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J. He
Huazhong University of Science & Technology, China

Z. Yang
Huazhong University of Science & Technology, China

D. Yang
Huazhong University of Science & Technology, China

Z. Tang
Huazhong University of Science & Technology, China

J. Hu
Huazhong University of Science & Technology, China

See next page for additional authors

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Abstract

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Authors

J. He, Z. Yang, D. Yang, Z. Tang, J. Hu, and Chuntung Chou

Analysis and Representation of Statistical Performance of JPEG2000 Encoded Image Over Wireless Channels

Jianhua He, Zongkai Yang*, Daiqin Yang*, Zuoyin Tang*, Jing Hu* and Chun Tung Chou***

*Huazhong University of Science and Technology,
Department of Electronics and Information,
Wuhan City, P.R. China, 430074
**TITR Institute,
University of Wollongong,
Wollongong, Australia

ABSTRACT

JPEG2000 is a new coming image standard. In this paper we analyze the performance of error resilience tools in JPEG2000, and present an analytical model to estimate the quality of JPEG2000 encoded image transmitted over wireless channels. The effectiveness of the analytical model is validated by simulation results. Furthermore, analytical model is utilized by the base station to design efficient unequally error protection schemes for JPEG2000 transmission. In the design, a utility function is defined to make a tradeoff between the image quality and the cost for transmitting the image over wireless channel.

1. INTRODUCTION

Transmitting videos and images over wireless networks achieves wide commercial and research interests [1][2]. However, due to large variations on network bandwidth and user requirement on application quality, it's necessary to introduce strong scalability in video and image coding [3]. JPEG2000 is a recently introduced image compression standard with strong scalability [4]. When the image is transmitted over wireless channels, error correction codes are needed to guarantee the image quality [5]. Furthermore, to utilize the distribution of energy in an image, unequal error protection (UEP) scheme for image codestream has achieved wide interests [6]. However, in research experiments on UEP, the determination of error protection degrees to different parts of the image is normally based on some heuristic approaches [6].

To assist the design of efficient error protection schemes for JPEG2000 and thus well utilize the wireless resources, we present an analytical method to calculate the distortion statistics of the image transmitted over wireless channels under various channel situations. With such distortion statics, the base station is able to design efficient image protection schemes without further information from the image source. Although there are already some works in the standardization group of JPEG2000 on rate distortion optimization and investigating error resilience ability, those work are based on simulations and are different from the work presented in this paper. The left of the paper is organized as follows. In Section 2, background information on JPEG2000 is described. In Section 3, we present the analytical model to estimate the image quality. The analytical model is evaluated in Section 4. Also presented is an example of utilizing the analytical model for error protection. The last section concludes the paper.

2. BACKGROUND

In JPEG2000 standard, the image is divided into tiles with fixed size for wavelet transform [4]. Then each subband is partitioned into relatively small blocks of samples for coding. A separate highly scalable bit-stream is generated to represent each so-called code-block, $C(i)$. The bit-stream associated with $C(i)$ may be independently truncated to any of a collection of different lengths n_i where the increase in reconstructed image distortion results from these truncations with respect to an appropriate distortion metric. The compressed image data of each code-block is distributed across one ore more layers in the codestream. Each layer consists of some number of consecutive bit-plane coding passes from each code-block in the tile. Each code-block, $C(i)$, contributes certain bytes to each quality layer based on an optimal rate distortion algorithm. In each quality layer, code-blocks are organized into image packets. Normally each image packet includes twelve code-blocks. The final code stream is composed of main header, tile-part bit-streams with several kinds of markers to identify different segments in the code stream. In the tile-part stream are sequential image packets, which may be separated by

re-synchronous markers.

In the derivation of the analytical model, we simply assume that the whole image is protected by the same error correction code. But it's straightforward to extend the model to the case of the image being unevenly protected. The nomenclature used in the analytical model for quality estimation is listed as follows.

ρ: bit error ratio introduced to the image;

I_{hr}: bit number of the image header.

I_{om}: mean square error (MSE) between the original image and the image decoded from the original JPEG2000 bitstream.

$I_{ctm}(\rho)$: MSE betwen the images reconstructed from the original JPEG2000 bitstream and the JPEG2000 bitstream transmitted over a channel with bit error ratio of ρ.

