CONTRIBUTION TO THE APPLICATION OF OPTICAL FIBER OPTIMIZATION METHODS TO THE 5G TELECOMMUNICATIONS NETWORK SYSTEM

RANDRIANA Heritiana Nambinina Erica[1],
RANDRIAMITANTSOA Paul Auguste[2]

[1] PhD student, TASI, ED-STIII, Antananarivo, Madagascar
[2] Thesis director, TASI, ED-STII, Antananarivo, Madagascar

ABSTRACT

5G, the first commercial launches of which have just been announced around the world as well as in Madagascar. The only way to provide the densified radio access network (RAN) capacity needed for 5G will be through fiber optics, given the amount of data that will need to be carried over the network. For the optimization of the current fiber, we will be particularly interested in minimizing the dispersion factor of the fiber for optimal performance. The use of the Bragg grating allows to introduce a high positive and negative dispersion, moreover, it is adaptable in the whole spectral width of the WDM grating. For this purpose, a method of improving the phase mask in order to register variable-pitch Bragg gratings allowing the dispersion curve to be adjusted to compensate for the different terms of the chromatic dispersion.

Keyword: 5G, *optimization, fiber, dispersion, Bragg grating, spectrum.*

---

1. INTERNATIONAL MOBILE TELECOMMUNICATIONS-2020 (IMT-2020 Standard)

1.1 Introduction

Managing the slope of the dispersions becomes crucial in order to ensure good performance of optical links. The main problem with the optical link is dispersion. The use of the Bragg grating makes it possible to introduce a high positive and negative dispersion moreover, adaptable in the whole spectral width of the WDM grating. To this end, an enrollment method has been developed to enroll variable-pitch Bragg gratings to adjust the dispersion curve to compensate for the different terms of chromatic dispersion. Regarding this optimization of optical fiber in 5G telecommunications networks, we will, first of all, perform simulation models of optical fiber in a 5G network. All this in order to highlight the current limit of optical fibers according to the parameters of the matrix modeling of the transfer of the optical fiber. The second step of the simulation consists of modeling the Bragg gratings with a linear step which makes it possible to demonstrate the effects of the linear increase in the period along the grating on the reflection and the delay time. The linear variation of the delay time as a function of the wavelength makes it possible to estimate the dispersion of the grating. It is through these models that we will observe the effects of each parameter on the optical characteristics of uniform and non-uniform Bragg gratings. The performance of the innovated phase masks was compared to the current parameter values. Note that the phase mask is one of the basic elements of the performance of the Bragg grating. A minimum power of 1.6%, combined with 40% light power in order ± 1, was effectively obtained. Our objective in this thesis has been to obtain a power in the order 0 less than 2% while maximizing the power in the orders ± 1. This then made it possible to confirm all the optimization work for an adequate improvement of the optical network for its implementation in 5G.

1.2 The 5G telecommunications networks

The 5G technology is a new generation, it gives access to speeds that are exceeding the 4G technology by 2 orders of magnitude, first of all a very short latency times and reliability; It can also increase the number of simultaneous connections per covered area. It could also allow, once deployed, a benefit of speeds in several gigabits of data per second. [1]

1.3 Global architecture of 5G telecommunications networks

The global architecture of the 5G telecommunications network consists of a Radio or Next Generation RAN (NG-RAN) access and a network core or 5G Core (5GC). [1] [2]
The **Fig -1** illustrates this architecture.

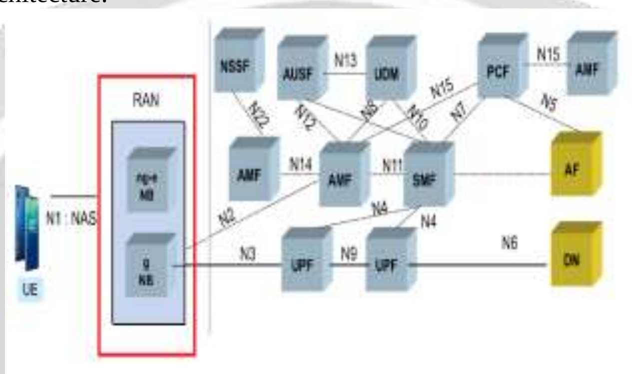

Fig -1: 5G architecture and interfaces between entities

AUSF : Authentication Server Function (AuC)

