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A Proposed Unequal Power Allocation (UPA) based Method for JPEG2000 Images Transmission Over Satellite Communication Link

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***Abstract*— In the present paper, a proposed method for protecting the transmission of Joint Photographic Expert Group2000 (JPEG2000) images over Low Earth Orbit (LEO) remote sensing satellite based on Unequal Power Allocation (UPA) is presented. The proposed method depends on mixing the benefits of the hierarchical structure of (JPEG2000) and the fact of the variation in the received signal power due to LEO specification. The proposed method increases the quality of received images at satellite ground station by transmitting the Region of Interest (ROI) and headers (markers and marker segments) of the JPEG2000 image when the received power level is maximum, according to link budget calculation. Other compressed data bits are transmitted during the remaining satellite communication session period. A digital communication system which incorporates a Binary Phase Shift Keying (BPSK) as a common modulation technique and hamming code as channel coding method is built for the purpose of verifying the proposed method performance. The performance of the proposed method is compared subjectively and objectively, to validate its superiority, with the traditional Equal Power Allocation (EPA) scheme.**

Keywords—Unequal Power Allocation (UPA), LEO satellite transmission, JPEG2000.

I. INTRODUCTION

Remote sensing satellite has a LEO orbit with a special communication channel. It has a varying link margins due to the variation of its orbital patterns. Also, it has a limited connection to one of its limited receiving earth stations. The satellite link budget equation and mission should be optimized with the transmitted power considering its weight and size.

The quality of the received images at the satellite ground station is the main measure used to qualify images. Reliable transmission of such huge images can be achieved by using different coding techniques (compressing and channel coding).

JPEG2000 compression coding technique recently became one of the most used techniques in image transfer, especially for satellite images [1]. In this paper, a proposed method based on UPA coding scheme is used as coding method beside the channel coding to increase the JPEG2000 image transfer immunity against channel losses.

The rest of this paper is organized as follows: section 2 describes the traditional EPA scheme. Section 3 describes the proposed method based on UPA scheme. Section 4 introduces the performance measures used in evaluation the proposed method. Simulation results are presented in section 5. Finally, conclusion is given in section 6.

II. TRADITIONAL EPA SCHEME

Classical theoretical structure for communication assumes that all information is equally important. In this structure, the communication system aims to provide a uniform error protection to all messages. This classical technique called Equal Error Protection (EEP). Also, transmitted messages can be protected with transmission of equal power. This classical technique called (EPA).In many communication scenarios, where uniformly good error protection becomes a luxury such as in satellite communication, providing such a protection to the entire information might be wasteful due to satellite limited resources. Instead, it is more efficient to protect an essential part of information better than the rest and this technique is called Unequal Error Protection (UEP) [2, 3].

Alternatively, UEP can also be achieved by means of unequal power allocation (UPA), i.e., using different transmission powers over the bit-stream in such a way that more power is allocated to the more important bits.

UPA scheme had been used in [4, 5] in transmitting different parts of the image based on using different transmitters with different power.

The proposed method in the present paper differs from those of [4, 5] by using the UPA scheme in conjunction with the link budget varying parameters of the LEO satellite for image transmission.

III. THE PROPOSED UPA BASED METHOD

The proposed UPA based method uses the benefits of mixing two facts. First, the fact that different parts of the JPEG2000 bit stream have different impact on the quality of the decoded image and subsequently, are of different importance.

JPEG2000 compressed bit-stream consists of two fundamental types of data:

1-compressed data in the form of packets
2-syntactical data in the form of markers and marker segments that define the characteristics of the image and delimit the code-stream.

Certain markers and marker segments are combined to form headers. Each header (Markers/Markers segment) and compressed data are represented with hexadecimal value [6, 7].

JPEG2000 has the capability of defining the regions of interest of any shape and size and code the selected regions with better quality than the rest of the image and is coded earlier than the rest of the image. ROI coding can be accomplished by encoding the quantized wavelet coefficients corresponding to the ROI with a higher precision relative to the background, e.g. Max-shift method can be used to code the ROI by scaling up the ROI coefficients or scaling down the background coefficients [8].

Second, For LEO, the satellite has a variable received power lever at satellite ground station due to the change in:

1- Slant range “distance from ground station to satellite”.
2- Elevation angle of ground station antenna.

