

Balancing QoE and Fairness of Layered Video Multicast in LTE Networks

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Abstract— In video streaming, user-perceived quality is more important rather than user-receiving data rate, as well as fairness of user satisfaction should be considered. In cooperation with the adaptive modulation and coding schemes, a layered video multicast transmission may provide an efficient way to handle receiver heterogeneity and wireless channel heterogeneity, since different modulation and coding schemes may be applied to the video layers, so different video layers may be distributed to the users located in different ranges.

In this paper, we present formal framework for optimal resource allocation in terms of throughput, PF(proportional fairness) w.r.t. throughput, QoE, and PF w.r.t. QoE. Comparing with QoE maximization strategy, we show the PF w.r.t. QoE allocation strategy enforces large fairness improvement with a little QoE degradation expense.

Keywords— Layered Video Multicast, Resource Allocation, QoE, Fairness, Adaptive Modulation and Coding

I. INTRODUCTION

While the single-rate multicast cannot simultaneously satisfy receivers with heterogeneous bandwidth requirements, a layered multicast transmission, which is a commonly used multirate approach, may handle receiver heterogeneity problem.

Recent advances in video coding technology such as H.264/SVC(Scalable Video Coding) provide functionalities such as graceful degradation in lossy transmission environments as well as bit rate, format, and power adaptation. Scalable video is particularly attractive for layered video multicast in the LTE(Long Term Evolution) networks which provide an adaptive modulation and coding scheme, where receivers of the same video often have different sustainable rates with senders and varying decoding and display capabilities. For each video layer, different modulation and coding method may be applied, and transmitted to the receivers with different data rates and different coverage from a base station. Consequently, video receivers may be experienced in different perceptual quality (QoE).

As far as video streaming is concerned, user-perceived quality is more important than throughput, and fairness of user satisfaction also should be considered. In this paper, we present formal framework for optimal resource allocation in terms of throughput, PF(proportional fairness) w.r.t. throughput, QoE, and PF w.r.t. QoE. Comparing with QoE maximization strategy. Also, we show an optimal

decomposition of a video stream into one or more video layers, derive optimal resource allocation for each video layer, and determine corresponding modulation and coding level so as to maximize user satisfaction in terms of QoE as well as for improving fairness without large degradation of perceptual quality.

II. APPLYING ADAPTIVE MODULATION AND CODING TO LAYERED VIDEO MULTICAST

A. Adaptive Modulation and Coding and Layered Multicast

The LTE base station eNodeB provides rate adaptation mechanism known as adaptive modulation and coding as shown in Table 1 [1, 2]. The base station monitors the channel quality of a mobile station and decides its achievable rate by applying the combination of available modulation and error correction code rate based on the measured signal-to-noise ratio.

Table 1. Representative LTE modulation and code rates

MC level	modulation	code rate	bits/symbol	SNR(dB)	distance (km)
1	QPSK	1/2	1	3.5	1.58
2	QPSK	3/4	1.5	5.5	1.44
3	16QAM	1/2	2	7.5	1.31
4	16QAM	3/4	3	11.8	1.06
5	64QAM	2/3	4	15.7	0.88
6	64QAM	3/4	4.5	17.5	0.80

In the layered video multicast, a raw video is compressed into a number of layers. The base layer contains the most important features of the video, while one or more enhancement layers contain the data that further refine the video quality. Layers can be mapped into different IP multicast groups. By joining corresponding multicast groups, a receiver can obtain cumulative data from the base layer up to a certain enhancement layer. So, lower layer should be assigned to be lower MC level, so that receivers subscribed to upper layers can receive lower layer.

Since propagation distances differ from underlying modulation and coding levels (MC levels), a cell area can be divided into several concentric rings. If different MC levels are applied into different video layers, video data in different layers shall be transmitted to the receivers inside of the corresponding rings [3-5].

B. Layered Video Multicast Model in LTE Networks

Suppose that the S symbol rate (symbols/sec) is pre-allocated for a video multicast session and there exist L different MC levels in this system. Assume that the possible number of video layers in this system is no more than L layers. Without loss of generality, assume that the possible number of video layers in this system is no more than L layers, and the MC level l is applied to each video layer l , $l=1, 2, \dots, L$.

