Improving The Error Rate In A VLC -EPPM System Using Turbo Product Codes And Bit Interlacing

By

Bonny Lindasy Gonzales Pulido
San Martin de Porres University
Email: bonny.gonzales1@usmp.pe

Juan Carlos Gonzales Suárez
San Marcos National University
Email: jgonzaless@unmsm.edu.pe

Abstract

Visible light communication (VLC) systems use EPPM modulation in indoor environments, therefore, in this study, the alternative procedure of using turbo product codes together with bit interleaving will be analyzed, in order to improve communication with the presence of thermal noise and shot noise in the bit error rate, as well as the inter-symbolic interference of a VLC system. The reason why it was chosen to improve this type of modulation is because brightness control can be obtained, which is important in indoor environments, unlike an Orthogonal Frequency Division Multiplexing (OFDM) system, which It does not have this type of control. Likewise, the modeling of the shot noise, the thermal noise, and the inter-symbolic interference will be carried out, in order to be able to compare results with investigations carried out and thus, the degree of improvement in terms of bit error rate obtained will also be evaluated using the proposed method. This research will propose an alternative to the current problems that exist in wireless communications used in indoor environments; such as in hospitals, areas such as magnetic resonance imaging (MRI) rooms, maternity wards or operating rooms; or in aircraft cabins, where signals can interfere with or damage communications.

Index Terms Indoor optical wireless communications, optical networks, visible light communications.

Introduction

In recent years, studies have been carried out on how to improve wireless communications, through new methods in addition to radiofrequency that allow a better transmission rate to be obtained and can be used in environments where its use is restricted. The communication study using visible light as a medium will be carried out based on previous research on wireless communications, allowing the observation of some benefits in communications in indoor environments.

Pulse Position Modulation (PPM), shown in the figure 1.1, is an M-ary technique that can be implemented non-coherently, and is therefore useful in ultra-broadband radio frequency systems and for free space optical (FSO) communications [7]; although On-Off Keying (OOK) modulation is the conventional binary modulation for FSO and Ultra Wide Band (UWB) communications, PPM is used in systems that are weak to the effects of inter-symbol interference. There is an observable advantage of PPM over OOK in fading channels, since it does not need a threshold level to decide on the symbol that has been received.

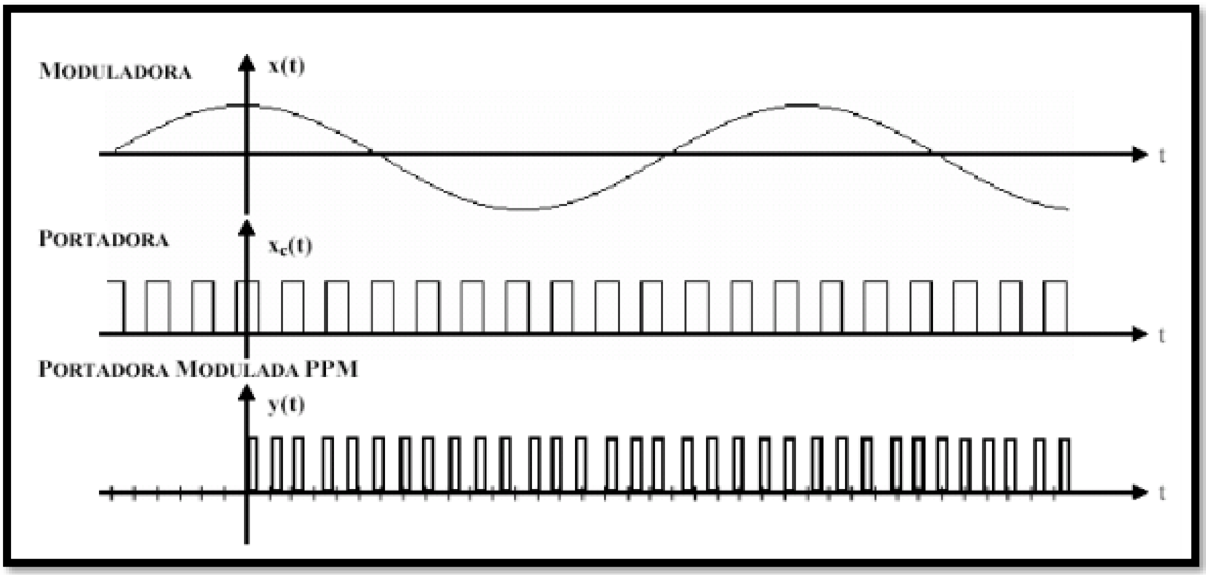

Figure 1.1 *PPM Modulation*

In [5] it is mentioned that visible light communications (VLC) in indoor environments suffer from the limited bandwidth of the LEDs (for this, different types of OFDM modulation were used to reach the maximum bandwidth to be used) , as well as inter symbol interference (ISI) due to multipath, so in this work, expunged pulse position modulation (EPPM) , schematized in the figure 1.2, is proposed as it can provide a wide peak average power (PAPR) needed for brightness control of interior lighting; a correlation decoder was also used in the receiver proving to be optimal for indoor VLC systems, counteracting shot noise and limited backlight.

