A Novel QoE-Based Carrier Scheduling Scheme in LTE-Advanced Networks with Multi-Service

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***Abstract*—Carrier aggregation is one of the key techniques for the advancement of long-term evolution (LTE-Advanced) networks. This article proposes a quality-of-experience (QoE)-based carrier scheduling scheme for networks with multiple services. The proposed scheme aims at maximizing the user QoE, which is determined by both the application-level and network-level quality of services. Packet delay, as an essential factor affecting QoE, is first discussed under the context of QoE optimization as well as the data rate. The component carriers are dynamically scheduled according to the network traffic load by the proposed novel scheme. Simulation results show that our approach can achieve significant improvement in QoE and fairness over conventional approaches.**

I. Introduction

The rapid development of wireless networks is making an ever-increasing population enjoy mobile communication anywhere and anytime. Mobile users have more access to multimedia services, such as video telephony, web browsing, online game, and so on, which demand higher data rates as compared to traditional voice and message services. Therefore, wide bandwidth, i.e., up to 100 MHz, is required for the 3rd generation (3G) long-term evolution and its advancement (LTE-Advanced) network, whose target is to support a peak data rate of 100 Mbps for high mobility and 1 Gbps for low mobility [1]. As a result, carrier aggregation (CA) is adopted as a solution to bandwidth extension for LTE-Advanced networks [2].

Nowadays, quality of experience (QoE) perceived by users under wireless environments has gained more attention. It is likely to be the main factor of multimedia service quality metrics for end users [3]. An end user's QoE depends on both network-level QoS (NQoS), concerned with the reliable delivery of service data over the network, and application-level QoS (AQoS), which is the quality metric of media resources [4], [5]. Therefore, the impact of these two factors on QoE has to be taken into account when designing the radio resource management schemes, such as carrier scheduling schemes for high quality multimedia services provision.

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Moreover, there are multiple services simultaneously provided by LTE-Advanced networks. How to make the limited radio resources fully utilized and also ensure high QoE of services becomes a significant issue. Previous works have proposed a variety of QoE-based cross-layer designs to enhance users' satisfaction, where QoE models are only determined by the data rate or packet error rate [5]–[7]. However, these parameters are not always essential factors affecting the QoE performance for all services. For instance, the QoE of web browsing service is more sensitive to delay factors [8]. Thus, a variety of QoS parameters are included in our multi-service QoE modeling and its application in this paper.

In LTE-Advanced networks with CA, multiple aggregated component carriers (CCs) transmit packets for various services. In order to achieve excellent QoE performance, we propose a QoE-based carrier scheduling scheme, which aims at maximizing the users' satisfaction and ensuring the fairness among services as well as users. The influences of different QoS parameters of services are reflected in the QoE modeling. A dynamic optimization algorithm is designed to obtain the optimal carrier configuration for the best performance with low computational complexity. The main contributions of this work encompass the following:

- QoE-based carrier scheduling scheme for multi-service;
- Delay-sensitive QoE cross-layer modeling and application;
- Dynamic algorithm for carrier scheduling to maximize QoE.

Furthermore, the proposed scheme can be easily adopted in any bandwidth constrained multi-carrier wireless systems.

This paper is organized as follows. Section II introduces the QoE cross-layer prediction models of various services. Section III describes the proposed carrier scheduling scheme and dynamic optimization algorithm for maximum the QoE of multi-service. Section IV presents the numerical results of the proposed scheme applied in LTE-Advanced networks. Finally, conclusions are drawn in Section V.

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II. QoE Prediction Models

Wireless multimedia services are generally classified into real time (RT) and non-real time (NRT) types [9]. RT services have continuous packets transmitted sequentially, such as voice over IP (VoIP), IP television (IPTV) and conference call. Conversely, NRT services place no restriction on the packet sequence, whose data demand is elastic with one or multiple packets, like E-mail, file download and web browsing. The mean opinion score (MOS), a continuous value between 1 and 5, is the most widely used metric to quantify the subjective perceptions of applications, thus adopted for QoE prediction modeling [10].

