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Research Article

Online Teaching Wireless Video Stream Resource Dynamic Allocation Method considering Node Ability

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At present, wireless network technology is advancing rapidly, and intelligent equipment is gradually popularized, which rapidly developed the mobile streaming media business. All kinds of mobile video applications have enriched people's lives by carrying huge traffic randomly. Wireless networks (WNs) are facing an unprecedented burden, which allocates very important wireless video resources. Similarly, in WNs, the network status is dynamic and the terminal is heterogeneous, which causes the traditional video transmission system to fail to meet the needs of users. Hence, Scalable Video Coding (SVC) has been introduced in the video transmission system to achieve bit rate adaptation. However, in a strictly hierarchical traditional computer network, the wireless resource allocation strategy usually takes throughput as the only way to optimize the target, and it is terrible to make more optimizations for scalable video transmission. This article proposed a cross-layer design to enable information to be transmitted between the wireless base station and the video server to achieve joint optimization. To improve users' satisfaction with video services, the wireless resource allocation problem and the video stream scheduling problem are jointly considered, which keep the optimization space larger. Based on the proposed architecture, we further study the design of wireless resource allocation algorithms and rate-adaptive algorithms for the scenario of multiuser transmission of scalable video in the Long-Term Evolution (LTE) downlink. Experimental outcomes have shown substantial performance enhancement of the proposed work.

1. Introduction

With the popularity of smartphones and the increase of mobile network bandwidth, in recent years, a dazzling array of video applications have appeared on the mobile side, and watching videos on mobile devices has become a habit of many people. Cisco's report [1] shows that mobile video traffic has grown rapidly, accounting for 60% of the total mobile traffic, and this proportion continues to rise and is expected to reach 78% in 2010. Figure 1 shows the growth trend of mobile traffic. A large number of video services have undoubtedly brought more and more challenges to mobile video transmission. On the one hand, different user devices have great differences in power, computing capabilities, and supportable resolutions. Therefore, it is necessary to provide differentiated services to different users according to the specific conditions of the user equipment. On the other hand, network conditions are constantly changing over time, which requires video transmission to adapt to changes in network conditions. The traditional video transmission technology obviously cannot meet the above requirements, and the bit rate-adaptive technology [2] came into being.

In [3], SVC is applied in the realization of bit rate-adaptive systems. In the LTE system widely deployed today, through adaptive modulation and coding (AMC) [4] technology, different modulation and coding methods (Modulation and Coding) are selected for different channel conditions schemes (MCS) to adapt to terminal heterogeneity. This means that when the wireless base station allocates resources, the channel quality can be obtained through the real-time feedback information of the user equipment. The channel quality has a very good guiding role in realizing code rate adaptation. At the same time, the allocation of wireless resources determines the bandwidth that users can

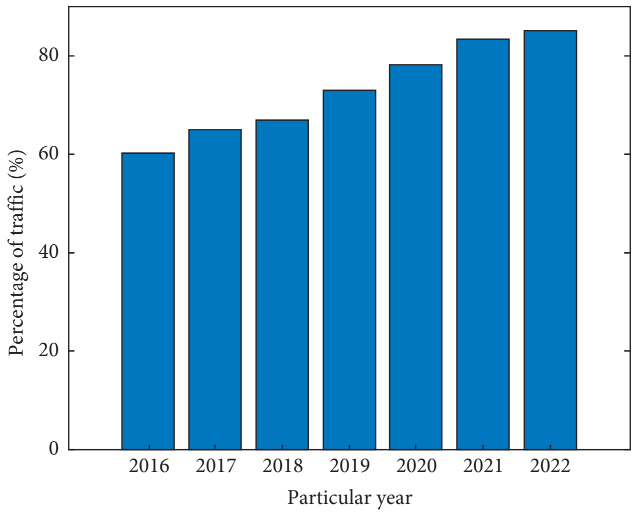

Figure 1: Mobile video traffic as a percentage of mobile traffic.

obtain, and the bandwidth determines the maximum video bit rate that can be supported. It can be seen from the above analysis that if wireless network resource allocation and bit rate-adaptive video transmission are considered jointly, more room for optimization can be obtained. In the current network architecture, the wireless network resource allocation and the video transmission protocol belong to different network levels, and it is difficult for the two to transmit information and work together.