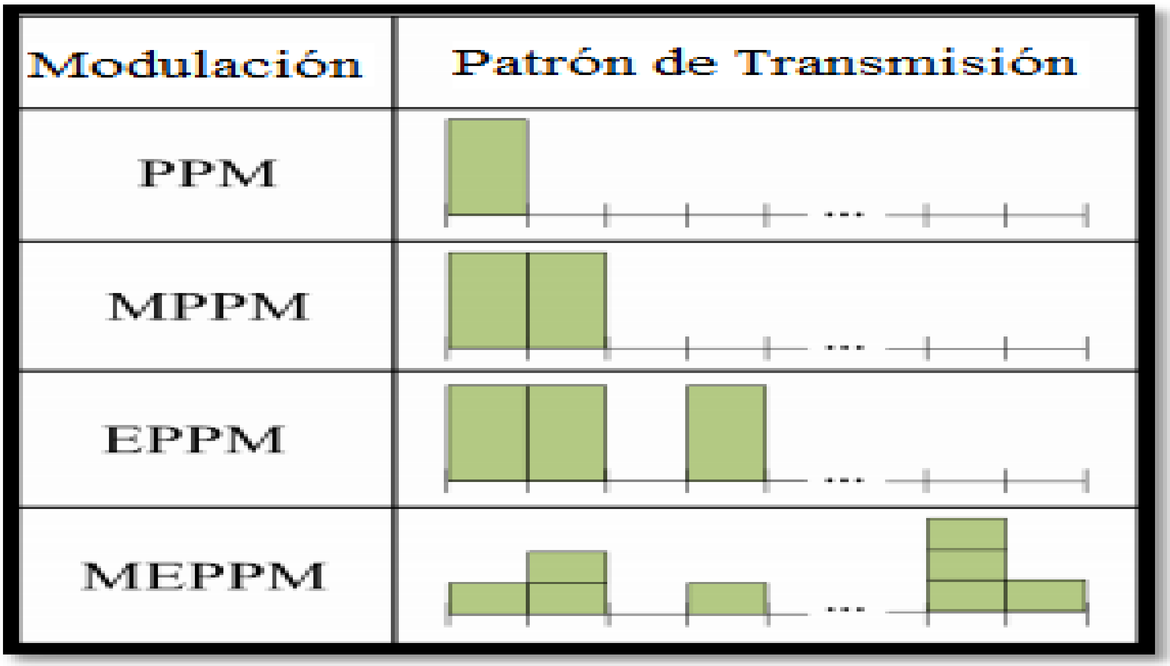

Figura 1.2 *Pulse position modulation schemes*

In case of experimenting with bit interleaving in EPPM-type channels that use dispersive VLC, the ISI effect can be reduced and the probability of error will also decrease significantly. In addition to this mentioned technique, turbo product codes (TPC) will be used as a complement to reduce the ISI value in VLC communication.

In Ozgur's article [8], VLC channel modeling including noise is studied, where the concept defines that the most important source of noise in VLC systems is shot noise, which is found in ambient light and is represented by a white Gaussian distribution. On the other hand, if there is no ambient noise, the only main source would be thermal noise in the receiver.

High-speed VLC communication is mainly used in indoor applications, but not outdoors because trigger noise can be very significant. In the enhancement approach, shot noise will be conceptualized and modeled to simulate what happens in indoor environments in order to reduce the bit error rate (BER) in a VLC-EPPM system.

In [3] Komine, T. and Nakagawa, M. is mentioned that in the interiors of an environment can be observed that the lights are distributed and that the equipment that produces the lighting will define the behavior of the irradiation of the light, too. Likewise, when I use an LED-type light device in VLC communication, the energy that is received is made up of optical paths that are differentiated in the propagation with which the same signal is transmitted simultaneously.

In [4] it is specified that pulse position modulation (PPM) is considered a main M-ary transmission technique for VLC communications, since it can be implemented inconsistently and will not depend on a threshold level for the decision in the circuit. receiver, which gives it a level of importance in the channels that suffer fading. Similar to PPM modulation, where low spectral efficiency is caused by interference within dispersive channels at successive time intervals.

Therefore, this low spectral efficiency is the main factor that will limit PPM modulation, causing a vulnerability to intersymbol interference (ISI) and the need to avoid its use in dispersive channels. This comment is the basis for turbo product codes and bit interleaving to be applied to reduce this limitation.

A comparison between the analytical BER of C-MEPPM (Coded-Multilevel Expunged Pulse Position Modulation) and a D-MEPPM (Divided-Multilevel Expunged Pulse Position Modulation) using the same Balances Incomplete Block design (BIBD) code, is shown in the Noshad article , M. and Brandt-Pearce [6] and presents a graph of BER against the number of users for three different maximum power levels, in which it is observed that when the number of users increases, a reduction in the value of BER.

The C-MEPPM system can simultaneously provide multiple access for up to 16 users. For D-MEPPM, different sets of 4 BIBD code words are assigned to the users, and therefore it follows that the maximum number of users is 16. For this, each user uses MEPPM type II with 4 levels and 70 symbols. Based on what was obtained, the error probability of C-MEPPM for weak power peaks is lower than that of D-MEPPM, since there is a greater distance between its symbols and its performance is only limited by the Multiple Access Interference (MAI), while D-MEPPM's performance is limited by shot noise.

In [1], an analysis of the effect of noise on the width of the VLC pulse signal in the case of digital signal processing is presented. It was also possible to review and check the results with a simulation test using the Manchester and Miller code. In the paper work a VLC communications receiver is proposed. The results show that when the SNR decreases, the pulse widths are increasingly affected by distortion and decoding errors are caused.

Due to the intrinsic and observable property, the Miller-type encoded signal has a better filtering, presenting less pulse distortions because it is longer in time, but it is affected by a more defined limit of tolerance to the SNR, which is the main cause of errors. In the case of the Manchester code, the digital filtering is less efficient since it has insufficient filtering but recovers due to its higher tolerance to pulse width variations.

Under these circumstances, the two codes have similar BER results. Since Manchester code and Miller code have similar performance but Miller code has better channel usage unlike Manchester code which can be considered suitable for single channel communications. Also, in MIMO applications, Miller is more suitable. It should be noted that in the Manchester code, where digital filtering is not very effective, since it is limited, it has a greater tolerance to variations in pulse width, thus allowing its recovery.

In reference [9], it is discussed that Turbo Product Codes can provide substantial coding gain with reasonable system complexity for optical systems with PPM modulation. One of the first reasons is that BER limits for TPC require a common marker for error events in all possible combinations of input weights and output weights. Second, since TPC are block codes, it is difficult to list error events that include more than one excursion from the all-zero state within the fixed block length. Third, since it is difficult to obtain the limit for any choice of permutation, the limit is developed as an average over the randomly chosen interleaves.

It should be noted that the study was carried out for applications that use laser sources, unlike the present work to be developed, which is oriented to visible light communications in interior spaces and to optimize said communications using PPM modulation with the application of the concepts of turbo product codes with the in order to decrease the bit error rate (BER).

Modelling of the proposed system

The modeling process of the proposed system was carried out taking into account the studies previously carried out in the base papers, on visible light communications in indoor environments, in the first place the type of modulation for the signal was taken into account, among which the most used were OFDM, shown in the figure 2.1, and PPM presented in figure 2.2. But, the first of them, compared to the other, presents a deficiency in not having control of the intensity of brightness, so it was chosen, given that the proposed system is for internal environments, to work with the EPPM modulation.

