Multicasting JPEG2000 Images over MIMO Systems

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Abstract—Increasing demand for high-speed and efficient multimedia transmission over wireless networks has driven tremendous research on enhancing the performance of multimedia communications over noisy channels. Multimedia applications increasingly require efficient transmission of still and moving images over wireless channels. In response to the rapidly increasing demand of the data-rate requirements, of particular importance is the so-called Multi-Input Multi-Output (MIMO) antenna. In this paper, we simultaneously exploit spatial multiplexing, diversity, antenna selection, and Unequal Power Allocation (UPA) techniques to transmit progressive JPEG2000 images over a MIMO downlink channel where communication occurs from a multi-antenna base station to multiple multi-antenna mobile terminals. We take advantage of the spatial diversity by utilizing a joint decoding in the JPEG2000 decoder. The aim is to reduce the average distortion among users. Simulation results show that our proposed algorithms provide significant image quality improvement when compared to schemes that do not consider antenna selection or UPA.

I. INTRODUCTION

Real-time transmission of image and video content over wireless channels is becoming very common in cellular networks. The ultimate goal of future-generation wireless communications is to provide ubiquitous seamless connections between mobile terminals such as personal digital assistants and computer servers, so that users can enjoy high-quality multimedia services at anytime without wires. Fundamental physical challenges such as channel fading and interference, however, have put strains on the radio resources, which makes achieving reliable wireless communication difficult. Development of Multi-Input Multi-Output (MIMO) systems has been a great achievement toward overcoming this problem. These systems provide high speed links while maintaining good quality of service. MIMO systems have the following desirable capabilities: increased bitrate if used in spatial multiplexing systems, decreased bit error rate if used in diversity mode, and extended transmission range by utilizing beamforming methods [1].

In this paper, we consider multicasting of JPEG2000 images over MIMO systems. JPEG2000 is the state-of-the-art image compression standard that outperforms other standards such as JPEG [2]. This standard generates a progressive bitstream with different scalable progressions, excellent error resilience features, and region of interest processing. The property of JPEG2000 focused upon in this paper is its "quality scalability", which means as more elements of the bitstream are received, the quality of the decoded image, increases accordingly [2], [3]. The aim of this paper is to present an antenna selection algorithm which efficiently transmits JPEG2000 images over a multiuser MIMO network, while making use of both spatial multiplexing and diversity benefits of MIMO systems. Due to the quality scalability of the JPEG2000 bitstreams, various parts of the encoded bitstream differ in importance, and it is thus crucial to assign the best channels in terms of Signal to Interference and Noise Ratio (SINR) to the most important parts in order to achieve the minimum distortion at the receiver.

Much research has been done considering optimized transmission of images and videos in wireless networks [4], [5], [6], [7], [8], [9]. In [4] power efficient MPEG4-FGS video transmission over MIMO-OFDM systems is discussed. The authors propose an optimal power allocation and transmission rate control algorithm with power-efficient assignment of scalable source to spatial sub-channels. They consider only point-to-point transmission of video. In [5] an unequal power allocation algorithm for JPEG transmission over MIMO systems is proposed. Their algorithm works only for the case of single user and unlike the algorithm proposed in this paper is based on the JPEG standard. [9] proposes an energy efficient JPEG2000 image transmission system over point-to-point wireless sensor networks. In this work, the users have single transmitting and receiving antennas.

Here, we consider transmission of JPEG2000 images to multiple users over MIMO channels with multiple transmitting and receiving antennas. The challenge of antenna selection in a multicast MIMO system is that different users impose different transmitting antenna orders, and the best antenna selection strategy for one user may be the worst for another user. Our proposed algorithm assigns substreams to transmitting antennas to reduce the distortion of the received images for different users. To ensure that all users receive the important parts of the data through their best channels, the algorithm uses diversity and sends the important parts of the bitstream through multiple channels. Hence, the chance that users accurately receive the important parts of the bitstream increases. Also, we may use this extra information at the JPEG2000 decoder by

jointly decoding the multiple copies of the same codestream. It is shown that applying antenna selection simultaneously for all the users, decreases the maximum distortion in the received images. Furthermore, wireless channels are subject to signal degradations such as noise, interference and fading and due to the nature of JPEG2000 coded bitstream, without adequate data protection, any transmission errors that occur in the coded image will be propagated to affect large image areas, causing visible and often objectionable, image quality deterioration. The JPEG2000 standard addresses the transmission error problem by including provisions for error resilience tools. Here we use the "error resilience" feature of JPEG2000 to improve the quality of received images [3].

