A Cross-Layer Approach to Fair Resource Allocation for Multimedia Service in WiMAX

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Abstract

In this paper, a cross-layer resource allocation mechanism is proposed for wireless multimedia service. In particular, a game theory based on quality of service (QoS) for multimedia users is introduced to deal with the fairness of network resource allocation in wireless networks. Moreover, the channel states of wireless users are additionally regarded under the cross-layer design in WiMAX environment. In details, the bargaining solution is adopted to discover the efficient and fair resource allocation strategy for multimedia service in considering QoS in the peak signal-to-noise ratio (PSNR) and the channel states in the carrier-to-interface ratio (CINR). The proposed mechanism is illustrated and evaluated by simulation results of transmitting video sequences in WiMAX environment.

Keywords: Wireless multimedia service, resource allocation, scalable video coding (SVC), cross-layer design, bargaining games

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1. Introduction

With rapid spread of mobile devices such as mobile phones, smart phones, and portable media players, mobile users cannot help competing for the limited resource in wireless networks. Meanwhile, wireless multimedia service became to require much more network resources since multimedia users are sensitive to quality of service (QoS) for video and audio data. ~~From~~For the reason, resource allocation problem is still a significant issue in wireless multimedia service in spite of the great growth of wireless communication technology.

A lot of researches on resource allocation in wireless communications have been conducted to optimize efficient utilization of resource, profits of service providers, and QoS of users. In case of multimedia services, efficiency and fairness of resource allocation have been emphasized to enhance QoS. To deal with the problem, several researchers have introduced to the wireless network the game theory, which provides mathematical techniques for economic behaviors of service users in telecommunication networks [1]. Furthermore, Park and van der Schaar analyzed fairness conditions of wireless multimedia services by adapting bargaining games to the multimedia resource allocation. Since the game theory was originally developed in economics to analyze human behaviors according to the utilities of users, the game theoretic approaches generally focus on QoS of users rather than the amounts of allocated resources as such. In our research, we also deal with the fairness of multimedia resource allocation based on QoS in multimedia network, especially peak signal-to-noise ratio (PSNR).

In this paper, a novel approach to multimedia resource allocation is introduced considering the cross-layer design in WiMAX. Even though several studies on fair multimedia resource allocation addressed the users' utilities or QoS in the application (APP) layer, they did not consider the physical (PHY) layer such as channel state information. Even though they can optimize the multimedia resource allocation in viewpoint of the base station, users' utilities from the received resources often vary according to the users' channel states. However, since the recent protocols such as WiMAX, considered in this paper, support the channel state information, more practical utilities of users can be predicted in PSNR for the fair resource allocation

In particular, the scalable video coding (SVC) is assumed as a video compression standard in our research. SVC can assure QoS by DTQ (dependency, temporal, and quality) levels depending on channel environments by applying the un-equal protection (UEP) technique [2-3]. Hence, the base station can transmit dynamically the proper size of multimedia sequences for the amount of allocated resources to the users. That is the reason why we adopt the SVC as video codec in this research.

The proposed mechanism of resource allocation in wireless multimedia service has three characteristics as follows:

- *Cross-layer design considering channel states in WiMAX*: Even if users are located in bad channel states, which are generally caused by path loss, fading, shadowing, and interference, they wish multimedia service to be provided in a fair manner. Fortunately, since WiMAX enables the user's feedback for the channel states, our mechanism of cross-layer resource allocation has been developed considering the PHY layer, as well as the APP layer.
- *Dynamic multimedia resource transmission in SVC*: Traditional video codecs such as MPEG2 and H.263, and the advanced video coding (AVC) have difficulty in transmitting

variable video resources, while SVC supports to dynamically decide and transmit the proper size of multimedia sequences according to the network environments of users.

- *Fair resource allocation based on game theory*: Bargaining games in game theory provide the several mathematical solutions for resource allocation that users can accord with each other in terms of their utilities under some axioms. In this research, the Kalai-Smorodinsky bargaining solution was adopted for the purpose of the fair satisfaction of users considering their multimedia network environment in terms of QoS (i.e. PSNR).

This paper is organized as follows. In Section 2, cross-layer design and resource allocation in wireless networks and scalable video coding are reviewed. In Section 3, the framework of cross-layer resource allocation is presented and then the detailed procedure is described. In Section 4, a simulation experiments are illustrated in order to evaluate the performance of the proposed resource allocation strategy. Finally, Section 5 concludes this paper.

2. Related Work

2.1 Cross-Layer Design

Since wireless multimedia transmission is bandwidth-intense, delay-sensitive, and loss tolerant, QoS is an extremely important issue in wireless multimedia service [4]. Recently, to improve QoS in APP layer, cross-layer design in wireless multimedia is being studied to consider different layers of the open systems interconnection (OSI) stack.

Cross-layer optimization (CLO) originally aims at optimizing different layers for advanced reliability of multimedia service in wireless networks. Shan [5] presented a CLO algorithm of minimizing transmission delay in APP layer by combining with MAC and PHY layers. Jang *et al.* [6] conducted work on adjusting the adaptive transmission rate in channel environment based on the real-time encoder.

In particular, some researches consider QoS for CLO. By combining importance of transmission data and link states in PHY layer, a function of subchannel division was provided based on the unequal error protection (UEP) [7]. In addition, studies on adaptive video streaming service over Mobile WiMAX was conducted using channel states in PHY layer [8].

In this paper, we considered the interaction between APP and PHY layers for the cross-layer design to address fair resource allocation issues in wireless multimedia service. Especially, channel states in PHY layer are reflected to discover the allocation strategies in terms of QoS in APP layer. In PHY layer, MCS level is adopted to obtain channel states of users, which may are affected by network environment such as path loss, fading, shadowing and interference, in orthogonal frequency-division multiple access (OFDMA). In detail, required bit-rate is decided by selecting adaptive modulation and channel coding according to the predicted carrier to interference and noise ratio.

To provide adaptive video services in wireless networks, SVC is adopted for the video codec in APP layer. Three factors (spatial, temporal and qualitative) are considered to stratify SVC. Due to this structure, all processes to restore higher layers should be preceded by the restoration of the basic layer [3]. SVC can send only some layers to decrypt the videos in case that all video layers cannot be sent due to the limit of the bandwidth in wireless networks. For that reason, SVC was adopted for the multimedia resource allocation in this paper.

