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Linear Unequal Error Protection for Region of Interest Coded Images over Wireless Channels

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Abstract

In this thesis, an unequal error protection scheme for transmitting JPEG2000 images over wireless channel is investigated. The rapid growth of wireless communication has resulted in a demand for robust transmission of compressed images over wireless networks. The challenge of robust transmission is to protect the compressed image data against the impairments of the radio channel, in such a way as to maximize the received image quality. However, for highly compressed images, it would be beneficial that regions of interest (ROI) are prioritized for interpretability. The thesis addresses this problem; investigating unequal error protection for transmitting JPEG2000 compressed images. More particularly, the results reported in this thesis provide guidance concerning the implementation of stronger error correction coding schemes (Golay code) for ROI and comparatively weaker coding (Hamming code) for non-ROI image spaces. Such unequal error protection can be utilized by the base station for transmitting JPEG2000 encoded images over next generation wireless networks.

Contents

Introduction

Wireless multimedia communications have gained considerable importance in the last few years. As a result, the transmission of still images over wireless channels has been emerged. The main challenges in transmitting compressed images are to protect the image data against error, in such a way as to maximize the image quality at receiver side. In addition, as wireless channels have limited allocated bandwidth and high bit error rate, compression techniques are used to reduce the amount of data to be transmitted. However, the compressed codestreams are highly sensitive to transmission errors, making the multimedia communications more challenging over wireless channels.

Recently, the JPEG2000 still image compression standard [1] has been established to provide a superior compression performance. The standard incorporates a set of tools that make the compressed information more resilient to errors. The only technique standardized is based on insertion of marker codes in the codestream, which may be used to restore high level synchronization between the decoder and the codestream. This helps to localize errors and prevent it from propagating through the entire codestream. Once synchronization is achieved, additional tools aim to exploit as much of the remaining data as possible. However, the use of the error resilient tools does not guarantee an error free received image since residual bit errors can still affect the coded information.

The possibility to define regions of interest (ROI) in an image with quality better than the background is one of the new features in the JPEG2000 standard. In such a case, these regions need to be encoded at higher quality than the background. JPEG2000 currently supports two methods to encode ROIs: the general scaling based method (GSBM) and the maximum shift (*MAXSHIFT*) method [1], [2]. During the transmission of the image, these regions need to be transmitted first. Reconstructing a specific region of an image before the background is useful in many applications. And it is particularly promising feature for the future wireless image transmission.

In recent years, a lot of effort has been put into protecting JPEG2000 codestreams while transmitting over wireless channel in presence of different channel conditions. The automatic repeat request (ARQ) technique is a simple way of providing more reliable transmission where the packets with bit errors are retransmitted. However, ARQ introduces additional delay (for retransmission) in the network. The forward error correction (FEC) techniques, on the other hand, include redundant bits so that limited bit errors can be corrected without retransmission. Although there is no delay involved in FEC, the overall bit rate increases because of the redundancy introduced.

In FEC techniques equal error protections (EEP) are generally supported and these are suitable for the worst channel conditions. In [4], turbo codes are proposed to protect JPEG2000 codestreams. These earlier works do not consider the problem of organizing the JPEG2000 coding parameters themselves; nor do they consider the application of different levels of protection to different quality layers in the codestream. If the information has a hierarchical structure, such as the JPEG2000 codestream, EEP techniques fail to optimally protect the coded data. On the other hand, unequal error protection (UEP) techniques are able to make proper use of the hierarchical organization of the codestream and can assign more redundancy to the most important parts of the coded data [9]. In [11], different Reed-Solomon (RS) codes are used to protect different parts of the codestream unequally. An unequal error protection technique is proposed in [8] also. The proposed technique takes advantage of the hierarchical organization of the JPEG2000 codestream and protects only the most important part by means of a rate compatible punctured convolutional code. An adaptive unequal error protection technique is proposed in [9], which adaptively selects the best protection scheme according to the channel conditions.

In this thesis, an unequal error protection scheme for transmitting JPEG2000 compressed images over wireless channel is proposed which is based on the hierarchical organization of the JPEG2000 codestream. Our selection of linear block codes is motivated by their ability to offer strong protection without excessive complexity. The results reported here provide guidance concerning the implementation of stronger error correction coding schemes (Golay code) for ROI and comparatively weaker coding (Hamming code) for non-ROI image spaces. The use of these block codes particularly simplifies switching between

different codes to protect different parts of the codestream unequally and significantly improves the quality of ROI at the receivers.

   The thesis is organized as follows. In Chapter 2, a high level description of a wireless communication system is presented. In Chapter 3, JPEG2000 image compression technique and ROI coding are mentioned. The proposed linear unequal error protection technique is described in Chapter 4. Chapter 5 presents the results and interpretation. Finally, Chapter 6 provides conclusions.

2.1 Introduction

In the mathematical analysis of a communication system, the well known block diagram in Figure 2.1 is often the starting point. In this conceptual model of information transmission, introduced in the late 1940s by C.E. Shannon, information is described by signals and stochastic processes. The centre building block, the channel, describes the behaviors of the transmission medium.
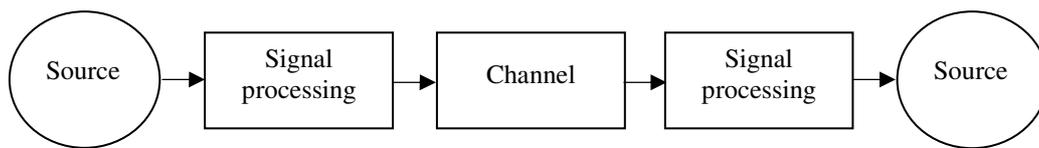
Figure 2.1: Classical model for communication systems.

Progressive image transmission has recently undergone enormous development since it can be widely used in current applications such as image transmission between wireless devices. The latest JPEG2000 standard provides for several types of progressive modes within the final codestreams. Figure 2.2 shows the block diagram of the considered wireless communication system. The model consists of a given source image and signal processing devices that are JPEG2000 encoder/decoder in this case. For the channel we assume a time-varying fading channel as a model of our mobile radio environment. In addition, we use some alternative channel coding schemes to protect different parts of the images from noise and other channel impairments. The modulation scheme is simply binary phase shift keying (BPSK).
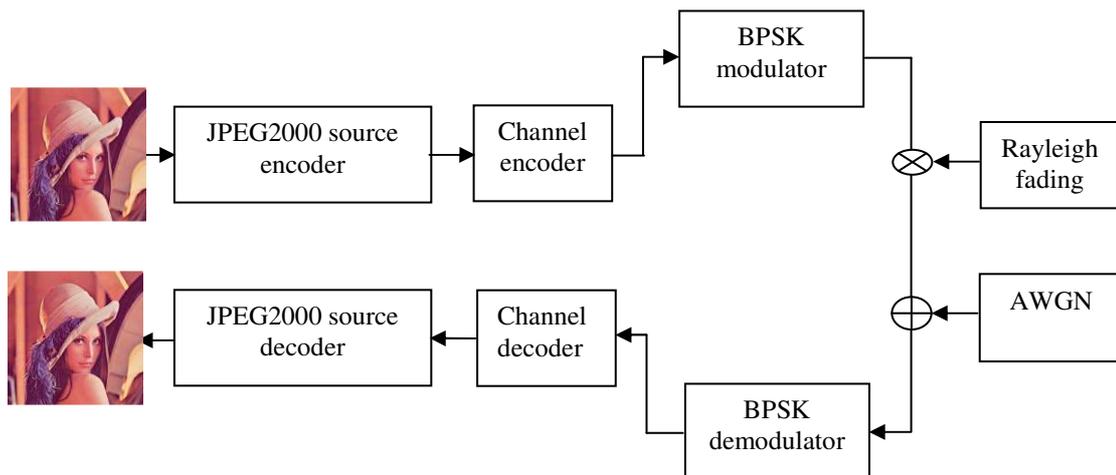
Figure 2.2 Block diagram of a wireless communication system.

2.2 Source encoding

Image compression standards for efficient representation and interchange of digital images have become essential due to the pervasive nature of digital imagery. Today, the most popular still image compression standard has been the work carried out by the Joint Photographic Experts Group (JPEG) committee. This group operates under the auspices of the Joint Technical Committee 1, Subcommittee 29, Working Group 1 (ISO/IEC JTC 1/ SC 29/ WG 1), a collaborative effort between the International Organization for Standardization (ISO) and the International Telecommunications Union Standardization Sector (ITU-T). Since March 1997 this committee worked towards the establishment of a new standard known as JPEG2000 (i.e., ISO/IEC/15444) [1], [2], [6].

The new standard normally supports lossy and lossless compression of single-component (e.g. grayscale) and multi-component (e.g. colors) imagery with superior compression performance. In addition to the basic compression functionalities, many other features have been provided, such as: progressive transmission by resolution, error tolerance and ROI coding. ROI coding is important in applications where certain parts of an image are of higher importance than the rest of the image. Chapter 3 describes details about JPEG2000 image compression technique.

2.3 Channel coding

Digital image transmission suffers from channel influence:

- o Severe (multipath) fading in terrestrial mobile radio communications.
- o Very low signal-to-noise ratio for satellite communications due to high path loss and limited transmit power in the downlink.
- o Compressed data (e.g. image signals) is very sensitive to transmission errors.

Channel coding protects data against transmission errors to ensure adequate transmission quality (bit error rate). Channel coding is power efficient: compared to the uncoded case, the same error rates are achieved with much less transmit power at the expense of a bandwidth expansion.

Channel coding theory has two main types of codes: block codes and convolution codes. A block code uses sequences of n symbols, for some positive integer n. Each sequence of length n is a code word or code block, and contains k information digits (or bits). The remaining n-k digits in the code word are called redundant digits or parity-check bits. They do not contain any additional information, but are used to make it possible to correct errors that occur in the transmission of the code. The encoder for a block code is *memoryless*, which means that the n digits in each code word depend only on each other and are independent of any information contained in previous code words. In a convolution code, the n digits of a code word also depend on the code words that were encoded previously during a fixed length of time.

