Satellite Images Broadcast Based on Wireless SoftCast Scheme

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***Abstract*— This paper proposes a novel coding and transmission scheme for satellite image broadcasting to a large number of receivers. First, the proposed scheme employs a hybrid 3D transform; it first applies a 1D low-complexity Karhunen-Loève transform (KLT) that used a clustering approach as spectral decorrelating transform, and then followed by 2D discrete cosine transform (DCT) to remove redundant information within a spatial band. Second, the transmission power is directly allocated to the data according to their distributions and magnitudes without forward error correction (FEC). Third, these data are transformed by Hadamard matrix and transmitted over a dense constellation. The proposed scheme supports approximately the best quality to multiple users with diverse channel conditions without FEC and modulation. Experiments on satellite images demonstrate that the proposed scheme improves the average image quality by 2.49dB, 3.52dB, and 4.20dB over LineCast, SoftCast-3D, and Softcast-2D, respectively, and it achieves up to 7.33dB gain over JPEG2000 with FEC.**

***Index Terms*—Satellite images, SoftCast, LineCast, wireless communications.**

I. INTRODUCTION

SATELLITE images have been used in wide variety of applications and remote sensing projects, ranging from independent land mapping services to government and military activities. Some of these applications and projects are desperately needed the using of wireless communication to transmit the satellite images [1]–[3]. Therefore, satellite wireless systems have become an important topic needs to study. In agriculture, the need for observational data, aircraft and satellite remote sensing is playing an expanded role in farm management with the huge volume of information rep-resented by the satellite images. Also for the Meteorologists, the satellite images play an essential role to explore water vapor, clouds properties, aerosols, and absorbing gases.

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Satellite images are generated by collecting bands representing the same area of the earth surface in different spectral sampling intervals. Therefore, Satellite images are also widely used to study classification problems in a large number of applications [4] [5].

Nowadays global positioning systems (GPS) [6] used the satellite images to provide the location and more information for the users, anywhere on the Earth. Google has announced that they can track ships at sea in real time through satellites and will provide this tracking as a public service on the Internet [3]. Therefore, transmission these satellite images have become one of the greatest challenges. In this paper, we proposed a new wireless coding and transmission scheme, for broadcasting satellite images to a large number of receivers. In contrast to the digital separate design [7] [8] and following the approach presented in [9] [10], the proposed scheme is able to broadcast one satellite image with different resolutions to fit various devices with different display resolutions.

The rest of the paper is organized as follows: Section II reviews some related works. Section III describes the proposed scheme. Section IV presents the experimental results and discussions. Section V concludes this paper.

II. RELATED WORKS

A. Digital Broadcasting

Satellite broadcasting systems separate source coding and channel coding based on Shannon's source-channel separation theorem [7] [8].

In the source code, there are many techniques that have been recently used to compress satellite images [11]. One of them is JPEG2000 [12] that used in this paper. The standard is based on the wavelet coding. JPEG2000 supports the 9/7 and the 5/3 integer wavelet transforms. After transformation, coefficient quantization is adapted to individual scales and subbands and quantized coefficients are arithmetically coded.

In channel coding, forward error correction (FEC) and digital modulation are used in the digital scheme.

B. SoftCast

SoftCast [9] [10] is one of analog approaches that design within a joint source-channel coding (JSCC) framework.

The SoftCast encoder consists of the following steps: transform, power allocation and direct dense modulation. In the transform, there are two versions for SoftCast: SoftCast-2D [9] and SoftCast-3D [10]. In the SoftCast-2D, a 2-dimensional discrete cosine transform (2D DCT) is used. However, Soft-

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Cast-3D used a 3-dimensional DCT (3D DCT) to removes spatial and spectral redundancies of a group of images/video frames.

In the second step, power allocation minimizes the total distortion by optimally scaling the transform coefficients. After that, SoftCast employs a linear Hadamard transform to make packets with equal power and equal importance.

Finally, the data is directly mapped into the wireless symbols by a very dense QAM. At the receiver, SoftCast uses a linear least square estimator (LLSE) as the opposite operation of power allocation and Hadamard transform. Once the decoder has obtained the DCT components, it can reconstruct the original image/video frames by taking the inverse of the transform.

C. *LineCast*

A line-based coding and analog-like transmission is proposed in [13], called LineCast, which uses the same distributed source coding (DSC) technique in [14], which partitions source space into several cosets and transmits only coset indices to the decoder.

