Watermarking Scheme for Blind Quality Assessment in Multimedia Mobile Communication Services

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Abstract

Due to the advancement in digital wireless communication 3rd/future generation mobile communication system expects to offer multimedia services and applications with negotiated end-to-end quality assurance. Hence devising a simple and effective billing system related to the quality of services (QoS) supplied becomes essential to the service providers. The paper proposes a low-cost spread spectrum (SS) watermarking scheme in multimedia data where the estimation of the tracing watermark at mobile station (MS) end would blindly assess the quality of services (QoS). Furthermore, the quality of tracing watermarks obtained from multipath can be used to combat the fading effect using diversity technique.

1. Introduction

During the last few decades there occurs tremendous growth in the field of wireless communication that has made possible today the worldwide mobility between the transmission and reception system. Accompanied advancement in digital signaling and coding techniques enable the convergence of voice, video, text, image and data etc in wireless network. As a result, various wireless mobile communication services today offer data transmission along with the voice based applications. It is then expected that 3rd/future generation mobile communication systems [IMT2000/Universal Mobile Telecommunications System (UMTS)] will provide multimedia services and applications with negotiated end-to-end quality assurance [27],[12]. Hence devising a simple and effective billing system, related to the quality of the services (QoS) supplied, is very much essential to the service providers. The crucial point is that assessment scheme should not increase data transmission rate, that may affect the unique spectrum availability problem of wireless channel.

Digital watermarking, although primarily developed to protect the intellectual property (copyright) of digital media, is also used nowadays in various other applications ranging from fingerprinting, broadcast monitoring, multimedia indexing etc [17]. Another promising new application of digital watermarking is blind assessment of the quality of the multimedia services in third/future generation mobile communication system. Reference watermark pattern (already available to the end user) is embedded in the multimedia host data and is transmitted through the channel. Host data and watermark suffer the same channel degradation, where alteration in watermark is used to assess the quality of the offered services.

The present application of digital watermarking requires (a) data imperceptibility to preserve quality of the offered services, (b) robustness to non malicious attacks like filtering, compression and noise addition offered by the transmission channel, (c) low computation cost and complexity along with ease of hardware implementation of the algorithm. Needless to mention that the security of the hidden data is trivial, since it is known that offered multimedia services already contain some auxiliary message. Spread spectrum (SS) modulation is a popular approach to meet the robustness and imperceptibility criterions of digital watermarking due to its anti jamming and interference rejection capability [18]. Several SS watermarking schemes are developed in DCT [7], Fourier-Mellin [22], wavelet [11],[14] domain but the algorithms are not suitable for the present applications due to the high computation cost and complexity associated with overhead in detection process.

Campisi et al developed [4],[5] DCT domain blind quality assessment schemes for multimedia services. But the mean square error (MSE) metric used in this work to assess QoS is not well matched to the perceived visual quality of images. Moreover, it is reported in the work of Ramkumar and Akansu [20] that Hadamard or Hartley transform offers higher data hiding capacity compared to DCT or Wavelet transform with capability of survival against high processing noise arising out of lower quality compression. So, Hadamard transform is expected to be better choice for data hiding in video frames, as the later is likely to suffer more processing noise than an average still image. Maity et al [15],[16] proposed compression resilient digital image watermarking schemes using Hadamard transform, but the algorithms can not be used for the present application due to their non blind detection process. We propose here a SS watermarking scheme in digital image, for blind quality assessment, which may also be applicable in video frames and other multimedia signals. The complexity and computation cost of the algorithm is low and hardware implementation is easy.

The paper is organized as follows: Section 2 describes mathematical models and expression used in this work. Section 3 describes the proposed QoS system embedding and the recovery process with brief discussion on related hardware realization. Sections 4 and 5 present some experimental results with discussion on QoS, and conclusion respectively.

2. Mathematical preliminaries

This section describes the image transformation, proper mathematical model to quantify the supplied services, quality measure of the recovered data etc.

