

# Performance of Double Binary Turbo Coding for Visible Light Communication Systems

Sung Wan Koo\*, Jin Young Kim\*

\* Department of Wireless Communication Engineering, Kwangwoon University, Seoul, Korea

Tel: +82-940-5867, Fax: +82-918-0357

[goodtti@kw.ac.kr](mailto:goodtti@kw.ac.kr), [jinyoung@kw.ac.kr](mailto:jinyoung@kw.ac.kr)

**Abstract**— At the ubiquitous age, applications of Wireless Personal Area Network (WPAN) technology using LEDs are in progress. However, visible light communication using LED have weakness, which deteriorates performance of communication. To reduce information losses, which is caused by optical noise, such as incandescent lamps, fluorescent lamps, sunbeam etc., proposed channel coding scheme, double binary turbo codes. In this paper, encoding and decoding scheme of the proposed system is described and simulation results are analyzed. We had expected improved performance by using double binary turbo codes. Finally, performances of the proposed system came up to our expectations.

**Keywords**— Visible light communication, Double binary turbo code, Channel coding, Turbo codes, Max-log MAP algorithm.

## I. INTRODUCTION

Nowadays, the whole world is being confronted with an exhaustion of resources and global warming. To solve this issue, technical development concentrates a more efficient use of energy and renewable energy. In process of it, a great change of lighting industry comes into the spotlight. Incandescent electric lamps which represents for the past hundred years during will be changed to LED lightings which are eco-products and type energy reduction light sources because the sale of them will be prohibited by policy of U.S.A and EU [1-2]. LED lighting appeared in lighting industry at 1996 have a hundred times long-lived than fluorescent lamps and lower power consumption than incandescent lamps. Also, LED lightings are following the Restriction of Hazardous Substances (RoHS) which is regulation to inhibit use of a heavy metal. If it is possible to communication using infrastructure of LED lighting mentioned previously, a cost rebuilding communications infrastructure would reduce and ubiquitous communications would realize in any place where LED light was installed. This is visible light communication which is an advanced convergence technology that integrates lighting device with wireless communications technology.

A great merit of visible light communication works information and illuminate at the same time because LED is a semiconductor diode that emits incoherent narrow-

spectrum light. The other merits is to possible transmitting information in broadband, is higher security, do not harm human beings, to do not possible cross radio frequency (RF) band and is no frequency permission and fee. On the other side, defects of visible light communication are short range of light because of attenuate character, interference phenomenon by interference lights such as solar light, fluorescent lamp, incandescent lamp and high price [3].

Devices related LED is already using around us such as lamp, traffic sign, street lamp, information service device and car's headlights, because of the advantage of LED mentioned. Lighting source of each device can be modulated and then the devices could send the information. Thus, visible light communication systems can be used around us everywhere.

In this paper, communicated between LED lighting of devices, double binary turbo codes to eliminate interference non-causally known at the transmitter is proposed to improve the BER performance. Channel coding is to reduce information rate through the channel and to increase reliability. The scheme is necessary to improve communication quality. Double binary turbo codes are one of the channel coding. It was introduced in the domain of turbo codes by Berrou et al, in 1999 [4].

The paper is organized as follows: In next Section II, it is described system model, which consists of encoding and decoding of double binary turbo codes, and wireless optical channel. Simulation results is illustrated in Section III. The conclusion and future work are given in Section IV.

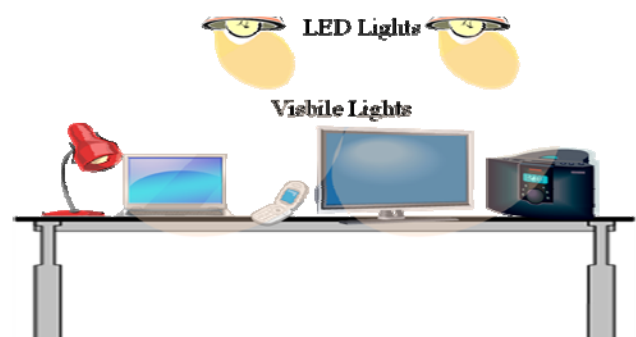


Figure 1. Visible light communication systems concept.