To solve this problem the idea of cross-layer optimization can be adopted. Breaking the network hierarchy so that information can be transmitted between the originally completely independent network layers and the network can be optimized globally. The cross-layer design has the following advantages. It improves the user's video quality, reduces the occurrence of interruptions, and saves resources. In summary, in modern wireless video transmission systems, bit rate adaptation can effectively solve the problems of network heterogeneity and channel dynamics. The use of cross-layer design is helpful to optimize the resource allocation algorithm of the wireless network and improve the effectiveness of the bit rate-adaptive algorithm. Therefore, studying how to use cross-layer design to improve the efficiency of the wireless video transmission resource allocation algorithm has theoretical feasibility and practical significance. The key contributions of this paper are summarized as follows.

(i) An SVC multiuser transmission system in the LTE network is designed, which can jointly optimize the wireless resource allocation problem and the bit rate adaptation problem. According to the mathematical model, a virtual queue is constructed to convert the problem into a queuing problem.

(ii) Modeling and optimizing the SVC multiuser transmission system.

(iii) Performing simulation verification on the proposed algorithm. A simulation platform based on MATLAB and the algorithm and comparison algorithm proposed in the article have been experimented with.

In Table 1, we represented all the abbreviations for concise reading.

The rest of the paper is structured as follows: Section 2 describes the related work. Section 3 describes the proposed methodology of fast optimal algorithms for LTE resource allocation problem. Section 4 is about the experimentation and results discussion and section 5 concludes the work done with the future research perspectives.

2. Related Work

To alleviate the burden on WNs caused by the rush of mobile video traffic, many researchers are concerned about the resource allocation of wireless video systems. Most of these approaches use cross-layer ideas to comprehensively optimize and improve system performance. Moreover, with the advances of rate adaptation technology, researchers began to introduce SVC technology into the wireless video system, while considering the resource allocation and rate adaptation of the wireless video system. This section discusses the main ideas and research results of these studies.

Due to the scarcity of wireless channel resources, resource allocation is an important issue in the LTE system. Traditional algorithms, such as RR [5], maximum carrier to interference ratio (Maximum C/I, Max C/I) [6], and PF [7], usually used the channel quality feedback as a condition to try to maximize the throughput of the system or to optimize the throughput while maintaining a certain degree of fairness among multiple users. Due to the isolation between traditional network levels, these algorithms do not consider the type of data transmitted by the base station and cannot be optimized for a specific service.

However, for video transmission systems, maximizing throughput does not mean maximizing user QoE. Based on the above reasons, many researchers are concerned about how to use cross-layer design to improve the performance of video transmission systems. In [8], a QoS-aware-based LTE scheduling algorithm is proposed for real-time video transmission on the LTE downlink, which optimizes the video quality received by users under the constraints of application delay. In this method, system throughput, application QoS constraints, and scheduling fairness are simultaneously integrated into a cross-layer design framework. Reference [9] focused on resource allocation problems when transmitting video in LTE mobile networks based on across-layer optimization. This method optimizes both the application layer and the lower layers of the network and is dedicated to improving the average perceived quality of users.

In [10], the cross-layer strategy is designed to optimize the resource allocation of the LTE system to improve the QoE of the video application in the LTE system. The research results of the abovementioned documents show that the across-layer model optimizes the allocation of wireless resources in the LTE system, which can effectively improve the performance of video applications. These works have more

Table 1: Representation of different abbreviations.

No.	Explanation	Abbreviations
1	Wireless network	WN
2	Scalable Video Coding	SVC
3	Long-Term Evolution	LTE
4	Adaptive modulation and coding	AMC
5	Channel conditions scheme	MCS
6	Round robin	RR
7	Proportional fair	PF
8	Quality of experience	QOE
9	Content-aware	CA
10	Space based	SB
11	Channel Quality Indicator	CQI
12	Signal to interference plus noise ratio	SINR
13	Tex-Tronics, inc.	TTI
14	Centroid quadrilateral localization	CQL
15	Channel Quality Indicator	CQI
16	Group of pictures	GOP
17	Degree constrained tree	DCT
18	Energy-efficient secure multipath routing protocol	EESM
19	Abstract multiple	AM
20	Gaussian model	GM
21	Frame peak signal-to-noise ratio	PSNR
22	Quadratic correction least squares	QCLS
23	Rate-distortion	RD
24	Scalable video traffic offloading	SVO
25	Heterogeneous networks	HetNet
26	Base layer	BL
27	Quality of experience	QoE
28	Enhancement layers	Els

significance for the design of cross-layer architecture and produce researchers' interest in cross-layer resource allocation in WNs. However, unfortunately, the drawback of the above works is that they overlooked considering the bit rate adaptation of the video. As the traditional fixed bit rate video stream has countless limitations and cannot adapt to the heterogeneity and time-varying nature of the network, the bit rate-adaptive technology is increasingly introduced into the video transmission system.