UDM : Unified Data Management (HLR/HSS)

AMF : Access and Mobility Management Function (MME)

SMF : Session Management Function (MME)

NSSF : Network Slice Selection Function

PCF : Policy Control Function

UPF: User Plane Function (S/PGW)

DN : Data Network (PDN)

AF : Application Function

UE : User Equipment

The User equipment (UE) communicates with the base stations either by a 5G radio link or by a 4G radio link. If the communication is in 5G, the base station is called next Generation Node Base Station (gNB), if the communication is in 4G, the base station is an advanced 4G eNB base station to interconnect with the 5G core network. The base station is called Next Generation -eNb (ng-eNb) or eLTE-eNB. [2] [3]
In the core network, we have the following blocks:

- Authentication Server Function (AUSF): Processes the authentication of the EU.
- Core Access and Mobility Management Function (AMF): Deals with the EU's mobility management.
- Policy Control Function (PCF): Deals with the management of any type of policy applicable to the EU (mobility management policy, QoS management, access technology selection management, etc.)
- Session Management Function (SMF): deals with session management of the EU.
- Unified Data Management (UDM): Serves as an interface to all network functions that require access to EU subscription data.

- User plane Function (UPF): processes the flows of the user plan leaving and entering the EU.
- Application Function (AF): can use the PCF interface to request the implementation of quality of service for a given IP flow.
- Network Slice Selection Function (NSSF): Used to identify the appropriate AMF function to support UE mobility management.
- Data Network (DN): concerns Data networks

1.4 Simplified architecture of IMT 2020

The architecture of the 5G technology is divided into 4 Groups:

- The user
- The base station
- The intermediate network
- The core networks

As our research is based on the base station, the use of an optical link between the RHH and the BBU is essential for an optimal high-speed link. The **Fig -2** below shows the simplified architecture of a 5G network and the optical link. [4]

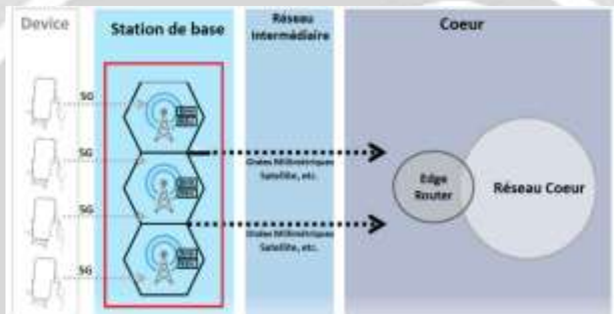

Fig -2: Simplified 5G architecture

BBU : Baseband unit (unité de bande de base)
RHU : Remote Radio Head

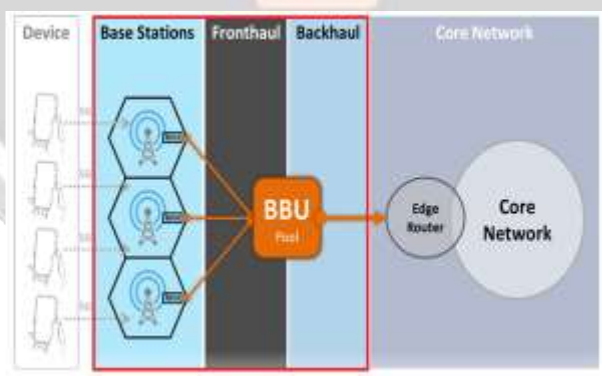

Fig -3: Network architecture Intermediate of the 5G link

BBU: Baseband unit (unité de bande de base)
RHU: Remote Radio Head
The research that we are developing relates to the blocks in red of the 5G architecture in **Fig- 1**, **Fig- 2** and **Fig -3**. Exactly between the RRH and the radio unit and the BBU. [4]

2. THE 5G TECHNOLOGY AND OPTICAL FIBER

2.1 Global architecture of an optical transmission chain in 5G

The dispersion management system is in this research innovated at the level of the Bragg grating in the Chromatic Dispersion Compensator block (CDC). These improvements are shown schematically here on the block in red. This research with the aim of improving the speed and the optical link [6] [6] [7]

Fig -4: Block diagram of an optical link in a 5G network

Tx: Transitter

AP: Amplifier

GFF: Gain Flattening Filter

CDC: Chromatic Dispersion Compensator

PMDC: Polarization Mode Dispersion Compensator

RTx : Detector

2.2 Innovation in the optical link by optimizing the Bragg grating

The Bragg gratings on optical fibers are now playing an essential role in telecommunications. We can observe in Fig- 4, a descriptive diagram of the method used for the propagation of information through several wavelengths (channels) which uses the method of WDM (Wavelength Division Multiplexing).

