Adaptive Combined Scalable Video Coding over MIMO-OFDM Systems using Partial Channel State Information

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Abstract

This paper proposes an adaptive combined scalable video coding (CSVC) system for video transmission over MIMO-OFDM (Multiple-Input Multiple-Output-Orthogonal Frequency Division Multiplexing) broadband wireless communication systems. The scalable combination method of CSVC adaptively combines the medium grain scalable (MGS), the coarse grain scalable (CGS) and the scalable spatial modes with the limited feedback partially from channel state information (CSI) of MIMO-OFDM systems. The objective is to improve the average of peak signal-to-noise ratio (PSNR) and bit error rate (BER) of the received video stream by exploiting partial CSI of video sources and channel condition. Experimental results show that the delivered quality using the proposed adaptive CSVC over MIMO-OFDM system performs better than those proposed previously in the literature.

Keywords: Adaptive CSVC, MGS, MIMO-OFDM, CSI, Video Transmission

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1. Introduction

The development of telecommunication technology and multimedia services require increasingly broadband data transmission. In particular, raising transmission data rate in mobile video services is the key solution to meet with market demands. The demands are realized with the technologies of 4G and beyond 4G (5G), which adopt MIMO-OFDM (multiple input multiple output-orthogonal frequency division multiplexing).

In multimedia services, video communication plays an important role because it consists of various interrelated information. In video transmission, real-time service is one of the most challenging problems. The development of video communication in wireless networks depends on the following conditions: (a) a user-specified bandwidth based on the transmission quality; (b) an effective video encoder/decoder with the minimum bit error rate (BER). To satisfy (a), MIMO-OFDM system can provide broadband services [1][2]. For (b), the method of *scalable video coding* (SVC) can divide a bitstream into several sub-bitstreams or layers according to network states, which can offer efficiency and superior quality video coding on broadband services compared to other video coding methods [3] [4]. There are two groups of the bitstream, one is the base-layer bitstream and the other contains some enhancement-layer bitstreams. Combination of base-layer and several enhancements-layers in decoder system will produce a high quality video, that is scalable technique of *combined scalable video coding* (CSVC). When an interruption or error occurs in video transmission, at least the base-layer can be received by the receiver [3].

Applications of MIMO-OFDM have been rapidly developed since proposed in [5]. Previous studies confirm that the application of MIMO-OFDM in the field of video transmission and multimedia telecommunication systems can be implemented. In [6], SVC method has been used with MIMO-OFDM, although the structure of the SVC is still commonly used. Zheng *et al*. proposed a novel scheme that integrates multiple description coding (MDC) by the structure of space-time code in video transmission over MIMO-OFDM systems in [7]. In [8], SVC was developed for multiuser MIMO-OFDM systems. Alternatively, other research on SVC over WiMAX system were proposed [9][10]. Moreover, there are also some researches on SVC over MIMO system without OFDM [11].

The utilization of CSI (channel state information) in MIMO-OFDM, either completely or partially has been applied to SVC in telecommunication system, aimed to create reliable and adaptive communication systems. The CSI can be completely or partially known at the transmitter and receiver sides. Sometimes, only statistical information on the channel state may be available. The adaptation of MIMO-OFDM system mainly focuses on a rapidly changing environment [12]. By using CSI, an adaptive channel selection system was proposed in [11] and an adaptive antenna selection system was shown in [13]. The exploitation of such channel information is conducted to increase system performance and reduce hardware complexity [14]. In practice, however, full CSI may not be directly available due to feedback overhead and feedback delay. In general, a transmitter does not have direct access to its own CSI. Therefore, some indirect means are required for the transmitter. In particular, CSI for the time-varying channel cannot be tracked completely by the transmitter and thus only partial information can be exploited [15]. In [16], the authors propose using the cross-layer design framework for efficient broadcasting using CSI in SVC over MIMO-OFDM, where a subcarrier allocation strategy is used to assign transmission channels for different users. The authors of [17] investigate an optimal solution for adaptive H.264/SVC video transmission over MIMO channels using CSI. The work in [18] proposes a novel joint H.264/SVC with rate control algorithm using CSI for video compression and transmission over MIMO systems. However, the approaches above have not exploited the potential of CSI in wireless video transmission over MIMO-OFDM systems for adaptive CSVC. Moreover, the application of MIMO-OFDM precoding method has not been used widely compared with antenna-selection method. In this work, we will mainly consider the precoding technique according to the making of adaptive systems in CSVC from MIMO-OFDM to improve PSNR and BER of the received video stream.

This paper is different from previous papers in two aspects. First, this paper exploits the potency of partial CSI over closed-loop precoding MIMO-OFDM for video transmission using SVC which is part of H.264/AVC standard with Joint Scalable Video Model (JSVM) test model [19][20]. Second, the adaptive characteristic of the CSVC encoder is based on the medium grain scalability (MGS), the coarse grain scalability (CGS) and the spatial scalability by using the same matrix from the partial CSI precoding MIMO-OFDM. MGS and CGS modes are the facilities of JSVM used to improve video coding for the efficiency and quality of signal-to-noise ratio (SNR) [4].

In this paper, we propose a new scheme of adaptive CSVC for wireless video transmission by partial CSI in MIMO-OFDM systems. The receiver chooses a matrix from a codebook based on current channel conditions and conveys the optimal codebook matrix to the transmitter, where an error-free and zero-delay feedback channel is assumed. This research is more focused on the adaptive CSVC method using limited feedback as further development of our previous work [21][22]. In [21], the testing scheme conducted in CSVC does not use yet CSI method in MIMO-OFDM systems, whereas in [22] it is only CSVC used in the scheme of WLAN (IEEE 802.11e standard) without MIMO-OFDM systems in the testing using Network Simulator II (NS-2). The main contribution of this paper compared to [21][22] is the use of Adaptive CSVC with the method of limited feedback of CSI scheme in MIMO-OFDM systems.

To the best of our knowledge, an adaptive CSVC scheme that uses the limited feedback of partial CSI to enhance the quality of video streaming through MIMO-OFDM systems has not been studied yet. In this work, we compare the adaptive CSVC with non-adaptive SVC based on modes of MGS, CGS and spatial scalability. The application of this scheme improves BER and average peak signal-to-noise ratio (PSNR) performance in the system. Furthermore, the system is robust towards noise changes in the transmission channel.

