Novel Layered Scalable Video Coding Transmission over MIMO Wireless Systems with Partial CSI and Adaptive Channel Selection*

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ABSTRACT

In this paper, we present a novel layered scalable video transmission scheme over multi-input multi-output (MIMO) wireless systems. The proposed layered scalable video transmission scheme is able to adaptively select the MIMO sub-channels for prioritized delivery of layered video signals based on only estimated partial channel state information (CSI). This scheme is fundamentally different from open loop (OL)-MIMO systems such as V-BLAST in which the CSI is only available at the receiver side. Without CSI at the transmitter, data sequences in OL-MIMO are transmitted simultaneously with equal power via multiple antennas. Therefore, OL-MIMO systems are not appropriate for transmitting compressed video data that need prioritized transmission. In this research, we assume that partial CSI, or the ordering of each sub-channel's SNR strength, is available at the transmitting end through simple estimation and feedback. The adaptive channel selection (ACS) algorithm we developed in this research shall switch the bit-stream automatically to match the ordering of SNR strength for the sub-channels. Essentially, we will launch higher priority layer bit-stream into higher SNR strength sub-channel by the proposed ACS algorithm. In this fashion, we can implicitly achieve unequal error protection (UEP) for layered scalable video coding transmission over MIMO system. Experimental results show that the proposed scheme is able to achieve UEP with partial CSI and the reconstructed video PSNRs demonstrate the performance improvement of the proposed system as compared with OL-MIMO system.

Keywords: Layered scalable video coding, partial channel state information, adaptive channel selection, MIMO, unequal error protection

1. INTRODUCTION

The demand for high-quality mobile wireless communication services (multimedia broadcasting, video streaming, video telephony, etc) beyond conventional voice communication is increasing at an explosive rate. However, the inherently limited channel bandwidth and the unpredictability of the propagation channel becomes significant obstacle for wireless communication providers to offer high quality multimedia services. To overcome such obstacles, multi-input multi-output (MIMO) system has recently emerged as one of the most prominent techniques [1][2][3][4]. In the past, multiple antenna systems were normally used to increase receiver or transmit diversity so as to reduce the high bit error rate (BER) of mobile wireless channel [1][2].

Recently, spatial multiplexing techniques [3][4] have been investigated to simultaneously transmit independent data in order to achieve high data rate wireless multimedia communications. If perfect channel state information (CSI) is available at the transmitter [5], closed loop (CL)-MIMO systems can maximize the channel capacity through well-known water-filling (WF) solution based on singular value decomposition (SVD). Assuming that the CSI is only available at the receiver side, open loop (OL)-MIMO systems such as V-BLAST [4] assign equal power to each antenna as optimal solution and then attempt to decompose high-rate bit-stream into independent sequences and transmit simultaneously.

One niche area of application in MIMO wireless systems is the transmission of video data. Scalable video coding (SVC) scheme is normally adopted to generate multi-layered video bit-streams so as to launch independent layer bit-

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stream to each antenna of MIMO system through parallel transmission scheme [14]. In this paper, we choose scalable extension of H.264/AVC [8] that is chosen as the starting point of MPEG's new SVC standard and enables a full spatio-temporal and quality scalable codec. Therefore, with this codec, we can create layered scalable video bit-streams more flexibly according to a given MIMO system as compared with the existing scalable codes such as MPEG-4 FGS [6][7].

There have been several research works to report layered video transmission over MIMO systems. In order to achieve robust video transmission over MIMO systems [13], space-time block codes (STBC) was employed to combat high bit error rates through increasing spatial diversity and then unequal error protection (UEP) channel codes are assigned to each source layer. In [14], power allocation was performed to optimize the error performance according to the importance of the source layer so as to achieve UEP. Layered scalable video transmission schemes over SVD-based MIMO systems could be found in [15][16][17]. By SVD, MIMO system is transformed to parallel SISO sub-channels. The optimal power allocation scheme with fixed modulation for minimizing the total system distortion based on joint source channel coding (JSCC) was proposed in [15] and extended for video broadcast scenario in [16]. In order both to maximize MIMO system throughput and to guarantee quality of service (QoS), power allocation scheme with adaptive modulation was proposed in [17].

