International Journal of Scientific & Engineering Research, Volume 11, Issue 5, MAI-2020
ISSN 2229-5518

Impact of error correction codes in the optical communication: case of fountain code

El Hadji Malick Ndiaye *, Mamadou D. DIOUF †, Idy Diop *, Max Fréjus O. SANYA x
* High School Polytechnic of Dakar (ESP), Dakar, Senegal
† Labolatory of Information Processing and Intelligence Systems(LTISI), Polytechnic School of Thies (EPT), Thies, Senegall
x GIT/EPAC, Bénin, University of Abomey-Calavi (UAC)
ndiayemalick915@gmail.com , mddiouf@ept.sn, idy.diop@esp.sn, owomax@hotmail.com

Abstract— In this proposal, we examine the impact of the error correction codes in optical communication, and more specifically in the optical wired communication, using the optical fiber. This influence of error correction codes in the optical communication has already been studied but with classic error correction codes, with fixed rate, as Reed-Solomon, Bose-Chaudhuri-Hocquenghem codes (BCH), or Low Density Parity Check (LDPC) codes . We propose here the use of another class of error correcting codes, called "rateless", namely fountain codes. Firstly, we show that the use of fountain codes in an optical transmission channel provides better performance compared to a case without coding, and this regardless of the level of noise in the channel. And secondly, we could also show that the use of fountain codes in this area, compared to a classic error correction code with fixed rate, as the LDPC code, provides better performance, in the case where the optical channel is very noisy.

Index Terms— Error correction code, fountain code, optical communication, optical fiber.

1 Introduction

WE are now in a period where the impressive development of the media has finished giving birth to new services such as broadband internet, mobile telephony or high-definition digital TV, services that are increasingly bandwidth-intensive. This causes changes constantly growing needs in terms of information transmission rates. And today, the fastest way to transmit information is of course light. Thus, to meet the ever increasing demands of flow rates higher and higher, optical communications established themselves as a very effective and efficient solution.

Optical communication has therefore become one of the main areas in which researches, with a view to improving the quantity and quality of information transmitted, are concentrated. So, to the coaxial cable (which naturally fail to follow the frantic pace of this increase in services and meet these needs), it was found an alternative much more efficient and beneficial to the telecommunications: optical fiber. The latter has become one of the most efficient transmission media for conveying information. With the combination of techniques such as WDM (Wavelength Division Multiplexing) and optical amplification, fiber optics can now transport an impressive amount of information on huge distances.

However, as in all transmission systems, one using fiber also known constraints. These constraints are related to optoelectronic components with which the fiber forming the transmission channel, but also the fiber itself, who also knows imperfections. These lead mainly to attenuation and dispersion phenomena that have consequences as a decrease in optical signal power and its spread in the time. Thus, the information passing through the fiber always arrives to the recipient with some degradation due to "transmission errors". Thereby, with this ever-increasing demands, especially in transmission rates, the use of fiber for transporting information should necessarily be done in parallel with the development of means and techniques which can lead to improved optical transmission performance, order and keep pace with this growth.

For thus overcome these "transmission errors" that we have just spoken, various solutions have been proposed in time. First we tried to associate with the fiber components generating little noise, but this solution proved to be very expensive and other routes were searched. Thus the use of error correction coding schemes has been proposed. Error correction codes allow generally more reliable transmission of information by protecting them against errors with the addition of redundancy in addition to useful data to be transmitted. They are classified into different families or classes of codes, depending on the manner in which the redundancy is calculated and inserted into the useful data. We distinguish two broad categories: block codes and convolution codes, whose main characteristics, including their coding and decoding, can be found in [1]. Many error correcting codes are thus succeeded in optical communication for the reliability of information.

The first corrector codes developed in the field of optical communications were based on block codes, easier to implement in optical systems. Indeed, the constraints in terms of time by the convolution codes are too important for their implementation in optics. Among the block codes, Bose-Chaudhuri-Hocquenghem codes (BCH) and Reed-Solomon codes (RS) were specifically contemplated for optics. Although the theory has been established in the 1960s, the first solutions deployed on transoceanic communication date from the 1990s [2], [3]. The RS (255,239) was the subject of international recommendations in a wide range of long distances standardized systems (ITU-G975 and G709) [4], [5]. This code RS (255,239), characterized by a low redundancy (6.7%) leads to a coding gain of about 5.8 dB for an error probability of 10^{-13} [1]. Another reason to choose this code is the low complexity of the decoding algorithm.