References [11–14] focused on the design of rate-adaptive algorithms. However, these studies did not combine rate-adaptive algorithms with wireless resource allocation and used cross-layer information to improve system performance. In response to this problem, researchers began to pay attention to how to use LTE technology to implement code rate adaptation, while LTE base stations perform resource scheduling. In [15], a scheduling approach is proposed for SVC video stream in the LTE system. To enable the base station to learn the SVC video information of the application layer. It is usually necessary to design explicit signaling and implement a specific optimization module to process this signaling, which certainly increases signaling overhead and system complexity.

To tickle this issue, [16] designed a scheduling algorithm based on CA scoring. Similarly, [17] presented a joint algorithm of multiuser resource scheduling and code rate adaptation for SVC transmission in the LTE system. Some studies focus on how to design across-layer architecture to perform bit rate adaptation on the video server-side. These studies also focus on SVC video layer selection and LTE resource allocation. In [18], across-layer models are presented for transmitting SVC video under the LTE system, based on channel quality for resource scheduling and code rate adaptation. The layer number decision method proposed is relatively simple and only divides the layer number according to the channel quality feedback from the users. However, due to the limited resources of the wireless base station, the high channel quality of the user does not mean that sufficient bandwidth can be obtained. Reference [19] Considered how to select the number of video layers and allocate resources when transmitting scalable video in the LTE network.

In [20], a dynamic cache stack algorithm is proposed with an average bandwidth restraint with the help of an SVC flexible adjustment procedure. This algorithm provides smooth and high-quality video playback under the existing average bandwidth. And it reduces video freezes and progresses the video service quality from all facets. Contrary to previous adaptive algorithms, experimental outcomes show that the presented algorithm has improved performance in the quality lifting speed and the average quality. Lastly, in [21], combining SVC and traffic unloading, they presented the SVO technique to deliver video streaming services in 5G HetNet. They aim to maximize the number of users getting the BL of the video and to maximize the mean QoE of operators by growing the number of received ELs of the video. They considered a multiobjective mixed-integer programming problem that links each user to either a macrocell or femtocell and assigns video layers to the users.

3. Fast Optimal Algorithms for LTE Resource Allocation Problem

Every social media user can run both real-time and delay-tolerant applications. In every single user equipment, every application has an application status that is different from other applications subject to its instant usage percentage. Further, the network operators make available subscriber differentiation by assigning every user equipment a subscription weight comparative to its subscription. This aims to optimally assign resources with a utility proportional equality policy.

3.1. Basic Idea of the Algorithms. The complexity of solving the original problem comes from the simultaneous selection of MCS and SB allocation. If the two can be separated, the solution of the problem can be greatly simplified. Reference [22] proposed a suboptimal method, but it can be seen from the experimental results that there is still a certain gap between the effect of the suboptimal method and the optimal solution. This is because the suboptimal method adopts a conservative approach to the selection of MCS, which is not allowed to select an MCS that exceeds the recommended CQI value for an SB. Studies have shown that, in the LTE resource allocation problem, a more aggressive approach can achieve better results [23]. The so-called aggressiveness means that some SBs are allowed to use too large MCS, which leads to larger SBs.

But the average bit error rate of multiple SBs allocated to the same user is within an acceptable range. In summary, a suboptimal algorithm can be designed to reduce computational complexity by separating SB allocation and MCS selection and adopting a more aggressive MCS selection strategy. The main idea of this method is as follows. First, it relaxes the MCS constraints and allocates SBs; it, then, estimates the average SINR of multiple SBs allocated to the same user (called the equivalent SINR at the packet-level) and selects the corresponding SINR based on this equivalent SINR and MCS. First, it relaxes the MCS constraint and performs SB allocation. Note that, if the MCS constraint does not exist, that is, the SB assigned to the same user in the same TTI can select different MCS, each subproblem corresponds to an SB scheduling, and the subproblem can be solved only by traversing the users, thereby reducing the time complexity. After relaxing the MCS constraint, you can choose to assign the highest MCS to any user; thus, in order to maximize the objective function, SB should be allocated to the user with the largest product of virtual queue and rate, which is represented by