2.1. Image transform

The forward Hadamard transform of a digital image $f(x, y)$ of size $N \times N$ (where $N = 2^n$) can be expressed as [10]

$$H(u,v) = 1/N \sum_{x=0}^{N-1} \sum_{y=0}^{N-1} f(x,y)(-1)^{\sum_{i=0}^{n-1}[b_i(x)b_i(u)+b_i(y)b_i(v)]} \tag{1}$$

and the inverse Hadamard transform as

$$f(x,y) = 1/N \sum_{u=0}^{N-1} \sum_{v=0}^{N-1} H(u,v)(-1)^{\sum_{i=0}^{n-1}[b_i(x)b_i(u)+b_i(y)b_i(v)]} \tag{2}$$

where $b_k(z)$ is the k-th bit in the binary representation of z. The summation in the exponent is carried out in modulo 2 arithmetic.

The kernel of Hadamard transformation is a symmetric matrix having orthogonal rows and columns. Thus, the same algorithm can be used for both the 2-D forward and inverse Hadamard or Walsh transforms without modification. Hence, the only one hardware block is sufficient to implement both forward and inverse transform. The main advantage of Hadamard transform over other unitary transforms like FFT, DCT, Fourier-Mallin, and wavelet is the low computation cost of the forward and inverse transformation due to its binary valued, +1 or -1, kernel. Hence floating point addition-multiplication is not required for forward and inverse transform when the digital image is convolved with signed integer valued kernel. This particular nature of kernel requires less computer storage and also offers low cost software and hardware realization. Moreover, higher order Hadamard kernel (H_{2N}) can easily be generated from its lower order form (H_N) using simple recursive relation. The other important advantage of Hadamard transformation lies in its higher data hiding capacity compared to DCT and Wavelet transform at low quality compression.

2.2. Image visual quality

The quality of the image signal can be measured using different models like average absolute difference, mean squared error, L^P norm, Laplacian mean squared error, and visible difference predictor (vdp) etc [26]. But none of these measures is well matched to perceived visual quality. In this work we have used a recently developed [24] structural similarity measure as image quality assessment and we briefly discuss about it for the convenience of our future analysis. The work of Wang et al [24] separates the task of similarity measurement, between the two signal X (cover) and Y (stego), into three comparison: luminance, contrast and structure.

The luminance comparison function $l(X, Y)$ is a function of μ_x and μ_y where the mean intensity μ_x of a discrete signal is represented as follows:

$$\mu = \frac{1}{N} \sum_{i=1}^{N} x_i \tag{3}$$

To estimate signal contrast unbiasedly they use standard deviation (the square root of variance) and the contrast comparison function $c(X, Y)$ is then the comparison of σ_x and σ_y where σ_x is represented as follows:

$$\sigma_x = (\frac{1}{N-1} \sum_{i=1}^{N} (x_i - \mu_x))^{1/2} \tag{4}$$

The structure comparison $s(X, Y)$ is conducted on the normalized signals $(X - \mu_x)/\sigma_x$ and $(Y - \mu_y)/\sigma_y$. The three components are relatively independent and are combined to yield Structural SIMilarity index (SSIM)

$$SSIM(X,Y) = [(l(x,y)]^{\alpha}.[c(x,y)]^{\beta}.[s(x,y)]^{\gamma} \tag{5}$$

where $\alpha > 0$, $\beta > 0$ and $\gamma > 0$ are parameters used to adjust the relative importance of the three components.

They use a mean SSIM (MSSIM) index to evaluate the overall image quality as follows:

$$MSSIM(X,Y) = \frac{1}{M}\sum_{j=1}^{M} SSIM(X_j, Y_j) \qquad (6)$$

where X and Y are therefore the reference and the distorted images respectively; X_j and Y_j are the image contents at the j-th local window; and M is the number of samples in the quality map.