Assume that the number of receivers is N in the outermost ring of cell, where is the coverage of MC level 1, the receivers are uniformly distributed in the cell. Let there exist n_l the receivers who can be located inside the coverage of MC level l , but not in the coverage of MC level $l+1$ [6]. We denote

$$w_l = \frac{n_l}{N}, \text{ where } \sum_{l=1}^L w_l = 1 \quad (1)$$

Assume that S_l symbol rate is allocated for video layer l .

$$S_l = \alpha_l \cdot S, \text{ where } \sum_{l=1}^L S_l \leq S \quad (2)$$

Then, we define resource allocation vector A as follows.

$$A = (\alpha_1, \alpha_2, \dots, \alpha_L), \text{ where } \sum_{l=1}^L \alpha_l \leq 1 \quad (3)$$

If the MC level l can modulate r_l bits per symbol, video layer l is encoded and transmitted in bandwidth

$$B_l = S_l \cdot r_l = \alpha_l \cdot r_l \cdot S \quad (4)$$

The resource allocation vector A describes what portion of resource constraint is allocated for each MC level, and so it determines the number of video layers, and their transmission data rates, i.e., their video encoding rates.

A receiver inside the coverage of MC level l , but not inside the coverage of MC level $l+1$ may receive data from video layer 1 to video layer l . If we assume ideal case such as no losses nor no noise environment, the cumulative received data rate R_l of the receiver is

$$R_l = \sum_{i=1}^l B_i = S \sum_{i=1}^l \alpha_i \cdot r_i = S \cdot x_l \quad (5)$$

$$\text{where } x_l = \begin{cases} 0, & \text{if } l = 0 \\ x_{l-1} + \alpha_l \cdot r_l, & \text{for } 1 \leq l \leq L \end{cases}$$

III. OPTIMAL RESOURCE ALLOCATION FOR QoE AND FAIRNESS

A. Optimal Allocation of Throughput and Fairness

Resource allocation to maximize total throughput is to find an allocation vector $A_{\max_thr}$ to maximize the sum of received data rates for all receivers.

$$\begin{aligned} A_{\max_thr} &= \arg \max_A \left(\sum_{i=1}^N R_i \right) = \arg \max_A \left(\sum_{l=1}^L n_l \cdot R_l \right) \\ &= \arg \max_A \left(\sum_{l=1}^L w_l \cdot R_l \right), \text{ subject to } \sum_{l=1}^L S_l \leq S \end{aligned} \quad (6)$$

Proportional Fairness (PF) was introduced in game theory, which is the typical scheduling method in a network for trade-off between resource efficiency and fairness, the goal of which is to maximize the total logarithms in the utility function [7]. If the utility function is identity function of received data rate, then we can derive

$$\begin{aligned} A_{\max_PFthr} &= \arg \max_A \left(\prod_{i=1}^N R_i \right) = \arg \max_A \left(\frac{1}{N} \prod_{l=1}^L R_l^{n_l} \right) \\ &= \arg \max_A \left(\sum_{l=1}^L n_l \cdot \log(R_l) \right) \\ &= \arg \max_A \left(\sum_{l=1}^L w_l \cdot \log(R_l) \right), \text{ subject to } \sum_{l=1}^L S_l \leq S \end{aligned} \quad (7)$$

B. QoE Model

The S-Curve is a model that generalizes the relationship between QoE (user-perceived quality) and video distortion, as in Eq. 8, QoE mapping function is expressed by the average video receiving rate R , where video encoding rate is R_s [8], [9].

$$Q(R) = \frac{1 - e^{-c_1 \left(\frac{R}{R_s} \right)^{C_2}}}{1 - e^{-c_1}} \quad (8)$$

C_1 and C_2 are environmental variable about video distortion. When $C_1=6$, $C_2=2$, generally assume that it is an ideal wireless channel environment, and $C_1=6$, $C_2=6$ is where error occurs in wireless channel section. $C_1=6$, $C_2=20$ is when channel environment rapidly changes, and makes more distortion than when $C_2=6$.