$$\arg\max_{n\in N} H_n(t)T^{(j)}, \quad j = J_{n,i}. \tag{1}$$

Then, after the SB is allocated, the same MCS is selected for the SB allocated to the same user. In the LTE system, the MCS selection is based on centroid quadrilateral localization (CQL), and the Channel Quality Indicator (CQI) is determined based on the block-level SINR. Similarly, the average SINR of multiple SBs allocated to the same user can be estimated, and the MCS can be selected based on this SINR. In this way, the user's packet-level bit error rate can be controlled within a certain range without causing an unacceptable bit error rate. Similar to the relationship between the maximum MCS, if the SINR of the packet level of user n is known, the MCS selection of the user can be determined by using equation

$$J_n = \max\left\{j|\Gamma_j \le \xi_n, \quad j = 0, 1, 2, \ldots\ldots\ldots J\right\}. \tag{2}$$

3.2. Performance Analysis. The algorithm proposed in this paper relies on optimization theory. In this section, the theoretical performance of the algorithm proposed in this paper is analyzed, and the influence of the selection of parameter V on the performance is discussed. Suppose there is an integer $\delta > 0$ and a video layer number selection decision sequence $l_n(t), t = kT, \quad k = 0, 1, 2, \ldots$ and an LTE resource allocation decision sequence make the following true in

$$\lim_{t\longrightarrow\infty} \frac{1}{K} \sum_{\tau=KT}^{KT+T-1} \mathbb{E}\left[\omega_n(\tau)\right] < \frac{1}{T} \sum_{\tau=KT}^{KT+T-1} \mathbb{E}\left[r_n(\tau)\right] - \delta, \quad \forall_n \in N. \tag{3}$$

In each GOP, the user's transmission rate can be greater than the video bit rate. In fact, under normal circumstances, such slack conditions are easy to meet. If the radio resources provided by the LTE base station are sufficient to transmit the basic layer for each user under a reasonable resource allocation algorithm, such a decision can be obtained. In fact, if such a decision does not exist, it indicates that the system has insufficient resources, and even the best decision-making algorithm is of no avail. If the above assumptions are true, the following conclusions can be drawn by using

$$\lim_{t\longrightarrow\infty} \frac{1}{t} \sum_{\tau=0}^{t-1} \mathbb{E}\left[U_P(\tau)\right] \ge \overline{U} \cdot -\frac{B}{VT}. \tag{4}$$

It can be observed that when V increases, the utility of the algorithm proposed in this paper gradually approaches the optimal solution with O $(1/V)$; at the same time, the upper bound of the mean of the queue length increases by O (V). It can be seen that the V value is a compromise between queue stability and system utility, which is consistent with the intuitive discussion in the previous article. Appropriately increasing V can improve the utility of the system. In this chapter, for the scenario of transmitting SVC video to multiple users in the LTE system, a cross-layer scheduling algorithm with dual time scales and low time complexity is proposed. To take advantage of the cross-layer architecture, SVC layer selection and LTE resource allocation are integrated into the same stochastic optimization problem. The structure of this problem is more complicated.

The optimization method enables the original problem to be separated into two independent problems, which provide a lot of convenience for the solution of the problem and the proposal of the algorithm. The two problems are independent in solving, but they influence each other through the length of the virtual queue, thus forming a joint optimization. As the optimal solution to the LTE resource allocation problem is difficult to obtain, a suboptimal approach is adopted in the LTE resource allocation and MCS selection algorithm to reduce the time complexity of the algorithm. In the time complexity analysis, it can be seen that the two parts of the algorithm are performed on different time scales, and the time complexity is both O (N); that is, the running time has a linear relationship with the number of users. Finally, the theoretical performance of the algorithm proposed in this paper is demonstrated through theoretical analysis, and the influence of parameter V selection on performance is discussed.

