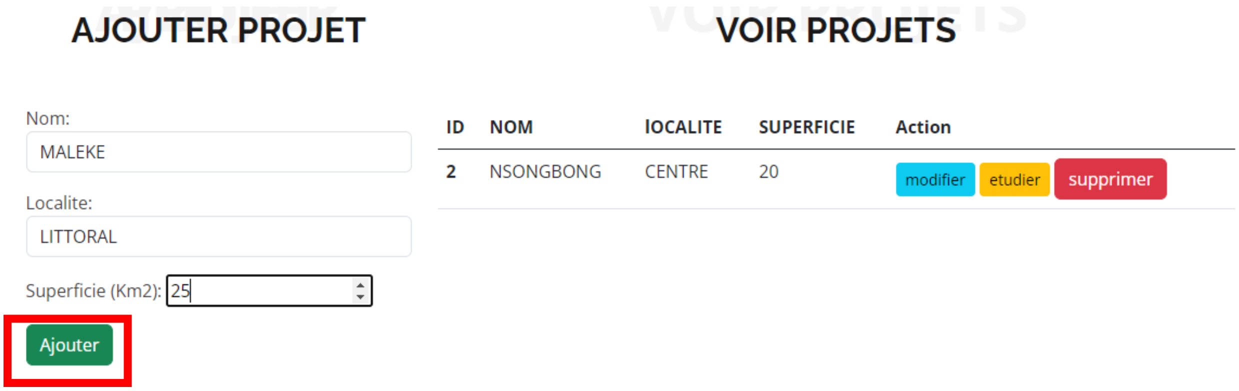
IHS Towers of strength

Figure 20**:** Home page

Once on the home page, the user can have access to the tabs :

- **Projects: where he can create projects or have visibility on projects already created.**
- **Help**
- **About**

When you choose the project tab, we have the choice to create a project or modify or consult the projects already created. This is illustrated in Figure 21 :



AJOUTER PROJET

Nom: MALEKE

Localite: LITTORAL

Superficie (Km2): 25

VOIR PROJETS

ID	NOM	lOCALITE	SUPERFICIE	Action
2	NSONGBONG	CENTRE	20	modifier etudier supprimer

Figure 21: Page of the Project tab

For the rest of our tests, we have chosen to study the Maleke project. A 25 km2 rural site. According to the specifications of our application which is to make a densification of the network (coverage planning and capacity), display of radiation diagrams according to the algorithms of the controller, and the planning of profitability. This is why when you created a project and you want to study it we have this interface visible in Figure 22 :

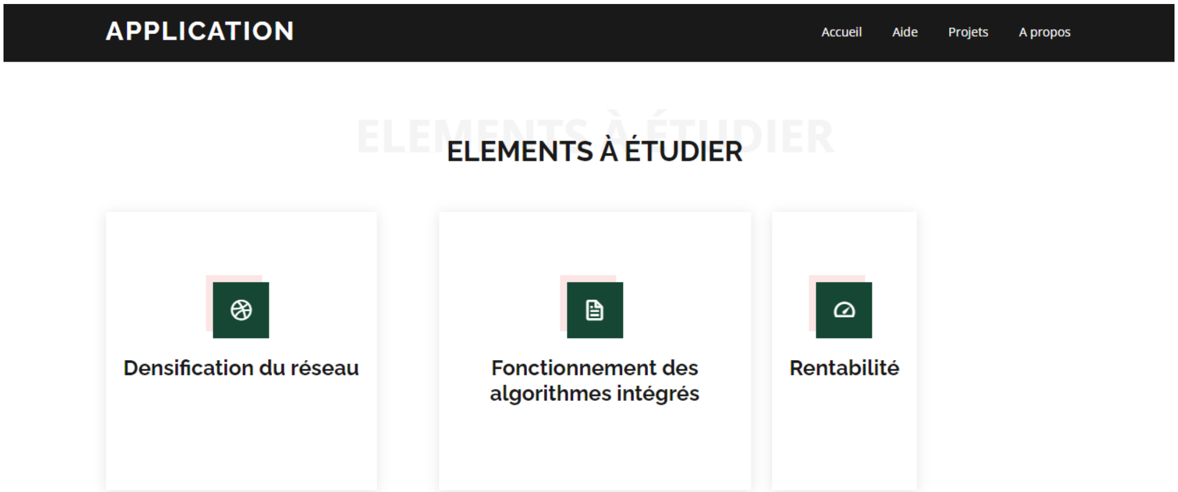


Figure 22: Page of the elements to be studied

4.2.3 Network densification

In the network densification component we have the coverage planning to determine the number of IRS that is necessary to cover a given area. We also have the capacity planning plan to determine the number of IRS it is necessary to meet high traffic requirements and to guarantee that the network is able to support the number of users and the demand for expected data. Figure 23 gives us an overview of the network densification tab :