Note that the proposed existing schemes all assume that the perfect CSI is available either at the receiver side or at the transmitter and receiver both sides. From practical point of view, the perfect CSI is not attainable and the delay of feedback CSI is inevitable. The performance of the existing layered video transmission schemes over MIMO systems is clearly dependent on the accuracy of the estimated CSI. Therefore, we need to consider more practical schemes.

For a realistic MIMO system, OL-MIMO system is more practicable than CL-MIMO system since power control is not required and no channel information is feedback to transmit. Therefore, OL-MIMO system just launches independently coded layer bit-streams to each antenna with equal power allocation and transmits using fixed modulation. However, for compressed video data, not all the bits (layers) are equally important. It is therefore desired to transmit more important bits (layers) over high SNR sub-channels in a MIMO system. Current OL-MIMO systems such as V-BLAST system with linear zero-forcing (ZF) or minimum mean squared error (MMSE) receiver does not match well with the spirit of layered scalable video coding (SVC) and transmission: protect more important bits or layers by transmitting these data over high SNR channels.

However, if the partial CSI, for example, the ordering of each sub-channel's SNR strength, can be obtained via the estimated CSI and feedback to the transmitter, we will demonstrate that we are able to launch higher priority layer of bit-steam to higher SNR strength sub-channel by an adaptive channel selection (ACS) technique developed in this research. With proposed ACS-MIMO system, we can automatically achieve unequal error protection (UEP) for layered scalable video coding transmission over MIMO systems. Note that the proposed partial CSI not only generates much less data than the full CSI and therefore induce much less delay time in the feedback but also does not require power control in order to achieve UEP. In addition, the proposed system is very robust to the error of the estimated partial CSI. In other words, with the worst partial CSI, the performance of the proposed system converges to OL-MIMO system without ACS.

The rest of this paper is organized as follows. In section 2, we will describe a novel layered video coding transmission scheme over MIMO systems with estimated partial CSI that unequally protects layered bit-stream according to layer priority in detail. In section 3, we present several experiments designed to show the performance of the proposed scheme under various channel conditions and with several standard videos. In section 4, we conclude this paper with a summary of this research.

2. SYSTEM DESCRIPTION

The proposed layered scalable video transmission over MIMO wireless system is shown in Figure 1. In this research, we consider a 4×4 MIMO system. At the encoder side, 4-layer scalable video bit-streams are generated by scalable extension of H.264/AVC, forward error correction (FEC) channel codes are added, fed to the proper sub-channel by ACS algorithm, modulated, and launched via multi-transmitter antennas. At the receiver side, the CSI is estimated using pilot symbols. The transmitted signals are detected by linear ZF (or MMSE) receiver and decided by demodulation. Then, decided symbols are loaded to the proper sub-channel buffer by ACS inverse algorithm, bit errors are corrected by channel coding, and finally transmitted video sequences are reconstructed.