3.3. Intra-Macroblock Distortion Calculation. In $K8 \times 8$, including brightness block and color difference block, there are j coefficients in each block. $X^j_{n,m,k}$, $X^o_{n,m,k}$ represent the value of the j-th coefficient of the m-th macroblock and the k-th macroblock of the nth frame after quantization at the encoder and channel transmission decoding reconstruction, respectively. Then the channel distortion $D^{mb\_i}_{n,m,}$ of the m macroblock in the nth frame can be expressed by using

$$D^{mb\_i}_{n,m,} = E\left[\left(X^{j}_{n,m,k}, X^{o}_{n,m,k}\right)^2\right] = \frac{1}{KJ}\sum_{k=0}^{K}\sum_{j=0}^{J}\left[\left(X^{j}_{n,m,k}, X^{o}_{n,m,k}\right)^2\right]. \quad (5)$$

Since the distortion in DCT domain is equal to that in pixel domain, $D^{mb\_i}_{n,m,}$ can be expressed by using

$$D^{mb\_i}_{n,m,} = \frac{1}{KJ}\sum_{k=0}^{K}\sum_{j=0}^{J}\left[\left(X^{j}_{n,m,k}, X^{o}_{n,m,k}\right)^2\right] = \frac{1}{KJ}\sum_{k=0}^{K}\sum_{j=0}^{H_{n,m,k}}\left[\left(P^{j}_{n,m,k}, P^{o}_{n,m,k}\right)^2\right]. \quad (6)$$

$P^{j}_{n,m,k}$ and $P^{o}_{n,m,k}$ represent that the H-th block of the m-th macroblock of the nth frame after quantization at the encoder and after channel transmission decoding reconstruction is not zero after DCT transformation. D represents the number of non-zero values of the m-th macroblock of frame n after DCT transformation. Since the quantized DCT coefficient of 0 will be replaced by 0 if it cannot be decoded correctly, the distortion is only caused by nonzero coefficients. After Z-scan, run-length coding, and entropy coding, each codeword represents a nonzero coefficient and the corresponding run length. The information of a macroblock has a certain structure in the code stream. Let the macroblock have h codewords, with an average of L bits per codeword. The header information and DC coefficient share LH bits. The error probability of each bit is the same and ρ. Due to variable length coding, the condition for correct decoding of the H-th nonzero value in the macroblock DCT domain is that there is no error in the last bit of the coefficient from the previous synchronization ID in the code stream. Therefore, the expectation of decoding is represented by

$$E\left(P^{j}_{n,m,k}\right) = \left[(1-\rho)^{L_h+hL}\right]P^{h}_{n,m,k}. \quad (7)$$

By introducing (7) into (6), we have

$$\begin{aligned} D^{nb\_i}_{n,m} &= \frac{1}{KJ}E\left[\sum_{h=1}^{H}\left(P^{h}_{n,m,k} - P^{o}_{n,m,k}\right)^2\right] \\ &= \frac{1}{KJ}\sum_{h=1}^{H}\left\{\left(P^{h}_{n,m,k}\right)^2 + E\left(P^{h}_{n,m,k}\right)^2 - 2P^{o}_{n,m,k}E\left(P^{o}_{n,m,k}\right)\right\} \\ &= \frac{1}{KJ}\sum_{h=1}^{H}\left[1 + (1-\rho)^{L_h+hL}\right]\left(P^{h}_{n,m,k}\right)^2. \end{aligned} \quad (8)$$

4. Experiments and Discussion

In this section, we conduct comprehensive experiments and discussions of the proposed work.

4.1. Packet-Level SINR Calculation Method Selection. Before evaluating the performance of the algorithm, we must first select a packet-level SINR calculation method for the algorithm proposed in this paper. In section 4.3.2 four SINR calculation methods are shown, namely EESM, AM, GM, and HM, where SINR calculation method does not affect the allocation of SB, let alone the choice of the number of video layers, but only affects the user. The transmission rate and bit error rate directly affect the user's throughput. To this end, compare the differences in the average throughput of users when the four methods are used. To compare the gap between the suboptimal algorithms described in Section 4.3, and the optimal solution, the branch and bound method are used to solve problem (4.18) to obtain the optimal throughput.

At the same time, the conservative method of selecting the lowest MCS among all SBs is adopted as a reference for the lower limit of performance. The experimental results are shown in Figure 2, which is used to show the relationship between SINR and throughput. It can be seen from Figure 2 that the throughput of the EESM method and the HM method is very close to the optimal solution, and the HM method is slightly better than the EESM method in most cases. Therefore, the HM method is selected as the packet-level SINR calculation method in the LTE resource allocation algorithm. In all experiments described later, the HM method was used.

