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Cross Layer 1, 2 and 5 Resource Allocation in Uplink Turbo-coded HARQ Based OFDMA Video Transmission Systems

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Abstract Wang et al. propose the cross layer resource allocation algorithm considering channel state information in layer 1 and rate-distortion function in layer 5, for uplink convolutional coded OFDMA video transmission systems. In this paper, we propose the use of hybrid automatic repeat request protocol (HARQ) and the turbo code to improve Peak-Signal-to-Noise Ratio (PSNR, the measure of the video quality). We define this HARQ overhead consumption and adjust PSNR for HARQ redundancy. The simulation results show that, for the HARQ redundancy adjusted PSNR, the proposed turbo-coded HARQ scheme outperforms the proposed convolutional coded HARQ scheme and the convolutional coded no HARQ scheme in Wang et al. by 3.25, and 3.95 dB, respectively, when maximum two retransmissions are allowed for HARQ. The proposed turbo-coded HARQ scheme achieved maximum HARQ redundancy adjusted PSNR for just 2 retransmissions allowed; while the proposed convolutional coded HARQ scheme achieve maximum (but still lower than the proposed turbo-coded HARQ scheme) for 4 retransmissions allowed. Thus the proposed turbo-coded HARQ scheme has smaller delay than the proposed convolutional coded HARQ scheme.

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1 Introduction

Recently, Orthogonal Frequency Division Multiple Access (OFDMA) become more and more popular in almost all areas of wireless communications including LTE-A. Because of the benefit of OFDMA, the demand for the quality of service (QoS) is growing fast. However, due to limited power and spectrum resources, the resource allocation to get better QoS (sum data rate, delay time, etc.) is a critical issue [3, 8, 10, 12, 16].

OFDMA is a flexible and low-complexity way of managing communication resources [21]. [9, 16, 22, 23] use the user's channel state information (CSI) to allocate power and spectrum resource. Instead of considering physical layer, [5], [2, 11, 15] focus on rate distortion (RD) function information of the user's video content and to allocate the communication resource base on it. However, they consider only one layer in the resource allocation.

A cross layer 1 and 5 resource allocation algorithm in uplink convolutional-coded OFDMA video transmission sytsem has been proposed in [19] (Scheme A). The algorithm combing physical layer (layer 1) information (CSI) and application layer (layer 5) information (RD) to allocate power and spectrum resource, and it shows that the average PSNR is better than the previous schemes only considering either layer1 CSI or layer 5 RD information.

In this paper, we add HARQ [13] to the scheme in [19] and propose the novel cross layer 1, 2, and 5 resource allocation algorithm in uplink convolutional-coded OFDMA video transmission sytsem (Scheme B) to increase target symbol error rate (for the same packet error rate constraint), then increase information rate, and finally improve the video quality PSNR. Although the HARQ is common in cross layer 1 and 2 resource allocation [7, 14], but has not appearred in cross layer 1, 2, and 5 resource allocation.

To improve PSNR further and reduce the times of retransmissions, we also propose to use the turbo code instead of the convolutional code (Scheme C). Moreover, we define the extra overhead consumption due to HARQ retransmissions and compare the proposed Schemes B and C fairly with the convolutional coded no HARQ case in [19], Scheme A.

The contribution of this paper is as follows:

(1)   We extend [19] and propose cross layer 1, 2, and 5 resource allocation algorithm where HARQ is added in layer 2. Previous schemes are cross layer 1 and 2 [7, 14], or cross layer 1 and 5 [19].

(2)   We propose to replace the convolutional code by the turbo code.

(3)   We define the extra overhead consumption due to HARQ into account and compute HARQ-overhead-adjusted PSNR gain.

The rest of this paper is organized as follows: Sect. 2 introduces system model and video distortion model. The cross layer resource allocation algorithm in [19] is briefly summarized in Sect. 3. The simulation results are presented in Sect. 4. Finally, the conclusion is drawn in Sect. 5.

2 System Model

2.1 Uplink OFDMA System Description

The system block diagram is shown in Fig. 1. The blocks in gray are different from those in [19]. The HARQ-Chase Combining is applied, and the convolutional code is replaced by turbo code. Consider a cellular OFDMA video communication system with the set of users k = {1, 2, 3,…, K}, where K is the number of users. The system occupies a total frequency band of W (Hz) which is equally divided into M orthogonal subcarriers m = {1, 2, 3,…, M}.

