Optimal Joint Subcarrier Assignment and Power Allocation for Multi-user Video Streaming over OFDMA Downlink Systems

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Abstract. In this paper, we present a cross-layer design for multi-user video streaming over OFDMA (orthogonal frequency-division multiple-access) downlink systems, based on the joint optimization of subcarrier assignment and power allocation. The objective is to maximize the received video quality of all the users subject to the network resource constraint. With the optimal joint subcarrier assignment and power allocation, the proposed scheme can maximally satisfy the requirements of the packet scheduling from the higher layer. Employing the Lagrange dual decomposition method, we can obtain the global optimal solution to the optimization problem. Simulation results show that the proposed algorithm has superior performance compared to the existing alternatives.

Keywords: resource allocation, OFDMA, multi-user, optimization, lagrange dual decomposition.

1 Introduction

The demand for video transmission over wireless networks is growing dramatically. Video transmission is characterized not only by a large amount of required data-rate, but also by a significant variability of the data-rate over time. The requirements are becoming aggravating if multiple users request video streams from a single access point, which serves a given wireless cell. In the multi-user scenario, the packet scheduling for different packets of different users will incur different video qualities, due to the various video contents. Therefore, the decision of packet scheduling is important for the end-to-end video qualities. The wireless resource allocation should satisfy the requirements of packet scheduling from the higher layer.

It is really a challenge for the video transmission over wireless networks, due to the time-varying nature and the scarcity of the wireless resources. Moreover, advanced wireless access technique should be studied for the multi-user video transmission. The Orthogonal Frequency Division Multiple Access (OFDMA) is such an advanced technique. OFDMA can provide great flexibility for subcarrier assignment to maximize the system capacity and the spectral efficiency. Therefore, the problem for

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video transmission over OFDMA networks is how to manage the wireless resources to satisfy the requirements of packet scheduling by using effective subcarrier assignment and power distribution.

Packet scheduling for video transmission and subcarrier allocation for data transmission are both well-studied topics. The problem of dynamic subcarrier allocation for OFDMA systems is also well investigated [1]-[2]. The methods of adaptive subcarrier assignment focus on improving the data throughput and the spectrum efficiency, and guaranteeing the fairness among users as well. These methods in [1]-[2], however, are only available for data transmission, and cannot be directly applied to video applications. The increase of the throughput or the spectrum efficiency does not always correspond to the improvement of received video quality.

A lot of works have focused on the problem of real-time video transmission over OFDMA systems in recent years. By jointly considering the video content and channel condition, references [3] and [4] investigate the determination of the video encoding modes and the design of the transmission policy. These methods, however, are not applicable to the transmission for the pre-coded video streams, for which the video streams have been pre-encoded elsewhere. Therefore, video encoding parameters cannot dynamically change according to the variation of the wireless channel.

Many schemes for the transmission of pre-coded, non-scalable video are also proposed [5]-[11]. In [8], a cross-layer design for video transmission for OFDMA systems is proposed. Based on the distortion analysis for video applications, the subcarrier assignment policy is selected from a preset policy domain in order to maximize the video quality. However, the subcarrier assignment and power allocation were not mentioned in these schemes, and the improvements of the video quality are thus limited. In [9], the video quality, which is modeled as a function of video bit rate, is maximized using a piecewise continuous objective function. Therein, the maximization of the objective function is achieved by optimally allocating the wireless resources. However, the continuous objective functions proposed in [9] are not fit for video transmission. In the applications of packet switching, the packet, rather than the bit, is the unit for decoding. If a packet is not completely received, it would be fully dropped in the lower layers, such as the link layer in redundancy check. In [10], a stepwise scheme is presented, where the contribution of each packet to the video quality is measured by a gradient function. With this in mind, the packet which contributes most to video quality is scheduled in priority, and then the resources are allocated. The stepwise scheme is not optimal, because the packet with the largest contribution to video quality may consume over-many wireless resources. In our previous work in [11], we proposed a cross-layer packet scheduling algorithm in order to maximize video qualities. However, the wireless resource allocation is not considered.