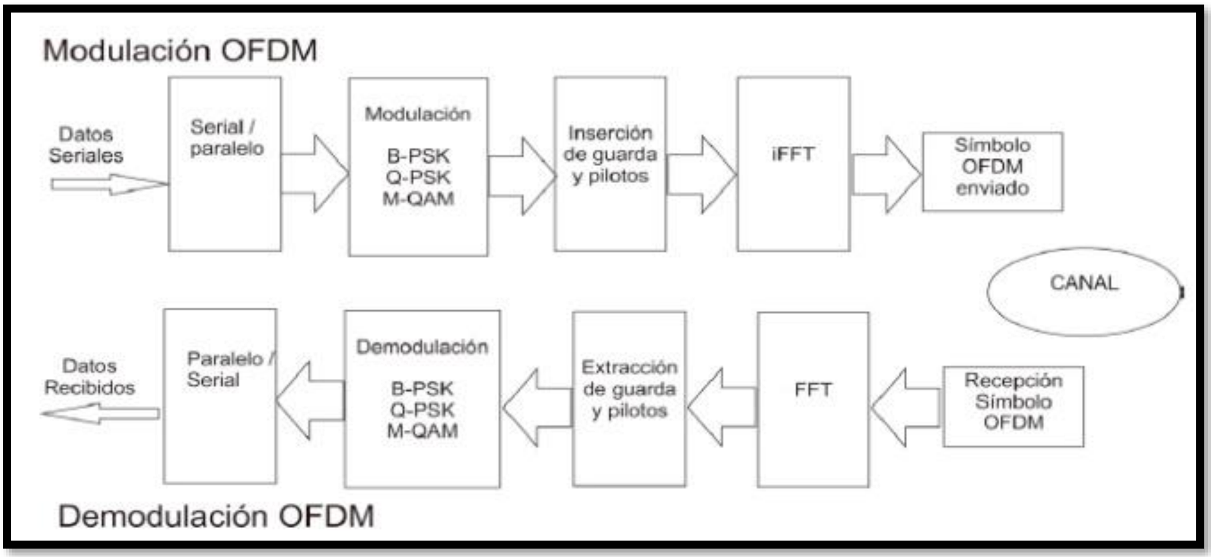

Figure 2.1 *OFDM general scheme*

In addition to this, the bit interleaver method was used as a technique to improve EPPM performance in multipath channels and the use of turbo product codes is being proposed in order to obtain better BER performance.

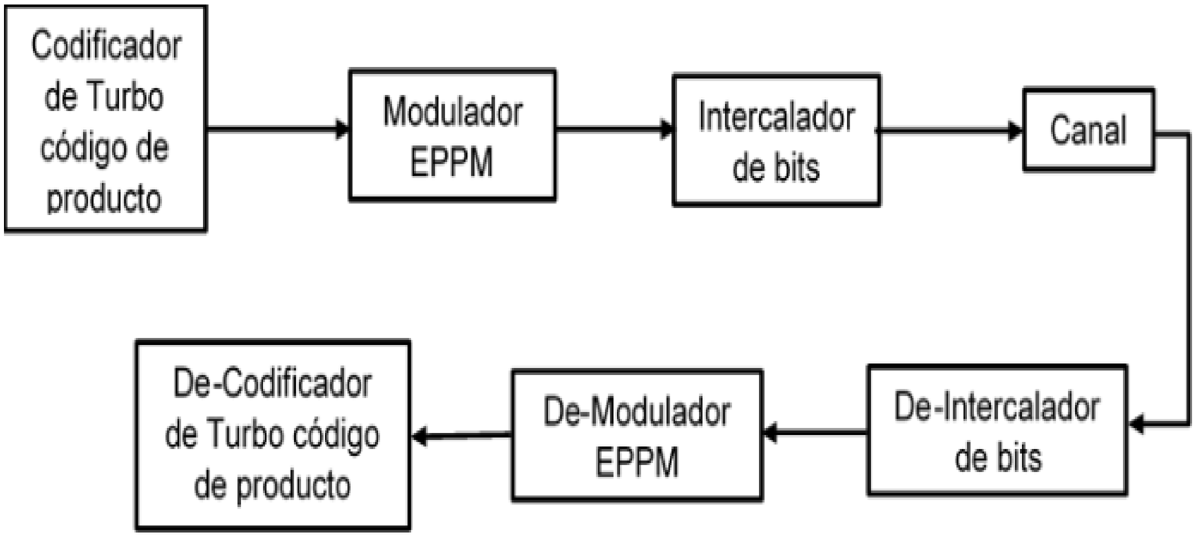

Figure 2.2 *Solution Block Diagram*

System Modelling Process

In the modeling process of the parts of the proposed system, it begins by proposing different ways of obtaining a visible light source signal and, as it is due to a simulation environment, it is decided to review different characteristics to generate a random digital signal that provide a layout similar to one generated physically.

For the generation of the EPPM coding, we start with the PPM modulation (given that it is the base modulation and that when applying the BIBD coding it is called EPPM modulation), for digital signals with which the tests were carried out to also choose the type bit interleaving to be used in the proposed system, according to the scheme of figure 3.1.

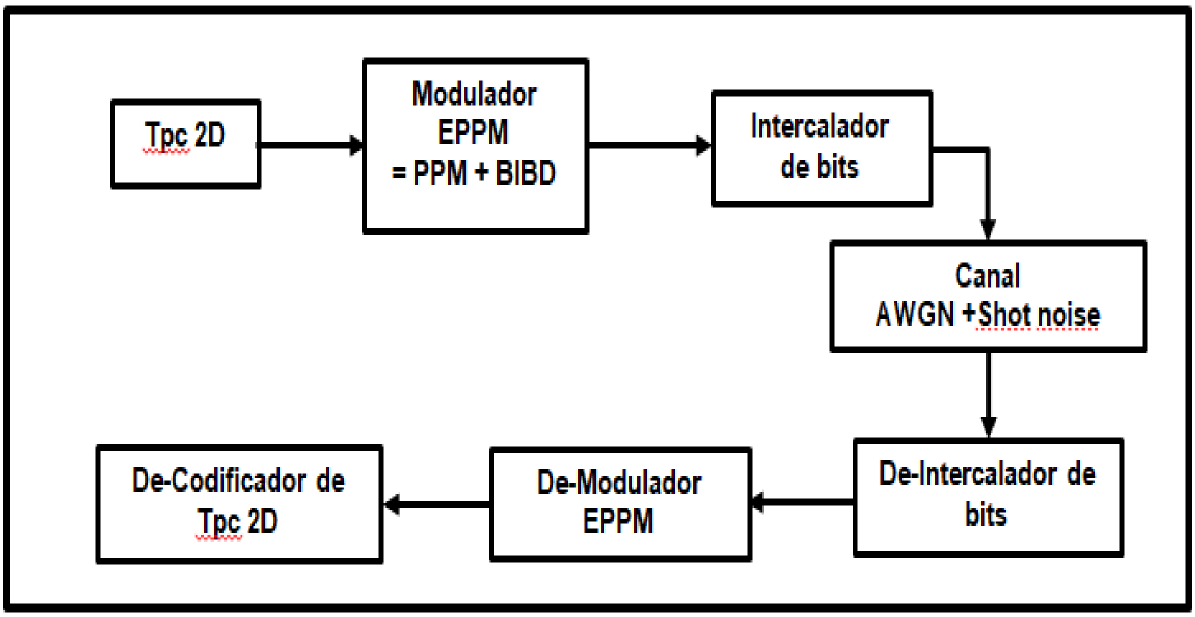

Figure 3.1 *Block diagram of the solution*

The proposed model is based on an improvement of EPPM modulation techniques for VLC in indoor environments with the use of bit interleaving and turbo product codes, to provide high-speed communications for systems with limited sources of bandwidth, channels slightly dispersive due to inter-symbolic interference and with variation of brightness intensity.