The following sections describe two particular types of error-control codes, the "Golay" and "Hamming" code. The characteristics of the codes are described, concentrating on those that make it particularly useful for this thesis work. The various forms of these codes are also discussed.

2.3.1 The Binary Golay Code

The binary form of the Golay code is of particular significance since it is one of only a few examples of a nontrivial perfect code [15]. A t-error-correcting code can correct a maximum of t errors. A perfect t-error correcting code has the property that every word lays within a distance of t to exactly one code word. Equivalently, the code has $d_{min} = 2t + 1$, and covering radius t, where the covering radius r is the smallest number such that every word lays within a distance of r to a codeword.

Golay was in search of a perfect code when he noticed that [15]

$$\binom{23}{0} + \binom{23}{1} + \binom{23}{2} + \binom{23}{3} = 2^{11} = 2^{23-12} \tag{1}$$

which indicates the possible existence of a (23, 12) perfect binary code that could correct up to 3 errors. In 1949, Golay discovered such a perfect code, and it is the only one known capable of correcting any combination of three or fewer random errors in a block of 23 elements [15]. This (23, 12) Golay code can be generated by either of the following so-called generator polynomials

$$g_1(X) = 1 + X^2 + X^2 + X^4 + X^5 + X^6 + X^{10} + X^{11} \tag{2}$$

$$g_2(X) = 1 + X + X^5 + X^6 + X^7 + X^9 + X^{11} \tag{3}$$

2.3.2 The Extended Golay Code

Binary Golay codes can be easily extended by adding an overall parity check to the end of each code word [15]. Let C be any (n, k) code whose minimum distance is odd. We can obtain a new (n+1, k) code C' with the new minimum distance $d'_{min} = d_{min} + 1$ by adding a 0 at the end of each code word of even weight and a 1 at the end of each code word of odd weight.

The (23, 12) Golay code can be extended by adding an overall parity check to each code word to form the (24, 12) extended Golay code. This (24, 12) extended Golay code has minimum distance $d_{\min} = 8$ and has a code rate exactly R=1/2. The weight of every code word is a multiple of 4, and is invariant under a permutation of coordinates that interchanges the two halves of each code word. There are 2^{12}, or 4096, possible code words in the extended Golay code and like the unextended (23, 12) Golay code, it can be used to correct at most three errors [15].

2.3.3 Hamming Code

A set of codes was invented by Richard Hamming with the minimum number of extra parity bits [10]. If we wish to correct single errors, and are willing to ignore the possibility of multiple errors, this code is the perfect one with generally less overhead.

Each extra bit added by the channel encoder allows one check of a parity by the decoder and therefore one bit of information to be used in identifying the location of the error. For example, if three extra bits are used, the three tests could identify up to eight error conditions. One of these would be "no error" so seven would be left to identify the location of up to seven places in the pattern with an error. Thus the data block could be seven bits long. Three of these bits could be added for error checking, leaving four for the original data. Similarly, if there were four parity bits, the block could be 15 bits long leaving 11 bits for original data.

Table 2.1 Perfect Hamming codes.

Block size n	Information bits k	Parity bits n-k	Code rate R=k/n
7	4	3	0.57
15	11	4	0.73
31	26	5	0.84
63	57	6	0.90
127	120	7	0.94

Table 4.2 lists some Hamming codes. The second entry, with four parity bits, is used in this thesis because of it's comparatively higher code rate and better error performance.

2.4 Modulation

The use of an appropriate waveform for baseband representation of digital data is basic to its transmission from a source to destination. To generate a BPSK signal we have to represent the input binary sequence in bipolar form. In a bipolar format, a positive pulse is transmitted for symbol 1 and a negative pulse for symbol 0 (see Figure 2.3 (a)).
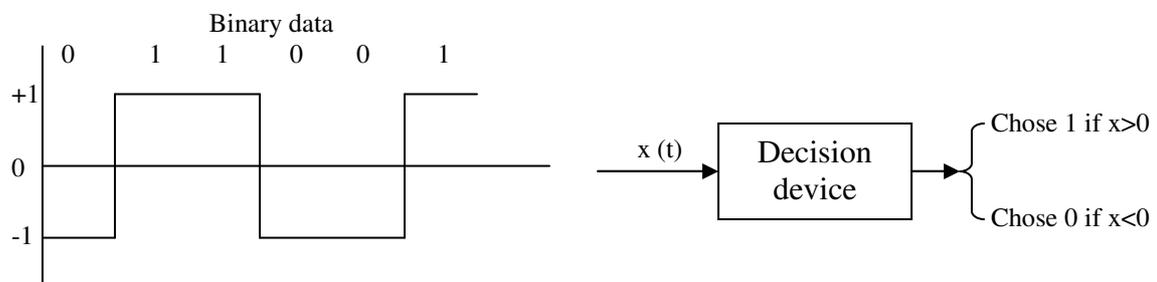
Figure 2.3: a) Bipolar waveform. b) BPSK demodulation.

To detect the original binary sequence of 1s and 0s, we apply the noisy BPSK signal to a decision device. In Figure 2.3(b), the input x is compared with a threshold of zero. If x>0 the receiver decides in favor of symbol 1. On the other hand, if x<0, it decides in favor of symbol 0.

2.5 The channel

Radio waves propagate from a transmitting antenna and travel through space undergoing absorption, reflection, diffraction and scattering. They are greatly affected by the ground terrain, the atmosphere, and the objects in their path, like buildings, bridges, hills, trees, etc. These multiple physical phenomena are responsible for most of the characteristic features of the received signal. In most of the mobile or cellular systems, the height of the mobile antenna may be smaller than the surrounding structures. Thus, the existence of a direct or line-of-sight path between transmitter and receiver is highly unlikely. In such a

case, propagation is mainly due to reflection and scattering from the buildings and by diffraction over and/or around them. So, in practice the transmitting signal arrives at the receiver via several paths with different time delays creating a multi-path situation. At the receiver, these multi-path waves with randomly distributed amplitudes and phases combine to give a resultant signal that fluctuates in time and space. Therefore, a receiver at one location may have a signal that is much different from the signal at another location, only a short distance away, because of the change in the phase relationship among the incoming radio waves.

2.5.1 Rayleigh fading distribution

   The JPEG2000 codestream is expected to be transmitted over a mobile noisy channel. In this thesis, we consider a Rayleigh fading channel as the transmission channel. If no line of sight (LOS) component is present, the signal envelope will be roughly Rayleigh distribution [16]. In Rayleigh fading, as there is no LOS path between the transmitting antenna and the mobile, the mobile unit receives a number of reflected and scattered waves. The instantaneous received signal is a random variable because of the varying path lengths. The signal received on path i, $s_i(t)$, has an amplitude $a_i(t)$ and a phase $\theta_i(t)$, $i = 1$, ..., n. The total signal received by a mobile, $s(t)$, is the sum of the signals received on the different paths, and can be expressed as [16]

$$s(t) = \sum_{i=1}^{n} a_i(t)\cos(\omega_c t + \theta_i(t)) \tag{4}$$

where $\omega_c = 2\pi f_c$ and f_c is the carrier frequency. The phase $\theta_i(t)$ depends on the varying path lengths, changing by 2π when the path length changes by a wavelength. This means that the phases can be modeled by random variables, uniformly distributed over [0, 2π].

   Equation 1 must be modified when there is relative motion between the transmitter and receiver. If the received signal on path i, $s_i(t)$, arrives at the receiver from an angle α_i relative to the direction of motion of the mobile, the Doppler shift of this signal is given by

$$f_{di} = \frac{v f_c}{c}\cos\alpha_i \tag{5}$$

where v is the velocity of the mobile, c is the speed of light, and the angle α_i is uniformly distributed over $[0, 2\pi]$. The received signal $s(t)$ can now be written as

$$s(t) = \sum_{i=1}^{n} a_i(t)\cos(\omega_c t + \omega_{di} t + \theta_i(t)) \tag{6}$$

where $\omega_{di} = 2\pi f_{di}$. It is an advantage to describe bandpass signals with baseband signals that have their energy concentrated around zero frequency because bandpass signals are not convenient to analyze. In addition, it is easier to handle low-pass signals in hardware and software implementations of signal processing algorithms. Equation 3 can be rewritten using the low-pass signals $x(t)$ and $y(t)$ which are often denoted the in-phase (I) and quadrature (Q) components of the signal:

$$s(t) = x(t)\cos\omega_c t - y(t)\sin\omega_c t \tag{7}$$

where we have

$$x(t) = \sum_{i=1}^{n} a_i(t)\cos(\theta_i(t)) \tag{8}$$

$$y(t) = \sum_{i=1}^{n} a_i(t)\sin(\theta_i(t)) \tag{9}$$

The received signal can also be expressed as

$$s(t) = \text{Re}\left[z(t)e^{2\pi f_c t}\right] = \frac{1}{2}(z(t)e^{j2\pi f_c t} + z^*(t)e^{-j2\pi f_c t}) \tag{10}$$

where the complex envelope of s(t) is a low-pass signal given by

$$z(t) = x(t) + jy(t) = r(t)e^{j\theta(t)} \tag{11}$$

The envelope of the signal z(t) is denoted by r(t)

$$r(t) = \sqrt{x^2(t) + y^2(t)} \tag{12}$$

The probability density function of r(t), denoted by p(r) is called the Rayleigh distribution [14].

$$p(r) = \begin{cases} \dfrac{r}{\sigma^2}\exp\left(-\dfrac{r^2}{2\sigma^2}\right) & (0 \leq r \leq \infty) \\[4mm] 0 & (r<0) \end{cases} \tag{13}$$

where σ is the rms value of the received voltage signal before envelope detection, and σ^2 is the time average power of the received signal before envelope detection.

2.5.2 AWGN

To allow for real-world noise conditions such as thermal noise of the receiver, we include an Additive White Gaussian Noise (AWGN) source with the channel. The noise should have the variance $N_0/2$, where N_0 is the single-side power spectral density of white noise.