The system operates in a slotted manner and the length of one time slot is T_s (sec). One Group of Pictures (GOP) will be transmitted in one time slot. Let T be the data duration and T_{cp} be the length of the cyclic prefix. We define $T_0 = T + T_{cp}$ to be the duration of an OFDM symbol.

If the modulation format is M-QAM, from [17], the symbol error rate (SER) can be approximated as

$$\text{SER} \approx 4Q\left(\sqrt{\frac{3}{M-1}\frac{P_{k,m}\left|H_{k,m}\right|^2}{P_N}}\right) \tag{1}$$

where $P_{k,m}$ is the transmission power of user k in subcarrier m, and the noise power P_N can be calculated as [19].

The channel response $\left|H_{k,m}\right|^2$ for user k in subcarrier m consists of both the path loss and multi-path fading, and the magnitude square of the channel [6] is given by

$$\left|H_{k,m}\right|^2 = \alpha^2 \cdot K_0 \cdot \left(\frac{d_0}{d_k}\right)^\gamma \tag{2}$$

where $\gamma = 2.4$ is the path-loss exponent [6]. d_k is the distance between user k and the base
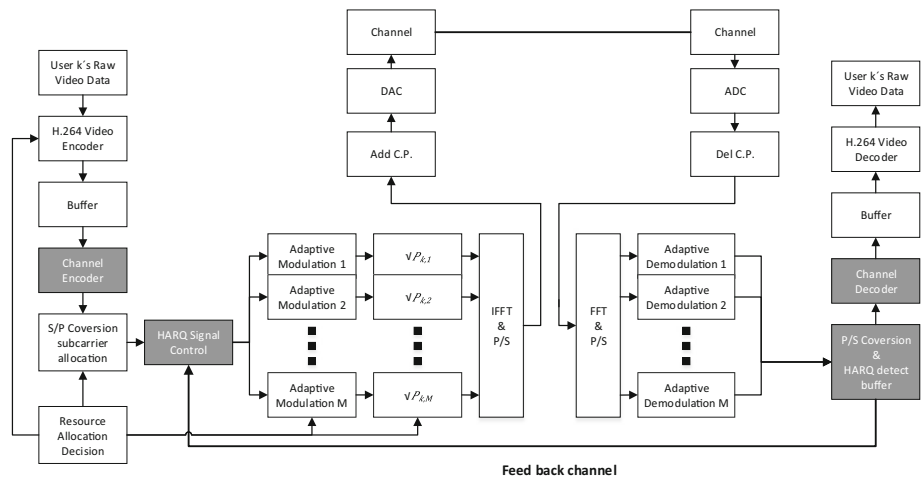

Fig. 1 Cross layer 1, 2, 5 system adding HARQ-chase combining in layer 2

station, and d_0 is set to 10 m [6]. α is a Rayleigh random variable, and K_0 is a constant of -24 dB.

Given the target symbol error rate SER_t, we obtain the information rate (bits/symbol) as

$$R_{k,m}\left(P_{k,m}, H_{k,m}\right) = min\left\{\log_2\left[1 + \eta P_{k,m}\left|H_{k,m}\right|^2\right], R_{max}\right\} \tag{3}$$

where $\eta = \frac{3}{P_N}\left[Q^{-1}\left(SER_t/4\right)\right]^{-2}$ and R_{max} is the largest alphabet size the system allows.

In this paper, we add HARQ-Chase Combining and divide data in packets of fixed number of symbols. On the contrary, there is no HARQ-Chase Combining in [19]. By adding HARQ-Chase Combining, we can increase SER_t and keep its packet error rate close to that of the original SER_t without HARQ-Chase Combining. Because Q^{-1} function is a decreasing function, η increases as SER_t increases, and so will $R_{k,m}$.

2.2 Video Rate-Distortion Model

The video rate distortion model is the same as that in [19]. Define $D_k^s(B)$ is the rate distortion function of the k-th user in time slot s, where B is the number of bits the encoder generated. For each Group of Pictures (GOP), the mean square error (MSE) distortion can be approximated as [18]

$$D_k^s(B) = a_k + \frac{\omega_k}{B + \upsilon_k} \tag{4}$$

where a_k, υ_k and ω_k are the constants depending on the video content. For the video with high complexity (e.g., high motion), ω_k is relatively large.

$$B_k = u \cdot R_{k,m}\left(P_{k,m}, H_{k,m}\right) \cdot T_s/T_0 \tag{5}$$

To protect the data, a channel code of fixed rate u is added. If we substitute (5) into (4), then the MSE distortion for the k-th user is

$$a_k + \frac{b_k}{R_{k,m}\left(P_{k,m}, H_{k,m}\right) + c_k} \tag{6}$$

where $b_k = \frac{\omega_k}{(u \cdot T_s/T_0)}$, and $c_k = \frac{\upsilon_k}{(u \cdot T_s/T_0)}$.

