Int'l J. of Communications, Network and System Sciences, **2011, 4, 388-394**
doi:10.4236/ijcns.2011.46046 Published Online June 2011 (http://www.SciRP.org/journal/ijcns)

Performance Study of the Association TCM-UGM/STBC to Reduce Transmission Errors of JPEG Images

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Received February 24, 2011; *revised March* 20, 2011; *accepted March* 31, 2011

Abstract

The purpose of this work is to associate the channel encoder called 'trellis-coded modulation with Ungerboeck-Gray mapping' (TCM-UGM) to 'space-time block code' (STBC), in order to study its performance to correct the transmission errors of a JPEG image. The performance of the proposed scheme is evaluated in senses of bit error rate (BER), frame error rate (FER) and peak signal-to-noise ratio (PSNR) of the reconstructed image. Compared to the association TCM/STBC for a throughput of 2 bits/s/Hz, TCM-UGM/STBC permits to obtain a PSNR gain up to 2 dB.

Keywords: Trellis-Coded Modulation, Trellis Coded Modulation with Ungerboeck-Gary Mapping, Logarithm of Maximum a Posteriori, Space-Time Block Code, JPEG

1. Introduction

In future wireless communication systems, high data rates need to be reliably transmitted over time-varying band limited channels. The wireless channel mainly suffers from time-varying fading due to multipath propagation and destructive superposition of signal received over different paths. Fortunately, the effects of fading can be substantially mitigated by the use of diversity. Different transmit diversity techniques have been introduced. In [1], Tarokh *et al*. proposed space-time trellis coding by jointly designing the channel coding, modulation, transmit diversity and the optional receiver diversity. The proposed space-time trellis codes perform extremely well at the cost of high complexity. In addressing the issue of decoding complexity, Alamouti [2] discovered a remarkable scheme for transmissions using two transmit antennas. A simple decoding algorithm was introduced, which can be generalised to an arbitrary number of receive antennas. This scheme is significantly less complex, than space-time trellis coding using two transmit antennas, although there is a loss in performance [3]. Despite the associated performance penalty, Alamouti's scheme is appealing in terms of simplicity and performance. This proposal motivated Tarokh *et al*. [3,4] to generalise the scheme to an arbitrary number of transmit antennas, leading to the concept of space time block codes. Space-time block codes were designed for achieving the maximum diversity order of $n \times m$ for n transmit and m receive antennas. However, they were not designed for achieving additional coding gain.

Hence, in this contribution, we combine space-time block codes with Trellis Coded Modulation (TCM) [5,6], and TCM-UGM [7] in order to achieve additional coding gains. The simulation results showed that the TCM-UGM outperforms the original TCM scheme proposed by Ungerboeck by 2.59 dB over Rayleigh fading channel [7]. The comparison is done at a Bit Error Rate (BER) of 10 - 5. Visual signals such as compressed still images are very vulnerable to channel noise.

Usually, channel coding is utilized to protect the transmitted visual signals. The Joint Photograph Experts Group (JPEG) standard [8] proposed in 1992 is widely used for still image compression and transmission. JPEG has 4 distinct modes of operation: sequential DCT-based, progressive DCT-based, lossless, and hierarchical [9]. JPEG, a DCT-based image compression algorithm [10], is the current ISO standard for the encoding of still images. The JPEG algorithm follows a block-based compression approach. It divides the input image into 8 × 8 pixel blocks, transforms each block using DCT, and then codes the DC and AC coefficients. In this paper, we provide an efficient scheme for transmitting JPEG compressed images using the concatenation of STBC with

TCM-UGM system (TCM-UGM/STBC). The considered image is compressed using JPEG compression algorithm then coded with TCM-UGM/STBC or TCM/STBC. At the receiver, symbol-by-symbol MAP TCM-UGM or TCM decoding algorithm is applied, and the image is reconstructed by decompression algorithm.