Our contributions are as follows.

- We exploit and analyze the potential of partial CSI over closed-loop precoding MIMO-OFDM for video transmission using CSVC. The adaptive characteristic of the CSVC encoder is based on the medium grain scalability (MGS), the coarse grain scalability (CGS) and the spatial scalability by using the same matrix from the partial CSI precoding MIMO-OFDM.
- We propose a new scheme of adaptive CSVC for wireless video transmission by partial CSI in MIMO-OFDM systems. The receiver chooses a matrix from a codebook based on current channel conditions and conveys the optimal codebook matrix to the transmitter, where encoder of CSVC makes choice of three conditions depending on CSI.
- We demonstrate effectiveness of our proposed scheme through computer simulation. The experimental results confirm that the MGS mode performs significantly better compared to the CGS and Spatial mode scheme, and show that the delivery quality improves average peak signal-to-noise ratio (PSNR) and bit error rate (BER)

performance over those previously proposed work. We also show how the scheme is robust towards the changes in the value of additive white Gaussian noise (AWGN). Adaptability of the proposed scheme is evaluated based upon PSNR and BER performance in fluctuating channels. The performance of the adaptive CSVC scheme with partial CSI is better than non-adaptive CSVC system (without CSI); more precisely, the results in the MGS mode have a gain of 2.7 – 3.1 dB for Y-PSNR and 0.5 - 1.5 dB improvement in signal-to-noise ratio (SNR) at BER of 10^{-3}. The proposed scheme is a promising approach for wireless video transmission on broadband services in the future.

The following sections of this paper are organized as follows. Section 2 presents a description of the system including CSVC, MIMO-OFDM systems using partial CSI feedback. A new proposed algorithm for adaptive schemes CSVC is presented in Section 3; meanwhile Section 4 describes the results and discussion. Finally, conclusions are presented in Section 5.

2. System Descriptions

In this section, we introduce how to produce SVC and CSVC from JSVM test model of H.264/AVC standards, some concepts of partial CSI in MIMO-OFDM systems, and then describe system model of the proposed framework scheme on adaptive CSVC.

2.1 CSVC

There are three basic types of scalability: (a) quality (SNR) scalability, (b) spatial scalability and (c) temporal scalability. A SVC system consists of encoder and decoder shown in Fig. 1 (a) and (b), respectively. In the encoder system, there are two groups; one is the base-layer bitstream and the other contains some enhancement-layer bitstreams. The base-layer bitstream contains vital information and the enhancement-layer bitstreams have the residual additional information to improve the transmitted video quality according to network conditions and user demands.

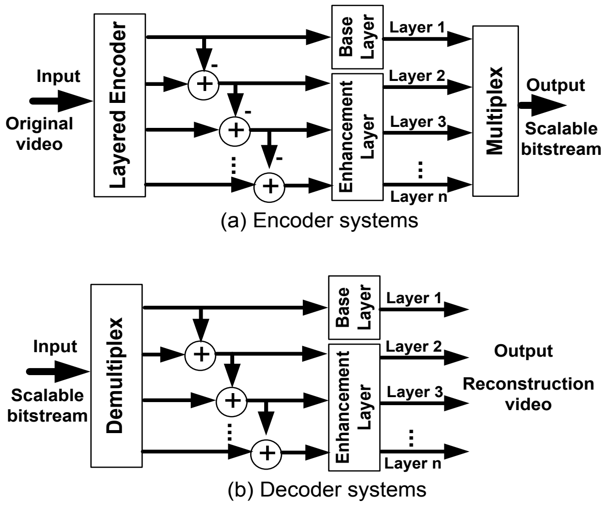


Fig. 1. Scalable video encoding and decoding systems

The combined-scalability is an appropriate solution because of the diversity in the characteristics of the input or video input, fluctuating network conditions, and multi terminals on the network [23]. Some researches employ several layers of combined-scalability, including one base-layer and some enhancement-layers. In [25], the authors proposed a system whose encoder contains three layers of combined scalability as shown in Fig. 2. Frequently used CSVC mode are medium grain scalable (MGS), coarse grain scalable (CGS) and spatial scalability, which we can choose based on efficiency, characteristics, and the computation of the systems [23][24][25][26].

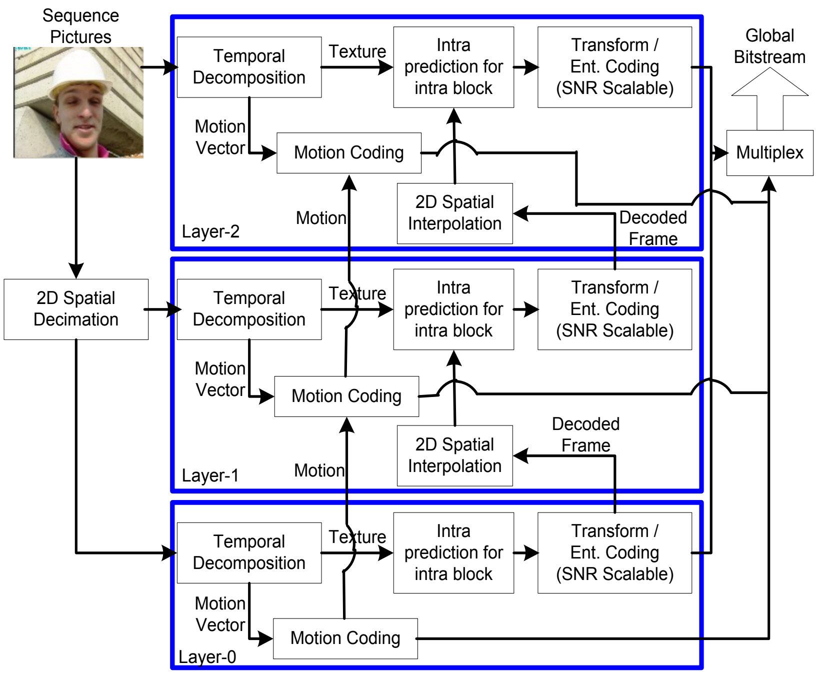


Fig. 2. The Structure of an encoder containing three layer CSVC

2.2 Limited Feedback Method using Partial CSI over MIMO-OFDM

Space-time block code (STBC) is a technique of wireless communication to transmit multiple copies of data/bitstream over fading channels [1][27]. MIMO-OFDM technology, especially in multimedia communication services, has become a main issue in wireless communications [2]. Some researches of SVC transmission over MIMO-OFDM adopt the results from the previous works, and mainly focus on the impacts of multipath fading and additive white Gaussian noise (AWGN) [6][7][8].