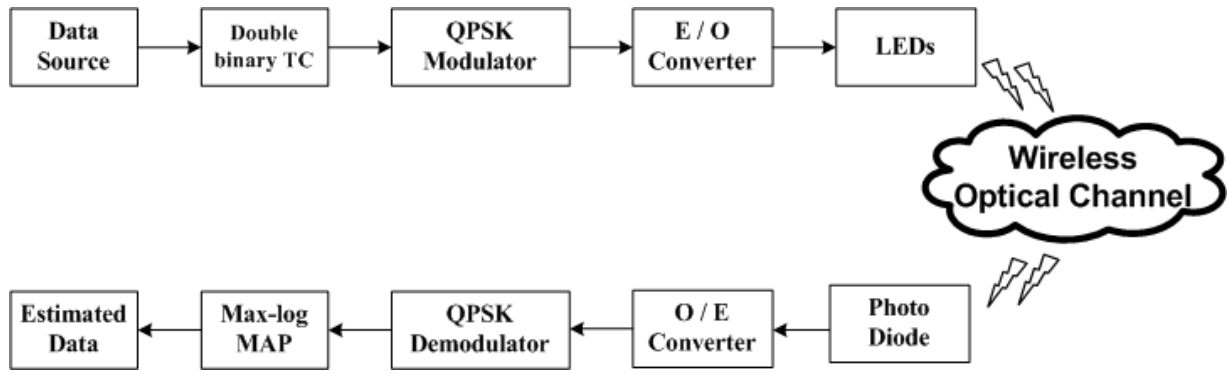


Figure 2. The proposed visible light communication system block model.

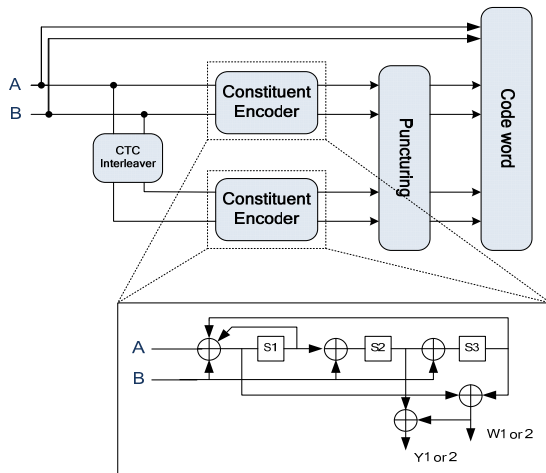


Figure 3. Double binary turbo codes encoder.

## II. SYSTEM MODEL

In this section, we explain the visible light communication system with double binary turbo codes. The proposed scheme is depicted in Fig 1.

### A. Double Binary Turbo Codes

Double binary turbo codes proposed by Berrou *et al.* in 1999 show an improved error correction capability than binary codes for equivalent implementation complexity. The scheme has been adopted by the European Telecommunications Standards Institute (ETSI) for Digital Video Broadcasting with Return Channel via Satellite (DVB-RCS) [11]. Fig. 3 shows the proposed double binary turbo encoder, including two constituent encoders. It uses two double binary Circular Recursive Systematic Convolutional (CRSC) encoders. The bits of the data are alternatively fed to A and B to be encoded, starting with the MSB of the first byte being fed to A, followed by the next bit being fed to B. The encoder is fed blocks of bits.

CRSC have to know initial and final state to improve the decode performance at decoder. To solve, it use the tail biting algorithm. It is to make initial state and final state equally.