The application-level QoS of an RT service is related to the parameters of media, namely the sampling/frame rate, compression ratio, etc [4]. Under the circumstance of excellent AQoS, like rapid frame rate and low compression ratio, QoE might be enhanced. However, more radio resources are required to carry high bit-rate traffic. This possible overloading may lead to congestion and decrease NQoS. Therefore, application rate adaption is crucial for RT services to adjust their source parameters to fit the radio channel condition. However, NRT services can hardly be controlled at the application level due to its elastic packet demand characteristics determined by users.

We denote the multi-service set by

$$\mathbf{M} = \{1, 2, \ldots, M\}, \tag{1}$$

where $M = |\mathbf{M}|$ is the number of various services. Each service is denoted by $m, 1 \leq m \leq M$. The overall QoE prediction model measured in the MOS is given by

$$MOS_m = \eta\left(\upsilon_m, \tau_m, \mathbf{z}_m^{(i)}\right), \tag{2}$$

where υ_m is the average data rate of a service m user, τ_m is the average packet delay of a service m user, and $\mathbf{z}_m^{(i)}$ is a selected adjustable application parameter set of service m. One service may have a group of application parameter sets, denoted by $\mathbf{Z}_m = \{\mathbf{z}_m^{(i)} | i = 1, 2, \ldots, |\mathbf{Z}_m|\}$. Each parameter set determines the features of the sending packet flow, such as the probability distribution function (PDF) of the packet length s_m and packet rate λ_m. The application-level parameter set $\mathbf{z}_m^{(i)}$ also influences the MOS function $\eta\left(\upsilon_m, \tau_m, \mathbf{z}_m^{(i)}\right)$.

Here we only consider the QoE prediction models of two RT services, i.e., VoIP and IPTV, and two NRT services, i.e., file download and web browsing as examples.

A. VoIP

The E-model defined by the International Telecommunication Union (ITU) is used for the VoIP QoE prediction modeling [11], which regards the MOS as a function of a transmission rating factor denoted by Ω. It combines all the relevant parameters of the concerned user, i.e.,

$$\Omega = \Omega_o - I_s - I_d - I_{e-eff} + A, \tag{3}$$

TABLE I
VOICE TRANSMISSION STANDARDS AND PARAMETERS [12]

Standards	**bit rate** (bps)	$T_s(ms)$	I_{e-eff}
G.711	64.0	20	0
G.728	16.0	30	7
G.729	8.0	20	10
G.723.1	5.3	30	19

where Ω_o is the basic signal-to-noise ratio, I_s is the sum of all impairments during transmission, I_d is the impairment factor representing the delay of voice signals, I_{e-eff} is the equipment impairment factor, and A is the advantage factor related to the scenario. In an ideal environment, we can set $\Omega_o = 94$ and $I_s = A = 0$.

For simplicity, I_d is a function of the absolute delay T_a, including the core network delay τ_c and radio network delay τ_r. Hence, the end-to-end delay is $T_a = 2\tau = 2(\tau_c + \tau_r)$. When $T_a \leq 100\,ms$, the absolute delay can hardly be perceived, i.e., $I_d = 0$. In the case of $100\,ms < T_a \leq 2(\tau_c + T_s)$,

$$I_d\left(T_a\right) = 25\left\{\left(1 + X^6\right)^{\frac{1}{6}} - 3\left[1 + \left(X/3\right)^6\right]^{\frac{1}{6}} + 2\right\}, \tag{4}$$
$$X = \log_2\left(T_a/100\right),$$

where T_s is the fixed packet interval determined by voice transmission standards. When $T_a > 2(\tau_c + T_s)$, namely $\tau_r > T_s$, implying that the service fails due to an excessively high packet rate, thus factor $I_d = \infty$.

The value of I_{e-eff} is associated with the voice transmission standard under the ideal condition. Four various standards with their parameters and I_{e-eff} values are given in Table I.