However, for optical communication rates above 10 Gbit/s, the signals are more sensitive to non linearities and more powerful error correcting coding schemes are needed to increase the

International Journal of Scientific & Engineering Research, Volume 8, Issue 1, January-2017
ISSN 2229-5518

coding gain. For higher coding gains, a conventional solution is to add more redundancy, which reduces the throughput. This can be done by concatenating several correcting codes, increasing complexity [3], [6]. This solution, based on the use of the concatenation is part of the second generation of error correcting systems for optical communications and is the subject of a new standardization [7]. Two codes are generally used in cascade and separated by an interleaver whose role is to disperse the errors that may be not corrected by the first decoder. By using two RS codes (255,239) concatenated, coding gain increases as well up to 10^{-12} about 7.4 dB. The best performance in concatenation correspond to a coding gain of about 9.4 dB. To further improve performance, we had to be interested to more powerful solutions called third generation.

The advent of turbo codes has revolutionized the field of channel coding for mobile radio communications. The use of turbo codes in blocks has been proposed and applied to optical communications [8]. However, the turbo decoding is hardly compatible with the optical technology and has an important degree of complexity for this type of transmission.

Although long set aside, LDPC codes (Low Density Parity Check) using graph theory have been the subject of recent studies for new communication patterns. These have proved very effective performance, especially on additive Gaussian noise channel. The advantage of these codes is to have, by their very sparse structure, a significantly simplified decoding complexity. The use of LDPCs in the case of optical communications has been developed and has been the subject of many work in particular by Djordjevic and Vasic [9]. One of the newest uses of LDPC codes in the optical domain was made by Ibrahima Gueye et al. [10] in a job where they use a cooperative system in the wireless optical communication channel, with the use of these codes at the relay. And we note the good performance than these codes are shown in this last work in terms of protection of information. However, although they appear to be very relevant for optical communications, the implementation complexity in practice remains a significant problem for LDPC codes and appears to be the major drawback in using these codes.

Thus, we can realize that from RS code to LDPC code, passing by turbo codes, error correcting codes used in optical communications have nevertheless always had, despite some interesting performance, significant constraints due to implementation complexity, or decoding, or also to compatibility problems with optical technology. We thus propose here the use of fountain codes. Overall, the interest of the fountain code resides in the fact that it is a code without predefined rate and redundant symbols can then be generated on the fly until all information is received by recipient (s). These codes also allow among others to adapt to changes in the channel condition. We count in this article use these interesting features of fountain codes to try to optimize the performance of error correction coding in the optical communication and accordingly allow to improve the reliability and the efficiency of optical transmissions.

To do this, in the next section, we present the fountain codes and particularly the family used, which is the LT code (Luby Transform), including the characteristics of the coding and decoding. We study in the following section (section 3) the optical fiber communication, with the constraints observed in such a channel and justifying the use of error-correcting coding systems. We will continue in section 4 with the presentation of the channel model used to represent our optical system, and on which we have conducted the various simulations. We also present in this section our different schemes proposed. In the section 5, we present and analyze the different results obtained before concluding the paper in section 6, that we will complete with prospects.

2 Principles of Fountain Codes

2.1 Some notions to understand

Here we define some important concepts that will be used later, to better understand the document.

1. ***Fragments f_i***: From fragmentation (which is often accompanied by a bit stuffing or *padding* for homogeneous sizes), they represent all the initial symbols constituting the message and are referred to as $F = \{f_1, f_2, \dots, f_K\} \in \mathbb{F}_2^K$.
2. ***Packets p_j:*** They represent the symbols of the transmitted code word and are referred to as $P = \{p_1, p_2, \dots, p_N\} \in \mathbb{F}_2^N$.
3. ***Degree of a packet (or a symbol)***: We will note it d and it can be defined as the number of fragments or source blocks (or symbols) involved in the generation of the packet or encoding symbol.
4. ***Degree distribution***: The distribution degree defines the probability that a packet of degree d is emitted by the encoder, that is, the probability where d fragments are selected to be combined in the transmitted packets.

2.2 Presentation of fountain codes

The fountain codes are part of the family of error-correcting codes. However, unlike classic error-correcting codes like RS (Reed-Solomon), these codes can potentially have an infinite number of encoding packets. Thus, transmission of encoded packets may continue until the complete receipt of the information, regardless of the number of lost packets. The transmission principle of fountain codes is similar to the case of a water fountain: to fill a glass with the fountain (Fig. 1) we are only interested in the amount of water necessary to fill the glass without considering the scheduling of water drops or those which fall beside the glass [11]. This idea leads to the achievement of codes having this feature. Note that each packet p_j is a linear combination in $\mathbb{F}_2$ of fragments f_i taken among the K in $F = \{f_1, f_2, \dots, f_K\}$ representing the initial message, and the decoding is performed entirely after receiving N ($N > K$) packets to the destination.

