QoE-Aware Resource Allocation for Video Transmissions over MIMO Systems

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ABSTRACT

With the rapid increasing demands of wireless media applications, it becomes more and more important on video transmission technologies. With the rapid growth of media application, QoE (quality of experience), that is the standard of quality of service, many researchers focus on the topic of the application of QoE in wireless communications. This paper presents an energy effective QoE-aware resource allocation algorithm in multiuser Multiple Input Multiple Output Orthogonal Frequency Division Multiplexing (MIMO-OFDM) systems. The resource allocation problem is formulated to maximize the overall QoE by jointly considering the subcarrier allocation under the total power constraint. We have analyzed the performance of wireless communication according to both RD (rate distortion) in the upper layer and the channel condition in the PHY layer (physical layer). In the simulation results, we can see that the proposed resource allocation algorithm has maximized the quality of video under the minimum of the sum distortion of all video streaming with the time-varying wireless channels under total constraints of power.

KEYWORDS

QoE; Cross layer design; MIMO; Resource allocation; video transmission.

1 INTRODUCTION

With the rapid increasing applications of wireless video transmission, it becomes more and more important on video transmission technologies [1]. Traditionally, the objective metrics, such as throughput, are employed to measure the performance of wireless networks. However, they do not reflect user preferences. The concept of QoE came into being, and from the traditional communication systems and applications, not only the performance, but also the subjective views of users [2]. As QoE index reflects the user's subjective experience directly, resource allocation technology improves the resource utilization ratio of QoE and its service quality (QoS). Extensive research has been carried out on Sustainable QoS-QoE mapping and can rely on a QoS parameter [3][4][5] for different scenarios. In order to optimize the overall user experience for video transmission in wireless networks, it is necessary to propose cross layer design, which is generally driven by QoE directly [5].

At the same time, the new video compression technology has greatly increased the transmission efficiency of multimedia. The updated H.264/AVC standard [6] has been improved to obtain nearly 60% bit compared to the previous MPEG standard. Recently, the new efficient video coding (HEVC) [7] is expected to further improve the coding efficiency of H.264 codecs. With the improving demand for multimedia applications, video transmission turns the most popular applications in the future wireless communication system. [8][9].

Recently, many studies have been carried out on video transmission in MIMO systems, in which the PHY layer structure and application layer video coding characteristics are considered to improve the quality of the received video. QoE can peak signal-to-noise ratio (PSNR) [10] [11], etc., and QoE value can be obtained according to power constraints, channel condition in the PHY layer, and video coding rate in the APP layer. In [11], an optimal power allocation scheme is proposed to minimize the visual distortion of MIMO systems, H.264/AVC video, and theoretical link capacity is considered. In [12], the authors present a novel scheme on the challenges of video streaming considering QoE in MIMO-OFDM.

QoE-aware wireless network video transmission technology often adaptive use of resources, user experience enhanced directly. However, due to the complex mechanism of QoE and the resource allocation problem of MIMO networks, it is typically non convex, which cannot meet the needs of wireless resource allocation using QoE knowledge. And our best knowledge, some work requires physical /application cross layer optimizations to improve video quality, increase power consumption of network capacity, and consider issues related to QoE.

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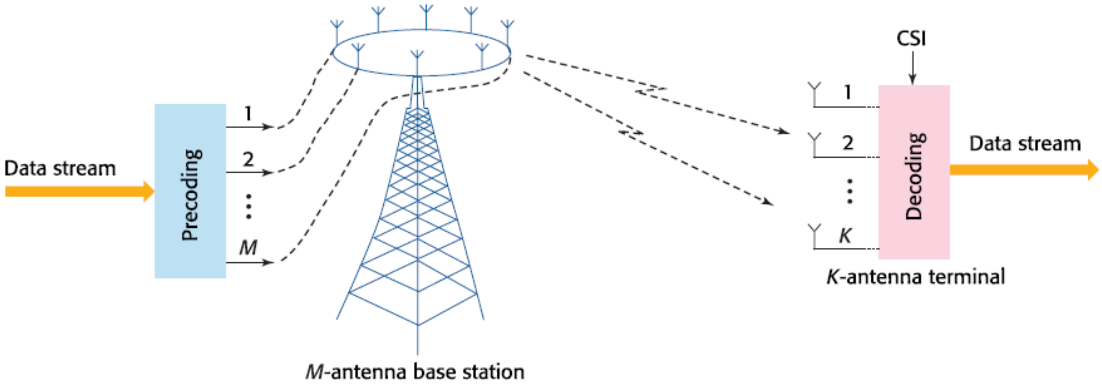

Figure 1. The structure of the proposed MIMO-OFDM System

In this paper, we proposed a cross layer optimization of MIMO-OFDM. We research QoE aware resource allocation policies by considering APP layer and PHY layer information. In order to optimize the overall video performance of the system, the communication resources of the physical layer are allocated according to the requirements of each video user under the different channel characteristics.