The MOS of VoIP can be calculated with obtained Ω as

$$\eta_{VoIP} = \begin{cases} 1.0, & \Omega < 0, \\ 1 + 0.035\Omega + \frac{7R(\Omega-60)(100-\Omega)}{10^6}, & other, \\ 4.5, & \Omega \geq 100. \end{cases} \tag{5}$$

B. IPTV

The cross-layer video QoE prediction model defined in [4] is used, which considers both AQoS including the frame rate (FR) and send bit rate (SBR), and NQoS including the packet error rate (PER) of the video transmission. The MOS function is given by

$$\eta_{IPVT} = \max\left\{1.0, \frac{\alpha_1 + \alpha_2 FR + \alpha_3 \ln\left(SBR\right)}{1 + \alpha_4 PER + \alpha_5 \left(PER\right)^2}\right\}, \tag{6}$$

where $\alpha_1 \sim \alpha_5$ are coefficients set to -0.0228, -0.0065, 0.6582, 10.0437 and 0.6865 when assuming rapid movement (RM) videos are transmitted. Similar to voice services, the packets of video streaming are transmitted continuously with a fixed interval of T_s. We calculate the PER by counting the number of the oversize packets transmitted beyond the packet interval T_s. The FR and SBR are adjustable parameters for application rate adaption. A typical RM video sample, "coastguard," is used with its packet sequence in the optimization [4]. Its FR is set to 30 fps, while the SBR varies from 10.9 kbps to 54.6 kbps with 5 levels of compression.

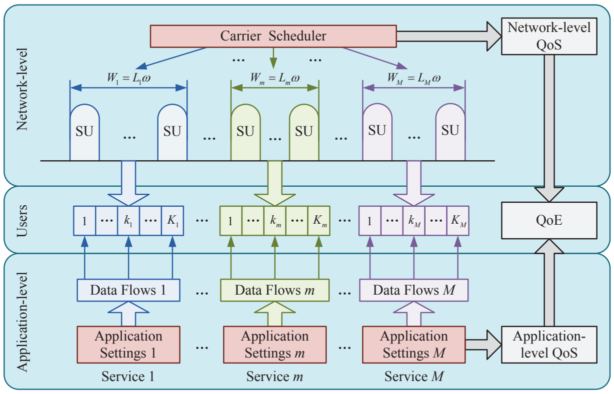


Fig. 1. Illustration of the carrier scheduling model.

C. File download

File download (FD) and web browsing are elastic services, which have no continuous packets arriving in sequence. For the FD service, users' satisfaction is only related to the effective data rate, since the delay of a transmission task is proportional to its size. Moreover, it has no adjustable application-level settings. Therefore, the QoE model of file download service is defined as

$$\eta_{FD} = \begin{cases} 1.0, & \upsilon < 8\text{kbps}, \\ b_1 \log_{10}(b_2\upsilon), & 8\text{kbps} \le \upsilon < 315\text{kbps}, \\ 5.0, & 315\text{kbps} \le \upsilon, \end{cases} \tag{7}$$

where b_1 and b_1 are coefficients set to 2.5037 and 0.3136.

D. Web browsing

Unlike the file download service, web users are not concerned with the demanded page size but do not like long waiting time. An experimental test was designed in [8], which obtained the MOSs of the subjective user experience of web browsing. An analytic function fitting the MOS results is

$$\eta_{Web} = 5 - \frac{578}{1 + (11.77 + 22.61/\tau)^2}, \tag{8}$$

where $\tau = \tau_c + \tau_r$ is the response time.

The lognormal distribution, $\ln\mathcal{N}(\mu, \sigma^2)$, provides a good fitting to the empirical PDF of the web page sizes with the coefficients $\mu = 10.33$ and $\sigma = 2.16$ [8].

A long waiting time for the response of web demanding will make users lose patience, and consequently decreases the MOS to 1.0. Therefore, a page size limit (PSL) is set in this paper as a kind of application-level control. When an oversize web page larger than the PSL is requested, an error notice will be sent to the user who will then be unsatisfied the same as long-time waiting. However, this dropping mechanism saves radio resources for minor web page requests which can be responded more quickly and thus enhance QoE.