The ground station antenna tracks the satellite to get maximum power level to noise ratio. According to link budget equation calculation, the variation of these parameters during the communication session period has a significant effect on the calculation of Signal to noise Ratio (SNR). The SNR during the communication session period changes as it has a maximum value when minimum slant range and maximum ground station antenna elevation angle, and the value decrease as the satellite goes far from the ground station as illustrated in equations (1) and (2) [9, 10].

$$[SNR] = [EIRP] + [G_R] - [LOSSES] - [k] - [T_{sys}] - [B_N] \quad (1)$$

where: K is Boltzmann’s constant, T_{sys} is the system noise temperature, B_N is the noise bandwidth, EIRP is the Effective Isotropic Radiated Power, and G_R is the receiving antenna gain.

$$[LOSSES] = [FSL] + [RFL] + [AML] + [AA] + [PL] + [Rain\ losses] \quad (2)$$

[FSL] = free space spreading loss.
[RFL] = receiver feeder loss.
[AML] = antenna misalignment loss.
[AA] = atmospheric absorption loss.
[PL] = polarization mismatch loss.

The important parameter which makes the biggest difference in calculation of SNRs is FSL which depends on the slant range and the frequency which is constant [11].

$$[FSL] = 32.4 + 20\log r + 20\log f \quad (3)$$

According to the slant range, the difference between two SNRs is calculated by the following equation.

$$\frac{SNR_2}{SNR_1} = 20\log\left(\frac{r_1}{r_2}\right) \quad (4)$$

Another parameter that has an effect on the calculation of SNRs is the elevation angle of ground station antenna which used in calculation in some losses such as atmospheric and rain losses. This paper uses the International Telecommunication Union for Radio communication (ITU-R) method for calculating these noises depending on theses equation:

- Atmospheric losses (ITU-R P.676-5):

$$A_{gas} = \frac{A_z}{\sin\emptyset} = \frac{\gamma_0 h_0 + \gamma_w h_w}{\sin\emptyset}\ \mathrm{dB} \quad (5)$$

Where:

γ_w : is the specific attenuation for water vapor.
γ_0 : is the Specific attenuation for dry air.
h_0 : is the equivalent height for dry air.
h_w : is the equivalent height for water vapor.
$\emptyset$: is the elevation angle of antenna.

- Rain losses (ITU-R P.838):

$$L_{Rain} = \gamma_R D_{Rain} \quad (6)$$

Where:
D_{Rain} is the path length through the troposphere.
γ_{Rain} is the specific attenuation.

$$D_{Rain} = \frac{H_{Rain} - H_{antenna}}{\sin(e)} \quad (7)$$

$H_{Rain}, H_{antenna}$: are the height of rain and antenna.
e : is the elevation angle of antenna.

The proposed method exploits the hierarchical structure of the JPEG2000 coded bit-stream during the communication session. The important parts of the JPEG2000 images are sent when the satellite has minimum slant range and maximum ground station antenna elevation angle (maximum SNRs) and other parts of JPEG2000 images are transmitted during the other values of SNRs. SNR are earlier calculated taking into consideration the size of the transmitted image, the period of the session and the size of the important parts as shown in the following equations.

$$L_{image} = L_1 + L_2 \quad (8)$$
$$T_{session} = T_1 + T_2 \quad (9)$$

where:
L_{image} : is the size of the transmitted image.
$T_{session}$: is the period of the communication session.
L_1 : is the size of important parts of image and ROI.
T_1 : is the period required to transmit the important parts and ROI.
L_2 : is the size of other parts of JPEG2000 image.
T_2 : is the period required to transmit the other parts of JPEG2000 image which divided to two parts equally.

The proposed method divides the communication session according to L_1 such that, transmitting L_1 at the period T_1 at maximum SNRs. The calculations of the link budget equation of all communication sessions are evaluated at ground station antenna elevation angle above 5°.

Simulation of satellite path for different seven communication session scenarios is performed to qualify the proposed method. The values of the slant range, ground station antenna elevation angle and SNR are calculated during all sessions period as shown in Fig.1 through Fig.3. The satellite has the longest slant range in the beginning and the end of communication session and the value is decreased approximately in the middle of the session, also the elevation angle of ground station antenna begins and ends the session with minimum values and in the middle of session this value increases.