2.2 Resource Allocation in Wireless Networks

In order to ensure QoS, many studies have been searching for solutions that would provide effective bandwidth allocation in wireless video service to overcome problems of rapidly changing resources or rate adaptation [9]. However, the existing resource allocation methods have a limitation that they do not consider interactions between base and mobile stations. To this end, ReSerVation Protocols (RSVPS) [10] are used, but they cannot respond to severe changes in resources depending on available resources and users' participations. Especially, the above mentioned solutions that are based on fixed reservations do not consider the characteristics of videos and thus are not very suitable to be applied to multimedia services. Therefore, in order to allocate appropriate resources to many multimedia users, several fairness strategies have been proposed so far.

The simplest method to allocate resources to many users is to allocate resources to participants in the same quantities but this method does not consider the characteristics of video contents and the channel states in the network. Kelly, Maulloo, & Tan introduced a resource allocation method based on the bit-rate requirements of users [11]. However, they do not consider the picture quality of videos and thus is not suitable to content-aware multimedia application, which is considered in our paper.

In recent years, the game theory was adopted to analyze economic behaviors in telecommunication network. In particular, bargaining games [12-16] were introduced for effective resource allocation strategies so that resources can be efficiently and fairly allocated to users. Since bargaining solutions can consider heterogeneity between users, they can be usefully used in managing the resources of multimedia application services. However, the existing approaches to game theoretic resource allocation in wireless networks considered only the amounts of resources which could be allocated to users, not the amount of resources which users could receive.

In other words, even if resources are appropriately allocated in a base station considering users' requirements, the resources which users receive often differ from the allocated resources according to the channel states of users. As a result, to allocate suitable resources in the viewpoint of users, our proposal in this paper tries to allocate resources by considering bandwidths of users by means of feedback of PSNR in WiMAX environment.

In the meantime, the researches on CLO-based resource allocation were also conducted. The interaction between PHY and APP layers is optimized for the purpose of cross-layer resource allocation [17-18]. In this paper, our approach to the cross-layer resource allocation regards channel states of users in WiMAX environment in order to realize the fairness of QoS such as PSNR in the viewpoints of multimedia users.

3. Cross-Layer Resource Allocation for Multimedia Service

3.1 Cross-Layer Design

In this subsection, a framework of cross-layer resource allocation is introduced for wireless multimedia service. The framework is based on cross-layer design considering the interaction between PHY and APP layers as shown in **Fig. 1**. In a word, to improve QoS in APP layer, the channel states of users in PHY layer are considered for the purpose of fair resource allocation for wireless multimedia transmission.

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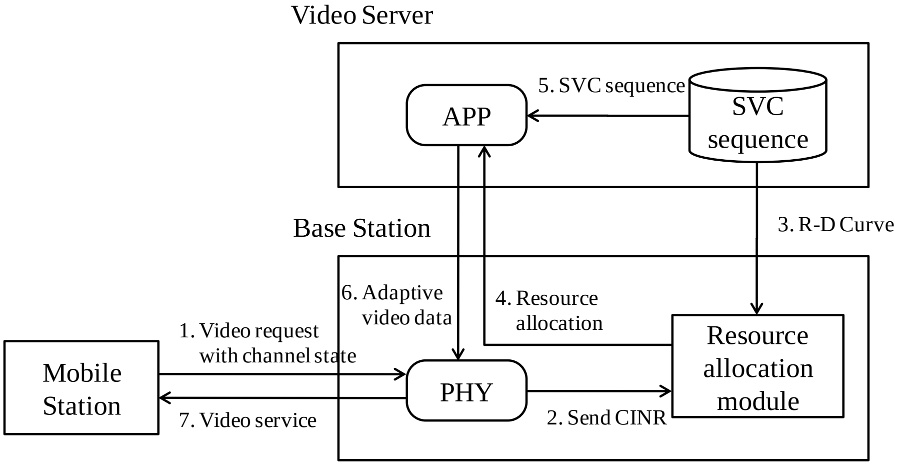


Fig. 1. The framework of cross-layer resource allocation for wireless multimedia service

The framework is composed of a base station, a video server, and several mobile stations. In the base station, the *PHY* layer is interacting with mobile stations for video service to request the proper resource allocation to the *Resource allocation agent*. The agent makes a strategy of fairly allocating the resources (i.e. bit-rates) of video sequences based on the rate-distortion (R-D) curves of the requested video sequences in the *SVC sequence* storage and the channel states (i.e. CINR) of users. To achieve the allocation strategy, a bargaining solution is adopted considering QoS (i.e. PSNR) for users. Then, *APP* layer sends adaptive video data to each user according to the coding level of SVC which is the best for the available bit-rate allocated to the user.

Recent studies in WiMAX are carried out by obtaining the channel state information. Since our proposal of the cross-layer design is based on the PHY layer, the approach has advantages in terms of accuracy, speed, and the ability in detecting diverse user environments [19-20]. In detail, resources received by individual users can be predicted by the CLO. In PHY layer, in case of OFDMA based downlink channels, AMC ode is provided that alternates a modulation method with an encoding method in accordance with channel environments. PHY layer collects the ratio of carrier waves to interfering noises and information on the density of received signals in order to observe channel situations between the sending terminal and the receiving terminal and predict the adaptation/modulation encoding mode based on the collected information. At this time, a channel bandwidth is determined by the adaptation/modulation encoding mode, the ratio of carrier waves to interfering noises and the encoding method.

3.2 SVC and QoS

To make a strategy of fair resource allocation, how to calculate QoS for each user is described in this subsection. We assumed the Rayleigh fading channel and a base station can receive the feedback from mobile station. In general, many studies in mobile communication assume that there is no delay to the feedbacks on channel estimation and thus the predicted channel information is the same as the real one [21-22].

Table 1 shows an example of the modulation and coding scheme (MCS) level for the carrier-to-interface ratio (CINR) which satisfy PER≤1%. Based on the table, when CINR is given to a user, how much bit-rate is necessary can be determined for the adaptive modulation and coding (AMC) considering channel coding block length, modulation scheme and coding rate. For instance, if CINR of a user is 4.4, the bit-rate of 144 is necessary for the appropriate modulation of (block length, modulation scheme, coding rate) = (720, QPSK, 1/2). The relationship between CINRs and bit rates is illustrated in **Fig. 2**.