2. Space-Time Block Codes

A Space Time Block Code describing the relationship between the original transmitted signal and the signal replicas artificially created at the transmitter for transmission over various diversity channels is defined by an $n_T xp$ dimensional transmission matrix. The entries of the matrix are constituted of linear combinations of the *k*-airy input symbols $x_1, x_2, \cdots, x_k$ and their conjugates. The k-airy input symbols $x_i i = 1 \cdots k$ are used to represent the information-bearing binary bits to be transmitted over the transmit diversity channels. In a signal constellation having 2^m constellation points, a number m of binary bits are used to represent a symbol x_i. Hence, a block of *kxm* binary bits are entered into the STB encoder at a time and it is, therefore, referred to as a STB code. The number of transmitter antennas is n_T and p represents the number of time slots used to transmit *k* input symbols. Hence, a general form of the transmission matrix of a STBC is written as

$$\begin{pmatrix} g_{11} & g_{21} & \cdots & \cdots & g_{p1} \\ g_{12} & g_{22} & \cdots & \cdots & g_{p2} \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ g_{1n} & g_{2n} & \cdots & \cdots & g_{pn} \end{pmatrix} \quad (1)$$

where the entries g_{ij} represent linear combinations of the symbols $x_1, x_2, \cdots, x_k$ and their conjugates. More specifically, the entries g_{ij}, where x_i, $i = 1, \cdots, n_T$ are transmitted simultaneously from transmit antennas $1, \cdots, n_T$ in each time slot $j = 1, \cdots, p$.

The transmission matrix in Equation (1) (which defines the STBC) is based on a complex generalized orthogonal design, as defined in [3]. Since there are *k* symbols transmitted over *p* time slots, the code rate of the STBC is given by

$$Rate = \frac{k}{p} \quad (2)$$

At the receiving end, one can have an arbitrary number of n_R receivers. A simple transmit diversity scheme for two transmit antennas was introduced by Alamouti in [2]. The transmission matrix is

$$G_2 = \begin{pmatrix} x_1 & x_2 \\ -\overline{x}_2 & \overline{x}_1 \end{pmatrix} \quad (3)$$

It can be seen in the transmission matrix $\boldsymbol{G}_2$ that there are $n_T = 2$ (number of columns in the matrix $\boldsymbol{G}_2$) transmitters, $k = 2$ possible input symbols, namely, x_1, x_2 and the code spans over $p = 2$ (number of rows in the matrix $\boldsymbol{G}_2$) time slots. Since $k = 2$ and $p = 2$, the code rate is unity. The associated encoding and transmission process is shown in **Table 1**. At any given time instant *T*, two signals are transmitted simultaneously from the antennas Tx_1 and Tx_2. For example, in the first time slot $T = 1$, signal x_1 is transmitted from antenna Tx_1 and signal x_2 is transmitted simultaneously from antenna Tx_2. In the next time slot $T = 2$, signals $-\overline{x}_2$ and $\overline{x}_1$ (the conjugates of symbols x_1 and x_2) are simultaneously transmitted from antennas Tx_1 and Tx_2, respectively.

Figure 1 shows the base band representation of a simple two-transmitter STBC, namely, that of the $\boldsymbol{G}_2$ code seen in Equation (3) using one receiver. We can see from the **Figure 1** that there are two transmitters, namely, Tx_1 as well as Tx_2 and they transmit two signals simultaneously. As it can be seen from the **Figure 1**, the transmitted symbol x_1 and x_2 propagates through two different fading channels, namely, h_1 and h_2. As mentioned earlier,

Table 1. Encoding and transmission process for the STBC.

	Antenna	
Time slot, *T*	Tx_1	Tx_2
1	x_1	x_2
2	$-\overline{x}_2$	$\overline{x}_1$

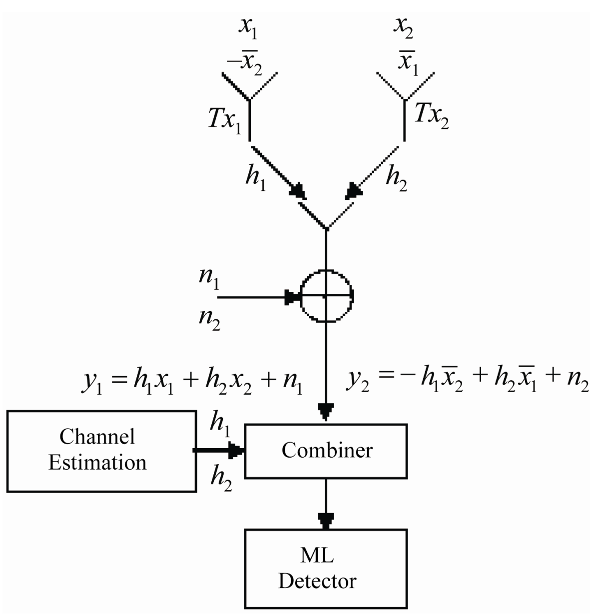

Figure 1. Base band representation of the simple two transmitters STBC $\boldsymbol{G}_2$ of (3) using one receiver.