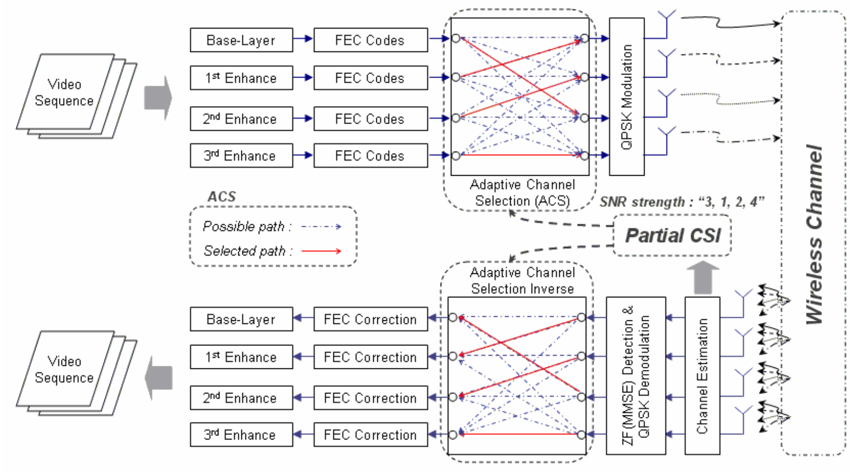

Figure 1: The proposed MIMO system

2.1 Scalable Extension of H.264/AVC

With the proposed video transmission scheme over MIMO system, multi-layered video bit-streams are essential and thus created by scalable extension of H.264/AVC [8] in this research. In this section, we briefly review this video codec. There are two different ways for scalable video codec: either by using a technique that is intrinsically scalable (such as bit-plane arithmetic coding) or by using a layered approach. Scalable extension of H.264/AVC supports a combination of the two approaches so that a full spatio-temporal and quality scalable codec is achieved. Base layer of this scalable codec is compatible with H.264/AVC [9][10] main profile by using a representation with hierarchical B pictures of the lowest provided spatial resolution. Temporal scalability is enabled by the motion compensated temporal filtering (MCTF), whereas spatial scalability is provided using a layered approach. The MCTF is based on the lifting scheme that consists of three types of operations: poly-phase decomposition, prediction (for high-pass H), and update (for low-pass L). The detail description of this method can be found in [11].

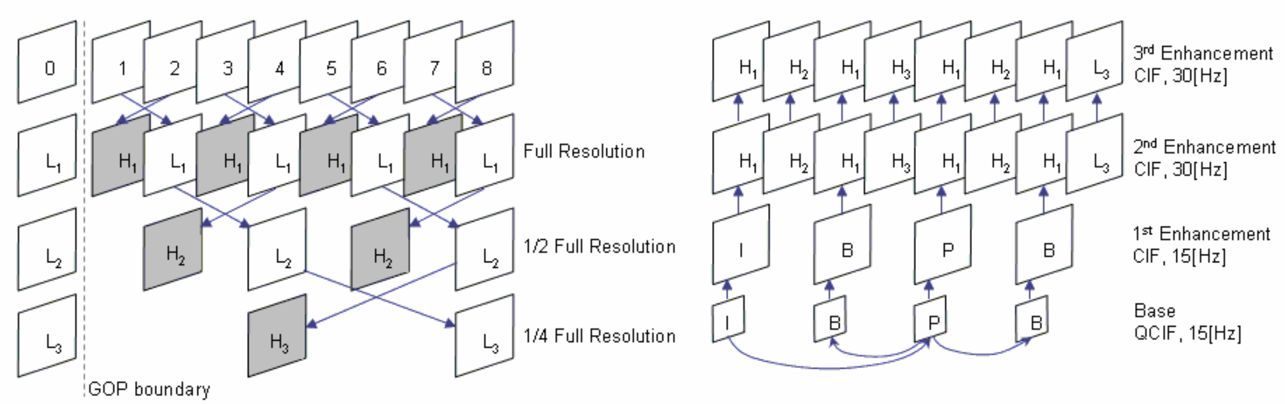

Figure 2: Scalable extension of H.264/AVC scalability
(left) an example of temporal decomposition (right) an example of combined scalability

In the left of Figure 2 illustrates an example for temporal decomposition of a group of 8 pictures. For quality (or SNR) scalability [8][12], the texture base layer is encoded using AVC entropy coding. Within each spatial resolution SNR scalability is achieved by encoding successive refinements of the transform coefficients, starting with the minimum quality provided by AVC compatible texture encoding. This is done by repeatedly decreasing the quantization step size and applying a modified CABAC entropy coding process akin to sub bit-plane coding. This coding mode is referred to as progressive refinement. An example of combined scalability with group of picture (GOP) 8 is described in the right of Figure 2.

