THE ANALYSIS OF DIFFERENT ENCODING AND MODULATION TECHNIQUES AT THE SIGNAL TRANSMISSION IN THE OPTICAL MEDIUM

Filip Čertík

Institute of Telecommunications, FEEIT, Slovak University of Technology in Bratislava, Slovak Republic

E-mail: Filip.certik@gmail.com

Received 30 April 2015; accepted 06 May 2015

1. Introduction

New techniques are deploying to satisfy the increasing demand for higher data rate and capacity of systems. New technologies are developed and deployed in the signal transmission through optical fibers that offers optimal performance of system to satisfy these increasing demands. Constructing new optical transmission paths can be time consuming, expensive and sometimes not available solution. In the electric domain, utilizing new high-speed modulators or using error-correcting codes can lead to increasing of the transmission capacity. Such solutions can be easily integrated. With increasing of modulation rates, linear and nonlinear influences on transmitted optical signal are growing and by this way additional bit errors in information signals are generating. Therefore, it is important to choose error correction codes that ensure a desirable value of the Bit Error Rate (BER).This paper presents LDPC encoding technique with binary modulation techniques. For analysis, simulations of the signal transmission in the optical fiber using MATLAB Simulation tools are utilized.

First, basic characteristics of the encoding techniques are introduced and closer analysis and design of RS, BCH and LDPC codes is shown. In the next part, binary modulation techniques are presented. The simulation of modulated transmitted signal and their blocks are shown. In the final part, the LDPC code is used with different binary modulation techniques to improve the BER performance. The comparison of different error codes with modulation techniques is presented.

2. Analysis of the encoding techniques

A Forward Error Correction FEC technique (also known as the Error Correcting Code ECC) is a system, where additional data are inserted to data message so that it can be recovered by a receiver even when a number of errors due to transmission occur. These FEC codes are widely used in systems where retransmission of the data is not an option such as broadcasting and high haul optical transmission systems [1,2]. FEC codes are usually distinguished between convolutional and block codes:

- Convolutional codes that are processed on a bit-by-bit basis,
- Block codes that are processed on a block-by-block basis.

For analysis, block codes, especially cyclic block codes are considered. Cyclic block codes are widely used in data communication because their structure makes encoder and decoder circuitry simple. Cyclic block codes are defined as the cyclic *(n, k)* code if *C* is a linear code of length *n* over a finite field and if any cyclic shift of a codeword is also a codeword as shown in:

$$c_0, c_1, ..., c_{n-1} \in C \Rightarrow c_{n-1}, c_0, c_1, ..., c_{n-2} \in C \quad (1)$$

The information data with length *k* are coded with polynomial *g(x)* using (2).

$$c(x) = i(x)g(x) \tag{2}$$

where $c(x)$ represents polynomial with degree (n-1), $i(x)$ is the information polynomial of degree (k-1) and the generator polynomial $g(x)$ must be of degree (n-k).

The Reed-Solomon RS codes that belong to cyclic block codes are widely used in many communication fields [2,3]. The RS codes are related with BCH codes and can be defined as a primitive BCH code of length n, where:

$$n = q - 1 = 2^s - 1 \quad over \quad GF(q) = GF(2^s) \tag{3}$$

RS codes are specified as $RS\ (n,k)$ or $RS\ (n,k,d)$, where n represent code length, k represents information length and d is hamming distance. Let t is number of errors that can be corrected, then shows the correction (t) or detection(2.t) ability for the specified code. There exist two encoding types for RS codes:

- nonsystematic, where $c(x) = i(x)g(x)$
- systematic, where $c(x) = i(x)x^{n-k} + i(x)x^{n-k} \bmod g(x)$

The decoding for RS codes is based on syndrome equations:

$$s_k = \sum_{i=1}^{t} Y_i X_i^k; \quad k = 0,1,....,2t-1 \tag{4}$$

where X_i is locator i-th error and Y_i represents its value (detection of location and value). More information about RS encoding techniques can be found in [3].