2.3 HARQ-Chase Combining

In HARQ-Chase Combining, maximal-ratio combining (MRC) is a method of diversity combining. The received packets from each transmission (original and retransmissions) are saved even if they cannot be decoded correctly. We consider an example of N transmissions. The least squares solution in this case is known as MRC and

$$\hat{s} = \frac{h_0^* y_0 + h_1^* y_1 + h_2^* y_2 + \cdots + h_{N-1}^* y_{N-1}}{|h_0|^2 + |h_1|^2 + |h_2|^2 + \cdots + |h_{N-1}|^2} \tag{7}$$

where h_i^* is the channel coefficient in the i-th transmission, and y_i is the received signal in the i-th transmission, $i = \{0, 1, 2,..., N - 1\}$.

2.4 Turbo Code

In [19], the channel encoder of data transmission is a rate 1/2 convolutional code with memory 4 and generator polynomial $g(D) = \begin{bmatrix} 23 & 35 \end{bmatrix}$.

To reduce the number of retransmissions, we propose the use of the turbo code instead of the convolutional code. The turbo code encoder uses the same $g(D)$ but in recursive form. Because of the need to meet the packet size of 2000 bytes (16,000 bits) before encoding, we use Berrou–Glavieux interleaver with block length $= 16384$ in [1, 4]. We take $N = 128, L = 128$ and define eight primes $p(1) = 17, p(2) = 37, p(3) = 19, p(4) = 29, p(5) = 41, p(6) = 23, p(7) = 13, p(8) = 7$. For each $0 \leq i < N \cdot L$, the corresponding positions is given by:

$$\pi(i) = c(i) + L \cdot r(i) \tag{8}$$

where $r(i) = mod(p(l+1) \cdot (c_0 + 1) - 1, N), \quad c(i) = mod\left(\left(\frac{L}{2} + 1\right) \cdot (r_0 + c_o), L\right), r_0 = mod(i, L), c_o = \frac{i - r_0}{L}, l = mod((r_0 + c_0), 8)$.

3 Resource Allocation Algorithm

The iterative cross layer resource allocation algorithm is the same as that in [19]. In this section, we describe this iterative algorithm in [19] briefly. For details, please see [19].

1. Initially assigning each subcarrier to the user with the maximum channel coefficients.
2. Each user uses water filling to upgrade performance.
3. Each user computes the rate at each subcarrier.
4. The slope of each user's rate-distortion curve is computed, and the user with the steepest slope is given an extra subcarrier currently assigned to another user.
5. The user chosen to give up a subcarrier is the one whose distortion is increased the least.

4 Simulation Results

The simulation parameters are mostly the same as [19]: an uplink OFDMA system with 16 subcarriers, each with a 50 kHz bandwidth, and the modulation format of M-QAM, with $M = 4, 8, 16, 32, 64, 128$ or 256. The channel response is also the same as [19]. The average SNR (dB) is calculated by

$$\text{ave SNR} = 10 \times \log_{10} \frac{\sum_{k=1}^{K} \frac{\sum_{m \in A_k} P_{k,m}^* |H_{k,m}|^2}{M_{A_k}}}{K} \tag{9}$$

where $P_{k,m}^* |H_{k,m}|^2$ is the user k's transmitted power using water filling multiplied by channel response, A_k is the set of subcarriers that system assigned to user k, M_{A_k} is total number of subcarriers in this set, and K is the number of users. Subcarriers are assumed to fade independently. The coherence time of the fading channel in each subcarrier is one time slot (a GOP), T_s (s).

However, the HARQ-Chase Combining is not used in [19], so data is not divided into packets of symbols. In this paper, we set the size in one HARQ-Chase Combining packet to be 2000 bytes (16,000 bits), which follows the standard of IEEE 802.11 [20].

A sequence of CIF videos (the same as [19]) of total length 50 s at 30 frames per second was used. The group of pictures (GOP) size is 15 frames and the frames inside one GOP are encoded using H.264 rate control. The number of symbols of each users was assigned by the randomly start points of the same video, and the resource allocation decision is done in each time slot (GOP).