$I_{otm}(\rho)$: MSE between the original image and the image reconstructed from the JPEG2000 bitstream corrupted with bit error ratio of ρ.

$I_{otp}(\rho)$: PSNR calculated between the original image and the image reconstructed from the JPEG2000 bitstream corrupted with bit error ratio of ρ.

L_n: number of quality layers.

$L_r(i)$: bit number of the ith layer.

$L_{cm}(i,\rho)$: MSE between the images reconstructed from the original JPEG2000 bitstream and the JPEG2000 bitstream, in which only the ith layer is corrupted with bit error ratio of ρ.

P_n: number of image packets included in a quality layer. P_n is the same in different quality layer.

$P(i,j)$: the ith image packet in the jth quality layer.

$P_{dr}(i,j)$: bit number of $P(i,j)$.

$P_{hr}(i,j)$: bit number of the packet header in $P(i,j)$.

$P_{cm}(i,j,\rho)$: MSE between the images decoded from the original JPEG2000 bitstream and the JPEG2000 bitstream in which only $P(i,j)$ is corrupted with bit error ratio of ρ.

C_n: number of code-blocks in the image;

$C_n(i,j)$: number of code-blocks included in $P(i,j)$.

$C(i)$: the ith code-blocks in the image.

$C_{om}(i,\rho)$: MSE between the original image and the image decoded from the JPEG2000 bitstream, in which only bitstream coming from $C(i)$ is corrupted with bit error ratio of ρ.

$C_{cm}(i,\rho)$: MSE between the images decoded from the original JPEG2000 bitstream and the JPEG2000 bitstream, in which bitstream coming from $C_b(i)$ is transmitted over a channel with bit error ratio of ρ.

$C_b(i,j,k)$: bitstream of code-block $C(k)$ included in $P(i,j)$.

$C_r(i,j,k)$: bit number of $C_b(i,j,k)$.

$C_{cm}(i,j,k,\rho)$: MSE between the images decoded from the original JPEG2000 bitstream and the JPEG2000 bitstream in which only $C_b(i,j,k)$ is corrupted with bit error ratio of ρ.

$CB_n(i,j,k)$: number of bit-planes included in $C_b(i,j,k)$.

$CB_b(i,j,k,l)$: bitstream of the lth bit-plane included in $C_b(i,j,k)$.

$CB_{cm}(i,j,k,l,\rho)$: MSE between the images decoded from the original JPEG2000 bitstream and the JPEG2000 bit-

stream in which only $CB(i,j,k,l)$ is corrupted with bit error ratio of ρ.

$CP_n(i,j,k)$: number of coding passes included in $C_b(i,j,k)$.

$CP_b(i,j,k,l)$: bitstream of the lth coding passes included in $C_B(i,j,k,l)$.

$CP_{cm}(i,j,k,l,\rho)$: MSE between the images decoded from the original JPEG2000 bitstream and the JPEG2000 bitstream in which $CP(i,j,k,l)$ is corrupted with bit error ratio of ρ.

Furthermore, several assumptions are made to estimate final quality of transmitted JPEG2000 image. The assumptions are base on the codestream syntax and the characteristics of approximate orthodoxy wavelet transform.

1. Any bit errors in main header of the image codestream will make the image undecodable.

2. Any bit errors in packet header will make the image packet not useful.

3. Bit errors in one code-block is contained within that code-block.

4. The contribution from each code-block to distortion in the reconstructed image is additive [4].

From the forth assumption, we have,

$$I_{om} = \sum_{i}^{C_n} C_{om}(i,0). \tag{1}$$

After the image is corrupted by bit error ratio of ρ, we have

$$I_{otm}(\rho) = \sum_{i}^{C_n} C_{om}(i,\rho), \tag{2}$$

and

$$I_{ctm}(\rho) = \sum_{i}^{C_n} C_{cm}(i,\rho). \tag{3}$$

3. ESTIMATION OF IMAGE QUALITY

Based on the definitions and assumptions in Section 2, we present an approximate approach to estimate the quality of transmitted image. The JPEG2000 image is first coded with a given set of configuration and coding parameters, such as I_r, L_n and $L(i)$. Then record the inherent information which can be easily obtained from the compressed bitstream, such as H_r, $L_r(i)$ and so on. Measure or predict the distortion of the image when some coding passes, packets or layers are removed from the image bitstream, such as $L_{cm}(i)$ and $P_{cm}(i,j)$. Based on the measured or predicted information on distortion, estimate the overall MSE value of the image reconstructed from the codestream corrupted with a given bit error ratio.