2.3. Quality of extracted watermark

We embed a binary image pattern in Hadamard coefficients of the cover image using SS modulation technique. We consider watermark embedding in host data and its extraction at user end as a digital communication problem and use mutual information as an objective measure to quantify the quality of the extracted watermark. The quality of the extracted watermark in turn estimates the quality of the multimedia services. Random variables X and Y represent respectively the original watermark and its decoded version obtained from the multimedia data. If $p(x_i)$ represents the probability of occurrence of the i-th pixel value in watermark message and $p(y_j/x_i)$ represents the channel transmission matrix, $I(X;Y)$ that represents the average amount of information received from the signal degradation, can be expressed as follows [13] :

$$I(X;Y) = \sum_i \sum_j p(x_i)p(y_j/x_i) \log \frac{p(y_j/x_i)}{\sum_i p(x_i)p(y_j/x_i)} \qquad (7)$$

where i, j=0,1.

3. Proposed algorithm

SS watermarking scheme spreads narrow band tracing watermark signals over many frequency bins of the cover so that watermark energy content of each bin becomes small and quality of the media remain intact due to embedding. QoS system embedding We use a gray scale image as cover image and a binary image as tracing watermark. Since the relative quality of the extracted tracing watermark indicates the quality of the supplied services we call this data hiding as QoS system embedding. The steps of QoS system embedding are described as follows:

Step 1: Image decomposition

The cover image of size $(M_c \times N_c)$ is decomposed using Fast Hadamard transform.

Step 2: Generation of code patterns

The widely used code pattern for SS modulation technique is pseudo noise (PN) sequence and is generated using LFSR (Linear feedback shift register)[23]. The size of the PN sequence is identical to the size of the Hadamard coefficient matrix. Thus a set of PN matrices denoted by (P_i) of number $(M_m.N_m)$ are generated.

Step 3: Modulation of code pattern using Hadamard basis

The PN codes generated by LFSR exhibit some correlation among each other. Mayer et al [17] reported that the code patterns used for SS watermarking should possess low correlation, among each other, for better detection i.e. $< P_i, P_j >$ value should be very small for $j \neq i$. Ideally, sequences P_i and P_j should be orthogonal whenever $j \neq i$. We generate two dimensional Hadamard kernel identical to the size of the Hadamard coefficient matrix of the host data. The elements of +1 and -1 of Hadamard kernel are mapped to 1 and 0. Each PN code pattern is then modulated by the modified Hadamard kernel.

Step 4: Watermarked image formation

If any bit (b) of the message vector is '0'or '1' the respective PN matrix i.e.P_i is then added to the corresponding element of Hadamard coefficient matrices respectively, according to the data embedding rule as follows:

$$X^e = \begin{cases} X + kP & \text{if} \quad b = 0 \\ X - kP & \text{if} \quad b = 1 \end{cases}$$

where X is Hadamard coefficient of the cover image, X^e is the Hadamard coefficient after watermark embedding, k is the modulation index, P is the PN matrix. Two dimensional discrete inverse Hadamard transformation of the modified coefficients would then generate watermarked image.

One may use linear, power-law or any other modulation function to implement signal adaptive SS watermarking scheme as stated below so that embedding distortion is reduced with improved detection but computation cost will be increased along with an increase in complexity of hardware realization. If linear and power-law functions are used for embedding, the coefficients will be represented as follows:

$$X^e = X \pm k_1.X.[P_i] \qquad (8)$$

$$X^e = X \pm X^{\mu}[P_i] \qquad (9)$$

In the equation (8), k_1 is the ratio of minimum Hadamrd coefficient to maximum Hadamard coefficient - a negative quantity, μ in the equation (9) is the modulation index. The

modulation index μ is negative numeric quantity with fractional value. QoS system decoding The tracing watermark recovery process requires the sets of PN matrices (P_i) that were used for data embedding. The supplied services i.e. multimedia signals are decomposed using Hadamard transform. Correlation value between Hadamard coefficients and each code pattern of the set (P_i) is calculated. We have a total of $(M_m.N_m)$ (equal to the number of watermark bits) mean correlation values $(\mu_i) where$ i=1, 2,.. $M_m.N_m$. From these mean correlation values, we calculate an overall mean correlation value (T), used as the threshold or decision variable for binary watermark decoding. The decision rule for the decoded watermark bit is as follows:
(i) for $\mu_i \geq T$, the extracted bit is '0'
(ii) for $\mu_i < T$, the extracted bit is '1'.

