

Image Transmission Using Joint Source Channel Coding over Wireless Channel

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Abstract: We consider the use of residual redundancy method in combination with the convolutional channel coding for various channel conditions which include the BSC and GEC channel. The results show that the redundancy for an intelligent decoding is useful for wireless communication, as long as this redundancy is combined with some knowledge of the channel statistics. The approach suggested by the SMAP was found to produce optimum performance when the redundancy factor has been varied.

Key words: Joint source channel coding, sequence maximum a posteriori method, channel modelling

INTRODUCTION

The transmission of multimedia contents over unreliable data links has become of paramount importance. This type of transmission must reconcile the high data rates involved in multimedia contents and the noisy nature of the considered channels, be it wireless, mobile, or packet oriented. New communication systems design methodologies have been emerging for the last decade, under the general denomination of Joint Source-Channel (JSC) coding. In the past, the design of the source coder and channel coder has been performed separately. This often makes excellent practical sense and it could be theoretically justified by the separation theorem of Shannon^[1]. As we try to operate under more and more restrictive conditions, such as the mobile communication channel, the separation axiom does not hold for all channels^[2]. Where it does hold, it requires the use of an optimal source coder channel coder pair which may not be feasible in practice.

Sayood *et al.*^[3] classify the approaches to joint source channel coding into four broad categories: •) joint source channel coders, where the source and channel coding operations are truly integrated; •) concatenated source/channel coders, which allocate a fixed bit rate between a cascaded source coder and a channel coder; •) unequal error protection source/channel coders in which the output of the source encoder is afforded unequal protection based on the effect of errors on the reconstruction sequence and •) constrained joint source source/channel coders, where a given source and/or decoder is modified to account for the presence of a given noisy channel. A subset of the latter class are those coders that use some knowledge of the source properties to mitigate the effects of the noisy channel. Ideally, a source coder removes all redundant information in the

source and produces a sequence of independent code bits, but in practice, lack of exact information about the source results in residual redundancy in the source coder output sequence. A constrained JSC receiver uses knowledge of this residual redundancy, similarly to the manner in which channel coders use knowledge of explicit redundancy, to protect against channel errors. Differential Pulse Code Modulation (DPCM) systems are example systems where there is residual correlation in the source coder output^[4,5].

Several studies^[3-7] have investigated the use of residual redundancy in the JSC decoder for the case of image transmission over a Binary Symmetric Channel (BSC). However, for wireless communication, the channel is best modeled as a finite state Markov Process rather than BSC^[8-10]. This study will look into the case of two-state Markov model which is well known as Gilbert-Elliott Channel (GEC) model.

MATERIALS AND METHODS

Methods based on residual redundancy do not attempt to remove excess rate from the source via entropy coding or improved prediction; rather, they use this redundancy as a form of implicit channel coding. A properly chosen JSC decoder can capitalize upon the excess rate. The approach used here is known as Sequence Maximum A Posteriori (SMAP) method^[5,6]. It determines the most probable transmitted sequence given the observed sequence. This technique looks at the joint source channel decoder as a sequence estimator and incorporates the residual structure in the source coder output into the distance metric used by the sequence estimator.

For a discrete memoryless channel, let the channel input and output sequences be denoted by

$Y = \{y_0, y_1, \dots, y_{L-1}\}$ and $\hat{Y} = \{\hat{y}_0, \hat{y}_1, \dots, \hat{y}_{L-1}\}$. By using the fact that the channel is memoryless and by successively applying conditional probability and imposing first-order Markov assumption on $\{y_i\}$, Sayood *et al.*^[5] had shown that an optimum receiver select a sequence Y given an observed sequence \hat{Y} if it maximizes

$$\log [P(\hat{Y}/Y) P(Y)] = \sum \log [P(\hat{y}_i/y_i) P(y_i/y_{i-1})] \quad (1)$$

This is similar in form to the path metric of a convolutional decoder. Thus, the source decoder can be the Viterbi decoder, which uses Eq (1) as the path metric. The first term, $\log P(\hat{y}_i/y_i)$, depends on the information about the channel. The second term, $P(y_i/y_{i-1})$, depends only on the statistics of the input sequence. Therefore, knowledge of both the channel and source statistics is necessary for implementing this path metric. In our simulation, we have obtained the channel statistics by assuming the channel to be either BSC or GEC with known transition probability; source statistics were obtained using a training sequence. The test and training sequences are different.