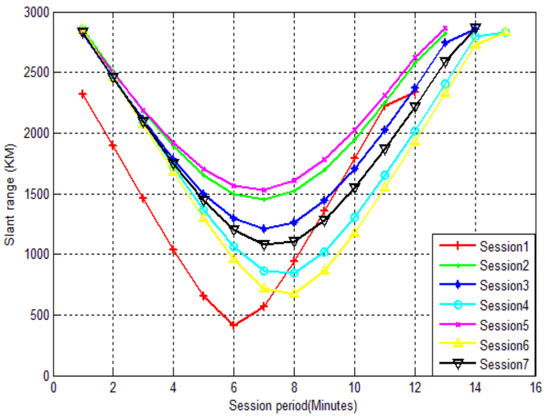

Fig.1. Slant range against session period during all communication sessions

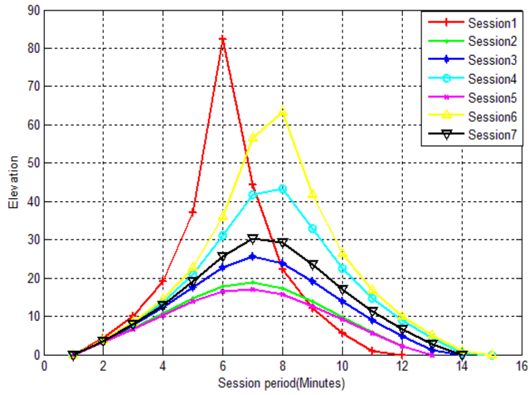

Fig.2 Elevation angle of ground station antenna against session period during all communication sessions

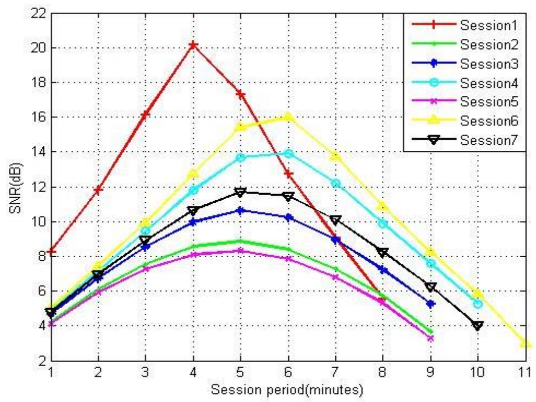

Fig.3. Calculated SNR during the period of all the communication sessions

All these variations have an effect on the total losses as shown in Fig.4. Losses have its maximum in the beginning and end of the sessions and minimum values during the middle of the sessions. The difference between losses during sessions period has variable values from approximately 5dB up to 14.6 dB as shown in TABLE 1. These losses values change the power level at the ground station as shown in Fig.3.

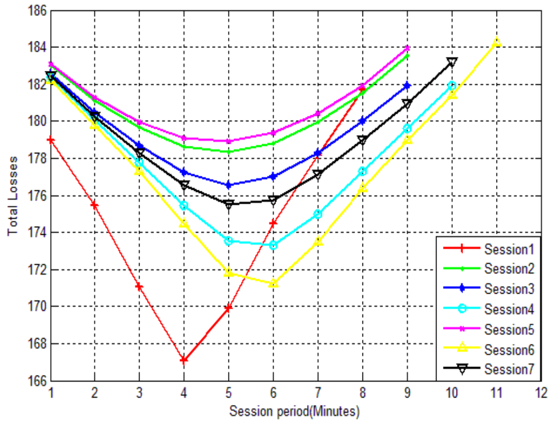

Fig.4. The total losses of the system in communication sessions

Table 1. Values of the total losses in communication sessions

	Minimum (dB)	Maximum (dB)	Difference (dB)
Session1	167.0545	181.665	14.6105
Session2	178.339	183.552	5.213
Session3	176.576	182.546	5.97
Session4	173.307	182.366	9.059
Session5	178.9	183.925	5.025
Session6	171.225	184.228	13.003
Session7	175.523	183.22	7.697