Table 1. An example of the modulation and coding scheme (MCS) level. (carrier frequency=2.5GHz, # of FFT point=1024, # of data subcarriers=768, # of pilot subcarriers=96, subchannels/OFDMA symbol=16, data subcarriers/subchannel=48, subchannelization=PUSC, PER ≤1%)

CINR	block length	modulation scheme	coding rate	bit-rate
-3.9	480	QPSK	1/12	96
-1.45	480	QPSK	1/6	96
1.65	480	QPSK	1/3	96
4.4	720	QPSK	1/2	144
8.15	960	QPSK	2/3	192
9.5	1440	16QAM	1/2	288
13.65	1920	16QAM	2/3	384
15.7	2160	16QAM	3/4	432
19.2	2880	64QAM	2/3	576
27.5	3600	64QAM	5/6	720

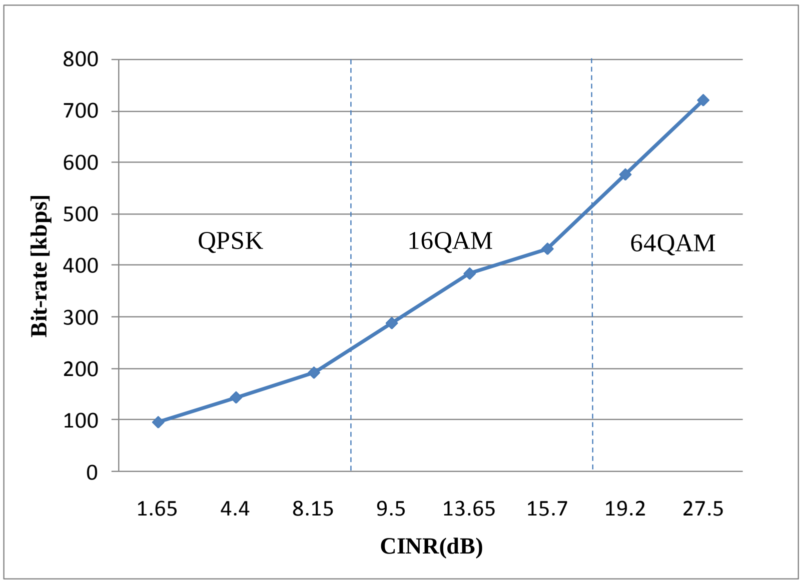


Fig. 2. Bit-rate level as CINR with AMC mode

Then, the maximum bit-rate that is provided to a user is selected according to his/her CINR on basis of the MCS table. Finally, QoS (i.e. PSNR) can be expected based on R-D table for each video sequence which the base station holds in the storage of SVC sequence in **Fig. 1**.

Since the network environment is often not stable in wireless communications, users wish adaptive video service according to their channel states. If the base station applies traditional codecs (e.g. H.263, MPEG2) or the AVC for wireless video service, users cannot be provided with any video service when the allocated resource is less than the bit-rate available to the decoding. On the contrary, SVC can transmit the adaptive level of video sequences according to the amount of allocated resources which are decided by the allocation strategy. In a word, SVC is requisite to the scalable and adaptive video transmission we consider in our paper.

In this research, to quantify QoS for SVC users, PSNR is often used. PSNR is similar to signal-to-noise ratio (SNR), which indicates the variance of the signal against the variance of the noise in the signal. While SNR considers signal powers of all images, PSNR uses the maximum possible power of a signal, denoted MAX_I , as shown in Equation (1). In general, 255 is substituted for MAX_I to 8 bit images. Mean square error (MSE) is calculated from the errors of the pixels at the sample location of two images, I and K, which sizes are m×n.

$$PSNR = 10\log_{10}(\frac{MAX_I^2}{MSE}) \quad (1)$$

$$MSE = \frac{1}{mn}\sum_{i=0}^{m-1}\sum_{j=0}^{n-1}\| I(i,j) - K(i,j) \|^2 \quad (2)$$

Unfortunately, the formula cannot be used for the base station to predict PSNR when sending video sequences to users because MSE cannot be calculated without the received image information in mobile stations of users. For this reason, the R-D table of each video sequence is used to predict PSNR of video service based on the available bit-rate and SVC method.

The R-D table can be obtained by coding levels of SVC. **Table 2** shows R-D table for SVC coding of an example video sequence ("Habour") [23]. The SVC method decide the DTQ (dependency, temporal, and quality) levels: the dependency level supports QCIF(176×144) and CIF(352×288), the temporal level does four levels from 3.75Hz to 30Hz, and the quality level does five levels from 0 to 4. For example, if the bit-rate available to a user is 550kbps, the best feasible DTQ level is (CIF, 30Hz, 2) and thus PSNR of 31.4974 is expected.

In summary, the base station can predict PSNR for the available bit-rates of users as shown in the R-D curve of **Fig. 3.** The R-D curves of the provided video sequences, which are stored in the base station, are used to establish the fair resource allocation strategy of multimedia service in our research.

Table 2. Rate-Distortion (R-D) of "Habour" sequence

Dependency	Temporal	Quality	Bit-rate	PSNR
QCIF	3.75	0	96.0256	22.3262
	7.5	0	112.024	25.9946
	15	0	128.0248	29.6394
	15	1	160.0224	30.9373
	15	2	191.984	31.9173
CIF	30	0	384.0288	34.652
	30	1	448.0264	35.2604
	30	2	512.028	35.7875
	30	3	640.0264	36.9742
	30	4	768.0008	37.7881

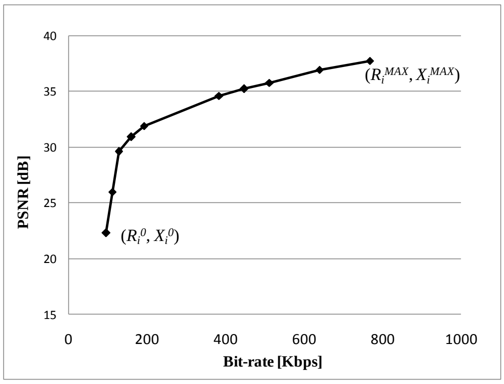


Fig. 3. R-D curve of "Habour" sequence

3.3 Game Theoretic Resource Allocation

A bargaining game deals with a situation that two or more players co-operate with each other in accordance with certain axioms. According to the axioms, bargaining solutions such as Nash bargaining solutions (NBS) [13] and Kalai-Smorodinsky bargaining solution (KSBS) [14] are chosen to discover optimal strategies of players in a mathematical manner. In case of telecommunication network, the bargaining solutions are introduced to allocate the shared network resource in terms of efficiency and fairness based on QoS, so-called utility.