the complex fading envelope is assumed to be constant across the corresponding two consecutive time slots.

$$h_1 = h_1(T = 1) = h_1(T = 2) \quad (4)$$

$$h_2 = h_2(T = 1) = h_2(T = 2) \quad (5)$$

At the receiver, independent noise samples, n_1 and n_2 are added in each time slot; hence the signals received over non dispersive or narrow-band channels can be expressed with the aid of Equation (3) as

$$y_1 = h_1 x_1 + h_2 x_2 + n_1 \quad (6)$$

$$y_2 = -h_1 \bar{x}_2 + h_2 \bar{x}_1 + n_2 \quad (7)$$

where y_1 is the first received signal and y_2 is the second. Note that the received signal y_1 consists of the transmitted signals x_1 and x_2, while y_2 consists of their conjugates. In order to determine the transmitted symbols, we have to extract the signals x_1 and x_2 from the received signals y_1 and y_2. Therefore, both signals y_1 and y_2 are passed to the combiner, as shown in **Figure 1**. In the combiner-aided by the channel estimator, which provides perfect estimation of the diversity channels in this example simple signal processing is performed in order to separate the signals x_1 and x_2. Both signals x_1 and x_2 are then passed to the maximum likelihood detector of **Figure 1**, based on the Euclidean distances between the combined signal x and all possible transmitted symbols. The simplified decision rule is based on choosing x_i if and only if

$$\mathrm{dist}(\hat{x}, x_i) \le \mathrm{dist}(\hat{x}, x_j) \quad \forall i \ne j \quad (8)$$

where dist(A, B) is the Euclidean distance between signals A and B and the index j spans all possible transmitted signals. From Equation (8), we can see that maximum likelihood transmitted symbol is the one having the minimum Euclidean distance from the combined signal $\hat{x}$.

3. Trellis Coded Modulation with Ungerboeck-Gray Mapping

The TCM scheme, proposed by Ungerboeck, was designed for throughput of m bits/sec/Hz, where m bits are input to the encoder (among input bits $\tilde{m} \ge 0$ are uncoded) and m + 1 bits are output and mapped with 2^{m+1}-airy modulation using set partitioning yielding a coding rate

$$R = \frac{m}{m+1} \quad (9)$$

In this case the mapping by set partitioning (called also Ungerboeck mapping) is applied. The Ungerboeck TCM encoder was chosen by maximizing d_f. In [5], d_f is compute by an algorithm that replaces the search in TCM trellis for the path that maximizes d_f. In [7], the TCM-UGM scheme considered, for a throughput of m bits/sec/Hz, that the mapper is a 2^{m+1}-airy that uses a mapping technique combining Ungerboeck mapping and Gray code mapping. In this case, $m - \tilde{m}$ bits are input to the encoder, and systematically output and mapped using Ungerboeck mapping. The Gray mapping is applied on the remaining $\tilde{m}$ $(\tilde{m} \ge 1)$ uncoded bits and the generated parity bit. When no uncoded bits are considered ($\tilde{m} = 0$), this scheme is equivalent to Ungerboeck TCM scheme with $\tilde{m} = 0$. In [7], the optimal encoder code-generator is obtained by searching in the trellis, of two different paths (with a minimum Euclidean distance) that begin at state zero and finish to the same state. The optimal code-generator is obtained by maximizing *df*. In this work, the TCM-UGM encoder, illustrated in **Figure 2**, considers m = 2 input bits of which no uncoded bits are considered ($\tilde{m} = 0$).

4. Proposal System

Figure 3 represents the image transmission system for which we evaluate the FER and PSNR after decoding. An input image is compressed by JPEG. The binary symbols resulting from the JPEG compressing constitute the sequence of data to be transmitted. The information data is first encoded by the TCM or TCM-UGM encoder exposed in section 3. The complex constellation symbols, generated by mapper, are interleaved and fed into the space-time block encoder described in section 2 (with n_T transmit and n_R receive antennas). At each time slot T, the output symbols x_i are modulated and transmitted simultaneously each from a different transmit antenna. At the receiver end, the received noisy symbol is decoded using space-time block decoder and deinterleaved giving a soft-decision exploited by TCM or TCM-UGM decoder and is used for the reconstruction image.