The rest of this paper is organized as follows: In the Section II , it describes the system models, and the cross layer optimization framework. In the Section III, it introduces our proposed QoE-aware resource allocation algorithm. The simulation results are presented in Section IV, and Section V draws the conclusion.

2 SYSTEM MODEL

We consider a MIMO system in which users send their video stream to an base stations via massive antennas (It is shown in Figure 1).

2.1 MIMO System Model

We consider multimedia communication system in MIMO-OFDM with the set of users i={1, 2, 3 ... I}. The system frequency band denotes W (Hz). It is equally divided into M orthogonal subcarriers m={1, 2, 3 ... M}. Thus, the bandwidth of each subcarrier is $\Delta W = W/M$ (Hz).

We denote $P_i^{m,t}$ that is the power of theuser i transmits the video packet. Thus the maximum power denotes $P_i^{\max}$. The SINR (signal to interference plus noise ratio) for user i can be expressed as

$$SINR_i^{m,t} = \frac{\gamma_i P_i^{m,t} \left|h_{ij}^{m,t}\right|^2}{\Omega_i^2 + \sum_{k \neq i} P_j \left|h_{kj}^{m,t}\right|^2} \tag{1}$$

where γ_i represents the spreading gain and $h_{ij}^{m,t}$ denotes the channel frequency response from the transmitter of the link i to the receiver of the link j on the sub-channel $m \in \mathrm{M}$, in the time slot t. Ω_i^2 represents the noise power of user i. The link capacity of different user is expressed as

$$C_i = B\log_2(1+SINR_i) \tag{2}$$

Where B is the channel bandwidth. According to the result in [12], the link capacity (2) can be approximated as

$$C_i \approx B\log_2\left(\frac{\gamma_i P_i^{m,t} \left|h_{ij}^{m,t}\right|^2}{\Omega_i^2 + \sum_{k \neq i} P_j \left|h_{kj}^{m,t}\right|^2}\right) \qquad (3).$$

Where T is the time of GOP. H_i^m represents the channel gain of user i. The transmission rate of video transmission in MIMO-OFDM can expect is:

$$\tilde{R}_i = \sum_{m=1}^{M} R_i^m(P_i^m, H_i^m)/T \tag{4}$$

To improve the QoE of each user, a fixed rate u of video transmission is added. The physical layer channel can support the information that data rate is:

$$R_i = \mu\sum_{m=1}^{M} R_i^m(P_i^m, H_i^m)/T \tag{5}$$

In Section III, we will evaluate the effect of channel errors. The QoE of each user under varying channel condition will be simulated in Section IV.

2.2 QoE Evaluation of Multiuser

Quality of experience (QoE) as a user related metric is a key success factor for current and future wireless communication systems. We use utility functions to describe QoE, providing different applications for different users. User QoE can represent Q *()* as a quality function. In this paper, we use the logarithmic mass function, similar to [13], which is the rate of a concave function. For a typical user and base station m, we assume that the speed assigned to me is the user's QoE, can represent as:

$$Q_i(R_i) = \frac{\ln(1+R_i)}{\ln(1+R_i^{req})} \tag{6}$$

Where R_i^{req} is the requested data rate of the i-th link.

2.3 Video RD Function

Since the video is compressed in units of GOPs, the RD function is measured by GOP-to-GOP. We assume $D_i^k(\sigma)$ is the rate distortion function of user *i* in time slot *k*. From above [14][15], the MSE distortion can be expressed as

$$D_i^k(\sigma) = \alpha_i + \frac{w_i}{B+\eta_i} \tag{7}$$

Where α_i, w_i and η_i are fixed according to the QoE of users. The differences in RD trade-offs among different users constitute the diversity of APP layers, which will be cross layer designed for PHY layer channel condition.