Channel model: Two channel models are considered in this research, Binary Symmetric Channels (BSC) and Gilbert-Elliott Channels (GEC). The BSC for the memoryless channel is the simplest channel model, it has only one parameter, Bit Error Rate (BER), to describe the error condition. The GEC model is widely used in representing the error characteristics of a wireless channel between two stations. The GEC model has two states: good state and bad state^[8]. However, the channel is assumed to be BSC in each state. In the good state, errors occur with low probability P_G , while in the bad state they occur with high probability P_B . Due to the underlying Markov nature of the channel, it has memory that depends on the transition probabilities between the states. The transition probabilities from one state to the other are represented by b and g as shown in Fig. 1. $(1-b)$ and $(1-g)$ are the probabilities staying at good state and bad state, respectively. The average bit error rate produced by the GEC is^[11]

$$BER_{avg} = \frac{gP_G + bP_B}{g + b} \quad (2)$$

The choice of these parameters may not be arbitrary^[8]. P_B can vary between 0 and 0.5 and it should be larger than P_G . From Eq, it can be noticed that BER_{avg} increases if there is any increase in b or P_B , however, it will decrease when g increases. For our simulation, we study the performance of the system for the case $g=0.01$, $b=0.05$, $P_G=0.01$ and P_B varies from 0.01 to 0.40.

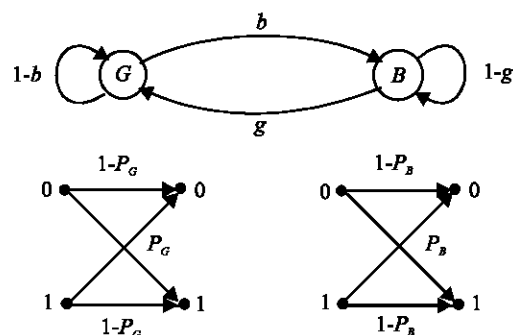


Fig. 1: Gilbert-Elliott channel model. P_G and P_B are the channel crossover probabilities in the “good” and “bad” states and g and b are transition probabilities between states

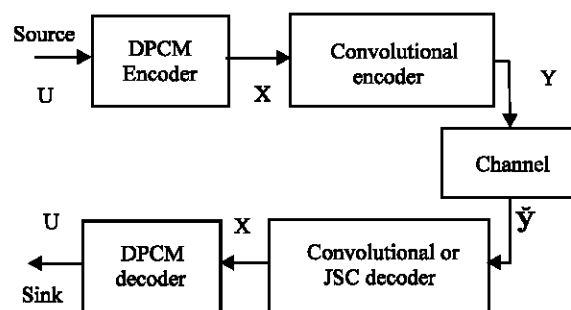


Fig. 2: System model

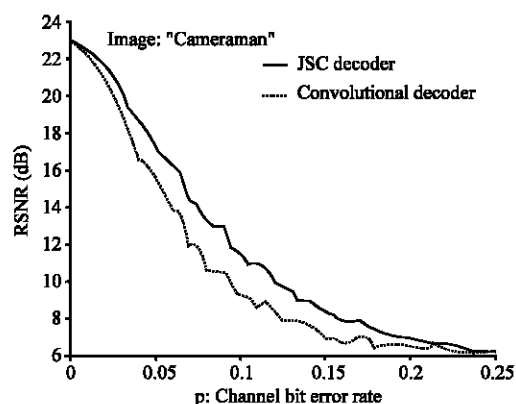


Fig. 3: RSNR performance of (4, 2, 1) coder with conventional and SMAP decoders for BSC channel