In this paper, an optimal resource allocation scheme for pre-coded multi-user video transmission over OFDMA networks is presented. By optimal joint subcarrier assignment and power allocation, the proposed scheme can maximally satisfy the requirements of the packet scheduling from the higher layer. The goal of the scheme is to maximize the video quality over all video users.

The rest of the paper is organized as follows. In Section 2, we outline the presented system architecture and formulate the problem. Section 3 proposes the optimal resource allocation scheme. Section 4 describes the simulation model and gives the results. Finally, conclusions are drawn in Section 5.

2 System Overview and Problem Formulation

We consider an application scenario where a BS delivers video streams to K MUs located within its cell. The BS receives video streams from a media server via the backbone network, which is of high bandwidth and lossless. The media server stores the pre-coded video sequences. All MUs are assumed to share the same network resources but request different video streams. All connections communicate with the BS using a combination of TDM and OFDMA.

The major issues for the end-to-end video transmission include packet scheduling and wireless resource allocation. The former deals with the problem that which packet of which user should be transmitted in priority. While the latter decides that which subcarrier in which OFDM symbol is employed for packet transmission. There have already existed the optimization methods for packet scheduling and wireless resource allocation, respectively. However, the joint consideration of the two for optimizing the end-to-end video quality is still open.

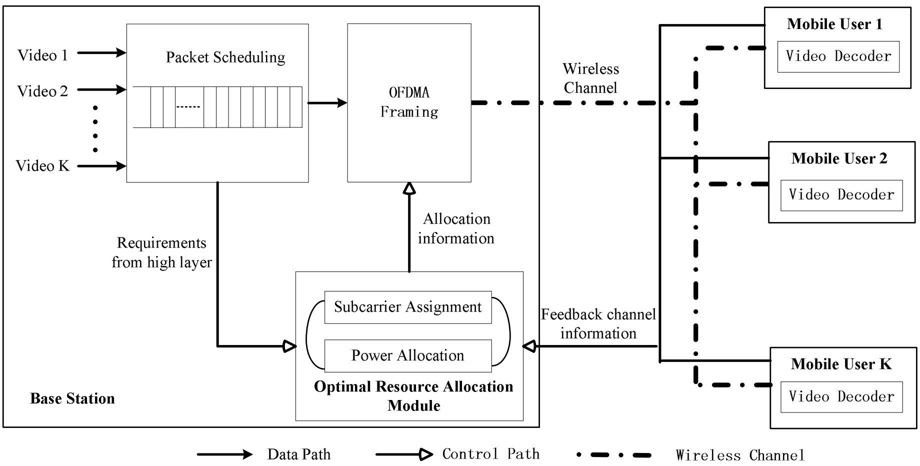

Fig. 1. The cross-layer design model of an OFDMA system

2.1 System Architecture

Fig. 1 depicts the system framework. Once a video stream is requested by a MU, the packets are transmitted over a backbone network to the video queue in the BS. In the queue, the video packets are scheduled by the scheduling schemes in order to guarantee the video qualities and the delay requirements. Meanwhile, the channel state information (CSI) is supposed to be ideally estimated by the MUs and sent to the Optimal Resource Allocation Module through the feedback channel. Note that the subcarriers suffer different channel responses for different users. Therefore, at a specific time, the CSI is a two-dimension matrix, in which the row and the column represent users and subcarriers, respectively. Then, the resource allocation scheme will be employed by jointly assigning the subcarriers and allocating the power. The OFDMA frames are formed as the optimal decision. At the receiver, each MU extracts its own information from the OFDMA frame. Then, the video are decoded and displayed.

2.2 Problem Formulation

To maximize the end-to-end video qualities of all users, we should adopt the effective packet scheduling algorithm and the wireless resource allocation scheme, as shown in Fig. 2. The packet scheduling algorithm deals with the optimized order of packets, considering the video contents, the error concealments algorithm, and the channel conditions. Then, the wireless resource allocation scheme works to satisfy all the users' rate requirements by the scheduling order. In this paper, we focus on the issue of the resource allocation for the scheduled packets, which is in the box in Fig. 2.