JPEG2000 and ROI coding

3.1 Introduction

Image compression falls under the general umbrella of data compression. JPEG is an acronym for Joint Photographic Experts Group. JPEG was a group of several hundred individuals who were working with the International Standards Organization, or ISO. A portion of JPEG was working on the JPEG2000 standard, a standard that had got the ISO approval in August 2000 and soon became known to the world as ISO 15444 [1], [2]. JPEG2000 allows high compression ratio with very little appreciable degradation in image quality. It has a lossy and lossless version of image compression. This standard has made a considerable progress in the communications of multimedia information such as images over error prone wireless channels. In addition to the basic compression functionalities, many other features have been provided in JPEG2000 including [6],
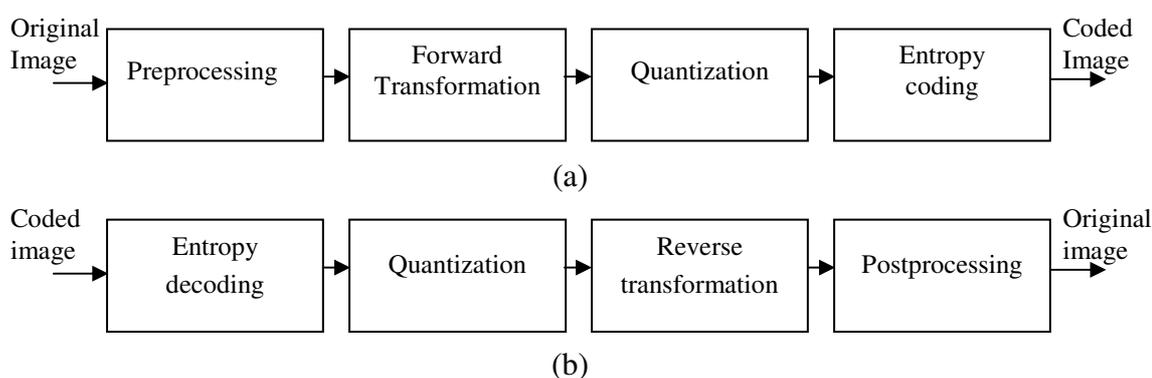
- Progressive recovery of an image by resolution.
- Random access to particular regions of an image without the help of decoding the entire codestream.
- Region of interest coding, whereby different parts of the image can be coded with different fidelity.
- Error Resilience Tools.

Digital image transferring has become an integral part of the wireless communication systems. So, wireless devices are expected to be capable of transmitting a large amount of multimedia data and images efficiently. Due to excellent coding performance and many other attractive features, JPEG2000 has a strong potential for wide adaptation in next generation wireless imaging areas.

3.2 The JPEG2000 compression engine

The JPEG2000 image compressor is based on wavelet/subband coding techniques [2] and borrows ideas from the embedded block coding with optimized truncation (EBCOT) scheme [5]. The general structure of the JPEG2000 compression engine is shown in block diagrams in Figure 3.1 with the form of the encoder given by Figure 3.1(a) and the decoder given by Figure 3.1(b). Each functional block in the decoder either exactly or approximately inverts the effects of its corresponding block in the encoder. Forward transformation, quantization and entropy coding can be grouped together as core processing. The codestream has some specific syntax to represent the coded image. The concepts of precincts, code blocks, layers and packets are implemented. So, from these figures the main processes associated with the JPEG2000 compression engine can be identified as:

1. Preprocessing/postprocessing.
2. Core processing.
3. Codestream formation.

Original Image → Preprocessing → Forward Transformation → Quantization → Entropy coding → Coded Image

(a)

Coded image → Entropy decoding → Quantization → Reverse transformation → Postprocessing → Original image

(b)

Figure 3.1: General block diagram of the JPEG2000 compression engine.

The structure of the (a) encoder and (b) decoder.

3.2.1 Preprocessing

Digital image is a collection of 2-D arrays of samples, with finite extent in each dimension. In JPEG2000, an image is comprised of one or more components. All of the components are associated with the same spatial extent in the source image, but represent different spectral information. The encoder describes the geometry of the various components in terms of a rectangular grid called the reference grid. Components are mapped onto the image area of the reference grid. The images may also be divided into non-overlapping rectangular tiles. A group of samples from one component that fall within a tile is called a tile-component. Larger tiles perform visually better than smaller tiles. For the present study we are not interested in this feature. Instead our attention is in the scenario where the entire image is processed as a single tile.

Input sample data in JPEG2000 encoder should have a *nominal dynamic range* centred about zero. As a result, a number of simplifying assumptions can be made in the design of the encoder (e.g., with respect to context modelling, numerical overflow, etc.) [6]. Level shifting does not affect variances. The encoder then implements forward colour transformation. The decision to use a colour transform is left to the discretion of the encoder. Only two colour transforms are defined in JPEG2000 Part 1 are: the *reversible colour transform* (RCT) which is integer-to-integer in nature and *irreversible colour transform* (ICT) which is real-to-real in nature. The basic idea is to map image data from RGB to the YCbCr colour space. The ICT may only be used in the case of lossy coding, while the RCT can be used in either the lossy or lossless case.

The ICT is nothing more than the classic RGB to YCbCr colour space transform. The forward transform is defined as

$$
\begin{pmatrix} Y \\ C_b \\ C_r \end{pmatrix} = \begin{pmatrix} 0.299 & 0.587 & 0.114 \\ -0.16875 & -0.33126 & 0.5 \\ 0.5 & -0.41869 & -0.08131 \end{pmatrix} \cdot \begin{pmatrix} R \\ G \\ B \end{pmatrix}
\tag{14}
$$

Here R, G and B are the input components corresponding to the red, green and blue colour planes respectively and the output parameters Y is the luminance, C_b and C_r the chrominance components. The inverse transform can be written as

$$
\begin{pmatrix} R \\ G \\ B \end{pmatrix} = \begin{pmatrix} 1.0 & 0 & 1.402 \\ 1.0 & -0.34413 & -0.71414 \\ 1.0 & 1.772 & 0 \end{pmatrix} \cdot \begin{pmatrix} Y \\ C_b \\ C_r \end{pmatrix}
\tag{15}
$$

On the other hand, the RCT forward transform is given by

$$
\begin{pmatrix} Y \\ C_b \\ C_r \end{pmatrix} = \begin{pmatrix} \left\lfloor \dfrac{R + 2G + B}{4} \right\rfloor \\ R - G \\ B - G \end{pmatrix}
\tag{16}
$$

The reverse transform can be shown as

$$
\begin{pmatrix} G \\ R \\ B \end{pmatrix} = \begin{pmatrix} Y - \left\lfloor \dfrac{C_b + C_r}{4} \right\rfloor \\ C_b + G \\ C_r + G \end{pmatrix}
\tag{17}
$$

After the colour transform stage in the encoder is the intracomponent transform stage where wavelet transform technique is applied on individual components. With the help of the discrete wavelet transform (DWT), a component is split into numerous frequency bands called subbands. Both reversible and non-reversible wavelet transforms are employed in the JPEG2000 codec. In the lossy case, a non-reversible real-to-real wavelet

transform is applied and in the lossless case, reversible integer-to-integer transform is applied. At each level of transformation the codeblock is divided into four subbands:

- horizontally and vertically lowpass (LL)
- horizontally lowpass and vertically highpass (LH)
- horizontally highpass and vertically highpass (HL)
- horizontally and vertically highpass (HH)

At each resolution level (except the lowest) the LL band is farther decomposed as in Figure 3.2. Due to the statistical properties of these subband signals, the transformed data can usually be coded more efficiently than the original untransformed data.
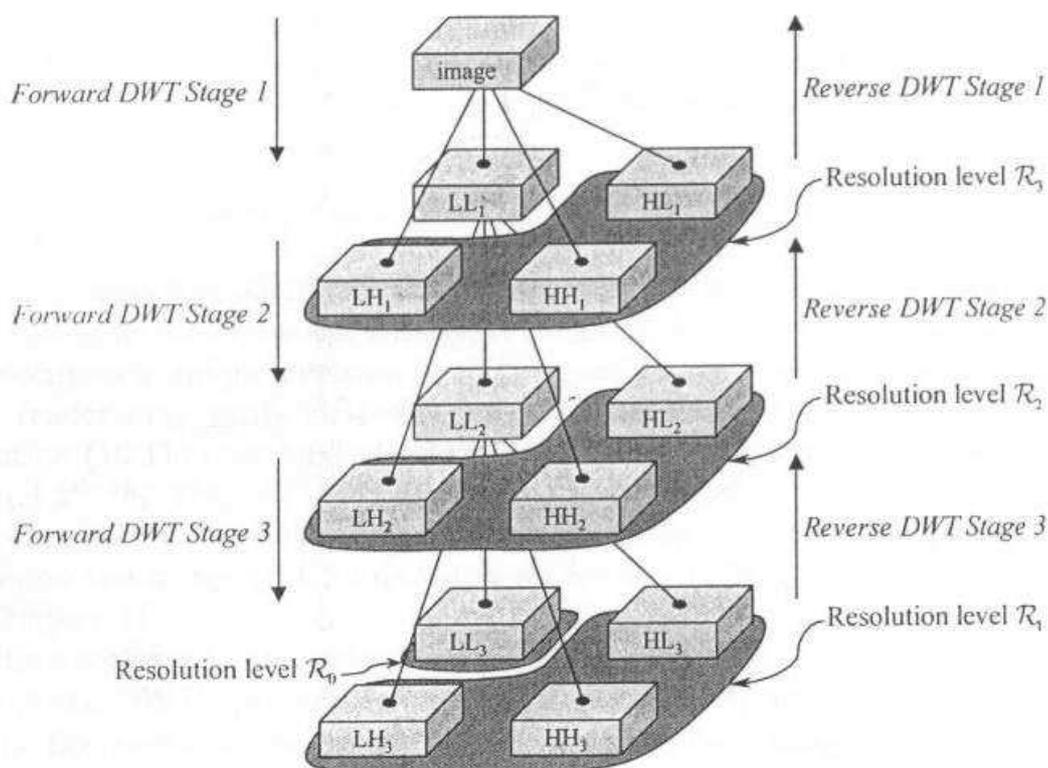
Figure 3.2: Wavelet decomposition structure [5].