3.1. Hardware realization

The proposed QoS embedding and recovery scheme uses Hadamard transform and a set of PN code patterns generated by an LFSR. Implementation of LFSR in hardware is straightforward. Walsh-Hadamard transform involves simple binary integer arithmetic and can thus readily be mapped to digital hardware. Further, its modularity, block diagonal structure, and inherent parallelism of computation lead to several known efficient implementations [8],[25],[2],[3]. Custom design IP-cores and FPGA-based designs have also been studied recently [9],[1]. Several commercial DSP chips for computation of the transform are also available [6]. Thus, an on-chip co-processor may be provided to compute the transform for use in QoS system embedding and recovery purpose in real-time.

4. Results and discussion

In this section we report the experimental results that highlight the effectiveness of proposed scheme to access QoS. This algorithm is efficient in term of processing time. It took approximately 1 second for the embedding process and approximately 2 seconds for extraction using a MATLAB 6 platform running on a Pentium III 400MHz PC system. In UMTS, multimedia signals are compressed first and thus a coded bit stream is obtained. This coded bit stream is then transmitted through noisy channel. Mobile station (MS), the end user of mobile communication system, extracts the tracing watermark from the supplied services and compare with the original watermark pattern. Since the original multimedia signal is not available to the MS, the relative quality of the tracing watermark is the indication about the quality of the offered services. Fig. 1(a) is a test image Lena (8 bits/pixel, 256×256) with tracing watermark in Fig. 1(b). The tracing watermark is a binary image of size (4×4) and watermarked image is shown in Fig. 1 (c). The MSSIM value for the watermarked image is very high 0.9878 and Peak Signal to Noise Ratio (PSNR) value of the watermarked image (The other measure of watermarked image quality) is also very high of 40.23 dB. The presented QoS assessment scheme has been tested for JPEG and JPEG-2000 coder followed by additive white gaussian noise offered by the transmission channel. Each mutual information value corresponds to the relative quality of the tracing watermark, that in turn indicates MSSIM value, i.e. quality of the offered services. Fig. 2 represents relative quality of the tracing watermark when extracted from the various noisy compressed images. Fig. 3 Shows the relative quality of the offered services i.e. MSSIM measure of noisy compressed images. Fig. 4 represents the graphical plot that is used to estimate the quality of services from MSSIM value when mutual information for the tracing watermark is received from MS. At this point we discuss few issues related to QoS information.

(1) In practical UMTS environment MS calculates mutual information value for the tracing watermark and the value is used as feedback information to the service provider for billing information. A fraudulent user, to obtain any benefit, declares that the received quality is lower than the provided one. Campisi et al suggests an adhoc solution against false declaration on QoS through (a) improvement of service quality of base station or (b) interrupt the communication process for a few seconds. They provided the solution as in (b) is due to the fact that if there occurs frequent declarations of poor or null quality from a MS, the admission call manager may refuse the access to further calls of the same user, al least until the MS has moved to a region with less noise or interference.

(2) The quality of the tracing watermark may lead to a false quality assessment of the supplied services due to the mutipath effect of mobile radio channel. Due to fading effect MS declares that the received quality is lower than the actually transmitted. One popular approach is the use of various diversity techniques to combat the fading effect. In maximal ratio combiner (space or antenna diversity) or RAKE receiver for spread spectrum CDMA (time diversity) signals from M- branches are weighted (after correlation in case of RAKE receiver) according to their individual signal voltage to noise power ratio and then summed [26]. But in practice weight factor is determined using $(S + N)/N$ since it is difficult to measure SNR alone [27]. At this point our suggestion is to use the relative quality of the tracing watermarks, extracted from the multiple replicas of the transmitted signal obtained from multipath. The weight factors should be determined proportional to the tracing