The determination of the transfer matrix lets us perform improvement to the model of Bragg gratings differently. This is divided into N sections containing a uniform Bragg grating. Each section can be a varying of lengths from 1 to several periods. However, in the case of modeling a network with a step-changing incrementation, we must pay attention to the maximum size of the block used.

The optical responses of each "l" size section will add to each other to finally obtain the "L" length Bragg grating response. It is consequently possible to assign a different period to each section to simulate non-uniform Bragg gratings. So, mathematically, we get:

$$[T_L] = [T_1][T_2] \dots [T_N] \tag{1}$$

Which give:

$$\begin{bmatrix} a(0) \\ b(0) \end{bmatrix} = [T_N][T_{N-1}] \dots [T_1] \begin{bmatrix} a(L) \\ b(L) \end{bmatrix} \tag{2}$$

The purpose of calculating wavelengths is to estimate the transfer matrices for each section and multiply them to finally get the Bragg grating response.

So, we acquire a transfer matrix T in the form:

$$[T] = \begin{bmatrix} T_{11} & T_{12} \\ T_{21} & T_{22} \end{bmatrix} \quad (3)$$

In this way, we obtain the reflection "r" and "θ" the phase of light thanks to the coefficient r:

$$r = \left|\frac{T_{21}}{T_{11}}\right| \quad (4)$$

$$\theta = \arg\left(\frac{T_{21}}{T_{11}}\right) \quad (5)$$

For a uniform network with uniform effective refractive index and period, we obtain:

$$r(L,\lambda) = \frac{K^2 sinh^2(SL)}{\Delta\beta^2 sinh^2(SL) + K^2 cosh^2(SL)} \quad (6)$$

Therefore, for the Bragg wavelength λ_B,

With:

$$\Delta_\beta = 0 \quad (7)$$

We then get:

$$r(L,\lambda_B) = tanh^2(KL) \quad (8)$$

In order to estimate the impact of chromatic dispersion on system performance with short simulation times, we have developed a simple model based on the formula $r(L,\lambda_B)$. Knowing that the chromatic dispersion presents a spreading of the pulse in the time domain, and, as we know, there are no losses due to this phenomenon. The most significant parameters that we have evaluated for the modeling are the width T and the amplitude H of the central lobe of the spread pulse in the fiber. The two parameters evaluated are containing the maximum optical power.

Thus, the following figures represent the characteristics of the modeling of the optical fiber in MATLAB. The **Fig -5** represents the period of the Bragg grating in the optical fiber as a function of the position. This first figure makes it possible to demonstrate the distribution of the Bragg grating uniformly in the optical grating.

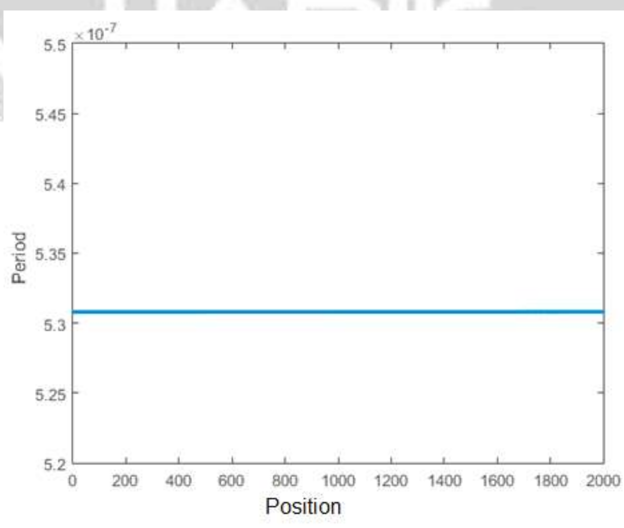

Fig -5: Network period according to its position

The uniform period of the fiber networks shown in Fig -5 consists of a periodic trouble of the property of the optical fiber, usually the refractive index of the core. And that is divided into two general classifications over the period of the grid as shown in **Fig -5**.