The Bose Chaudhuri Hocquenghem BCH code is a cyclic polynomial code over a finite field with chosen polynomial generator. BCH codes are t-error correcting codes defined over finite fields GF(q), where $2t + 1 < q$. The advantage of BCH codes is using syndrome to decode errors in which there exist good decoding algorithms that correct multiple errors. The generating of a binary BCH code over an extension field GF(q^m) is easy to construct. The polynomial generator $g(x)$ is needed to obtain a cyclic code [2,3,4]. For any integer $m \geq 3$ and $t < 2^m - 1$, there exists a primitive BCH code with parameters: $n = 2^m - 1$, $n - k \leq m.t$, $d_{min} \leq 2t + 1$. The generator polynomial $g(x)$ of t-error-correcting primitive BCH codes of length 2^m - 1 is given by:

$$g(x) = LCM\{m_1(x), m_2(x), ..., m_{2t-1}(x), m_{2t}(x)\} \tag{8}$$

where LCM represent Least Common Multiple. Then the code is generated using (2).
BCH codes are decoded with various algorithm based on calculation of syndromes values for the received codeword.

The Low Density Parity Check LDPC code belongs to linear encoding techniques that can transmit data close to the Shannon theorem (channel capacity). The main disadvantage of the LDPC code is the time consumption of the code algorithm, which often limits the use in high data rate optical transmission systems. However, it is possible to encode more channels and then merge them into one high data rate signal. The high data rate signal can be transmitted via the optical transmission system.

The LDPC coding is defined by LDPC H matrix. Assuming, the length of information bits K, the length of encoded bits N and the average weight column $w > 2$ (weight vectors represents the sum of non-zero components of the vector), then the $M = (N - K)$ is the sum of the parity check in code. The LDPC matrix H is composed of M rows and N columns. The generation matrix G is necessary to encode coding sequence [3,4].

The block schemes of RS, BCH and LDPC encoding techniques are shown in fig. 1 and fig. 2. The blocks are created using Bernoulli generator that generates random binary bits represented information signal. The signal is then encoded with the adequate encoding technique. The final signal is filtered with Gaussian filter representation real signal. The

LDPC block is using 10 Bernoulli generators, where each generator is encoded with its self LDPC encoding technique and these encoded signals are merged into the one high data rate signal.