In the simulation results, we consider the following schemes:

- Scheme A [19]: The channel code is the rate 1/2 convolution code and $SER_t = 0.1$.
- Scheme B (proposed): HARQ-Chase Combining is used. and $SER_t = 0.3$. The channel code is still the rate 1/2 convolution code. The maximum retransmission for HARQ is 6 times.
- Scheme C (proposed): HARQ-Chase Combining is used. and $SER_t = 0.3$. The channel code is changed to the rate 1/2 turbo code. The maximum retransmission for HARQ is 6 times.

We presume the $SER_t = 0.1$ without HARQ-Chase Combining can be modified to $SER_t = 0.3$ by HARQ-Chase Combining without affecting the packet error rate, and the simulation result in Fig. 2 shows that presumption can be supported.

The average PSNR is calculated by $10 \times \log_{10} \frac{255 \times 255}{MSE}$ like [19], and it's derived from the average of all users' PSNR.

The average video PSNR performance (without considering extra overhead consumption due to HARQ) as a function of the number of retransmissions allowed is shown in Fig. 3. In terms of the average PSNR, Scheme B outperforms Scheme A by 2–5 dB because of HARQ, Scheme C is better than that of Scheme A by 4 ~ 5 dB due to HARQ
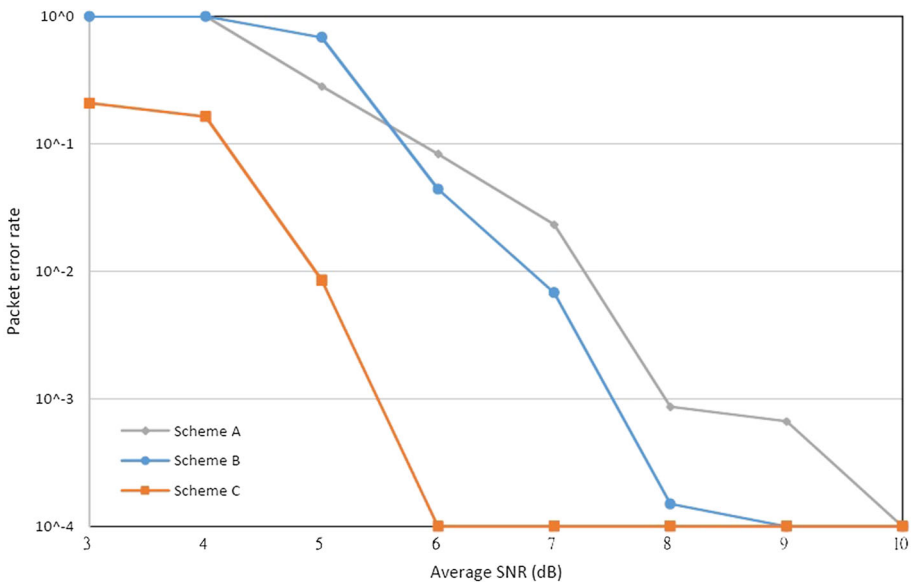

Fig. 2 Packet error rate versus average SNR, 16 subcarriers, one packet has 2000 bytes (16,000 bits)

and turbo code. We note that Scheme C reaches saturation performance if maximum two retransmissions allowed but Scheme B does so if maximum four retransmissions allowed. Therefore, the extra overhead (redundancy) and latency due to HARQ is expected to decrease for Scheme C, compared to Scheme B.

The average redundancy (HARQ overhead) is shown in Fig. 4. The redundancy τ is defined by

$$\tau = 10 * \log_{10}(\varphi_{total}/\varphi_0)\,(\text{dB}) \tag{10}$$

where φ_{total} is total number of original and retransmitted packets, and φ_0 is number of original packets. For example, $\varphi_{total} = 14{,}076$ and $\varphi_0 = 10{,}000$, it means 10,000 original packets and there are 4076 retransmitted packets in total during all retransmissions (each original packet can be retransmitted at most 6 times).

In Fig. 5, the average HARQ overhead adjusted PSNR gain over Scheme A, g, is shown. g is defined as

$$g = PSNR\ of\ Scheme\ B\ or\ C - PSNR\ of\ Scheme\ A - \tau \tag{11}$$

We can see that Scheme C > Scheme B > Scheme A in terms of HARQ overhead-adjusted PSNR.