The Fig-6 below shows this network reflectivity as a function of wavelength.

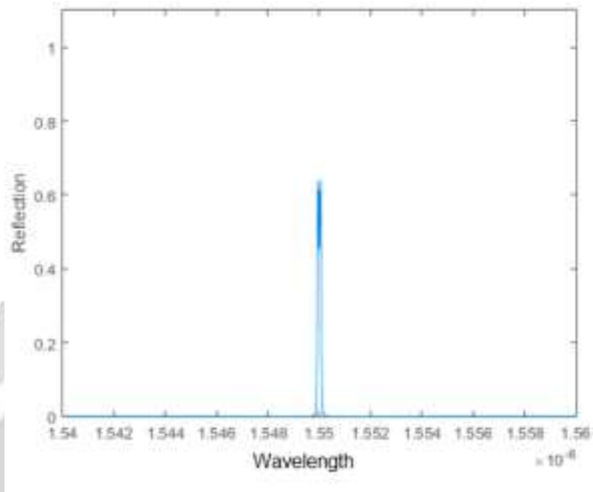

Fig -6: Network reflectivity as a function of wavelength

Indeed, the greater the difference in index between two locations, the bigger are the reflection at the interface of these two locations. Our observation depends on the fact that the index difference is important at both ends of the Bragg grating. We can also say that, by locating these positions, we can find the optical length of the Bragg grating which is here at 1550nm. From **Fig -6**, we have a maximum reflectivity at the wavelength of 1550nm using the Bragg grating technique.

The following **Fig -7** shows the phase of the system as a function of the wavelength.

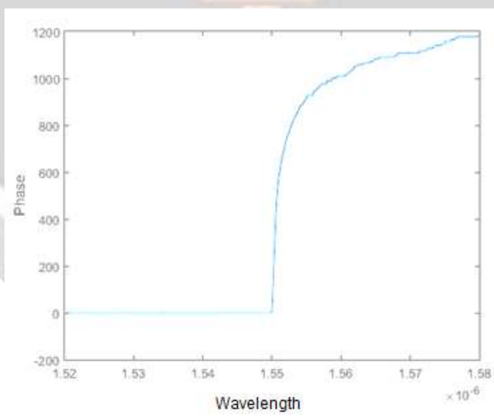

Fig -7: Network phase as a function of wavelength

The Fig -7 results from the Bragg grating phenomenon. The growth of the phase curve at 1550nm is essential for the performance of our system. This is because waves diffracted in the +1 and -1 orders and create a steady interference field that are composed of equal plane of intensity which are perpendicular to the plane of the mask. The step of the index modulation is equal to the width of the lines printed in the phase mask.

In the following **Fig -8**, the group delays as a function of wavelength are shown.

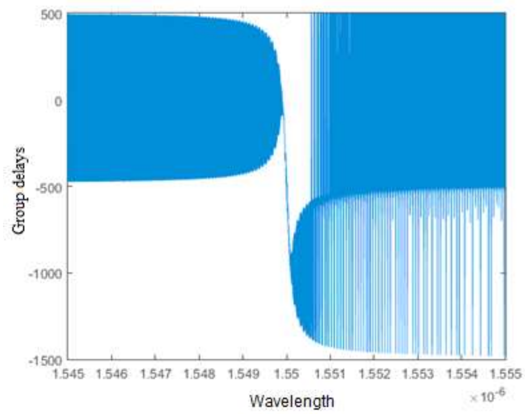

Fig -8: Group delays as a function of wavelength

From **Fig -8**, the group delays are greatest between the interval 1545nm and 1550nm and 1551nm at 1555nm. The group dispersions are minimized at the limits of the 1550nm frequency using the Bragg grating technique.

According to the ENST technique which directly gives the real and imaginary parts of the interferogram via the synchronous detection, that are represented by Figure 9 and Figure 10. In our simulation, with a Bragg grating uniform, the calculation of the Hilbert transform of the interferogram allows us to obtain the complex part.