The organization of this paper is as follows. In section II, the system model is presented. In section III, the proposed method is explained, and section IV provides simulation results and discussion. Finally, we conclude this paper in section V.

II. SYSTEM DESCRIPTION

The system is modeled as a two user MIMO, in which both users have the same requirements and have the same priority for the base station. All the transmitters and receivers have the same number of antennas, which we have chosen to be four in this paper. The general model of the system is shown in Fig. 1, with a description of different components given below.

It should be noted that although we consider only two users in our proposed algorithm, the algorithm can be easily generalized for the case of more than two users by little modifications. Also, the two user scenario can be considered in cases where the users are clustered into two multicast groups, where each group includes several users with similar channel conditions but different from the other group. Users will subscribe to either of the multicast groups based on their channel conditions and each group can be considered as a single user [10].

A. Channel Model

We assume that the channels between the base station and different users have the same statistics. Each of these channels is a 4 by 4 MIMO channel and is assumed to be Rayleigh flat fading. The channel matrix entries are i.i.d. Gaussian complex random variables, with independent real and imaginary parts, each with zero mean and variance $1/2$. We assume that the channel is known at the receiver. The noise is assumed to be AWGN with unit variance. We use 4-QAM for modulating the bitstream, although extension to higher order modulation is readily possible. The channel is slowly time varying and is assumed to be constant over every T symbol intervals.

B. Transmitter

The transmitter consists of two parts. The first part is the source encoder which converts the input images to compressed bitstreams. In this paper, the input images to the system are encoded using the JPEG2000 still image compression standard in the quality progressive mode. To encode the raw image, JPEG2000 first divides it into disjoint rectangular tiles. The subband/wavelet transform is applied to each tile-component to generate subbands, which are then divided into rectangular-shaped precincts, and further divided into square-shaped codeblocks. Each bitplane of a codeblock is then encoded by an arithmetic encoder in three codingpasses. This provides a progressive bitstream for each of the codeblocks. Coding passes are then interleaved to create the scalable JPEG2000 bitstream. We enable the error resilient feature of the JPEG2000 encoder by using the RESTART/ERTERM option. We have used Kakadu as our JPEG2000 codec with 64×64 codeblocks and 128×128 precincts [3]. In all simulations, the header information throughout the bitstream is separated and assumed to be transmitted error free. At the receiver, headers are re-inserted at their original location before JPEG2000 decoding.

The second part of the transmitter is the channel assignment unit. In this unit, after the removal of headers, the raw bitstream is divided into two equal length substreams, SS_1 and SS_2. Each substream is divided into non-overlapping blocks of lengths $2T$, where T is the number of symbols for which we assume the channel to be constant, and the number of bits per symbol for 4-QAM modulation is 2. Our proposed channel assignment algorithm then runs on each of these blocks independently. The total transmit power from all the antennas during each symbol period is kept constant at any given symbol interval. In effect, the channel assignment unit determines the substreams that are transmitted through each antenna and the required power for transmitting them. It also determines how the final bitstream should be composed from the substreams that each user receives and sends this side information to the users. This part is explained in more detail in section III-A.

C. Receiver

We have used a Minimum Mean Square Error (MMSE) receiver. This is a linear receiver which first separates the transmitted substreams and then decodes each substream independently [11].These substreams are then passed to our modified JPEG2000 decoder which will be discussed in section III-B.

III. PROPOSED METHOD

In this section, the channel assignment algorithm and our proposed modified JPEG2000 decoding scheme are discussed.