International Journal of Scientific & Engineering Research, Volume 8, Issue 1, January-2017
ISSN 2229-5518

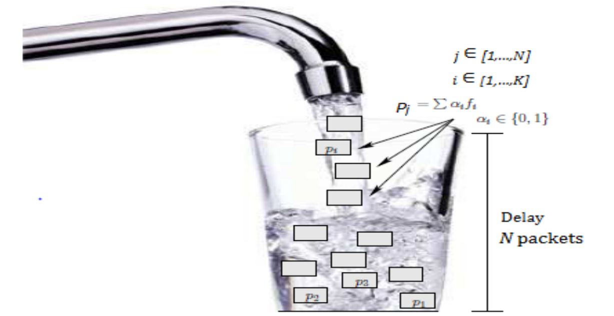

Fig. 1. Analogy of the fountain code with the filling of a glass with a water fountain.

Unlike fixed rate codes, the fountain codes (or rateless codes generally) adapt their transmission rate according to the capacity of the transmission system. Because of this random feature, it is important to provide to the decoder characteristics of the code that can restore the original message. According to the various applications, there are several mechanisms for communicating such information. Michael Luby [12] provides us some of these mechanisms. First, it tells us that the degree and a list of neighbors can, for example, be explicitly given to the decoder for each symbol or encoding packet. Another example, the degree and the list of neighbors of each symbol or encoding packet can be calculated implicitly by the decoder on the basis, for example, of the reception time of the encoding symbol (or packet) or its position relative to those of other encoding symbols or packets received. As a third and final example, a key may be associated with each encoding symbol or packet, then the encoder and the decoder apply the same function to the key to produce the degree and the set of neighbors of the encoding symbol or packet. This was developed a little more detail in [12].

There are several families or categories of fountain codes, but there are three that are said key (which derive many other variants): these are random fountain codes (or RLF, *Random Linear Fountain*), LT codes and Raptor codes. In this article we use fountain code family LT, that we present in the following paragraphs.

2.3 Principles of LT Codes

RLF code is very efficient for the protection of information in general. However, its major drawback was the relatively high complexity of decoding it presents. Researches have then been initiated to remedy this. Thus Luby proposed in [13] a family of codes which the decoding is less complex than the RLF code. And his work led to the birth of Luby Transform codes (LT) in 2002 [12], with the use of *Belief Propagation* decoding (BP). LT code retains good performances of RLF code, while having a net reduction of encoding and decoding complexity. LT code is the first class of universal fountain code (the performance is asymptotically optimal on all transmission channels). The symbol lenght for these codes can be arbitrary: from one-bit binary symbols to "*m*-ary" symbols of *m* bits.

BP decoding is based on the iterative resolution of what is called a bipartite graph (Fig. 2) and allows for a tradeoff between complexity and effectiveness of decoding: the algorithm is more simple, but it decodes less rapidly. For optimal performance with BP decoding algorithm, the packets must be encoded in a specific manner. Indeed, fragments that are combined in a packet shall be selected according to some statistical distribution. Luby proposed the "robust soliton" law or *Robust Soliton Distribution* (RSD) as an optimal solution in terms of capacity.

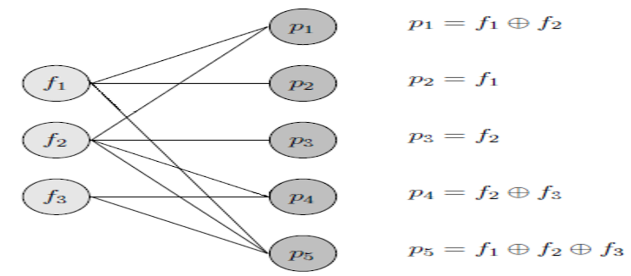

Fig. 2. Representation of the LT code on a bipartite graph.

2.4 LT code encoding

The encoding of LT codes is achieved according to the ***Algorithm 1*** which has as important parameter RSD distribution (that we present just after). This distribution is defined relative to the odds of choosing exactly d fragments to combine in a given packet. The combination of fragments is done in $\mathbb{F}_2^K$ by addition modulo 2. This algorithm stops when the decoder receives enough packets to decode or when a maximum wait time *(timeout)* is reached.

Algorithm 1 : LT code encoding

while we have not received an indication to stop **do**
  choose the degree d using the RSD distribution
  choose randomly and uniformly d fragments from K such that the set of fragments selected F equals $\{f_1, f_2, \dots, f_d\}$
  define and send $p_j = f_1 \oplus f_2 \oplus \dots \oplus f_d$
  increment N_{tx} (the total number of transmissions)
end while

2.5 Robust Soliton Distribution

The Robust Soliton Distribution (RSD) has been proposed for the BP decoding to continue effectively. It is necessary that the degree of the packet is large enough to ensure that each fragment f_i is contained in at least one packet p_j. In addition, the degree of the packets should be kept low so as to allow the progress of the decoding process in each iteration. Theoretically, the Ideal Soliton distribution (Fig. 3) proposed by Luby verifies these properties:

$$\rho(d) = \begin{cases} \frac{1}{K} & for \quad d = 1 \\ \frac{1}{d(d-1)} & for \quad 2 \le d \le K \end{cases} \tag{1}$$