Several limited feedback methods with closed-loop method has been widely used until now. Based on information available at the transmission, there are three types of CSI methods, namely the instantaneous, statistics of the channel, and partial or quantized CSI. Partial or quantized CSI is the most practically used [11][12][13][14][15][16][29]. Development of partially limited CSI feedback is the topic of this research.

2.3 System Model

The proposed framework scheme is shown in Fig. 3. The use of OFDM on MIMO systems [1][2][12] with the operation of IFFT (inverse fast Fourier transform)/FFT (fast Fourier transform) and CP (cyclic prefix) are performed at each transmitter (x_n) and receiver (y_n). The received signal y_i, which is $M_R \times 1$ vector with the subcarrier i-th (i=0, 1,…, N-1) in MIMO-OFDM system, can be represented by [28][29] as

$$y_i = \sqrt{\frac{\rho}{M_T}} H_i x_i + z_i , \tag{1}$$

where ρ denotes the signal-to-noise power ratio, x_i is the signal emitted by matrix $M_T \times 1$ which is independent with distribution of $\mathcal{CN}(0,1)$, and z_i complex Gaussian noise with a matrix $M_R \times 1$, which is i.i.d. as $\mathcal{CN}(0,1)$. The channel frequency response is given by

$$H(e^{j2\pi\theta}) = \sum_{l=0}^{L-1} h_l e^{-j(2\pi/N)l\theta} \quad , 0 \le \theta < 1 , \tag{2}$$

where $H(e^{j2\pi\theta})$ is the $M_R \times M_T$ matrix-valued channel impulse response and h_l represents the l-th tap (l=0,1,…,L-1).

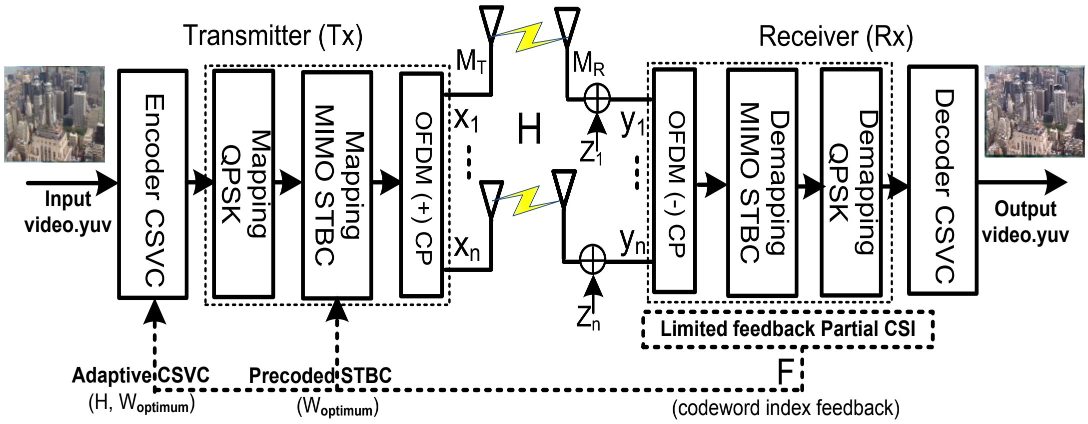


Fig. 3. Schematic and structure of the system being considered

In the MIMO-OFDM system with N_c subcarriers, the data flowing through OFDM modulators will be processed by IFFT on blocks along N_l followed by the parallel-to-serial (P/S) conversion. OFDM signal is generated along the symbol $N_l + L_{cp}$ emitted simultaneously from each antenna. At the receiver R_x signal passes through OFDM demodulation, first eliminating the CP and then the N-point FFT processing. The output of the OFDM demodulation is eventually separated and decoded as shown in Fig. 3.

By aggregating N_c sub-carriers, the vector can be derived from (1) as

$$\begin{bmatrix} y_1 \\ \vdots \\ y_{N_c} \end{bmatrix} = \begin{bmatrix} H_1 & \cdots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \cdots & H_{N_c} \end{bmatrix} \begin{bmatrix} x_1 \\ \vdots \\ x_{N_c} \end{bmatrix} + \begin{bmatrix} z_1 \\ \vdots \\ z_{N_c} \end{bmatrix} . \tag{3}$$

Based on (1) and (3), MIMO-OFDM equation can be rewritten as

$$y_{N_c} = \sqrt{\frac{\rho}{M_T}} H_{N_c} x_{N_c} + z_{N_c} \quad . \tag{4}$$

Given channel gain H that is estimated on the receiver side (R_x) and L refers to the size of a codebook, the index of the corresponding codeword is chosen to represent the estimated condition of H. In contrast to the nature of the full CSI, the partial CSI is represented only in a set of indices that are feedback corresponding to the transmission side (T_x). Each index can be expressed by the number of bits F_B, which correspond to the total number of codeword $L = 2^{F_B}$ of the codebook. If W_i is expressed as a codeword *i-th*, $i = 1,2,3,\cdots,L$, for a codebook $F = \{W_1, W_2, ..., W_L\}$, the codeword is selected by a mapping function $f(.)$. The matrix F is chosen by a function $f : \mathbb{C}^{M_T \times M_R} \rightarrow F = \{W_1, W_2, \ldots, W_L\}$. On the condition of the channel H, codebook method can be represented as follows

$$\begin{aligned} W_{opt} &= f(H) \in F \\ &= \{W_1, W_2, ..., W_L\}, \end{aligned} \tag{5}$$

where W_{opt} is the codeword that best represents H from the mapping function $f(.)$. If $C \in \mathbb{C}^{M \times T}$ is expressed as a space-time codeword of length M, it is expressed as

$$C = \left[c_1, c_2, ..., c_T\right], \tag{6}$$

where $c_k = [c_{k,1}\ c_{k,2}\ ...\ c_{k,M}]^T$, $k = 1,2,...,T$, and $M \leq M_T$.