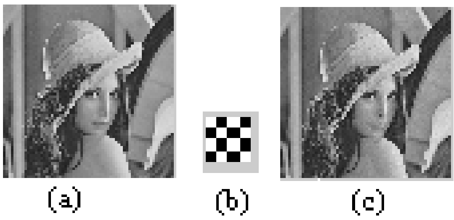

Figure 1. (a) Cover image (b) Tracing watermark (c) Watermarked image

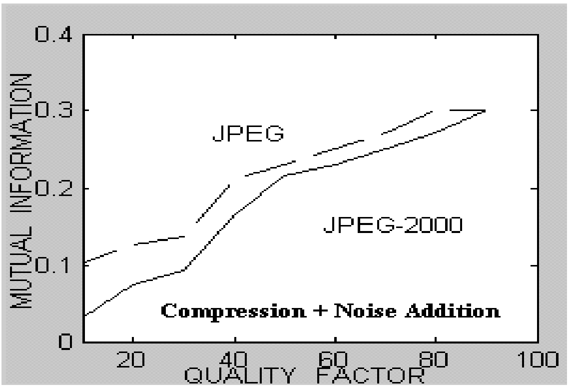

Figure 2. Quality of tracing watermark for various QoS

watermark quality in order to achieve a better estimate of the transmitted signal. According to our opinion quality of the tracing watermark will determine better weight factor than SNR values since watermark must be embedded in the significant transform coefficients of the multimedia signal to make it resilient against channel noise. On the other hand SNR is calculated from the original domain analysis which is reported in various literatures as less robust compared to transform domain approach.

(3) The properties of the code patterns play a significant role in reliable detection of the tracing watermark. If orthogonal codes are used for data embedding, much improved detection is possible even from the low quality of services.

(4) The selection of modulation function has also an effect on reliable detection. Signal adaptive SS watermarking scheme i.e. equations (8) and (9) or any other form offer better detection compared to conventional non adaptive SS scheme. There is scope that a fraudulent service provider, to obtain benefit, may use one type of modulation function during negotiation and other type of function for QoS used only for billing purpose.

5. Concluding remarks

Blind assessment of QoS in third/future generation mobile communication network is discussed in this paper and low cost SS watermarking scheme is proposed for that purpose. The novelty of the scheme lies in its easy hardware realization that makes it suitable for real time multimedia mobile communication applications. The estimation of the tracing watermark at mobile station will provide detailed information about the quality of services, status of the link, information related to billing purpose etc. Furthermore, the quality of the tracing watermarks may be explored in diversity techniques for cancellation of the fading effect arising out of multipath propagation. At present research work is going on to develop VLSI design of the proposed algorithm using FPGA (Field Programmable Gate Array).

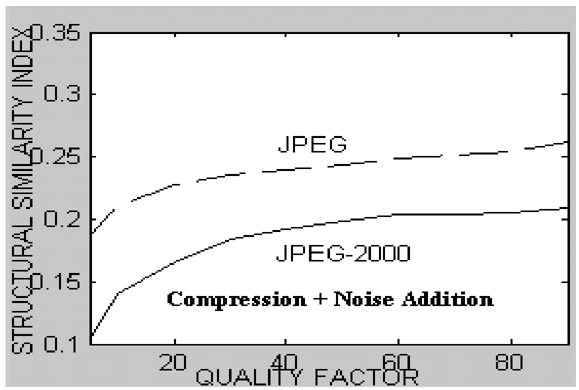

Figure 3. Quality of various offered services at MS

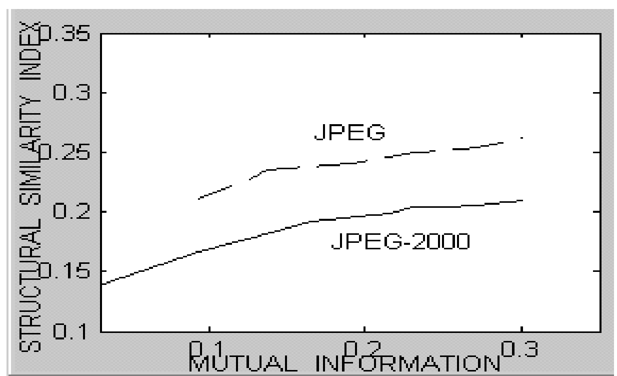

Figure 4. Estimation of the quality of services from the relative quality of the tracing watermark

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