

# Contribution for Efficient Planning of Millimeter Wave Frequencies: Case of the 80 GHz E-Band for High-Speed Broadband Transmissions

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## Abstract

Due to the very high demand for Internet data capacity from mobile and fixed customers as well as the saturation of conventional frequency bands by numerous services, many countries have opened the E band, for broadcasting services. E-band involves the creation of a significant number of links in a given area. The present work addressed the problem that arises in the context of transmission is that of assigning the frequencies of this band to these multiple transmission links. The aim of this work is to study and plan the radio links of the 80 GHz frequency and to implement them in a tool in order to define an optimal distribution on the telecommunications network by guaranteeing maximum flow of data traffic while minimizing the interference. The contribution of this work is part of its unique subject: the planning of E-band frequencies for improving the quality of service of transmission in the network of telecommunications operators. Also, it intends to contribute to the resolution of unsatisfied situations of poor planning of E-band radio frequencies in telecommunications networks. With the aim of opening several opportunities for alternative high-speed data transport solutions, our work has helped prove that E-band transmission links are very efficient with capacities in the gigabyte range.

## Keywords

Radio Beams, E-Band, Frequency Planning, Microwave

## 1. Introduction

In recent years, mobile telecommunications networks have experienced unprec-

edented growth, due in part to the desire of mobile telecommunications operators to adapt and evolve in order to meet the exponential increase in demand for consumers in Internet data capacity. This also results in an increasing demand for high-capacity point-to-point and point-to-multipoint wireless transmission links within telecommunications networks to provide high-capacity wireless connectivity.

The E band is part of the extremely high frequency (EHF) portion of the radio spectrum (30 GHz to 300 GHz), corresponding to wavelengths between 1 mm and 1 cm, hence the term “millimeter waves”. Internationally, the E band includes frequencies between 71 - 76 GHz and 81 - 86 GHz. Due to the short wavelength of E-band frequencies, the potential for interference between neighboring links is reduced, compared to lower frequency bands. This implies that National Telecommunications Authorities have much more possibilities to implement simplified coordination mechanisms for licensing transmission links in the E frequency band, compared to other frequency bands used for point-to-point services [1] [2].

It should be emphasized that the properties of E-band frequencies, in particular the available bandwidth and channel size (which being multiples of 250 MHz [3], offer the possibility of providing considerably higher capacity per link than which is possible in other frequency bands allocated to fixed services), make this band perfectly suited to meeting demands for Internet data capacity.

This work helps facilitate the appropriate assignment of E-band frequencies to respond to an increasing traffic while maintaining good transmission quality. Generally speaking, the main objective pursued within the framework of this work is to offer the various players in the sector (regulators, telecommunications operators) a tool to help plan frequencies in the E band to ensure the deployment of microwave links while limiting interference.

## 2. Planning of Radio Relay Transmissions

### 2.1. Hertzian Beam

A radio link is a signal transmission system allowing the interconnection of remote sites through the use of radio waves. A radio beam transmission makes it possible to connect two (02) fixed points, this is called a point-to-point connection as shown in **Figure 1**. It's an alternative to a wired telecommunications network. A mobile telephone operator can develop its communications infrastructure using microwave links. It only needs to reserve frequency ranges to be able to transmit and receive transmission signals.

#### 2.1.1. Use of Frequency Bands

A given point-to-point radio communication link is designed using, when available, the most appropriate frequency band that suits the specific connection and application:

- Low frequencies can reach longer distances and would be wasted for short links. Therefore, low frequency bands (typically up to 11 - 13 GHz) are commonly used for long distance applications (rural or island connectivity);

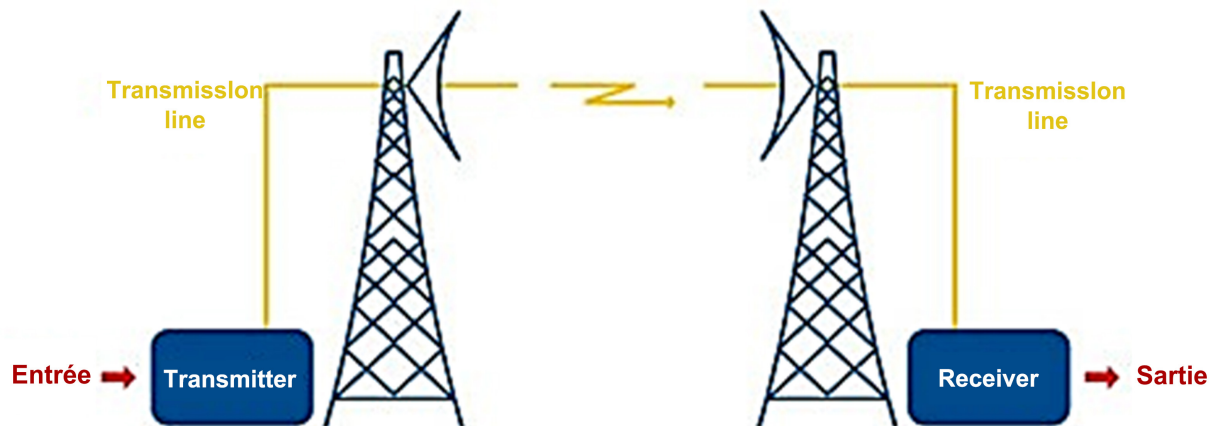


Figure 1. Point-to-point radio beam transmission.

- Mid-frequency bands are used for suburban use cases;
- The higher bands are used for urban scenarios and shorter links (with a decrease in the maximum link length depending on the frequency band).

Figure 2 is a high-level summary of the bandwidth reserved for the fixed service in the different frequency bands, together with the indication of the reference channel spacing.

The frequency bands that are generally used (traditional frequency band) range from 6 GHz to 42 GHz [4]. Frequency bands generally used in digital microwave transmission as shown in Figure 3:

*1G|8G|11G|13G|15G|18G|23G|26G|32G|38G* (Defined by ITU-R recommendations).

### 2.1.2. Allocation of a Frequency Band

The allocation of a frequency band refers to the management of the frequencies of this band for the purposes of its use by one or more services. This task is normally carried out by the ITU [5].

ITU basic provisions

The components of a frequency band defined by the ITU-R are illustrated in Figure 4.

The ITU-R Recommendations specify the center frequency of the band, the T/R spacing (duplex spacing), the T/T adjacent channel spacing (co-polar and inter-polar) and the number of channels. The center frequency ( $f_0$ ) is the middle frequency around which the channels are arranged. A number of channels with a specific channel spacing are identified on the frequency band of that specific plan. Sometimes the channels are spaced with alternating polarizations. Care must therefore be taken when specifying channel spacing requirements, whether co-polar or inter-polar spacing is referenced.

**Recommendation ITU-R F.2006** gives the arrangements of radio channels and radio frequency blocks for fixed wireless systems operating in the range 71 - 76/81 - 86 GHz, which can be used for broadband applications and other high-speed networks. This is the one put into effect by OCM for the E band.

Frequency Band	Duplex Spacing (MHz)	BW (MHz)	Channel Size (MHz)	Typical Applications
L6 GHz	252.04	2×266.85	8×29.65	Rural long-haul
U6 GHz	340	2×230	8×40	
L7 GHz	161	2×119	16×7	
U7 GHz	154	2×112	2×56	
L8 GHz	311.32	2×266.85	8×29.65	Sub-urban medium-haul
U8 GHz	119	2×84	6×14	
11 GHz	490	2×480	12×40	
13 GHz	266	2×224	5×56	Urban short-haul
15 GHz	420	2×168	3×56	
18 GHz	1010	2×935	17×55	
23 GHz	1008	2×504	9×56	
26 GHz	1008	2×868	16×56	Urban short-haul
28 GHz	1008	2×875	16×56	
32 GHz	812	2×742	12×56	
38 GHz	1260	2×1120	20×56	
70/80 GHz	1000	2×5000	19×250MHz	

Figure 2. Microwave frequency bands [6].

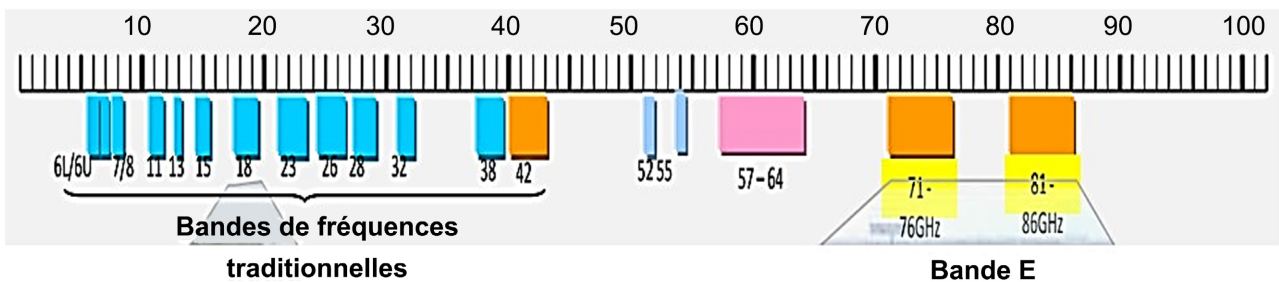


Figure 3. Arrangement of ITU-R frequency bands.

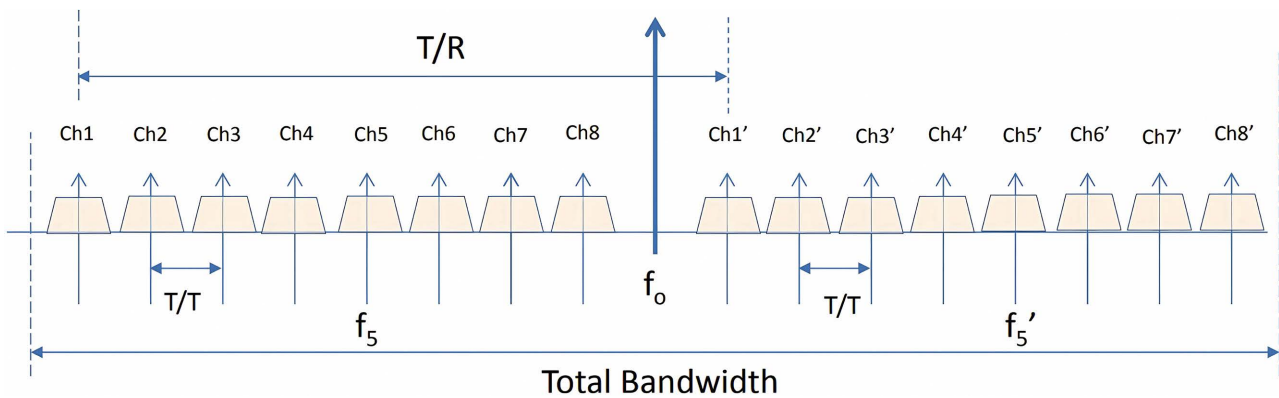
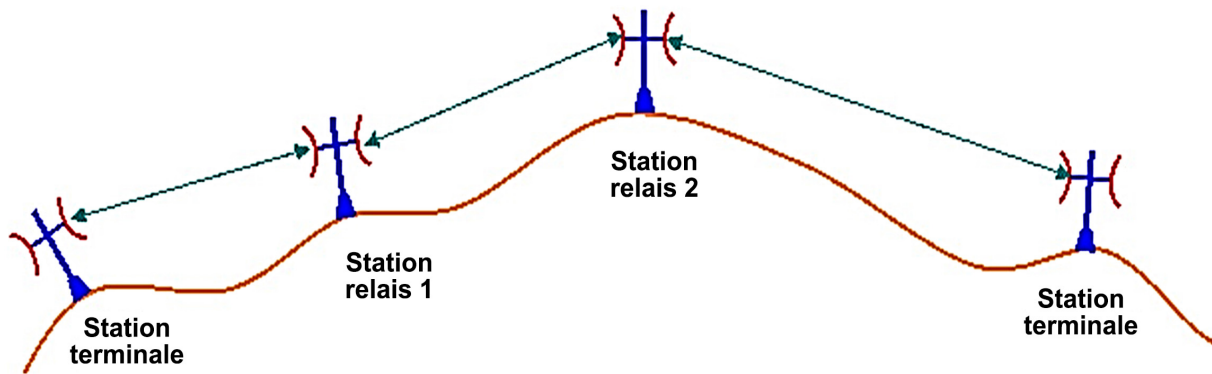


Figure 4. Layout of an ITU-R frequency band [7].

### 2.1.3. Propagation Mode

When carrying out a transmission between a transmitter and a receiver:

- Propagation in open space: the receiver receives a direct wave emitted by the transmitter. The radio waves which propagate between the antennas must be clear of all obstacles, it is a line of sight. Antennas are installed on high points, towers or pylons; for reasons of distance and visibility, the radio path between the transmitter and the receiver is often divided into several sections, called hops, connected by relay stations as shown in Figure 5.



**Figure 5.** Example of architecture with relay station.

#### 2.1.4. Transmission Distance

In general, millimeter wave bands above 60 GHz exhibit favorable properties for providing high-capacity wireless links, due to the large amount of spectrum available in these bands. This is one of the main drivers for the use of millimeter wave bands, compared to lower frequency bands which allow links to operate over greater distances, but with less available capacity.

For example, a research report published by the UK regulator Ofcom, illustrates the increase in capacity typically available in the millimeter wave bands, relative to link distance as shown in **Figure 6**.

The transmission distance increases as the availability level and rainfall rates decrease. Rainfall statistics are well known for locations around the world, so range and availability can be accurately predicted as shown in **Figure 7** [5].

For a given hop distance, typical multi-band combinations that would increase capacity include: the 18 - 42 GHz bands linked to the very wideband 70/80 GHz for hop distances up to about 5 km or the bands narrow 6 - 15 GHz bands linked to the wider 18 - 42 GHz bands for longer hopping distances. The multi-band solution is very flexible and all locally available frequency combinations that meet the targeted performance can be used.