5. Simulation Result

The performance simulation of the associations TCM/

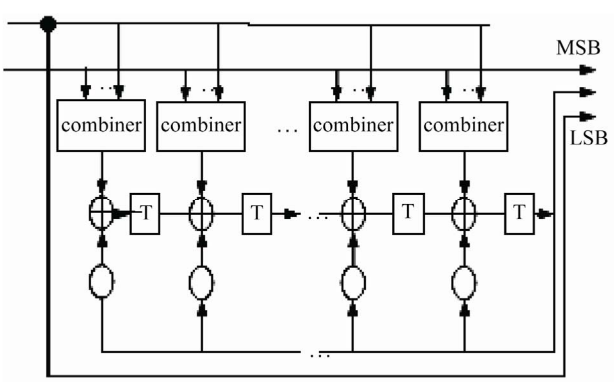

Figure 2. TCM-UGM encoder for 2 bits/s/Hz.

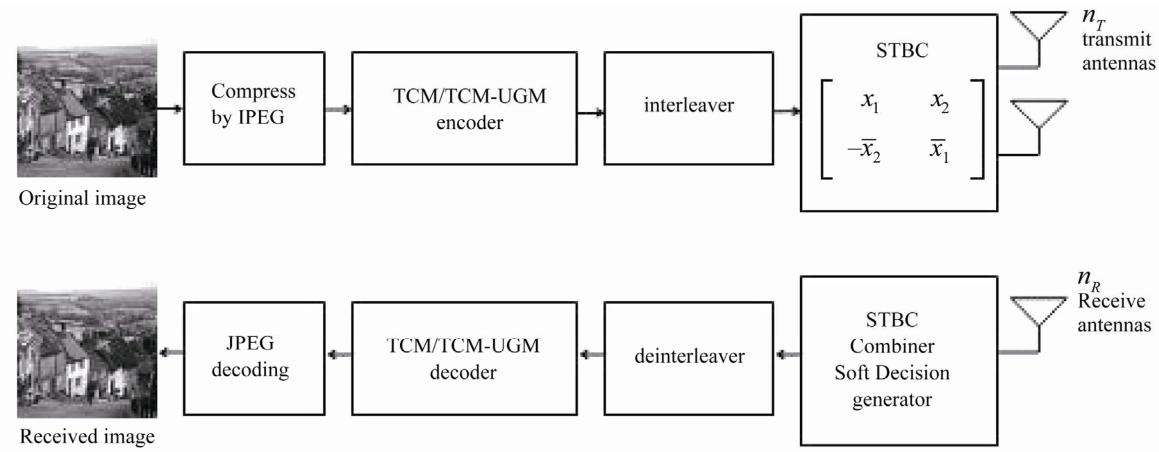

Figure 3. A block diagram of a communication system, $n_T = 2$; $n_R = 1$.

STBC and TCM-UGM/STBC using 8PSK Ungerboeck mapper (for TCM) and Ungerboeck-Gray mapper (for TCM-UGM) are investigated for throughput 2 bit/s/Hz for JPEG image transmission. Rate 2/3 and 16-state TCM or TCM-UGM encoder is considered. Transmission over MRF channel, using one receiver antenna, is simulated employing STBC with $\boldsymbol{G}_2$ as orthogonal code. The optimal encoders' code-generator (in sense of d_f) for the used TCM and TCM-UGM encoders are illustrated in **Table 2** (the average power per dimension in the constellation is normalized to 1/2).

In simulation, a variety of raw images with high resolution (512 × 512 pixels) are used (boat image in **Figure 9**, goldhill image in **Figure 12** and concord aerial in **Figure 15**). The images transmitted have different bit per pixel (bpp) (**Table 3**) to illustrate the effectiveness of the proposed system

The performance of the encoding schemes is evaluated in terms of BER (Bit Error Rate) and FER (Frame Error Rate) versus bit energy to noise ratio (E_b/N_0). The FER computation considers a frame length of 1024.

Figures 4 and **5** illustrate the performance in sense of BER and FER, respectively, of TCM/STBC and TCM-UGM/STBC considering one receiver antenna for the transmission of this JPEG images. It can be observed that the system TCM-UGM/STBC presents better results than the TCM/STBC from a E_b/N_0 of 10 dB for BER curves and 7 dB for FER curves. The TCM-UGM/STBC system outperforms the performance of the association TCM/STBC by 0.4 dB at BER = 10^{-5} and 0.9 dB at FER = 10^{-3}.