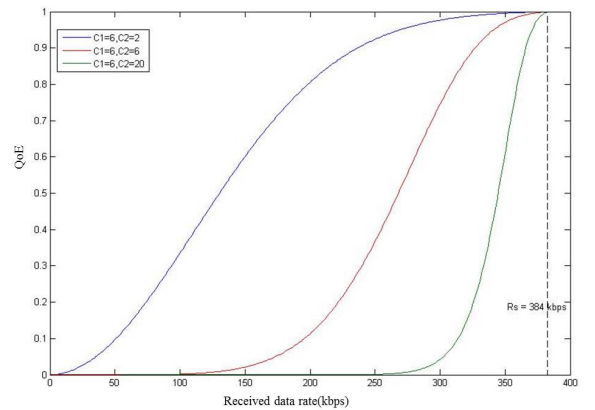


Figure 1. QoE functions

C. Optimal Allocation of QoE and Fairness

Assuming user-perceived quality is the function of received data rate R , resource allocation strategy to maximize the sum of perceptual qualities for all receivers.

$$\begin{aligned} A_{\max_QoE} &= \arg \max_A \left(\sum_{i=1}^N Q(R_i) \right) = \arg \max_A \left(\sum_{l=1}^L n_l \cdot Q(R_l) \right) \\ &= \arg \max_A \left(\sum_{l=1}^L w_l \cdot Q(R_l) \right), \text{ subject to } \sum_{l=1}^L S_l \leq S \end{aligned} \quad (9)$$

If we consider the fairness between receivers, max-min fairness scheduling will show more fair perceptual quality than PF scheduling. However, PF scheduling with respect to QoE may provide more practical solution for trade-off between perceived quality and fairness of user.

$$\begin{aligned} A_{\max_PFQoE} &= \arg \max_A \left(\prod_i Q(R_i) \right) = \arg \max_A \left(\frac{1}{N} \prod_l Q(R_l)^{n_l} \right) \\ &= \arg \max_A \left(\frac{1}{N} \sum_{l=1}^L n_l \cdot \log(Q(R_l)) \right) \\ &= \arg \max_A \left(\sum_{l=1}^L w_l \cdot \log(Q(R_l)) \right), \text{ subject to } \sum_{l=1}^L S_l \leq S \end{aligned} \quad (10)$$

D. Fairness Estimation

To estimate fairness of perceptual quality among receivers, if $\bar{Q}$ denotes the average QoE of the N receivers, we define a fairness index as follows [6]:

$$\begin{aligned} F(Q(R_1), Q(R_2), \dots, Q(R_N)) \\ &= 1 - \frac{1}{2(N-1)} \sum_{i=1}^N \left| \frac{Q(R_i)}{\bar{Q}} - 1 \right| \\ &= 1 - \frac{N}{2(N-1)} \sum_{l=1}^L w_l \cdot \left| \frac{Q(R_l)}{\bar{Q}} - 1 \right| \end{aligned} \quad (11)$$

IV. SIMULATION AND RESULTS

A. Assumptions

For performance analysis, simulations are performed under following assumptions:

- eNodeB provides the 6 typical LTE modulation and coding levels and their propagation distances are as shown in Table 1,
- Mobile stations are uniformly distributed,
- Raw video is SVC-encoded at a rate of $R_s = 384\text{kbps}$,
- The number of video layers is less than or equal to the number of different modulation and coding levels,
- Overhead for layering scalable video is ignored.

B. Resource Efficiency and Fairness

By using one-to-one communication in unicast, the appropriate MC level for video transmission is decided depending on the receivers channel environment. For this reason, in single-rate multicasting, typically the weakest receivers prefer relatively lower MC levels and limit the multicast transmission rate.

But through modulation and coding of low MC level, receivers will get a fair receiving rate, but low receiving efficiency and in the end it will result as a low multicast performance.

On the other hand, video transmission efficiency doesn't measure throughput like the normal data transmission, but measures it through user-perceived quality (QoE). The user-perceived quality has been estimated by the QoE model with 3 different video distortion characteristics described in Eq. 8 in our simulation.