With input parameters such as bit error ratio and packet size, we can calculate and output the corresponding MSE and PSNR of the decoded JPEG2000 image. However, due to bit errors may appear in different bitplanes of a code-block, it's very difficult, if not impossible, to analytically calculate the value of $C_{om}(i,\rho)$ and $C_{cm}(i,\rho)$, for $\rho > 0$. To estimate I_{otm} and I_{ctm}, some approximations are necessary,

$$C_{om}(i,\rho) = C_{om}(i,0) + C_{cm}(i,\rho)$$

$$C_{cm}(i,\rho) = \sum_{l=1}^{CB_n(i,j,k)} CB_{cm}(i,j,k,l,\rho)$$

$$CB_{cm}(i,j,k,l,\rho) = \sum_{l=1}^{CP_n(i,j,k)} CP_{cm}(i,j,k,l,\rho).$$

$$\tag{4}$$

With above approximations, we get,

$$I_{otm}(\rho) = I_{om} + I_{ctm}(\rho). \tag{5}$$

From (5), (3) and (4), it's shown that if the values of $CB_{cm}(i,j,k,l,\rho)$ are available, the image quality I_{otm} will be obtained.

For the convenience of quality estimation, we assume that bit errors randomly appear in the wireless channels. The assumption is reasonable, because bits interleaving techniques are widely used in wireless networks, which make burst bit errors in the wireless channel appear randomly after decoding. Without loss of generality, we calculate the value of $CB_{cm}(i,j,k,l,\rho)$ In JPEG2000 standard, the bitstream of the processed bit-plane comes from the ith code-block, and is organized into the bitstream of image packet $P(j,k)$. If the arithmetic coder terminates after every coding pass, then bit errors in a coding pass will not propagate to other coding pass. For the sake of simplicity, we assume that any bit error appearing in a bit-plane will make the bit-plane discarded Then we get,

$$CB_{cm}(i,j,k,l,\rho) = CB_{cm}(i,j,k,l,1)*[1-(1-\rho)^{(I_{h,r}+P_{h,r})}]. \tag{6}$$

A heuristic method is used to estimate the value of $CB(i,j,k,l)$ to reduce processing time. It's described as follows. First, get the value of $L_{cm}(i,1)$, for $0 < i < L_n$. Then calculate $P_{cm}(i,j,1)$ using the following formulas,

$$P_{cm}(i,j,1) = L_{cm}(i,1) * \frac{P_{dr}(i,j)}{\sum_{m=1}^{P_n} P_{dr}(i,m)}$$

$$C_{cm}(i,j,k,1) = P_{cm}(i,j,1) * \frac{C_r(i,j,k)}{\sum_{m=1}^{C_n(i,j)} C_r(i,j,m)}, \tag{7}$$

and

$$CB_{cm}(i,j,k,l,1) = \frac{2^{-l} * CB_r(i,j,k)}{\sum_{m=1}^{CB_n(i,j,k)} 2^{-m} * CB_r(i,j,k,m)} * C_{cm}(i,j,k,1), \tag{8}$$

where $0 < i < L_n$, $0 < j < P_n$, $0 < k < C_n(i,j)$ and $0 < l < CB_n(i,j,k)$. The heuristic method is used in the left of the paper. Using a method similar to that used to calculate I_{otm}, the value of I_{otp} can be achieved.