The LineCast encoder consists of the following steps: 1) read image line by line, decorrelate each line by a 1-dimensional DCT (1D DCT), 2) scalar modulo quantization, and 3) power allocation and transmission. As SoftCast, LineCast employs a linear Hadamard transform to get resilience against packet losses. After that, the data is directly mapped into the wireless symbols by a very dense 64K-QAM without digital forward error correction and modulation.

At the receiver, LineCast uses LLSE to reconstruct the line signal from the DCT components. Moreover, the side information is generated to aid the recovery of transform coefficients in scalar modulo dequantization. Finally, the minimum mean square error (MMSE) is used to denoising the reconstructed signal.

III. Proposed Scheme

The proposed scheme first proposes to do a simple preprocessing by subtraction of the integer mean value for satellite image data $\boldsymbol{x}$. After that, the processed data $\boldsymbol{r}$ is transforms by a 1D low-complexity Karhunen-Loève transform (KLT) followed by 2D DCT to remove redundant information within a band as well as across spectral dimension for each image. Owing to the fact that the output $\boldsymbol{q}$ has different distributions, a power allocation technique is employed to $\boldsymbol{q}$ to protect it against channel noises. Before transmission, the proposed scheme employs a Hadamard transform to redistribute energy as used in communication systems. Finally, the weighted frequencies $\boldsymbol{y}$ transmitted through raw OFDM channel without FEC and digital modulation. Figure 1 depicts the server side of the proposed scheme.

The client side of the proposed scheme is depicted in Fig. 2. After the PHY returns the list of coded DCT $\boldsymbol{y}'$, a LLSE is applied to provides a high-quality estimate of the recovery DCT components $\boldsymbol{q}'$. After that, it can reconstruct the processed image data by taking the inverse of the 2D DCT, followed by the inverse KLT. Finally, once the decoder has obtained the reconstructed image data $\boldsymbol{r}'$, the reprocessing step applied to reconstruct the whole satellite image in $\boldsymbol{x}'$.

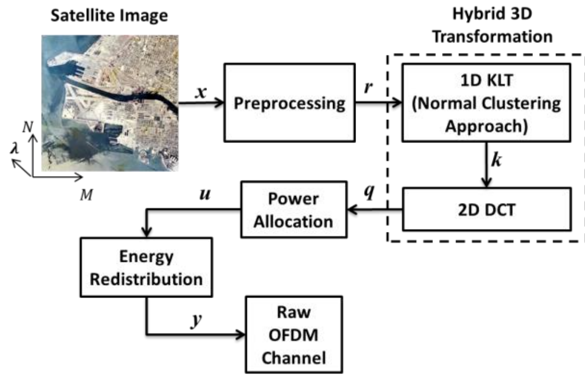


Fig. 1. Server side of the proposed scheme.

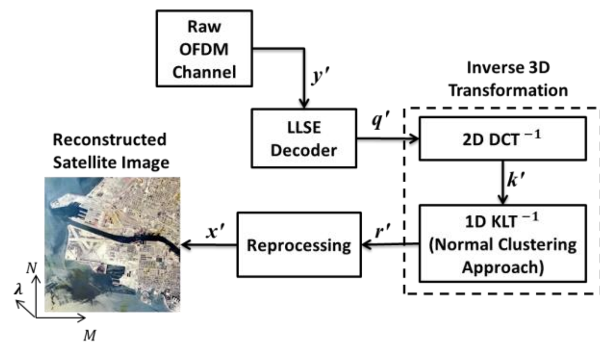


Fig. 2. Client side of the proposed scheme.

In the following subsections, we will describe each part of the proposed scheme.

A. *Preprocessing and Transforming Satellite Image*

Before the transformation, the satellite image $\boldsymbol{x}$ is first preprocessing to normalize the energy.

$$\boldsymbol{r} = (\boldsymbol{x} - \boldsymbol{m})\text{, and} \tag{1}$$

$$\boldsymbol{m} = \left|\text{mean}(\boldsymbol{x})\right|_{\text{Round}} \tag{2}$$

where each image $\boldsymbol{x}$ contains $\boldsymbol{N}$ rows, $\boldsymbol{M}$ columns and $\boldsymbol{\lambda}$ bands. For each image $\boldsymbol{x}$, the mean value $\boldsymbol{m}$ need to be transmitted to the receiver as metadata so that $\boldsymbol{x}$ can well recovered.