The state calls circulation state. Constituent encoder described in Fig. 3 can express state vector equation. State vector  $S_k$  is a functional equation of previous state  $S_{k-1}$  and input vector  $X_k$ . The equation is given by

$$S_k = G \cdot S_{k-1} + X_k, \quad (1)$$

where  $X_k$ ,  $S_k$  and matrix  $G$  is

$$S_k = \begin{bmatrix} S_{0,k} \\ S_{1,k} \\ S_{2,k} \end{bmatrix}, X_k = \begin{bmatrix} A_k + B_k \\ B_k \\ B_k \end{bmatrix}, G = \begin{bmatrix} 1 & 0 & 1 \\ 1 & 0 & 0 \\ 0 & 1 & 0 \end{bmatrix}. \quad (2)$$

Relation between state vector  $S_k$  at time  $K$  and initial state vector  $S_0$ :

$$S_k = G^K \cdot S_0 + \sum_{p=1}^K G^{K-p} \cdot X_p. \quad (3)$$

When circulation state defines  $S_c$ ,  $S_c = S_K = S_0$  is satisfied.  $S_c$  is derived from equation (3),

$$S_c = \langle I + G^K \rangle^{-1} + \sum_{p=1}^K G^{K-p} \cdot X_p, \quad (4)$$

where  $I$  is the identity matrix. When the encoder is initialized in the “all zero” state, at time  $K$ , state vector  $S_K^0$  is given by

$$S_K^0 = \sum_{p=1}^K G^{K-p} \cdot X_p. \quad (5)$$

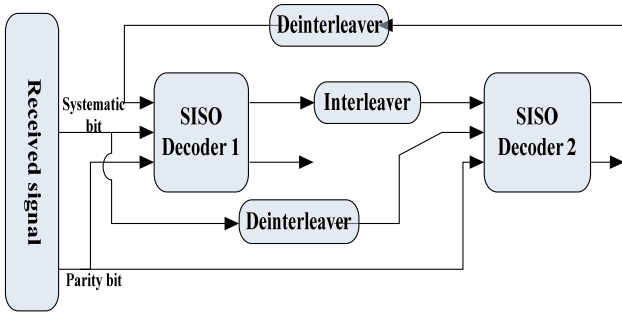


Figure 4. Decoder structure of double binary turbo codes.

Circulation state  $S_c$  can represent using  $S_K^0$  :

$$S_c = \langle I + G^K \rangle^{-1} S_K^0. \quad (6)$$

Relation of  $S_K^0$ ,  $S_K^0$  and  $K$  is calculated [6]. The equation can be calculated when inverse matrix of  $I + G^K$  exist.

After initialization by the circulation state, the first encoder is fed the data bits. Then, the second encoder is fed by the interleaved data bits.

The performance of double binary turbo code is influenced by interleaver structure. In this paper, we use interleaver adopted in IEEE 802.16. The interleaver of CTC encoder in IEEE 802.16 has two steps as follows [11]:

Step 1: Invert the couple.

If  $j \bmod 2 = 0$  ( $j = 0, \dots, N-1$ ),

Let  $(A, B) \rightarrow (B, A)$ .

Step 2:  $j \rightarrow$  new position  $i$ .

If  $j \bmod 4 = 0$ ,  $i = (P_0 \cdot j + 1) \bmod N$ ,

If  $j \bmod 4 = 1$ ,  $i = (P_0 \cdot j + 1 + N/2 + P_1) \bmod N$ ,

If  $j \bmod 4 = 2$ ,  $i = (P_0 \cdot j + 1 + P_2) \bmod N$ ,

If  $j \bmod 4 = 3$ ,  $i = (P_0 \cdot j + 1 + N/2 + P_3) \bmod N$ .

The used turbo decoder is composed of two Maximum A Posteriori (MAP) decoders. According to the principle of iterative decoding algorithm, the decoder of double binary CRSC codes is designed as shown in Fig. 4. It consists of two SISO decoders and each one interleaver and deinterleaver between them. Decoding process in a turbo decoder is performed iteratively through the two SISO decoders via the interleaver and the deinterleaver [8].