Although it is commonly assumed to be greater than 1, the refractive index can actually take on quite different values. In our simulation, the refractive index is a complex number whose imaginary part accounts for the attenuation of the wave.

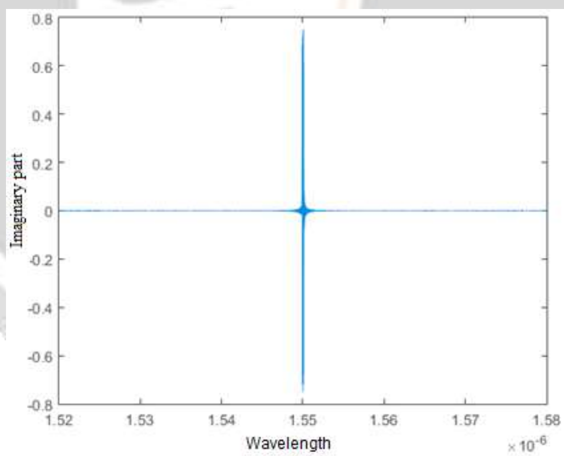

Figure 9: Imaginary part of the network as a function of the wavelength

The form $n = n_1 + n_2$of the optical index can be extended to the real and imaginary parts of the complex index. Self-focusing is a phenomenon related to the real part of the optical index. For a real part of positive n_2, the phenomenon leads to self-focusing, but for an optical link having a negative real part n_2, this leads to self-focusing. The imaginary part of the index represented by **Fig -9**, on the other hand, is associated with the phenomenon of absorption.

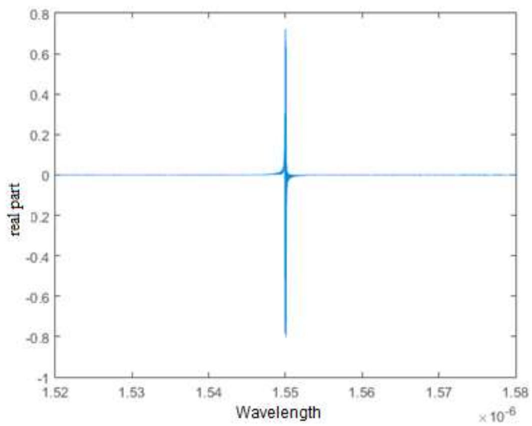

Fig -10: Real part of the network according to the wavelength

The physical quantity that calculates the speed of electromagnetic waves in the optical fiber from the speed of electromagnetic waves in space is the refractive index n of the material. It is defined as the quotient of the speed of electromagnetic waves in a space, noted c, by the speed of these same waves in the material. from **Fig -11** below, the refractive index varies slightly depending on the doping and the Bragg grating.

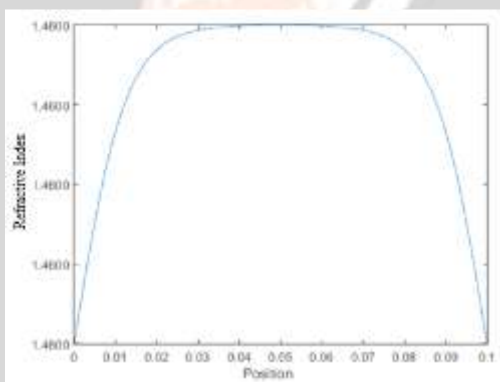

Fig -11: The refractive index as a function of the position of the grating

The **Fig -11** shows the variation of this index according to the position or the distance of the network. This figure shows the efficiency of the Bragg grating in our network because the refractive index reaches the value 1.46 in almost all of the optical network.

Note that the ideal value of the index is $n = 1{,}467$.

Demonstration:

♣

The angles are always marked with respect to the normal at the interface (the normal at the interface is shown in dashed line on the diagram above). The reflection takes place with a reflected angle θ_3 equal to the angle of incidence θ_1.