III. Multi-Service Carrier Scheduling

As illustrated in Fig. 1, we propose a QoE-based carrier scheduling scheme for multiple services in the LTE-Advanced network in this section. For service m, there are K_m users enjoying the service during a certain period. Thus, there are a total of $K = \sum_{m\in\mathbf{M}} K_m$ users in the LTE-Advanced network. The restrained bandwidth in the system is denoted by $W = L\omega$, where ω is the minimum scheduling unit (SU) in this paper. Each SU occupies a 5 MHz bandwidth, i.e., 25 resource blocks (RBs) in LTE-Advanced [14]. The assigned bandwidth for service m is $W_m = L_m\omega$, which aggregates L_m SUs. The average data rate of a user equipment (UE) depends on the distributed wireless resources and the radio link quality, which can be expressed as

$$\upsilon_m = \upsilon\left(u, \frac{L_m}{K_m}\right) = \frac{L_m}{K_m} u, \tag{9}$$

where L_m is the number of aggregated SUs allocated to service m, and u is the throughput of a UE with single SU and related to the UE's location, which is modeled by a PDF denoted by $f(u)$ according to the given scenario. Then, the average packet delay τ_m can be calculated as

$$\begin{aligned} \tau_m &= \tau_r\left(u, \frac{L_m}{K_m}, \mathbf{z}_m^{(i)}\right) + \tau_c \\ &= \int_0^\infty \frac{s_m}{\upsilon(u, L_m/K_m)} g_m^{(i)}(s_m)\, ds_m + \tau_c, \end{aligned} \tag{10}$$

where $g_m^{(i)}(s_m)$ is the PDF of packet length s_m, determined by the selected application parameter set $\mathbf{z}_m^{(i)}$, and τ_c is the core network delay. The MOS function of the throughput, delay and application-level settings for a service m user is

$$\bar{\eta}_m = \bar{\eta}\left(\frac{W_m}{K_m}, \mathbf{z}_m^{(i)}\right) = \int_0^\infty \eta\left(\upsilon_m, \tau_m, \mathbf{z}_m^{(i)}\right) f(u)\, du. \tag{11}$$

With the objective of maximizing the sum (MS) of all users' MOSs, the optimization problem can be modeled as

$$\begin{aligned} &\max \sum_{m\in\mathbf{M}} K_m \bar{\eta}_m, \\ &\sum_{m\in\mathbf{M}} L_m \le L. \end{aligned} \tag{12}$$

We design a dynamic optimization algorithm based on the multi-choice knapsack problem (MCKP), as described in Algorithm 1 [13]. The optimal application-level settings of the services and their maximum MOSs under the restrained bandwidth per user are given by

$$\mathbf{z}_m^*\left(\frac{W_m}{K_m}\right) = \arg\max_{\mathbf{z}_m^{(i)}} \left\{\bar{\eta}\left(\frac{W_m}{K_m}, \mathbf{z}_m^{(i)}\right) | \mathbf{z}_m^{(i)} \in \mathbf{Z}_m\right\}, \tag{13}$$

$$\bar{\eta}_m^*\left(\frac{W_m}{K_m}\right) = \bar{\eta}\left(\frac{W_m}{K_m}, \mathbf{z}_m^*\right), \tag{14}$$

which are the inputs of Algorithm 1. Since the bandwidth of SU ω is constant in the network, and the user number K_m

remains invariant during a certain period, $\bar{\eta}_m^*(W_m/K_m)$ is reduced to $\bar{\eta}_m^*(L_m)$ as an input of the algorithm.

Algorithm 1 Dynamic optimization algorithm.