#### 2.1.5. Link Assessment

If  $P_{TX}$  is the transmitted power and  $P_{RX}$  is the received power, the total losses and gains can be expressed in a basic equation as follows:

$$P_{TX} + \text{TotalGain} - \text{TotalLosses} = P_{RX} \quad (1)$$

The characteristics of the end equipment to be taken into account for the calculation of the energy balance are [8]:

- **Transmitting power:** This is the signal strength that the radio equipment can deliver. It is commonly between 20 and 30 dBm.
- **Reception thresholds:** Defined in relation to a given bit error rate ( $TEB = 10^{-3}$  or  $10^{-6}$ ), they reflect the capacity of the receiver to process the weakened signal after propagation (with respect to thermal noise). Depending on the frequency band, bit rate and type of modulation, they are generally between -70 and -95 dBm.

Gamme de fréquences	Distance réalisable pour les liaisons point à point	Largeur de bande de liaison réalisable pour les liaisons point à point
En dessous de 3GHz	Large, par exemple des dizaines de km	Petit : généralement inférieur à 10Mbit/s
3-10GHz	Large, par exemple des dizaines de km	Moyenne : jusqu'à 100s de Mbit/s par liaison
10-20GHz	Moyenne, par exemple 10-20 km	Moyenne : jusqu'à 100s de Mbit/s par liaison
20-50GHz	Petit, par exemple moins de 10 km	Large : 500Mbit/s et plus
50GHz et plus	Très petit, par exemple quelques km	Large : 1Gbit/s ou plus

Figure 6. Spectrum properties used for point-to-point links [4].

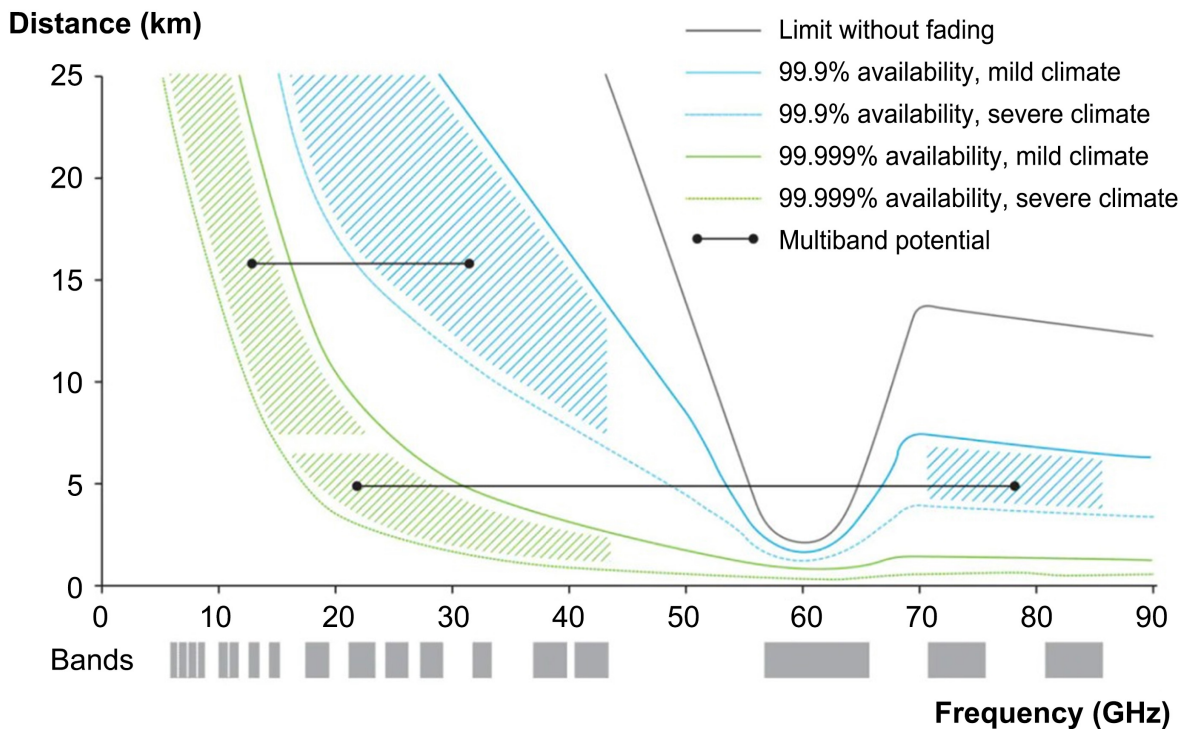


Figure 7. Distances achievable with a high capacity microwave link [9].

- **Connection losses** (wave-guide, connectors, etc.): For equipment without integrated antennas, it is necessary to connect the transmitter/receiver to the antenna using a coaxial cable or wave-guide. These offsets induce linear losses of 1 to several dB, to which are added the losses due to connectors and other connection elements.
- **Antenna gain:** The antennas, mainly parabolic, provide a power gain (of the order of 25 to 45 dB) that is greater as their diameter increases. The directivity of the beam increases with the frequency band and the diameters of the antenna.

## 2.2. E-Band

### 2.2.1. E-Band Overview

The E-band is part of the extremely high frequency (EHF) portion of the radio spectrum (roughly 30 GHz to 300 GHz), corresponding to wavelengths between 1 mm and 1 cm, hence the term “millimetre waves”). The three E-band spectrum segments (71 - 76, 81 - 86, and 92 - 95 GHz) have been allocated as a shared service for short-range line-of-sight radios with mission capability comparable to communications by optical fiber [5].

Remark: The 92 - 95 GHz band is intended for indoor applications only, so it is not a part to be developed. Internationally, the E band includes the frequencies 71 - 76 GHz and 81 - 86 GHz.

### 2.2.2. Regulations Regarding the Uses of the E Band

The ITU publishes recommendations in the field of telecommunications, recommendations which have been adapted for radiocommunications are published in the ITU-R. The following clauses summarize the CEPT, ITU-R and FCC regulations as the most representative for the majority of the market:

- In 2003, the Federal Communications Commission (FCC) issued a ruling on opening up 13 GHz of “millimeter wave” spectrum in the 71 - 76 GHz, 81 - 86 GHz, and 92 - 95 GHz bands to much higher frequencies. Higher than those previously available commercially. This spectrum provided for the first time the resources for cost-effective broadband connectivity at data rates in the gigabit range and beyond.
- In 2005, the European Post and Telecommunications Commission (CEPT) published a Europe-wide frequency channel plan for fixed service systems in these bands, and the following year, the European Institute for Technical Standards (ETSI) has published technical specifications covering these bands.
- Later in 2009, the ECC recognized the great importance of this band for the high density deployment planned also for 3G/4G mobile back-hauling; therefore, a revision of ECC/REC (05)07 was carried out.
- In 2012, the ITU-R published Recommendation F.2006 [4] which essentially took up the options provided by ECC/REC (05)07 by adding the option of a possible allocation of blocks.

Each country has a regulator who is responsible for national policy and the choice of a particular channel plan for each frequency band to be implemented in that country.

### 2.2.3. Application Domain

E-band frequencies (typically 71 - 76 GHz and 81 - 86 GHz) are particularly useful for providing high-capacity wireless transmission links for two (02) reasons:

- The existing international allocation of this frequency band for the use of the fixed service (which has the advantage that radio equipment has been developed for this band);

- The availability of harmonized bandwidth (up to  $2 \times 5$  GHz, in multiples of 250 MHz), which provides a large amount of potential capacity [2].

### 2.2.4. Some Technical Specifications from International Standardization Organizations

The following table summarizes the main ETSI technical specifications for E-band operation as shown in **Table 1** and **Figure 8**.

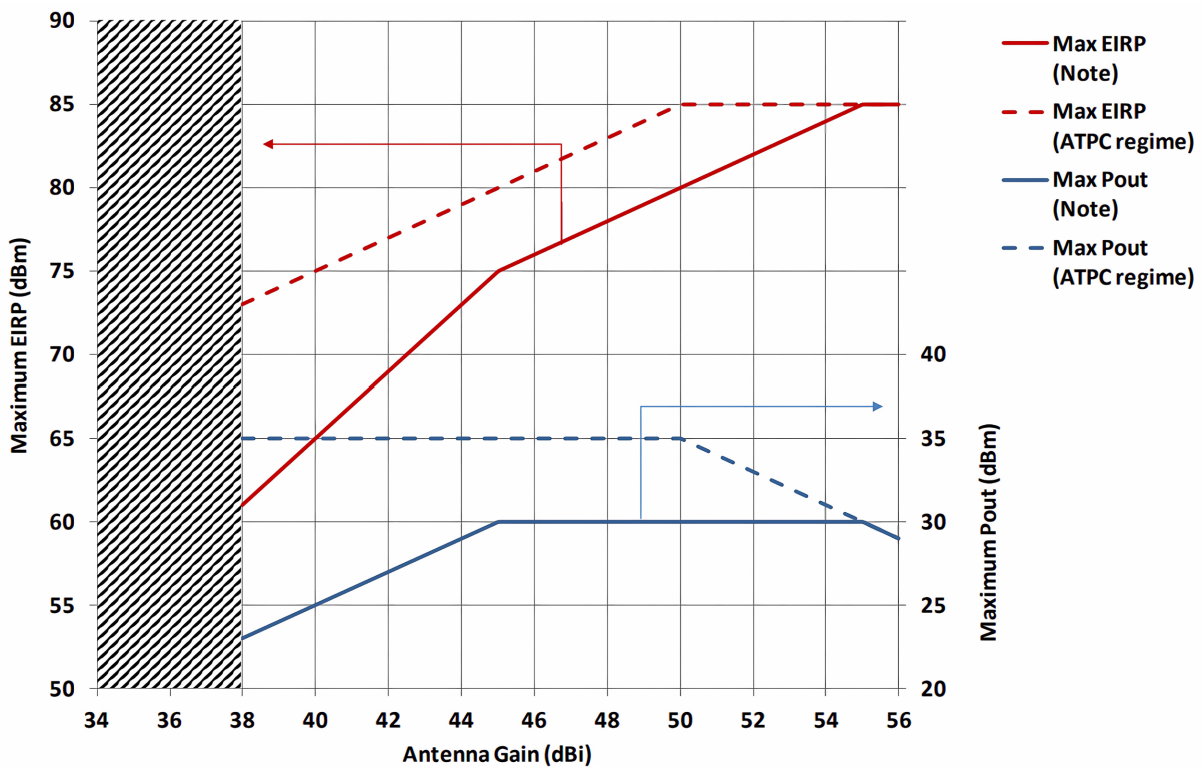
The full set of ETSI specifications is present in ETSI EN 302 217 part 2.

### 2.3. Frequency Planning

The objective of frequency planning is to allocate the available channels to the different network links without exceeding the quality and availability objectives of the individual links due to radio interference or to allocate frequencies to a network using the least amount of frequency. Possible frequencies and in such a way that the quality and availability of the radio link path are least affected by

**Table 1.** ETSI—Technical specifications [1].

ETSI-Technical specifications for E-band operation	
Maximum power limit	30 dB
Equivalent isotropically radiated power (EIRP)	85 dBm = 55 dBW
Automatic transmit power control (ATPC)	In option
Maximum antenna gain	85-Pout (dBm)



**Figure 8.** Limitation of emissions (ETSI EN 302 217-2-2) for the bands 71 - 76 and 81 - 86 GHz.



interference. Frequency planning for some paths can be done manually, but for large networks it is strongly recommended to use a transmission design software tool [5].

Good frequency planning involves reusing channels as many times as possible before switching to a different channel. By reusing channels in a planned manner, it is possible to reduce disturbances while optimizing the use of the spectral resource. Exact interference limits can be calculated using the methodology described by the ITU [4].

### **Sites A and B (Top/Bottom Arrangements) [5]**

For radio links, channel pairs are always used. A signal is transmitted from site A to site B with a certain transmit frequency and the receive frequency of site A is the transmit frequency of site B. These are called forward and reverse channels. Forward channels transmit in the lower half of the band and are sometimes called “transmit low” and are denoted by  $f_n$ , where  $n$  is the channel number. Return frequencies transmit in the upper part of the band, are sometimes called high transmit and are denoted by  $f_n$ . The basic principle of allocating frequencies within the same band is the Hi-Lo principle (this means that once a site has been designated as high transmitting as shown in **Figure 9**, all links originating from that site will transmit high). This high site transmits to a low site, that is all links from the high site receive low, and those from the low site receive high.

#### **Planning scenarios [6]**

##### 1) Two (02) frequency plan (one pair)

The most efficient reuse plan is one in which only one frequency pair is used throughout a route. Consider the interference at the repeater site (nodal) and the problem at sites further down the route (overshoot) as shown in **Figure 10**.

##### ➤ **Nodal Interference**

Nodal interference occurs when we reuse the same frequency channel at a node. Nodal interference occurs in the antenna of the adjacent link, at the same site, as shown in **Figure 11**.

Choosing a high-performance antenna with low side lobes and an excellent front-to-back (F/B) ratio allows a scheduler to reuse a channel multiple times at a node. Bands like E-band with their very small antenna apertures make it possible to group a large number of links into a node. In terms of nodal interference, changing the polarization only reduces interference when the interfering link is directed toward the front half of the antenna.

##### ➤ **Overtaking Interference**

Overtaking Interference, This type of interference occurs at the next site in a radio route, where the receiver is tuned to the two-link transmitter site, as shown in **Figure 12**. For each site, the high transmission (TX-H), transmit low (TX-L), receive high (RX-H), or receive low (RX-L) are specified.

Diagram showing overshoot interference in a microwave radio system as shown in **Figure 12**.

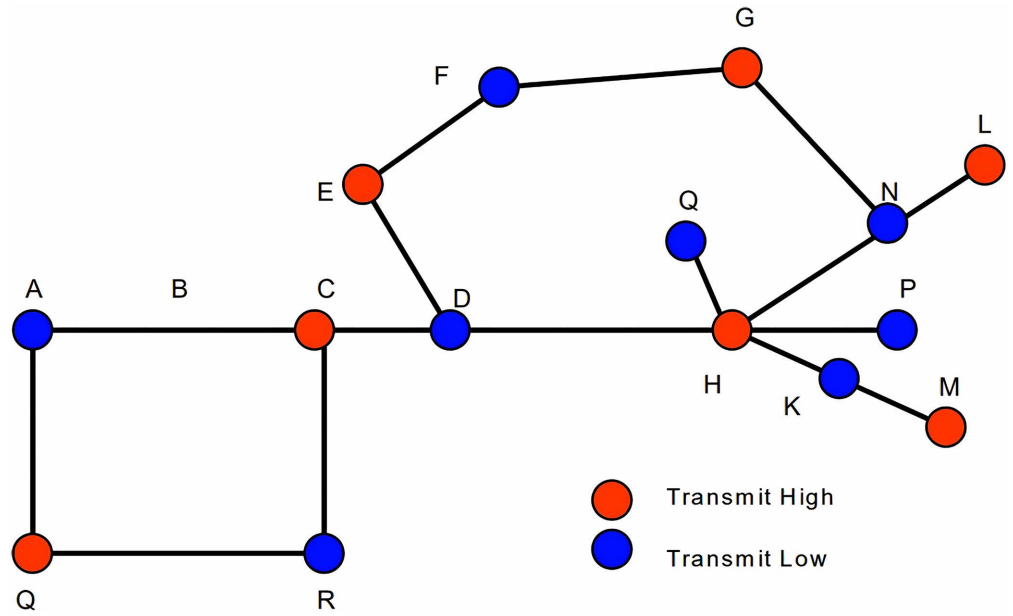


Figure 9. Frequency planning: Hi-Lo layout [10].