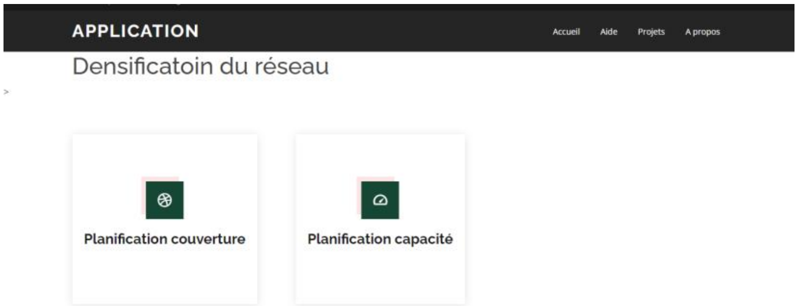


Figure 23: network densification page

4.2.3.1. Cover planning

In the coverage planning, we have the choice to make a deployment plan in a semi environment cleared or cleared according to how is the area to be covered materialized in figure 24:

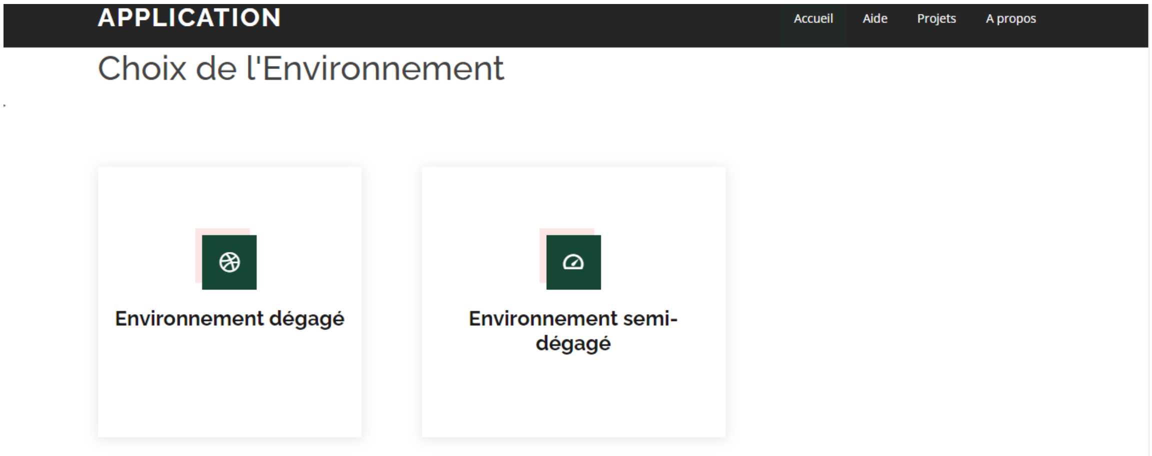
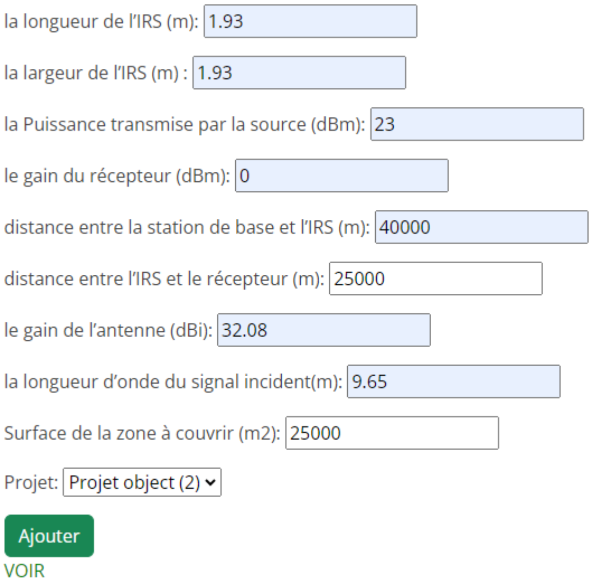