System description: To study the effect of the residual redundancy techniques in the decoder, we developed the system shown in Fig. 2 where a two-bit DPCM encoder/decoder is employed. Four images are used as the source: cameraman, car, fruit and the clown. The last two were used for training and the first ones are used for testing. As in^[5], we found that convolutional coders that

used an input word length of two were able to utilize the residual redundancy for the two bit DPCM. For this reason, the 1/2 rate (4, 2, 1) coder is selected. The connection vectors for this coder are^[5]

$$\begin{matrix} g_1^{(1)}=6 & g_1^{(2)}=0 & g_1^{(3)}=6 & g_1^{(4)}=4 \\ g_2^{(1)}=0 & g_2^{(2)}=6 & g_2^{(3)}=4 & g_2^{(4)}=2 \end{matrix}$$

Two types of communication channel will be considered here, the BSC and the GEC model. The JSC decoder is a Viterbi decoder with a path metric as in(Eq 1), whereas, the conventional decoder uses the standard Viterbi decoder. The performance of the different systems was evaluated using the Reconstruction Signal-to-Noise Ratio (RSNR) measures which is defined as

$$RSNR = 10\log_{10} \frac{\sum 255^2}{\sum (u_i - \hat{u}_i)^2} \quad (3)$$

where u_i is the input to the source coder and \hat{u}_i is the output of the source decoder.

RESULTS AND DISCUSSION

The system described in the previous section was implemented for various cases using MATLAB software. In the first experiment, the communication channel is represented by the BSC model with crossover probability p . The channel matrix needed in the decoder is evaluated based on the values of p . Fig. 3 and 4 compare the performance of the communication system with the JSC and convolutional decoder. The system with the JSC decoder has comparable performance at low-error rates; but better performance as the error rates increases. When the channel cross probability gets higher than 0.15, the performance of the system decreases again until it becomes comparable to the conventional system. These results confirm what has been found in previous studies^[5,6]. The next point that needs to be investigated is the performance of the system if the communication channel follows the GEC model which is the case for most wireless systems. This issue is tackled in the next experiment.

Our objective in the second experiment is to highlight the benefit of using the residual redundancy method in wireless environment. For this reason, we study the performance of the system for the case where the GEC model has the following parameters: $g=0.01$, $b=0.05$, $P_G=0.01$ and P_B varies from 0.01 to 0.40. The channel matrix is determined from the average bit error rate. Fig. 5 and 6 shows the performance of the system with the JSC decoder and convolutional decoder. Again, the use of the

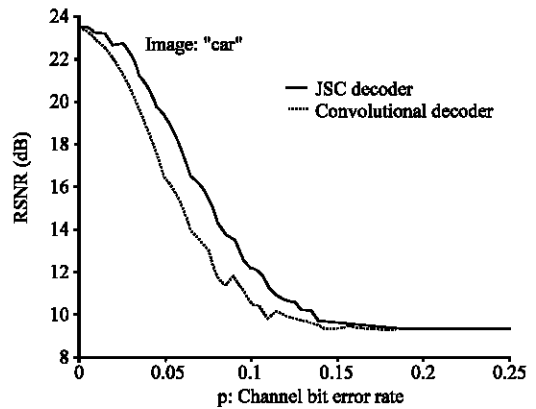


Fig. 4: RSNR performance of (4, 2, 1) coder with conventional and SMAP decoders for BSC channel

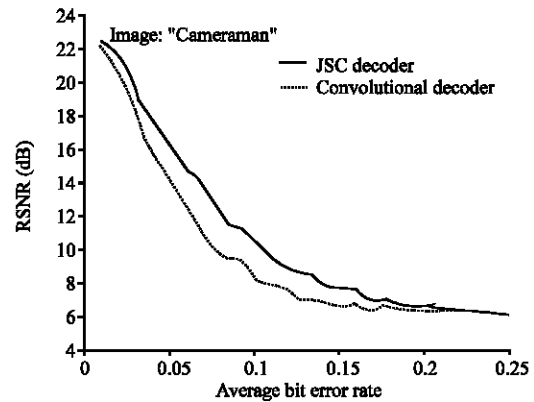


Fig. 5: RSNR performance of (4, 2, 1) convolutional coder with conventional and JSC decoders for GEC channel with parameters: $P_G=0.01$, $b=0.05$, $g=0.01$ and $0.01 < P_B < 0.30$

residual redundancy improves the performance of the system when the average bit error rate varies from 0.01 to 0.15. This demonstrates the importance of using this technique for wireless communication.