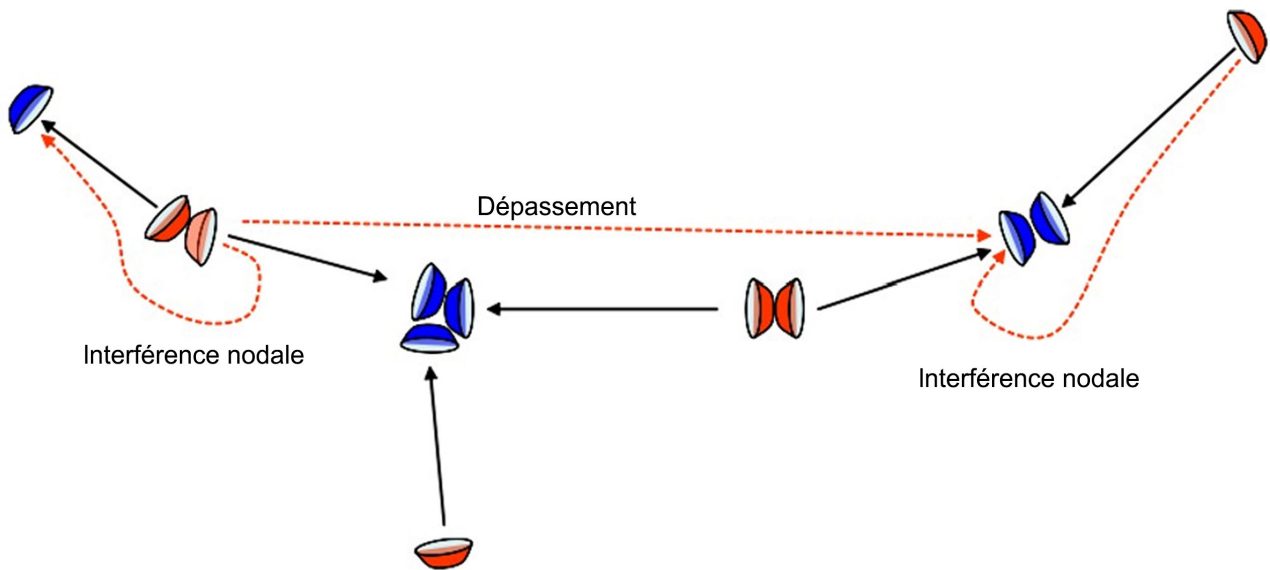


Figure 10. Interference resulting from frequency planning [10].

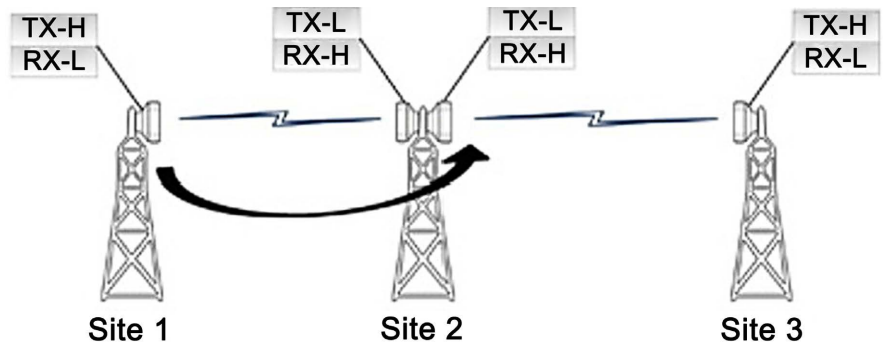
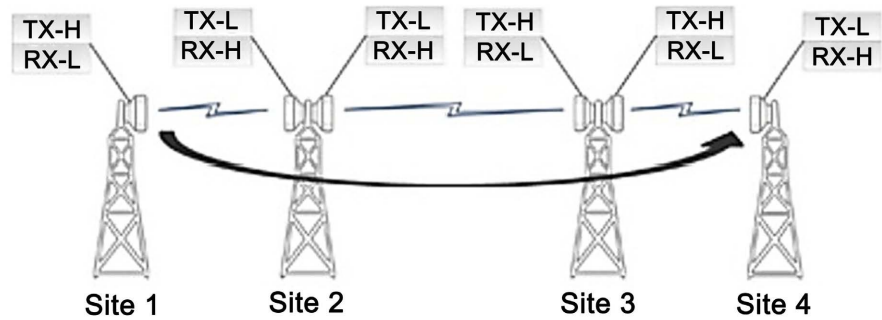


Figure 11. Nodal interference.



**Figure 12.** Overtaking interference.

In this case, the interference is located in front of the antenna, and alternating polarization is therefore a good strategy. From the analysis above, it can be seen that an entire radio channel could be designed on a single frequency pair using the following planning guide:

Canal 1 (H) – Canal 1 (H) – Canal 1 (v) – Canal 1 (v) – etc.

It should be noted that if polarization alternation is already exploited for network capacity reasons, then it cannot be reused for interference reduction.

2) Four-frequency plan (two pairs)

If the inter-polar discrimination (XPD) of the antennas is insufficient to solve the overshoot problem using a single pair of frequencies, a second set of frequencies is necessary. In this case, the frequency and polarization must be alternated every two jumps. This results in the overshoot path to the third hop being a different frequency, and the opposite bias ensures that adjacent channel interference is minimized. This is illustrated in **Figure 13**.

If the second frequency pair is needed to overcome antennas with insufficient F/B ratio, the frequencies should be alternated every hop and the polarization alternated every third hop. The common polarization for every two nodes is not an issue with regard to the F/B ratio since there is practically no polarization discrimination behind the antennas. The third hop bias shift is required for overshoot protection. This is illustrated in **Figure 13** and **Figure 14**. With this four frequency plan, high performance antennas will not normally be required at alternate sites where two frequency pairs are used.

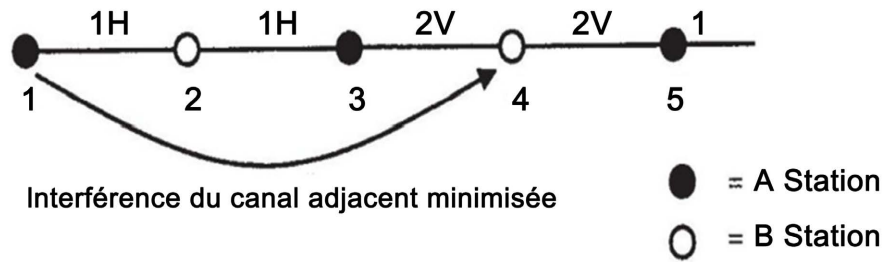
3) Six-frequency plan (three pairs)

If F/B and overshoot cannot be resolved with previous plans, then an additional frequency pair will be required. These will be assigned in frequency pairs 1, 2 and 3 with one bias, then 1, 2 and 3 with the bias alternated, and so on.

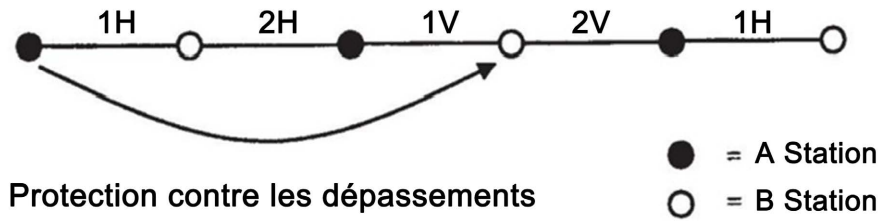
a) Basic recommendations [5]

In this section, we summarize some recommendations that will help reduce interference between links [5]:

- ❖ Use of star and hub configurations for small networks and ring configuration for large networks [5];
- ❖ The use of high-performance antennas in urban areas to minimize interference;



**Figure 13.** Four-frequency plan with alternating polarization for antennas with insufficient XPD.

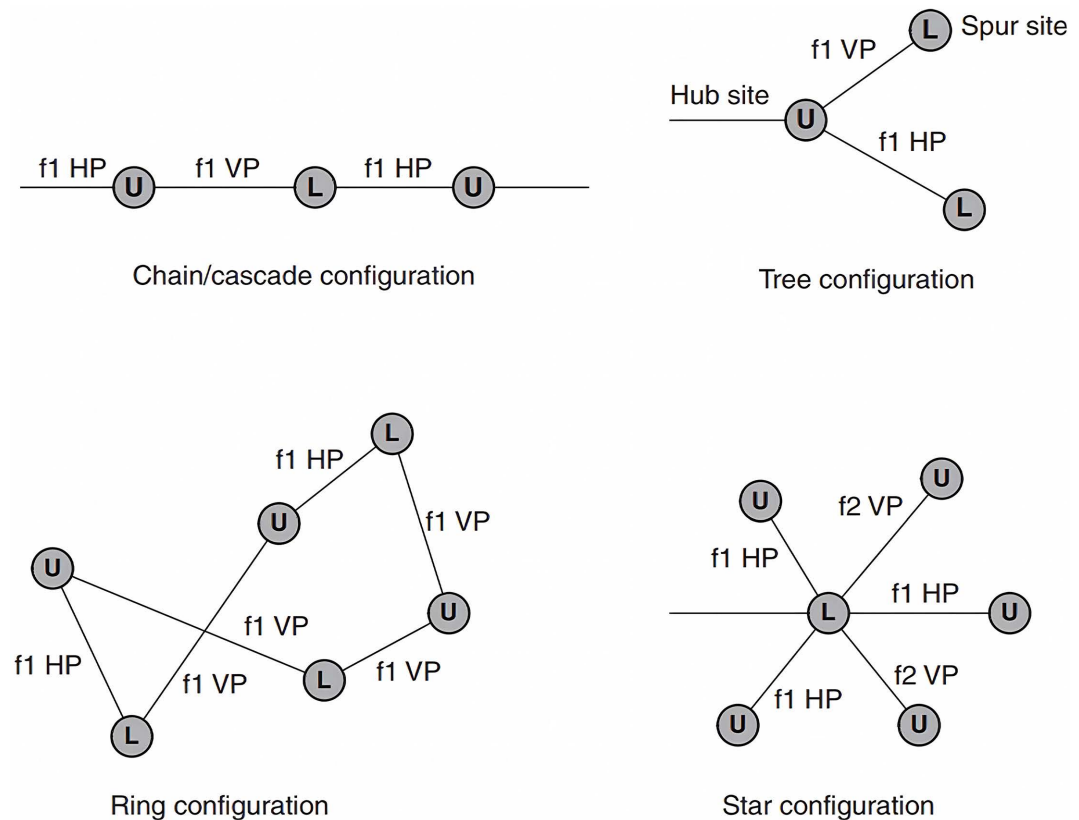


**Figure 14.** Four-frequency plan with alternating frequencies for antennas with insufficient F/B ratio.

- ❖ The use of unprotected systems (1 + 0) only for secondary sites, links of low capacity and/or generally of low importance. Use protected systems (1 + 1) for all important and/or high capacity links [5];
- ❖ The reflection coefficient (and therefore the chances of multipath fading) decreases with frequency;
- ❖ Vertical polarization is less sensitive to reflections;
- ❖ Vertical polarization is less susceptible to attenuation due to rain;
- ❖ Spatial diversity is a very expensive way to improve microwave link performance, and it should be used with caution and as a last resort;
- ❖ Use of updated maps that are not more than one year old. The magnetic inclination as well as the terrain itself can change dramatically in a very short time. Make sure everyone on the project uses the same maps and coordinate systems [5];
- ❖ The selection of the datum or datum ellipsoid should be the same for data, image, and site elevation files. The same map projection should be used for image and elevation files [5];
- ❖ Frequency planning activity for future network extensions. It should be possible and easy to add new hops as the network grows [5];
- ❖ Keep in mind during trail surveys that trees and other vegetation are growing and plan for at least 10 years of growth, preferably even 20 years [5].

b) The stages of frequency planning [5] The frequency planning process can be described as follows as shown in **Figure 15**:

- i) Define the overall network structure by determining the location of all nodes that need to be connected;
- ii) Allocate appropriate quality and availability targets for each portion of the



**Figure 15.** Frequency allocation for different network configurations [5].

network (no frequency is involved in this step) and perform quality and availability calculations;

iii) Estimate traffic needs and capacity. It is a good practice to start frequency planning with the highest capacity links in the most concentrated node. This will normally result in the number of frequencies needed in the network, and other links would need to reuse the same frequencies;

iv) In some cases it may be necessary to use channels from more than one frequency band due to the limited number of channels available in the first selected band;

v) Start assigning half duplex (lower/upper) for the transmitter in network sites. Generally, quasi-interference should be avoided as much as possible by strictly allocating the same upper or lower half-duplex to all transmitters (or receivers) at the same site. Generally, depending on the different network configurations, we have:

- In the chain configuration, using the same channels by changing the polarization (HP/VP) can be a good alternative to using two alternating channels in the chain, **Figure 15** shows the same channel used alternately with one horizontal (HP) and vertical (VP) polarization. The upper (U) and lower (L) duplex halves for the transmitters are shown in each site;
- In the tree configuration, and for sharp angles, polarization discrimination ensures the possibility of using the same channel with different polarizations

(HP and VP). Both transmitters on the common node have the same half duplex (U);

