Performance Analysis of Trellis Coded Modulation and Diversity Combining on Wireless Channel

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Abstract. The use of trellis coded modulation (TCM) and diversity maximal ratio combining (MRC) are applied in this research in order to overcome the impairment of information signals caused by fading and noise. TCM is chosen due to its ability to correct error without increasing the transmit power and channel bandwidth. MRC is used to obtain multiple data streams corresponding to the transmitted image at the receiver. The testing of the system is carried out by calculating peak signal to noise ratio (PSNR) and bit error rate (BER). The result of this simulation shows that the use of TCM and MRC in the image transmission system improves significantly compare to the system which only use TCM without MRC.

1. Introduction

Currently, people tend to use multimedia communication over wireless channels and becomes the important technologies in the telecommunications market. Wireless communication uses information such as data, voice, images, and video [1]. However, wireless communication systems are prone to fading and noise phenomena which cause burst errors in the transmission channel [2]. This fading phenomenon is random and causes problem to image transmission in wireless channels when compared to image transmission in cable environment channels [3].

One of the simple and the efficient techniques to overcome the impairment of information signals caused by fading is to use diversity maximal ratio combining (MRC) [4-9] and Trellis Code Modulation (TCM) [10-11]. This technique will take advantage of the random propagation of radio waves that is by finding a method to generate and extract independent signal paths [11-13]. The concept of diversity is very simple, that is, if one path of radio waves experiences interference caused by fading, it is possible that there are other trajectories that have better signals. With the number of signal paths to choose, the average signal to noise ratio(SNR) can be improved at the receiver [1-13].

TCM is used for data communication which aims to obtain noise immunity through uncoded transmission without changing data rates. The use of TCM is also to improve the system performance without increasing the transmit power and channel bandwidth. Modulation Quaternary Phase Shift Keying (QPSK) is used in TCM to increase data transmission rate [11].

One of the ways to determine the quality of a digital transmission system is to measure the peak signal to noise ratio (PSNR) and bit error rate (BER) [10-11]. PSNR is a useful parameter to determine the quality of reconstruction image. PSNR calculation is done by comparing the pixel value of the
original image with the pixel value of the reconstructed image. PSNR shows the quality of the reconstructed image. The higher the PSNR value is obtained, the better the quality of the image [14-15]. BER is calculated by comparing the transmitted bit sequence and the received bit, in which the number of errors is calculated [14-15].

Several techniques have been used to improve the performance of systems such as the use of diversity technique equal gain combining on radio frequency [7-9, 15]. This technique is good apply because the increment of signal to noise ratio (SNR) will increase peak signal to noise ratio (PSNR) and also will degrade bit error rate (BER) [15]. The use of diversity maximum ratio combining on wavelet domain improves the performance of image reconstruction[15]. Diversity techniques use on wavelet domain is to get better reconstruction image that used a two-state Gilbert-Elliott channel [14].

In this research, TCM and MRC are chosen due to its high ability in detecting and correcting errors on the image that caused by fading and noise. The experiment is done by comparing the TCM with and without using MRC on radio frequency. The evaluation of the improvement quality system on the image transmission is calculated by the use of BER and PSNR. In the simulation, image information with size 8 bpp is compressed by SPIHT with bit rate 0.8 bpp. The purpose of using SPIHT [16] compression is to minimize signal bandwidth so that the use of transmission channel become more efficient.

The design system of SPIHT compressed image transmission use TCM with and without MRC on radio frequency can be seen in figure 1. The transmission image is a 8-bit 512 x 512 Grayscale Lena Image. Before compressing the image, the image is decomposed with a wavelet transform. This transformation uses Haar wavelet and to optimize the system performance, a transformation with the maximum decomposition level is used. This maximum level will divide the image into 28 subbands which consist of 1 low resolution subband and 27 detail subbands, of which 1 low resolution subband consists of 1 pixel. The output of wavelet transform on image is compressed with the SPIHT [16] algorithm, which resulting bits stream. These bits stream are the result of bit rate 0.8 bpp. The TCM encoder uses Trellis diagram. This system uses poly2trellis which has constraints length \( l = 7 \) and the code generator \( g_0 = 1 + x^1 + x^2 + x^3 + x^6 \) and \( g_1 = 1 + x^2 + x^3 + x^5 + x^6 \) [11].