For decoding, Max-log MAP algorithm was employed in this paper. Max-log MAP algorithm is the best compromise among other algorithms in terms of performance and implementation complexity. The decoding process in MAP algorithm performs calculations of the forward and backward

state metric values to obtain the Log Likelihood Ratio (LLR) values, which have the decoded bit information and reliability values. To avoid numerical problems without degrading the decoding performance, it calculates the MAP algorithm in the Log-domain [9]. The mathematical formulas are described in [10].

### B. Wireless Optical Channel Model

Considering correctly the reflection, both reflex and diffusion is considered. In indoor, however, diffusion characteristics of representative materials are displayed Lambertian reflector model, plaster wall, acoustic-tiled walls, carpets, and unvarnished woods etc. Therefore, wall or ceiling is calculated as Lambertian reflector. For the theoretical analysis a suitable channel model is required. The channel model used is that proposed by Barry *et al.* [7]. For the LOS case with no reflections and assuming that the source and receiver separation squared  $R^2$  is much greater than the receiver area  $A_R$ , Fig. 5, the channel impulse response can be approximated by a scaled and delayed Dirac delta function:

$$h(t; S, R) \approx \frac{n+1}{2\pi} \cos^n(\psi) d\Omega \text{rect}\left(\frac{\theta}{FOV}\right) \delta\left(t - \frac{R}{c}\right), \quad (10)$$

where  $d\Omega$  is defined as the solid angle subtended by the receiver's differential area

$$d\Omega \approx \cos(\theta) \frac{A_R}{R^2}, \quad (11)$$

where  $\theta$  is the angle between  $\hat{n}_R$  and  $(r_S - r_R)$

$$\cos(\theta) = \hat{n}_R \cdot \frac{(r_S - r_R)}{R}, \quad (12)$$

$\psi$  is the angle between  $\hat{n}_S$  and  $(r_R - r_S)$

$$\cos(\psi) = \hat{n}_S \cdot \frac{(r_R - r_S)}{R}, \quad (13)$$

$n$  is the mode number associated with the directivity of the source and calculated from the source half-angle,  $\alpha_H$ , using a equation (14)

$$\alpha_H = \cos^{-1}(0.5)^{\frac{1}{n}} \\ \Rightarrow n = \frac{\log 0.5}{\log(\cos \alpha_H)}. \quad (14)$$

The number of physical parameters such as the source mode number  $n$  was not available from the datasheets and hence had to be experimentally and calculated.

The visible light communication systems channel can be modelled with an AWGN model. In optical channels, the quality of transmission is typically dominated by shot noise. Because receiver employs a narrow band optical filter, however, the system can neglect the shot noise caused by signals. Accordingly, the optical wireless channel model is expressed as follows:

$$y(t) = r \cdot x(t) \otimes h(t) + n, \quad (15)$$

where  $y(t)$  represents the received signal current,  $x(t)$  represents the transmitted optical pulse,  $n(t)$  represents the AWGN noise, and the symbol  $\otimes$  denotes convolution.  $r$  represents an Optical / Electric (O/E) conversion efficiency.

In this paper, we use channel impulse response and depicted in figure 5. It considers bounces of the ninth times.

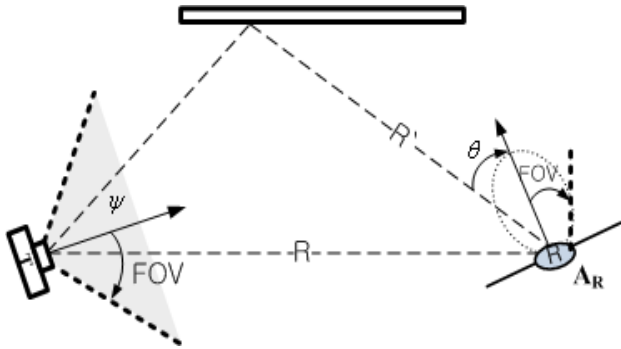


Figure 5. Diffused LOS links.