Turbo Product Code Encoder

Initially, a binary data frame will be taken, which will be encoded using the 2D turbo product code technique and since the system requires small BER values, TPCs can significantly improve the total BER performance.

The product turbo code block uses two Hamming codes for column and row coding, this has improved the Hamming coding bug fix. Additionally, BPTC provides interleaved block coding to disorganize the transmission sequence before it is transmitted, in order to avoid a burst of errors when the signal encounters a multipath channel.n un principio se tomara una trama de datos binarios, los cuales serán en una codificados mediante la técnica de turbo códigos de producto 2D y dado que el sistema que requiere valores pequeños de BER, los eTPC pueden mejorar significativamente el rendimiento total de BER.

The product turbo code block uses two Hamming codes for column and row coding, this has improved the Hamming coding bug fix, whose flow is in figure 3.2. Additionally, BPTC provides interleaved block coding to disorganize the transmission sequence before it is transmitted, in order to avoid a burst of errors when the signal encounters a multipath channel. Of which we are left with (7, 4) and (4, 3) for their performance with the entire system, allowing a lower processing load when going through the EPPM modulation stage when the BIBD encoding must be carried out.

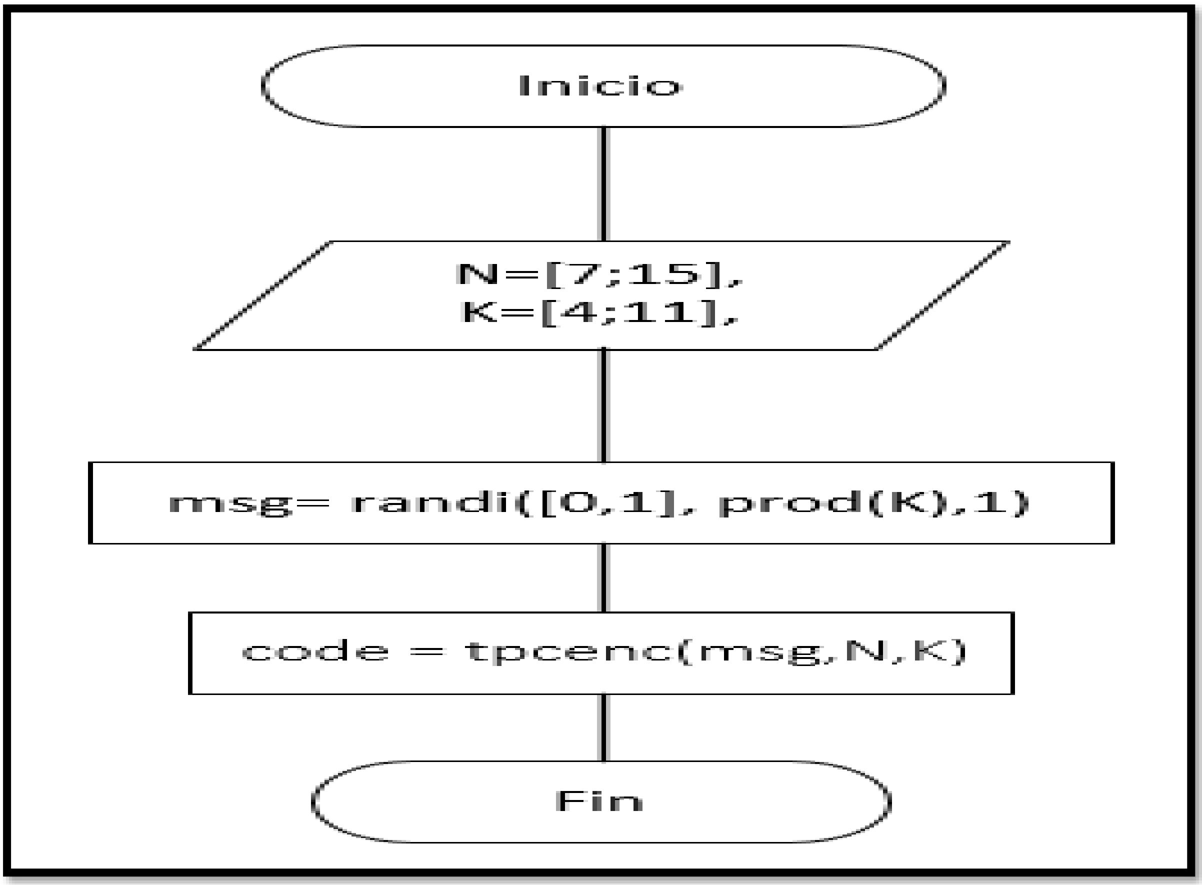

Figure 3.2 *Flow diagram of the turbo product code*

The tests were carried out with the values of table 1, which were the following

Table I. *Code Types for TPC*

Code type	Component Code Pairs(NR,KR) and (NC,KC)	Error-Correction Capability (T)
Hamming code	(15, 11)	1
	(7, 4)	1
Parity check code	(4, 3)	-

Intercalador de bits

The multipath effect is a limiting factor on the bitrate of indoor VLC systems. The multipath effect broadens the transmitted pulses and imposes the ISI on the transmitted data. Interleaving is introduced here as a technique to improve EPPM performance on multipath channels for dispersive communication systems.

Therefore, a random interleaver will be used, that reorganizes the data by performing a random reorganization of it, likewise a specific value will be used to determine from which state the permutation will be performed randomly (Figure 3.3).