Figure 1. The design system of SPIHT [16] compressed image transmission with TCM and MRC technique in Radio Frequency Domain.
The output of TCM Code is then modulated QPSK before it is transmitted to the wireless channel. This modulation removes the carrier component so that the signal that has been produced is in a complex form [10-11]. The equation for modulation signal is given below:

\[
s_{bb}(t) = X_I(t) + jX_Q(t) \tag{1}
\]

\[
X_I(t) = A \cdot \cos \phi(t) \tag{2}
\]

\[
X_Q(t) = A \cdot \sin \phi(t) \tag{3}
\]

\[
s_{bb}(t) \text{ is the equation of the modulation signal, } X_I(t) \text{ and } X_Q(t) \text{ are the inphase and quadrature components of the information signal. Fading used in this channel model is a type of slow flat fading with Rayleigh distributed. Generating of signal fading is done by using the summing sine method as shown in the following equations } [10-11]:
\]

\[
h_I(nT_s) = \frac{1}{\sqrt{M}} \sum_{m=1}^{M} \cos \left( 2\pi f_D \cos \left( \frac{(2m-1)\pi + \theta}{4M} \right) \cdot nT_s + \alpha_m \right) \tag{4}
\]

\[
h_Q(nT_s) = \frac{1}{\sqrt{M}} \sum_{m=1}^{M} \sin \left( 2\pi f_D \cos \left( \frac{(2m-1)\pi + \theta}{4M} \right) \cdot nT_s + \beta_m \right) \tag{5}
\]

\[
h(nT_s) = h_I(nT_s) + j \cdot h_Q(nT_s) \tag{6}
\]

where:

- \( h_I(nT_s) \) = inphase fading components
- \( h_Q(nT_s) \) = quadrature fading components
- \( h(nT_s) \) = Rayleigh fading
- \( M \) = number of multipath components
- \( f_D \) = maximum Doppler spread
- \( T_s \) = periodic sampling
- \( \theta, \alpha, \) dan \( \beta \) = random variable uniform distribution [0,2π]

The receiver captures two signals that are independent on fading and noise from the transmission channel. Then, the signals from each antenna diversity are co-phased and weighted, both of which are carried out by estimation process. The co-phase process and weighting are carried out by the equation [5]:

\[
s_{MRC1} = A_1 \cdot e^{-j\phi_1} \cdot s_{kanal1} \tag{7}
\]

\[
s_{MRC2} = A_2 \cdot e^{-j\phi_2} \cdot s_{kanal2} \tag{8}
\]

where \( A \) and \( \phi \) are the weights and estimation phases of signals diversity branch. These two results are then summed to produce the signal as the results of diversity MRC. MRC output is demodulated QPSK

\[
s_{bb}(nT_s) \text{ is then multiplied by the fading signal } h(nT_s), \text{ so that amplitude and phase fluctuations occur, as formulated below } [11]:
\]

\[
s_{fd}(nT_s) = s_{bb}(nT_s) \cdot h(nT_s) \tag{9}
\]

After eliminate the bits training sequence from the output of the QPSK demodulator, the bit sequence is converted to decimal form for the input from the TCM decoder. The decoder process of TCM produces bit stream that has minimum error. To test the errors that occur in the system
performance of TCM with and without MRC on radio frequency, BER is calculated by comparing the bit streams of TCM encoder input with the TCM decoder output as seen in equation (10). TCM decoder output is then processed in inverse wavelet transform by using partitioned grouping which based on wavelet characteristics. This process produces image reconstruction. PSNR is used to test the image quality of the system performance. PSNR measurement can be seen in equation (11).

2. Materials and methods
This research is carried out by doing a simulation with the Matlab program to get the optimum performance and system reliability, as well as design accuracy before it is implemented. The transmission method used in this research is TCM in the coder and the decoder. The diversity technique used is MRC [2] on the Radio Frequency and the channel models used are additive white Gaussian noise (AWGN) and Rayleigh Fading [11].

2.1. System performance test
The system performance test in this study uses two parameters, namely BER and PSNR. BER is used to measure how many errors occurred at the receiver. PSNR is used to determine the quality of the reconstructed image at the receiver. BER and PSNR parameters can be explained as follows:

1. The Calculation of BER
The BER is measured by dividing the number of bit errors by the total number of transferred bits. The measurement of BER can be given by the following equation [11]:

\[
BER = \frac{n}{N}
\]  
(10)

where: 
- \(n\) = number of incorrect bits of information at the receiver
- \(N\) = number of bits of information transmitted.