The Peak Signal-to-Noise Ratio (PSNR) is the most commonly used as a measure of quality of reconstruction in image compression. The PSNR were identified using the following formulae:

$$\mathrm{MSE}^2 = \frac{1}{\mathrm{MxN}} \sum_{i=1}^{i=N} \sum_{j=1}^{j=M} \left(I(i,j) - \hat{I}(i,j) \right)^2 \tag{10}$$

Mean Square Error (MSE) which requires two MxN grayscale images I and $\hat{I}$ where one of the images is considered as a compression of the other is defined as: The PSNR is defined as:

$$\mathrm{PSNR} = 10 \log_{10} \left(\frac{(\text{Dynamics of image})^2}{\mathrm{MSE}} \right) \tag{11}$$

Usually an image is encoded on 8 bits. It is represented by 256 gray levels, which vary between 0 and 255, the extent or dynamics of the image is 255.

Figure 6 to **Figure 8** illustrate the performance curves of the PSNR of the reconstructed image vs E_b/N_0. From these figures, it can be shown clearly that the proposed system based on TCM-UGM gives better performance. For an E_b/N_0 of 11 dB a PSNR improvement of around 2 dB is obtained for Boat and Goldhill images and around 0.6 dB to the Concord-aerial image.

Figures 10 and **11** represent, respectively, the reconstructed Boat image after transmission using the TCM-UGM/STBC and TCM/STBC for E_b/N_0 equals 11 dB; we can observe a clear visual improvement made by the proposed system. The same remark can be done for the other images (**Figure 13** and **Figure 14** for the Goldhill

Table 2. Code-generator for throughput 2bits/s/Hz STBC encoding and transmission process for the STBC.

	d_f^2	Memory order	Code-generator		
			h_0	h_1	h_2
TCM	5.172	4	31	14	30
TCM-UGM	5.172	4	23	34	15

Table 3. Bit Per Pixel rate for different images.

Image	Concord-aerial	Boat	Goldhill
Bit per pixel	0.5	0.4	0.61

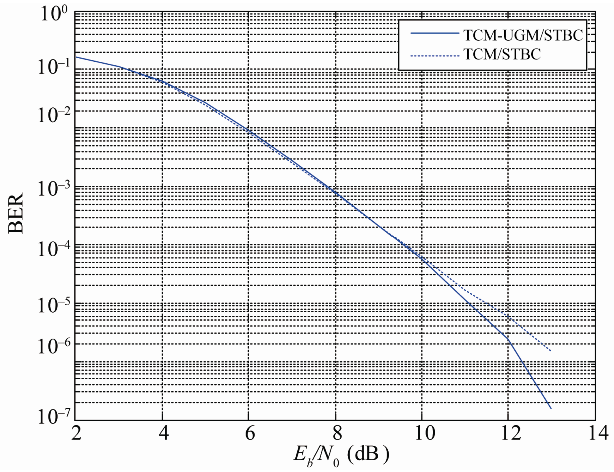

Figure 4. BER performance of TCM/STBC and TCM-UGM/STBC schemes over MRF channel (n_R = 1).

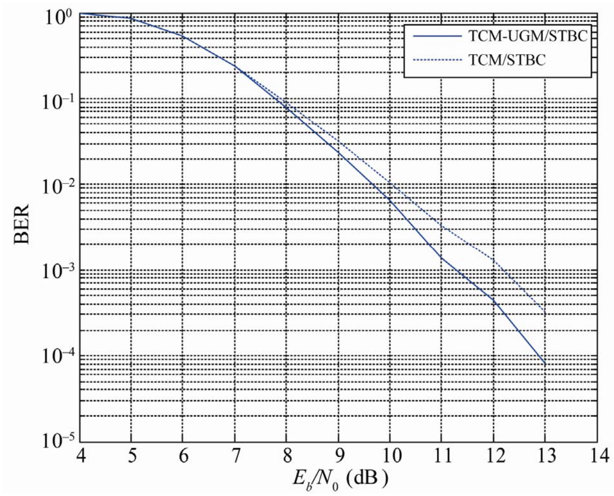

Figure 5. FER performance of TCM/STBC and TCM-UGM/STBC schemes over MRF channel (n_R = 1).