Step 1 - Initialization:
$\bar{\eta}_{MS}^*(0) = 0, \bar{\eta}_{MS}^*(l) = -\infty, 0 < l \le L$, the maximum sum of MOSs while the total number of SUs is l;
$L_m^*(l) = 0,\ 0 < l \le L$, the optimal number of aggregated SUs allocated to service m.
Step 2 - Input:
$\bar{\eta}_m^*(L_m), 0 \le L_m \le L$, the maximum MOS of each user when L_m SUs are allocated to service m.
Step 3 - Dynamic Comparison:
loop $l = L...0$, for every service $m = 1...M$,
  loop $L_m = 0...l$,
    $C = K_m \bar{\eta}_m^*(L_m)$,
    if $\bar{\eta}_{MS}^*(l) < \bar{\eta}_{MS}^*(l - L_m) + C$, **then**

$$\bar{\eta}_{MS}^*(l) = \bar{\eta}_{MS}^*(l - L_m) + C, L_m^*(l) = L_m.$$

    end if
  end loop
end loop
Step 4 - Output:
$\bar{\eta}_{MS}^*(L)$ is the maximum sum of all users' MOSs.
$l = L$,
loop $m = M...1$,
  $L_m^*(l)$ is the number of aggregated SUs for service m,
  $l = l - L_m^*(l)$.
end loop

The computational complexity of the designed algorithm contains $C_{L+1}^2 \times M$ comparative operations, while the complete search needs C_{L+M-1}^{M-1} comparisons. When there are more than three various applications, i.e., $3 < M \le L$, the designed dynamic algorithm consumes considerably less computational resources.

To ensure the fairness among users of each service, the optimization objective can also be expressed as

$$\max \sum_{m \in \mathbf{M}} K_m \log \bar{\eta}_m, \tag{15}$$
$$\sum_{m \in \mathbf{M}} L_m \le L,$$

where the optimization target is to maximize the sum of logarithm (MSL) of MOSs. To achieve this objective, step 3 of Algorithm 1 has to be modified as $C = K_m \log \bar{\eta}_m^*(L_m)$.

IV. Simulation and Numerical Results

In this section, the proposed scheme is applied in an LTE-Advanced network with four services as described in Section II. In the simulation, we consider the service traffic in a wireless network during the daytime from 6:00 to 18:00. The scheme updates the optimal carrier configurations in each hour, according to the periodically varying user numbers of different services. The main parameters of network configuration and wireless environment are listed in Table II [14].

TABLE II
SIMULATION PARAMETERS

System Parameters	Value
inter-site distance (ISD)	500 m
carrier frequency	2 GHz
number of sectors	3
bandwidth (W)	100 MHz
number of SU (L)	20
bandwidth of SUs (ω)	5 MHz
channel model	Urban Macro (UMa)
core network delay (τ_c)	100 ms

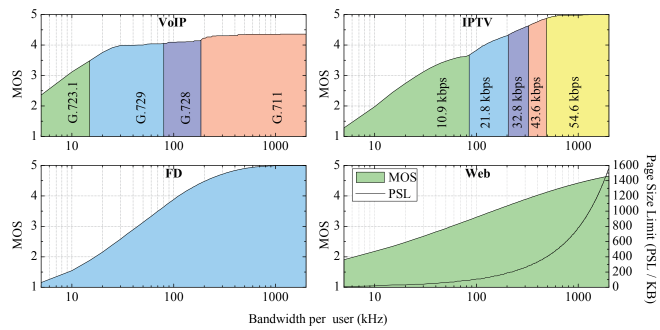


Fig. 2. The optimal application-level setting and MOS of each service.

Suitable application settings can increase the MOS with limited radio resources. Under the condition of certain bandwidth per user, the optimal setting for the maximum MOS of a single user is shown in Fig. 2 for each service. For RT services, i.e., VoIP and IPTV, the application data rate increases for better AQoS, when the user gains more channel resources to guarantee NQoS. Without adjustable application settings, FD has a logarithmic MOS function of throughput, which is proportional to the bandwidth. Web service is regulated by the PSL, which lifts the threshold as bandwidth increases, since a larger web page could also be responded timely. These results are used in Algorithm 1 as inputs $\bar{\eta}_m^*(W_m/K_m)$.