Figure 24: Environmental choice

For the rest of our tests, we will take the option of the semi-registered environment. We have therefore entered parameters approaching as much as possible from reality, this is visible in Figure 25:



la longueur de l'IRS (m): 1.93

la largeur de l'IRS (m) : 1.93

la Puissance transmise par la source (dBm): 23

le gain du récepteur (dBm): 0

distance entre la station de base et l'IRS (m): 40000

distance entre l'IRS et le récepteur (m): 25000

le gain de l'antenne (dBi): 32.08

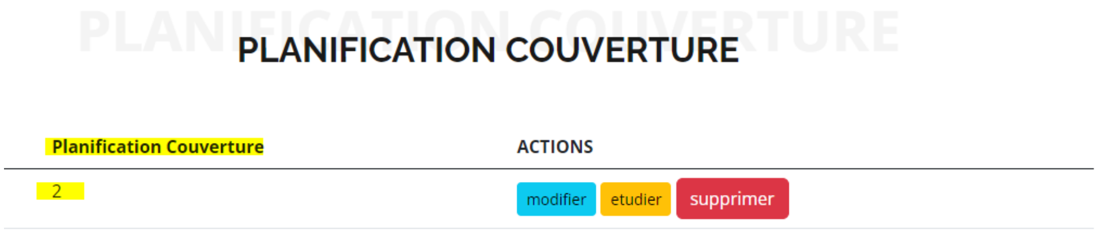
la longueur d'onde du signal incident(m): 9.65

Surface de la zone à couvrir (m2): 25000

Projet: Projet object (2)

Figure 25: Coverage planning for semi-registered environment

By clicking on see we have the result which is the number of IRS to deploy to ensure the coverage. Consequently, the next page is displayed as present in Figure 26 :



PLANIFICATION COUVERTURE

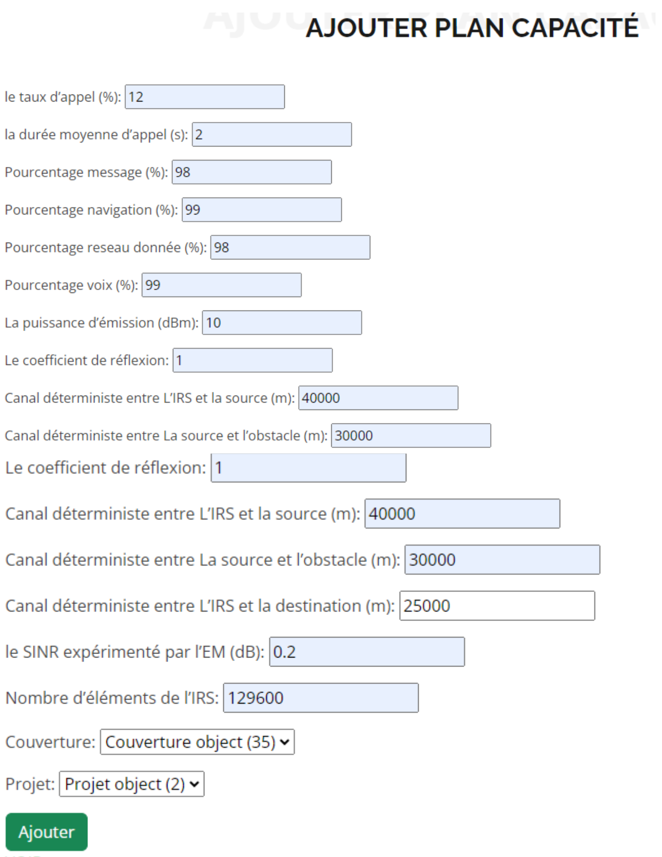
Planification Couverture	ACTIONS
2	

Figure 26**:** Cover planning result

On the cover column, we have the number of IRS it is necessary to cover the area and for the case of Maleke, these are 2 IRS.

4.2.3.1. Capacity planning

Like the coverage planning, the same principle is used to be able to make capacity planning. It will be a question of creating a capacity plan and Figure 27 represents the equivalent page :



AJOUTER PLAN CAPACITÉ

le taux d'appel (%): 12
la durée moyenne d'appel (s): 2
Pourcentage message (%): 98
Pourcentage navigation (%): 99
Pourcentage reseau donnée (%): 98
Pourcentage voix (%): 99
La puissance d'émission (dBm): 10
Le coefficient de réflexion: 1
Canal déterministe entre L'IRS et la source (m): 40000
Canal déterministe entre La source et l'obstacle (m): 30000
Le coefficient de réflexion: 1
Canal déterministe entre L'IRS et la source (m): 40000
Canal déterministe entre La source et l'obstacle (m): 30000
Canal déterministe entre L'IRS et la destination (m): 25000
le SINR expérimenté par l'EM (dB): 0.2
Nombre d'éléments de l'IRS: 129600
Couverture: Couverture object (35)
Projet: Projet object (2)