After the preprocessing step, we apply a 1D KLT to remove redundant information within a spectral dimension. After that, we adopt a 2D DCT for every band as a spatial decorrelator.

KLT achieves good performance in the satellite images compression [15]. However, the high complexity of this transformation is the biggest challenge. Different research teams have proposed several works to lessen the computational complexity problem [16]–[21]. In the proposed scheme, we used a normal clustering approach to reduce the computational complexity of KLT that proposed in [16], [21]. KLT transform is given by

$$\boldsymbol{k} = \boldsymbol{KLT}_{\Sigma_r}(\boldsymbol{r}) = \boldsymbol{V}^{\boldsymbol{T}}(\boldsymbol{r}) \tag{3}$$

where $\Sigma_{\boldsymbol{r}}$ is the covariance matrix of $\boldsymbol{r}$, and $\boldsymbol{V}$ is the orthogonal KLT transform matrix for $\boldsymbol{r}$. The orthogonal matrix $\boldsymbol{V}$ is obtained from the singular value decomposition (SVD) of $\Sigma_{\boldsymbol{r}} = \boldsymbol{V}\Lambda\boldsymbol{V}^{-1}$ $(\Lambda = \mathrm{diag}(\lambda_1,\ldots\lambda_{\boldsymbol{N}}), \lambda_1 \geq \lambda_2 \geq \ldots \geq \lambda_{\boldsymbol{N}})$. Note that the transform matrix $\boldsymbol{V}$ need to be transmitted to the receiver as metadata so that $\boldsymbol{r}$ can well recovered.

The KLT components $\boldsymbol{k}$ contains $\boldsymbol{\lambda}$ bands, for each band we adopt a 2D DCT.

$$\boldsymbol{q_i} = \boldsymbol{DCT}(\boldsymbol{k_i}), \text{ where } \boldsymbol{i} = 1,2,\ldots,\lambda \tag{4}$$

B. Power Allocation and Transmission

The proposed scheme used an optimal scaling factor $\boldsymbol{w}$ for $\boldsymbol{q}$ so that the total distortion on $\boldsymbol{q}$ is minimized. Scaling the transmitted signal according to [12] provides resilience to channel noise.

$$\boldsymbol{w} = \lambda^{-1/4}\left(\sqrt{\frac{\boldsymbol{P}}{\sum_{\boldsymbol{i}=1}^{\boldsymbol{F}}\sqrt{\lambda}}}\right) \tag{5}$$

where λ is the variance of $\boldsymbol{q}$, $\boldsymbol{F}$ is the number of frequencies, and $\boldsymbol{P}$ is the total transmission power. The signal $\boldsymbol{q}$ after power allocation is

$$\boldsymbol{u} = \boldsymbol{w} \cdot \boldsymbol{q} \tag{6}$$

To redistribute energy, we protect the weighted signal $\boldsymbol{u}$ against packet losses with multiplying it by a Hadamard matrix H.

$$\boldsymbol{y} = \boldsymbol{H} \cdot \boldsymbol{u}. \tag{7}$$

In contrast to digital communication, the proposed scheme transmitted signal using the raw OFDM without FEC and modulation steps. In addition to the image data, the encoder sends a small amount of metadata contains $\boldsymbol{m}$, $\boldsymbol{V}$ and λ to assist the decoder in inverting the received signal. The metadata is transmitted in the traditional way (i.e., OFDM in 802.11 PHY with FEC and modulation).

C. LLSE Decoder

At the receiver, for each transmitted signal $\boldsymbol{y}$, we receive a noisy signal

$$\boldsymbol{y}' = \boldsymbol{n} + \boldsymbol{y} \tag{8}$$

where $\boldsymbol{n}$ is a random channel noise (additive, white and Gaussian noise). The LLSE is used to reconstruct the original signals as follows:

$$\boldsymbol{q}' = \Lambda_{\boldsymbol{q}}\boldsymbol{R}^{\boldsymbol{T}}(\boldsymbol{R}\Lambda_{\boldsymbol{q}}\boldsymbol{R}^{\boldsymbol{T}} + \Lambda_{\boldsymbol{n}})^{-1}\boldsymbol{y}' \tag{9}$$

where $\boldsymbol{R} = \boldsymbol{H}\cdot\boldsymbol{w}$, $\Lambda_{\boldsymbol{n}}$ is the covariance matrix of $\boldsymbol{n}$ and $\Lambda_{\boldsymbol{q}}$ is a diagonal matrix whose diagonal elements are the variances, $\lambda_{\boldsymbol{i}}$, of the received signal.