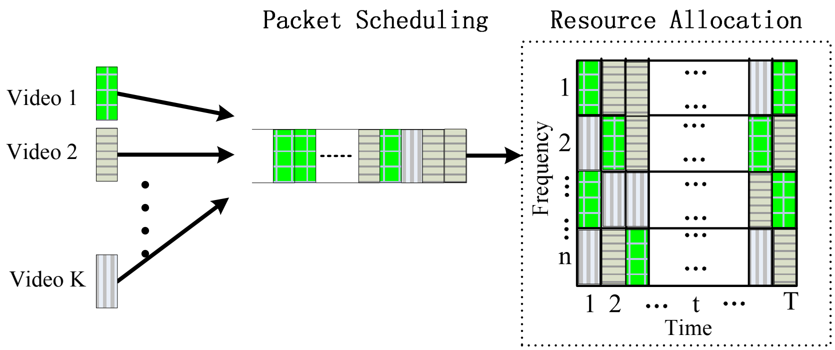

Fig. 2. The diagram of the formulated problem

Denote the packets in the scheduling queue as the order $\{\pi_1^{k,j}, \pi_2^{k,j}, ..., \pi_m^{k,j}, ..., \pi_M^{k,j}\}$, where $\pi_m^{k,j}$ means the packet j of the user k is scheduled in the mth position in the queue. Therefore, our objective is to transmit as many packets as possible in the queue according to the scheduling order. Mathematically, the problem can be formulated by

$$find\ M_a = \max m \tag{1}$$

s.t.

$$\sum_{m=1}^{M_a} R_k(m) \le W \cdot \sum_{n=1}^{N} s_{k,n} \log_2(1 + p_{k,n} \cdot \alpha_{k,n}) \tag{2}$$

$$\sum_{k=1}^{K}\sum_{n=1}^{N} s_{k,n} p_{k,n} \le P_{total} \tag{3}$$

$$p_{k,n} \ge 0 \tag{4}$$

$$s_{k,n} \in \{0,1\} \tag{5}$$

$$\sum_{k=1}^{K} s_{k,n} = 1 \tag{6}$$

where $R_k(m)$ is the size of the packet in the mth position in the queue of user k. $a_{k,n}$ and W are given as

$$\alpha_{k,n} = h_{k,n}^2 / (N_0 \cdot B / N) \tag{7}$$

$$W = tm \cdot (B / N) \tag{8}$$

Note that constraint (2) guarantees that the resources assigned to the user k should be sufficient to transfer the selected packets to be transmitted. (3) constrains that the consumed total power can not exceed the maximum power limit P_{total}. Constraint (5) denotes $s_{k,n} \in \{0,1\}$ as the binary variable for subcarrier assignment, where $s_{k,n} = 1$ represents subcarrier n is assigned to user k and $s_{k,n} = 0$ otherwise. Next, we will propose the optimal solution of the problem.

3 Optimal Resource Allocation

In this section, the optimal resource allocation scheme is proposed to estimate how many packets can be successfully transmitted given the scheduling decision.

3.1 How Many Packets Can Be Transmitted

Restricted by the scheduling queue order, the wireless resource should be allocated according to the requirements of all users.

The video packets firstly are sorted by the contribution for the video quality in descending order. The packet with higher contribution for the video quality is scheduled in priority. Then, the optimal power distribution is employed to transmit the queued video packets. Compared the optimal power to the available power, the number of the packets which can be transmitted is estimated by adopting the dichotomy.