However, this distribution is not very effective in practice. The decoding is occasionally interrupted due to a lack of low

International Journal of Scientific & Engineering Research, Volume 8, Issue 1, January-2017
ISSN 2229-5518

degree packets. In addition, some fragments do not appear often in packets. To counter these problems, Luby proposed improvement of this distribution with the RSD distribution. We assure that the expected number of packets of degree "one" is approximately equal to:

$$S \equiv c \ln\left(\frac{K}{\delta}\right)\sqrt{K} \tag{2}$$

with c and δ given real numbers. In this way, Robust Soliton distribution can be expressed as:

$$\mu(d) = \frac{\rho(d)+\tau(d)}{Z}, \tag{3}$$

With

$$Z = \sum_d \rho(d) + \tau(d), \tag{4}$$

and

$$\tau(d) = \begin{cases} \frac{S}{dK} & for \;\; 1 \le d \le \frac{K}{S} - 1 \,, \\ \frac{S\ln\left(\frac{S}{\delta}\right)}{K} & for \;\; d = \frac{K}{S}\,, \\ 0 & for \;\; d > \frac{K}{S}\,. \end{cases} \tag{5}$$

Examples of ideal soliton and robust soliton distributions are shown in **fig. 3** and **fig. 4** respectively [11]. We particularly note a specific value called *spike* around the $K \approx 60$ value with the RSD distribution. We point out also that these distributions are presented for code of dimension $K = 100$.

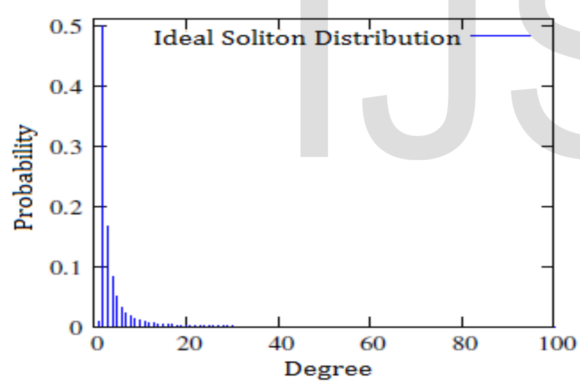

Fig. 3. Ideal Soliton Distribution.

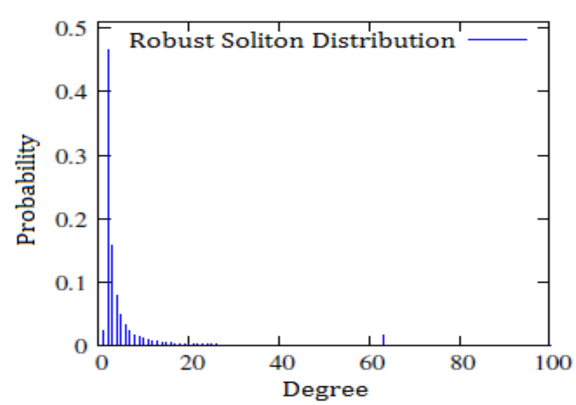

Fig. 4. Robust Soliton Distribution.

2.6 LT code decoding

As we said earlier, the LT code therefore uses the decoding by belief propagation (BP). This technique is based on the fact that the degree 1 packets can be considered decoded. Thus, using the already decoded packets, the decoder at each iteration reduces the degree of coded packets until all fragments are decoded. The amount of required packets in order to decode without errors is of the order of $K + \epsilon$ where ϵ represents the redundancy rate of the code. This BP decoding method can be described by ***Algorithm* 2** [14] :

Algorithm 2 : LT code decoding

while decoding is not finished and there are still in memory *B* at least
one packet of degree 1 do
  f_i ← packet of degree 1 of the memory
  for ∀p ∈ B do
    if p contains f_i then
    $p \leftarrow p \oplus f_i$
    end if
  end for
end while

3 Optical Fiber Communication

The classic scheme of an optical fiber transmission channel can be represented by the **fig. 5** following:

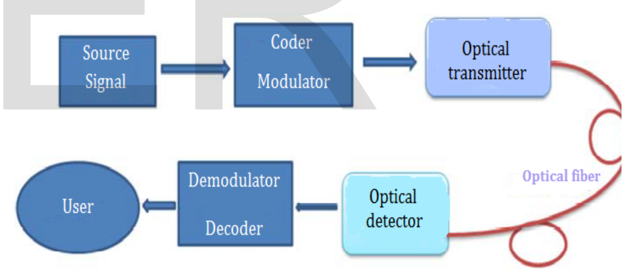

Fig. 5. Optical fiber transmission channel.