D. Inverse Transforms and Reprocessing

First, we recover the KLT coefficients $\boldsymbol{k}'$ by applying the inverse DCT for each band $\boldsymbol{i}$, then we recover the processed signals $\boldsymbol{r}'$ by applying the inverse KLT.

$$\boldsymbol{k_i}' = \boldsymbol{IDCT}(\boldsymbol{q_i}'), \text{ where } \boldsymbol{i} = 1,2,\ldots,\lambda \tag{10}$$

$$\boldsymbol{r}' = \left(\boldsymbol{V}^{\boldsymbol{T}}\right)^{-1}\boldsymbol{k}' \tag{11}$$

In the final step, we reconstruct the final image data $\boldsymbol{x}'$ as follows:

$$\boldsymbol{x}' = (\boldsymbol{r}' + \boldsymbol{m}) \tag{12}$$

IV. Experimental Results

A. Dataset

The proposed scheme has been tested on several satellite images (see Fig. 3). The selected images are from the Aerials volume of the USC-SIPI image database [22]. The Aerials images with a resolution of 1024×1024×3 are represented by 8 bits per pixel per band (bpppb). All images are publicly available for download [22].

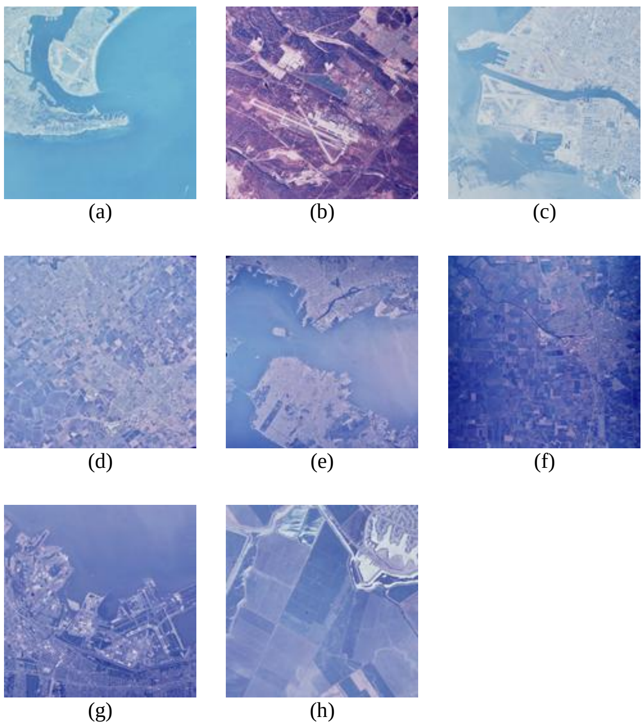


Fig. 3. Selected satellite images. (a)–(h) Satellite image 1, 2, 3, 4, 5, 6, 7 and 8, respectively.

B. Quality metric

Quality is computed comparing the original image $\boldsymbol{x}(\boldsymbol{M}, \boldsymbol{N}, \boldsymbol{\lambda})$ with the recovered image $\boldsymbol{x}'(\boldsymbol{M}, \boldsymbol{N}, \boldsymbol{\lambda})$. We evaluate these methods using the peak signal-to-noise ratio (PSNR).

$$\mathrm{PSNR}_{(\mathrm{dB})} = 10 \cdot \log_{10}\left(\frac{\boldsymbol{L}^2}{\mathrm{MSE}}\right) \ (\mathrm{dB}) \tag{13}$$

$$\mathrm{MSE} = \frac{1}{\boldsymbol{M} \cdot \boldsymbol{N} \cdot \boldsymbol{\lambda}} \sum_{\boldsymbol{i}=1}^{\boldsymbol{M}} \sum_{\boldsymbol{j}=1}^{\boldsymbol{N}} \sum_{\boldsymbol{k}=1}^{\boldsymbol{\lambda}} \left[\boldsymbol{x}(\boldsymbol{i},\boldsymbol{j},\boldsymbol{k}) - \boldsymbol{x}'(\boldsymbol{i},\boldsymbol{j},\boldsymbol{k})\right]^2 \tag{14}$$

where $\boldsymbol{\lambda}$ is the number of satellite image bands, and $\boldsymbol{L}$ is the maximum possible pixel value of the satellite image (i.e., $\boldsymbol{L} = 2^{\mathrm{B}-1}$, where B is the bit depth). Typical values for the PSNR in lossy satellite image compression are between 30 and 50 decibels (dB), provided the bit depth is 8 bits, where higher is better.