2.2 Wireless MIMO Channel Model

In this work, the primary MIMO channel model under consideration is a quasi-static, frequency non-selective, and Rayleigh fading channel model. For a single user flat-fading channel over MIMO system with M_T transmitter antennas and M_R receiver antennas, the system equation is

$$y = Hx + n \tag{1}$$

where H is the quasi-static and $M_R \times M_T$ complex channel matrix, y is the $M_R \times 1$ received signal vector, x is the $M_T \times 1$ transmitted signal vector, and n is the $M_R \times 1$ noise vector from i.i.d. Gaussian collection with zero mean, independent real and imaginary parts, with variance σ^2. When the CSI is only available at the receiver, the optimal power allocation at the transmitter is P/M_T with global power P.

2.3 Channel Estimation

Normally, the channel state information can be obtained by two different methods. One is called blind channel estimation [18][19], which uses the statistical property of the channel and properties of the transmitted signals. The other is called training-based channel estimation [20], which is based on the training sequences which are known at the receiver. Though blind channel estimation doesn't cause any increase in overhead, it requires long data record. In other words, it is very sensitive to the CSI feedback delay and is only applicable to slowly time varying channels. Therefore, in this work, the CSI is estimated by employing pilot symbols [20].

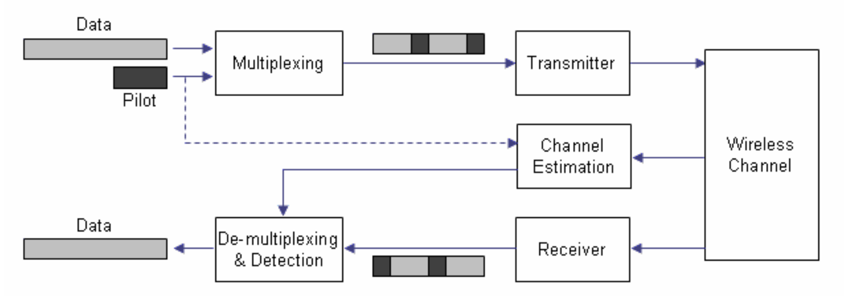

Figure 3: Block diagram of a PAT transceiver

The pilot symbols are traditionally time multiplexed and the block diagram of a simplified pilot assisted transmission (PAT) is illustrated in Figure 3. The training sequence of i-th transmit antenna is represented as $x_i = [\ x_i(0)\ x_i(1)\ \ldots\ x_i(L-1)\ ]$ where $i = 1, 2, \ldots, M_T$ and L is the length of the training sequence. Then, the training sequence matrix is generated as follows

$$X = [\, x_1 ;\ x_2 ;\ \ldots ;\ x_{M_T} \,] \tag{2}$$

The training sequence received signals can be represented as the matrix

$$Y = HX + N \tag{3}$$

where Y and N are $M_R \times L$ matrices.

Then, the maximum-likelihood (ML) estimation of the channel matrix is given by

$$\hat{H} = YX^{+} \tag{4}$$

where $(.)^{+}$ represents pseudo-inverse.

By linear zero-forcing (ZF) detection algorithm, the received signal is modified as

$$r = \hat{G}y = \hat{G}(Hx) + \hat{G}n \quad (5)$$

where $\hat{G} = (\hat{H})^{+}$.

With assumption $\hat{H} \approx H$, the equation (5) can be written as

$$r = x + \hat{G}n \quad (6)$$

Then, i-th sub-channel's SNR is given by

$$\rho_i = \frac{E[xx^*]}{\sigma^2 \|\hat{G}_i\|^2} \quad (7)$$

where $\hat{G}_i$ is i-th row of $\hat{G}$, $\|.\|$ is norm, and $(.)^*$ is transpose-conjugate. Therefore, based on the estimated channel information, the ordering of each sub-channel's SNR strength that will be used for partial CSI can be obtained. To estimate the transmitted symbols through linear MMSE detector, the received signal is calculated as

$$r = \frac{P}{M_T} H^* \left[\sigma^2 I + \frac{P}{M_T} HH^* \right]^{-1} y \quad (8)$$

2.4 Adaptive Channel Selection

In this section, the proposed adaptive channel selection (ACS) algorithm that automatically switches the bit-stream so as to match the ordering of SNR strength for the sub-channels can be summarized as following five steps.