A. Channel Assignment Algorithm

The channel assignment algorithm, calculates the post processing SINR for all the receiving antennas of each user every T symbols [12]. Because we have used MMSE receiver, each transmitted substream will be decoded from its corresponding receiver. The calculated SINRs determine the best transmitting antennas in terms of post processing SINR for each user. This constitutes the antenna selection order of each user. Based on the antenna selection order requested by each user, the algorithm assigns the antennas to substreams aiming at reducing the average distortion among all users. The algorithm
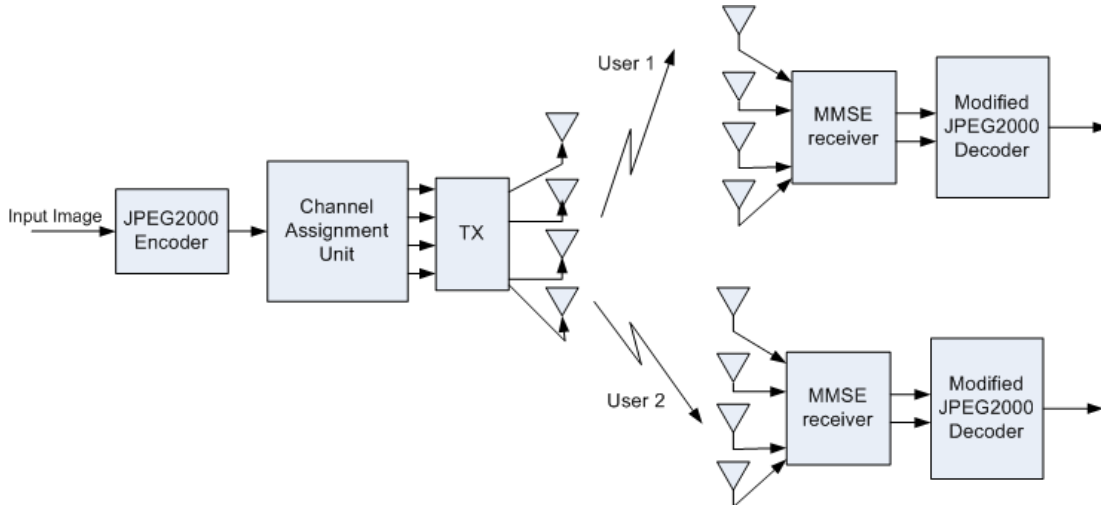
Fig. 1. System model for multicasting JPEG2000 images over MIMO channels

is based upon the progressive nature of the JPEG2000 coded bitstream, i.e., the first substream needs more protection and should be transmitted through channels with the lower Bit Error Rates (BERs). The challenge of antenna selection when transmitting images to multiple users will arise when different users request different transmitting antenna orders, and the best antenna selection order for one user may result in great quality degradation for another user.

The algorithm assumes that the total transmit power at each symbol period is $4p$. According to the antenna selection orders requested by each user, the algorithm decides on one of the following scenarios: i) Choose two best antennas and send one copy of each substream with power $2p$ from each of the selected antennas. The other two antennas are not used for transmission. ii) Send two copies of each substream transmitting from all four antennas each with power p. iii) Send one of the substreams with power $2p$ from one antenna and two copies of the other substream from two other antennas each with power p. The fourth antenna is not used for transmission.

It should be noted that in cases where we send two copies of the same substream from two transmitting antennas, the MMSE receiver will decode each copy separately and each user will receive two copies of that substream, obviously with different BERs. We call the copy transmitted over the channels with higher and lower SINR, the *main* and the *secondary* copy, respectively. The transmitter also lets each user know which substream has been transmitted from each antenna.

The channel assignment algorithm is summarized in **Algorithm 1**, where SS_{k1} and SS_{k2} refer to the two copies of the kth bitstream, $k = 1, 2$, and A_{ij} refers to the jth best antenna of user i, $i = 1, 2$, $j = 1, \ldots, 4$.

B. Modified JPEG2000 decoder

In the original JPEG2000 decoder (in the ERTERM/RESTART mode) if an error is detected in a codingpass, all the remaining coding passes within that codeblock are discarded [3]. The modified JPEG2000 decoder, however, takes advantage of the diversity in the received data during the time intervals that more than one copy of codestream is available. This is done by jointly decoding the two different received copies of the original data. At first, the decoder uses the *main* codestream to decode the image. Once the decoder detects an error in a coding pass, the decoder tries to correct the erroneous byte(s) by using the information contained in the *secondary* codestream. If the decoder is successful in correcting the damaged codingpass, it restarts its operation from the beginning of the erroneous codingpass. Otherwise, it operates normally. The modified JPEG2000 decoder is summarized in **Algorithm 2**.