Figure 27: Capacity Planing

When we click on "See" you have the number of IRS that you need to cover the Makepe village in the capacity and it is 3 IRS. From then on, the next page is displayed after Figure 28:

PLANIFICATION CAPACITÉ

PROJET	Planification Couverture	Planification Capacite	ACTIONS
	2	3	modifier etudier supprimer

Figure 28**:** Capacity planning result

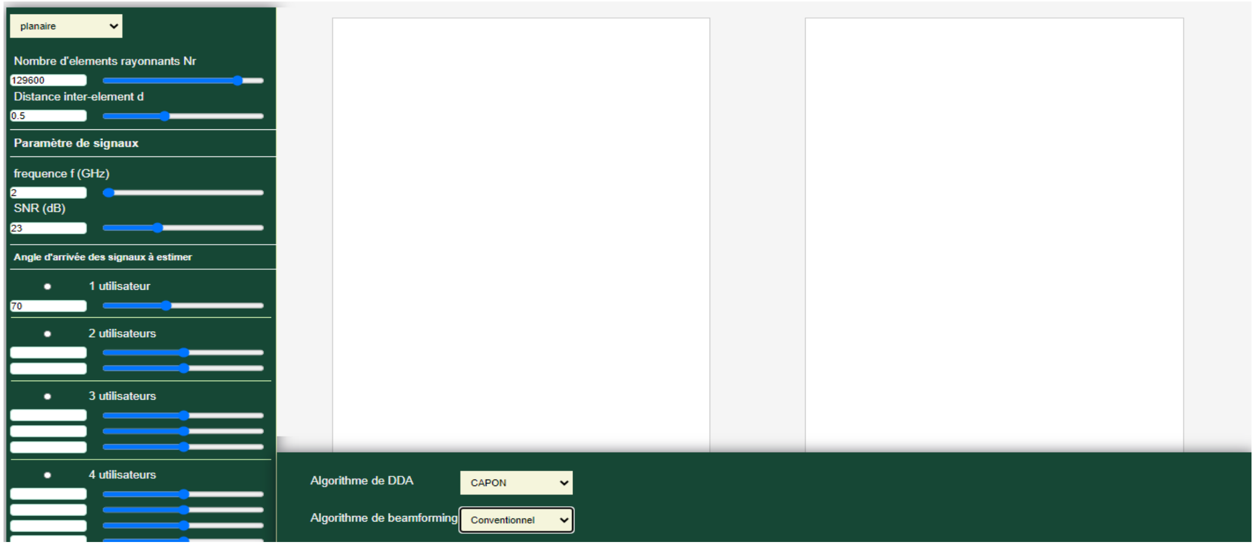
4.2.5 Page of the operation of integrated algorithms

In this tab, it will be a question for the user to enter the variables linked to the IRS who will be deployed, he will also have to choose the DDA and BeamForming algorithm which he wants to integrate into the controller. The sources of this part are inspired by [6].

- **DDA algorithms**

For our simulations, we used 3 DDA estimate algorithms in order to be able to compare them and deduce the most efficient.

Scenario: Or a planar network of 129,600 radiant elements regularly spaced with a distance D = 0.5λ on which frequency signals F = 2 GHz arrive, from SNR = 23 dB from direction 20 °.
Figure 29 presents the form that the user must fill out to register the input variables in the database:



planaire

Nombre d'elements rayonnants Nr: 129600

Distance inter-element d: 0.5

Paramètre de signaux

frequence f (GHz): 2

SNR (dB): 23

Angle d'arrivée des signaux à estimer

1 utilisateur: 70

2 utilisateurs

3 utilisateurs

4 utilisateurs

Algorithme de DDA: CAPON

Algorithme de beamforming: Conventionnel

Figure 29: Graphic display form

.