The use of the optical fiber for the transport of signals requires a double conversion (electrical/optical at the beginning and optical/electrical at the arrival) provided by optoelectronic components that are the photoemitters and the photodetectors respectively. We use most of the time for these components those based on semiconductors. Generally, for photoemitters, the Laser Diode is used (LD) or the Light Emitting Diode (LED). And for the photodetectors, we use the PIN photodiode (Positive Intrinsec Negative) or the APD (Avalanche PhotoDiode).

3.1 General principle

To transmit the information via optical fiber, the signal is generally initially coded according to a known sequence and which can thus be controlled at the reception (using a decoder). It will then be modulated to match the transmission channel represented by the fiber. This modulation can be directly (that is to say when data to be transmitted are the transmitter input current), or with the use of an external modulator which will

International Journal of Scientific & Engineering Research, Volume 8, Issue 1, January-2017
ISSN 2229-5518

modulate the output of an optical signal continuously emitted by the optical source (principle of the external modulation). The signal will be injected into the fiber by that optical source or photoemitter (combined or not so to a modulator) having thus first performed its conversion, from electrical to optical. Note that it will ensure a good coupling with fiber to insert maximum light. The fiber thus carries a modulated optical carrier containing information. Optical amplifiers are often placed at regular intervals to avoid that the signal, which gradually attenuates during propagation, is completely lost at a certain distance. And at its output of the fiber, the inverse operations take place for the signal, and in the opposite direction. It will be hosted at the receiving block, demodulated, handed in its electrical form by a photodetector, before being decoded to recover the original message. Note also the steps of optical pre-amplification by an optical amplifier, and power amplification provided by a power amplifier, before and after photodetection respectively.

3.2 Constraints and disturbances during transmission by optical fiber

For communications over optical fibers, several phenomena may contribute to the degradation of the signal representing the information. There are phenomena whose measurements simultaneously represent important characteristics for a fiber, such as attenuation and dispersion. These two linear phenomena are with non-linear effects (mainly Kerr and Raman-Brillouin effects), the main phenomena which faces the optical signal as it travels along the fiber. Attenuation is particularly signal weakening in propagation through the transmission channel and end in a loss of power of the incident signal. It mainly results from absorption, diffusion and radiation effects. The dispersion includes several sub phenomena, the chromatic dispersion, the intermodal dispersion, the polarization mode dispersion… may be mentioned. All these dispersion phenomena contribute to signal distortion, specifically to its temporal broadening; this limits the transmission rates because it forces to increase the time between two pulses. Non-linearities induce several consequences in the signal transmission such as self-phase modulation, cross phase modulation, four wave mixing, the non-linear phase noise... which are also phenomena disturbing the propagation of the signal.

In addition to these phenomena mainly related to the optical fiber and to the propagation of the message within it, other limiting factors of transmission performance may be noted. In addition to the optical fiber, the transmission channel also generates noise via optical amplifiers which are inserted periodically. These amplifiers amplify for example the spontaneous emission noise due to laser and contribute at the same time to the fluctuation of noise in the channel. There is also, at the transmission and reception, noise observed, and which is mainly due to the components used. Indeed, the used lasers also generate noise, like the spontaneous emission noise. We can also note the phenomenon of "chirp" representing a parasitic optical frequency modulation (or wavelength) accompanying the intensity modulation, effected with the direct modulation technique. It is the same for photoreceptors which generate among other quantum noise (also called photonic noise or shot noise or Schottky noise).

Various disruptions can therefore be observed for transmission over optical fiber, whether disruptions from emission, at the transmission channel or at the reception. These disturbances contribute to a degradation of the transmitted signal and a distortion of the original message. The error correction coding overcomes these problems.

4 Channel model used and schemes proposed

We have just seen in the previous section most of the disturbances that can participate in the degradation of the optical signal and distortion of information in general. Two channel models can generally be considered to model all these disturbances and to account for imperfections due to the elements of the transmission channel. The simplest model to characterize the received signal is a model considering all the disturbances before detection as an additive white gaussian noise. This model is realistic if we consider the noise of amplified spontaneousemission (or ASE) predominant. However, the optoelectronic conversion following a quadratic law creates beats ("beatings") between the different components of the noise and signal but also between those of the noise itself. So, the distribution of the decision variable follows a non-gaussian particular law. Since it is considered that the overall noise before detection is additive gaussian nature, beats caused by the quadratic detection reveal squared gaussian variables, whose average depends on the transmitted signal. By definition, the resulting variable has a χ^2 distribution type, centered or non-centered according to the transmitted data.

Thus, to characterize the entire optical channel, can be considered a simple model type AWGN (Additive White Gaussian Noise), or a statistical χ^2 model. For this article, we chose the AWGN model on which we applied our different simulation schemes. In the following, we present this model as well as our different simulation schemes developed for the comparative study.