IV. SIMULATION RESULTS

In this section, we provide experimental results to investigate the performance of our proposed algorithms. Images are encoded by enabling the quality progression option of the JPEG2000 encoder. Also, to take advantage of the error resilient feature of JPEG2000, we enable the ERTERM/RESTART mode at the encoder. Consequently, the decoding should be done in the error resilient mode as well. We assume that the channel is constant for $T = 250$ symbols to ensure that the slowly time varying condition is satisfied [5]. The results shown here are for the 512×512 Lena image with a maximum source coding rate of 1.0 bit per pixel (bpp).

We compare the performance of our proposed system with two other cases. The Peak Signal to Noise Ratio (PSNR) is used as a measure of the reconstruction quality [13]. The

Algorithm 1 Channel Assignment Algorithm

for Every T symbols **do**

    Calculate the post processing SINR for all the receiving antennas of each user and sort the antennas based on their corresponding SINRs .

    if The two best antennas of each user match **then**

        Power $(SS_1) = 2p$

        Power $(SS_2) = 2p$

        Transmit SS_1 from A_{11}

        Transmit SS_2 from A_{12}

        Do not transmit from remaining antennas

    end if

    if Only the best antennas of each user match **then**

        Power $(SS_1) = 2p$

        Power $(SS_{21}) = p$

        Power $(SS_{22}) = p$

        Transmit SS_1 from A_{11}

        Transmit SS_{21} from A_{12}

        Transmit SS_{22} from A_{22}

        Do not transmit from the remaining antenna

    end if

    if The best antennas of the two users are different **then**

        Power $(SS_{11}) = p$

        Power $(SS_{12}) = p$

        Power $(SS_{21}) = p$

        Power $(SS_{22}) = p$

        Transmit SS_{11} from A_{11}

        Transmit SS_{12} from A_{21}

        Send SS_{21} and SS_{22} from the remaining antennas in any order

    end if

end for

Algorithm 2 Modified JPEG2000 Decoder

for All the codingpasses in the codestream **do**

    Decode the codingpass

    if Decoder declares occurrence of an error in the codingpass **then**

        Find all the mismatches between the *main* and the *secondary* codingpasses

        for each mismatch **do**

            Swap the corresponding values of the two codestreams

            Reinitialize the decoding from the start of the codingpass

            if decoding is successful **then**

                Break;

            else

                swap the values of the two codestreams again and repeat the procedure with the next mismatch

            end if

        end for

    end if

end for

PSNR for an image is a function of the Mean Squared Error (MSE) between the decoded image and the original image:

$$PSNR = \log_{10} \frac{(2^L - 1)^2}{MSE} \qquad (1)$$

where L represents the number of bits used to encode the pixel values, typically 8 bits.The results are shown in Fig. 2.

In the first case, we do not use any of our proposed algorithms. We simply encode the image at 1.0 bpp, and the generated bitstream is divided into four equal length substreams. We transmit the four substreams according to the antenna selection order requested by User1. In effect, we are giving complete priority to the needs of User1 and we are applying no antenna selection for User2. The PSNR curves for User1 and User2 are shown in Fig. 2, labeled with "User1 based-U1" and "User1 based-U2", respectively. We also calculated the average PSNR for the two users, labeled with"Ave U1 and U2" in the figure.

In the second case, only the proposed modified JPEG2000 decoder algorithm is used. Here, the encoded image is divided into two equal length substreams. These substream together with a copy of each, are transmitted from all four antennas simultaneously and with equal power. We transmit the more important substream through the channel with better quality. We call this method "EPA-MD", standing for Equal Power Allocation-Modified Decoder. In this case, the image is encoded at a rate of only 0.5 bpp, to ensure the same transmission time and power consumption as the previous case, for fair comparison.

In the third case, both proposed algorithms are implemented, i.e., we use the channel assignment algorithm in conjunction with the modified JPEG2000 decoder algorithm. Again, the image is encoded at a rate of 0.5 bpp for fair comparison. We call our proposed method, "Joint Antenna Assignment and Modified JPEG2000 Decoder" (JAAMD). Also, since this method may result in transmitting with different powers (0,p, or $2p$), the corresponding performance curve is labeled as "UPA-JAAMD" in the figure, to signify the unequal power allocation employed here.