Fig. 3 illustrates the average number of users using each service per hour. The simulation results in Fig. 4 present the carrier configurations and the MOSs of different services by maximizing the throughput (MTP), MS and MSL schemes. The MTP scheme allocates CCs to each service for the maximum sum of throughput. Fig. 4 indicates that VoIP and web services are strict with delay performance, hence

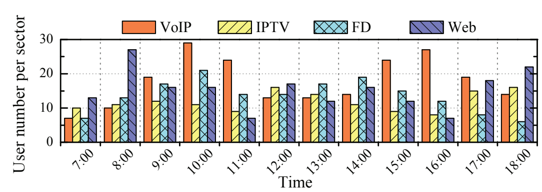
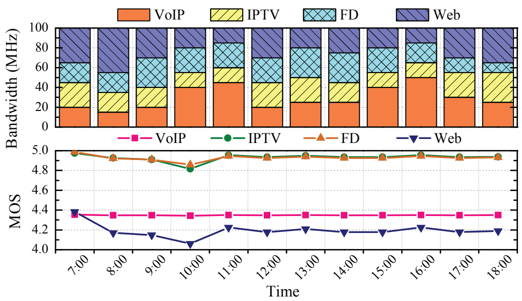
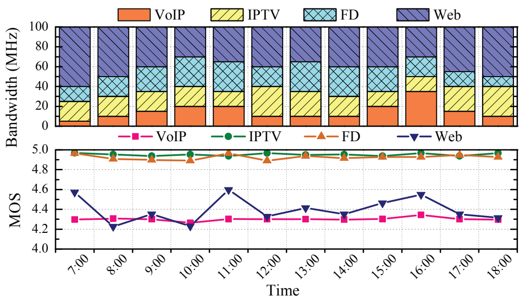


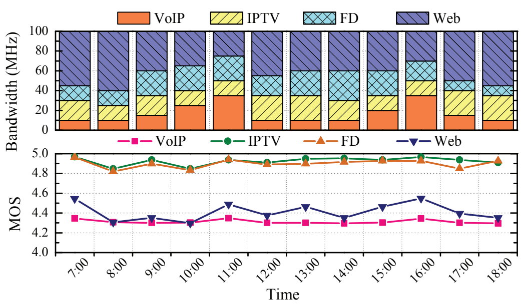
Fig. 3. Average user numbers of various services during daytime.



(a) MTP



(b) MS



(c) MSL

Fig. 4. The carrier configurations and MOSs of various schemes.

can hardly keep relatively high MOSs. However, the users enjoying IPTV and file download may be satisfied more easily and have MOSs above 4.8. During the daytime, CCs allocated to multi-service vary according to the changes in the number of users periodically to fit the network traffic. The MTP scheme achieves much worse QoE of web service than the MS and MSL.

The performances of the mean values and standard deviations (STDs) of multi-service MOSs with different schemes are compared in Fig. 5. The mean MOSs obtained by the two objective-oriented optimizations are nearly the same and both much higher than the MTP. However, the MSL scheme attains the smallest STDs, implying better fairness among services.

The proposed dynamic algorithm obtains the optimal result with 840 times of comparison, while the complete search needs 1771 times. Therefore, our algorithm can greatly reduce the processing costs, especially when there are more manifold application types.

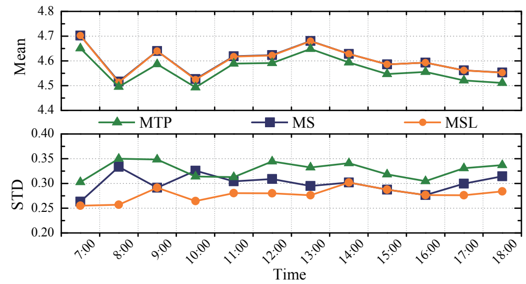


Fig. 5. Statistical comparison of various schemes.

V. Conclusion

In this paper, a QoE-based carrier scheduling scheme is proposed for multi-service LTE-Advanced networks. The QoE models of RT and NRT services are analyzed in terms of both AQoS and NQoS, considering the delay factors more than the previous bitrate-based works. These models are utilized to design the carrier scheduling schemes with the aim of enhancing the QoE performance. The results of the MS and MSL schemes obtained by the dynamic optimization are significantly superior to the MTP one with less complexity. Moreover, the MSL gains more fairness of multi-service than the MS. These schemes can also be applied in any other multi-carrier wireless networks.

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