C. Broadcasting Results

In experiments, we evaluate the performance of the proposed scheme under broadcasting channels and compare it against: 1) SoftCast-2D [9], 2) SoftCast-3D [10], 3) LineCast [13], and 4) JPEG2000 [12] with different combinations of FEC rates and modulation methods.

We have implemented all frameworks using MATLAB R2014a. The number of tests is five runs. We used the listed bitrate for the conventional framework based on JPEG2000 in Table I. For SoftCast, LineCast, and our scheme, there are no bitrate but only channel symbol rate. We assume the channel noise is Gaussian and the channel bandwidth is equal to the source bandwidth. All the frameworks consume the same bandwidth and transmission power.

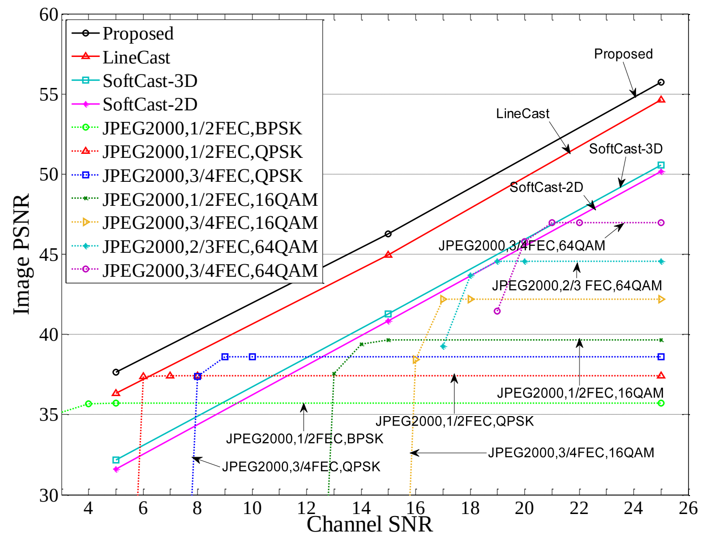
In the LineCast scheme, every scanned line of an image is compressed by the transform-domain scalar modulo quantization without prediction. We have implemented the LineCast scheme [13] for every band, separately, in the selected satellite images. The SoftCast is the state-of-the-art 3D broadcasting scheme. The LineCast differs from the SoftCast because of using a 3D transformation to remove both spectral and spatial redundancies form the satellite image data. The full band is transformed in the proposed implementation. We compare proposed scheme with the 3D version of SoftCast based on 3D DCT in [10].

In our experiments, JPEG2000 with principal components analysis (PCA) in the spectral decorrelator is used in the digital source coding. The satellite image data is first decorrelated with PCA and then a 2D DWT with 5 levels decomposition are used as spatial decorrelating. In the DWT the 9/7 filter has been used and the reference software BOI [23] is used for implementation. The experimental results for the digital separable source channel coding are listed in Table I.

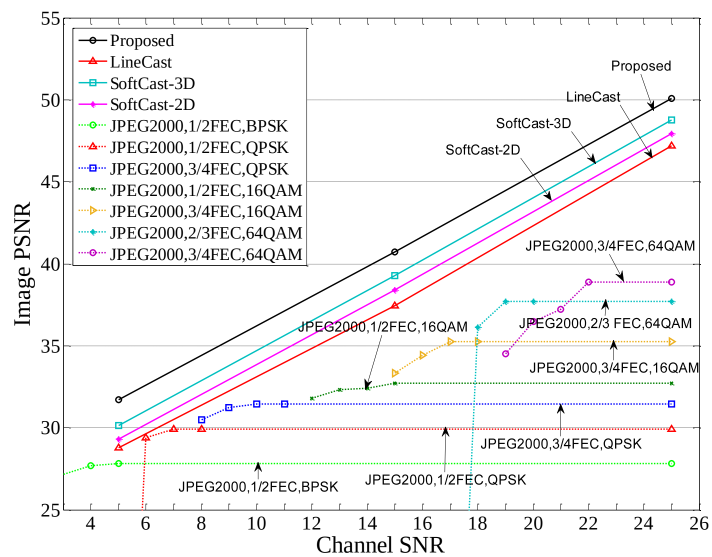
The reconstructed satellite images PSNR of each scheme under different channel SNR between 5dB to 25dB is given in Fig. 4. We can see that our proposed scheme achieves performs better than other schemes in broadcasting satellite images. It is clear that the proposed scheme avoids the annoying cliff effect (i.e., when the channel SNR increases, the reconstruction PSNR increases accordingly, and vice versa).