It is important to note that the JSC decoder requires some knowledge about the channel statistic in order to produce better results. These statistics depends on channel parameter. If the channel is assumed to follow a BSC model, while it is actually more closer to GEC model; lower performance will be obtained. Consider for example the case where the mobile has a speed of 30 km h, the channel is modeled as GEC with the following parameters: $g=0.21700$, $b=0.028282$, $P_G=0.001$ and $P_B=0.12$ [12]. If the appropriate channel matrix are used, the $RSNR=12.058$ dB, if not $RSNR= 6.0160$ dB. The difference between the two values is quite high.

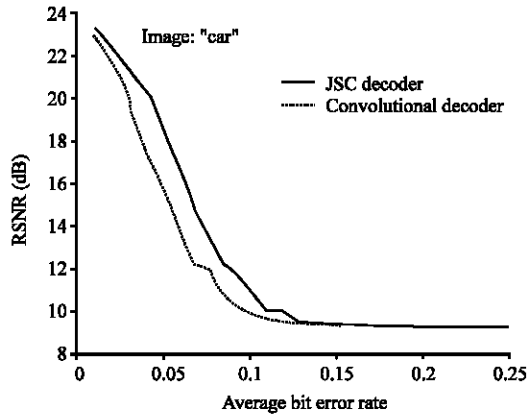


Fig. 6: RSNR performance of (4, 2, 1) convolutional coder with conventional and JSC decoders for GEC channel with parameters: $P_G=0.01$, $b=0.05$, $g=0.01$ and $0.01 < P_B < 0.30$

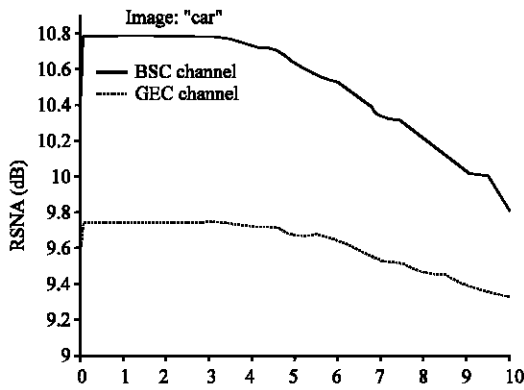


Fig. 7: Performance of the system with JSC decoder using BSC channel with $p=0.1$ and GEC channel with $b=0.05$, $g=0.01$, $P_G=0.01$ and $P_B =0.12$

In the final experiment, we study the influence of the redundancy factor on the performance of the system for both the BSC and GEC channel. The path metric in Eq 1 is modified as following

$$\text{Path metric} = \sum \log [P(y_i)] + \lambda \sum \log [P(y_i/y_{i-1})] \quad (3)$$

where λ is a positive real number. This equation corresponds to the path metric of a standard convolutional decoder if $\lambda = 0$. As λ increases, the effect of the residual redundancy on the system can be observed. The system in this experiment uses the JSC decoder with the path metric as in (3). Fig. 7 shows the performance of the system with JSC decoder for various values of λ and for two channel conditions. In one case, a BSC channel with cross over probability $p=0.1$ is

considered. In the second case a GEC channel is used with the following parameters $b=0.05$, $g=0.01$, $P_G=0.01$ and $P_B =0.12$. In both cases, the performance of the system reaches quickly a steady state for a range of $0.1 < \lambda < 3$ for the BSC and $0.1 < \lambda < 5$ for GEC. Then, it starts to deteriorate as λ exceeds these ranges. Similar results were obtained for other channel conditions. Therefore, a value of $\lambda=1$ is a reasonable choice since RSNR is at the optimum level.

CONCLUSION

This study studies the use of residual redundancy method in combination with the convolutional channel coding for various channel conditions which include the BSC and GEC channel. The sequence maximum a posteriori method, which is one of the residual redundancy approaches, is used in the simulation. The results show that the redundancy for an intelligent decoding can be useful for wireless communication, as long as this redundancy is combined with some knowledge of the channel statistics. In addition, the study investigated the effect of the residual redundancy component on the system by modifying the expression for the path metric. The approach suggested by the SMAP produces optimum performance.

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