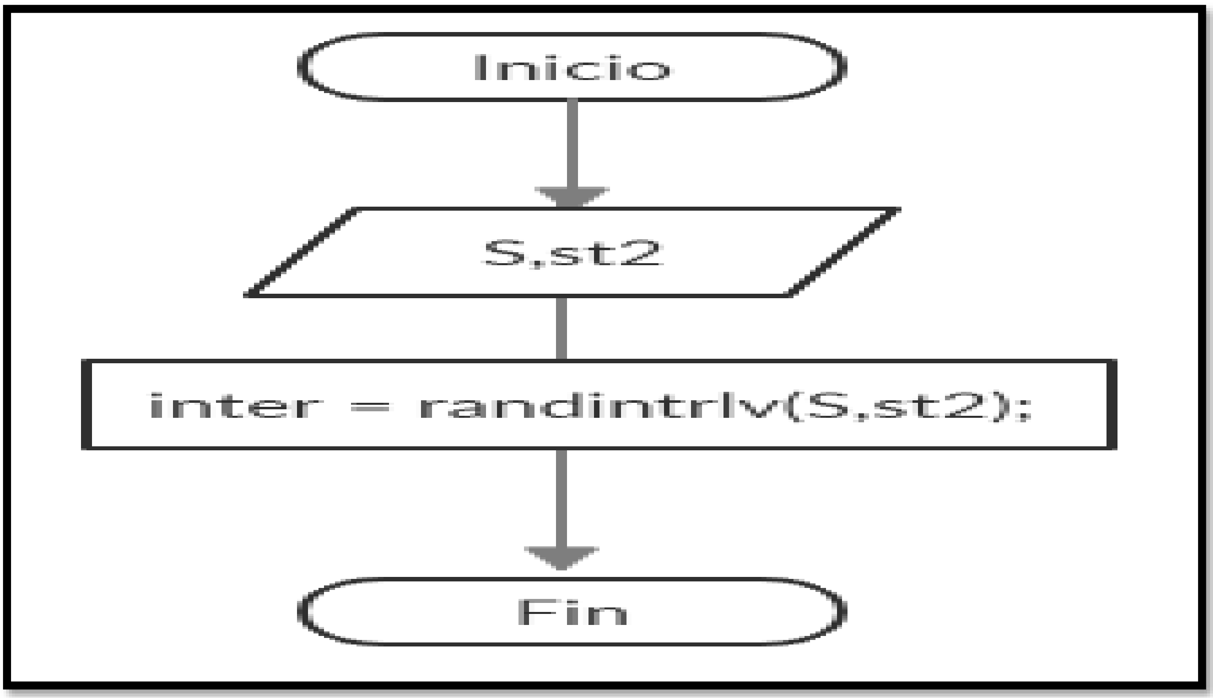

Figure 3.3 *Bit Interleaver Flow Chart*

EPPM Modulator

For the EPPM modulation, the input signal that has been interleaved and previously encoded with 2D turbo product codes will be taken; the procedure to carry out the modulation is a BIBD coding, according to the antecedents that has been revised according to the number of blocks to be carried out

BIBD Coding

In order to carry out the tests required in the development of the research, different combinations of v, b, r, k, lmbd had to be used, (v=varieties, b=blocks, r=repetitions of the varieties, k=varieties per block and lmbd=repetitions of pairs of varieties) to be able to demonstrate that the BIBD encoding that was being carried out is correct.

In the tests that were carried out, the following combinations of values (Table 2) were used

Table 2. *Bibd Coding Combination*

v	b	r	k	lambda
4	4	3	3	2
6	6	4	2	1
6	6	10	4	1
7	7	3	3	1
14	14	10	5	1
16	16	6	6	3
19	19	9	9	4

After this, the combinations shown in Table 2 were taken and the flow of Figure 3.4 was carried out for the experiments, observing the number of errors to be presented as well as the delay in processing them.,

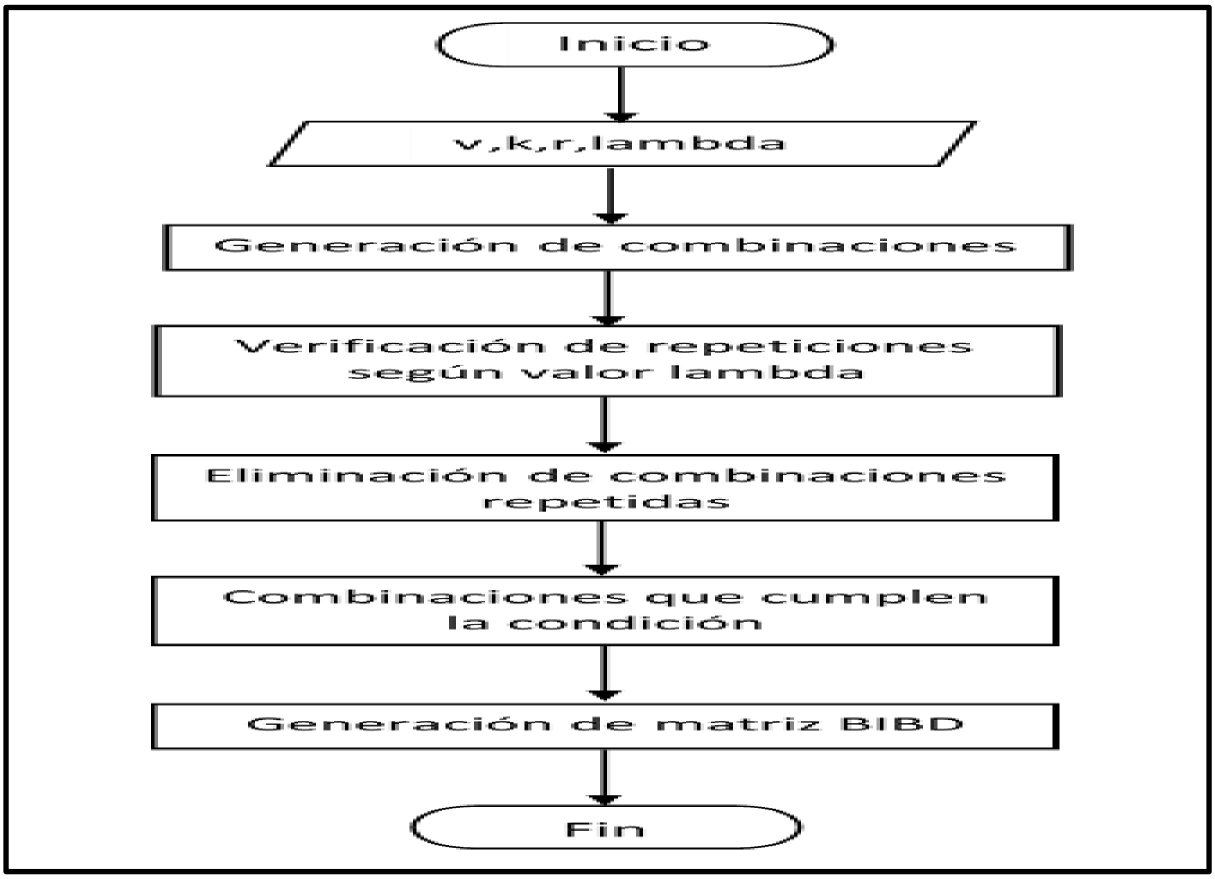

Figure 3.4 *BIBD Coding Flowchart*

PPM Modulation

In the PPM modulation sub-stage (Figure 3.5), the symbol time is divided into Q equal cyclic time intervals, only one of which contains a pulse, forming a code of cardinality Q. [5].