D. Visual Quality

The visual quality comparison is given in Fig. 5. The channel SNR is set to be 5dB. Satellite image 8 is selected for comparison. The proposed scheme shows better visual quality than the others. Our proposed scheme delivers a PSNR gain up to 2.49dB, 3.52dB, 4.20dB and 7.33dB over LineCast, SoftCast-3D, SoftCast-2D, and JPEG2000 with FEC and modulation, respectively.



(a)



(b)

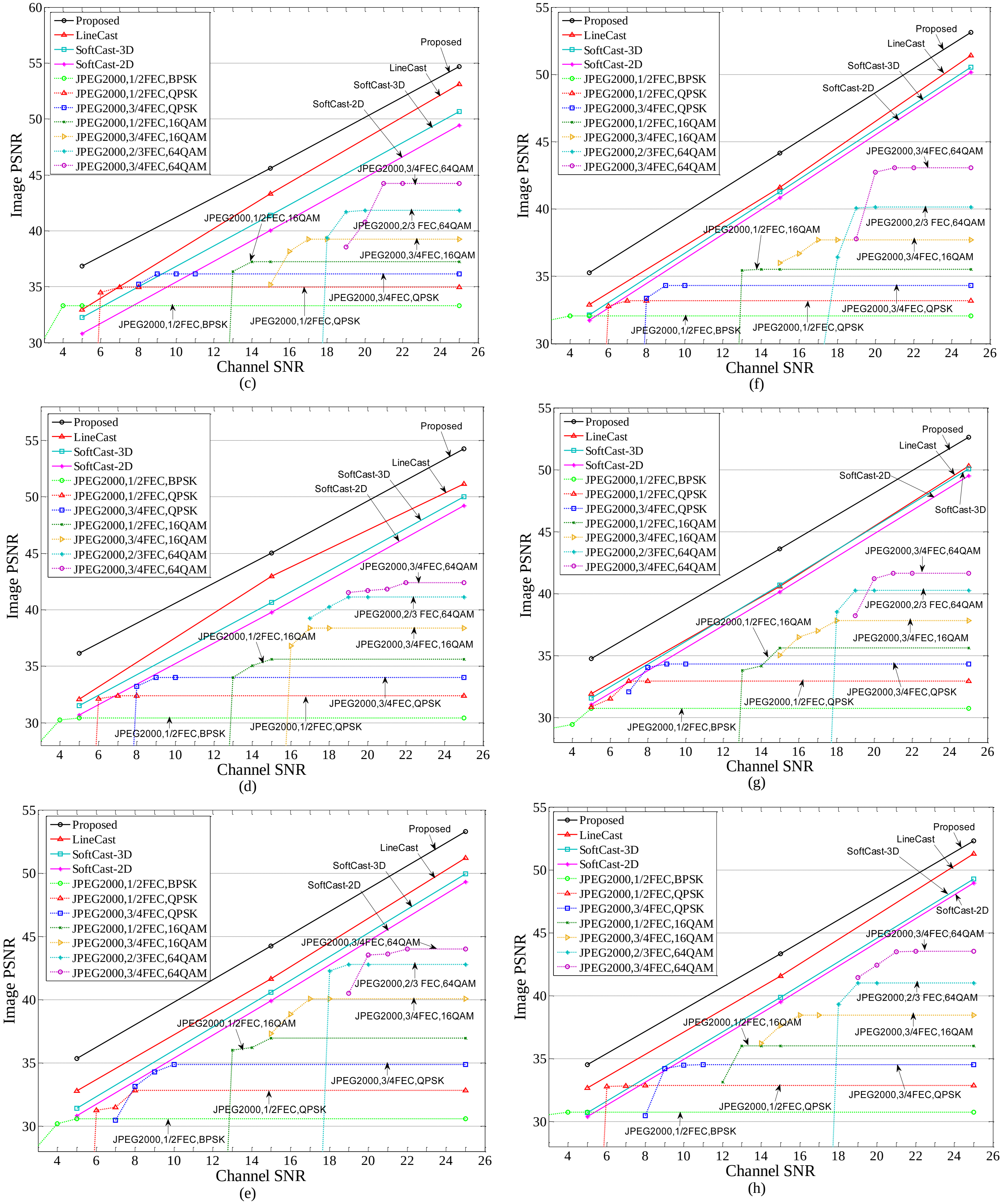


Fig. 4. Broadcasting performance comparison. (a)–(h) Satellite image 1, 2, 3, 4, 5, 6, 7, and 8, respectively.

TABLE I
COMBINATIONS OF SOURCE RATES, FEC RATES AND MODULATION IN JPEG2000

FEC + Modulation	Source Rate (bpppb)	Reconstruction PSNR without channel noises (dB)							
		Image							
		1	2	3	4	5	6	7	8
1/2 FEC + BPSK	0.25	35.70	27.83	33.31	30.44	30.56	30.73	30.74	32.04
1/2 FEC + QPSK	0.5	37.43	29.91	34.95	32.40	32.80	32.86	32.96	33.19
3/4 FEC + QPSK	0.75	38.62	31.47	36.15	34.03	34.85	34.50	34.33	34.33
1/2 FEC + 16QAM	1.0	39.64	32.72	37.23	35.61	36.97	36.03	35.61	35.51
3/4 FEC + 16QAM	1.5	42.18	35.25	39.27	38.40	40.08	38.44	37.81	37.69
2/3 FEC + 64QAM	2.0	44.55	37.69	41.84	41.13	42.79	41.01	40.26	40.16