4.2. Video Quality and Interruption Rate. Using PSNR as a measure of video quality and experimenting with different numbers of users, the average PSNR is shown in Figure 3. With the increase of users, the PSNR gap between the two algorithms is gradually obvious. The gap between the two mainly comes from two parts.

(1) Layer Selection. The QCLS algorithm uses the client to estimate the available bandwidth according to the receiving rate and then makes a decision based on the estimated bandwidth and the average rate of the video layer. For the situation where the network condition fluctuates or the video rate of the same layer changes greatly over time, the decision is made that the effect may decrease. The algorithm proposed in this article is determined by the video server. The video server stores the video quality and video bit rate of each GOP of the SVC video. At the same time, it obtains the real-time feedback of the queue length of the base station and makes decisions based on this, maximizing video quality on a stable basis.

The difference in this part can be considered as a result of the difference in cross-layer architecture. *(2) Resource Allocation.* The QCLS algorithm performs SB allocation based on a fixed (not time-varying) R-D curve; however, even if the number of transmitted video layers is the same, the video bit rate may fluctuate greatly due to changes in the video scene. For example, when the video enters a static scene with less motion, the video bit rate will decrease, but, due to the dependence on the average bit rate, the QCLS algorithm will still adopt a conservative strategy. Therefore, if the relationship between code rate and PSNR fluctuates greatly over

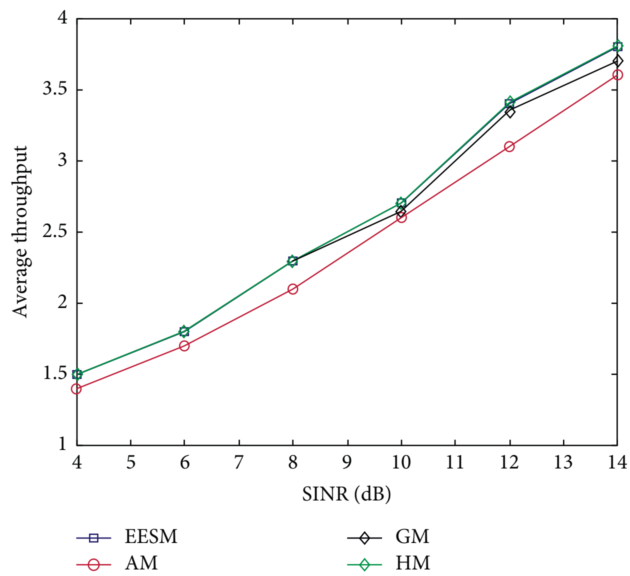

FIGURE 2: The relationship between SINR and throughput.

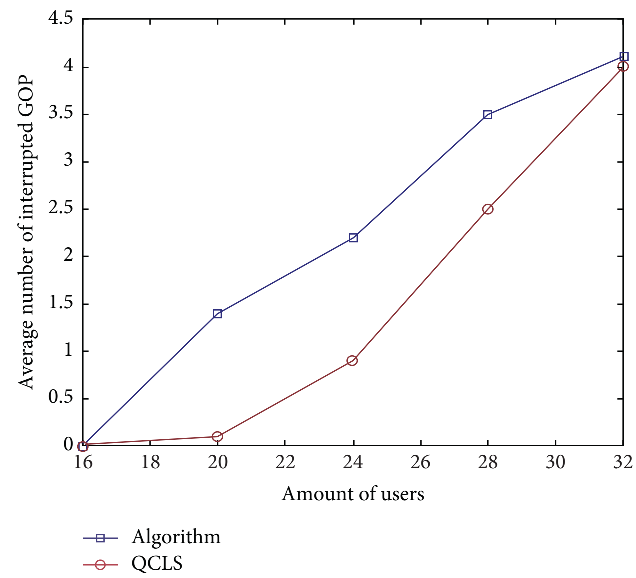

FIGURE 4: Average number of interrupted POGs for all users.