In *orthogonal space-time block code* (OSTBC)-OFDM precoded systems, space-time codeword C is the multiplication of a precoding matrix W, which is selected from the codebook F in (5). Assuming that the channel M_T is in a static condition for T symbols, the received signal y in (4) can be expressed as

$$y = \sqrt{\frac{\rho}{M_T}} HWC + z \quad . \tag{7}$$

For a given channel matrix H and precoding matrix W, the codeword is considered as the *pairwise error probability* (PEP) $\Pr(C_i \rightarrow C_j|H)$. The probability of the codeword C_i is transmitted whereas C_j with $j \neq i$ is decoded. Upper bound condition of the PEP is given as

$$\Pr(C_i \rightarrow C_j \mid H) = Q\left(\sqrt{\frac{\rho \left\| HWE_{i,j} \right\|}{2M_T}}\right) \leq \exp\left(-\frac{\rho \left\| HWE_{i,j} \right\|_F^2}{4M_T}\right), \tag{8}$$

where $\rho = E_x/N_0$ is SNR, $E_{i,j} = C_i - C_j$ on STBC scheme, and $\|HWE_{i,j}\|_F$ is the Frobenius-norm of the matrix $HWE_{i,j}$ [29]. From (8), part of $\left\| HWE_{i,j} \right\|_F^2$ is required to be maximized in order to minimize the PEP [15]. This leads to the following codeword selection criterion

$$W_{opt} = \underset{W\in F,\ i\neq j}{\arg\max} \left\| HWE_{i,j} \right\|_F^2 = \underset{W\in F}{\arg\max} \left\| HW \right\|_F^2 \ . \tag{9}$$

In the case of non-deterministic channel, the following criteria are used in the codebook design,

$$E\left\{ \min_{W\in F} \left(\left\| HW_{opt} \right\|_F^2 - \left\| HW \right\|_F^2 \right) \right\} \ . \tag{10}$$

Regarding the minimization problem, it can be solved by using Grassmannian subspace packing [29]. The solution of Grassmannian packing which is based on the amount of M_T, the length of the codeword M, and the size of the codebook L is time consuming and gives an indirect solution. Therefore, the consideration of the practical completion of the suboptimal method is done by utilizing the Discrete Fourier Transform (DFT) matrix [30], as shown below

$$F = \left(W_{DFT}, \theta W_{DFT}, \cdots \quad W_{DFT} \right) \ . \tag{11}$$

The first codeword W_{DFT} is obtained by selecting M columns of the $M_T \times M_T$ matrix DFT, which the input (k,l)th given as $e^{j2\pi(k-1)(l-1)/M_T} / \sqrt{M_T}$ where k,l = 1,2,…,M_T. Thus, θ is a diagonal matrix

$$\theta = diag\left(\left[e^{(j2\pi u_1/M_T)} \ e^{(j2\pi u_2/M_T)} \ \ldots \ e^{(j2\pi u_{M_T}/M_T)} \right] \right) \tag{12}$$

where the independent variables $\{u_i\}_{i=1}^{M_T}$ have been determined. If the initial codeword W_{DFT}, the codeword (L-1) is obtained by multiplying W_{DFT} and θ^i, i = 1,2,…,L-1. Independent variables $\{u_i\}_{i=1}^{M_T}$ in (12) are determined by maximizing the minimum chordal distance, so that

$$u = \underset{\{u_1,u_2,\cdots}{\arg\max} \ \min_{l=1,2,\cdots} \ d(W_{DFT}, \theta^l W_{DFT}) \ . \tag{13}$$

Note that IEEE 802.16e specification for mobile WiMAX system employs this particular designed method. **Table 1** shows the values of $u = \{u_1, u_2, \cdots, u_{M_T}\}$ that are adopted from IEEE 802.16e standard for various values of M_T, M, and L [28]. For example, when $M_T = 4$, $M = 3$, and $L = 64$, W_1 is stated as

$$W_1 = \frac{1}{\sqrt{4}} \begin{bmatrix} 1 & 1 & 1 \\ 1 & e^{j2\pi\times 2/4} & e^{j2\pi\times 3/4} \\ 1 & e^{j2\pi\times 4/4} & e^{j2\pi\times 6/4} \\ 1 & e^{j2\pi\times 6/4} & e^{j2\pi\times 9/4} \end{bmatrix} . \tag{14}$$

Table 1. Codebook design parameters for OSTBC in IEEE 802.16e

No. of *Tx* Antennas (M_T)	No. of Data stream (M)	Codebook size (feedback bits) (L/F_B)	Column indices (c)	Rotation vector (u)
2	1	8/3	[1]	[1,0]
3	1	32/5	[1]	[1,26,28]
4	2	32/5	[1,2]	[1,26,28]
4	1	64/6	[1]	[1,8,61,45]
4	2	64/6	[0,1]	[1,7,52,56]
4	3	64/6	[0,2,3]	[1,8,61,45]

The remaining precoding matrices W_i are obtained from

$$W_i = diag\left(\left[e^{j2\pi\times 1/4} \quad e^{j2\pi\times 8/4} \quad e^{j2\pi\times 61/4} \quad e^{j2\pi\times 45/4} \right]\right)^{i-1} W_1 , \tag{15}$$

where $i = 2,3,4,\cdots,64$.

3. The Proposed Algorithm

The proposed adaptive CSVC algorithm for wireless video transmission is described as follows.

Step 1: Channel Initialization

Process in Step 1 is the initialization channel on the transmitter (*Tx*). Pseudocode used to estimate channel of MIMO-OFDM systems are shown in **Table 2**.