(i) Training sequences are transmitted for channel estimation at the transmitter every bursty period.

(ii) The MIMO channel is estimated by known training sequences using (4) at the receiver side.

(iii) With the estimated CSI, each sub-channel's SNR strength is calculated using (7) and the ordering of SNR strength as partial CSI is feedback to the transmitter with delay.

(iv) At the transmitter side, each layer bit-stream is loaded to the proper channel according to the estimated partial CSI and transmitted during bursty period. As an example, if the ordering of SNR strength is "3, 1, 2, 4", the bit-loading of each layer bit-stream is therefore described in Figure 1.

(v) The bit-unloading of the estimated transmission symbols is inversely processed at the receiver side as described in Figure 1.

In this work, we assume that the estimated partial CSI can be feedback over reliable channel and synchronized at the both transmitter and receiver through keeping fixed feedback delay.

3. EXPERIMENT RESULTS

We provide numerical examples to show how the proposed ACS-MIMO system is able to achieve UEP for layered SVC transmission with the estimated partial CSI. In this work, we will use 4×4 MIMO systems under independent Rayleigh fading. The elements of the MIMO channel matrix H are obtained from Clarke and Jakes' model [20][21] with F_d (Doppler frequency) 10 [Hz]. Equal power is allocated to each sub-channel and QPSK is used for modulation. The data rate of each sub-channel is considered with 256[Kbits/sec] or 384[Kbit/sec]. The known training sequences with L = 4 is transmitted every 0.001 [sec]. The ordering of sub-channel's SNR strength obtained at the receiver and feedback to the transmitter with time delay T. At the receiver side, for the detection of transmitted signals, we adopt liner ZF or MMSE receiver.

3.1 BER Performance of ACS-MIMO vs. OL-MIMO

In traditional OL-MIMO systems with linear decoder, we can assume that each sub-channel's BER is same. Therefore, the left of Figure 4 shows the BER of 4×4 OL-MIMO system with various SNR (sub-channel transmit power to noise variance) in case of CSI (perfect H) and channel estimation (CE). MMSE detector shows better performance than ZF detector since the noise variance is considered for detecting transmitted signals. Therefore, we will consider only MMSE detector from now. Without ACS, the only way for UEP of layered scalable video bit-streams is assigning different channel coding rates according to the importance of each layer [13]. Therefore, it would induce high redundancy, specially, for base layer, as compared with the proposed system.