In our research, KSBS, one of the bargaining solutions, is used to establish the resource allocation strategy in the base station so that the multimedia resource can be fairly distributed to the users. The reason that KSBS is adopted is that the solution guarantees proportional fairness for the different amounts of maximum resource requirements of users on basis of the axioms of

KSBS: Pareto optimality, scale invariance, individual monotonicity, and symmetricity [14]. The four axioms mean that resource allocations made by the KSBS will be always beneficial to users if the sets of effective benefits increase in a direction beneficial to a user. That is, the KSBS will allocate resources so that users of multimedia service can feel the same quality deterioration from the highest quality they can receive.

In our bargaining game for resource allocation, it is assumed that all users have their R-D curves as utility functions. The R-D curve provides PSNR of the best SVC coding for available bit-rate.

Suppose that there are N users in the multimedia service network. PSNR of user i is denoted by X_i for the available bit-rate R_i. And, the maximum PSNR in the R-D curve of user i and the corresponding resource are denoted by and X_i^{MAX} and R_i^{MAX}, respectively. Note that the maximum PSNR is restricted by the DTQ level of SVC coding. In addition, we assume that each user should be guaranteed for the minimum PSNR X_i^0 as a basic condition to participate in the game. Therefore, the available resource becomes R_{MAX}-ΣR_i^0.

In our research, to solve the fair resource allocation problem based on KSBS, the intersection point of the bargaining set B in Equation (5) and the proportionally fair line L in Equation (6) is obtained [15].

$$B = \{X \mid \sum_{i=1}^{n} \frac{\mu_i X_i}{c - D_{0i} X_i} = R_{MAX} - \sum_{i=0}^{n} R_{0i}, X_i > 0 \; for \forall i\} \tag{5}$$

$$L = \{X \mid \frac{X_1 - X_1^0}{\alpha_1 (X_1^{MAX} - X_1^0)} = \cdots = \frac{X_N - X_N^0}{\alpha_N (X_N^{MAX} - X_N^0)}, \quad where \sum_{i=1}^{N} \alpha_i = 1, \alpha_i \geq 0 \; for \; \forall i\} \tag{6}$$

On the one hand, all points on the curve B guarantee efficient utilization and cannot be improved to give more benefit to any user without another's loss. In the game theory, the bargaining set B is said to satisfy Pareto optimality. On the other hand, all points on the line L allow the allocated resources to users to be proportionally fair toward the maximum requirements of users.

3.4 Considering Channel States

Since the quantities received by users depend on channel states of users in wireless communications, the amount of resources received to the mobile stations are often different from that of resources allocated to them. Channel states of users in wireless communications vary according to path loss, fading, shadowing and interference, which are more sensitive to QoS than in wired environment. Hence, if the base state can consider the channel states of users, it can be more effective in allocating the resource and guaranteeing QoS to users. Moreover, In WiMAX environment, since the channel states of users are recognized by prompt feedbacks, channel states can additionally be considered in allocating the network resource fairly based on the bargaining solution described in Section 3.2. In this subsection, it is explained how to consider channel states in finally adjusting the resource allocation strategy by using the bargaining solution in wireless multimedia networks.

In our research, the *CINR* are used to adjust available bandwidths through which users will receive the resource. To adjust the allocation to users in the bargaining solution, we can control the bargaining powers in Equation (6). To consider channel states in resource allocation of our proposal, the bargaining power of a user α_i is defined as follows:

$$\alpha_i = \frac{1}{N-1}\left(1 - \frac{CINR_i}{\sum_{i=0}^{N} CINR_i}\right) \tag{7}$$

In the equation, $CINR_i$ is the power received by user i in wireless environment. Note that multiplied by 1/(N-1), the sum of α_i is 1 (i.e. $\Sigma\alpha_i$=1). Base on Equation (7), if channel environment of a user becomes worse and the resource less than what are required by users are received, the resources will be compensated by the users' based on fairness. Conversely, if a user's channel environment is good and resources to be allocated to the user are more than required, the remaining resources can be distributed to other users in not so good channel environments.

While the efficiency of the resource allocation is considered in Equation (5), the fairness of the allocation is done according to channel states of users by adjusting the bargaining powers of users α_i's in Equation (6). The phenomenon that as the transmission speed decreases, the CINR value required becomes smaller was reflected on the adjustment of bargaining powers in Equation (7).

4. Performance Evaluation

4.1 Experimental Design

The performance of the proposed resource allocation strategy was evaluated by simulation experiments. In the experiments, we assume the Rayleigh fading channel in WiMAX network and thea base station can get feedback from mobile users without any delay. For MCS level, 10 levels in **Table 1** were used and they satisfy PER≤1% under the following conditions: carrier frequency=2.5GHz, number of FFT point=1024, number of data subcarriers=768, number of pilot subcarriers=96, subchannels/OFDMA symbol=16, data subcarriers/subchannel=48, subchannelization=PUSC.

Four video sequences ("soccer", "football", "mobile", and "harbor") were encoded by JSVM9.13 encoder which is provided in JVT standard. The SVC sequences were encoded in 10 DTQ levels (see the example in **Table 2**). According to the levels, R-D curves were generated to predict PSNR of the video services as shown in **Fig. 4**.