3.2 Can Be Transmitted for Given Packet Numbers

This subsection will estimate whether the given packets can be successfully transmitted, under the restriction of the wireless resource. For the given packets of all users, we propose an optimal resource allocation scheme for the subcarrier assignment and the power allocation as the following optimization problem:

$$P_{used} = \min_{\{\mathbf{p},\mathbf{s}\}} \sum_{i=1}^{N} \sum_{j=1}^{K} s_{k,n} p_{k,n} \tag{9}$$

$$s.t. \quad \text{Eq.(2)(4)(5)(6)}$$

Here, P_{used} is the minimum power needed to transmit the given packets. If P_{used} is less than the total power P_{total} which the base station can provide, the given packets can be successfully transmitted. To solve the optimization problem, we obtain the globally optimal solution by employing the Lagrange dual decomposition method.

The Lagrangian of the problem is defined over domain ξ as

$$L(\mathbf{p},\mathbf{s},\boldsymbol{\beta}) = \sum_{n=1}^{N}\sum_{k=1}^{K} s_{n,k} \cdot p_{n,k} - \sum_{k=1}^{K} \beta_k \left(W \cdot \sum_{n=1}^{N} s_{n,k} \cdot \log_2\left(1 + p_{n,k}\alpha_{n,k}\right) - R_k \right) \tag{10}$$

where the domain ξ is defined as the set of all non-negative $p_{n,k}$ such that for each n, only one $p_{n,k}$ is positive for all users. Then, the Largrange dual function is

$$g(\boldsymbol{\beta}) = \min_{\{p_{k,n}, s_{k,n}\} \in \xi} L(\mathbf{p},\mathbf{s},\boldsymbol{\beta}) \tag{11}$$

Eq.(10) suggests that the maximization of L can be decomposed into the following N independent optimization problems

$$g'(\boldsymbol{\beta}) = \min_{\{p_{k,n}\} \in \xi} \left\{ \sum_{k=1}^{K} p_{k,n} - W \cdot \sum_{k=1}^{K} \beta_k \log_2\left(1 + p_{k,n}\alpha_{k,n}\right) \right\} \tag{12}$$

for $n = 1,...,N$. Then, the Lagrange dual function becomes

$$g(\boldsymbol{\beta}) = \sum_{n=1}^{N} g_n'(\boldsymbol{\beta}) + \sum_{k=1}^{K} \beta_k \cdot R_k \tag{13}$$

With a fixed $\boldsymbol{\beta}$, the object of the minimization in (12) is a concave function of $p_{k,n}$. By taking the derivative of this object regarding $p_{k,n}$, the next optimality condition, which minimize $g'(\boldsymbol{\beta})$, is obtained as

$$p_{k.n}(\boldsymbol{\beta}) = \left(\frac{W \cdot \beta_n}{\ln 2} - \frac{1}{\alpha_{k,n}} \right)^+ \tag{14}$$

where $(x)^+ = \max(0, x)$. Substituting (14) into (12), we can rewrite (12) as

$$g_n'(\boldsymbol{\beta}) = \sum_{k=1}^{K} \left(\left(\frac{W \cdot \beta_n}{\ln 2} - \frac{1}{\alpha_{k,n}} \right)^+ - W \cdot \beta_k \log_2 \left(1 + \left(\frac{W \cdot \beta_n}{\ln 2} - \frac{1}{\alpha_{k,n}} \right)^+ \alpha_{k,n} \right) \right) \tag{15}$$

By computing all K possible user assignments for subcarrier n, the optimal subcarrier allocation to minimize $g(\boldsymbol{\beta})$ can be obtained as

$$s_{n,k} = \begin{cases} 1, & k = \arg\min_{k} \left(\left(\frac{W \cdot \beta_n}{\ln 2} - \frac{1}{\alpha_{k,n}} \right)^+ - W \cdot \beta_k \log_2 \left(1 + \left(\frac{W \cdot \beta_n}{\ln 2} - \frac{1}{\alpha_{k,n}} \right)^+ \alpha_{k,n} \right) \right) \\ 0, & otherelse \end{cases} \quad (16)$$