If we take (3) into (7), then t(7) can be expressed as follow,

$$D_i^k(\sigma) = \alpha_i + \frac{\dfrac{w_i}{w \bullet {}^{T_s}\!/_{T_0}}}{\sum_{m=1}^{M} \mu R_i^m(P_i^m, H_i^m) + \dfrac{\eta_i}{\eta \bullet {}^{T_s}\!/_{T_0}}} \tag{8}$$

The allocation ruler will be updated as both CSI and RD are updated. Meanwhile, our resource allocation aims to minimize the sum of distortions among *i* users at each time slot *k*. The optimization objective is

$$\min D_i^k(\sigma) \tag{9}$$

$$\begin{aligned} s.t. \quad & \text{if } i' \text{ such that } P_{i'}^m \neq 0 \text{, then } P_i^m = 0, \forall i \neq i' \\ & \sum_{i=1}^{N} P_i^m \leq P_b \end{aligned}$$

3 QOE-AWARE CROSS LAYER OPTIMIZATION FORMULATION

We proposed the QoE-aware resource allocation by cross-layer optimization. The purpose of the design is to maximize the various links of QoE. The two factors that affect the user experience of multimedia streaming application is the quality and fluency of the video. Therefore, with the goal to maximize the video quality, but also smooth video, by keeping at an appropriate level of data rate, and reduce the maximum symbol rate changes, the optimization framework based gain maximization can be formulated as,

$$\begin{aligned} \max. \quad & \sum_{n=1}^{N} \sum_{i \in I} Q(R_i^{t_n}) - \gamma \Phi(R_i^{t_n} - R_s) \\ s.t. \quad & \sum_{i=1}^{N} \frac{1}{m_i r_i} R^i(q_i, l_f) \leq R_s, \\ & \sum_{i=1}^{N} P_i(Q_i) \leq P_b \\ & q_{\min} \leq q_i \leq q_{\max} \end{aligned} \tag{10}$$

where γ is a control parameter. $\Phi(\bullet)$ is a penalty function for variations of rate. R_s is the symbol rate of the MIMO-OFDM system and n_i, $1 \leqslant i \leqslant N$ denotes the number of users, where *N* is the total number of groups. $Q_i = Q^i(q_i, l_f)$ and $R^i(q_i, l_f)$ denotes the QoE and Rate of the i^{th} video streaming with the variation parameter q_i and constant frame rate l_f. We assume that the system has a total power constraint of P_b over all users. The adaptive MQAM modulation order m_i corresponding to the number of bits per symbol and r_i as code rate of the i^{th} video stream.

We can see that the above problems in (10) which are convex. And the optimization framework can be converted into a standard form of convex optimization problems by varying the optimization objectives for [14],

$$\min. \quad -\sum_{n=1}^{N} \sum_{i \in I} Q(R_i^{t_n}) - \gamma \Phi(R_i^{t_n} - R_s) \tag{11}$$

The above resource allocation problem (11) can be iteratively obtained by taking the Karush-Kuhn-Tucker (KKT). The Lagrangian function $L(\bar{q}, \lambda, \bar{\mu}, \bar{\delta})$ for the maximization problem is expressed as,

$$\begin{aligned} L(\bar{q}, \lambda, \bar{\mu}, \bar{\delta}) = & -\sum_{i=1}^{N} n_i (\bar{\beta}_i q_i + \bar{\gamma}_i) \\ & + \lambda \Big(\sum_{i=1}^{N} k_i e^{d_i(1 - q_i/q_{\min})} - R_s\Big) \\ & + \sum_{i=1}^{N} \mu_i (q_i - q_{\max}) + \sum_{i=1}^{N} \delta_i (q_{\min} - q_i) \end{aligned} \tag{12}$$

where λ, μ_i, δ_i , $1 \leqslant i \leqslant N$ are Lagrange multipliers, $\bar{\beta}_i \triangleq e_i Q_{\max}^i Q_t(l_f) \beta_i$, $\bar{\gamma}_i \triangleq e_i Q_{\max}^i Q_t(l_f) \gamma_i$, and R_i^{max} is the maximum bitrate corresponding to the i^{th} video stream. The quantity k_i is defined as,

$$k_i \triangleq \frac{R_{\max}^i}{m_i r_i} \Big(\frac{1 - e^{-c_t l_f / t_{\max}}}{1 - e^{-c_t}}\Big) \tag{13}$$