Each subband is partitioned into small blocks called codeblocks. Codeblocks are the smallest structure in JPEG2000. Each codeblock is coded independently, producing its own codestream. Three spatially consistent rectangles (one from each subband at each resolution level) comprise a packet partition location or precinct as in Figure 3.3 (a). Initial quantization and bit-plane coding are performed on these codeblocks. Compressed data from each precinct is collected into so called packets. Each packet consists of a packet head and a packet body, which together identify and contain incremental contributions from the codeblock belonging to relevant precinct.

3.2.2 Core processing

In the encoder, after the tile-component data has been transformed, all coefficients are quantized. Transform coefficients are quantized using a dead-zone scalar quantizer in Part I of the JPEG2000 standard [2].

JPEG2000's uniform dead-zone quantizer is an embedded quantizer and quantization can be regarded as a two-step process. In the first step, a quantization step size is specified for each subband: the subband coefficients are represented by signed integers. In the second step, the signed integers within each codeblock of each subband are optimally truncated making use of a *bi-plane* coding technique. This is equivalent to optimally modifying the quantization step size of each code block to achieve the desired compression ratio. Thus, the resulting quantization only depends on the optimal truncation algorithm, as long as the quantization step size is chosen small enough. If the quantization step size is chosen too large, compression quality may be jeopardized. On the other hand, too small quantization step size will lead to achieve the desired quality but compromise codec efficiency.

The bit-plane coding process generates a sequence of symbols for each coding pass. Some or all of these symbols may be entropy coded. For the purpose of entropy coding, a context based adaptive binary arithmetic coder is used. More specifically it is called the MQ coder [2]. JPEG2000 uses the Elias entropy code to do this. In the Elias entropy code, it is not necessary to transmit the entropy coding table with the compressed file. A utility that decompresses the file will already know how the data was manipulated. Since the image is broken up into subbands and tiles, it is possible to apply the entropy encoding to

every tile in parallel. This means we can significantly decrease the time needed to compress or decompress the file while retaining the same level of quality.

<div align="center">(a)</div>

<div align="right">(b)</div>

<div align="center">(c)</div>
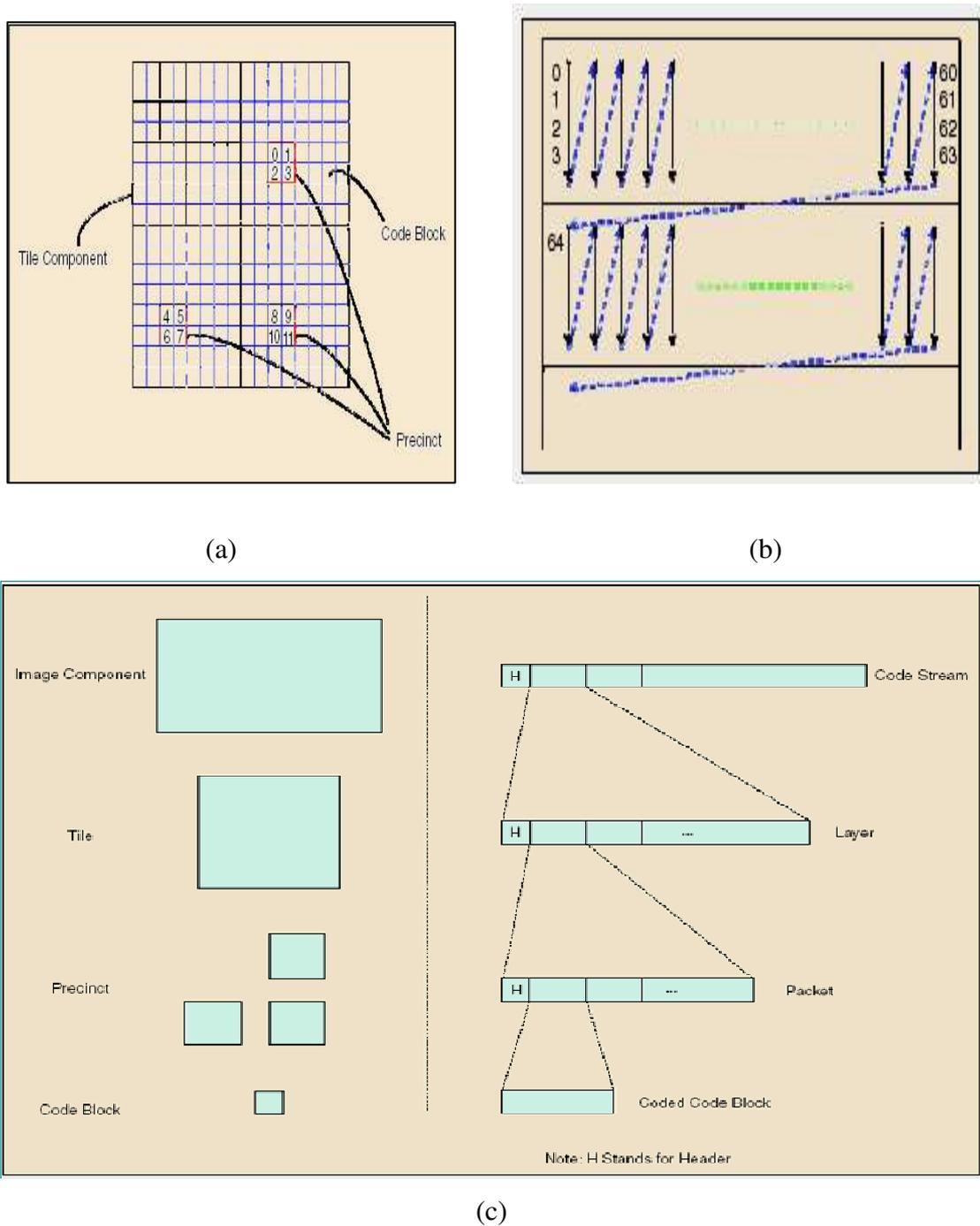
Figure 3.3: Codestream formation. a) Partition of tile component into code blocks and precincts. b) Scan pattern of each bit-plane of each codeblock. c) Conceptual correspondence between spatial and the codestream representation [2].

Quantization of transform coefficients is one of the primary sources of information loss in the coding path, unless the quantization step is 1 and the coefficients are integers, as produced by reversible integer wavelet. On the other hand, controlling quantizer step size in the *MAXSHIFT* method is the most appropriate technique for lossy ROI coding.

3.3 Final codestream structure

JPEG2000 supports several packets ordering scheme in the codestream. There are five supported progressions in the JPEG2000 standard:

- resolution-layer-component-position
- layer-resolution-component-position
- resolution-position-component-layer
- component-position-resolution-layer
- position-component-resolution-layer.

The first position refers to the index which progresses most slowly, while the last refers to the index which progresses most quickly. For each subband, we visit the codeblocks belonging to the precinct of interest in raster scan order as shown in Figure 3.3 (b).

The compressed codestream from each codeblock in a precinct comprise the body of a packet. A collection of packets, one from each precinct of each resolution level, comprises the layer as in Figure 3.3 (c). Each layer successively and monotonically improves the image quality, so that the decoder is able to decode the codeblock contributions contained in each layer in sequence. The final codestream is organised as a succession of layers.

The basic building block of the codestream is the marker segment. As shown in Figure 3.4, a marker segment is comprised of three fields: the type, length and parameters fields. A codestream is simply a sequence of marker segments and packet data organized as shown in Figure 3.5. The codestream consists of a main header, followed by tile-part header and body parts, followed by body trailers. Parameters specified in markers

segments in the main header serve as defaults for the entire codestream. All marker segments, packet headers, and packet bodies are a multiple of 8 bits in length.

| Type (16 bits)	Length (16 bits) (if required)	Parameters (variable length) (if required)

Figure 3.4: Marker segment structure.
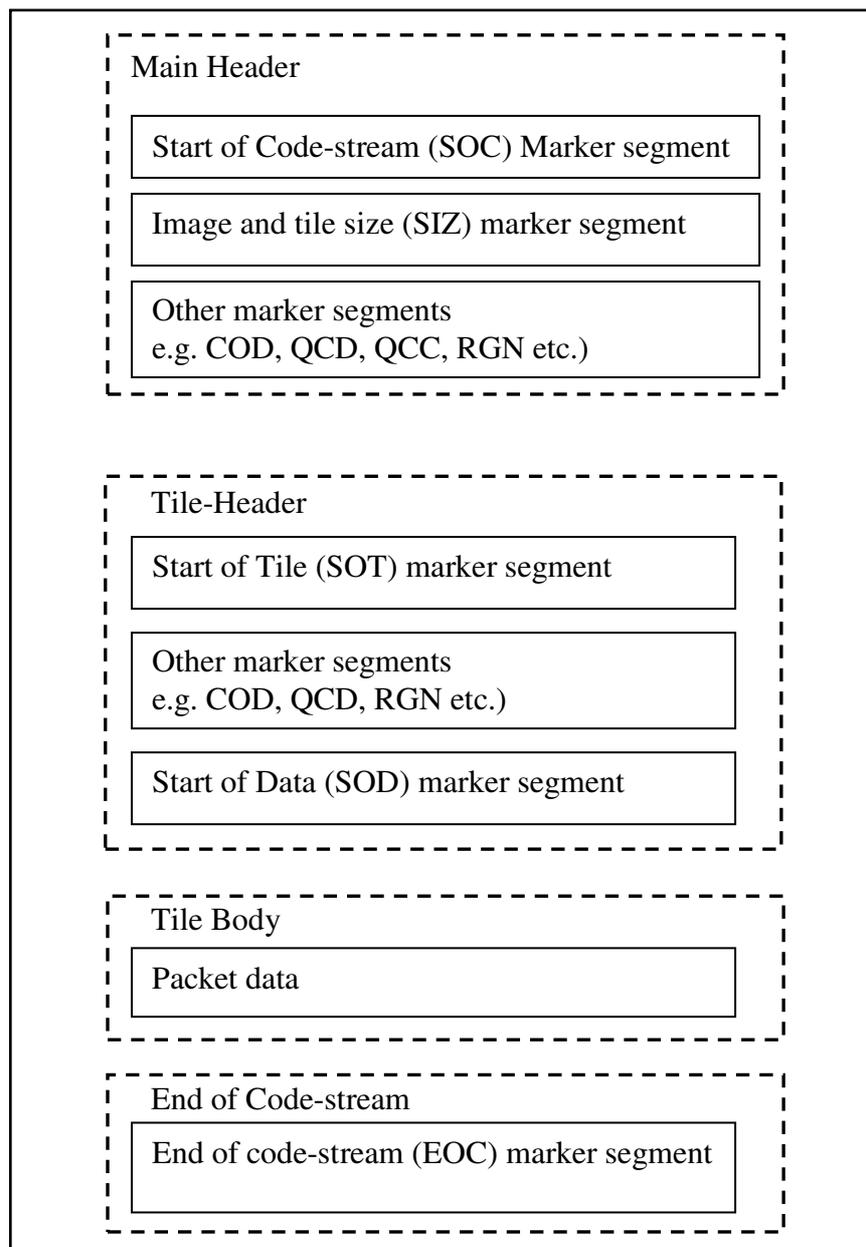
Figure 3.5: Codestream structure [11].