- In the ring configuration, the same channel, with the same polarization, is used in perpendicular paths but with different polarization in parallel paths. The transmitters are alternately labelled upper (U) and lower (L) duplex halves. Although the image does not depict a physical ring configuration, the logical configuration and traffic flow are indeed ring in nature. If the ring consisted of an odd number of sites, there would be a conflict of duplex halves, and changing the frequency band would be a good alternative;
- In the star configuration, as stated previously, all transmitters in the common node must have the same half duplex (L). Keep in mind that this configuration displays a difficult frequency planning scenario and is very sensitive to geometry (mutual angles). If the node is a concentration point for high-capacity links, high bandwidth is required, making it quite complicated to allocate smaller channels in other parts of the network. It is recommended that the link carrying traffic out of the hub use a frequency band other than that used inside the cluster.

vi) Consider antenna discrimination aspects in the early stages of frequency planning. For example, in a common site (e.g., a node or hub), links with sufficient separation angle can use the same channels. In addition to angular separation, distance separation (coupling loss) between two antennas can also provide some degree of discrimination;

vii) At microwave frequencies, antenna discrimination increases rapidly with angular separation and is an extremely effective factor in suppressing interference. Thus, if the two links are not closely aligned on a common line and the transmitters (upper or lower) transmit in the same direction (in other words, no overshoot), it is normally possible to reuse frequencies between two of these connections;

viii) In congested areas, it may be necessary to use antennas that have high front-to-back ratios and great side lobe suppression. This results in a good saving frequency and, ultimately, good overall network economics. High-performance antennas may be a suitable alternative;

ix) Reuse frequencies and polarization as often as possible;

x) Recalculate quality and availability (after frequency assignment) and identify links that do not meet quality criteria and availability objectives. The interference calculation is performed, and receivers with relatively high degradation threshold values are likely among the links that do not meet the quality and availability objectives. Make appropriate changes (polarization, channel, frequency band, antenna size, etc.) and ensure that a new interference calculation results in lower impairment threshold values;

xi) In some situations, higher output power from a transmitter can improve quality and availability figures without significant interference contribution to the network. These favorable situations, however, are not very common, so it is

not advisable to use higher output transmit power than necessary. It is a good idea to start frequency planning with the lowest available output power;

xii) If the choice is between higher transmitter output power and a larger antenna, choose (if possible) a larger antenna;

xiii) Repeat step 10 until the quality and availability objectives of all parts of the network are met.

## 2.4. Radio Link Design Analysis

The design of a microwave link is a methodical process consisting of several stages as shown in **Figure 16**.

The design of a microwave link therefore includes the following activities:

- Loss calculations;
- Erase and cross fade margin calculations;
- Frequency planning and interference calculations;
- Quality and availability calculations.

As part of the work on mmWave link frequency planning, we don't need to study loss calculations, fade margin calculations, and quality and availability calculations, we will study the interference analysis.

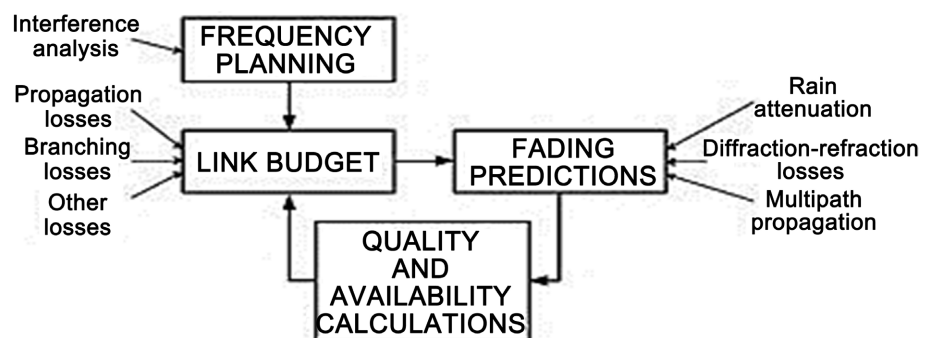
## 3. Tools and Method

### 3.1. Microwave Design Tools

Most microwave network design software tools are developed by radio manufacturers and are therefore geared towards the manufacturers' own equipment. In other cases, the tool may be proprietary and not sold on the open market. Some microwave equipment manufacturers insist on using their own software tools, some operators and consultants prefer to use commercially available tools. [5]

#### 3.1.1. Path-Loss Software

Microwave communication network design can be a complex and sometimes daunting task. Fortunately, engineers and technicians working on microwave network planning can use tools and software like Path-loss to ensure a methodical and thorough approach to their task. Path-loss software is a state-of-the-art



**Figure 16.** Microwave link design process.

tool for the complete design of paths and links operating in the frequency ranges from 30 MHz to 100 GHz. Designed for use worldwide with diverse equipment and widely varying atmospheric conditions, the Path-loss tool uses terrain databases, equipment files, and local weather files to design and model microwave systems.

Radio equipment parameters for equipment from any vendor, channel tables, antenna diagrams, etc. are set and stored in the default settings database for easy retrieval. This tool is widely accepted by microwave system design engineers around the world.

The process of designing microwave links using Path-loss includes steps that span a network's five link design modules and four network design modules. Network design modules include:

- ❖ Network module that provides a graphical representation of a network of sites;
- ❖ Automatic link building, which includes creating, designing and modifying links;
- ❖ Intra-system interference operation performed on the network module;
- ❖ Local and area surveys for coverage, and can be done from the network module.

The liaison program includes five (05) modules which are as follows:

- Transmission analysis which provides detailed data input for equipment and path parameters;
- The Field Data Module is used to create and modify a path profile;
- Antenna heights module to calculate antenna heights that satisfy all clearance criteria;
- The Multipath Reflection Module which uses ray tracing techniques to determine the reflective characteristics of a constant or variable refractive gradient path;
- The diffraction attenuation module is used to calculate diffraction attenuation as well as tropospheric scatter attenuation on the transmission and interference paths.

### **3.1.2. Google Earth Pro**

Google Earth Pro is a computer program that renders a 3D representation of the Earth, mainly from satellite images. It also overlays satellite images, aerial photographs and GIS data onto a 3D globe, allowing users to see cities and landscapes from different angles. Recently, Google revealed that Google Earth now covers more than 98% of the planet and has captured 10 million miles of Street View imagery, a distance that could circle the globe more than 400 times. In addition to Earth navigation, Google Earth provides a series of other tools through the desktop app, including a distance measurement tool.

## **3.2. Frequency Planning Organization Chart**

Frequency planning organization chart is showing in **Figure 17**.



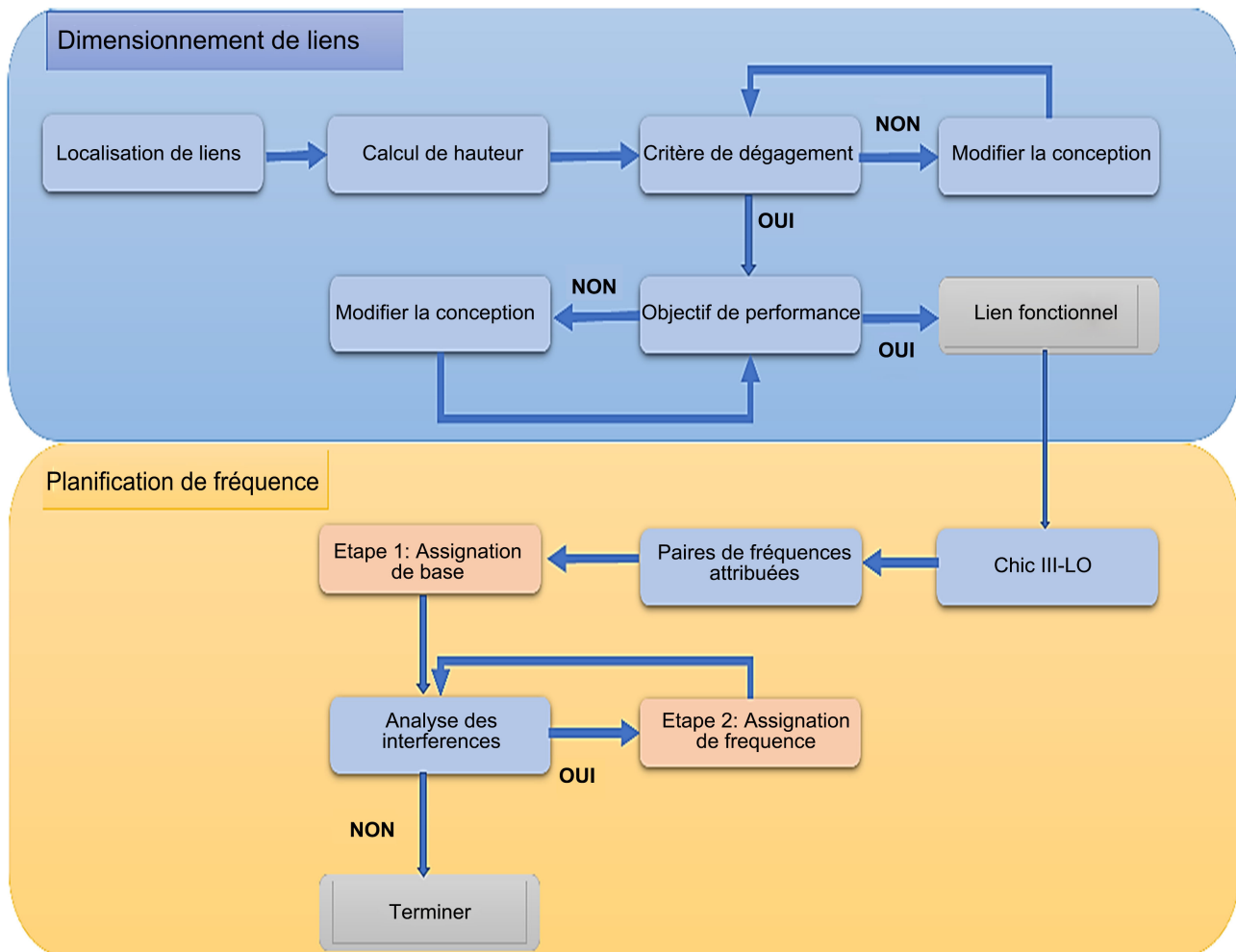


Figure 17. Frequency planning flowchart.

Legend:

- The blocks in blue represent the steps carried out on pathloss5;
- The blocks in gray represent the state of the links;
- The blocks in orange represent the steps carried out by the developed tool.

### 3.2.1. Sizing of Microwave Links

In order to proceed with the assignment of frequencies, it should be noted that the dimensioning of the different transmission links must be established, that is to say that for each link, the receiver must be capable of receiving the signal from the corresponding transmitter (frequency assignment is not involved in this step). Therefore, the links must be designed according to whether loss calculations, fading margin calculations and quality and availability calculations have been carried out.

MARYLYNE MA-ENO in “Study and dimensioning of a millimeter wave link in the city of Douala: modelling and calibration of the propagation channel” described the loss calculations, the fading margin calculations and the quality and of availability necessary for the design of a microwave link in its theoretical and

practical aspect by implementing it on pathloss5.

1) Link location

This step consists of giving the coordinates (latitude and longitude) of the sites to be studied in the path-loss program in the “Site List” section FREQUENCY as shown in **Figure 18** and **Figure 19**.

2) Antenna Heights

Antenna heights primarily depend on clearance criteria which consequently affects the resulting clearance.

3) Clearance criterion

The Fresnel zone is a theoretical “envelope” around the line of sight that has several important implications as shown in **Figure 20**. The most common use of Fresnel zone information on a profile plot is to check for obstructions that enter the zone. Although line of sight is important, it is not always adequate. Even if the path has a clear line of sight, if obstacles (such as terrain, vegetation, buildings, etc.) enter the Fresnel zone, there will be signal attenuation.

4) Performance objectives

The performance objectives of a link define the percentages of allocated time during which the signal must be received with sufficient quality and availability. The quality objectives refer to any month and result in the following criteria: Second Erroneous and Second Seriously Erroneous ( $BER < 10^{-3}$ ). The quality of a link is mainly affected by multipath phenomena. Availability goals refer to a longer observation period ( $BER > 10^{-3}$  for at least 10 consecutive seconds). Apart from material damage and maintenance operations, the availability of a link is mainly affected by guidance phenomena and attenuations due to hydrometeors.

5) Edit design

	Site name	Latitude	Longitude	Call sign	Stati
1	site-01	03 53 50.80 N	011 31 26.50 E		
2	site-02	03 54 23.60 N	011 31 58.80 E		
3	site-03	03 54 32.40 N	011 30 56.94 E		
4	site-04	03 55 05.59 N	011 30 49.86 E		
5	site-05	03 54 57.73 N	011 33 27.97 E		
6					
7					
8					
9					
10					
11					
12					
13					
14					

**Figure 18.** Site location.

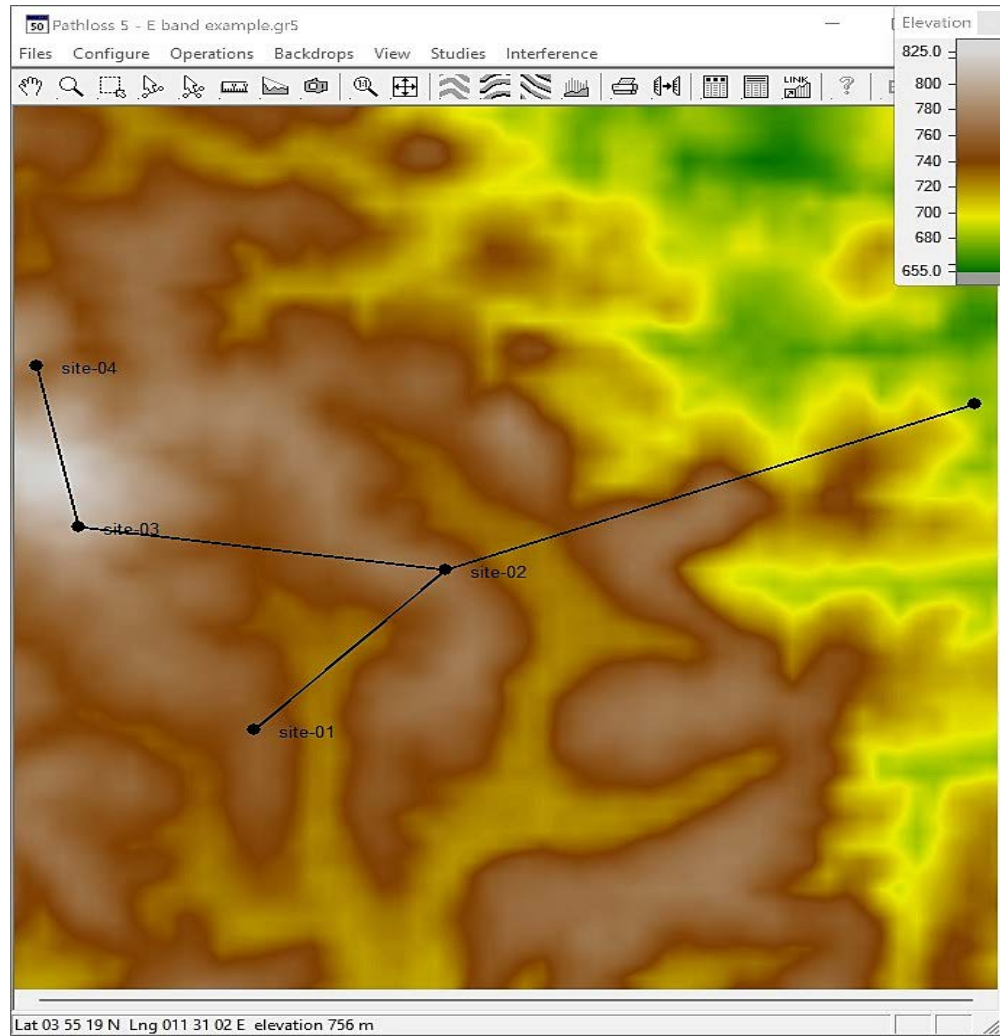


Figure 19. Location overview.