As can be seen from Fig. 2, our algorithm performs significantly better in terms of PSNR in the channel Signal to Noise Ratio (SNR) range of $0 - 30$ dB. For example, at an SNR of 15 dB, the EPA-MD results in 5 dB improvement in the average user PSNR, compared to the case labeled as "Ave U1 & U2". Further more, by implementing the channel assignment algorithm we gain an additional 2 dB. Simulation results show that it is more beneficial to transmit a lower rate encoded image with higher channel protection, than a higher rate encoded image with less protection.

To show the visual quality of our proposed method, results for Lena image transmitted with different algorithms through

a channel with SNR of 15 dB are shown in Fig. 3. Again, noticeable visual quality enhancement is achieved through our proposed algorithms.
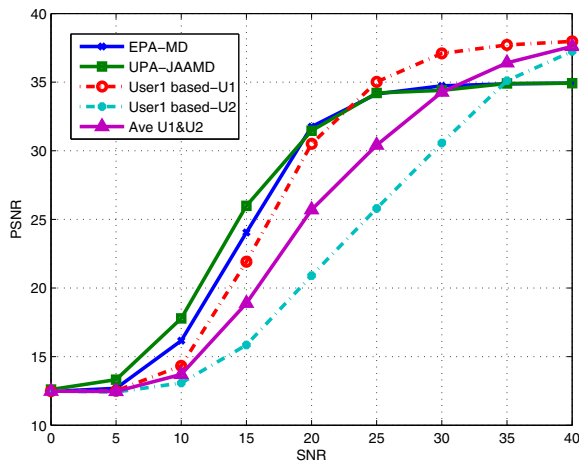

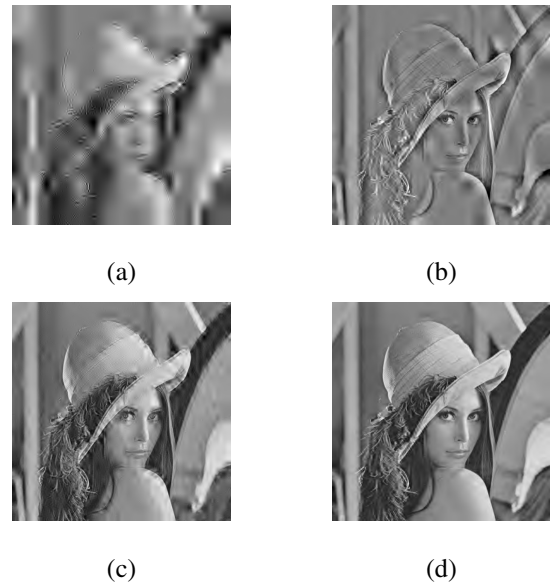
Fig. 2. PSNR curves for different schemes

Fig. 3. Lena image results for different schemes at SNR=15 dB (a) Received image by User 2 with antenna selection based on User1, PSNR=13.95 dB (b) Received image by User 1 with antenna selection based on User1, PSNR=18.12 dB (c) EPA-MD, PSNR=25.92 dB (d) UPA-JAAMD, PSNR=29.22 dB

V. CONCLUSION

In this paper, we present an algorithm for multicasting of JPEG2000 images over MIMO systems. According to different antenna selection orders requested by different users, the channel assignment unit decides to transmit the substreams with different power levels from each antenna. The decoder is modified such that when two copies of a substream are available, they are used jointly to decode the image, using the error resilient feature of JPEG2000 decoder. The proposed method, takes advantage of spatial multiplexing as well as diversity in MIMO systems, while applying UPA. Simulation results show that our algorithm provides a significant gain over other presented schemes, both in PSNR measurements and visual quality.

The advantages of our proposed system are in the simplicity and speed of its algorithms and the fact that it requires only two levels of transmission power, i.e., p and $2p$. Further improvements in quality can be expected by optimizing the channel assignment algorithm such that a continuous range of powers is used for UPA. Employing a sophisticated error correction coding schemes to replace the simple swap and restart method proposed here may improve the received PSNR. These improvements are obviously achieved at the cost of added complexity and delay.

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