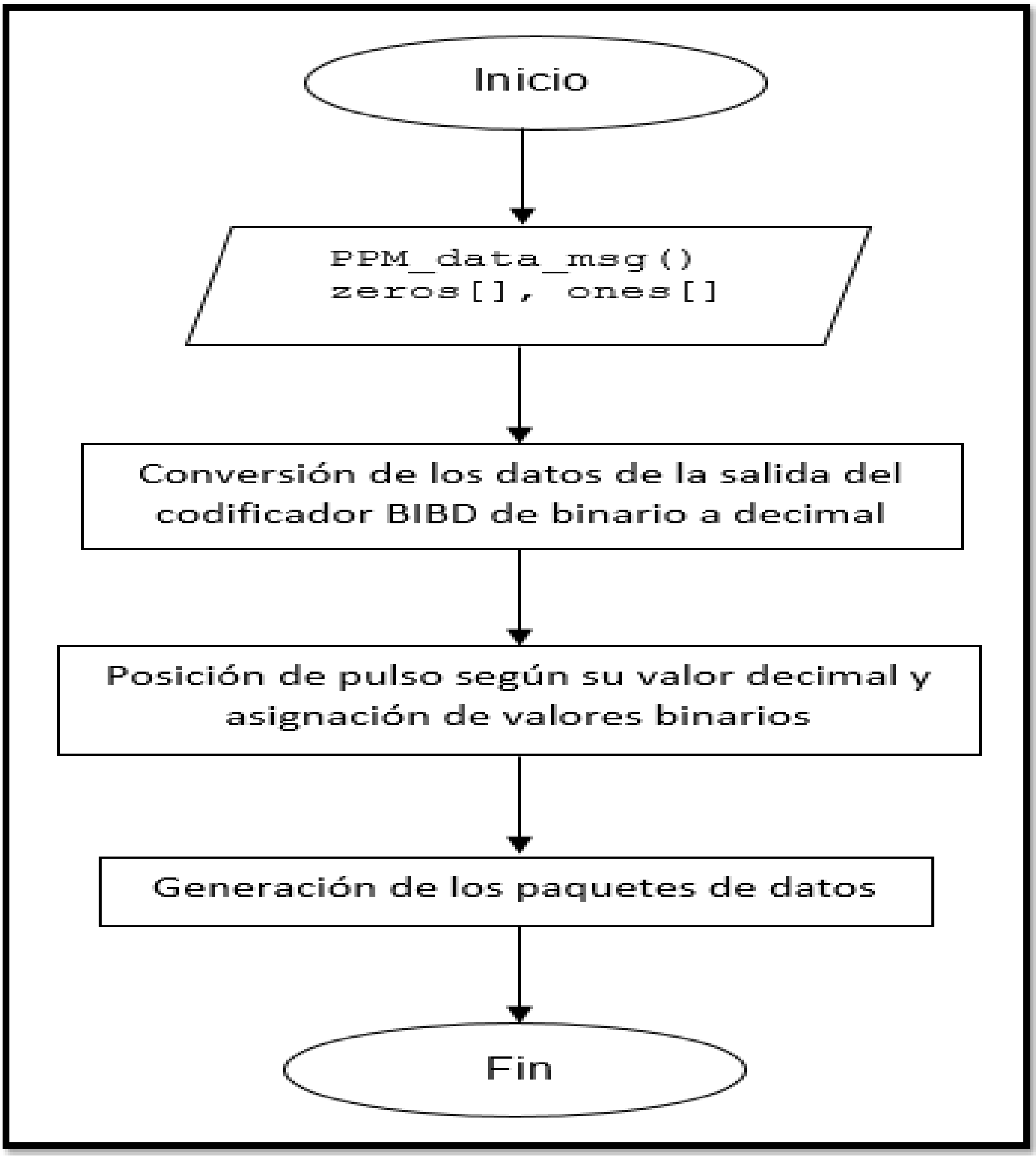

Figure 3.5: *PPM Modulation Flow Chart*

Communication Channel

The channel model that was used for the development of the study was based on Gaussian noise - AWGN, whose behavior is already known and its incidence on the signal to be treated and this will allow a better decoding to be obtained to have a lower BER.

For this, it was taken into account that in an AWGN channel there can be two types of algorithms for PPM modulation, such as: [2]

Hard decision decoding, using a threshold detector

Soft decision decoding, using the maximum value a posteriori

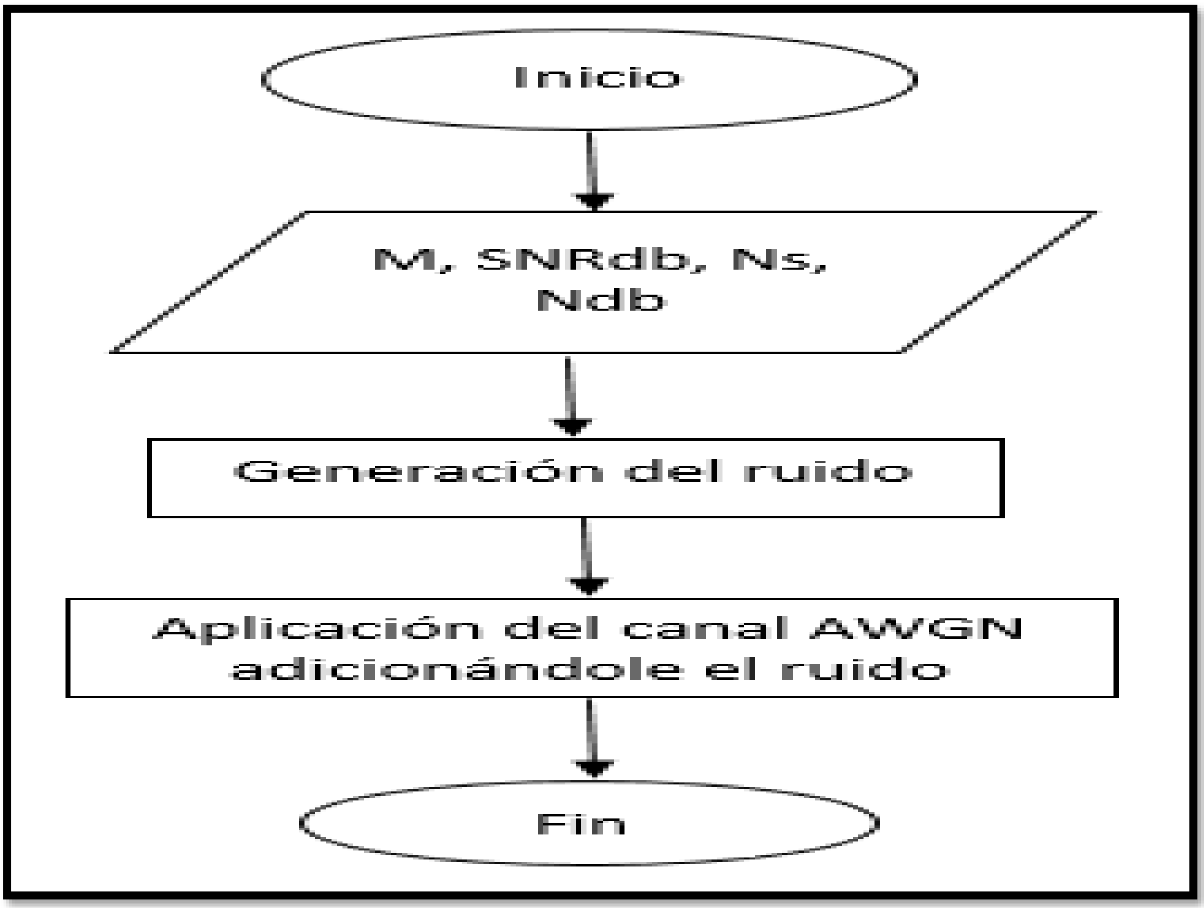

Figure 3.7: *AWGN Channel Flow Chart*

Model Initialization

For the simulation of the system to be improved, a random binary data packet was taken as a basis, which will allow having an input signal that is similar to the data packet emitted through an array of LEDs or a light source.