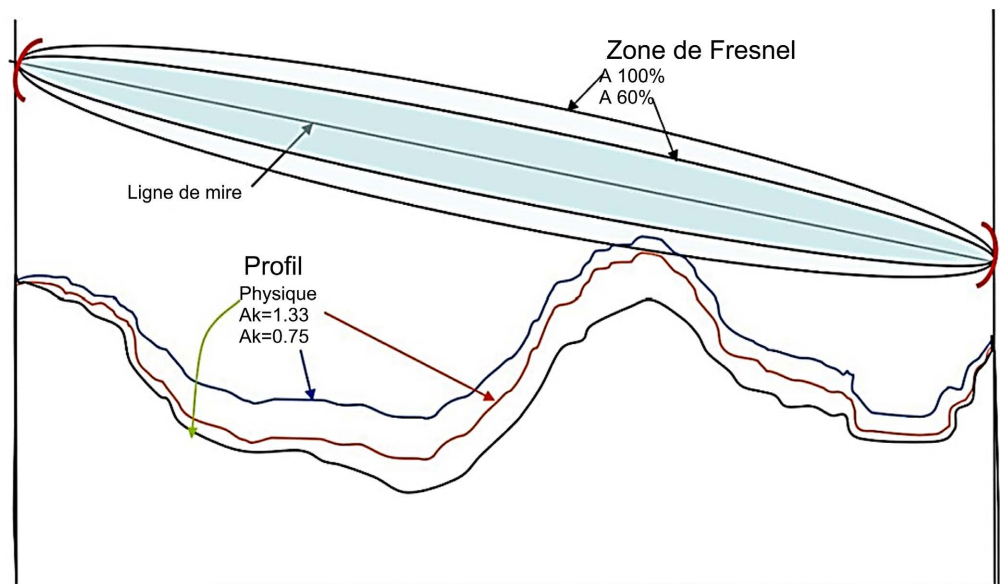


Figure 20. Fresnel zone.

This step involves changing certain link design parameters to meet performance goals. These parameters can be as shown in **Figure 21**.

- The antenna height to satisfy the clearance criterion;
- Wave guide type;
- Antenna size;
- Tx output power;
- Site coordinates (Azimuth or distance between two sites).

### 3.2.2. Frequency Planification

#### 1) Hi-lo shock

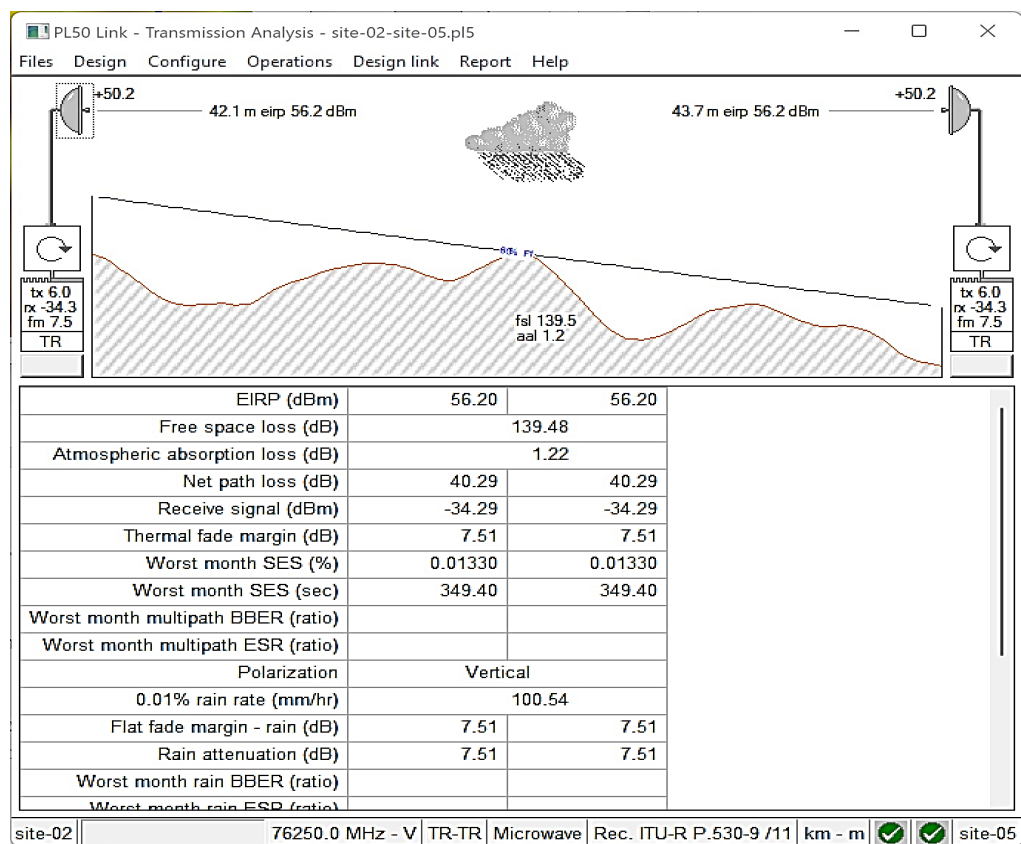
This step consists of defining the sites which will transmit in the upper band (the high sites) and the sites which will transmit in the lower band (the low sites) as shown in **Figure 22**.

#### 2) Assigned frequency pairs

This step consists of defining the frequency plan and the channels that will be used for the frequency assignment, for example in **Figure 23**.

#### 3) Interference analysis on Pathloss5

Interference is calculated between two sets of links. One set of links can act as interfering transmitters and the other set as victim receivers or both sets can act as interfering transmitters. These sets of links can be a selection, a named group of links, all links.



**Figure 21.** Transmission analysis of the site-02 site-05 link.

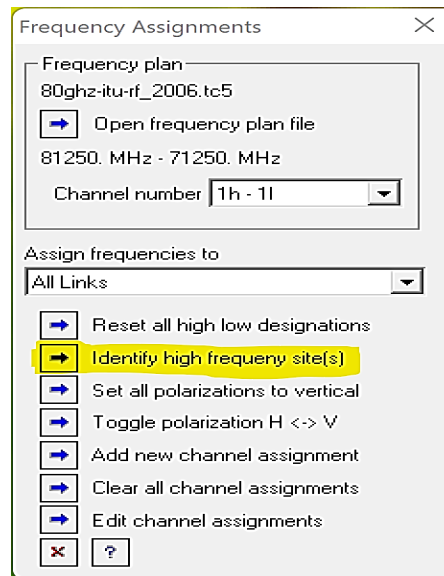


Figure 22. Frequency assignment.

TX channel assignments site-02 - site-05										
	site-02 TX					site-05 TX				
	Ch ID	TX (MHz)	ATPC	Pwr.Rd.	Pol	Ch ID	TX (MHz)	ATPC	Pwr.Rd.	Pol
1	1l	71250.			V	1h	81250.			V
2					V					V
3					V					V
4					V					V
5					V					V
6					V					V
7					V					V
8					V					V
9					V					V
10					V					V
11					V					V
12					V					V

Figure 23. Assignment of transmission channels for the site-02 site-05 link.

Intra-system interference is calculated in the network view. The calculation is organized in groups. Only visible layers will be used in the calculation. The calculations use antenna and radio data files. The minimum conditions for calculating intra-system interference are listed below:

- ◆ A Path-loss data file (pl5) must be associated with each link to be used in the calculation.
- ◆ An antenna data file must be specified for each antenna in the Path-loss data file.
- ◆ The transmission analysis must be complete at the level of a reception signal calculation.

◆ Transmit and receive frequency assignments must be specified for the Path-loss data files used in the calculation.

**a) Interference calculation procedure**

Select the Interference tab from the network view menu bar to calculate the interference. The “Intra System Interference” dialogue box defines the calculation options as shown in **Figure 24**.

- **Default Minimum Interference Level**

In the notification threshold example above, the interference level required to achieve the threshold degradation objective was calculated from the receiver noise floor. If the receiver noise floor is not available, the default minimum interference level will be used as the interference level required to achieve the threshold degradation objective. The reporting threshold level will then be given by the default minimum interference level minus the calculation margin.

- **Calculation margin**

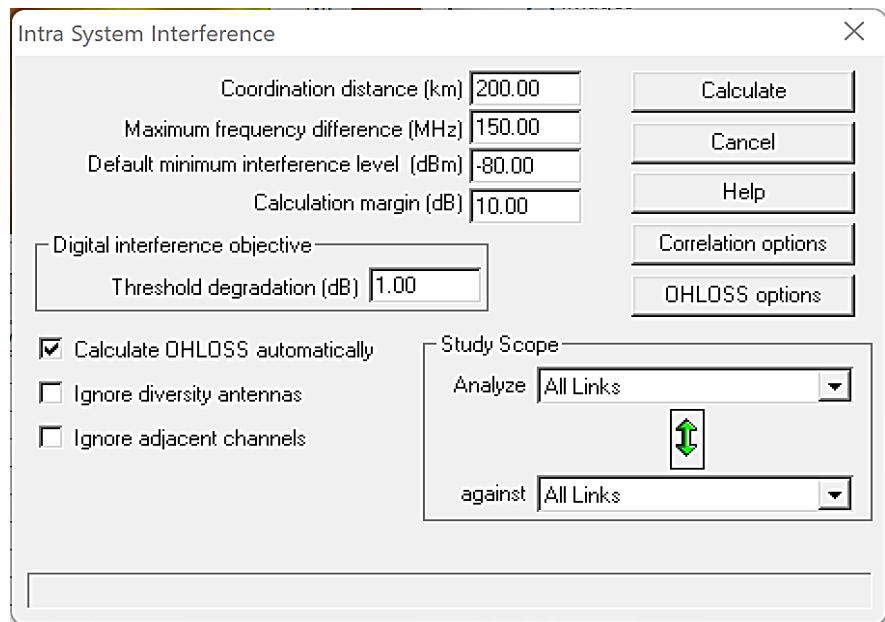
It sets a tolerance on the signalling of cases of jamming. If the interference level objective for the receiver under test is -104 dBm and the calculation margin is set to 10 dB, all interference cases above -114 dBm (-104 - 10) will be reported. The threshold degradation objective will be converted into an interference level objective for each receiver in the calculation.

- **Coordination distance**

Interference is not calculated if the interfering path length is greater than the specified coordination distance.

- **Maximum frequency separation**

Interference is not calculated if the difference between the frequencies of the interfering transmitter and the victim receiver is greater than the maximum value specified.



**Figure 24.** Intra-system interference parameter.

- **Ignoring diversity antennas**

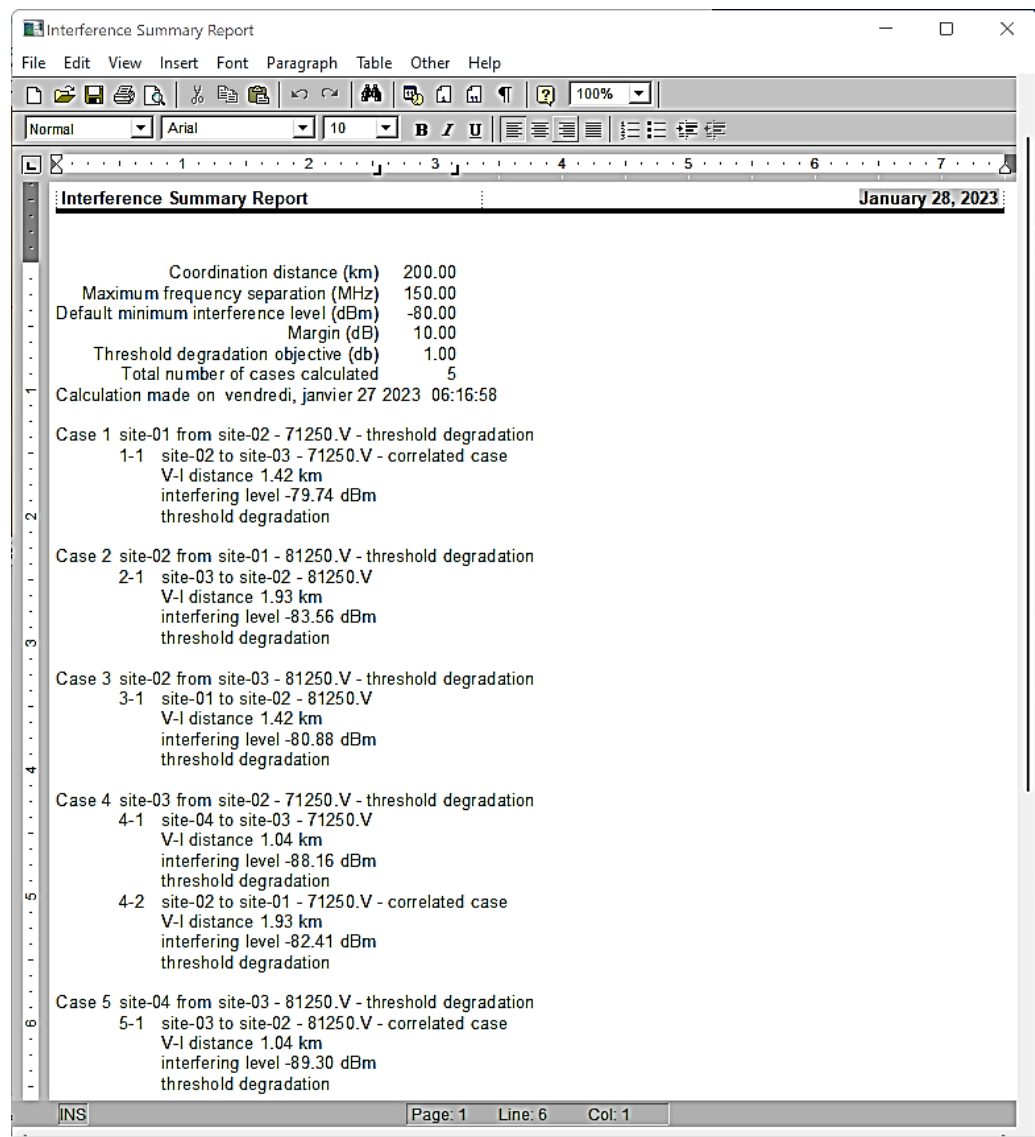
This option ignores all receive frequencies associated with a spatial diversity receive antenna only. In the initial frequency analysis, this option will reduce the number of cases by 50%. If the gains of the main and diversity antennas are different, then the final analysis must take into account the diversity antennas.