Table 2. Initialization channel and input video sequence

```
1:  Input = 1/sqrt(2)×((M_T (input video) – 1) + j(M_T (input video) – 1));  \\ Input video
2:  Fd_{T_xb} = T_xb(1 – L);  \\ Frequency domain
3:  Td_{T_xb} = F_IFFT (Fd_{T_xb}) ;  \\ Time domain
4:  CP = [(L_CP + 1 : end);  (Td_{T_xb}) ];  \\ Appending of Cyclic Prefix
5:  x_{M_T} = sqrt(L_IFFT / (L_IFFT + L_CP) × reshape(CP,1, L×(L_IFFT + L_CP));
    \\ Parallel to Serial
```

In **Table 2**, L is the length of the frame, F_{IFFT} is the IFFT matrix, CP is the cyclic-prefix; T_{xb} is the total bits sent through the channel to reach the receiver (R_x); L_{CP} is the length of CP, L_{IFFT} is the frame size of IFFT, and x_{M_T} is bitstream from the transmitter.

Step 2: Processing of Precoded STBC

Step 2 is a process that utilizes precoding STBC limited feedback CSI by using matrix W_{opt}. **Table 3** presents the steps to determine the F, W_i, and W_{opt} according to (11), (15), and (5).

Table 3. Processing of precoded STBC-OFDM

1:	Selection of the index column matrix F (based on (11));
2:	Determination of the matrix codebook W_i (based on (15));
3:	Determination of STBC-OFDM precoding matrix W_{opt} (based on (5)).

Step 3: Processing of Adaptive CSVC

In this step, the determination carried out through the adaptive process at encoder CSVC utilizes the information on limited feedback CSI from the matrix W_{opt}. Determination of the maximum index of the norm matrix H in the codebook as the Frobenius-norm of the matrix codebook W and H is done using the function of *max*(*cal*). The corresponding subroutine is shown in **Table 4**.

The range of values of the max(cal) function are $0 \leq \max(cal) \leq 1$, which depends on the condition of the transmission channel. There are three conditions for adaptive systems, i.e. using mode MGS, CGS, and Spatial Scalability. The conditions that will be used in the method of adaptive CSVC in the encoder by using the CSI limited feedback method require two bits of feedback (F_B). The codebook W_{opt} and W_i can be obtained based on (5) and (15). Max(cal) function is given as $cal(i) = \text{norm}[H \times W_{opt}(:,:,\text{i}),\text{'fro'}]$ as shown in **Table 4.**

The worst case is the option of $max(cal) = 0$, i.e. the condition in which the transmitter (T_x) does not get CSI from receiver (R_x), so the encoder of CSVC will choose spatial scalable mode. Selection of spatial modes is based on the consideration of computational complexity from CGS and MGS modes. In the best conditions ($max(cal)$ approaches the value 1) in which the encoder uses MGS selection mode.

Table 4. Processing of adaptive CSVC

Pseudo-code to determine the function of *cal*(*i*) and *max*(*cal*):

```
for i=1 : code length
    cal(i) = norm[H×W_opt(:,:,i), 'fro'];  \\ 'fro' is a Frobenius-norm function
end
[val, index] = max(cal);  \\ Function of adaptive CSVC system
```

Value of *max*(*cal*) is used to determine the adaptive condition of CSVC. The conditions offered by the system are:

```
if 0.5 <= max(cal) <= 1.0
    input = mgs mode;
else
    if 0 < max(cal) < 0.5;
        input = cgs mode;
    else
        max(cal) = 0;
        input = spatial mode;
    end
end
```

Step 4: Post Processing

The received signal at the receiver (R_x) in pseudo-code is shown in **Table 5**, where L is the length of frame, L_{M_T} is the length of data, H_{est} is the channel matrix of predicted results; T_{xb} is the total bits sent through the channel to the receiver (R_x); σ^2 is the noise variance, and M_R is the number of receivers. After all steps are completed, Step 1 is repeated for new input (video sequence).

Table 5. Post processing

Multipath fading and noise on channel transmission:
1: *for* $i = 1 : L+1$
2: $h_{M_T,M_R}(i) = 1/\mathrm{sqrt}(2) \times [randn(1, L_{M_T}) + (\mathrm{j} \times \mathrm{randn}(1, L_{M_T}))];$
\\ Multipath fading (frequency selective fading)
3: $R_x(i) = y_{R_x}(i) + h_{M_T,M_R}(i)[y_{T_{xb}}(1, L-l+1);$
4: $z(i) = \sigma^2(i)(1, L(R_x(i))) + j(1, L(R_x(i)));$ \\ Noise (AWGN)
5: *end*
Received signal at the receiver (R_x):
1: $H_{est} = H \times W_{opt}(:, :, index);$ \\ Estimate of the H function
2: *for* i = 1 : L
3: $R_x(i) = H_{est} \times T_{xb} symbol(i) \times R_x(i) + z(i)$; \\ Signal at R_x
4: *end*

The approach above can also be summarized in the **Table 6.**

Table 6. Summary of algorithm

Step 1:	Initialization channels and input video sequences.
Step 2:	Processing of precoded STBC: • Selection process index of matrix F (based on (11)). • Determination of STBC-OFDM precoding matrix W_i (based on (15)). • Determination of the optimal matrix codebook W_{opt} (based on (5)).
Step 3:	Processing of adaptive CSVC: Determination of the function *max(cal)* for adaptive CSVC conditions (refers to Table 4).
Step 4:	Post processing: • Determination received signal at the receiver (R_x) (refers to **Table 5**) • Repeat step 1 for new input.

4. Results and Discussions

Computer simulations were conducted to verify the performance of the proposed adaptive CSVC method. Parameters used in this research are listed in **Table 7**.