We employ the KKT conditions for the above Lagrangian optimization question and count with $\lambda \geq 0, \bar{\mu}_i \geq 0, \bar{\delta}_i \geq 0$, we obtain,

$$-n_i \bar{\beta}_i - \lambda k_i \Big(\frac{d_i}{q_{\min}}\Big) e^{d_i(1 - q_i/q_{\min})} + \mu_i - \delta_i = 0 \tag{14}$$

From (10), the KKT contradict condition according to the power constraint is described as,

$$\lambda \sum_{i=1}^{N} k_i e^{d_i(1 - q_i/q_{\min})} - R_s = 0 \tag{15}$$

Thus, the Lagrangian parameter λ^* according to the optimal quantization parameter of QoE for each video user when $\mu_i = 0$ and $\delta_i = 0$. The Lagrangian parameter λ^* can be derived as,

$$\lambda^* = -\frac{q_{\min}}{R_s} \Big(\sum_{j=1}^{N} \frac{\bar{\beta}_j n_j}{d_j}\Big) \tag{16}$$

From (16), we can derive the function for the optimal quantization parameter q_i^* as,

$$q_i^* = \frac{q_{\min} - q_{\min} \ln(\frac{q_{\min} \bar{\beta}_{ii} m_i r_i}{\lambda^* k_j d_j})}{d_j} \tag{17}$$

$$= \frac{q_{\min} - q_{\min} \ln(\frac{R_s}{k_i} \frac{n_i \bar{\beta}_i (d_i)^{-1}}{\sum_{j=1}^{N} n_j (d_i)^{-1}})}{d_j}$$

The above expression is the optimal quantization parameter q_i^* for the video streaming. Therefore, we propose a closed form expression obtained by a fast and low computational complexity scheme, compared with a convex solver that is suitable for unicast and multicast schemes. Moreover, the proposed QoE-aware optimization resource allocation, which constrains the sub-carrier allocation to maximization, is not limited to the linear bidding model and can be easily used for a large class of utility functions.

Furthmore, the proposed optimal framework for speed constrained time-frequency allocation is not limited to the linear optimization model for QoE maximization, and can be easily adopted as a large function Q( ) of utility. QoE-aware resource allocation maximization can be formulated as,

$$\begin{aligned} \max. \quad & \sum_{i=1}^{N} n_i \log_{10}(Q_i) \\ s.t. \quad & \sum_{i=1}^{N} \frac{1}{m_i r_i} R^i(q_i, l_f) \le R_s \\ & \sum_{i=1}^{N} \log_{10}(Q_i) \le P_b \\ & q_{\min} \le q_i \le q_{\max} \end{aligned} \tag{18}$$

We can take (6) into (18) and obtain the QoE-aware optimization resource allocation algorithm, which constrains the sub-carrier allocation to maximization, is not limited to the linear bidding model and can be easily used for a large class of utility functions.

$$\begin{aligned} \max. \quad & \sum_{i=1}^{N} n_i \log_{10}(\frac{\ln(1+R_i)}{\ln(1+R_i^{req})}) \\ s.t. \quad & \sum_{i=1}^{N} \frac{1}{m_i r_i} R^i(q_i, l_f) \le R_s \\ & \sum_{i=1}^{N} \log_{10}(\frac{\ln(1+R_i)}{\ln(1+R_i^{req})}) \le P_b \\ & q_{\min} \le q_i \le q_{\max} \end{aligned} \tag{19}$$

The following simulation results demonstrate the performance of the proposed algorithm for rate adaptation of video transmission.

4 SIMULATION RESULTS

In this section, we present simulation results for the performance of an MU-MIMO OFDM system with a total of 32 subcarriers, each of which has a bandwidth of 100 kHz. We evaluate performance by the PSNR, defined as: $PSNR = 10\log_{10}\frac{255\times 255}{MSE}$. The total power constraint for each video streaming is set to be $P_t = 300\ mW$, and the noise power density is −150dB/Hz. The path-loss exponent in fading channel is assumed to be $\gamma = 2.5$. Where B_c is the bandwidth of the MIMO-OFDM system. For simplicity, we assume that the coherence bandwidth is always an integer multiple of the subcarrier bandwidth. $B_c = \zeta W / M_c$, $\zeta \in$ Z+ in the simulation.

In Figure 2, we measure the backlog of queues in cells. We can observe that the proposed cross layer approach is able to maintain network stability versus IWF with max-rate subcarrier allocation (the subcarrier allocation based on iterative water-filling). In addition, it is possible to increase the average data rate of the users in the two cells compared to IWF with max-rate subcarrier allocation. The proposed cross layer approach is capable of achieving maximum of rate by reducing inter cell interference. Figure 2 shows the instantaneous and average data rates of the two methods.