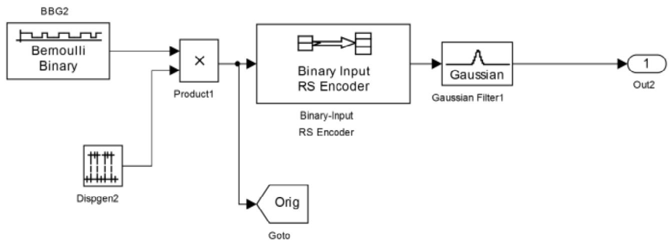

Fig.1:*The block scheme for the signal generation using RS and BCH encoding.*

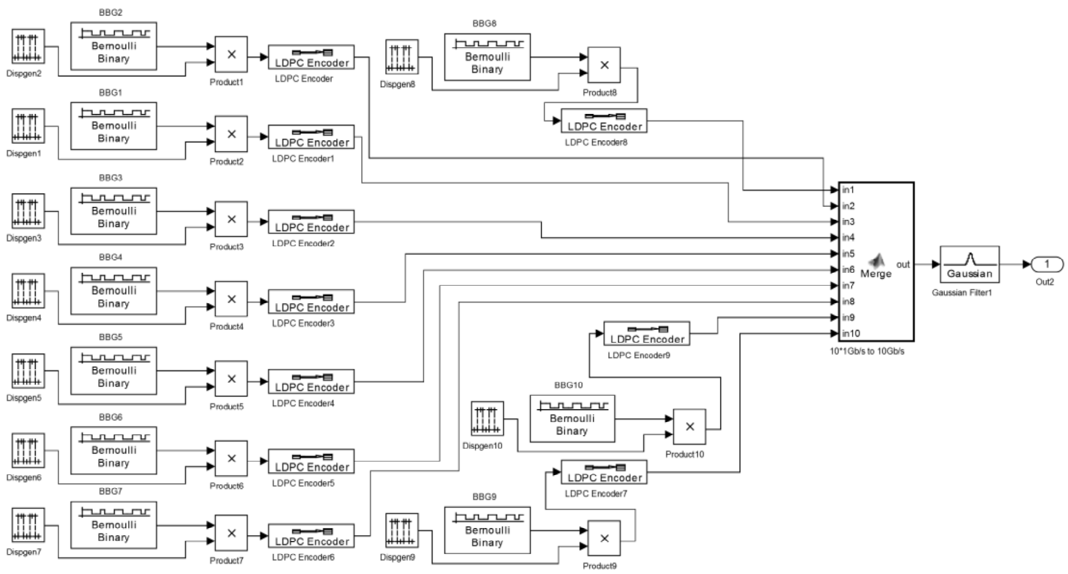

Fig.2: *The block scheme for the signal generation with LDPC encoding.*

3. Analysis of the modulation techniques

In the simulation model, the On-Off Keying OOK, the Binary Phase Shift Keying BPSK and the Differential Binary Phase Shift Keying DBPSK are realized in following blocks of Data signal and Mach-Zehnder Modulator MZM. This simulation uses MZM physical principles that are based on the interaction of two polarized waves (an interference of waves or a destruction of waves). In a case of the OOK modulation, two linearly polarized waves with same polarization interfere. In a case of BPSK and DBPSK modulations, two waves are linearly polarized but there is the π radian phase shift. In the first case, when an electric signal is present, then optical waves interfere each other creating wave propagating in the z direction. The absence of electric data signal, optical waves interfere to destructive state resulting to no signal. In a case of the PSK modulation, when an electric data signal is absent, optical waves interfere creating a polarized wave that propagates in the z direction with power $P$and if the electric signal is present, waves interfere creating the same wave but the opposite polarization direction.

4. Simulation and analysis of encoding techniques

The presented simulation model comes out from the simulation model for optical communications introduced in [7,8,9]. A modeling is performed in the Matlab Simulink 2014 environment. The simulation model presents an influence of linear and nonlinear effects in the optical transmission media such as attenuation, chromatic and polarization mode dispersions, FWM, SPM, XPM, SRS and SBSon binary modulated transmission signalusingencoding techniques. More detailed design for each effect of the optical transmission medium is shown in [9,10]. For executed analysis, the simulation model is realized for the Samsung single mode UltraPassTM Non-zero dispersion-Shifted optical fiber [11] that meets the specification ITU-T G.656 [12].

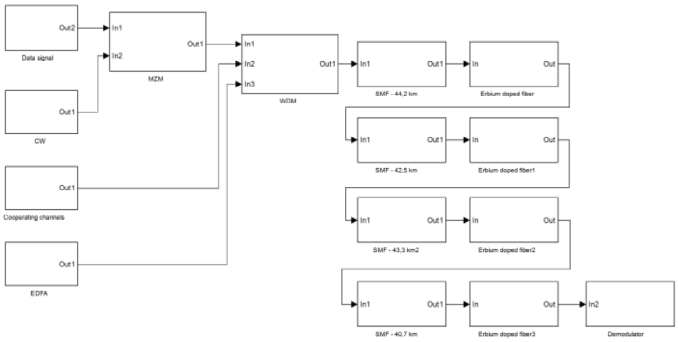

Fig.3: *The complete scheme of the optical transmission path.*

For describing and comparing various combinations of formats, a bit error rate (BER) calculation and estimation from Q factor are presented. The BER calculation is done by comparing input and output bits for each example. Because the BER calculation is a very time consuming process, we calculate the BER estimation of each approach. The Q factor can be obtained from Optical Signal to Noise Ratio OSNR. The SNR block is used to determine OSNR parameter.