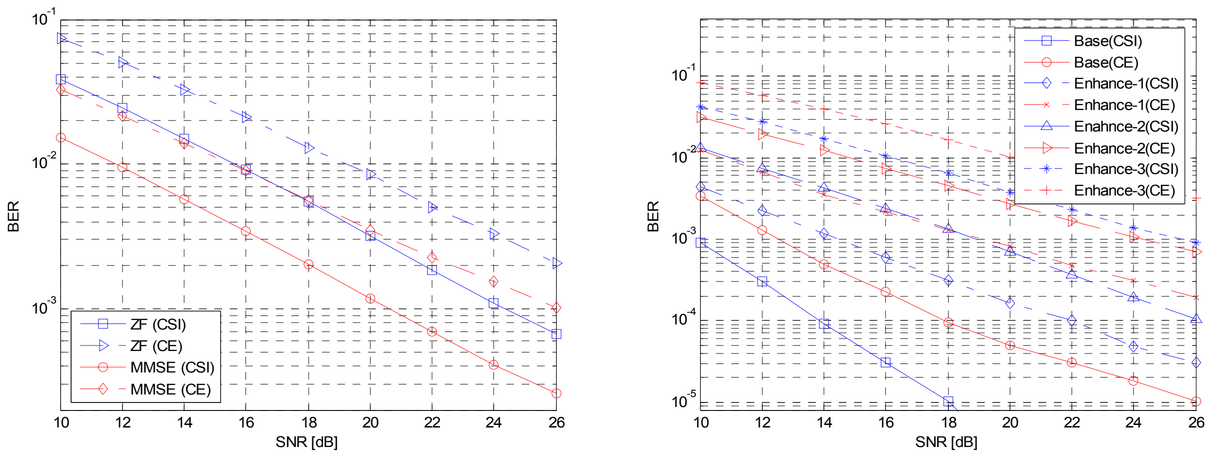

Figure 4: BER performance of ACS-MIMO vs. OL-MIMO
(left) OL-MIMO system without ACS (right) proposed ACS-MIMO system

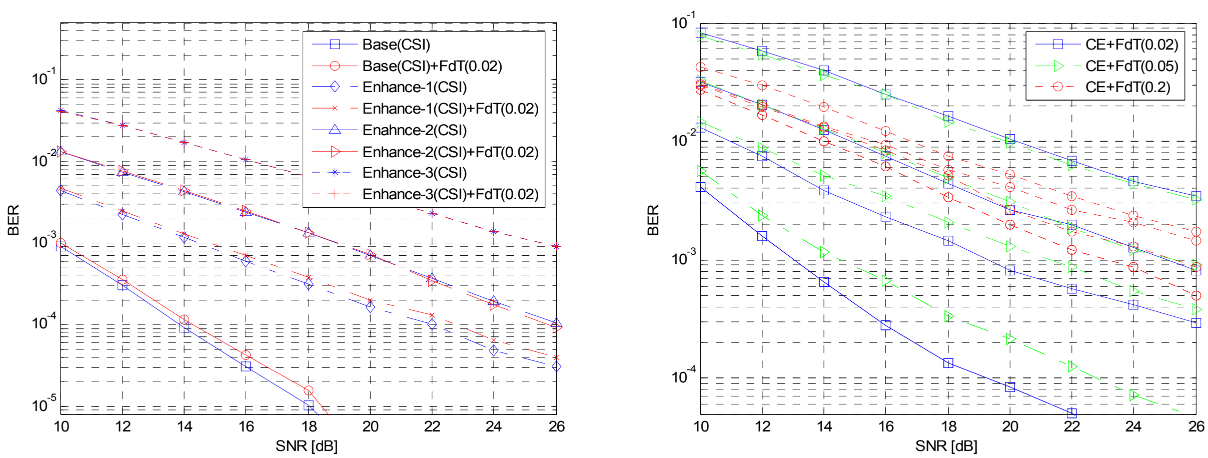

Figure 5: BER performance of ACS-MIMO system
(left) BER against feedback delay (right) BER against CE error and feedback delay

In order to demonstrate the performance of the proposed ACS algorithm, we conduct experiments in terms of channel estimation error and feedback time delay. The right of Figure 4 shows the BER performance with CSI (perfect *H*) vs. channel estimation error while CSI (perfect *H*) vs. and feedback time delay in the left of Figure 5. From these figures, if the MIMO channel is slowly time-varying such as indoor wireless system, the performance of the proposed system more depends on the channel estimation accuracy. The BER performance against both channel estimation error and feedback time delay is given in the right of Figure 5. This figure clearly demonstrates that the proposed ACS-MIMO system can achieve automatic UEP for layered video coding over MIMO system. The robustness of the proposed system against incorrect partial CSI is also shown in the right of Figure 5. It shows that the performance of the proposed ACS-MIMO system is converged to OL-MIMO system without ACS in worst case (long feedback delay).