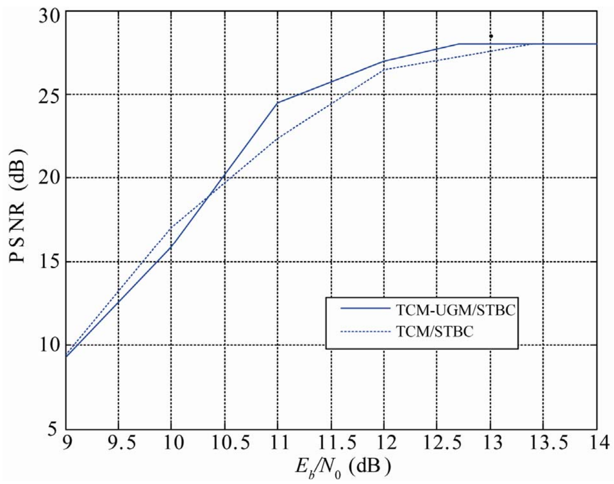

Figure 6. Performance PSNR vs E_b/N_0 for JPEG boat image transmission bpp = 0.4.

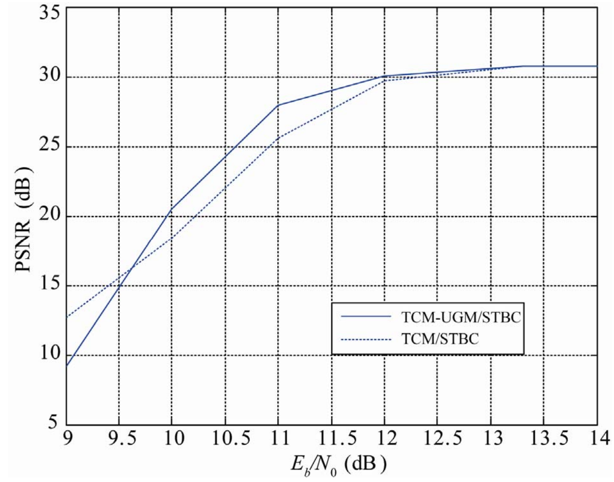

Figure 7. Performance PSNR vs E_b/N_0 for JPEG goldhill image transmission bpp = 0.61.

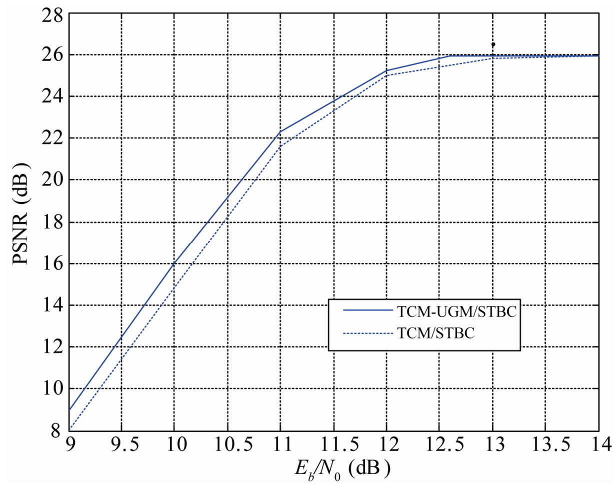

Figure 8. Performance PSNR vs E_b/N_0 for JPEG concord-aerial image transmission bpp = 0.5.

Figure 9. Original Boat image.

Figure 10. Reconstructed Boat image for TCM-UGM/STBC, bpp = 0.4, E_b/N_0 = 11dB, PSNR = 24.52 dB.

Figure 11. Reconstructed Boat image for TCM/STBC, bpp = 0.4, E_b/N_0 = 11 dB, PSNR = 22.28 dB.

Figure 12. Original goldhill image.

Figure 13. Reconstructed Goldhill image for TCM-UGM/STBC bpp = 0.61, E_b/N_0 = 11dB, PSNR = 27.92 dB.

Figure 14. Reconstructed Goldhill image for TCM/STBC bpp = 0.61, E_b/N_0 = 11 dB, PSNR = 25.58 dB.

Figure 15. Original concord-aerial image.

Figure 16. Reconstructed concord-aerial image for TCM-UGM/STBC bpp = 0.5, E_b/N_0 = 11 dB, PSNR = 22.26 dB.

Figure 17. Reconstructed concord-aerial image for TCM/STBC bpp = 0.5, E_b/N_0 = 11 dB, PSNR = 21.58 dB.

image and, **Figure 16** and **Figure 17** for the Concord-aerial image).

6. Conclusions

In this work, TCM-UGM/STBC encoding scheme has been used to correct compressed JPEG images transmission errors. The simulation results over MRF channel have shown that the proposed scheme offers better performance in sense of FER and PSNR of the reconstructed images, compared to TCM/STBC scheme. For a throughput of 2 bits/s/Hz and an E_b/N_0 of 11 dB, TCM-UGM/STBC permits to obtain a PSNR gain of 2 dB.

7. References

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