IV. PERFORMANCE MEASURES

This paper uses Mean Square Error (MSE) and Peak Signal to Noise Ratio ($PSNR$) as error metrics [12] to evaluate the performance of the proposed method relative to that of the traditional EPA method. It is useful to know that the human eye does not have enough sensitivity to detect changes in visual data for $PSNR$ measurements above approximately 50 dB, although this may vary in a minor way for each person. Higher values would normally indicate that the reconstruction is of higher quality (less pixel difference between the images) as shown in Table 2. It is most easily defined via (MSE) which defined as:

$$\text{MSE} = \frac{1}{m \times n}\sum_{i=0}^{m-1}\sum_{j=0}^{n-1}[I(i,j) - K(i,j)]^2 \qquad (10)$$

$$\text{PSNR} = 10 \times \log_{10}\left(\frac{\text{MAX}^2}{\text{MSE}}\right) \qquad (11)$$

Where MAX: is the maximum possible pixel value of the Image. I or K one of the images is considered as a noisy approximation of the other. ($m \times n$) is the dimension of the image.

Table 2. The Peak Signal to Noise Ratio and its description.

PSNR	Description
Over 40 dB	Excellent image (i.e., being very close to the original image).
30 - 40 dB	Good image (i.e., the distortion is visible but acceptable).
20 - 30 dB	Acceptable.
Lower than 20 dB	Unacceptable.

V. SIMULATION RESULTS

In this paper, subjective and objective evaluation of the proposed method are carried out and compared with the traditional EPA scheme for the same compression ratio for five test images over seven simulated satellite sessions at minimum height of 400Km. Every session is divided into three regions according to the size of the ROI, image size, and the received power level.

Kakadu software V6.4 [13] is used for compression of JPEG2000 images and assigning the following parameters: - JPEG2000 image compressed by five decomposition levels, three layers, ROI is equal to quarter the size of the used image.

Compressed image is used with the following simulated parameters using MATLAB to obtain the simulation results of evaluating the performance of the proposed method.

-LDPC code rate =1/2 for simulation, with number of information bits=32400 and block length=64800.
-Transmitted power=2.5dBW.
-Diameter of transmitting antenna=0.1 m.
-Diameter of receiving antenna=2m.
-Bit rate =200Mb/s.
-Thermal noise =18dBK.
-Receiver feeder losses=1.5dB.
-Antenna misalignment losses =1.5dB.
-Polarization losses=1dB.
-Frequency=8GHz

A. Subjective Results

Subjective results when applying the proposed UPA on the JPEG2000 image is shown in Fig.5. This figure shows an image of each session as an example. It is clear from this figure that the obtained images by applying the proposed UPA at different session are better than that of the traditional EPA. The entire image in traditional EPA can be received at any time of the session. The difference between the two methods is obvious in the sessions when maximum elevation angle is low which indicates long slant range as in session numbers 2 and 5. Session 6 has high elevation angle but the received image is bad when the image is received at the end of the session. Fig.6 indicates the maximum elevation angle of ground station antenna in each session.