3.4 Region of Interest (ROI)

The JPEG2000 codec allows different regions of an image to be coded with differing fidelity. This is known as ROI coding. The functionality of ROI is important in applications where certain parts of the image are of higher importance than others. For example, in facial images the quality of the face portions as in Figure 3.6 should have higher importance than other regions. In such a case, these regions need to be encoded at higher quality than the background. During the transmission of the image, these regions may need to be transmitted first or at a higher priority as in Figure 3.7.
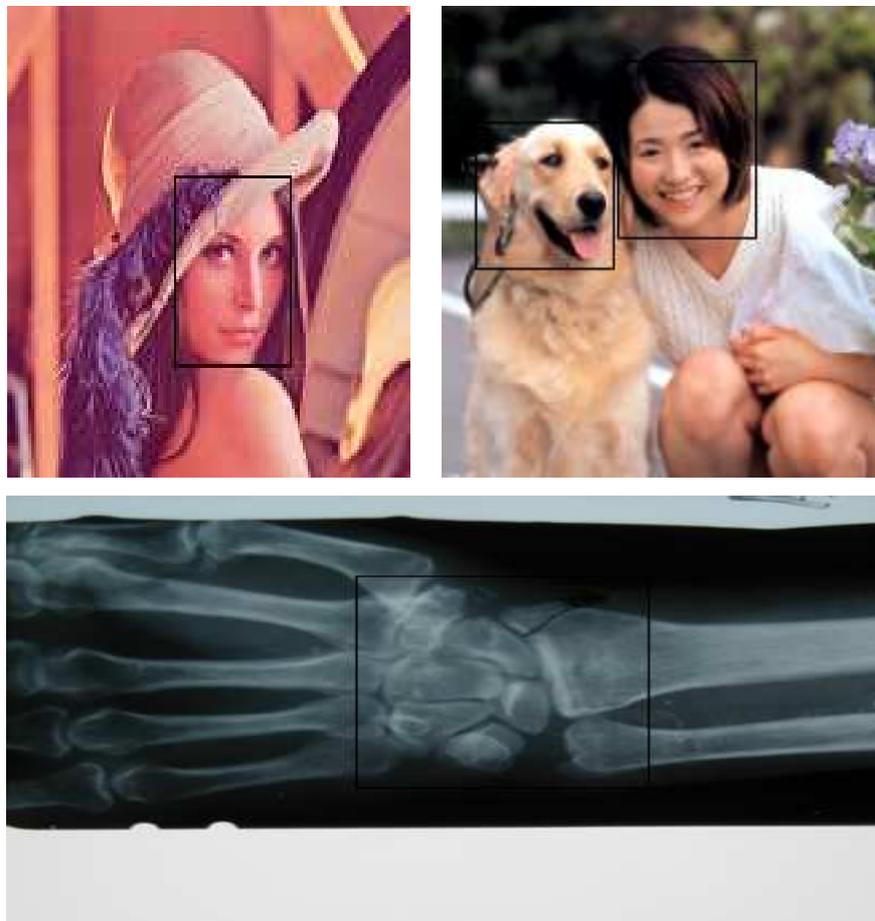
Figure 3.6: Typical regions of interest (ROI) areas in different images.

In order to support ROI coding, a very simple yet flexible technique is employed. Here, some of the transform coefficients are identified as being more important than the others.

The coefficients of greater importance are referred to as ROI coefficients, while the remaining coefficients are known as background coefficients.

JPEG2000 header	ROI data bytes	Other data bytes
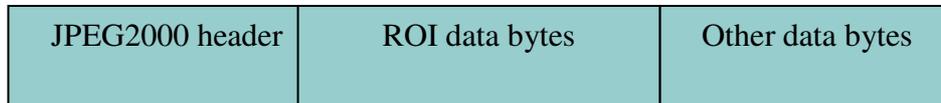
Figure 3.7: Codestream structure.

In the encoder, before the quantized coefficients for the various subbands are bit-plane coded, the ROI quantized coefficients are scaled upwards by a power of two (i.e., one bit left shift). This scaling is performed in such a manner as to ensure that all bits of the ROI quantized coefficients lie in more significant bit-planes than the potentially nonzero bits of the background quantized coefficients. In this way, the ROI can be reconstructed at a higher fidelity than the background.

For ROI coding, the encoder first examines the background quantized coefficients for all the subbands looking for the index with the largest magnitude. If this index has its most significant bit in bit position N-1, all of the ROI quantized coefficients are then shifted N bits to the left, and bit-plane coding proceeds as in the non-ROI case. The ROI shift value N is included in the codestream as depicted in Figure. 3.8. This method is called *MAXSHIFT* method which is described in detail in [5].

In the decoder, any quantized coefficient with nonzero bits lying in bit-plane N or above can be identified as belonging to ROI set. All coefficients in ROI set are then scaled down by a right shift of N bits. This undoes the effect of scaling on the encoder side.
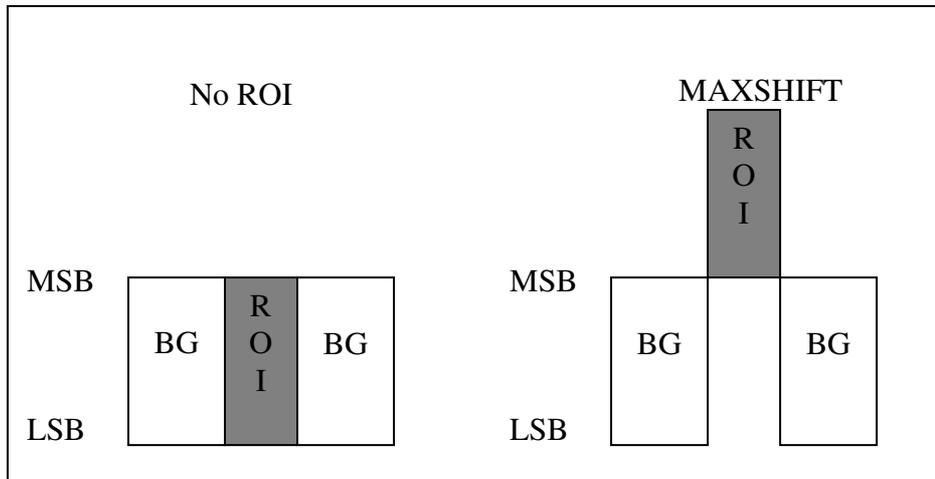
Figure 3.8: Scaling of the ROI coefficients [2].

3.5 Error Resilience in JPEG2000

Partitioning the codestream into different segments helps to isolate errors in one segment and prevent them from propagating through the entire codestream. JPEG2000 provides several error resilience tools [18], to help minimize the impact of corruption in the packet data. In Kakadu v4.2 (software implementation of the JPEG2000 used in this thesis) [17], we see a collection of mode switches which provide support for enhanced error resilience.

In JPEG2000 the resynchronization marker (SOP=Start of packet) plays an important role in error resilient parsing of the codestream. SOP marker segments may optionally be inserted in front of each codestream packet. In the event of a corrupt packet header, the length of the packet's header and/or body are likely to be misread, so that the next packet's SOP marker will not be encountered in the expected location. The SOP marker segment contains a sequence number, which may be used to recover from errors of the form described above. SOP marker is inserted in front of every packet when the option is enabled.

One of the mode switches used in Kakadu v4.2 is the *ERTERM* predictable termination strategy. Using this, decoder can localize any errors encountered in the codestream with reasonably high confidence. Once an error is detected, the decoder can discard the affected

coding pass and all further coding passes, thereby minimizing the impact of error upon reconstructed image quality. This strategy is known as error concealment.

Kakadu v4.2 also offers an additional feature to assist the decoder in localizing errors in a codeblock's codestream. In this case, a special four symbol code, known as a *SEGMARK*, is inserted immediately before the first new coding pass in each magnitude bit-plane. A bit error in any of the preceding coding passes is likely to corrupt at least one of the four *SEGMARK* symbols, allowing the decoder to detect the error. When *ERTERM* and *SEGMARK* are used together, most codeblock codestream errors can be detected and concealed.

As discussed earlier the main component of the codestream is the packet. Encoding and decoding of codeblocks are independent processes, so bit errors in a codestream of one codeblock will not affect other codeblock. The codeblock contributions inside the body of the packet can be independently decoded. However, if a packet header is corrupted, the codeblock contributions from that packet's body cannot generally be correctly recovered. Moreover, subsequent packet headers for the same precinct are often not decodable without the previous ones. This suggests that errors in a packet header can be expected to have more devastating impact on image quality than the errors in the packet body. For this reason, this work considers the benefits of protecting packet headers more strongly than corresponding bodies.

This thesis is concerned with the development of an unequal error protection scheme for JPEG2000 compressed imagery. More particularly, we are interested in maximizing the received image quality, in the presence of random bit errors. Such conditions might be expected in the context of wireless image transmission.