Through the above analysis about optimal power allocation and subcarrier assignment at a given dual point $\boldsymbol{\beta}$, the following task of the optimization problem is to iteratively search the optimal value of dual point. This leads to the optimization problem expressed as

$$\max\ g(\boldsymbol{\beta}),\ s.t.\ \boldsymbol{\beta} \geq 0 \quad (17)$$

The dual problem (17) is a convex optimization problem, even though the primal problem (9) is not convex. Hence, a subgradient method can be used to maximize $g(\boldsymbol{\beta})$ subject to $\boldsymbol{\beta} \geq 0$. In this paper, we define $\Delta\boldsymbol{\beta}^l = (\Delta\beta_1^l, \Delta\beta_2^l, \cdots, \Delta\beta_K^l)$ as the gradient of the $g(\boldsymbol{\beta})$ at the dual point $\boldsymbol{\beta}^l$,where l indicates the number of the iteration. $\Delta\boldsymbol{\beta}^l$ can be obtained as follows:

$$\Delta\boldsymbol{\beta}^{l-1} = W \cdot \sum_{n=1}^{N} s_{n,k}(\boldsymbol{\beta}^{l-1}) \cdot \log_2\left(1 + p_{n,k}(\boldsymbol{\beta}^{l-1})\alpha_{n,k}\right) - R_k \quad (18)$$

In the $l-th$ iteration, $\Delta\boldsymbol{\beta}^l$ is updated by the following formula:

$$\Delta\boldsymbol{\beta}^l = \boldsymbol{\beta}^{l-1} + \varepsilon^l \Delta\boldsymbol{\beta}^{l-1} \quad (19)$$

Here, ε^l is the step size and its update conforms to the rule:

$$\varepsilon^l = \varepsilon^{l-1} / \sqrt{l} \quad (20)$$

Having solved the optimization (17), we now obtain all the information needed to perform the optimal subcarrier assignment and power allocation.

4 Simulation Results

Six video sequences with varied content (Highway, Foreman, Dancer, Container, Mother & Daughter, and News), in CIF (352*288) format are used for the simulations. The video sequences are encoded in H.264 (JVT reference software, JM 10.2) with a frame rate of 25fps. All frames except the first one are encoded as P frames. To increase the error resilience, 15 random I MBs are inserted into each frame, and constrained intra prediction is used at the encoder. A slice consists of a row of MBs, enabling a good balance between error robustness and compression efficiency. Each video has 1800 frames, in which each sequence is repeated for 6 times. Each video sequence is encoded with a bit rate of 500 kbit/s.

We have six users demanding for six different video sequences and 512 subcarriers to be assigned. The time length of an OFDMA symbol is 4 ms. The total power constraint is 1W, and the total bandwidth is 1 MHz. The wireless channel used in the simulator is modeled as a frequency-selective channel consisting of six independent Rayleigh multipaths. The component of each path is calculated by the Clarke's flat fading model. The relative power values of the six multipath components are [0,-8. 69,-17.37,-26.06,-34.74,-43.43] dB. The power spectral density of AWGN is -70dB.

The simulations are used to verify the performance of the proposed scheme. We compare four methods as follows.

(1) DSA (dynamic subcarrier allocation scheme): the scheme proposed in [2]. The DSA allocates the subcarriers to the user with best channel response in order to optimally maximize the throughput.

(2) SA (stepwise allocation scheme): the scheme for packet scheduling and subcarrier assignment, which is a revised version of the one proposed in [10]. The packet scheduling is first done based on a content-aware utility function, and the subcarriers proceed to be allocated for the selected packet.

(3) SAEP (Stepwise-allocation with equal power scheme): It is similar to SA, except the equal power allocation on each subcarrier.

(4) PROPOSED: the scheme proposed in Section 3. We adopt the packet scheduling scheme proposed in [10] in order to compare with the SA algorithm to express the superiority of the resource allocation algorithm of proposed scheme.