- **Ignore adjacent channels**

This option applies to 1 for N systems. Once the adjacent channel impairment threshold is established, use this option to limit the number of interference cases.

**b) Analysis of interference cases**

All cases of a selected site can be viewed and parameters affecting the interference can be changed as shown in **Figure 25**. The results are immediately recalculated and displayed. This is a fully interactive process. Once completed, changes can be made to the Pathloss5 data files.



**Figure 25.** Interference case report.

### 3.2.3. Implementation of the Tool

We have implemented a digital tool to define an optimal distribution of the frequency spectrum on the electronic communications network while minimizing interference. We named this tool PAFE to “E-Band Frequency Assignment Program”.

Our tool is designed according to the following considerations, it must:

- ❖ Be easy to use;
- ❖ Take as input values that the company can have;
- ❖ Be able to contain several input values in order to be able to generalize the results;
- ❖ Provide results that can be exported.

These needs pushed us to use Excel files to store and provide input parameters as well as to retrieve results by PAFE.

#### 1) Functional analysis

The main features of our system are:

- ❖ Entity management: the user adds, modifies and deletes data relating to the transmission network such as link parameters or rainfall data;
- ❖ User management: the user logs in, logs out and changes his password;
- ❖ Raw file management: the tool processes data that it recovers in Excel files provided by the user. It is on the basis of this data that it assigns the frequencies to each link.

#### 2) Non Functional analysis

The technical constraints to which the application is subject are as follows:

- ❖ Security needs: the platform is accessed only after authentication, and the features available depend on the type of user;
- ❖ Site names should not have spaces;
- ❖ The fields corresponding to the antenna configurations, channel identifier must be filled in.

#### 3) Use case diagram

The actors of our system are the natural persons who have an account. In our context, this person is notably an engineer or a technician. **Figure 26** represents the use case diagram of our tool.

Our tool’s use case is to assign optimal frequencies: the word “include” means that authentication is required.

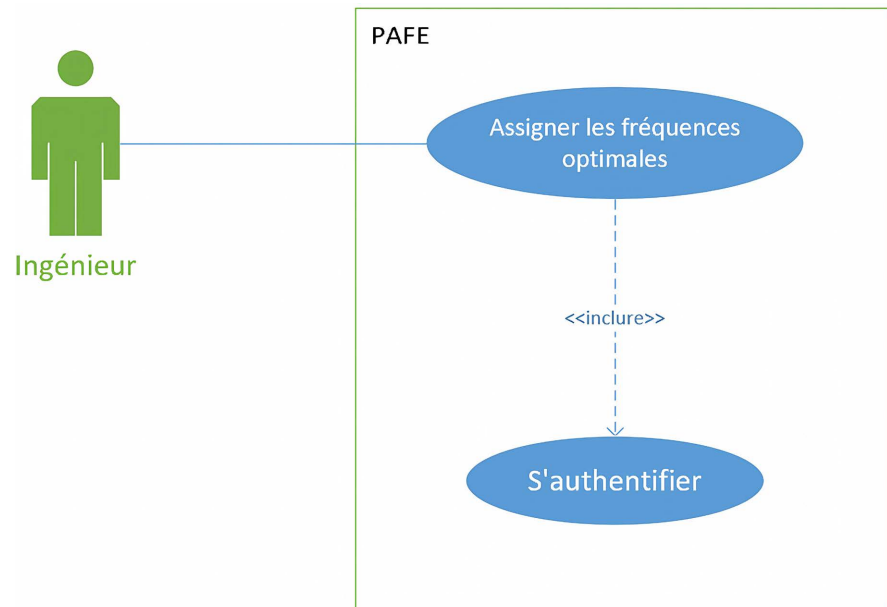
##### ❖ Step 1: (Without taking into account interference)

Here, the engineer follows the procedures in order to assign the frequencies to the different links. The Excel files containing the list of sites to be studied and the frequency plan of the E band whose contents initials, will be used by PAFE to create an Excel file `liste_site_base` containing transmission links with their frequency (which is the first channel of the frequency plan).

##### ❖ Step 2: (taking into account interference)

The Excel file containing the links and the text file of the pathloss5 interference summary report of these links will be used by PAFE to produce an Excel





**Figure 26.** Use case diagram.

file “end\_list.xlsx” containing the links with a distribution adapted to the interference problems that have occurred.

Note: After analyzing the interferences by the pathloss5 program, if there are cases of interferences, we save the interference summary report as a text file.

#### 4) Sequence diagram

**Figure 27** represents the sequence diagram of the PAFE stage 1 use case: frequency assignment without taking into account interference.

**Figure 28** represents the sequence diagram of the PAFE Stage 2 use case: a frequency assignment taking interference into account.

#### 5) Functional block of the tool

The functional block shows us the internal structure of PAFE as shown in **Figure 29**. It makes it possible to provide an abstract representation of the system objects which will interact to carry out the use cases.

Our functional block is made up of 6 sub-blocks and looks as follows:

The Input I block

It records the data contained in the files *liste\_sites.xlsx* and *plan\_de\_frequence.xlsx* (the transmission frequencies and the reception frequencies) and transmits them to the Processing 1 block. The data from the file *liste\_sites.xlsx* recorded by the Entry 2 block are: the fields *Site name S1*; *Site name S2*; *TR configuration S1*; *TR configuration S2*; *#1 Channel ID S1*; *#1 Channel ID S2*; *#2 Channel ID S1*; *#2 Channel ID S2*.

The Treatment I block

It determines the transmission frequencies of each site using the data provided by the Input1 block and sends them to the Output 1 block.

The Output I block

It uses the data sent by the Processing 1 block to complete the fields *#1 Design*

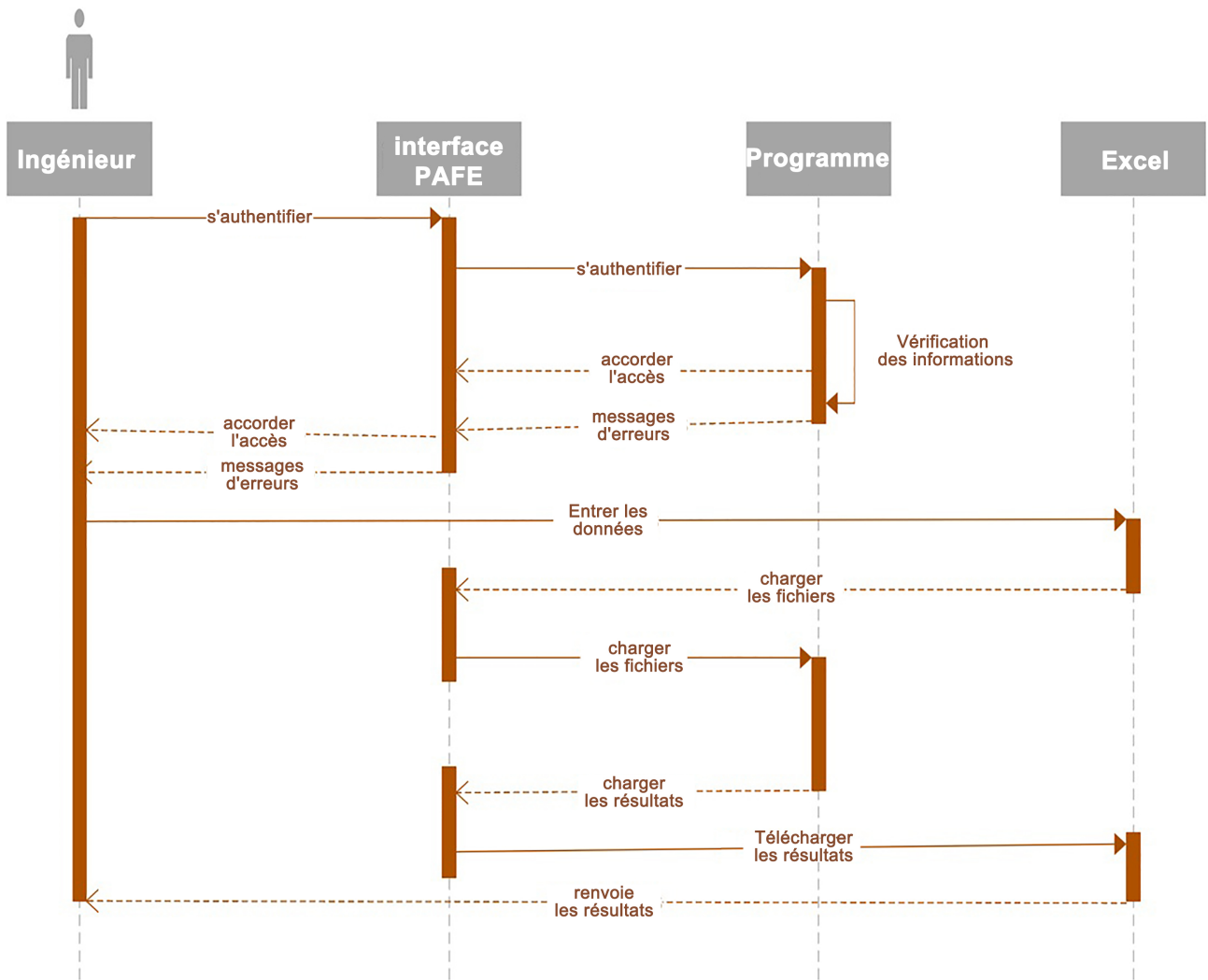


Figure 27. PAFE step 1 sequence diagram.

frequency S1, #1 Design frequency S2, #2 Design frequency S1, #2 Design frequency S2 of the file liste\_sites.xlsx.

*The Input I block*

It saves file data plan\_de\_frequence.xlsx (transmission frequencies and reception frequencies) liste\_site\_base.xlsx, Interference summary report.txt and the Minimum interference level dBm from the home page of our platform provided by the engineer.

File data liste\_site\_base.xlsx recorded by the Entry 2 block are: the fields *Site-nameS1*, *Site-nameS2*, TR configuration *S1*, TR configuration *S2*, #1 Channel ID *S1*, #1 Channel ID *S2*, #2 Channel ID *S1* et #2 Channel IDs2.

For each case of interference contained in the Intererence summary report.txt, the data used by PAFE is:

- The name of the site victim of interference, her frequency and his polarization as well as the level of interference Suffered by this site and finally the p2p connection from which this site comes.

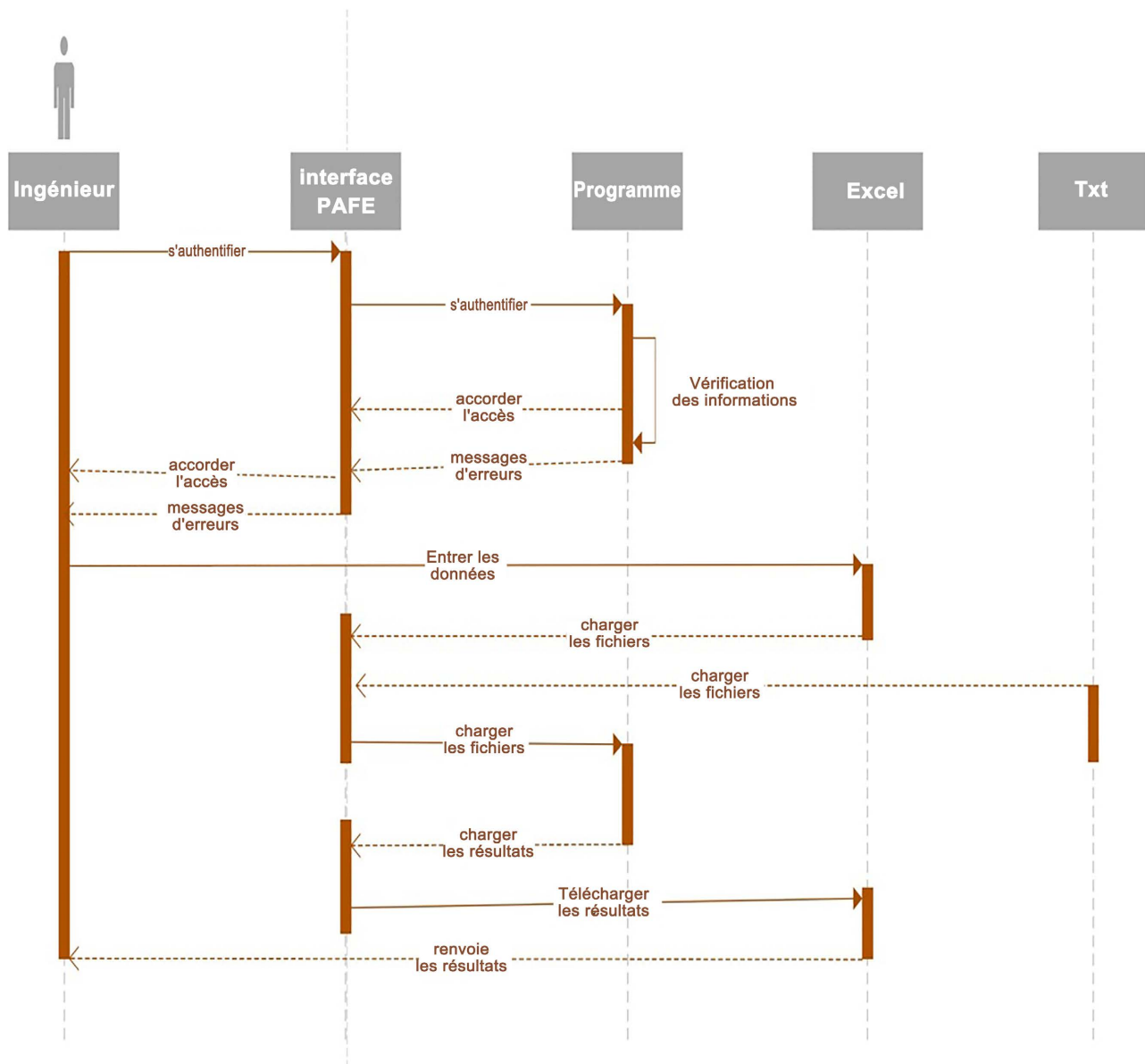


Figure 28. PAFE step 2 sequence diagram.