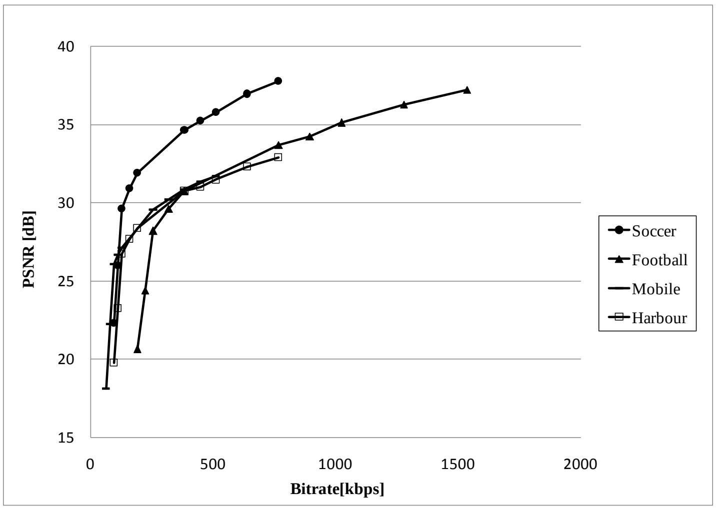


Fig. 4. SVC R-D curves

We conducted two experiments of two-user and four-user cases. To evaluate the performance of the proposed resource allocation mechanism, strategy of cross layer bargaining allocation (CLBA) was compared with three other allocation strategies in terms of fairness for wireless multimedia transmission: equal rate allocation (ERA), maximal rate allocation (MRA), and single layer bargaining allocation (SLBA). ERA allocates same amounts of bit-rates to all users independent of characteristics of video sequences [24]. MRA allocates possible resources to the users with better channel states prior to others [22]. SLBA obtains bargaining solution to discover fair resource allocation considering PSNR of users in APP layer. But, it does not consider the channel states in PHY layer. CLBA is a same strategy as SLBA except for reflecting the channel states (i.e. CINR) on the bargaining powers.

4.2 Single- and Cross-layer Resource Allocations

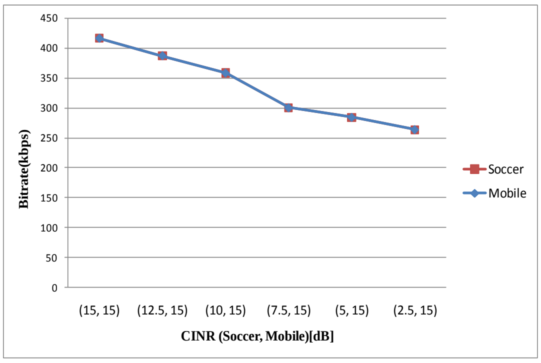
(1) Two-user Case

In the first experiment, two users request “mobile” and “soccer” video sequences, respectively. While the channel state of user “mobile” is fixed, that of user “soccer” is getting bad. In a word, CINR of user “mobile” is 15dB. CINR of user “soccer” changes from 15dB to 2.5dB by 2.5dB. The total available resource of the base station is assumed to be 1Mbps.

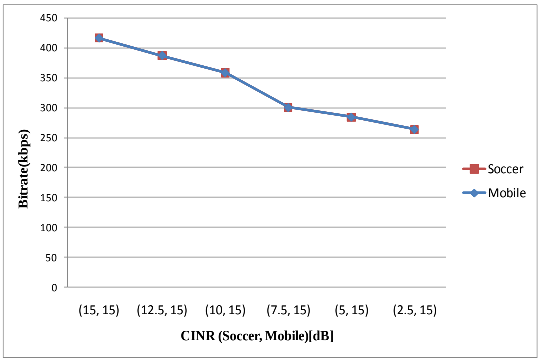
From the results of two-user experiment, the comparison of bit-rates is illustrated for four strategies in **Fig. 5**. The bit-rates show the amount of resources which each user is predicted to receive. From the reason, the sum of the bit-rates of two users is around 800kbps at the start of ($CINR_{soccer}$, $CINR_{mobile}$)=(15, 15). But, the sum decreases as the channel state of user “soccer” gets bad and channel loss becomes bigger.

In **Fig. 5** (a), ERA makes predicted bit-rates of two users be the same by considering their channel states. The allocation is even, but it does not consider the change of QoS (i.e. R-D curve) according to different video sequences of the two users. In **Fig. 5** (b), MRA does not care about the change of the channel states of user “soccer”. In **Fig. 5** (c), although SLBA fairly allocates the resources in the base station considering QoS, the predicted amount of resources of user “soccer” decreases as the channel state of the user gets bad. Finally, in **Fig. 5** (d), although the predicted amount of resources decreases together, CLBS does not allocate the same amount of resources to the two users. It is because CLBS does not consider only QoS in R-D curves to allocate the resource fairly, but also the channel states (i.e. PSNR) to reflect on bargaining powers. The bargaining powers of two users in CLBA becomes (α_{soccer}, α_{mobile})=(0.500, 0.500), (0.545, 0.455), (0.600, 0.400), (0.667, 0.333), (0.750, 0.250), (0.757, 0.243), as the channel state of user “soccer” decreases from 15dB to 2.5dB.

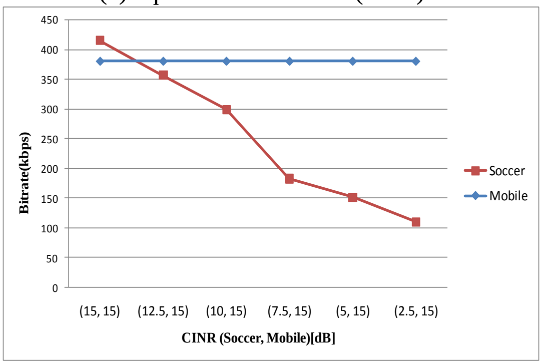
To analyze the results of the two-user experiment in terms of satisfaction of the users,comparison of QoS is illustrated for four strategies in **Fig. 6**. As the values of quantified QoS, PSNR are predicted from R-D curves corresponding to the users’ video sequences according to the predicted amount of resources. The changes of QoS in **Fig. 6** (b) to (d) show similar trends to those of the bit-rates in **Fig. 5**. The PSNR of two users by ERA in **Fig. 6** (a), however, show different values with each other because two R-D curves of the video sequences are different. In summary, both ERA and CLBA look fair because the PSNR of a user decreases as that of the other decrease.



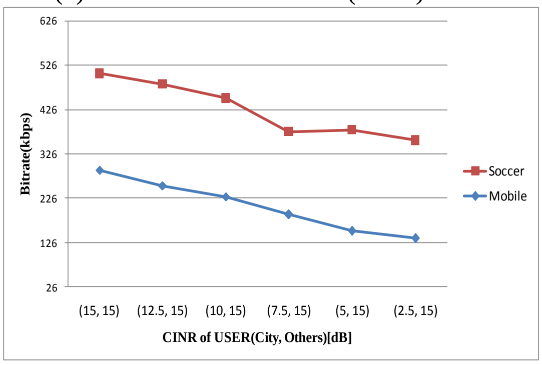
(a) equal rate allocation (ERA)



(b) maximal rate allocation (MRA)