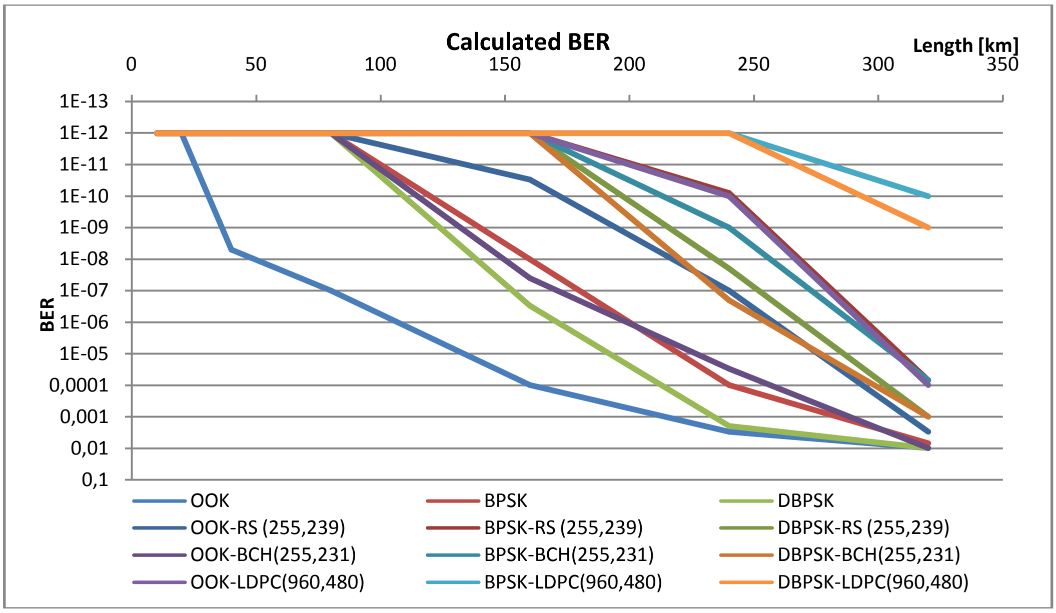

Fig.4: *The comparison of advanced signal processing.*

The fig. 4 shows a comparison for different encoding techniques with OOK, BPSK and DBPSK modulation techniques. The simulation for this optical path shows the OOK modulation range limit around 50 km. The encoding techniques improved the optical path range to 80 - 160 km for OOK modulation. The better system performance showed the BPSK and DBPSK, where the limit for both systems is around 80 - 100 km without encoding. The encoding techniques improved the signal transmission for the BPSK and DBPSK up to 160 km using RS and BCD encoding techniques and 230 km using LDPC encoding. The LDPC encoding shows the highest improvement and range for each modulation.

Conclusion

The paper presents analysis of advanced signal processing techniques in optical transmission systems. The simulation results show the limitation of binary modulation techniques and their improvement using FEC codes. The LDPC encodingshows the highest improvement for binary modulation techniques. On the other hand, the electric high data rate signal must be divided into some low data rate signals for utilizing the LDPC encoding. Afterwards, these low data rate signals are multiplexed in optical or electric domain into the one high data rate signal. The RS and BCH encoding is 50% less efficient, but easier implemented. In future analysis, we can design a new combination of high-bit rate modulation formats, such as QPSK, 8PSK, 16QAM and FSK, with advanced encoding techniques.

Acknowledgement

This work is a part of research activities conducted at Slovak University of Technology Bratislava, Institute of Telecommunications FEI, within the scope of the projects KEGA No. 039STU-4/2013 "Utilization of Web-based Training and Learning Systems at the Development of New Educational Programs in the Area of Optical Transmission Media".

References:

[1] R. Hill. A First Course in Coding Theory, Oxford: Clarendon Press.

[2] W. Trappe, L.C. Washington. Introduction to cryptography: with coding theory, 2nd ed. New Jersey: Pearson Prentice Hall

[3] J.H. van Lint. Introduction to coding theory, 3rd ed. Berlin: Springer Verlag.

[4] M. Bossert. Channel Coding For Telecommunications, New York: John Wiley Sons.

[5] F. G. Xiong. Digital Modulation Techniques, ArtechHouse, pp. 23-234, ISBN 0-89006-970-0, 2000.

[6] B.E.A. Saleh, M.C. Teich. Fundamentals of photonics, A Wiley-Interscience publication, pp. 739, TA1520.S2, 1991.

[7] R. Róka. Fixed Transmission Media, Technology and Engineering Applications of Simulink, InTech, Rijeka (Croatia), ISBN 978-953-51-0635-7, May 2012.

[8] R. Róka. The Simulation of Negative Influences in the Environment of Fixed Transmission Media, In: APSAC 2015, Vienna (Austria), 15.-17.3.2015, pp.58-68, ISBN 978-1-61804-286-6, ISSN 1790-5109.

[9] R. Róka, F. Čertík: Simulation Tools for Broadband Passive Optical Networks. In: Simulation Technologies in Networking and Communications: Selecting the Best Tool for the Test, CRC Press in Taylor&Francis Group, Boca Raton (USA), November 2014, ISBN 978-1-4822-2549-5.

[10] R. Róka, F. Čertík, Modeling of Environmental Influences at the signal transmission in the optical transmission medium, International Journal of Communication Networks and Information Security, Vol.4, No.3, S146-162, ISSN 2073-607X.

[11] Samsung Fiberoptics:
http://www.samsung.com/global/business/fiberoptics/optical-fiber/single-mode