We vary the number of users from 4 to 12 under. The system has 32 subcarriers. We simulate the MSE performance under different users. From Figure 3, we observe the MSE values by iteration for different number of users. The number of iterations is equal to the performance of an initialization step. The greatest performance improvement occurs in the first few steps of the iteration, and the MSE curve seems concave. After sixth steps, we can see the small improvement of system performance. As we can see, the overall complexity of our proposed cross layer scheme is much lower than exhaustive search.

Figure 4 shows the bit error rate under different power and constellation sizes. Through our QoE aware cross layer resource allocation scheme, we can obtain a certain amount of multimedia quality by considering the appropriate transmit power and modulation size. In Figures 4, we can see that higher transmission power results in lower bit error rates and larger modulation constellation sizes leading to higher bit error rates, but higher data rates are achieved. Therefore, reducing the bit error rate in the physical layer is the only way to increase QoE of multimedia users.

5 CONCLUSIONS

In this paper, in order to simultaneously meet the QoE requirements and improve the quality of video transmission, we propose an optimal subcarrier allocation that joinly video coding rates and power resources. Together we analyze the impact of multi-media transmission performance from video coding rates on the application layer, as well as power control at the physical layer. The two transmission error in PHY layer and video source coding characteristics (APP) layer are considered together in the proposed scheme. The base station enables subcarrier allocation decisions based on CSI and RD information to minimize the average video distortion of all users. The objective is to minimize the sum distortion of the delay and the power constraint for all users. Simulation results show that the proposed power allocation algorithm maximizes video quality while minimizing the sum distortion of all user delays and power constraints over time varying wireless channels.

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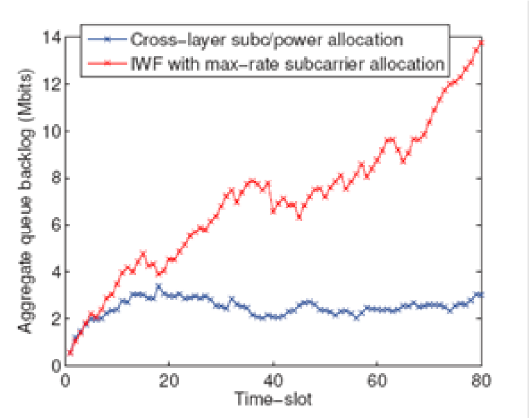

Figure 2. Aggregate queue backlog based on iterative

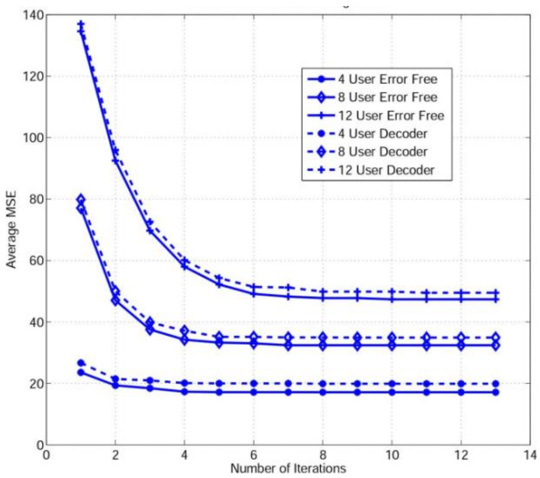

Figure 3: Average MSE with different number of users.

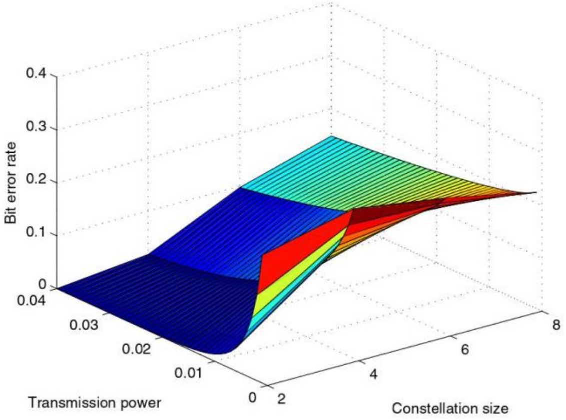

Figure 4: Bit error rate under different power and constellation size.

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