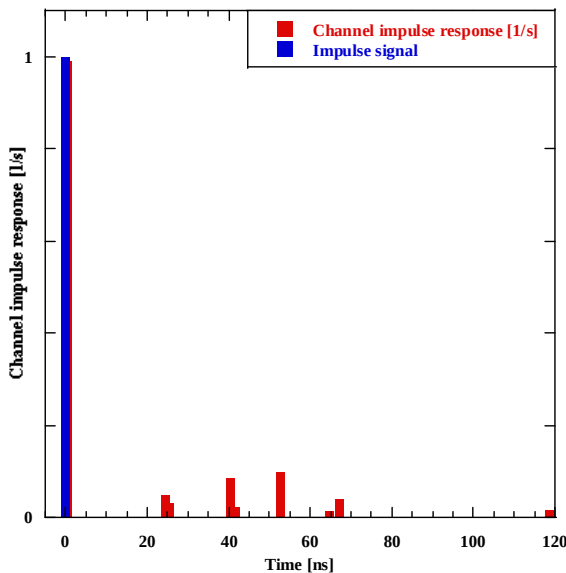


Figure 6. bounced channel impulse response, the ninth times.

### III. SIMULATION RESULTS

In this section, the proposed visible light communication system is simulated using channel impulse response calculated in indoor environments and AWGN. Primary modulation is QPSK, optical modulation is Intensity Modulation/Direct Detection (IM/DD), and O/E efficiency is 1 [A/W].

Figure 7 is represented BER performance of a comparison double binary turbo codes with un-encoded. We can get better BER performance about 6 [dB] in visible light communication channel using double binary turbo codes.

Figure 8 is showed BER performance with the number of iteration in visible light communication channel. We can know that the more the number of iteration increase, BER performance is improved.

Figure 9 is illustrated BER performance about code rate. It is simulated differently about code rate, 1/3, 2/5, 1/2, 2/3, 3/4, 4/5, and 6/7. The more code rates increase, the more BER performance gets worse.

Figure 10 and 11 are depicted performance about Frame Error Rate (FER). We can get performances like BER performance.

### IV. CONCLUSION

Visible light communication systems have a number of advantages, such as high bit rates as fast as 100 [Mbps], no interference to RF based devices, safety, and free of band licensing etc. However, disadvantages also exist: short distance, interference caused to solar light and other lighting, and high price. In the paper, in order to reduce a loss of information according to channel condition and transmission length, the proposed system is simulated using a computer simulation.

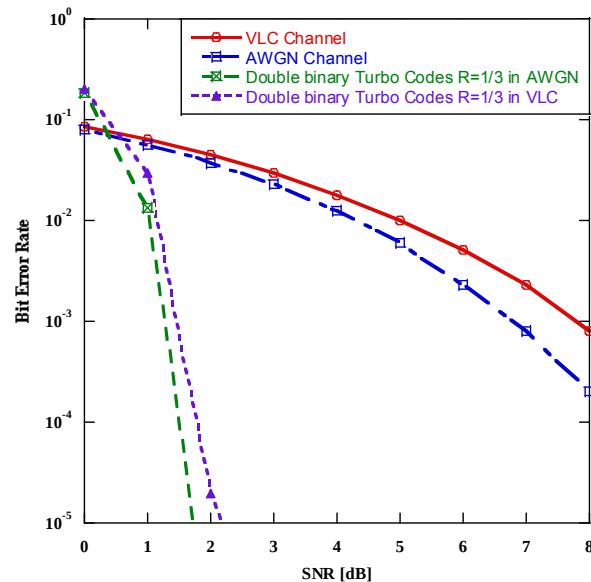


Figure 7. BER performance with double binary turbo codes.