## Linear Unequal Error Protection (LUEP) Technique

4.1 Introduction

A linear unequal error protection (LUEP) technique for transmitting JPEG2000 coded images over Rayleigh fading channels is proposed in this thesis. It assigns more channel protection bits to the packets that contain the most significant quality layers. The implementation of *MAXSHIFT* coding algorithm in Part I of the JPEG2000 standard results in a placement of the ROI data at the beginning of the codestream. This thesis is based on this particular organization of the codestream. The results reported here provide guidance concerning the implementation of stronger error correction coding schemes (Golay code) for ROI and comparatively weaker coding (Hamming code) for non-ROI image spaces.

4.2 Proposed method and its advantages

In this section, the proposed method and its significant benefits are described. It is worth emphasizing that an error in the header may lead to a decoding failure. Thus, our prime idea is to provide high error protection for the header and also for the higher order bit-planes which normally come from the most interesting part of the image spaces after compression.

A. *Extended codec structure*

The proposed method considers that JPEG2000 codestream is composed of multiple quality layers, which are generated from a single-tile image. In the sequel, we refer to our proposed method as the extended JPEG2000 codec. The coder side of the extended codec consists of the JPEG2000 part I encoder and an error protection encoder. Consequently, its decoder side consists of the error recovery block and the JPEG2000 part I decoder. Figure 4.1 illustrates the extended codec attached to the Rayleigh fading wireless channel.
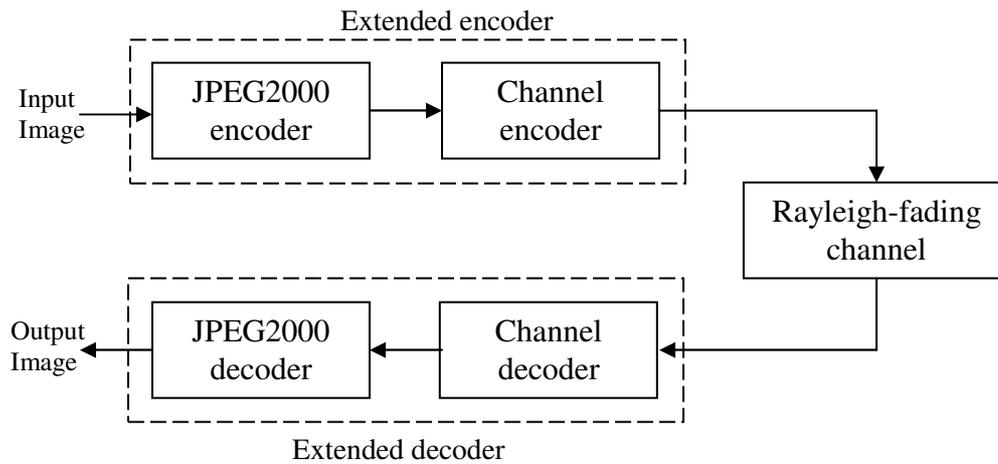
Figure 4.1 Extended codec structure in Rayleigh fading channel.

B. Encoding process

The image is compressed using the Kakadu JPEG2000 codec software [17]. The coded data is divided into different quality layers. With the help of *MAXSHIFT* method, the ROI is encoded before the remainder of the image. The main header and the data packets which belong to ROI area are protected by an extended Golay (24, 12) code. The remaining parts of the codestream are protected by Hamming (15, 11) code. The parameters of the proposed LUEP scheme are shown in Table 4.1.

There are two different issues which need to be considered in this step, namely:

i)   Length of ROI data boundary.

      The amount of data from the beginning of the codestream that will be required to ensure a certain quality of the image inside the ROI boundary.

ii)   Compression type and rate.

For irreversible compression some bits of ROI coefficients might be encoded together with non-ROI coefficients. For reversible low bit rate image compression, sometimes non-ROI data might be very few in the codestream.

The trade-off between those considerations determines the effectiveness of the extended codec.

Table 4.1: Parameters of the proposed LUEP scheme.

| Protection parts	FEC code	Error correction capability
Main header and ROI bytes	Golay (24, 12)	t=3
No ROI bytes	Hamming(15,11)	t=1

C. Decoding process

At the decoder side, channel decoding is performed before JPEG2000 decoding. After performing FEC decoding, most of the errors in the higher order quality layers of the codestream which is composed of the ROI area of the image is corrected. A comparatively higher BER may exist in lower bit-planes because of weaker error protection (Hamming code). Then, JPEG2000 decoding is done to obtain the reconstructed image.

D. Advantages of the proposed method

Several advantages of the proposed method are as follows. First, due to LUEP the JPEG2000 header can be received with very low bit error rate (BER) even in lower signal-to-noise (SNR) ratio. Hence, the resulting codestream can be decoded using JPEG2000 part I decoders. Secondly, the ROI area can be received with superior quality in comparatively lower SNR. Additionally, the error protection techniques (Golay and Hamming) are easy to implement.

5.1 The simulation environment

Figure 5.1 shows the block diagram of the used wireless system model. The model consists of an input binary codestream of a source image compressed in JPEG2000 format. The encoder implements two linear error protection mechanisms to protect different parts of the image. We use a Rayleigh fading channel as our mobile radio environment. AWGN is also imposed in the system. The modulation scheme is simply binary phase shift keying (BPSK). Table 5.1 shows the simulation parameters.
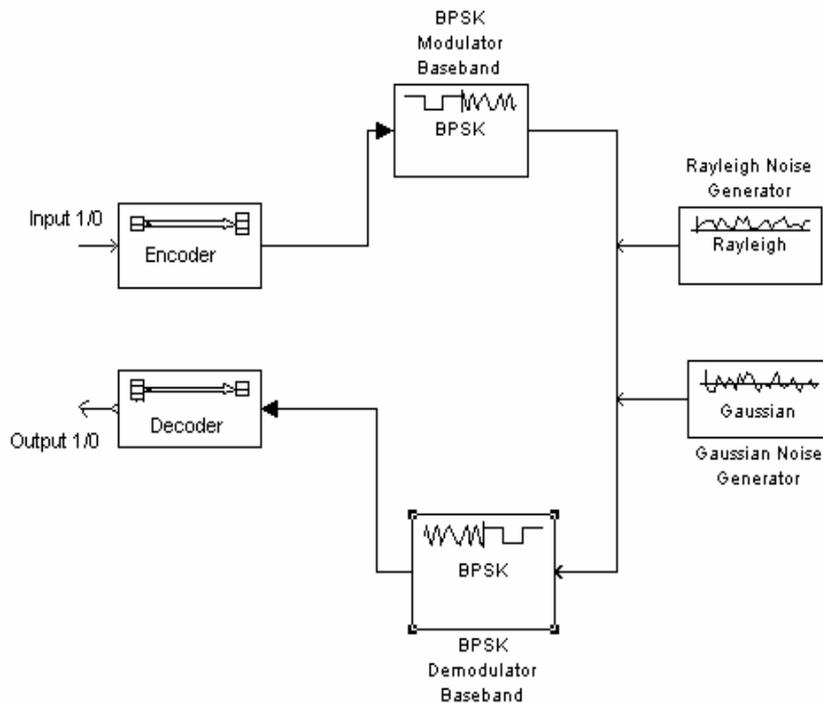
Figure 5.1: Wireless system model.

Table 5.1: Simulation parameters of wireless system.

Parameters	Description
Channel coder	Hamming (15,11) + Golay (24,12)
Modulation	BPSK
Channel model	Rayleigh + AWGN
E_b/N_0 [dB]	10-25

5.2 Progressive transmission of JPEG2000 codestream

The latest JPEG2000 standard provides for several types of progressive modes within the final codestream. In this thesis, we use layer-resolution-component-position progression order. The first one in the sequence refers to the index which progresses more slowly, while the last refers to the index which progresses more quickly.

The *MAXSHIFT* coding allows the region of interest image space to be coded in higher order bit-planes or in the top layers in the final codestream of a JPEG2000 coded image. Figure 5.2 shows the progression of image quality of a 10 layer compressed image with ROI coding.

| 1 Layer | 2 Layers | 3 Layers | 4 Layers | 5 Layers |

| 6 Layers | 7 Layers | 8 Layers | 9 Layers | 10 Layers |

Figure 5.2: Progressive transmission by pixel
accuracy and resolution with time.

5.3 Performance of channel coding

We used two different linear error protection techniques in our work. Figure 5.3 shows a comparison of bit error probability (P_b) of these block codes compared to uncoded technique. As can be seen from the Figure 5.3, the Golay code has superior bit error rate performance compared to Hamming code.
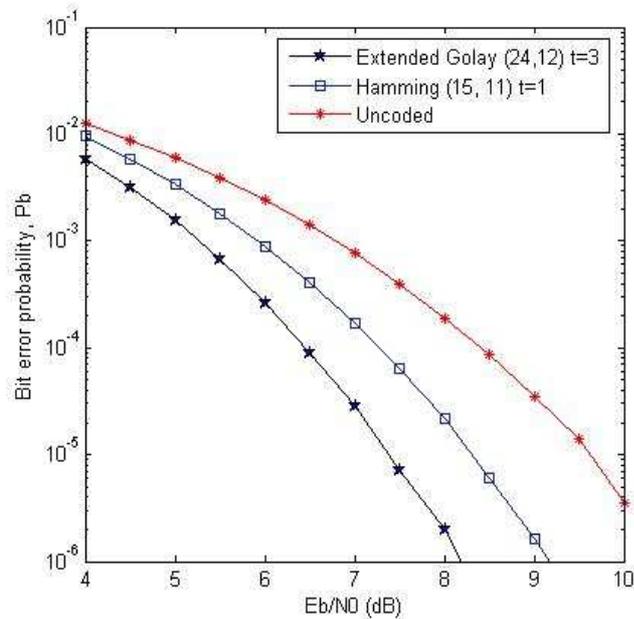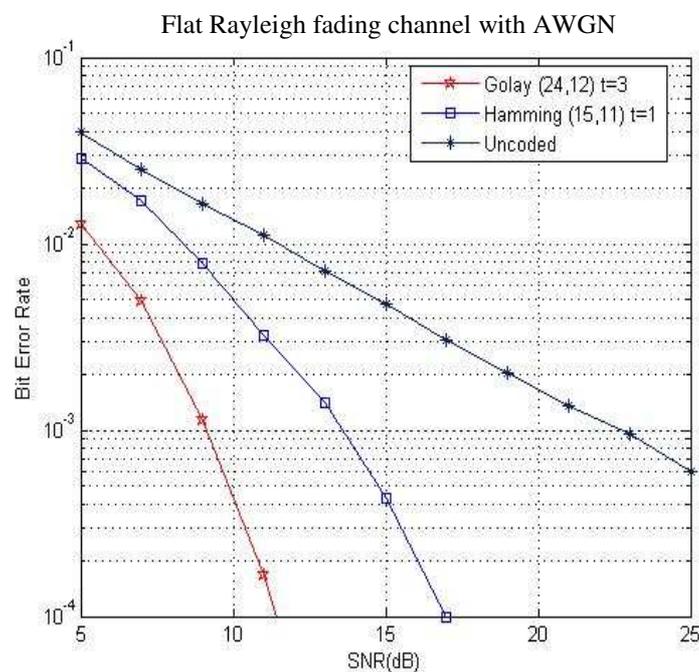

Figure 5.3: P_b versus E_b/N_0 for coherently demodulated BPSK over a Gaussian channel for the considered block codes.