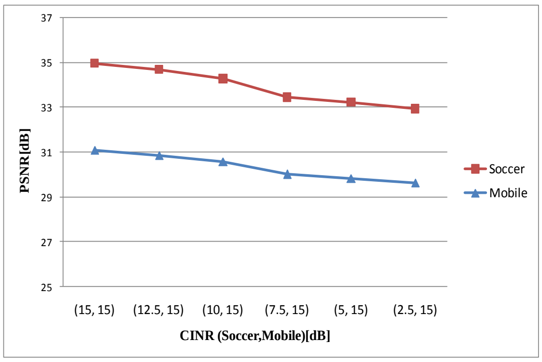


(c) single-layer bargaining allocation (SLBA)

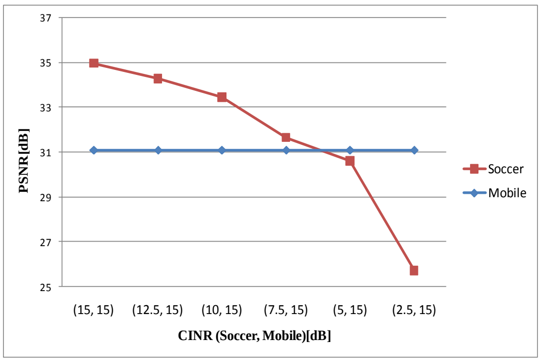


(d) cross-layer bargaining allocation (CLBA)

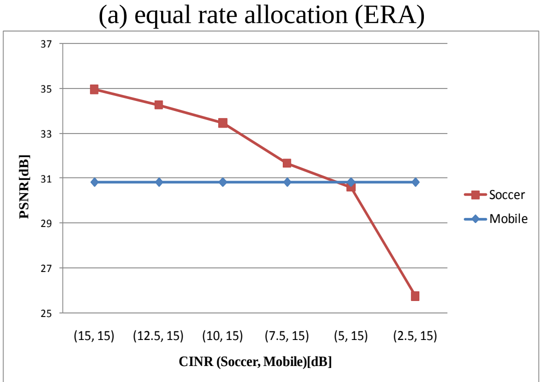
Fig. 5. Bit-rate comparison of four resource allocation strategies in two-user case



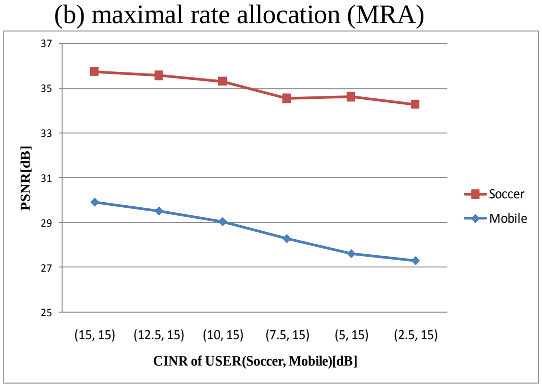
(a) equal rate allocation (ERA)



(b) maximal rate allocation (MRA)



(c) single-layer bargaining allocation (SLBA)



(d) cross-layer bargaining allocation (CLBA)

Fig. 6. QoS comparison of four resource allocation strategies in two-user case

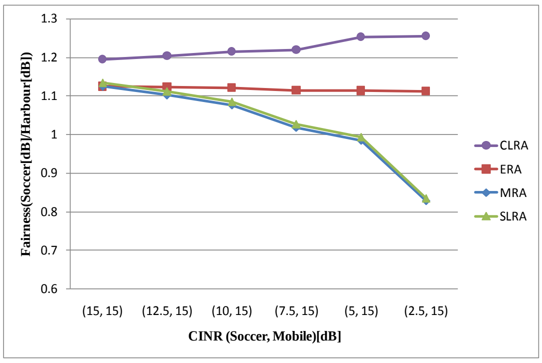


Fig. 7. Fairness comparison of four resource allocation strategies in two-user case

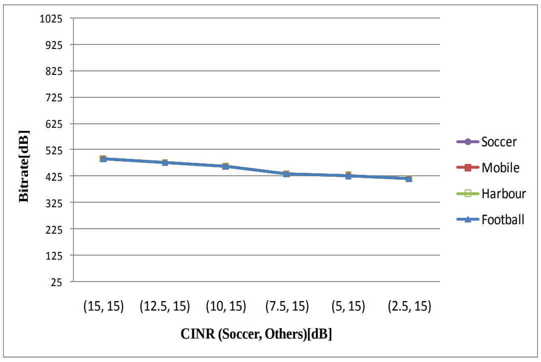
The fairness of four resource allocation strategies can be analyzed more clearly by comparing the ratio of PSNR of the two users as shown in **Fig. 7**. From the viewpoint of the users, MRA and SLBA are surely unfair in that channel states discriminate the PSNR of the users even though the states cannot be decided by users themselves. ERA and CLBA seem to be quite fair because the ratios of PSNR are nearly constant around 1.1 and 1.2, respectively. However, note that the two users have different capacities of PSNR as shown in **Fig. 4**. That is, the maximum PSNRs of the users “soccer” and “mobile” have different values of 38dB and 32dB, respectively. It means that if the available resources in the base station are enough, the user “soccer” can be more satisfied than the user “mobile”. That consideration has been reflected on bargaining solutions in CLBA. In the aspect, CLBA can be said to be so-called *proportionally* fair than ERA.

(2) Four-user Case

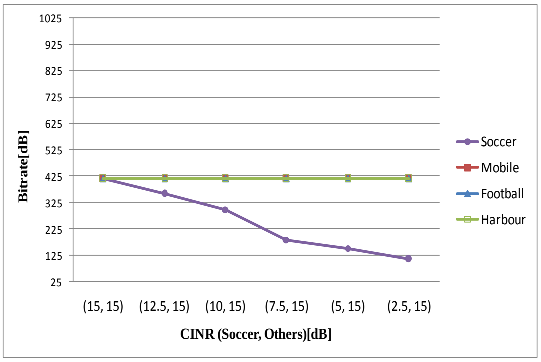
In the second experiment, four users request “soccer”, “football”, “mobile”, and “harbor” video sequences, respectively. In the same way as the two-user experiment, the channel state of three users are fixed, while that of the user “soccer” is getting bad. That is, CINR of the other users are 15dB, and only CINR of user “soccer” changes from 15dB to 2.5dB by 2.5dB. The total available resources of the base station is assumed to be 2Mbps.