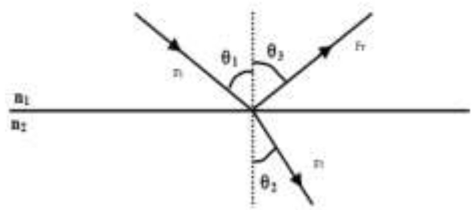

Fig -12: Illustration of refractive index in an optical fiber

The angles are always marked with respect to the normal at the interface (the normal at the interface is shown in dashed line on the diagram above). The reflection takes place with a reflected angle θ_3 equal to the angle of incidence θ_1. [8]

Illustration: the refractive index n_1 = 1.467 and n_2= 1.461 give, for θ_1 = 45 °, θ_2= 45.24 ° and θ_3 = 45 °.

Consequently, the law of reflection and refraction is verified:

Law of reflection:

$$\theta_3 = \theta_1$$

Law of refraction:

$$n_1 sin\theta_1 = n_2 sin\theta_2$$

♦

The evolution of the dispersion and the bandwidth as a function of the pitch of the 5 cm long Bragg grating were exposed with a pitch of varying from 6 nm / cm to 0.0125 nm / cm. The dispersion and bandwidth of these networks could be evaluated and compared with the results of the simulation. The results of the bandwidth and the dispersion are reported in **Fig -13**.

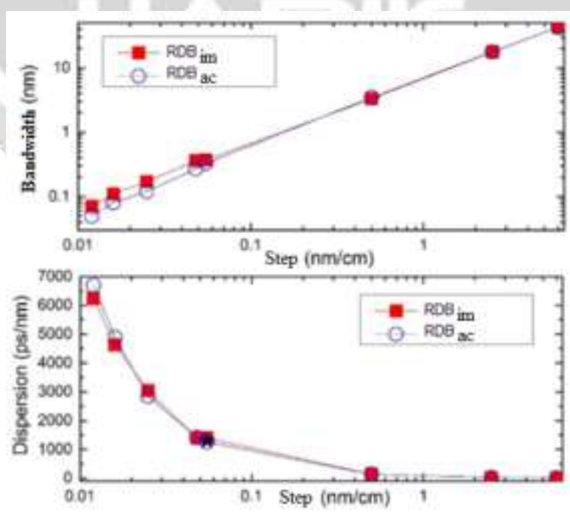

Fig -13: Actual and improved RDB comparison bandwidth and also the dispersion over 5cm long fiber with different network steps

As predicted by the simulation, a decrease of the dispersion as well as an increase of the bandwidth is observed when the network pitch is reduced. A maximum dispersion of 6200 ± 120 ps / nm is obtained with a passband of 0.07 nm for a step of 0.0125 nm / cm, while a dispersion of 11.5 ps / nm and a bandwidth of 50 nm are obtained for a step grating of 6 nm / cm. We can also note that a dispersion of 1402 ps / nm is obtained for a grating step of 0.055 nm / cm, which joins the measured value of 1311 nm / cm for a similar grating with an improved Bragg grating. We also note a difference between the actual Bragg grating and the innovative techniques proposed to decrease the dispersion.

In the next step of our simulation, we will study the delay time of the Bragg grating as a function of the length of the optical fiber and the pitch of the Bragg grating. The pitch of a Bragg grating can then be defined by the following equation:

$$p = \frac{\Lambda_2 - \Lambda_1}{L} \tag{9}$$

With

- Λ_1 and Λ_2: the periods at the ends of the network
- L: the length.

Thus, it is possible to model a network with diversified step values without increasing the simulation time.

In order to extend the bandwidth, the exposure of longer gratings is necessary, as described by the previous equation on the Bragg grating. For the simulation, we will use 10cm and 15cm gratings with our smallest possible grating step. That is with the aim of obtaining wider bandwidths. We can see in the following **Fig -14** the evolution of the reflection, the transmission and the delay time as a function of the RDB wavelength of length 5, 10 and 15 cm with a step of 0.0125 nm / cm.