Table 7. Simulation parameters

Parameters	Description/Value
Input Video (sequence)	City and Crew, 50 frames, 30fps
JSVM	Version 9.8 [20]
GOP size	16 frames
Spatial Scalable	2 layers
SNR Scalable	MGS (4 layers) and CGS (3 layers)
Motion search range	± 32
CPU Test Platform	Proc. Intel Xeon 2.66 GHz; RAM:15GB
MIMO	STBC 2×2
OFDM	64 code lengths

Transmission Channel	AWGN and multipath fading (frequency selective fading)
CSI	Codebook using limited feedback
CSI Channel	Error-free and zero-delay

Testing and analysis of video input (City and Crew sequences) in this work are limited by only 50 frames due to the computational efficiency issues. The selection of the type of video sequence as input video is based on the characteristics of each of such sequences. In the City sequence, the movement of the camera is dominant to the background, while in the Crew sequence moving objects is dominant to the background. Peak signal-to-noise ratio (PSNR) is used to objectively measure the quality between an original sequence and a reconstructed sequence. This metric depends on the Mean Squared Error (MSE) given by

$$MSE = \frac{1}{W_{pix} \times H_{pix}} \sum_{x=0}^{W_{pix}-1} \sum_{y=0}^{H_{pix}-1} \left| f(x,y) - g(x,y) \right|^2 , \tag{16}$$

and PSNR is defined as

$$PSNR = 10\log_{10} \frac{(2^n - 1)^2}{MSE} , \tag{17}$$

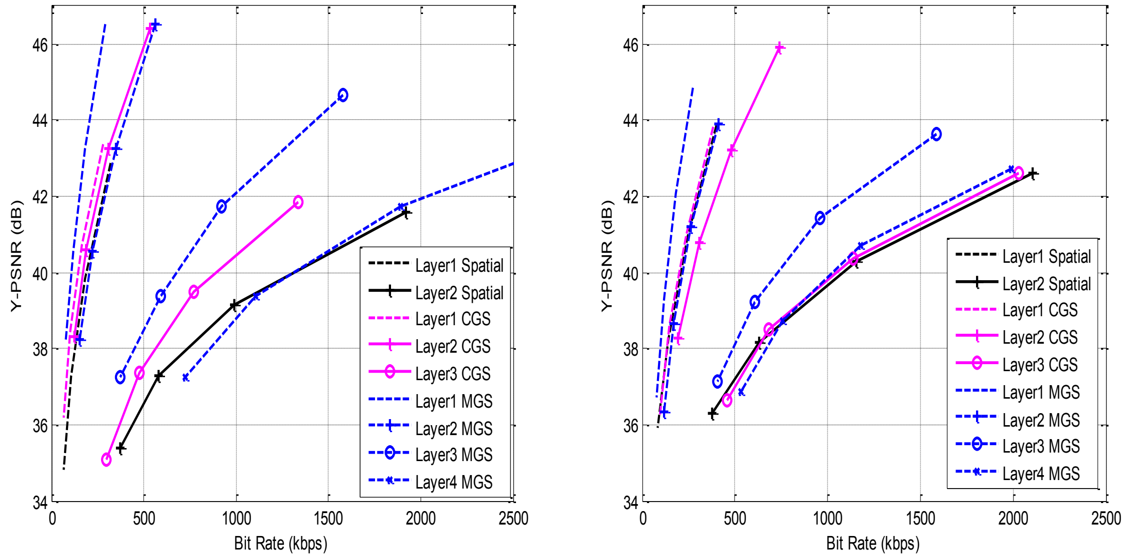
where W_{pix} is number of pixel/row, H_{pix} is number of row/frame, $f(x,y)$ is luminance intensity of pixel in the original frame, $g(x,y)$ is luminance intensity of pixel in the reconstructed frame, and n is the number of bits per pixel.

Calculation and analysis of the bit rate is use equation is given by

$$B_r = \frac{N_b}{N_f} \times M_f , \tag{18}$$

where B_r as bit rate, N_b total as bit, N_f as number of frames, and M_f as mean frame rate.

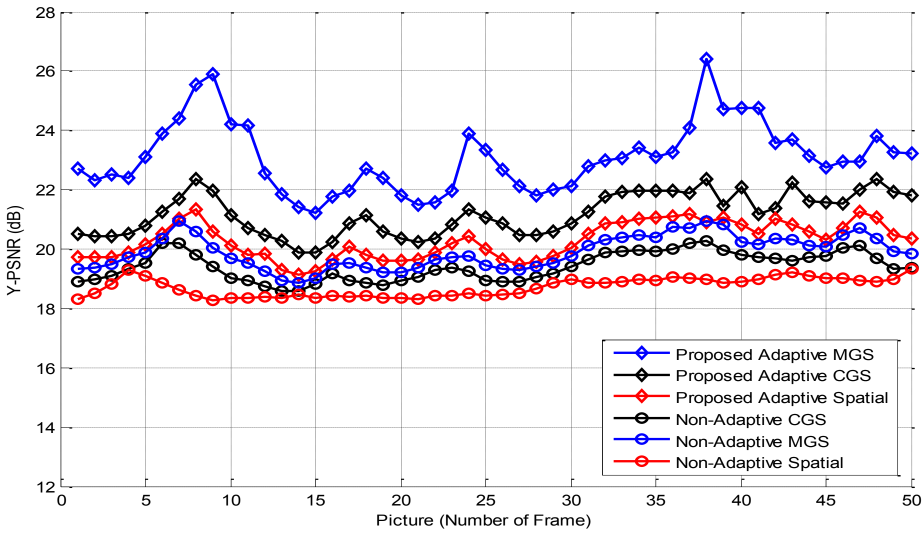
We analyze the coding efficiency of encoder CSVC from City sequence (a) and Crew sequence (b) as an input as shown in **Fig. 4**. The encoding were operated according to the JSVM algorithm [20]. Three modes are shown in the figure, namely spatial scalable, CGS, and MGS modes. The spatial scalable mode, CGS mode, and MGS mode use two, three, and four layers, respectively. In City sequence (**Fig. 4 (a)**), it shows that on layer 3, MGS mode gains Y-PSNR (luminance component of the video) about 2 dB above CGS mode at bit rate 1500 kbps. On the other hand, at Y-PSNR 42 dB, MGS mode has a gap about 400 kbps above CGS mode. On layer 2, we see that there is no significant difference, meanwhile on layer 1 there is 2.5 dB to 3 dB difference. The results for Crew sequence (**Fig. 4 (b)**); show that on layer 3, MGS mode gains Y-PSNR about 1 dB above CGS mode at bit rate 1000 kbps. On the other hand, at Y-PSNR 40 dB, MGS mode has a bit rate gap about 500 kbps above CGS mode. On layer 2 and layer 1, MGS mode gains Y-PSNR of 0.5 – 1.0 dB above CGS mode at bit rate 250 kbps. The result shows how the coding efficiency of MGS mode improves Y-PSNR over the CGS and Spatial mode.