Bit combinations were taken according to the data processing delay time in the proposed system, and the performance of the equipment used to carry out the simulations was also taken into account.

The Turbo product code stage was taken into account because so that the data is not corrupted by its neighboring data, the choice of the codes to be used was made through the provided table that allows observing the types of codes presenting their ability to bug fix.

According to this table, some combinations were made, however, in the end, a combination of Hamming code (7; 4) and Parity check code (4; 3) was chosen, since it presented a better performance. before the objective sought in this stage.

To carry out the BIBD coding program (v, b, r, k, lambda), tests had to be carried out with a variety of combinations for each of the defined variables. These values were the combinations 16,16,6,6,3 and 19,19,9,9,4 that are mentioned in table 3.1 referenced in the review by Noshad, M. and Brandt-Pearce, M. [5] .

It was also reviewed, how long it took to process each of these combinations and also, a separate function was created to be able to call it within the main program, so that it allows us to calculate the BIBD encoding as part of the EPPM modulation sub-stage.

Tabla: *Bibd Code (16, 16, 6, 6, 3)*

0	0	1	1	1	1	0	0	0	0	1	0	1	0	0
0	0	0	0	0	0	0	0	0	0	1	1	1	1	1
0	0	1	1	0	0	0	0	1	1	0	0	0	0	1
0	0	0	0	1	1	0	0	1	1	0	1	0	1	0
0	0	0	0	0	1	1	1	1	0	1	0	0	0	0
0	0	1	0	1	0	1	1	0	0	0	1	0	0	1
1	1	1	0	0	1	0	0	0	0	0	1	0	0	0
1	1	0	0	1	0	0	0	1	0	1	0	0	0	1
0	1	1	0	0	0	0	1	1	0	0	0	1	1	0
1	0	1	0	0	0	1	0	0	1	1	0	0	1	0
1	0	0	1	0	0	1	0	1	0	0	1	1	0	0
0	1	0	1	0	0	0	1	0	1	1	1	0	0	0
1	0	0	1	1	0	0	1	0	0	0	0	0	1	0
1	0	0	0	0	1	0	1	0	1	0	0	1	0	1
0	1	0	0	1	0	1	0	0	1	0	0	1	0	0
0	1	0	1	0	1	1	0	0	0	0	0	0	1	1

Since, we have used TPC and based on the original design we proceeded to use a one-bit interleaver, however no specific data was found on the type of interleaver used, so we proceeded to use a random bit interleaver

which takes the resulting data after the EPPM modulation and interleaves the bits according to a value (4831) [26] that is assigned in the state variable, thus allowing the improvement in the error rate within the system, since it orders the bits of the transmitted codes before an error occurs between neighboring data.

Bearing in mind that this simulation should be the closest thing to a real environment, the AWGN noise was added to the channel in order to observe how much the presence of this noise can infer from the data and be able to compare it with the graphs of the base paper. , also to simulate the types of noise that occur such as shot noise and thermal noise.

Likewise, in the analyzes it was taken into account to represent both the HDD and the SDD, for which it was necessary to evaluate the threshold closest to the position of the bit that is being processed and the detection is being carried out; since this type of detection was observed in the base paper [5].

Model Results

The figure 5.1 shows the signal at the channel output having been added the AWGN noise.

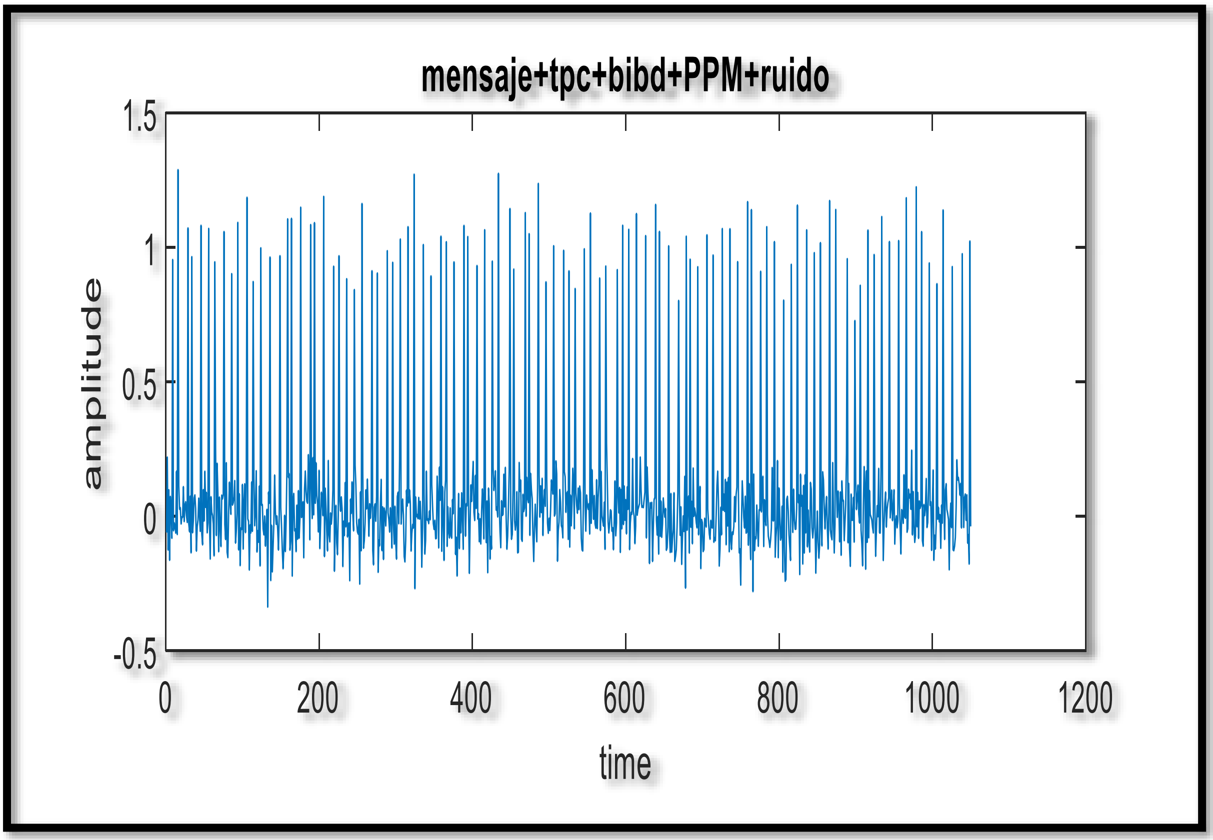

Figure 5.1: *Channel Output AWGN Channel Flow Chart*

According to the simulations, the curves of the bit error rates can be observed as they were initially made in the base paper, in order to confirm that the procedure to be carried out is being correct, whose result considering the Hard option decoding decision, using a threshold detector is shown below in figure 5.2.