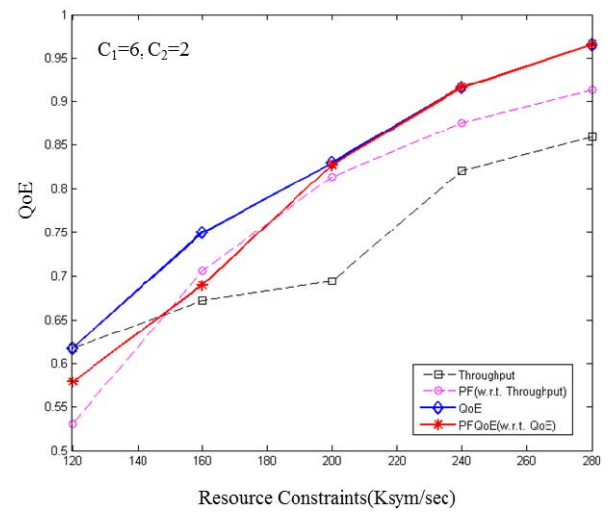


Figure 2. Average perceptual video quality

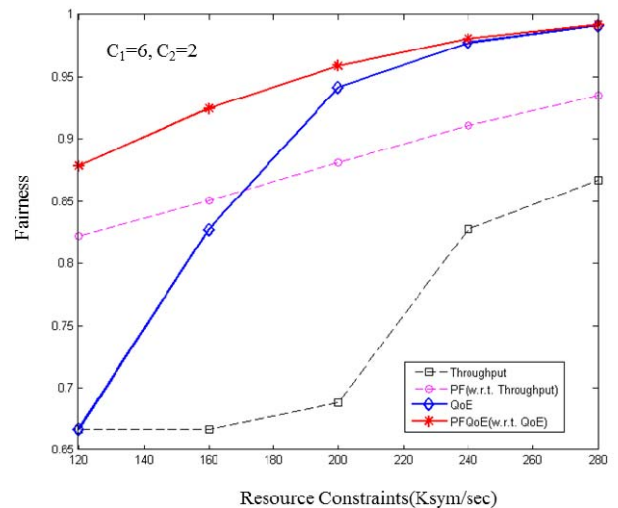


Figure 3. Fairness of user-perceived video quality

Figure 2 shows the average perceptual quality of users located inside the possible outermost cell boundary, where the data is modulated by the lowest MC level, according to the variation of resource constraints pre-allocated to this video multicast session in cases of 4 different resource allocation strategies:

- throughput maximization,
- PF with respect to throughput,
- QoE maximization,
- and PF with respect to QoE.

QoE maximization algorithm always outperforms throughput maximization as shown in Figure 2, and clearly, throughput maximization algorithm does not guarantee to maximize user satisfaction.

As far as fairness is concerned, it is clear that single-rate multicasting to all the receivers where the lowest MC level is applied, because receivers with the worst channel environment who may be relatively far from the eNodeB, so all of them receive the entire video data equally. Due to the nature that proportional fair(PF) scheduling maximizes geometric mean, it tends to find optimal point between resource efficiency and fairness.

As shown in Figure 3, PF algorithm regarding on throughput and QoE has get lots of gains in fairness with relatively small expenses of throughput and QoE degradation. More resources are provided for layered multicast session, PF with respect to QoE makes average perceptual video quality closer to the QoE maximization algorithm.

C. Balancing QoE and Fairness

In this section, we discuss trade-off between QoE maximization and PF with respect to QoE algorithm. Table 2 and Table 3 describe the optimal resource allocation policies to maximize the average user-perceived quality and to maximize proportional fairness with respect to QoE according to varying resource constraints. This shows the optimal video layering including the number of video layers to be decomposed, video encoding rate for each video layer, and it presents which modulation and coding scheme is applied to the data constituting the corresponding video layer, and the what amount of resources should be allocated to transmit each video layer. For instance, if symbol rate 160 ksym/sec is pre-allocated to this layered multicast session, we can get the maximum average QoE of 0.749 when

- the number of video layers is 2,
- encoding rates of base layer and enhancement layer are 216 kbps and 32 kbps, respectively,
- for the base layer, symbol rate of 144 ksym/sec is allocated and MC level 2 is applied (i.e. QPSK modulation and 3/4 code rate),
- for the enhancement layer, symbol rate of 16 ksym/sec is allocated and MC level 3 is applied (i.e. 16QAM and 1/2 code rate),
- 14.42% of receivers will receive only the base layer with QoE of 0.852, 68.08% of receivers will receive both of the base and enhancement layers with QoE of 0.920, and the remaining receivers will not receive video at all.