5.4 Bit error rate in Rayleigh fading channel

Fading is the most significant phenomenon in wireless communication. Here, the fluctuation of received signal amplitude causes very bad error conditions in the channel. In mobile radio channels, the Rayleigh distribution is commonly used to describe the statistical time varying nature of the received envelope of an individual multipath component.

Typical simulated Rayleigh fading at carrier
Receiver speed = 120 km/hr

Number of samples in 1μs
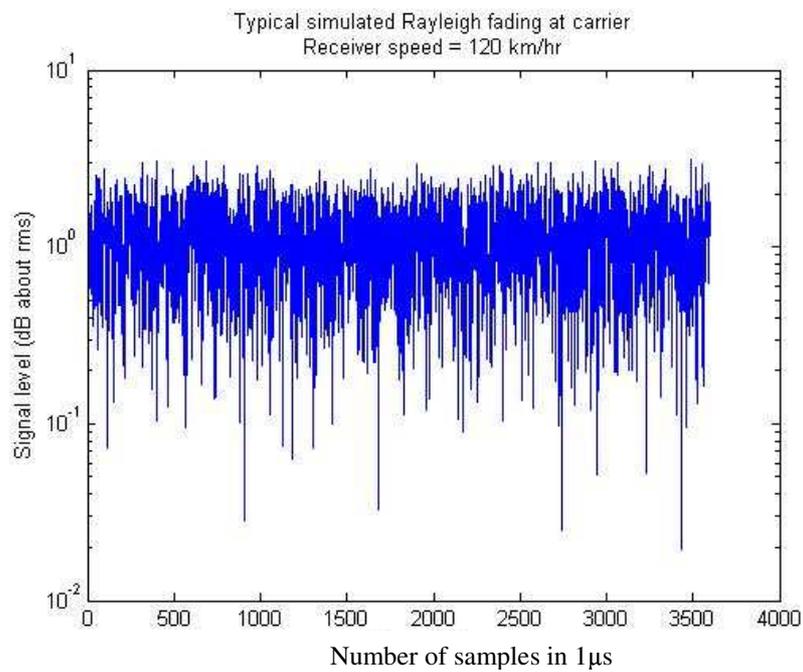
Figure 5.4: Received envelope of a Rayleigh fading
channel with respect to time.

Flat Rayleigh fading channel with AWGN

Figure 5.5: P_b versus Eb/N_0 for coherently demodulated
BPSK over a Rayleigh channel with AWGN.

The performance of the proposed LUEP technique is evaluated over a Rayleigh fading channel. Figure 5.4 shows the received signal envelope for a mobile unit traveling at *v=120 km/h*. Furthermore, the carrier frequency is $f_c=900MHz$ and sampling frequency $f_s=4f_c$. The signal is generated for a time interval of $\tau=1\mu s$.

Figure 5.5 shows the BER performance of different error correcting block codes in Rayleigh fading channel subject to AWGN.

5.5 Statistics of a sample image used in simulation

The 512x512 pixels colour Lena image is used as the test image. The original image is in bitmap (bmp) format and is shown in Figure 5.6. Only lossless compression (at two bit rates: 1.0 bpp and 3.0 bpp) is considered.

The image is compressed using the Kakadu JPEG2000 codec software [17]. For lossless compression, the reversible wavelet transformation is used. The image is decomposed for ten levels; the size of the codeblock is set to 64x64. The face of the image has been considered as the ROI. And the area of ROI is $1/10.6^{th}$ of original image. Five levels DWT (discrete wavelet transformation) are used to affect the ROI information. Block coder mode switches are also used to enhance error resilience. Quantization step size is kept to 0.03125. The arithmetic coder is terminated after each pass, and segmentation symbols are added to the encoded codestream.

Figure: 5.6: Sample 'Lena' image.

Table 5.2 shows different information of the image after compressing in JPEG2000 format in two different transmission rates of 1.0bpp and 3.0bpp. The ROI length is calculated from the start of codestream as the *MAXSHIFT* method will set ROI coefficients in the beginning. It can be noted that number of packets in ROI decreases with the increase of compression rate.

TABLE 5.2
Protection statistics for the JPEG2000 512x512 colour Lena image at 1.0bpp and 3.0bpp.
10 quality layers comprise the final codestream.

Compression rate	Image size (kb)	Total number of packets	Number of packets in ROI**	ROI length (kb)*	ROI PSNR	Whole image PSNR
1bpp	32.0	180	106	8.58	49.49	28.73
3bpp	95.6	180	52	8.92	53.77	40.93

Length is calculated from the start of the code stream
**The number is calculated on the basis of PSNR inside ROI boundary. These are the*
*minimum packets required to ensure ROI **PSNR>40dB***
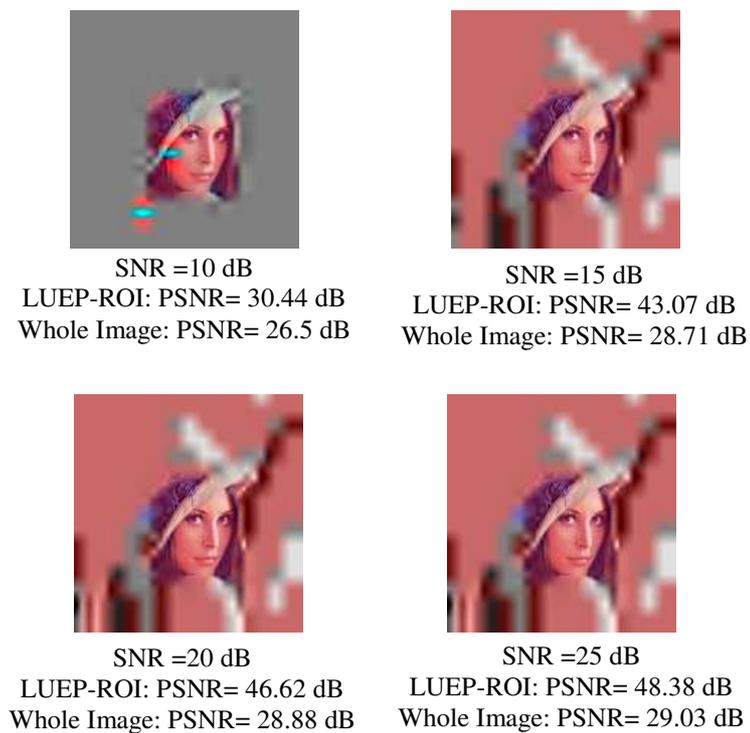
A. Compressed image transmission (1bpp)

The results below show the transmission of 1.0bpp JPEG2000 compressed image over a Rayleigh fading channel by the proposed LUEP technique. Each SNR level has been tested with 50 independent trials.

Figure 5.7 shows the compressed image in 1.0bpp. Figure 5.8 shows visual results of the received image in four different noise levels. The PSNR of the ROI as well as the whole image are measured. Figure 5.9 shows the average PSNR of the received images in the graphical form. The simulation is done with and without the error resilience tools and the results are shown accordingly. It should be noted that for very low SNR values, it could

appear that the received image header contains a large number of errors and the JPEG2000 decoder may not be able to decode the received codestream.

Figure 5.7: Compressed image in 1.0bpp

SNR =10 dB
LUEP-ROI: PSNR= 30.44 dB
Whole Image: PSNR= 26.5 dB

SNR =15 dB
LUEP-ROI: PSNR= 43.07 dB
Whole Image: PSNR= 28.71 dB

SNR =20 dB
LUEP-ROI: PSNR= 46.62 dB
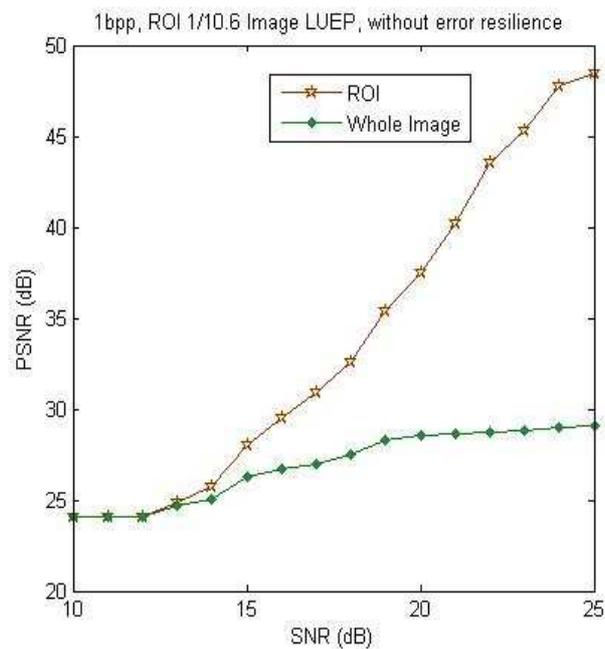Whole Image: PSNR= 28.88 dB