3.2 Reconstructed Video PSNR Performance of ACS-MIMO vs. OL-MIMO

In this section, we conduct experiments to show the reconstructed average PSNR of the decoded video sequences with various SNR. Three video sequences, 'Mobile', 'Carphone', and 'Foreman', are tested. All test sequences are 256 frames with CIF 30[Hz] and encoded by scalable extension of H.264/AVC to generate 4-layer scalable video bit-streams with GOP size 8. Reed-Solomon (RS) Codes [22] are adopted to protect the transmitted bit-streams since it maintains maximum erasure protection while produces a minimum of redundancy. We choose (255, 223) RS code for the proposed ACS-MIMO system. To fairly compare with OL-MIMO system, we assign UEP channel codes to OL-MIMO system: (255, 179), (255, 201), (255, 223), and (255, 233) RS codes from base-layer to 3rd enhancement-layer, respectively. The average reconstructed PSNR (luminance component) for 'Mobile', 'Foreman', and 'Carphone' with F_dT 0.02 and data rate 256[Kbits/sec] and 384[Kbits/sec] per sub-channel are shown in Figure 6, Figure 7, and Figure 8, respectively. These figures undoubtedly show that the PSNR improvement is achieved by adopting the proposed ACS-MIMO system against OL-MIMO without ACS system. The performance improvement is from the automatically obtained UEP in ACS-MIMO system.

4. CONCLUSION

We described in this paper a practical layered scalable video coding (SVC) transmission scheme over MIMO wireless system with considering both channel estimation error and information feedback delay. This scheme makes proper use of the feedback of the estimated partial channel state information in terms of the ordering of each sub-channel's SNR strength. Based on the feedback of the estimated partial CSI, unequal error protection (UEP) for layered SVC can be achieved by the proposed adaptive channel selection (ACS) algorithm: base-layer is launched to the best sub-channel and the highest enhancement-layer to the worst sub-channel among multiple transmitters. This proposed ACS-MIMO scheme enables us to both overcome the challenge of the perfect CSI that is assumed in the existing approaches and utilize the estimated CSI from the receiver so as to achieve UEP for layered SVC transmission over MIMO system. In addition, the automatically obtained UEP in this scheme does not require any power control at the transmitter. It was shown by various simulation results that the proposed ACS-MIMO system provides a better PSNR performance and shows the robustness against incorrect partial CSI in terms of channel estimation error and time delay.

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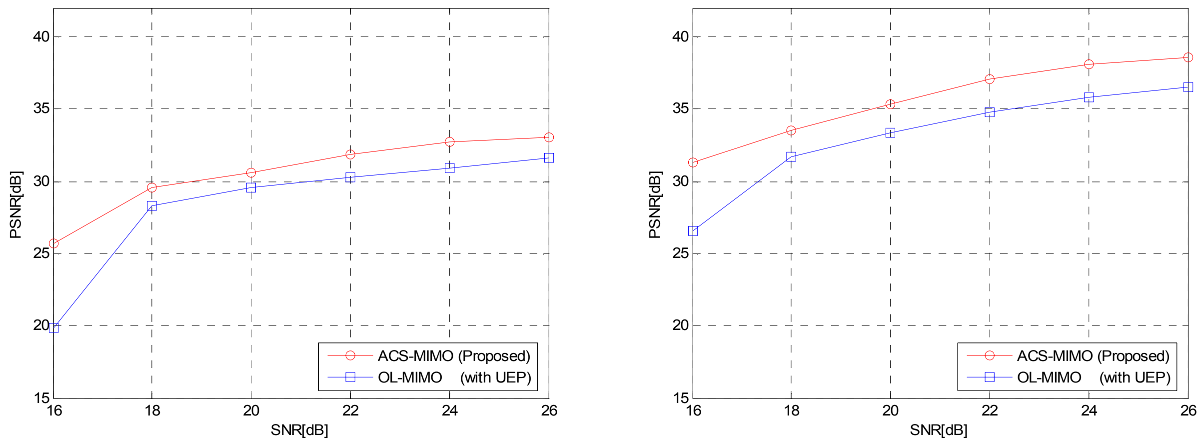