Table 2. Resource allocation to maximize QoE

(C ₁ =6, C ₂ =2)						
Const raints (ks/s)	Video layer	encoding rate@ (MC level, symbol rate)	QoE	Users (%)	Avg QoE	Fair ness
120	1	160@ (3, 120)	0.906	68.08	0.617	0.667
	2	32@ (3, 16)	0.92	68.08		
160	1	216@ (2, 144)	0.852	14.45	0.749	0.827
	3	32@ (3, 16)	0.90	68.08		
200	2	63@ (2, 42)	0.821	14.45	0.829	0.941
	1	142@ (1, 142)	0.561	17.47		
240	3	28.8@ (3, 14.4)	0.947	68.08	0.916	0.977
	2	36@ (2, 24)	0.902	14.45		
280	1	201.6@ (1, 201.6)	0.810	17.47	0.965	0.991
	3	22.4@ (3, 11.2)	0.97	68.08		
	2	29.4@ (2, 19.6)	0.959	14.45		
	1	249.2@ (1, 249.2)	0.922	17.47		

Comparing to the QoE maximization case, PF resource allocation strategy enforces to share the resources with wider range of users by dividing resources to more video layers so that fairness is improved as shown in Table 3.

In case of 120 ksym/sec resource constraint, the QoE maximization strategy enforces all the resources to the single-layered video and covers only 68.08% of users by modulating them at MC level 3. On the other hand, PF scheduling divides the resources into 3 layers and covers 100% of users by adapting lower modulation and coding levels at level 1, 2, and 3 to get more coverage. So, each of 17.47% of users receives video of layer 1 at data rate 80.4 kbps, each of 14.45% of users receives both of layer 1 and 2 at cumulative data rate 114.6 kbps, each of the remaining users may receive layers 1, 2, 3 at cumulative data rate 148.2 kbps. At the expense of 3.9% degradation in average QoE, PF scheduling allows us to get 21.1% gain in fairness. Under the constraint of symbol rate 160 ksym/sec, it gains 9.7% fairness improvement instead of 6% degradation in average QoE.

Table 3. Resource allocation to maximize PF w.r.t. QoE

(C ₁ =6, C ₂ =2)						
Const raints (ks/s)	Video layer	encoding rate@ (MC level, symbol rate)	QoE	Users (%)	Avg QoE	Fair ness
120	3	33.6@ (3, 16.8)	0.592	68.08	0.578	0.878
	2	34.2@ (2, 22.8)	0.415	14.45		
	1	80.4@ (1, 80.4)	0.231	17.47		
160	3	32@ (3, 16)	0.765	68.08	0.689	0.924
	2	36@ (2, 24)	0.63	14.45		
	1	120@ (1, 120)	0.444	17.47		
200	3	28@ (3, 14)	0.877	68.08	0.827	0.958
	2	36@ (2, 24)	0.799	14.45		
	1	162@ (1, 162)	0.657	17.47		
240	3	28.8@ (3, 12)	0.942	68.08	0.916	0.98
	2	36@ (2, 21.6)	0.904	14.45		
	1	206.4@ (1, 206.4)	0.825	17.47		
280	3	22.4@ (3, 11.2)	0.976	68.08	0.965	0.991
	2	25.2@ (2, 16.8)	0.958	14.45		
	1	252@ (1, 252)	0.926	17.47		

To analyse such trade-off between QoE and fairness more precisely, we consider three different cases of video distortion characteristics: ideal channel environment (C₁=6, C₂=2), wireless error channel (C₁=6, C₂=6), and more wireless error channel (C₁=6, C₂=20).

To sums up Table 2 and 3, Figure 4-a shows trade-off between average QoE and fairness as variance of resource

constraints. This clearly shows that PF maximization is better strategy than QoE maximization in optimizing resource allocation in terms of both of QoE and fairness, because it improves greatly fairness with a little amount of QoE degradation. More enough resources are provided these two strategies converge to the same result.

In severe video distortion environment, QoE increases very slowly as the receiving rate increases when the receiving rate is below a certain threshold or above the other threshold as shown in S-curve of Figure 1. In these range, QoE values getting from the receiving rate differs slightly, so resource allocation strategy cannot affect meaningfully. Until symbol rate 160 ksym/sec as shown in Figure 4-b, or 200 ksym/sec shown in Figure 4-c, two different strategies show that QoE and fairness are almost same.

When $C_1=6$, $C_2=6$, Figure 4-b shows it requires a high receiving rate than Figure 4-a 4 to supply the same QoE under the circumstances that it has the same resource limit. When resource constraints is $S=200$, $S=280$, PF resource allocation strategy gains 15.5% and 6.3% of fairness improvement instead of 5.6% and 4.6% of average QoE degradation.