By validating the input data, we have the curves of the radiation diagrams that are displayed. Figure 30 shows us the performance of the IRS if we include the Bartlett algorithm:

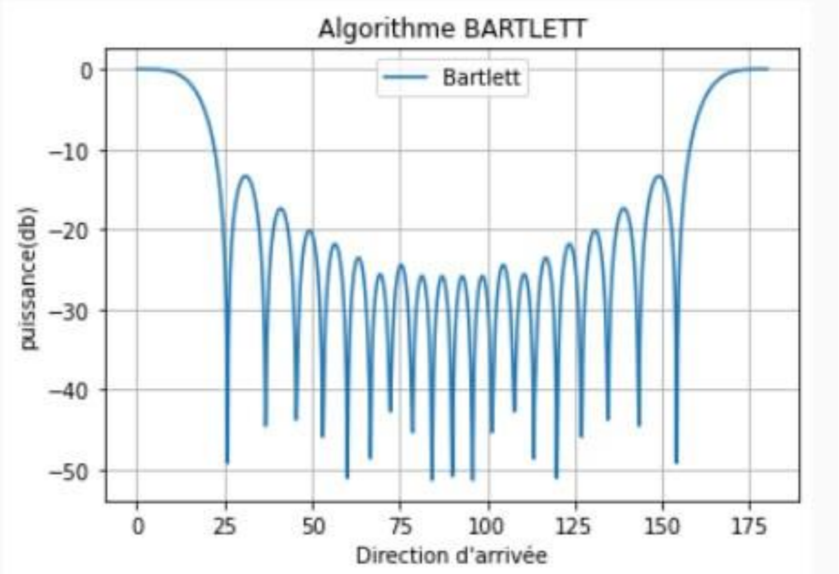


Figure 30: IRS performance if it is included the Bartlett algorithm

Figure 31 shows us the performance of the IRS if we include the Capon algorithm:

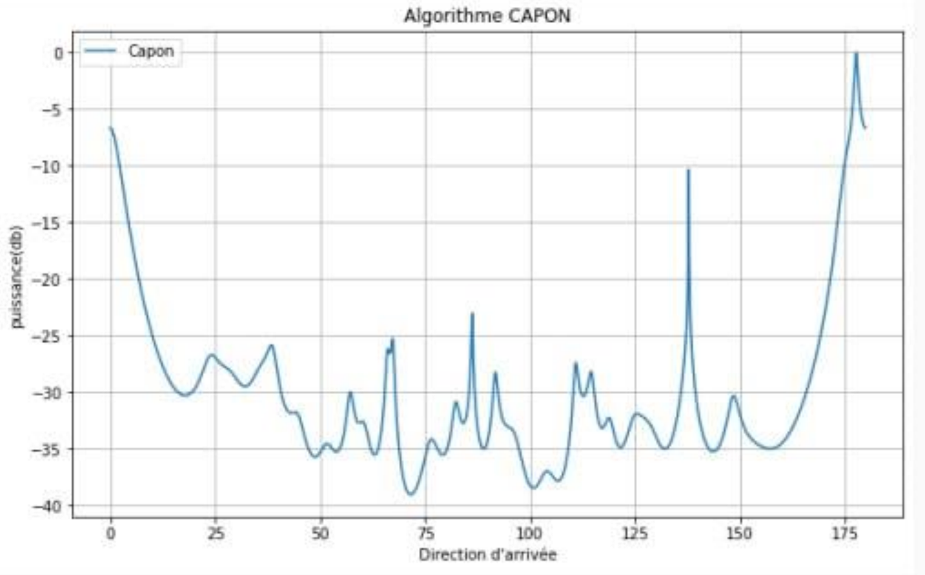


Figure 31: IRS performance if it is included the Capon algorithm

Figure 32 shows us the performance of the IRS if we integrate the MUSIC algorithm:

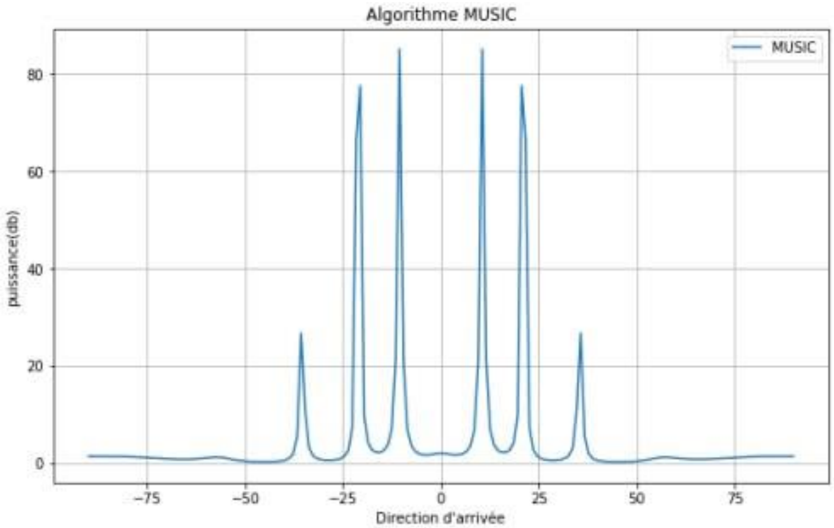


Figure 32: IRS performance if it is included the MUSIC algorithm

Various criteria allow us to determine the most efficient DDA algorithm:

- The precision of the estimate of the angle 20
- The observation of peaks in the direction 20
- These peaks must be of the highest possible powers.

After analyzing these criteria, it appears that the most efficient DDA estimate algorithm is: MUSIC.

Therefore, we can then conclude that the DDA algorithm indicated for the IRS controllers is **MUSIC.**

➢ **Beamforming algorithms**

Once the user angle is known, the intelligent antenna must radiate in this direction so that the beams are directed to users and that interference is minimized as much as possible.

Scenario: ie a planar network of radiating elements (129,600) regularly spaced with a distance D = 0.5λ. 2 GHz frequency signals, the SNR of which is 23 dB from

We have chosen to simulate conventional beamforming because of its simplicity of implementation. Figure 33 represents the IRS radiation diagram :

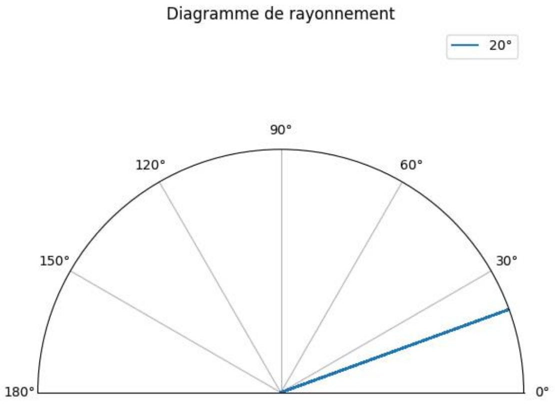


Figure 33 **:** IRS radiation diagram

On this graph is presented the radiation diagram of an IRS which will be deployed. On this graph, the main lobe of maximum power is distinguished, directed in the user direction and this without secondary lobes of lower powers representing interference.
We note that having chosen a large number of radiant elements, makes the beams and the interference more directive are canceled.
The help page presenting the summary of the functionalities of the tool is in Figure 34.

Objectifs de notre application

*Cet outil à été conçu dans le cadre du projet de fin d'études de Mlle **BITOM Pamela Brenda** sous la supervision de **Dr BAVOUA KENFACK Patrick Dany** et de l'**Ingénieur NGOUOLA François Xavier**.*
Pour IHS cet application s'inscrit comme une solution aux problèmes de la téléphonie rurale. Son objectif est la mise en place d'un outil de dimensionnement et de planification des surfaces réfléchissantes intelligentes pour des stations de bases dont les fonctionnalités sont entre autres :

✓ **Le calcul du nombre d'IRS nécessaire pour pouvoir couvrir une zone donnée (Planification couverture et de capacité)**

✓ **La démonstration du fonctionnement des algorithmes intégrés**

✓ **La Garantie d'un bon revenu**

Lien vers le mémoire de Pamela

Figure 34: help page

5. Conclusion

The main objective of this work was the improvement of mobile radio coverage in rural areas by the integration of IRS. In order to make a contribution to the decrease in the digital fracture in rural areas, while allowing operators to make profits. To do this, we have presented the fundamental concepts linked to IRS in intelligent communication radio environments, the rest of our work was devoted to the detailed description of an IRS dimensioning solution in rural areas coverage and capacity incorporating Algorithms for the management of arrival and beam training.

At the end of our work, we have designed a tool for planning and sizing mobile networks incorporating IRS. Its structural architecture, its interface and its features have been presented. The tool allowed us to determine the number of sites necessary to support a certain population of subscribers in a rural area with a given capacity and thus be able to meet the coverage requirements while optimizing the costs of infrastructure deployment. The tool also allowed us to choose after simulation of the radiation diagrams the best DDA algorithm for IRS controllers which is « MUSIC ».

This study clearly shows us the contribution of IRS to mobile networks which significantly contribute to reducing investment costs for the deployment of radios sites in rural areas and therefore participate in reducing the digital fracture.

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