SNR =25 dB
LUEP-ROI: PSNR= 48.38 dB
Whole Image: PSNR= 29.03 dB

Figure 5.8: Visual results at 1bpp over a Rayleigh fading channel
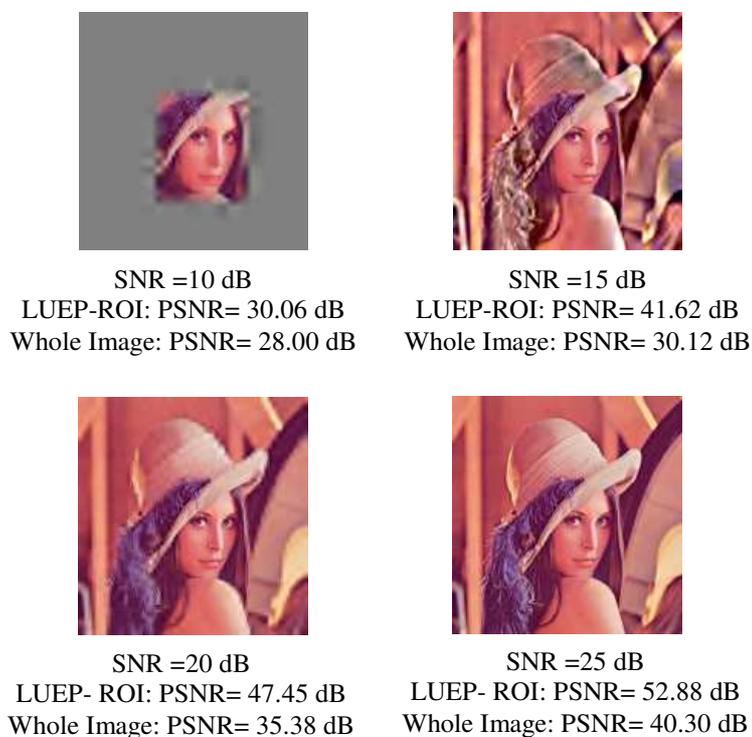with SNR= 10, 15, 20 and 25 dB using LUEP.
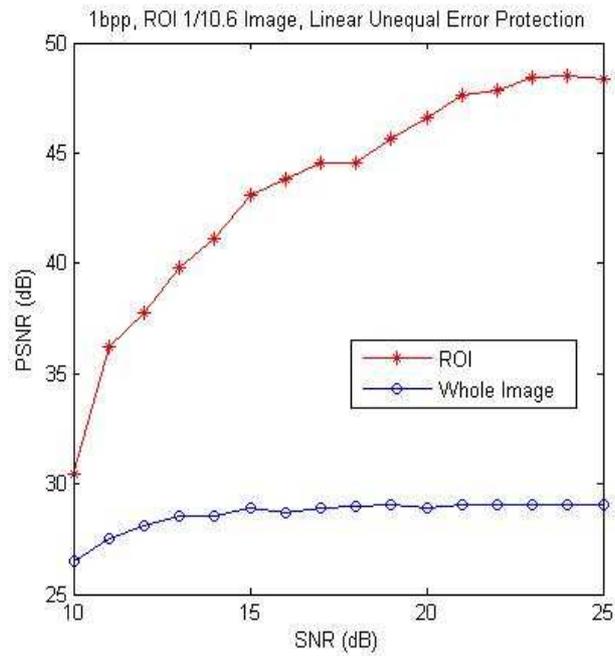
(a)

(b)

Figure 5.9: PSNR versus SNR for the JPEG2000 512x512 colour Lena image compressed with 1.0bpp after transmitting over a Rayleigh fading channel. a) Error resilience tools used in decoder b) No error resilience tools used.

B. Compressed image transmission (3bpp)

The results below show the transmission of 3.0bpp JPEG2000 compressed image. The simulation environment is kept the same as in the previous. Figure 5.10 shows the compressed image in 3.0bpp. Figure 5.11 shows visual results of the received image in four different noise levels. Figure 5.12 shows the average PSNR of the received images in the graphical form with and without the error resilience tools.

Figure 5.10: Compressed image in 3.0bpp.

SNR =10 dB
LUEP-ROI: PSNR= 30.06 dB
Whole Image: PSNR= 28.00 dB

SNR =15 dB
LUEP-ROI: PSNR= 41.62 dB
Whole Image: PSNR= 30.12 dB

SNR =20 dB
LUEP- ROI: PSNR= 47.45 dB
Whole Image: PSNR= 35.38 dB

SNR =25 dB
LUEP- ROI: PSNR= 52.88 dB
Whole Image: PSNR= 40.30 dB

Figure 5.11: Visual results at 3bpp over a Rayleigh fading channel
with SNR= 10, 15, 20 and 25 dB using LUEP.
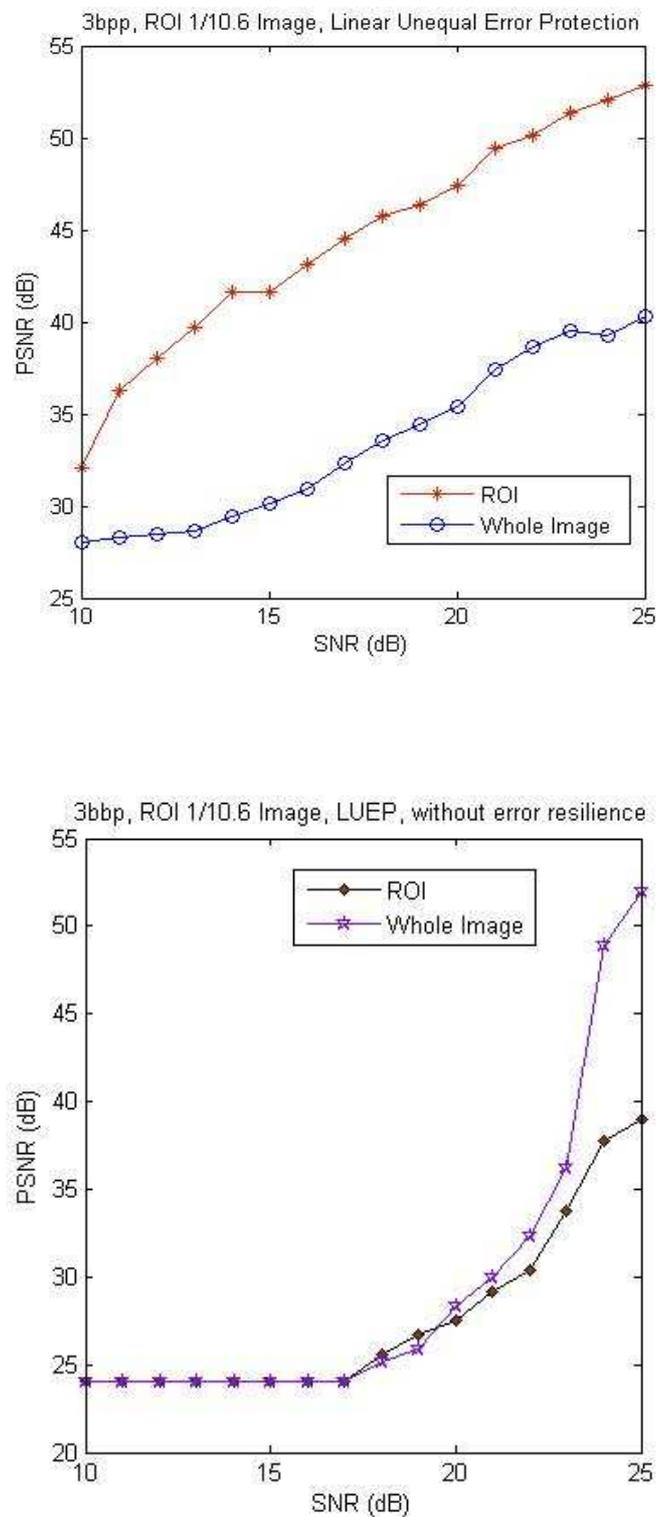
Figure 5.12: PSNR versus SNR for the JPEG2000 512x512 colour Lena image compressed with 3.0bpp after transmitting over a Rayleigh fading channel. a) Error resilience tools used in decoder b) No error resilience tools used.

Conclusions

JPEG2000 is the new standard for still image compression. High compression efficiency, ROI coding and error resilience are some of its tremendous features which can be easily adapted to wireless image transmission. With the help of channel coding we can significantly increase the received image quality.

We have proposed an LUEP technique for ROI coded and layered JPEG2000 codestream. The technique exploits the hierarchical organization of the JPEG2000 codestream and protects the main header and the packets that contain ROI data in the most significant bit-planes by a stronger error correction code and comparatively weaker channel protection for the rest of the codestream. The channel protection is achieved by Hamming code and an extended Golay code. The robustness of the technique has been verified over a Rayleigh fading channel in different channel conditions. Simulation results show that the ROI area can be received with superior quality in comparatively lower signal-to-noise ratio by the proposed protection technique.

We examined the impact of existing error resilience tools offered by JPEG2000. We find that these tools have substantial benefits to have better image quality in the receiving side. The ability of multiple quality layers enabled us to introduce forward error correction codes, to protect the layers unequally.

LUEP scheme were tested in the context of a Rayleigh fading channel model having SNR level ranging from 10dB to 25dB. All tests were carried out on 10 layers codestream structure. We assumed that the region of interest area of a facial image is the face itself. Only the face area was passed through *MAXSHIFT* coding.

From simulation we observed:

- Error resilience tools have significant impact in received image quality. ROI up shift (*MAXSHIFT*) value is important to get the ROI data in front of the code stream.
- ROI area is received with superior quality even in lower SNR.
- JPEG2000 image header should not be corrupted by the noise.
- As fading effect increases image quality decreases.

The transmission over noisy channels can be done using different systems in order to achieve a good quality of service. If one works with a retransmission system there is a problem with large transmission delays when the channel is noisy. The use of unequal error protection with error resilience tools might solve this problem. Such unequal error protection can be utilized by the base station for transmitting JPEG2000 encoded images over next generation wireless networks.

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