Fig. 3 shows the average PSNR of the received six video streams after transmission over OFDMA networks using the four different schemes. The total available transmit power is 1.1W. It can be seen that the average PSNR of the proposed scheme is 34.5913 dB, whereas those of DSA, SA and SAEP schemes are 28.7623 dB, 31.8023 dB and 29.1850 dB, respectively. The SA scheme separates the packet scheduling from the subcarrier allocation, and thus can not jointly optimize the two aspects. Therefore, the received PSNR of the video users degrades. The DSA scheme only pursues the throughput of the wireless networks, and allocates most wireless resource to the user with better channel condition. However, the higher throughput of the wireless networks does not always mean the higher received video quality. Fig. 4 shows the service rates of the four schemes. We can see the proposed scheme does not achieve the highest service rate despite of its achievability of the highest PSNR. Fig. 5 illustrates the average quality at each frame averaged over all the users for different four schemes. We also see that the performance of the proposed scheme is better than that of the other three counterparts.

Then, the performances of the schemes with various transmit power are simulated. As shown in Fig. 6, we can see that the average PSNR of the proposed scheme is also higher than other alternatives in each condition, although the performances have been improved by every scheme.

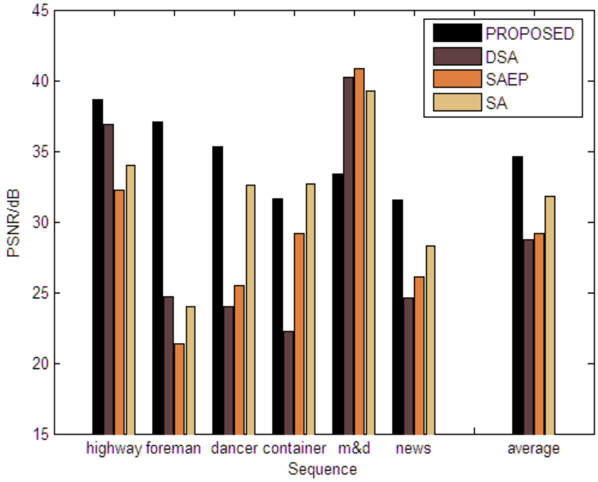

Fig. 3. Average PSNR for each video sequence

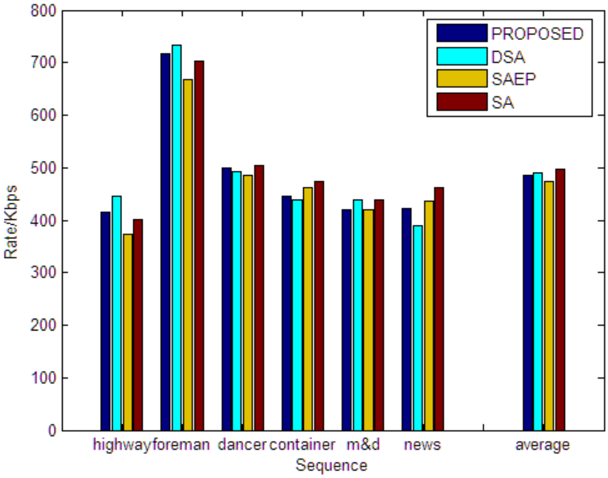

Fig. 4. Transmission rate for each frame

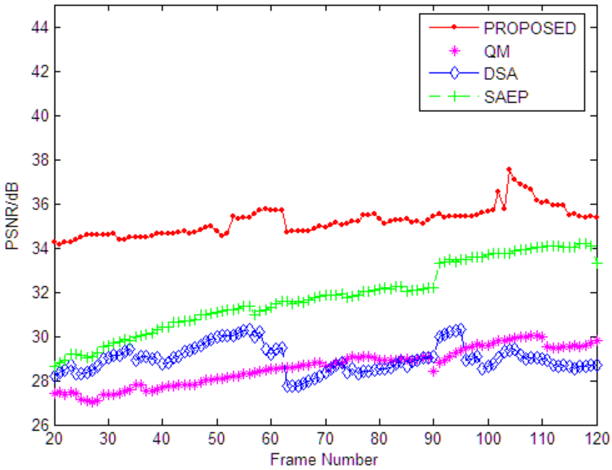

Fig. 5. Frame-by-frame PSNR over all users

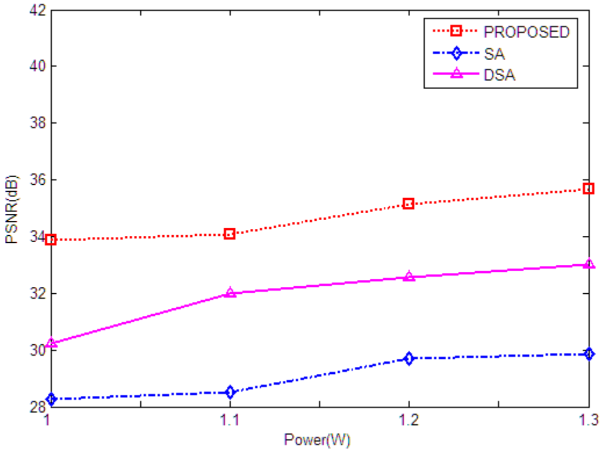

Fig. 6. Average PSNR over all users in various transmit power

5 Conclusion

A cross-layer design for multi-user video streaming over OFDMA downlink systems is present in this paper. Based on the joint optimization of subcarrier assignment and power allocation, the received video quality of all the users is maximized. Employing the Lagrange dual decomposition method, we can obtain the global optimal solution to the optimization problem. Simulation results show that our proposed algorithm outperforms 2.8-5.8 dB to the existing alternatives.