The results of four-user experiment are similar overall to those of two-user case. However, the figures in **Fig. 8** illustrate clearly whether the strategies consider the difference of the video characteristics such as R-D curves. ERA does not discriminate the three users except for the user “soccer” because they lie in the same channel states. On the contrary, SLBA and CLBA allocate different amount of resources to the three users by considering R-D curves. In case of MRA, the three users except for “soccer” receive the same and constant resources, while the user “soccer” receives less resources as the channels state gets bad. Meanwhile, just as the two-user case, the sum of the bit-rates of four users is nearly 1950kbps at the start, while the sum decreases as the channel state of the user “soccer” gets bad.

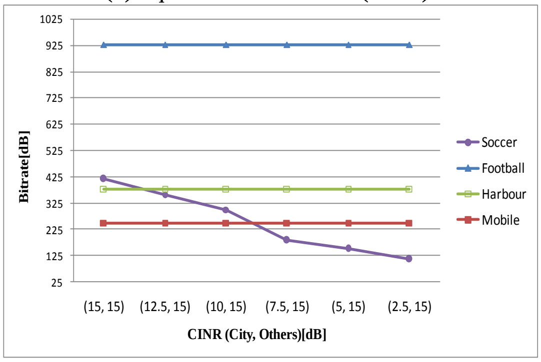
In the comparison of SLBA and CLBA, the user “soccer” was compensated when the channel state gets bad, by decreasing the allocation to the user “football”. Note that the R-D curve of “football” video sequence has much bigger maximum achievable resources than the others. The bargaining powers of the four users in CLBA were adjusted to (α_{soccer}, $\alpha_{football}$, α_{mobile}, $\alpha_{harbour}$)= (0.2500, 0.2500, 0.2500, 0.2500), (0.2608, 0.2463, 0.2463, 0.2463), (0.2727, 0.2424, 0.2424, 0.2424), (0.2857, 0.2380, 0.2380, 0.2380), (0.3000, 0.2333, 0.2333, 0.2333), (0.3157, 0.2280, 0.2280, 0.2280), as the channel state of the user “soccer” decreases from 15dB to 2.5dB.



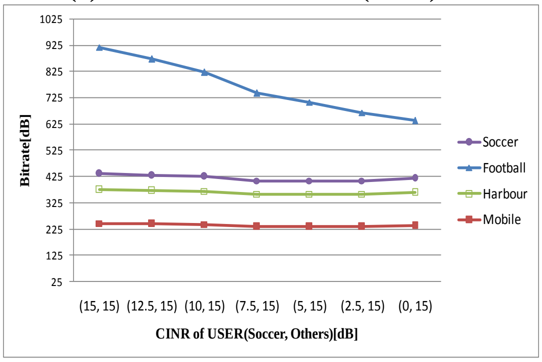
(a) equal rate allocation (ERA)



(b) maximal rate allocation (MRA)

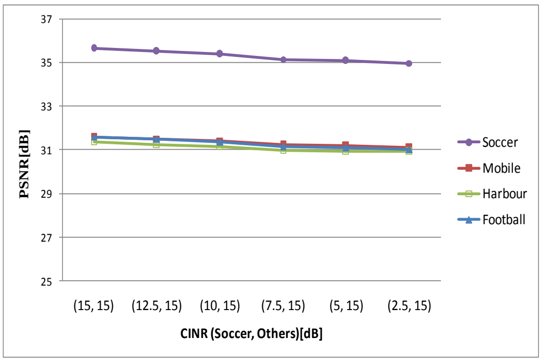


(c) single-layer bargaining allocation (SLBA)

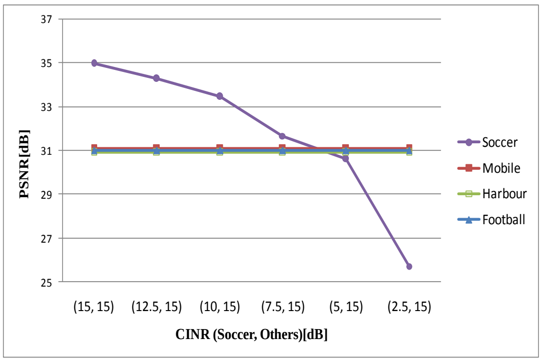


(d) cross-layer bargaining allocation (CLBA)

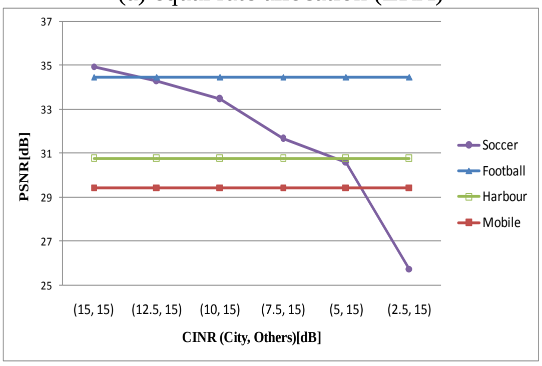
Fig. 8. Bit-rate comparison of four resource allocation strategies in Four-user Case



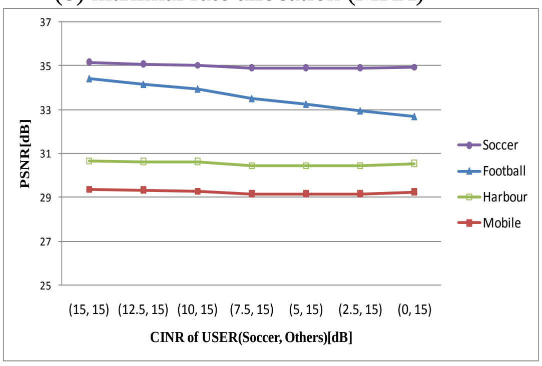
(a) equal rate allocation (ERA)



(b) maximal rate allocation (MRA)



(c) single-layer bargaining allocation (SLBA)

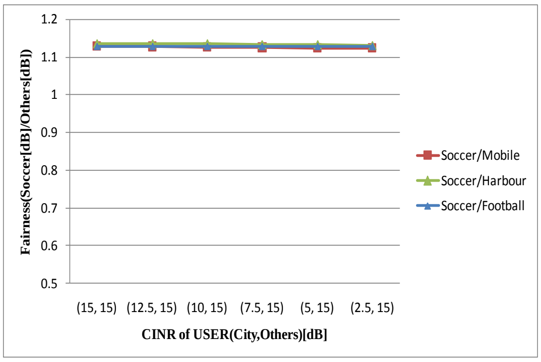


(d) cross-layer bargaining allocation (CLBA)