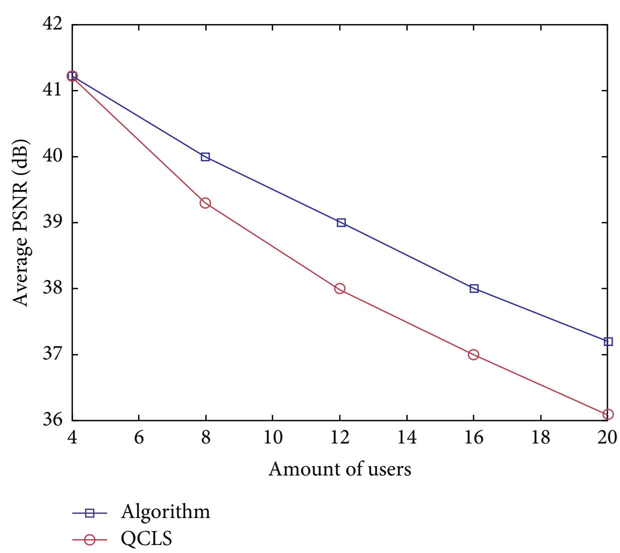

FIGURE 3: Average PSNR for all users.

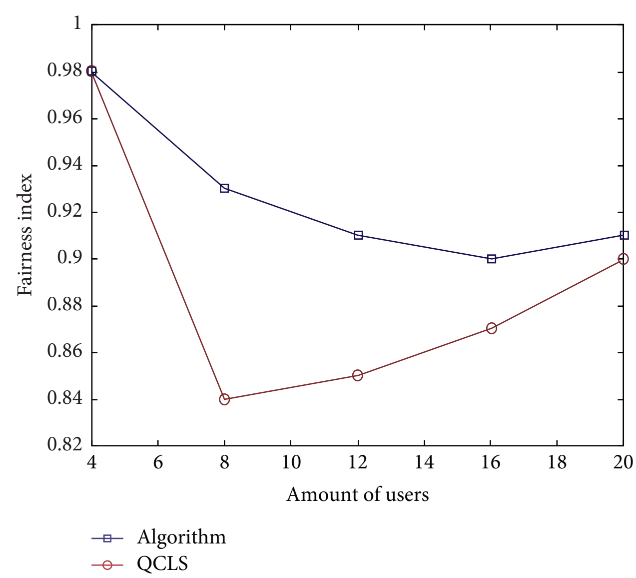

FIGURE 5: Fairness index.

time, the effect of the QCLS algorithm will be affected. When the algorithm proposed in this article is used, the change of the video bit rate over time will affect the length of the virtual queue, which in turn affects the resource allocation, so that the number of allocated resources can adapt to the change of the video bit rate. In addition, in the simulation experiment, it was found that the performance of the QCLS algorithm has a great relationship with whether the RD curve can fit well; because QCLS uses a quadratic function to fit the RD curve, the RD curve of some videos is close to the logarithmic function or the square root function causes a large error in the fitting curve and affects the performance of the QCLS algorithm. In addition to video quality, interruption rate is also an important indicator to measure QoE, and its impact on user experience even exceeds video quality. Figure 4 shows the difference in the number of interruptions between the two algorithms. The two algorithms have no interruption when the number of users is small. Only when the number of users is too large will there be a large number of interruptions due to the inability of resources to meet the transmission of the basic layer.

4.3. Algorithm Running Time. To evaluate the running time of the algorithm, two algorithms are run independently under the same environment, and the influence of the number of users on the total time consumed by the algorithm is observed. The experimental results are shown in Figure 5. First of all, it is easy to observe that the running time of the algorithm proposed in this paper and the QCLS algorithm is linear with the number of users. In Section 4.4, we have analyzed the time complexity of the algorithm to be

0 (N), which is completely consistent with the experimental results. At the same time, we noticed that, in the experimental results, the running time of the QCLS algorithm is significantly higher than the algorithm proposed in this article. This may be because QCLS is more complicated than the algorithm proposed in this article, such as sorting SB, but we cannot rule out the algorithm. In summary, it can be concluded that the algorithm in this paper and the QCLS algorithm have the same asymptotic time complexity.

5. Conclusion and Future Perspective

This article conducts a more in-depth study on the scenario of multiuser transmission of SVC video in the LTE system. First, a cross-layer architecture is designed to jointly optimize the wireless resource allocation problem and the bit rate adaptation problem. Then, a mathematical model is established for cross-layer architecture and the wireless resource allocation, and SVC layer number selection is optimized under the same goal. Then optimization method is used to analyze and solve the mathematical model, to obtain wireless resource allocation and SVC layer selection algorithm. Finally, simulation experiments verify the performance of the proposed algorithm.

In the future, we are planning to consider the concept of smart classrooms and distance education using the proposed techniques and, if needed, enhancement will be done.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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