2. The Calculation of PSNR
PSNR is a useful parameter to determine the quality of reconstruction image. PSNR calculation is done by comparing the pixel value of the original image with the pixel value of the reconstructed image. PSNR shows the quality of the reconstructed image. The higher the PSNR value obtained, the better the quality of the image. The PSNR can be formulated as follows [14]:

\[
PSNR = 10 \log_{10} \left( \frac{255^2}{\frac{1}{N} \sum \sum (p(i,j) - \hat{p}(i,j))^2} \right)
\]  
(11)

where:
- \(p(i,j)\) is the original image pixel value,
- \(\hat{p}(i,j)\) is Pixel value of reconstructed image,
- \(N\) is the number of pixels in image, while the 255 value is the highest value for grey scale image.

2.2 Research Variable
The variables used in this study are as follows:

1. Independent variables are the variables that can be manipulated. Bpp and SNR are the independent variables used in this study, where:
   a. Bpp is the variable which represents the average number of bits for each pixel of the compressed image.
   b. SNR is the variable that compare the signal power and noise power in the transmission channels.

2. Dependent variables are the variable that changes based on the changes in independent variables. BER and PSNR are dependent variables used in the study, where:
a. BER is calculated by comparing the bit streams of TCM encoder input with the TCM decoder output.
b. PSNR is calculated by comparing the pixel value of the original image with the pixel value of the reconstructed image.

3. Results and discussion
To evaluate the system performance of TCM with and without MRC on radio frequency in Rayleigh fading channel, several experiments had been carried out. The experiments that had been done were to test the BER and PSNR for Lena image with bit rate 0.8 bpp. BER and PSNR test results are given in table 1 and figure 2 and graph 1.

**Table 1.** The simulation results of the system performance of TCM with and without MRC with bit rate 0.8 bpp in Rayleigh fading channel on Radio Frequency.

| SNR (dB) | BER With Diversity | BER Without Diversity | PSNR (dB) With Diversity | PSNR (dB) Without Diversity |
|----------|--------------------|-----------------------|---------------------------|-----------------------------|
| 10       | 0.0193             | 0.0247                | 15.5542                   | 12.7464                     |
| 12       | 0.0165             | 0.0233                | 19.5597                   | 14.3743                     |
| 14       | 0.0142             | 0.0208                | 24.5915                   | 17.2786                     |
| 16       | 0.0122             | 0.0191                | 27.9301                   | 20.6029                     |
| 18       | 0.0113             | 0.0172                | 30.8535                   | 23.166                      |
| 20       | 0.0093             | 0.0166                | 34.7372                   | 26.090                      |

With diversity SNR (14 dB)

BER =0.0142
PSNR = 24.5915dB

Without diversity SNR (14 dB)

BER =0.0211
PSNR = 17.2786 dB

**Figure 2.** The simulation results of the system performance of TCM with and without MRC with bit rate 0.8 bpp in Rayleigh fading channel on Radio Frequency.
Table 1 represents the comparison of the TCM with and without MRC on radio frequency in Rayleigh fading channel with rate 0.8 bpp, with SNR 10dB, 12dB, 14dB, 16dB, 18 dB and 20dB. From the table, the system with MRC shows the improvement on the system performance. It can be seen on the error that decreased to the average of 0.006483 or 46.97 %, while for the quality of image reconstruction is increased to the average of 6.4946 dB or 25.43%.

Figure 2 shows the comparison of BER and PSNR of the system performance of TCM with and without MRC. The image with SNR 14 dB is the representation of one of the image reconstructions from table 1. For the TCM with MRC, there is a significant improvement at 14dB SNR in image reconstruction quality compared to other SNRs. This significant improvement is seen in the decrease of error by 0.0069 or 48.59%, and an increase in the quality of image reconstruction by 7.3129 dB or 29.37% compared to the system without MRC.

Graph 1. The simulation results of the system performance of TCM with and without MRC with bit rate 0.8 bpp in Rayleigh fading channel on Radio Frequency.

Graph 1 represents the comparison of the system performance of TCM with and without MRC with bit rate 0.8 bpp in Rayleigh fading channel on Radio Frequency, with SNR 10dB, 12dB, 14dB, 16dB, 18 dB and 20dB. Comparing to the system TCM with and without MRC. The system with MRC has an improvement in the system performance which could be seen from the decrease in error, while the quality of image reconstruction is improved significantly.