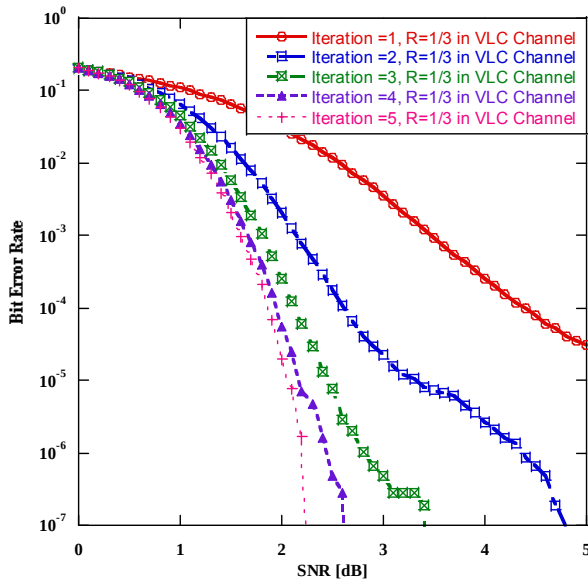


Figure 8. BER performance of double binary turbo codes with iteration number.

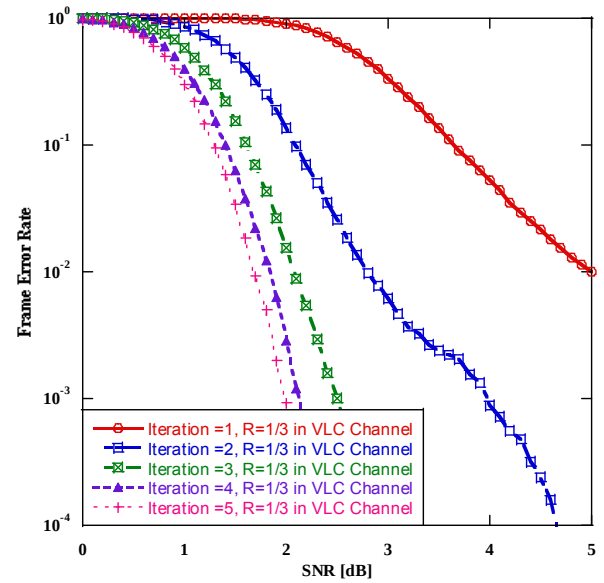


Figure 10. FER performance of double binary turbo codes with iteration number.

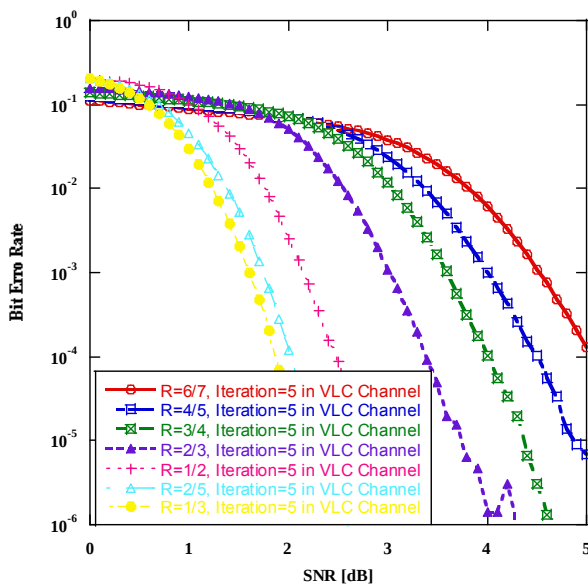


Figure 9. BER performance of double binary turbo codes with code rate.