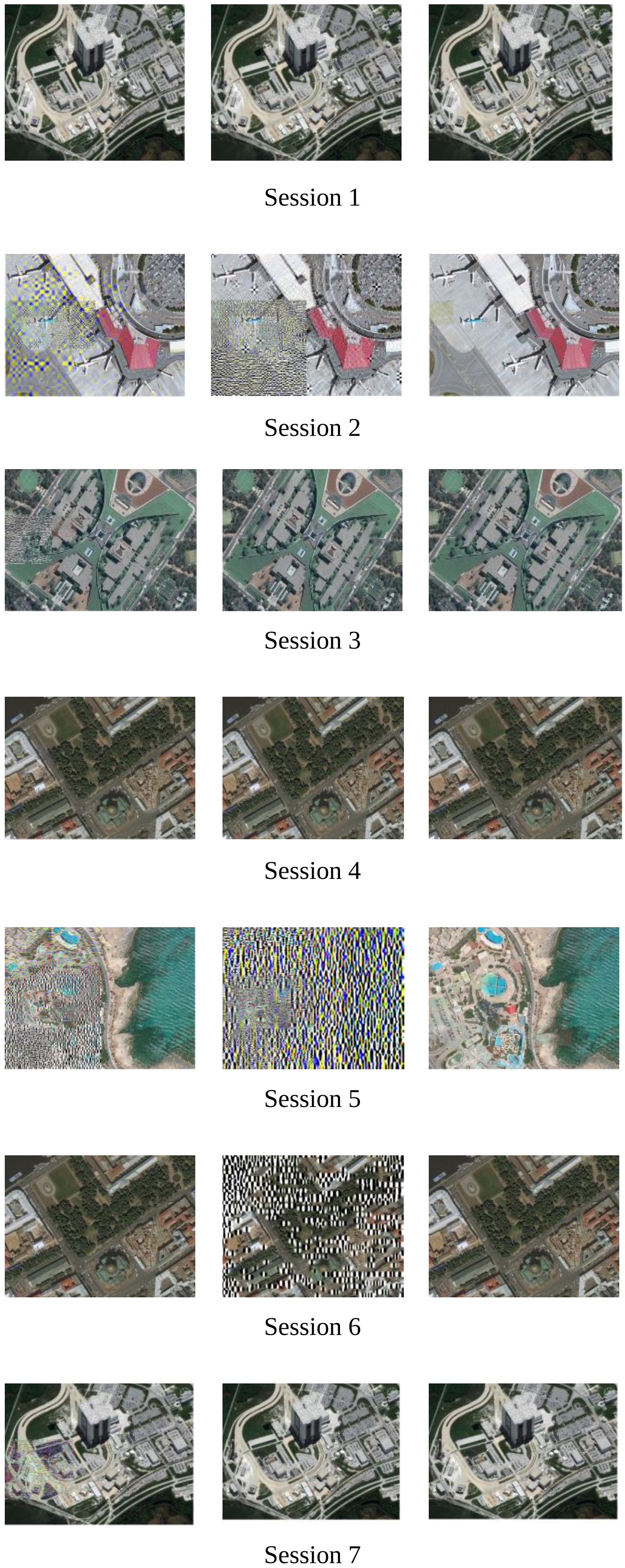

Fig.5. Subjective results (EPA in the left when receiving the image at the beginning of sessions, EPA in the middle when receiving the image at the end of sessions and UEP at the right) at different sessions.

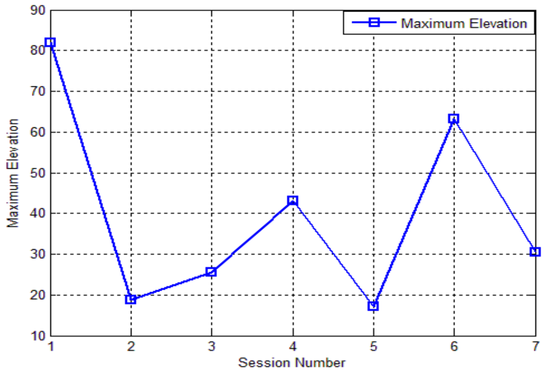

Fig.6. Maximum elevation angle of ground station antenna in each session

B. Objective Results

The performance of the proposed UPA scheme compared to the traditional EPA scheme over LEO satellite communication link from the view point of PSNR is shown in Fig.7. The value of the resulted PSNR of images is plotted in each session for a proposed UPA and EPA when the image received at the beginning and end of communication sessions. This figure shows that the proposed method has excellent images in sessions with high elevation angle and good images in session with low elevation angle (below 20°). But the traditional EPA method has excellent images in sessions with high elevation angle and bad images at lower elevation angle.

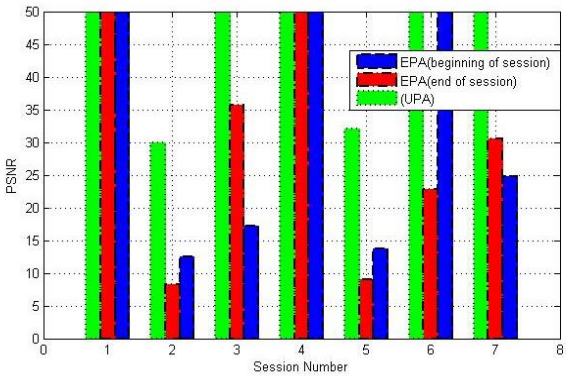

Fig.7. Average PSNR of images in each session

VI. Conclusion

In the present work, a proposed method based on UPA was used in transmission of remote sensing satellite image by using the variation of some parameters that affect the received power level at the ground station.

The superiority of the proposed method based on UPA over traditional EPA was validated objectively and subjectively. The proposed UPA presented an efficient solution for image transmission over LEO satellite communication link, and provided a high quality of service. The average difference between PSNR for UPA and EPA at session beginning was 14.8 dB and 27.5dB for the session end.

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