4.1 AWGN model

Therefore, we consider in this article that the optical channel is AWGN, that is to say, the signal received at the decision is made of the transmitted signal which is added white gaussian noise. This noise models as simple as possible so all noises disturbing the signal, whether from the emission, transmission or detection. The overall noise is completely characterized by its variance obtained as the sum of the variances of the different noises all assumed Gaussian and independent (spontaneous emission noise, thermal noise, beat noise between signal and noise, beat noise between the noise and itself...).

In terms of decision making, the decision variable Y is directly equal to $Y = r = e + n$, where e corresponds to the useful signal and n is a noise variable following a gaussian distribution, with zero mean and variance σ^2. Thus, the decision variable Y follows the normal law, of variance σ^2 and mean $m_Y = e$ depending on the transmitted bit $i = 0$ or 1. **Fig. 6** illustrates the modeling of the channel.

International Journal of Scientific & Engineering Research, Volume 8, Issue 1, January-2017
ISSN 2229-5518

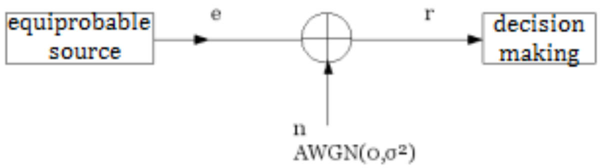

Fig. 6. Modeling of AWGN channel.

The probability density function of a variable X with gaussian statistics, zero mean and variance σ^2, is expressed as follows [15] :

$$p_X(x) = \frac{1}{\sqrt{2\pi}\sigma} e^{-\frac{x^2}{2\sigma^2}} \quad (6)$$

If the mean of the gaussian variable X of variance σ^2 is not zero ($m = \langle X \rangle \neq 0$), the distribution is normal and not centered. The probability density of X is given by:

$$p_X(x) = \frac{1}{\sqrt{2\pi}\sigma} e^{-\frac{(x-m)^2}{2\sigma^2}} \quad (7)$$

Performances on AWGN channel are usually evaluated based on the signal to noise ratio (SNR) expressed in dB. The SNR depends directly on the variance of the total noise σ^2 and on the average useful power per bit transmitted. And it's the same principle that we followed to create our different simulation schemes, which we present in the following paragraphs.

4.2 Briefing on simulation schemes developed

In this article, we develop three simulation schemes for the comparative study, a scheme "without coding", a scheme "with LT coding" and a last "with LDPC coding". The simulations were performed with the software MATLAB. We chose to make the comparison with the LDPC code because it's one of the classic correcting code the most recent to have been used in the optical domain with notably I. Gueye et al. [10].

4.3 Scheme "without coding"

The principle consists to define signal to noise ratio values (SNR) and see the bit error rate values (BER) obtained. A random binary message is initially generated and will be modulated BPSK (Binary Phase Shift Keying). For each value of SNR, 50 packets of the same modulated message (50 times the same message) are passed through the AWGN channel (with the corresponding SNR). At each iteration, the packet is demodulated at the output of the channel before calculating the BER corresponding. The overall BER corresponding to the sum of all individual BER on the number of packets is then calculated. The modeling of the scheme is shown in **fig. 7** and simulation parameters are given in **table 1**.

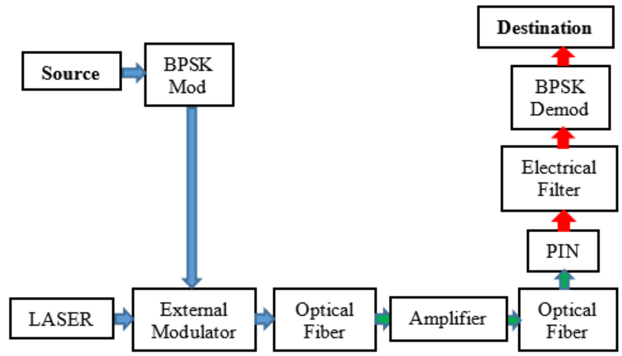

Fig. 7. Scheme proposed for the case "without coding".

TABLE 1
SIMULATION PARAMETERS FOR THE CASE "WITHOUT CODING"

Symbol or assignment	Description	Value
SNR	Signal to noise ratio	[0 :1:10] dB
packet_length	Length of a packet	1000 bits
Nbpacket	Number of packets sent	50

4.4 Scheme "with LT coding"

The same principle as with the case "without coding" is followed. However here the initial message is encoded LT first before being modulated BPSK. It then passes into the AWGN channel, and after BPSK demodulation when it leaves the channel, it is decoded using a LT decoder for AWGN channel using a belief propagation algorithm BP. The bit error rate is then calculated. The modeling of the scheme is presented in **fig. 8** . In the simulation of this architecture, we use K=1000 bits and the value of the RSD law parameter is 0.05. The number of encoded packets sent is 50.