Figure 6: Reconstructed average PSNR of Mobile (left) 256k (right) 384k

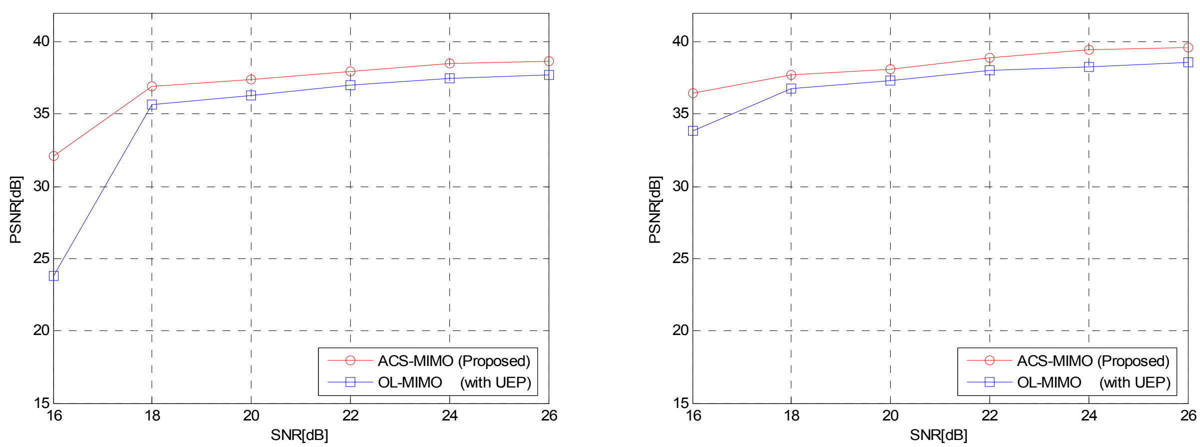

Figure 7: Reconstructed average PSNR of Foreman (left) 256k (right) 384k

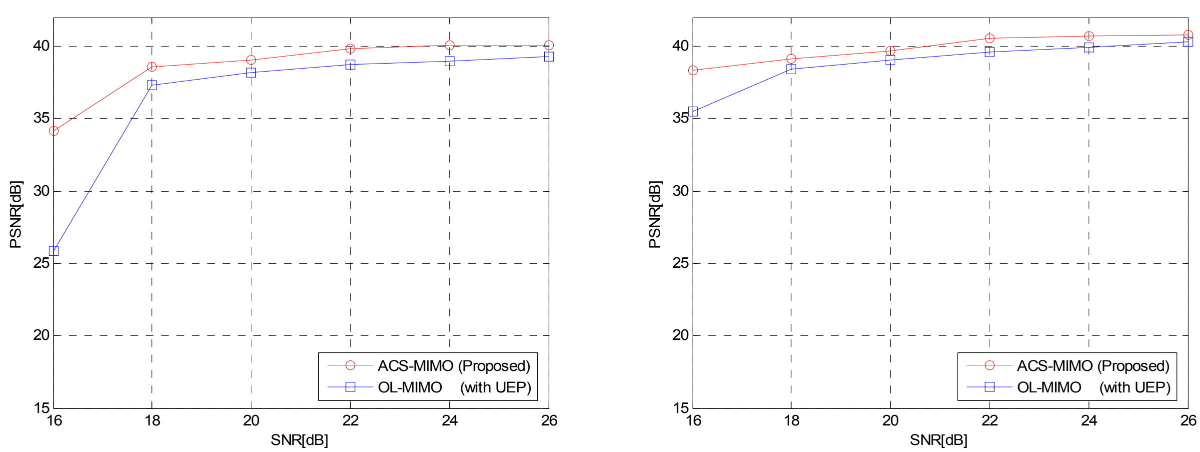

Figure 8: Reconstructed average PSNR of Carphone (left) 256k (right) 384k