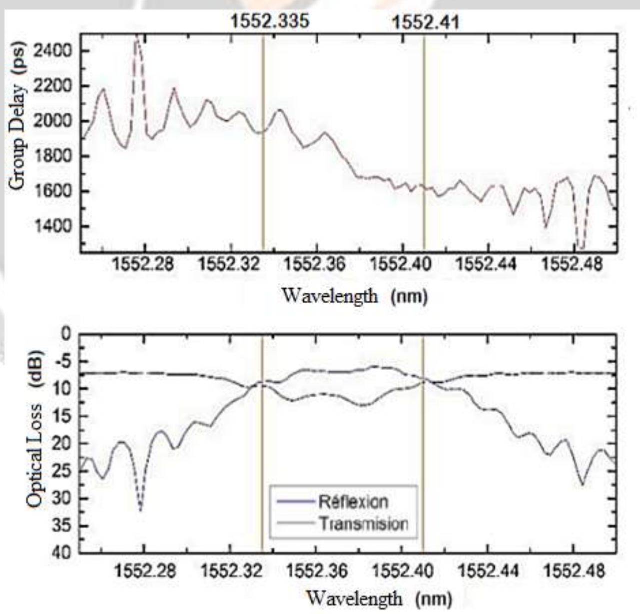

Fig -14: Delay and reflection time of an RDB on a 5cm- long fiber and with a step of 0.0125 nm / cm

The following Figure 15 shows the evolution of reflection in our optical transmission. The parameters of the simulation are the optical losses, the delay time as a function of the wavelength of the Bragg grating of length 10 cm with a step of 0.0125 nm / cm.

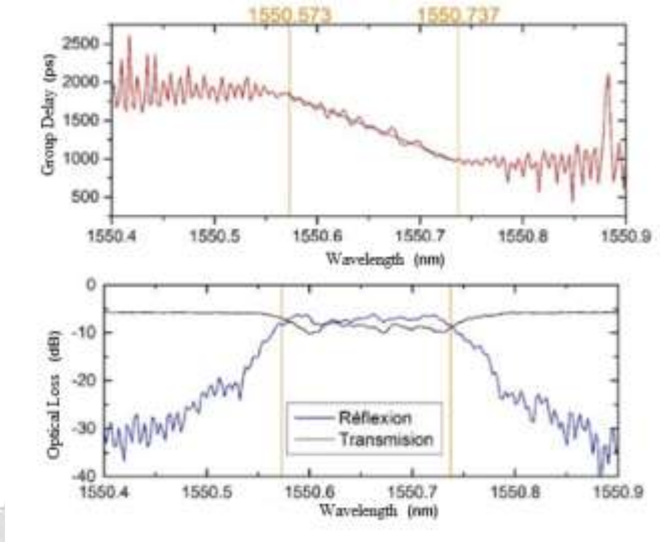

Fig -15: Delay and reflection time of an RDB on a 10cm- long fiber and with a step of 0.0125 nm / cm

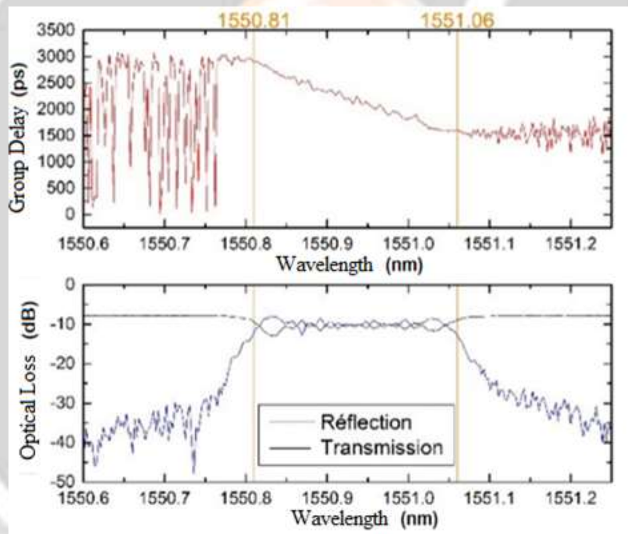

Fig -16: Delay and reflection time of an RDB on a 15 cm long- fiber and with a step of 0.0125 nm / cm

Each network was written on optical fiber with the same phase mask, namely 2 mJ / mm. The dispersion and bandwidth values corresponding to each of its networks are shown in **Fig -16** below, together with the current values and the innovation obtained by the simulation.