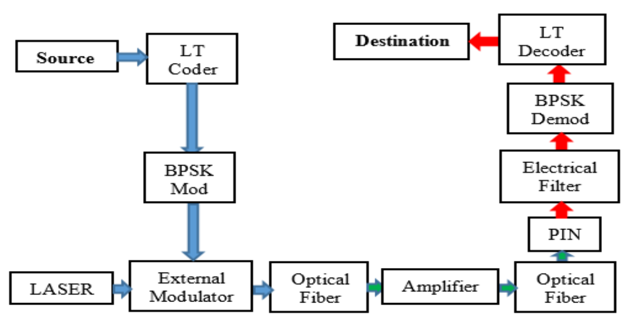

Fig. 8. Scheme proposed for the case "with LT coding".

4.5 Scheme "with LDPC coding"

The principle used is almost identical to that of the previous case ("with LT coding"). Some small differences have however to be note. Of course the LT encoding/decoding is for this case replaced by a LDPC encoding/decoding. But also the BPSK demodulation step is this time confounded with that of LDPC decoding. The generated initial message is this time made up of 50 different packets of the same size that will undergo the

International Journal of Scientific & Engineering Research, Volume 8, Issue 1, January-2017
ISSN 2229-5518

process one by one. The modeling of the scheme is shown in **fig. 9** In the simulation of this architecture, we use K=1000 bits and N=2000 bit for the Length of a packet before and after LDPC encoding respectively. The number of encoded packets sent is 50.

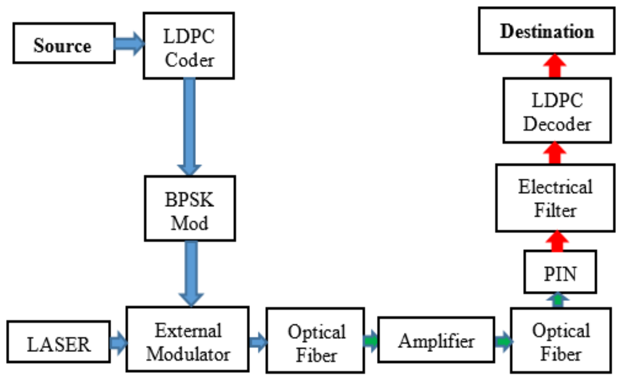

Fig. 9. Scheme proposed for the case "with LDPC coding".

5 Results and Discussions

Fig. 10 shows simultaneously the results obtained in the cases "without coding" and "with LT coding", and allows us to make the comparison.

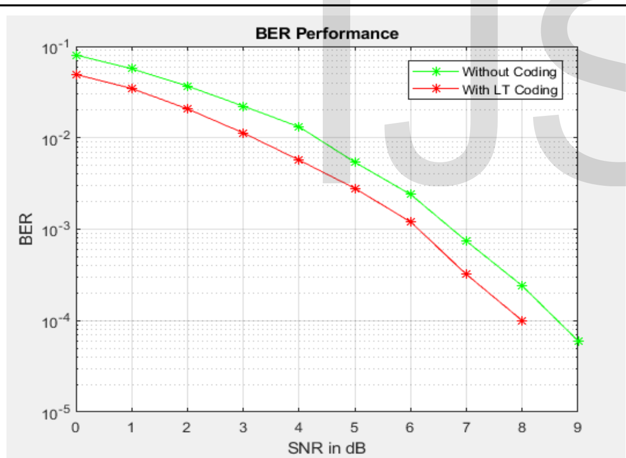

Fig. 10. Performance comparison in cases "without coding" and "with LT coding".

We note that for all values of SNR, the BER corresponding in the case "with LT coding" is lower than that of the case "without coding". To be more explicit, we can say that for the same BER value given in both cases "with LT coding" and "without coding", we have generally needed about 1 dB higher SNR in the case "without coding". This implies for the LT code a 1dB gain from the case "without coding" for these BER values. In other words, regardless of the level of noise in the channel, the LT code allows reliable information by reducing the risk of potential errors.

In the following **fig. 11**, we simultaneously present the results obtained in the cases "with LT coding" and "with LDPC coding".

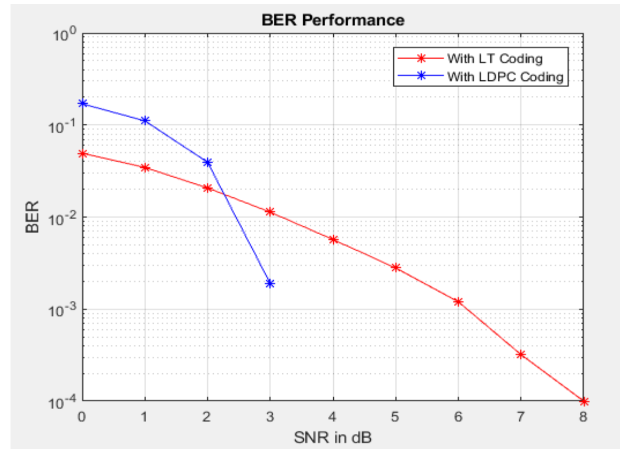

Fig. 11. Performance comparison in cases "with LT coding" and "with LDPC coding".