- The name of the interfering site, its frequency and its polarization as well as the p2p link from which this site originates.

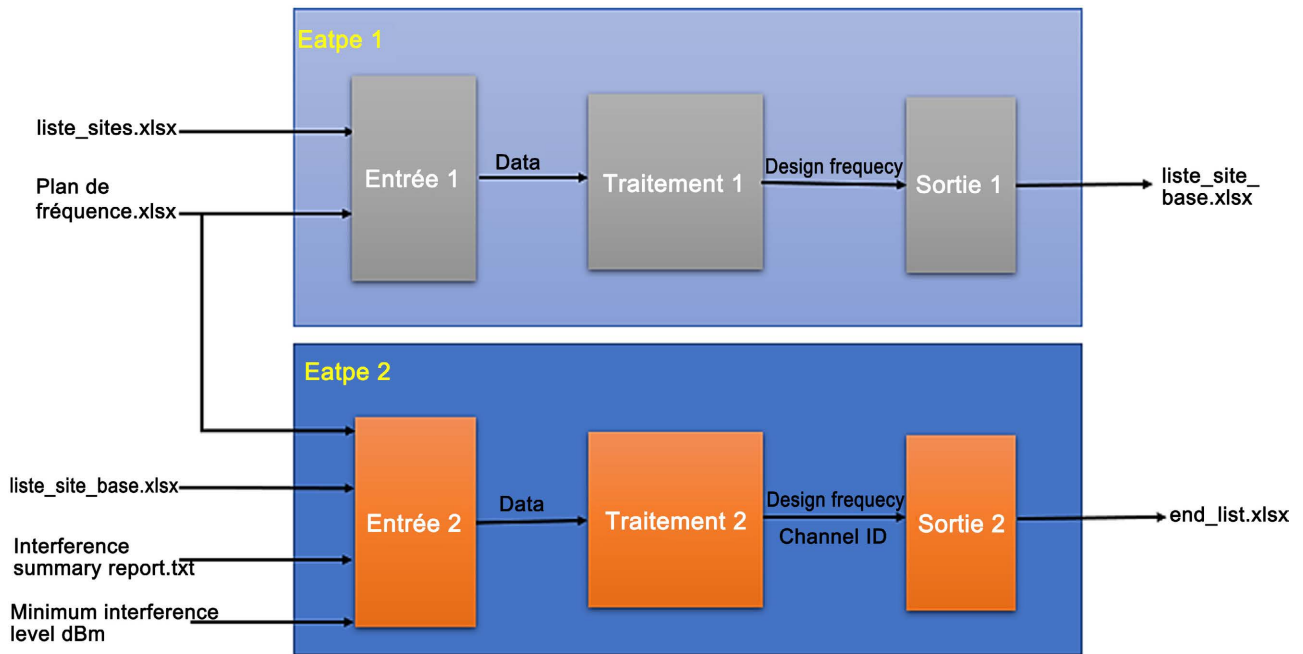
The victim link including the victim site, the victim frequency and its polarization, the interfering link including the interfering site, the interfering frequency and its polarization, the level of interference.

The Processing I block

It determines the broadcast frequencies and corresponding channel numbers for each site using the data provided by the Input2 block and sends it to the Output1 block.

The output I block

It uses the data sent by the Processing 2 block to complete the fields #1 Design frequency S1, #1 Design frequency S2 et #2 Design frequency S1, #2 Design



**Figure 29.** Functional block of PAFE.

*frequency S2* and also the field #1 *Channel ID S1*, #1 *Channel ID S2*, #2 *Channel ID S1*, #2 *Channel ID S2* of the file *liste\_site\_base.xlsx* in a file named *end\_list.xlsx*.

### 6) Tools for development

For the deployment of this tool, we used the Python programming language. We chose Python for the following reasons:

- ❖ It is free and open source;
- ❖ It is object oriented;
- ❖ It requires less coding compared to some other languages;
- ❖ It easily interacts with Excel files.

With the Python software we associated the framework Django which is a web development framework, it aims to make web 2.0 development simple and fast.

To be able to create our tool, we needed a working environment as well as tools allowing easy processing of data and facilitating the development of the interface with users. These tools include:

- ❖ Pycharm: It is an integrated development environment used to program in Python. It allows code analysis and contains a graphical debugger. It also allows the management of unit tests, the integration of version management software, and supports web development with Django.
- ❖ Openpyxl: It is a library written for the Python programming language allowing data manipulation and analysis. It allows Python to read Excel files.
- ❖ Pandas: Just like Openpyxl, it is a library written for the Python programming language allowing the manipulation and analysis of data. In particular, it offers data structures and operations for manipulating numerical arrays and time series. The pandas library allowed us to write in the excel files pre-

senting the results of the calculations carried out by our tool.

- ❖ CSS: (Cascading Style Sheets) is a computer language used to describe the presentation of HTML and XML documents. The standards defining CSS are published by the World Wide Web Consortium (W3C).
- ❖ Bootstrap is a CSS framework created by the developers of Twitter. Bootstrap also offers quality jQuery plugins to enrich the pages. Bootstrap is a CSS framework, but not only, since it also embeds HTML and JavaScript components.
- ❖ HTML: Hypertext Markup Language, commonly abbreviated as HTML, is the data format designed to represent web pages. It is a markup language for writing hypertext, hence its name. HTML also makes it possible to semantically structure and format the content of pages, to include multimedia resources including images, input forms, and computer programs. It allows you to create documents that are interoperable with a wide variety of equipment in a manner that complies with web accessibility requirements. It is often used together with programming languages (JavaScript) and presentation formats (cascading style sheets).

## 4. Results and Discussions

### 4.1. Structural Architecture of the Tool

**Figure 30** depicts the structural architecture of the tool:

Our tool consists of:

- ❖ Authentication pages including account creation and identification pages;
- ❖ From the home page which itself consists of a section “Minimum interference level dBm” and the “Upload” and “Download” buttons from steps 1 and 2.

### 4.2. Home Page

If the user’s identification is correct, he accesses the following home page as shown in **Figure 31**.

#### 4.2.1. Minimum Interference Level dBm

This value indicates the minimum level of interference considered by PAFE. Any interference below this value will be considered negligible by PAFE. This value is set by the engineer because it is given in the datasheet of the radio equipment used by the telephone operator, so the engineer can adjust the minimum level of interference depending on the equipment used. Here we used the value  $-120$  dB as the minimum interference level.

#### 4.2.2. STEP1

We will proceed to assign frequencies to the radio links between the sites arranged in **Figure 32**.

When the user clicks on the “load” button in Step 1, the platform displays the following page as shown in **Figure 33**.

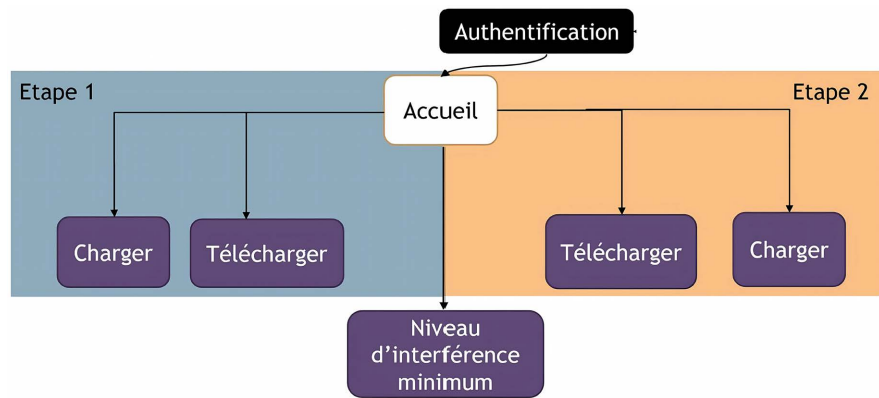


Figure 30. Structural architecture of the tool.

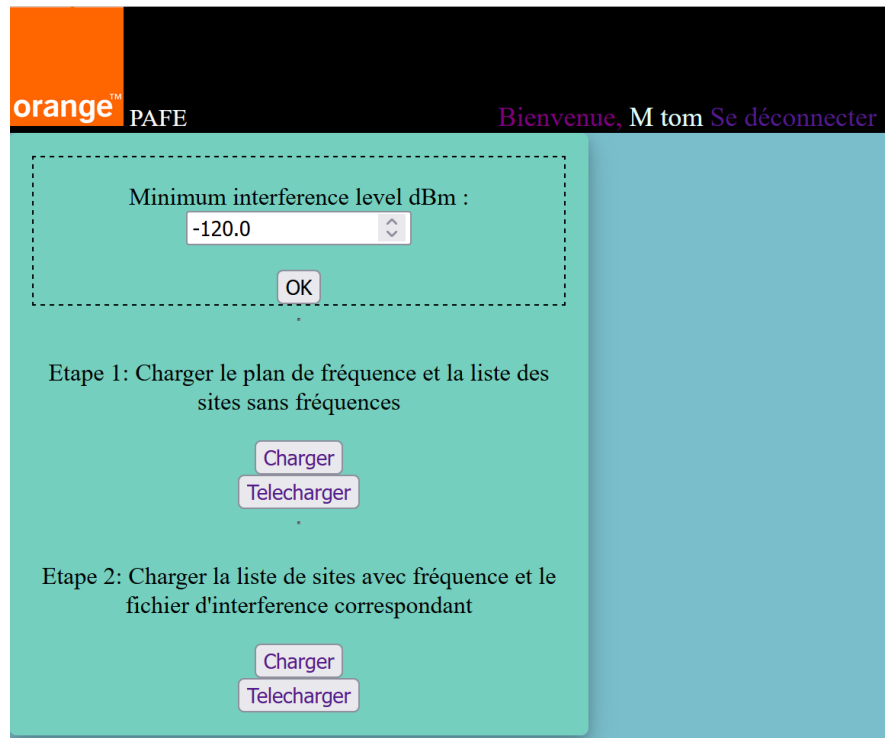
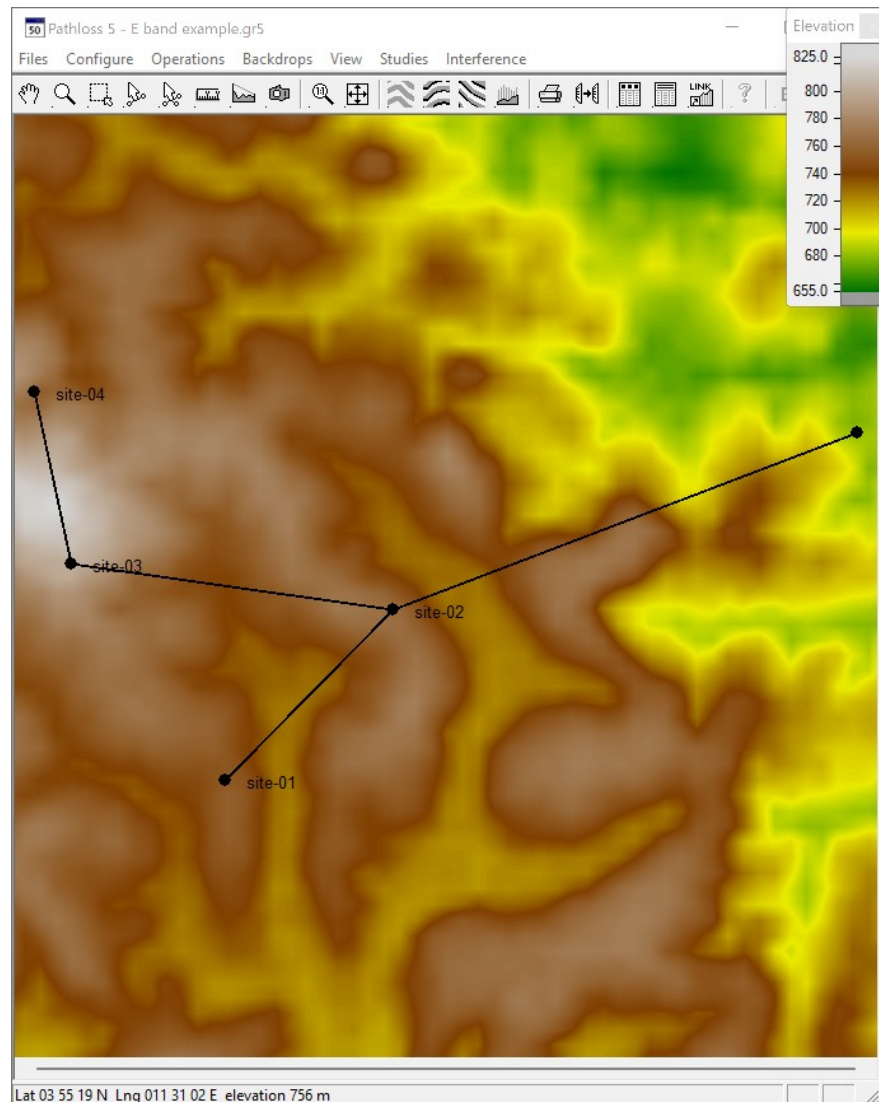


Figure 31. Home page.