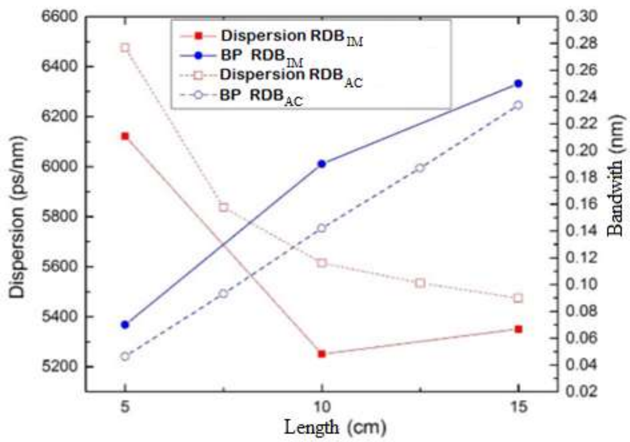

Fig -17: Evolution of dispersion and current bandwidth for improved RDBs with a step of 0.0125 nm / cm and lengths varying from 5 to 15 cm

From **Fig -17**, we notice an improvement in the network bandwidth due to the proposed technique, we also see a slight decrease in the dispersion in the optical fiber. The performance of our technique is therefore perceived only in the case of a limited optical fiber length.

We do consider a marked decrease in delay time oscillations when we are applying apodization during exposure. However, we observe relatively few differences for the two values of the coefficient a chosen: a = 10 being the value commonly used during COPL apodization and a = 4 being the one reported as optimal.

The corresponding dispersion and bandwidth values for these networks have been measured and listed in the following table. The standard errors of each linear regression used to estimate the dispersion are also presented in the following table.

Table -1: Example of dispersion values as a function of the bandwidths of 10cm long Bragg gratings and with a step of 0125nm / cm

Apodization Value (a)	Dispersion (ps/nm)	Bandwith (nm)
No apodisation	5221∓124	0.19
4	4805∓69	0.15
10	4781∓74	0.15

3. CONCLUSION

The performance of the innovated phase masks was compared to the current parameter values. Note that the phase mask is one of the basic elements of Bragg grating performance. A minimum power of 1.6%, combined with 40% light power in orders ± 1, has been effectively obtained. Also, an increase of the bandwidth and a decrease of the value of the dispersion in the network are observed. This then made it possible to confirm all the optimization work for an adequate improvement of the optical network for its implementation in 5G.

Indeed, too high energy infers an almost total reflection of the light, but also a saturation of the delay time. It was then necessary to adapt the energy used during the exposure to the pitch of the network to be exposed. Thus, a small step (<1 nm / cm) requires reducing the energy in order to avoid the phenomenon of saturation. A dispersion greater than 5000 ps / nm with a bandwidth of 0.22 nm was thus obtained by producing a Bragg grating of 15 cm length and with a step of 0.0125 nm / cm. To our knowledge, this is the largest dispersion obtained for an optical system, the length parameter of 15cm and with a step of 0.0125 nm / cm should therefore be avoided.

4. REFERENCES

[1] - B. Le Nguyen, *« Optical Fiber Communication Systems with MATLAB and Simulink Models »*, International Standard Book, Huawei Technologies, Second edition, p355-401,2017.

[2] - B. Le Nguyen, *« Ultra-fast fiber laser »*, International Standard Book, Huawei Technologies, Second Edition, p300-420, 2017.

[3] - B. J. Eggleton, T. Stephens, P. A. Krug, G. Z. Dhosi, Brodzeli, F. Ouellette, *« Dispersion compensation using a fibre grating in transmission »*, Electronics Letters, vol. 32, n°17, p1610-1611, 2016.

[4] - E. Desurvire, *« Erbium-doped fiber amplifiers, principles and applications »*, édition Wiley Interscience, 2015.

[5] - F. Gérome, *« Etude des télécommunications hautes fréquences »*, rapport de DEA de l'Université de Limoges, juillet 2017.

[6] - F. X Olivier, C. Zugno, S. Thompson, *« L'évolution des réseaux d'infrastructure DWDM à haut débit »*, Revue des Télécommunications d'Alcatel, p181-193, 3ème trimestre 2015.

[7] - G. Huss, *« Interféromètres stellaires réalisés à partir de composants d'optique guidée et intégrée »*, thèse de doctorat de l'Université de Limoges, 2011.

[8] - J. L. Auguste, *« Conception, réalisation et caractérisation d'une fibre à forte dispersion négative »*, Thèse de doctorat de l'Université de Limoges, 2011.