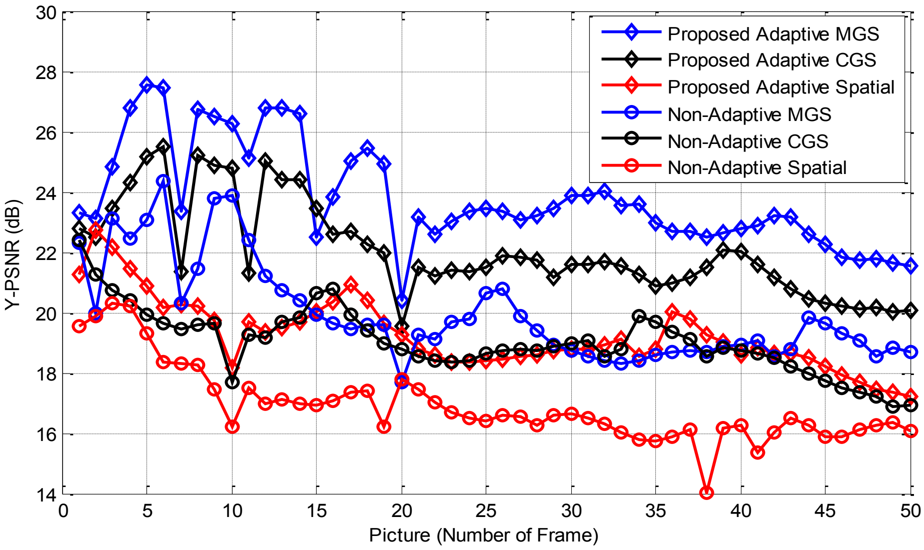
(a) City Sequence (b) Crew Sequence

Fig. 4. Coding efficiency comparison of mode of MGS, CGS, and Spatial scalable

Analysis of system performance according to the proposed scheme in **Fig. 3** gives the results as shown in **Fig. 5**. The average of Y-PSNR as output of the proposed scheme is shown in **Fig. 5** in which there are adaptive (using CSI) and non-adaptive (without CSI) systems. For adaptive system in City sequence (**Fig. 5 (a)**): Spatial scalable has a value of 19.5 dB, CGS has a value of 21.2 dB, and MGS is 23.1 dB. For non-adaptive (without CSI) system: Spatial scalable has a value of 18.46 dB, CGS has a value of 18.9 dB, and MGS is 20.4 dB. Also, in the case of Crew sequence (**Fig. 5 (b)**) with adaptive systems: the Spatial scalable, CGS, and MGS achieve SNR of 18 dB, 21.7 dB, and 23.6 dB, respectively. For non-adaptive systems (without CSI) in Crew sequence: the Spatial scalable, CGS, and MGS achieve SNR of 17.2 dB, 19.7 dB, and 20.5 dB, respectively. The performance of the adaptive CSVC (using CSI) is better than non-adaptive CSVC system (without CSI). More precisely, the results in the MGS mode have a gain of 2.7 – 3.1 dB for Y-PSNR. The use of MGS gives better result compared to CGS mode and spatial scalable mode. For comparison between the proposed systems, which adaptive CSVC is compared with non-adaptive system, it is shown that the proposed system is better than non-adaptive systems. The adaptive MGS mode has the best performance with Y-PSNR average is 23.1 dB in City sequence and 23.6 dB in Crew sequence. The result shows how the proposed scheme (adaptive CSVC) makes improvement on PSNR better than the non-adaptive (conventional) system.



(a) City Sequence



(b) Crew Sequence

Fig. 5. Y-PSNR as function of number of frames as output of the proposed adaptive CSVC

From the results of Monte Carlo simulation analysis in **Fig. 6**, we observe that the proposed system offers the best performance on adaptive MGS mode. The adaptive schemes is shown to have better performance than non-adaptive (not use the limited feedback of CSI), such as the scheme of Alamouti [31]. For the value of $BER = 10^{-3}$, the adaptive MGS mode has a gap of 1.5 dB in City sequence (**Fig. 6 (a)**) and 1 dB in Crew sequence (**Fig. 6 (b)**) compared to the non-adaptive MGS mode. There is a case where a spatially adaptive SNR has a gap of 1.5 dB in City sequence and 0.5 dB in Crew sequence compared with non-adaptive spatial, while the adaptive CGS mode also has a gap of 1.5 dB in City sequence and 0.5 dB in Crew sequence compared with non-adaptive CGS mode. Therefore, the performance comparison of the proposed scheme (adaptive system) is generally around 0.5 - 1.5 dB better than the non-adaptive system on the condition $BER = 10^{-3}$. Based on the result, we can conclude that the proposed scheme (adaptive CSVC) can improve BER better than the non-adaptive (conventional) system.

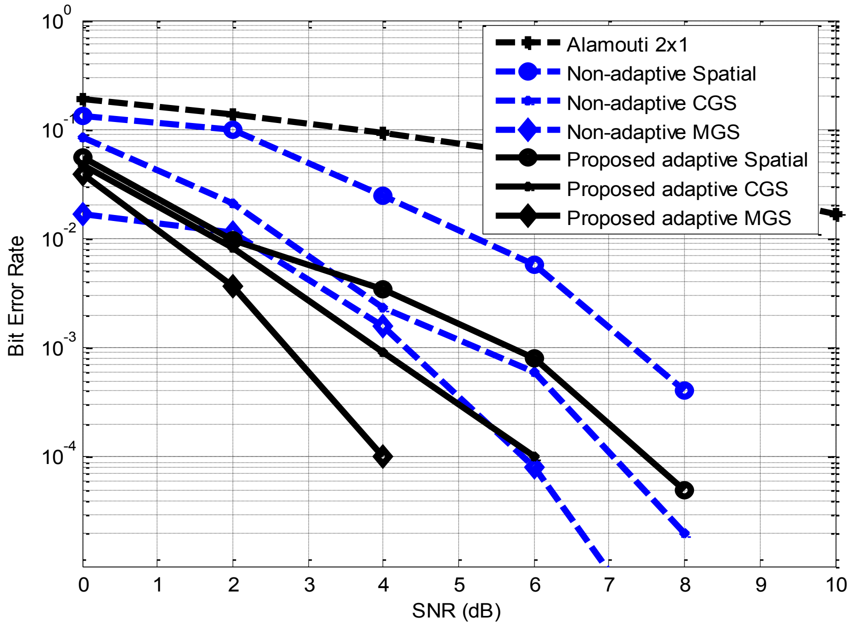
To analyze the influence of additive white Gaussian noise (AWGN) on the system performance, we varied the variance of the noise (σ^2), by using the following equation