4. EXPERIMENTAL RESULTS

4.1. Analytical results

To validate the effectiveness of the analytical estimation model, extensive simulations are carried out to examine various assumptions and compare the final image quality. Quality estimation for the JPEG2000 image is implemented in Matlab programming tool. The encoding and decoding are processed by verification model (VM) 8.0 of JPEG2000. For the limitation of the paper length, only comparisons of image quality obtained by analytical model and simulation method are presented in this paper. For each observed image quality value with a fixed bit error ratio, 70 simulations are run to obtain the average value and variation of the image quality metric. Fig.1 are some typical results of the experiment on standard test image "woman.pgm" with size of 256x256. The image is compressed in 5 quality layers, with 2.5bpp in Fig. 1. The nominal code-block dimensions used in coding is the default value 64x64. In the figure, simulation results are marked by downward triangle.
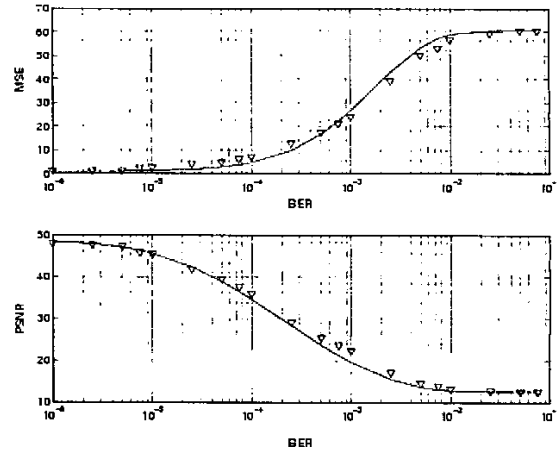

Fig. 1. Image quality versus channel bit error ratio.

From Fig. 1, it's clearly shown that the values obtained by analytical method approach closely to the

values obtained by simulation method.

4.2. Utilization of analytical model

As we know, different service subscriber would have different preference about transmitted image quality and the cost for receiving the image. Based on the analytical model, we are now able to design a flexible and accurate UEP schemes when the subscriber preferences are known. To quantify the subscriber's preferences on image quality and cost, we introduce a new variable, utility function, denoted by μ. With the utility function, the base station can decide which kind of UEP schemes to employ with a tradeoff between PSNR and image bit-stream length. Utility function μ is defined as following,

$$\mu = (P - P_p) - \alpha \frac{L - L_p}{\lambda} \qquad (9)$$

where P is the PSNR of received image, P_p is the preferred PSNR; L is the bit-stream length, and L_E is the preferred bit-stream length to be transmitted. λ is defined by service provider to adjust the cost of wireless bandwidth. α is called preference factor. It is defined by the service subscriber and represents the subscriber's preference between image quality and bandwidth cost.

To illustrate how to utilize the analytical model and the above utility function, we consider six simple UEP schemes. The transmitted image is the standard test image "woman256x256". It is compressed in 2.5 bps and with 5 layers. In each UEP scheme, the whole image is transmitted. The differences between the UEP schemes are in extra error protection of different layers. In UEP scheme 1, no layer is protected by error correction codes; while in UEP scheme i, $i \in [2,6]$, only the 1th layer to $(i-1)$th layer are protect by error correction codes. The Reed-Solomon code (255,223) is used for the purpose of error correction.

Some typical results of utility functions under different channel conditions are plotted in Fig. 2. On the x axes, six points from left to right represent the the corresponding UEP schemes respectively, In the figure, P_p=30, L_p =20000, λ =400. Two different preferences are considered. The solid line corresponds to $\alpha = 2/3$ and the dashed line represent $\alpha = 2$.

From Fig. 2, it's observed that, under the same channel condition, different preferences of α will result in different choice on the UEP schemes. For example, when the channel BER is 0.001, UEP scheme 5 should be chosen based on the utility function with $\alpha = 2/3$, and UEP scheme 4 should be chosen with α =2.

5. CONCLUSION

In this paper, an analytical model is presented to estimate the quality of transmitted JPEG2000 image over error-prone channels. Based on this model, the image quality can be obtained in real time. Experiments
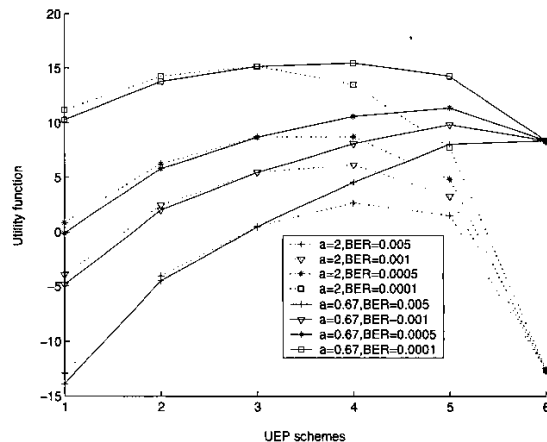

Fig. 2. Utility functions versus UEP schemes.

show that the model has a high accuracy on calculating the image quality. With the analytical model we also investigate the design of an efficient error protection schemes for transmission of JPEG2000 images over wireless networks.

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