3/4 FEC + 64QAM	2.5	46.96	38.87	44.24	42.40	43.99	43.51	41.64	43.08

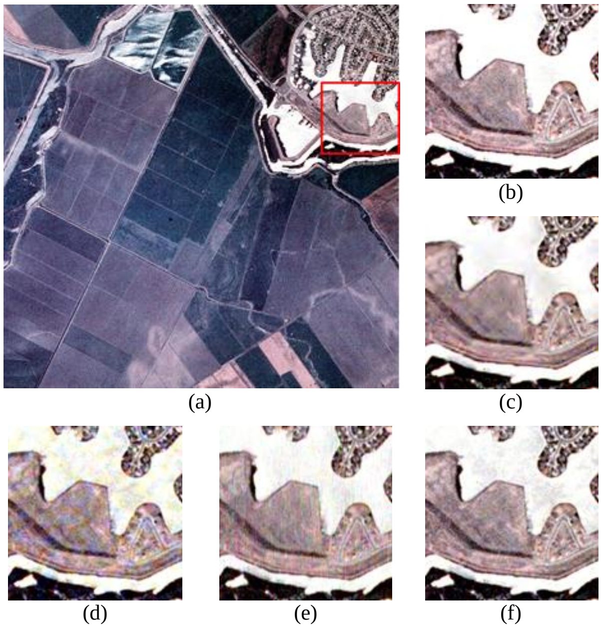


Fig. 5. Visual quality comparison at SNR=5dB. (a) Satellite image 8 full size (RGB). (b) Original selected rectangular region. (c)–(f) Reconstructed rectangular region with JPEG2000 at 0.25bpppb with 1/2 FEC and BPSK, SoftCast-3D, LineCast and Proposed scheme, respectively.

V. CONCLUSION

In this paper, we propose a novel scheme for satellite image broadcasting. Proposed scheme take advantage of the spectral redundancies in satellite image by the use of a simple and low-complexity Karhunen-Loève transform (KLT) as spectral decorrelation transform, followed by a 2D discrete cosine transform (DCT) as spatial decorrelation. The proposed scheme avoided the annoying cliff effect founded in the digital broadcasting schemes by using a linear trans-form between the transmitted image signal and the original pixels' luminance. Experimental results on the selected satellite images demonstrate that the proposed scheme is more effective than other schemes.

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