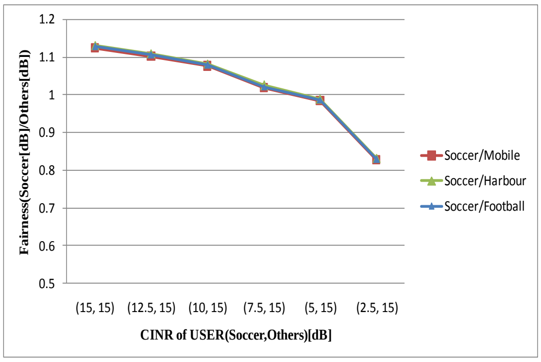
Fig. 9. QoS comparison of four resource allocation strategies in Four-user Case)

In the Four-user Case, the comparison of QoS is illustrated for four strategies in **Fig. 9**. In case of ERA in **Fig. 9** (a), although four users receive the same amount of resources, PSNRs become different according to the shape of R-D curves. For example, when ($CINR_{soccer}$, $CINR_{others}$)=(15, 15), the predicted amount of resources of each user are 493.17 in **Fig. 8** (a). At that time, PSNR of "soccer" is 35.63, while those of the other three are 31.36.

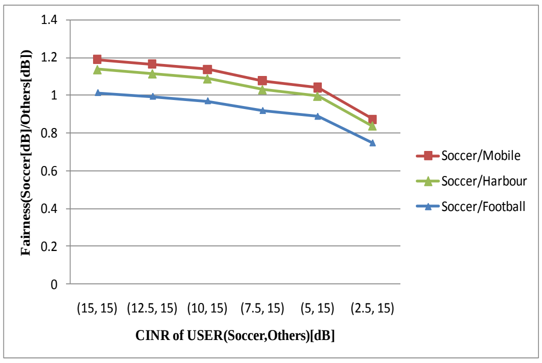
In **Fig. 9** (b), MRA allocated the same and constant resources to the three users except for the user "soccer" just as in the two-user case. In comparing SLBA and CLBA in **Fig. 9** (c) and (d), the user "soccer" has decreasing PSNR in SLBA, but almost constant PSNR in CLBA, and conversely, user "football" has almost constant PSNR in SLBA, but decreasing PSNR in CLBA. It is because the user "football" requests the most amount of resources (see **Fig. 4**) and it allows some resources to the user "soccer" when the channel state of the user "soccer" gets bad. As the result, the resource allocation of CLBA becomes proportionally fair in terms of PSNR, as well as considering the channel states.



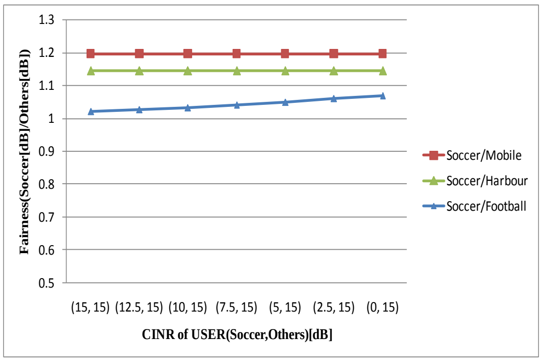
(a) equal rate allocation (ERA)



(b) maximal rate allocation (MRA)



(c) single-layer bargaining allocation (SLBA)



(d) cross-layer bargaining allocation (CLBA)

Fig. 10. Fairness comparison of four resource allocation strategies in Four-user Case

The ratios of PSNR of "soccer" to that of another were illustrated in **Fig. 10**. The graph helps to analyze the fairness of the four allocation strategies. That is, the ratios mean how much fair the PSNR of the user "soccer" by comparison with those of the other three users. In ERA, the ratios are nearly constant in any channel state of the user "soccer". MRA and SLBA look unfair because the ratio varies according to the channel states of the user "soccer". On the contrary, because the ratios of ERA and CLBA are nearly constant, they seem to be fair. It is because both strategies consider the changes of the channel states of the users. In particular, CLBA can be said to be proportionally fair just as explained in the two-user case.

5. Conclusions

This work started from motivation that if resources are allocated without considering channel states in wireless networks, the resources that users receive in mobile stations may be different from planned resources in base stations. Moreover, since the channel states cannot be decided by users themselves, the base stations should consider the channel states of users for fair allocation of multimedia resources in wireless networks.

For the reason, the cross-layer design was devised by considering interaction between-APP and PHY layers for the purpose of resource allocation for practical video streaming service in WiMAX environment. In addition, to realize the fair resource allocation in the cross-layer design, the game theory, a mathematical and economic tool, was adopted for establishing the strategy of resource allocation in the base station. By illustrating the simulation results, the proposed cross-layer resource allocation strategy has been proved to be superior to the other strategies such as equal rate allocation (ERA), maximal rate allocation (MRA), and single layer bargaining allocation (SLBA) in terms of fairness. In fact, it is insisted that proportional fairness is reasonable in heterogeneous video streaming service. Hence, the KSBS was adopted for establishing the allocation strategies.

The simulation experiments illustrated that ERA and CLBA were fair compared to MRA and KSBS from the viewpoint of users. That is because ERA and CLBA consider the channel states of users, which are enabled by the feedback of PSNR in WiMAX. In addition, two bargaining allocation strategies, SLBA and CLBA, can consider heterogeneity of video sequences because adapting PSNR to QoS. As the result, the proposed strategy of cross-layer bargaining allocation (i.e. CLBA) can be said to be proportionally fair considering both the channel states (i.e. CINR) in PHY layer and QoS (i.e. PSNR) in APP layer.

The novelty of this research is that the game theoretic approach was adopted for cross-layer design in wireless multimedia network. The game theory was often used to address cooperative behaviors in telecommunication network. However, there was no research which considers game theory for cross-layer wireless multimedia transmission.

Since wireless multimedia service surely spreads continuously with growth of wireless telecommunication devices, the practical consideration of QoS for multimedia users should be made with the in-depth cross-layer optimization of network stations in future.

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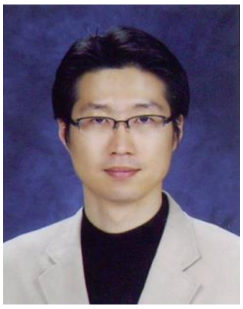

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