We note that Scheme C reached saturated overhead adjusted PSNR gain after 2 retransmissions and stay at top if maximum number of retransmission allowed is greater than 2 because the turbo code corrects almost all errors during the the first two retransmissions. We note also Scheme B reached saturated overhead-adjusted PSNR gain at 4 retransmissions and get worse if the number of retransmission is greater than 4 because too many retrnamissions introduce too much overhead. For maximum overhead adjusted PSNR, Scheme C has latency of 2 and Scheme B has latency of 6, so Scheme C outperforms Scheme B in terms of latency.
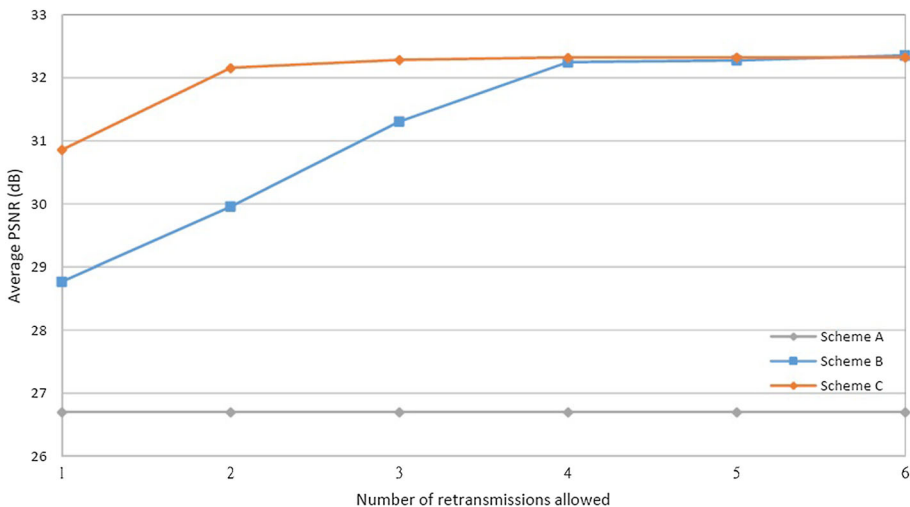

Fig. 3 Average video PSNR versus number of retransmissions allowed, average SNR = 8 dB, number of user = 12, 16 subcarriers

We also discuss the different coherence time with respect to retransmission time in Fig. 6. That coherence time = 6 retransmission time means channel coefficient for each retransmission is the same. On the other hand, that coherence time = 1 retransmission time means channel coefficient for each retransmission is independent. From Fig. 6, when the the cohenct time gets smaller, the PSNR performance better because the Chase-Combining gets larger diversity gain. The Figs. 2, 3, 4, and 5 assume coherence time = 1 retransmission time.
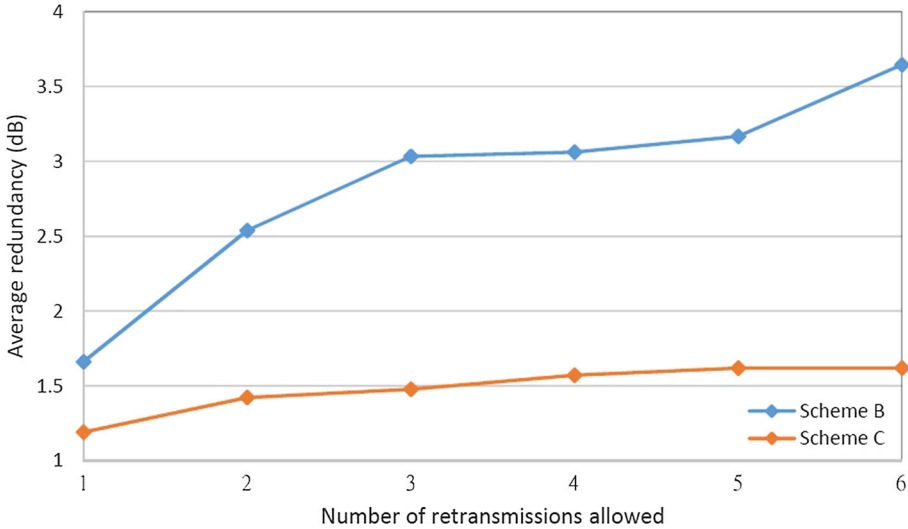