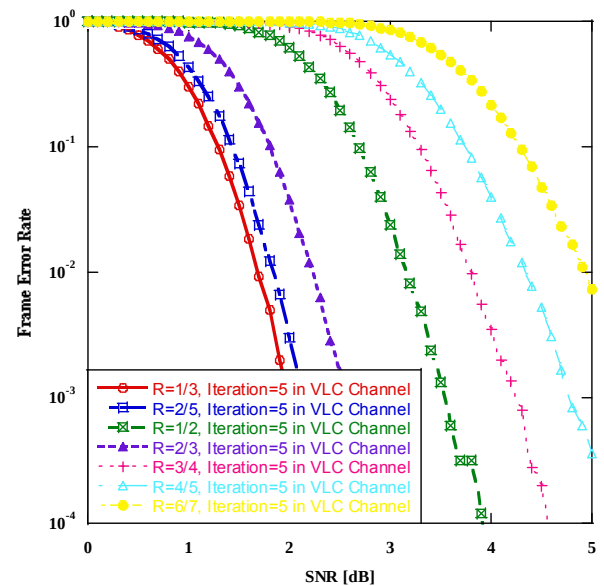


Figure 11. FER performance of double binary turbo codes with code rate.

Resulting of simulation, as rate of turbo code increases, it is know that the performance of BER is not good. If turbo codes are applied in visible light communication systems, it reduces information losses. Therefore, it will guarantee the reliability about information.

Hereafter, we will analyze the simulation over multi-path fading channel and according to distance.

Research of optical channel model and continuous improvement about a power loss between transmitter and receiver are required, in order that visible light

communication systems using LED illumination infra in indoor environment is used in real life.

## REFERENCES

- [1] Jin Young Kim, *Visible Light Communication Systems*. Seoul, Korea, MA: Hongreung Science Publishers, 2009.
- [2] T. Komine and M. Nakagawa, "Fundamental analysis for visible-light communication system using LED lights," in *Consumer Electronics, IEEE Transactions on*, vol. 50, no. 1, pp. 100-107, Feb. 2004.
- [3] Y. Tanaka, T. Komine, S. Haruyama and M. Nakagawa. "Indoor visible communication utilizing plural white LEDs as lighting," in

- Personal, Indoor and Mobile Radio Communications, 2001 12th IEEE International Symposium on*, vol. 2, pp. 81-85, Sep. 2001.
- [4] C. Berrou, A. Glavieux, and P. Thitimajshima, "Near shannon limit error-correcting coding : turbo codes (1)," in *Communications, 1993. ICC 93. Geneva. Technical Program, Conference Record, IEEE International Conference on*, vol. 2, pp. 1064-1070, May 1993.
  - [5] C. Berrou and A. Glavieux, "Near optimum error correcting coding and decoding: turbo-codes," in *Communications, IEEE Transactions on*, vol. 44, no. 10, pp. 1261-1271, Oct. 1996.
  - [6] J. B. Anderson and S. M. Hladik, "Tailbiting MAP decoders," in *Selected Areas in Communications, IEEE Journal on*, vol. 16, no. 2, Feb. 1998.
  - [7] J. R. Barry, *Wireless Infrared Communications*. Norwell, MA: Kluwer Academic Publishers, 1994.
  - [8] J. P. Woodard and L. Hanzo, "Comparative study of turbo decoding techniques: an overview," in *Vehicular Technology, IEEE Transactions on*, vol. 49, no. 6, pp. 2208-2233, Nov. 2000.
  - [9] P. Robertson, P. Hoeher, and E. Villebrun, "Optimal and sub-optimal maximum a posteriori algorithm suitable for turbo decoding," *European. Transactions on Telecommunication*, vol. 8, no. 2, pp. 119-125, Mar.-Apr. 1997.
  - [10] M. R. Soleymani, Y. Gao, and U. Viliyornasawai, *Turbo Coding for Satellite and Wireless Communications*. Norwell, MA: Kluwer Academic Publishers, 1994.
  - [11] J. Yu, M. L. Boucheret, R. Vallet, and G. Mesnager, "Interleaver parameter-selecting strategy for DVB-RCS turbo codes," in *Electronics Letters*, vol. 38, pp. 805-807, Jul. 2002.