On this page, the platform asks us to select the Excel files containing the frequency plan to use (The file “plan\_de\_fréquence.xlsx” and the list of sites (the file liste\_sites.xlsx are showing in **Table 2** and **Table 3**. To study then click on “Envoyer”

*Description of fields of the list of sites*

- The Site name S1 field: describes the name of the site S1;
- The Site name S2 field: describes the name of the site S2;
- The TR S1 Configuration field: describes the antenna configuration of the S1 site;
- The TR Configuration S2 field: describes the antenna configuration of the S2 site.



**Figure 32.** Overview of sites.

## Choisir les fichiers demandés

Plan de frequence : Actuellement: [plan\\_de\\_frequence/plan\\_de\\_frequence.xlsx](#)

Modification:  Aucun fichier sélectionné.

Liste des sites : Actuellement: [liste\\_de\\_sites/liste\\_sites.xlsx](#)

Modification:  Aucun fichier sélectionné.

**Figure 33.** Form to fill out to upload files.

- Field #1 Design frequency S1: describes the first transmission frequency in MHz as well as its polarization (H for horizontal polarization, V for vertical polarization) of the S1 site.

**Table 2.** Content of the file “plan de fréquence.xlsx”.

Bande E (Rec UIT-R F.2006)			
Espacement duplex = 10 GHz			
Numero de canal	Frequence d’émission	Frequence de reception	Espacement de canal
1	81,250	71,250	500
2	81,750	71,750	500

**Table 3.** List of connections “liste\_sites.xlsx”.

Site name S1	Site name S2	TR Configuration S1	TR Configuration S2	#1 Design frequency S1	#1 Design frequency S2	#2 Design frequency S1	#2 Design frequency S2	#1 Channel ID S1	#1 Channel ID S2	#2 Channel ID S1
site-04	site-03	1 + 0	1 + 0					500_1h	500_1h	
site-03	site-02	1 + 0	1 + 0					500_1h	500_1h	
site-02	site-01	1 + 0	1 + 0					500_1h	500_1h	
site-02	site-05	1 + 0	1 + 0					500_1h	500_1h	

- Field #1 Design frequency S2: describes the first transmission frequency in MHz as well as its polarization of the S2 site.
- Field #2 Design frequency S1: describes the second transmission frequency in MHz as well as its polarization (H for horizontal polarization, V for vertical polarization) of the S1 site.
- Field #2 Design frequency S2: describes the second transmission frequency in MHz as well as its polarization of the S2 site.
- Field #1 Channel ID S1: describes the spacing (MHz) and the number of the first channel used and the direction of transmission of the site S1 (h for high indicates that the site transmits in the upper half-band and l for low indicates that the site transmits in the lower half-band of the E band). Thus 500\_1h indicates that the channel spacing used is 500 MHz, the channel number used is 1 and the site transmits in the upper half-band so the site’s transmission frequency is 81,250 MHz.
- The #1 Channel ID S2 field: describes the spacing (MHz) and number of the first channel used and the transmission direction of the S2 site.
- Field #2 Channel ID S1: describes the spacing (MHz) and number of the second channel used and the direction of transmission of the S1 site.
- Field #2 Channel ID S2: describes the spacing (MHz) and number of the second channel used and the direction of transmission of the S2 site.

Remark: Orange Cameroon lists its sites in lists in the form of an Excel file, these lists have several fields; The fields that are used for frequency planning are the fields in the first row of the table in **Table 3**. The fields “Site name S1”, “Site name S2”, “TR Configuration S1”, “TR Configuration S2”, “#1 Channel ID S1”, “#1 Channel ID S2” must be filled in by the user to be able to use our platform and the fields “#1 Design frequency S1” and “#1 Design frequency S2” will be



filled in by PAFE with the frequencies of the first channel of the frequency plan used in an Excel file named `liste_site_base`.

This Excel file will then contain the list of links with the available frequencies of the frequency plan used in **Table 2** which have been assigned to these links without taking interference into account. The `liste_site_base.xlsx` file is obtained by clicking on the button “Telecharger” of Step 1 as shown in **Table 4**.

#### 4.2.3. STEP2

When the user clicks on the “Load” button in Step 2, the platform displays the following page as shown in **Figure 34**.

On this page, the platform asks us to select the Excel files containing the frequency plan to use (the `frequency_plan_plan.xlsx` file) and the list of sites (the `site_list_file.xlsx` file) to study then to click on “Send” as shown in **Table 4** and the report is given in **Figure 35** and **Figure 36**.

Remark: The interference summary report lists 5 cases of interference occurring on all of the sites studied (**Figure 36**). For example, for the 1st case of interference, the interference summary report indicates that the receiver of site-02 of the site 1 - site 2 link which receives with a frequency of 71250.00 MHz, also receives the signal of the same frequency to site 2 of the site 02 – site 3 link, there is therefore nodal interference, the interference level in this case is  $-79.74$  dBm which is lower than our minimum interference level ( $-120$  dBm), therefore PAFE will consider this case of interference and will treat it, and will do the same with other cases of interference.

**Table 4.** File contents `liste_site_base.xlsx`.

Site name S1	Site name S2	TR Configuration S1	TR Configuration S2	#1 Channel ID S1	#1 Channel ID S2	#1 Design frequency S1	#1 Design frequency S2
site-04	site-03	1 + 0	1 + 0	500_1h	500_1h	71250.00 V	81250.00 V
site-03	site-02	1 + 0	1 + 0	500_1h	500_1h	81250.00 V	71250.00 V
site-02	site-01	1 + 0	1 + 0	500_1h	500_1h	71250.00 V	81250.00 V
site-02	site-05	1 + 0	1 + 0	500_1h	500_1h	71250.00 V	81250.00 V

## Choisir les fichiers demandés

Interference : Actuellement: [interference/Interference\\_Summary\\_Report.txt](#)  
 Modification:  Aucun fichier sélectionné.

Liste des sites de base : Actuellement: [base\\_0/liste\\_site\\_base.xlsx](#)  
 Modification:  Aucun fichier sélectionné.

**Figure 34.** “Upload Files” fillable form.

```

Interference_Summary_Report - Bloc-notes
Fichier  Modifier  Affichage

Interference Summary Report
January 28, 2023

E band example.gr5
Page 1 of 1

Coordination distance (km) 200.00
Maximum frequency separation (MHz) 150.00
Default minimum interference level (dBm) -80.00
Margin (dB) 10.00
Threshold degradation objective (db) 1.00
Total number of cases calculated 5
Calculation made on vendredi, janvier 27 2023 06:16:58

Case 1 site-01 from site-02 - 71250.V - threshold degradation
1-1 site-02 to site-03 - 71250.V - correlated case
V-I distance 1.42 km
interfering level -79.74 dBm
threshold degradation

Case 2 site-02 from site-01 - 81250.V - threshold degradation
2-1 site-03 to site-02 - 81250.V
V-I distance 1.93 km
interfering level -83.56 dBm
threshold degradation

Ln 1, Col 1 | 100% | Windows (CRLF) | UTF-8
    
```

Figure 35. Interference summary report-1.

```

Interference_Summary_Report - Bloc-notes
Fichier  Modifier  Affichage

threshold degradation

Case 2 site-02 from site-01 - 81250.V - threshold degradation
2-1 site-03 to site-02 - 81250.V
V-I distance 1.93 km
interfering level -83.56 dBm
threshold degradation

Case 3 site-02 from site-03 - 81250.V - threshold degradation
3-1 site-01 to site-02 - 81250.V
V-I distance 1.42 km
interfering level -80.88 dBm
threshold degradation

Case 4 site-03 from site-02 - 71250.V - threshold degradation
4-1 site-02 to site-01 - 71250.V
V-I distance 1.93 km
interfering level -82.41 dBm
threshold degradation
4-2 site-04 to site-03 - 71250.V - correlated case
V-I distance 1.04 km
interfering level -88.16 dBm
threshold degradation

Case 5 site-04 from site-03 - 81250.V - threshold degradation
5-1 site-03 to site-02 - 81250.V - correlated case
V-I distance 1.04 km
interfering level -89.30 dBm
threshold degradation

Ln 1, Col 1 | 100% | Windows (CRLF) | UTF-8
    
```

Figure 36. Interference summary report-2.

After clicking the send button in the figure; PAFE then generates an Excel file containing the list of links with the frequencies assigned to these links taking into account intra-system interference from the Pathloss5 interference report in the home page.

The Excel file in question is obtained by clicking on the button “Telecharger” of Step 2 as shown in **Table 4**.

### 4.3. Results

#### ▪ Step 1: Basic frequency assignment

By loading the files “plan de frequence.xlsx” and “liste\_sites.xlsx” whose content is presented respectively in **Table 2** and **Table 3**, we obtain the file “liste\_site\_base.xlsx” presented in **Table 4**.

#### ▪ Step 2:

By loading the files “Interference Summary Report.txt” the content of which is shown in **Figure 35** and **Figure 36**, and “liste\_site\_base.xlsx” whose content in **Table 4**, we obtain the file “end\_list.xlsx” presented in **Table 4**.

Using the information contained in the pathloss5 interference report, the PAFE detects nodal site-03\_\_site-02 PAFE interference at the link and modifies it in the “end\_list.xlsx” file. By adapting the frequencies obtained by in the site-03\_\_site-02 link of pathloss5 as shown in **Figure 37**.

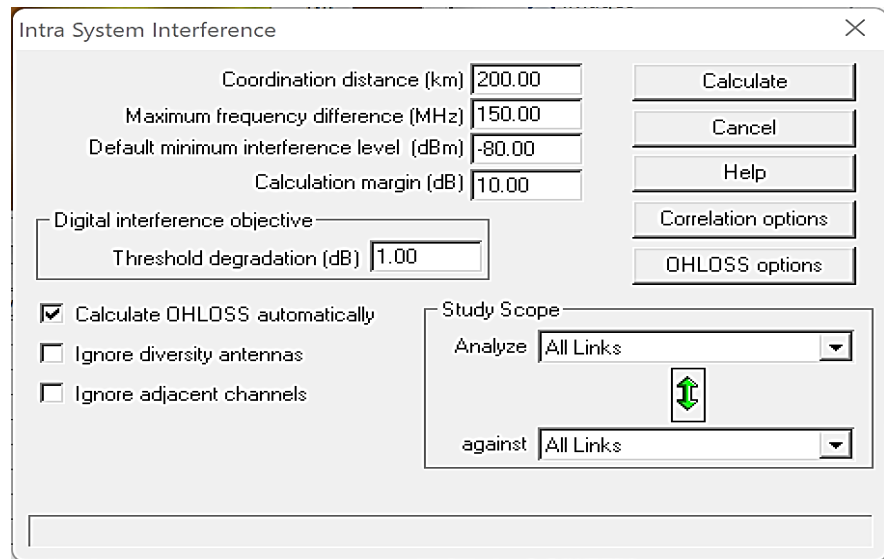
We reassign a new interference analysis taking into account the same interference parameters from the first analysis in **Figure 38**.

By calculating the intra-system interferences with the pathloss5 software, we obtain the following result as shown in **Figure 39**.

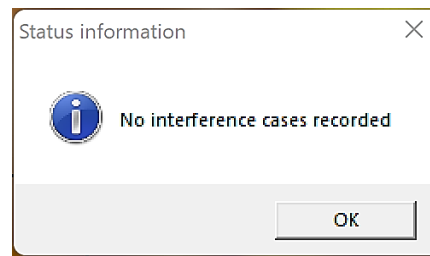
We note that the pathloss5 software no longer detected any cases of interference during this second analysis, unlike the first analysis where the software detected 5 cases of interference. We also notice that our tool with a single frequency change solved the interference problems.

site-03 TX					site-02 TX					
	Ch ID	TX (MHz)	ATPC	Pwr.Rd.	Pol	Ch ID	TX (MHz)	ATPC	Pwr.Rd.	Pol
1	2h	81750.			V	2l	71750.			V
2					V					V
3					V					V
4					V					V
5					V					V
6					V					V
7					V					V
8					V					V
9					V					V
10					V					V
11					V					V
12					V					V

**Figure 37.** Assignment of transmission channels of link site-03 site-02.



**Figure 38.** Calculation of intra-system interference.



**Figure 39.** Interference calculation results.

So therefore the problems that the transmission engineers of Orange Cameroon had when planning the frequencies (especially when the number of links of the sites to be studied exploded as in the case of the E band) namely: the risk of errors, considerable time wasters are resolved. Our tool therefore facilitates the work of the engineer by producing an optimal attribution. For example for our case, it is enough just to attribute to:

- Sites 2, transmission frequency: 71750 MHz;
- Sites 3, broadcast frequency: 81750 MHz.

The engineer here no longer needs to proceed case by case and deduce the emission frequency and polarization of each site, our tool performs this task, thus facilitating his work.

## 5. Conclusion and Outlooks

The task we had to carry out was to study and plan the 80 GHz radio links and implement them in a tool in order to define an optimal distribution of the frequency spectrum on the network guaranteeing maximum traffic flow while minimizing interference. We set the context by presenting the exponential demand for internet data capacity and the need of the telecommunications operator to satisfy this demand, then we presented the issues linked to the planning of the

frequencies of microwave links, in particular those of the band E. it was then a question for us to expand on an in-depth study of frequency planning in general followed by the analysis of interference occurring on millimeter wave links. While presenting the difficulty related to frequency assignment, we were able to conduct experiments on a literature-based tool regarding frequency planning.

At the end of this work, we therefore deployed and configured E-band transmission links in an experimental context by designing an E-band planning tool called “PAFE” usable by all telecommunications operators.

An analysis of interference between transmission links and sites in a mobile telecommunications network by our tool significantly reduces possible interference during spectrum engineering planning operations, which once again demonstrates the reliability of our contribution.

In terms of perspectives for the future in research on this subject we suggest:

- An in-depth study on the planning of transmission links between small cells in the E-band;
- An adaptation of the solution so that it takes into account not only the E band but also all the other bands and the different possible antenna configurations;
- The design of a module or program capable of calculating interference in the transmission network and resolving them automatically taking into account the available frequencies.

## Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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