This figure allows us to see that for the first SNR values (0 to 2, thus corresponding to a very high noise), the BER obtained with LT coding is much lower than that obtained with LDPC coding. We can conclude that when the channel is very noisy, the fountain code LT seems to be much better candidate than the LDPC code. By cons for higher SNR values, corresponding to a relatively low noise, performance is better for the LDPC code, but we can note nevertheless that the LT code keeps a very acceptable performance. This small deficit of the LT code compared to the LDPC code for high SNR values may be due to the AWGN channel choosen (it is known that LDPC codes are very reliable there). Another channel model (χ^2 for example) could possibly be more relevant for the LT code compared to the LDPC code at these SNR values. We will try to study this case in our future works.

6 Conclusion and Prospects

The fountain codes are part of the family of error-correcting codes, but are different from classic correcting codes with fixed rate, since they are no predefined rate. This article examines overall performance that can have these codes in optical communication, and in the optical fiber communication specifically, which becomes more and more essential in our telecommunications networks. For that we chose the fountain code LT family that relies on the belief propagation decoding. Three simulation schemes have been proposed for a comparative study. In addition to the scheme using the fountain code LT, a scheme without coding was proposed, but also a scheme using the classic error correction code with fixed rate LDPC. We chose the LDPC code because this is one of the newest to be used in the optical domain. These different schemes have been applied on the AWGN channel model. The results of our simulations have shown us that on the one hand, the fountain code LT gives better performance compared to the case without coding, and this regardless of the noise level in the optical channel. On the other hand, our

International Journal of Scientific & Engineering Research, Volume 8, Issue 1, January-2017
ISSN 2229-5518

results allow us to see that for small SNR values, in other words when the channel is very noisy, the use of the fountain code LT provides much better performance than the use of an error correcting code with fixed rate, namely in this article LDPC code.

In future works, we'll try to study performances that can have fountain codes in χ^2 channel model.

References

[1] Stéphanie Castan-Sahuguède, Codage de canal pour les communications optiques. These in Université de Limoges, Octobre 2009
[2] P. Moro and D. Candiani, "565 mb/s optical transmission system for repeaterless sections up to 200 km," *IEEE ICC 1991*, 3 :1217–1221, 1991
[3] S. Benedetto and G. Bosco, Channel coding for optical communications, E. Forestieri ed., pp. 63–78, Springer, New York, NY, USA, 2005
[4] International Telecommunication Union. *Forward Error Correction for Submarine Systems*. 2000. Telecommunication Standardization Sector G. 975
[5] International Telecommunication Union. *Interfaces for the Optical Transport Network*. 2003. Telecommunication Standardization Sector G. 709
[6] O.A. Sab et al. Concatenated forward error correction schemes for long-haul dwdm optical transmission systems. *European Conference on Optical Communication (ECOC) 1999*, 2 :290–291, Sept. 1999
[7] International Telecommunication Union. *Forward error correction for high bitrate DWDM submarine systems*. 2004. Telecommunication Standardization Sector G. 975.1
[8] T. Mizuochi. Increase of coding gain oered by fec in optical communication systems. *IEEE Journal of Selected Topics in Qantum Electronics*, Mai/Juin 2006
[9] B. Vasic and I.B. Djordjevic. Low density parity check codes for long haul optical communication systems. *IEEE Photononic Technololy Letters*, 14(8) :12081210, Août 2002
[10] I. Gueye et al. Performance of Cooperative System Based on LDPC Codes in Wireless Optical Communication. In *Proceedings of the Future Technologies Conference (FTC) 2019*, Cham, 2020, p. 745-757
[11] John W. Byers, Michael Luby, Michael Mitzenmacher, and Ashutosh Rege. A Digital Fountain Approach to Reliable Distribution of Bulk Data. In *Conference on Applications, Technologies, Architectures, and Protocols for Computer Communication (SIGCOMM)*, pages 56–67, Vancouver, BC, Canada, 1998
[12] Michael Luby. LT Codes. In *Proc. The 43rd IEEE Symposium on Foundations of Computer Science (FOCS)*, page 271, Vancouver, BC, Canada, November 2002
[13] Michael Luby, Michael Mitzenmacher, Mohammad Amin Shokrollahi, and Daniel A. Spielman. Efficient erasure correcting codes. *IEEE Transactions on Information Theory*, 47(2) :569–584, 2001
[14] Anya Apavatjrut. De l'usage des codes fontaines dans les réseaux de capteurs multisauts. *INSA de Lyon*, 2011
[15] John G. Proakis. *Digital communications 3rd ed*. McGraw-Hill, 1995. ISBN : 0070517266