Fig. 4 Average redundancy versus number of retransmissions allowed, target symbol error rate = 0.3, average SNR = 8 dB, number of user = 12, 16 subcarriers
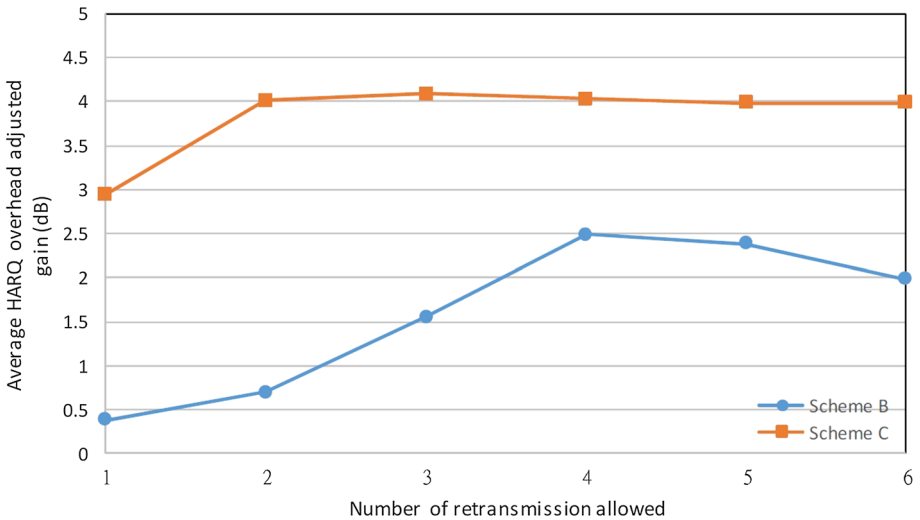

Fig. 5 Average HARQ overhead adjusted gain versus number of retransmissions allowed, target symbol error rate = 0.3, average SNR = 8 dB, number of user = 12, 16 subcarriers
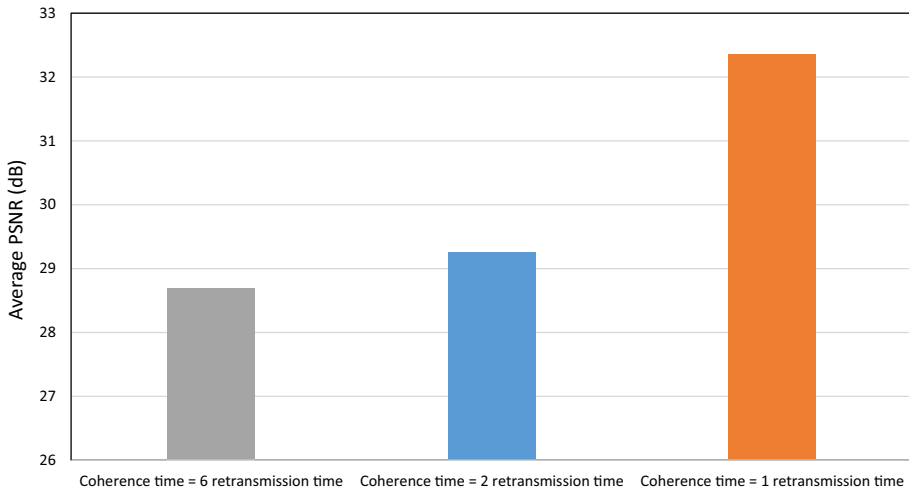
Fig. 6 Average video PSNR versus coherence time, target symbol error rate $= 0.3$, average SNR $= 8$ dB, number of user $= 12$, 16 subcarriers

5 Conclusions

We propose the cross layer 1, 2 and 5 resource allocation algorithm for turbo-coded uplink OFDMA video transmission systems adding HARQ-Chase Combing in layer 2. For comparison, the prior art in [19] is the cross layer 1 and 5 resource allocation algorithm for convolutional-coded uplink OFDMA video transmission systems. Because of the use of turbo code, the vast majority of the errors can be corrected during the first two retransmissions. The simulation results show that the proposed turbo-coded HARQ scheme outperforms the previous scheme in [19] by 3.95 dB in HARQ-Chase Combing overhead adjusted PSNR, when maximum two retransmissions are allowed for HARQ. The proposed turbo-coded HARQ scheme achieved maximum HARQ redundancy adjusted PSNR for just 2 retransmissions allowed and remains at the maximum for more than 3-6 retransmissions allowed; while the proposed convolutional coded HARQ scheme achieve maximum (but still lower than the proposed turbo-coded HARQ scheme) for 4 retransmissions allowed (larger delay than the proposed turbo-coded HARQ scheme) and drops from the peak if more than 4 retransmissions due to increased HARQ redundancy.

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