$$\sigma^2 = 0.5cM_T 10^{-SNR/10} \quad , \tag{19}$$

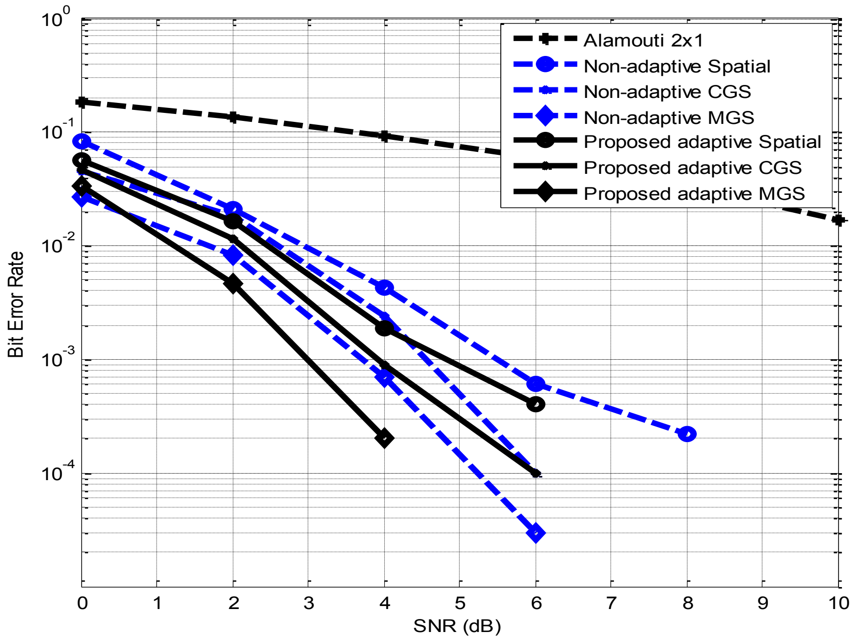
where SNR is Signal-to-Noise Ratio, c is the coefficient of noise variance, and M_T is the number of transmit antennas at the transmitter. The results of the analysis, based on (19) can be seen in **Fig. 7** shown that such system proposed in the value of $BER = 10^{-3}$ has an SNR gap of 4 dB in City sequence and 3 dB in Crew sequence, where the coefficients of noise variance (c) are 0.5 and 1. This shows the system robustness towards the changes in the value of AWGN variance.

5. Conclusions

In this paper, we have investigated adaptive CSVC over MIMO-OFDM systems with limited feedback. We present a new scheme for platform transmission video using adapted CSVC over MIMO-OFDM by using limited feedback CSI, where an error-free and zero-delay feedback channel is assumed. The important difference of the proposed adaptive schemes with other works is that the design scheme of adaptive precoding and CSVC utilizes partial CSI methods with the same codebook matrix. Evaluation and analysis of video transmission are based on the JSVM over broadband wireless networks. We also investigate the impacts of the use of MGS, CGS, and Spatial scalable modes of performance of this adapted system and show the system robustness towards the changes in the value of AWGN variance. The application of MGS mode on CSVC increases the performance compared to CGS and Spatial scalable modes. Experimental results show that the delivered quality using the proposed adaptive CSVC over MIMO-OFDM system with partial CSI improves average peak signal-to-noise ratio (PSNR) and bit error rate (BER) of the received video stream. In general, our scheme is implementable in video sequence of broadband wireless service.



(a) City Sequence



(b) Crew Sequence

Fig. 6. BER performance of adaptive CSVC over MIMO-OFDM systems

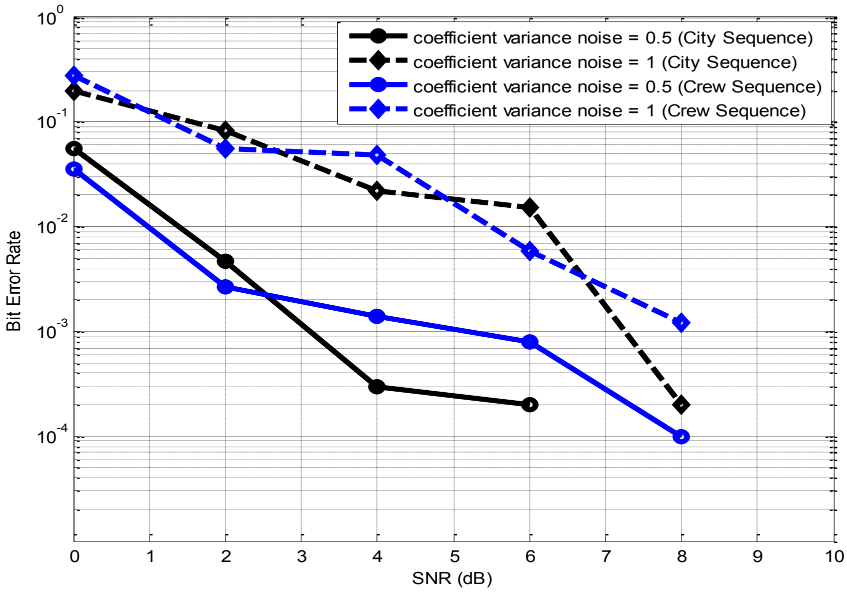


Fig. 7. BER performance of adaptive CSVC for analysis of system robustness

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