From the simulation above, it is clear that the system with and without MRC increase the PSNR and decrease the BER. This is because the PSNR or the quality of the reconstruction image is not only affected by the number of bits error, but it also depends on the location of the error bits in the decompressed SPIHT. In accordance with the characteristics of the SPIHT compression algorithm, which is progressive transmission, the important information is located at the beginning, so that the error on these initial bits will greatly affect the quality of the reconstruction image. While BER is
decreased because both of these systems use TCM which can combat errors that occur during transmission in the Rayleigh fading channel.

4. Conclusion
The result of the experiments which had been carried out is to test BER and PSNR on Lena image with bit rate 0.8 bpp by using TCM with and without MRC on radio frequency in Rayleigh fading channel. It is showed that there was a decrease in BER at the average of 0.006483 or 46.97 % while for PSNR there was an increase at the average of of 6.4946 dB or 25.43%. While at SNR 20 dB, the improvement for both BER and PSNR were significant because they had reached a maximum value. The results of this study showed that the use of TCM with and without MRC on radio frequency in Rayleigh fading channel can reduce errors and improve the quality of image reconstruction.

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References
[1]. N V Boulgouris, N Thomos and M G Strintzis 2003 Transmission of images over noisy channels using error-resilient wavelet coding and forward error correction Vol 13 (IEEE Trans Circuits Syst: Video Technol) pp 1170–1181
[2]. G Sherwood and K Zeger 1997 Progressive image coding on noisy channels Vol 4 (IEEE Signal Process: Lett) pp 189–191
[3]. P G Sherwood and K Zeger 1998 Error Protection for Progressive Image Transmission over Memoryless and Fading Channels Vol 46 (IEEE Trans: Commun) pp 1555–1559
[4]. Siavash M Alamouti 1998 A simple Transmit Diversity Technique for Wireless Communications Vol 16 (IEEE Journal on selected areas in Communications) pp 1451-1458
[5]. C –H Tse, K -W Yip and T -S Ng 2000 Performance tradeoffs between maximum ratio transmission and switched-transmit diversity Vol 2(in Proc. 11th IEEE Int. Symp. on Personal Indoor and Mobile Radio Comm) pp 1485–1489
[6]. R M Radaydeh and M M Matalgah 2005 Performance analysis of multiple carrier M-ary FSK system with diversity combining over generalized fading channels Vol 4(in Communications, 2005. ICC 2005. 2005 IEEE International Conference on Communication) pp 2357–2361
[7]. A Annamalai, C Tellambura and V K Bhargava 2000 Equal-gain diversity receiver performance in fading channels Vol 48 (IEEE Trans. Comms) pp 1732–1745
[8]. Q T Zhang 1997 Probability of error for equal-gain combiners over Rayleigh channels: some closed-form solutions Vol 45 (IEEE Trans. Comms) pp 270–273
[9]. MA Najib and V K Prabhu 2000 Analysis of equal-gain diversity with partially coherent fading signals (IEEE Trans. Veh. Tech) pp 783–791
[10]. Sklar B 2001 Digital Communications: Fundamentals and Applications. Channel Coding (Upper Saddle River: Prentice-Hall2nd) chapter 5 pp 314–376
[11]. Theodore S Rappaport 2011 Wireless Communications Principles and Practice Equalization Diversity and Channel Coding(Pearson Prentice Hallese2nd)chapter 7 pp 355-412
[12]. V Chande and N Farvardin 2000 Progressive transmission of images over memoryless noisy channels Vol 6(IEEE Journal onSelected Areas in Communications) pp 850-860
[13]. N Thomos, N V Boulgouris and M G Strintzis 2005 Wireless image transmission using turbo codes and optimal unequal error protection Vol 14(IEEE Trans. Image Process) pp 1890–1901
[14]. Liane C Ramac and Pramod K Varshney 2000A Wavelet Domain Diversity Method for Transmission of Images over Wireless Channels Vol 18(IEEE Journal on Selected Areas in Communication) pp 891–898
[15]. Q T Zhang 1999 A simple approach to probability of error for equal gain combiners over Rayleigh channels Vol 48 (IEEE Trans. Veh. Tech) pp 1151–1154

[16]. A Said and W A Pearlman 996 A New, Fast, and Efficient Image Codec Based on Set Partitioning In Hierarchical Trees Vol 6 (IEEE Trans. Circuits Syst Video Technol) pp 243-250