When $C_1=6$, $C_2=20$, this case requires a higher bandwidth than in $C_1=6$, $C_2=6$ to get the same degree of QoE. Figure 4-c shows that it gains 13.1% of fairness improvement instead of 0.7% of average QoE degradation where the resource constraints is as $S=200$.

V. CONCLUSIONS

As far as video streaming is concerned, user-perceived quality is more important than throughput, and fairness of user satisfaction also should be considered. When doing video multicast in wireless environment, providing same user-perceived quality to different receiver with different channel environment will lower the whole multicast performance. As in LTE environment where adaptive modulation and coding schemes are supported, layered video multicast is an effective transport tool to support receiver heterogeneity and wireless transmission channel heterogeneity as well as to provide the fairness.

For an effective layered video multicast, we have presented the decision of the modulation and coding and the amount of resource symbol rate to be allocated to each layer, and to decide the video layer hierarchy in the cases of 4 different resource allocation strategies: throughput, PF, QoE, PF w.r.t. QoE maximization. It has been shown that PF w.r.t. QoE allocation strategy enforces large fairness improvement with a little QoE degradation expense.

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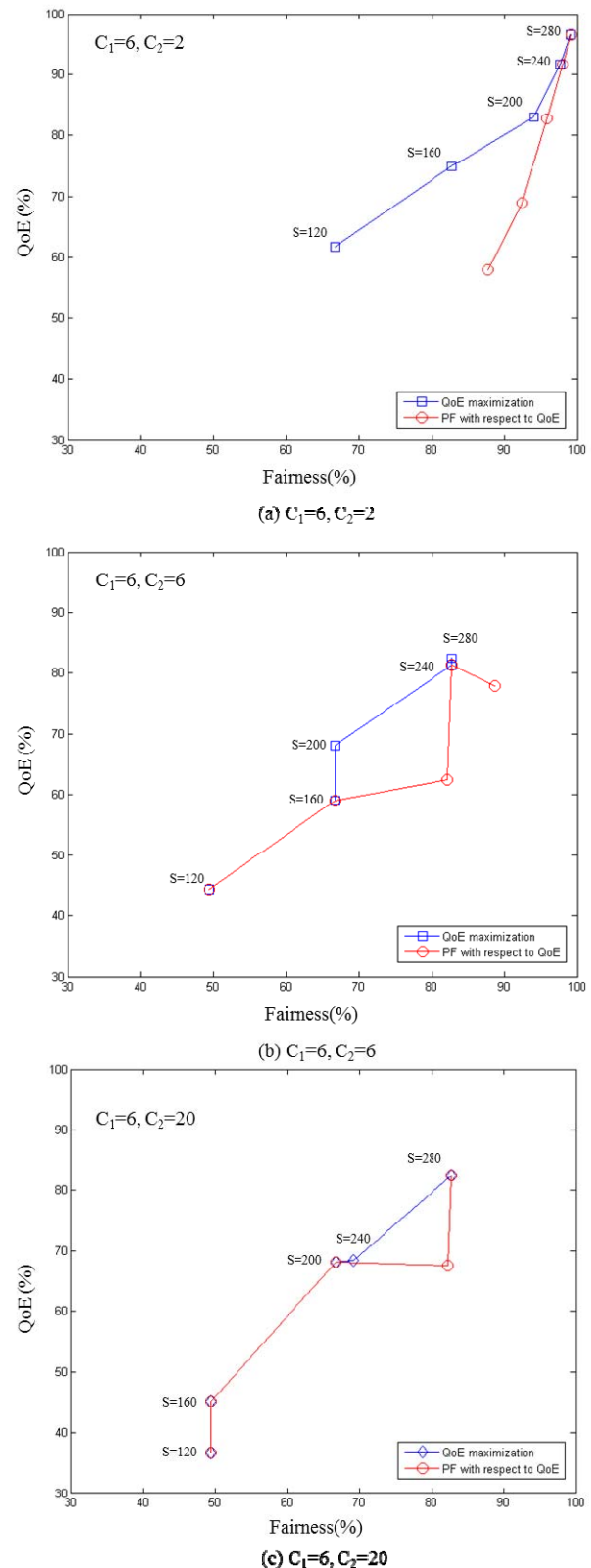


Figure 4. Trade-off between QoE and fairness

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