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References

1. Biagioni, A., Fantacci, R., Marabissi, D., Tarchi, D.: Adaptive subcarrier allocation schemes for wireless ofdma systems in wimax networks. IEEE Journal on Selected Areas in Communications 27(2), 217–225 (2009)
2. Song, G., Li, Y.: Cross-layer optimization for OFDM wireless networkspart II: algorithm development. IEEE Trans. Commun. 4(2), 625–634 (2005)
3. Zhang, R., Regunathan, S.L., Rose, K.: Video encoding with optimal Inter/Intra-mode switching for packet loss resilience. IEEE J. Select. Areas Commun. 18, 966–976 (2000)
4. He, Z., Cai, J., Chen, C.W.: Joint source channel rate-distortion analysis for adaptive mode selection and rate control in wireless video coding. IEEE Trans. Circuits Sys. Video Technol. 12(6), 511–523 (2002)
5. Chan, C., Bambos, N., Wee, S., Apostolopoulos, J.: Scheduling algorithms for broadcasting media with multiple distortion measures. IEEE Transactions on Wireless Communications 8(8), 4188–4199 (2009)
6. Xu, J., Shen, X., Mark, J.W., Cai, J.: Quasi-optimal channel assignment for real-time video in OFDM wireless systems. IEEE Trans. Wireless Communications 7(4), 1417–1427 (2008)
7. Bokhari, F.A., Yanikomeroglu, H., Wong, W.K., Rahman, M.: Cross-Layer Resource Scheduling for Video Traffic in the Downlink of OFDMA-Based Wireless 4G Networks. EURASIP Journal on Wireless Communications and Networking, 2009, Article ID 212783, 10 pages (2009)
8. Khan, S., Brehmer, J., Kellerer, W., Utschick, W., Steinbach, E.: Application-driven Cross-layer Optimization for Coded OFDMA Systems. In: 9th WPMC 2006, San Diego, USA (September 2006)
9. Shen, C., van der Schaar, M.: Optimal resource allocation for multimedia applications over multiaccess fading channels. IEEE Transactions on Wireless Communications 7(9) (September 2008)
10. Pahalawatta, P., Berry, R., Pappas, T., Katsaggelos, A.: Content-aware resource allocation and packet scheduling for video transmission over wireless networks. IEEE Journal on Selected Areas in Communications 25(4), 749–759 (2007)
11. Li, F., Liu, G., He, L.: Cross-layer Scheduling for Multiuser H.264 Video Transmission over Wireless Networks. IET Communications 4(8), 1012–1025 (2010)