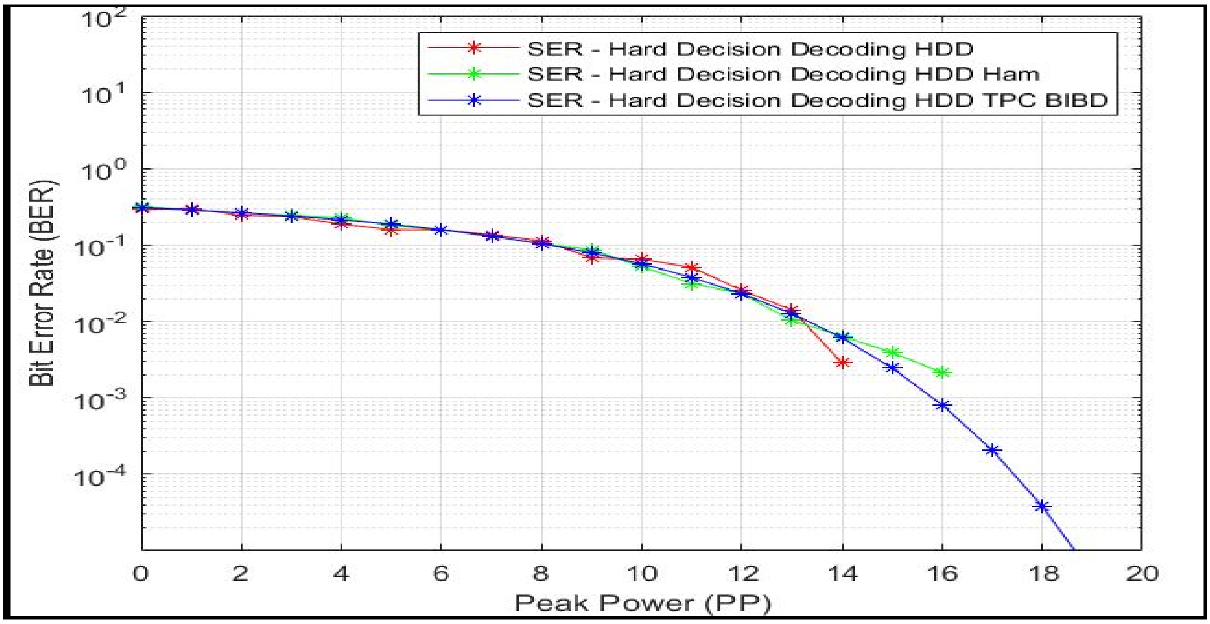

Figure 5.2: *Simulation of BER versus Peak Power using HDD*

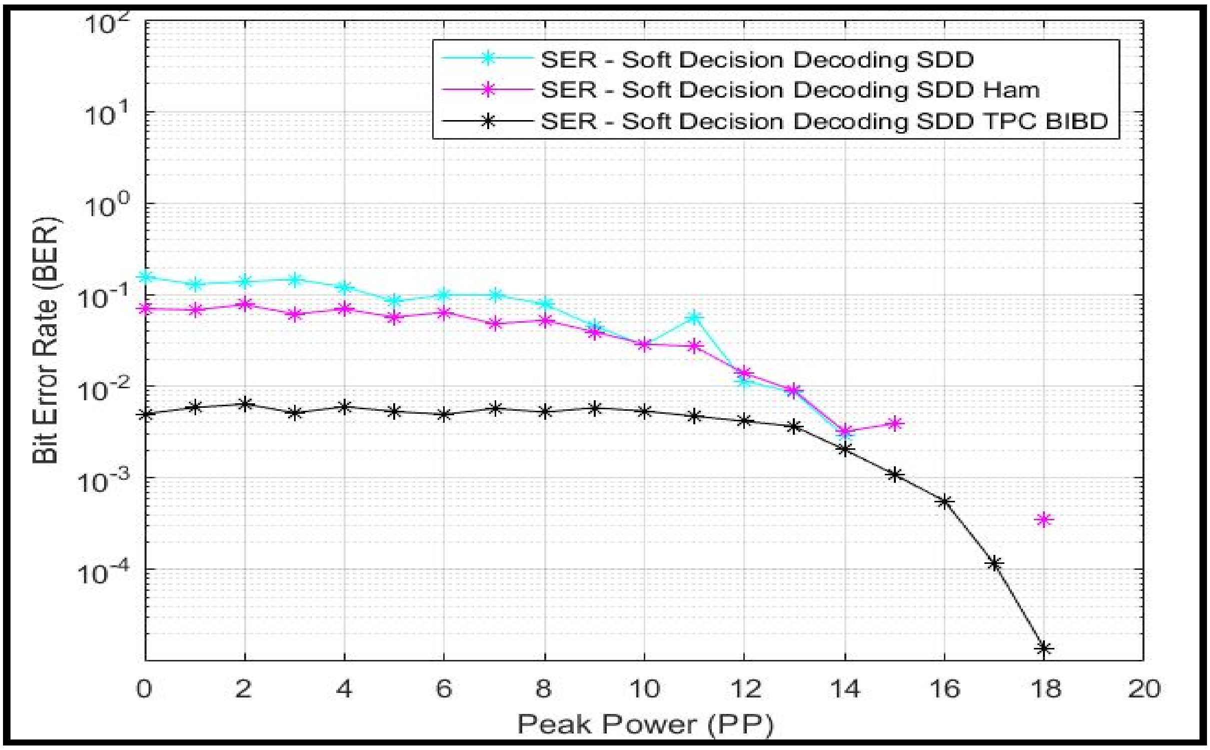

Figure 5.3: *Simulation of BER versus Peak Power using SDD.*

While using the case of Soft decision decoding, using the maximum posterior value, we can see the results in figure 5.3

Conclusions

According to the tests carried out, in the simulation of VLS environments with EPPM modulation in indoor environments with turbo product codes in conjunction with bit interleaving, it can be mentioned that the thermal noise rate is reduced, as well as the shot noise that was modelled.

On the other hand, inter-symbolic interference can be reduced, which is reflected in the decrease in errors as the peak power consumption indicated with TPC-BIBD increases in the resulting diagrams.

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