Downlink Wireless Adaptive Modulation and Coding Scheme (AMC)-based Priority Queuing Scheduling Algorithm for Multimedia Services

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ABSTRACT

To realize the wireless packet scheduler which efficiently considers both the effect of adaptive modulation and coding (AMC) scheme due to variable wireless communication channel information from physical layer and the QoS differentiation of multimedia services from internet protocol (IP) layer, this paper proposes a new downlink AMC-based priority queuing (APQ) scheduler which combines AMC scheme and service priority method in multimedia services at the same time. The result of numerical analysis shows that the proposed APQ algorithm plays a role in increasing the number of services satisfying the mean waiting time requirements per each service in multimedia services because the APQ scheme allows the mean waiting time of each service to be reduced much more than existing packet scheduler having only user selection processor.

Keywords: Downlink Packet Scheduling, Multimedia Services, Adaptive Modulation and Coding, Priority Queuing, Outage Probability, QoS Requirement

1. INTRODUCTION

With the rapid growth in the popularity of wireless communication systems and with the increase in demand for multi-media applications, it is expected that a lot of wireless communication systems [1-5] provide services for heterogeneous classes of traffic with different quality of service (QoS) requirements. Currently, there is an urgent need to develop new technologies for the provision of QoS differentiation and guarantee in wireless networks. Among all the technical issues that need to be solved, packet scheduling is one of the most important issues. Packet scheduling algorithms have a design objective maximizing resource utilizations in the multimedia services satisfying their required QoS parameters and realizing the low complexity of implementations. To achieve the above objective for the multimedia services with high priority such as real-time (RT) traffic and with low priority such as non-real-time (NRT) traffic in wireless communication systems, packet scheduling algorithms should consider both user selection process in multiple users and service type selection process in multiple services at the same time. Also, the packet scheduling algorithm needs to consider an adaptive modulation and coding (AMC) scheme provisioning an alternative link adaptation method [6]. The AMC scheme provides the flexibility to match the modulation-coding scheme to the average channel conditions for each user. With the AMC scheme, the intensity of the transmitted signal is held constant over a frame

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interval, and the modulation and coding format is changed to match with the current received signal quality or channel conditions [7].

Therefore, through the numerical analysis, this paper examines the effect of the proposed downlink AMC-based priority queuing (APQ) algorithm, which considers AMC scheme to find a user depending on current channel condition among many users (it is called user selection process) and service differentiation to select service depending on required QoS parameter among multimedia services (it is called service type selection process) at the same time. According to the result of numerical analysis, it is found that the proposed scheme effectively increases the total number of multimedia services meeting their QoS requirements. This paper is organized as follows. Section 2 explains existing packet scheduling algorithm in wireless network. Also, Section 3 introduces the proposed APQ packet scheduling algorithm. The numerical analysis and result for the APQ scheme are explained in Section 4 and Section 5. Concluding remarks are given in Section 6.

2. EXISTING PACKET SCHEDULING ALGORITHM

Fig. 1 shows a simplified medium access control (MAC) architecture consisting of the packet classifier, the buffers for incoming traffic flows, and the packet scheduler. Incoming packets to the MAC layer are first assorted by the packet classifier depending on their belonging traffic flows. The classified packets are then queued into corresponding buffers, and if needed, out-of-order packets are rearranged in order. The buffers regularly report to the buffer management (BM) the status about their priorities, current length, and required link service. Based upon information of service type selection processor and user selection processor, the packet scheduler decides which buffer should be selected for the next transmission. When trans-

mitting packets of the buffers, the scheduler sends the data in a bit-by-bit manner regardless of individual packet boundaries. This bit-based transmission aims to minimize wasted capacity by filling all the physical layer frames with data. The bit-stream generated by the scheduler is passed down the physical layer, along with information about the service requirements. At the receiving side of the wireless link, the packets have to be re-assembled before passing them up to the upper layer. This can be achieved since the scheduling information transmitted to the receiving side enables to determine which bytes belong to which flows. Therefore, it is efficient that the downlink APQ scheme consists of user selection process and service type selection process.

There are many packet scheduling algorithms which play a role of user selection processor in wireless networks. They perform user selection operation for efficient user selection among multiple users to be scheduled considering mainly wireless channel conditions expressed as signal to interference ratio (SIR). They consists two kinds
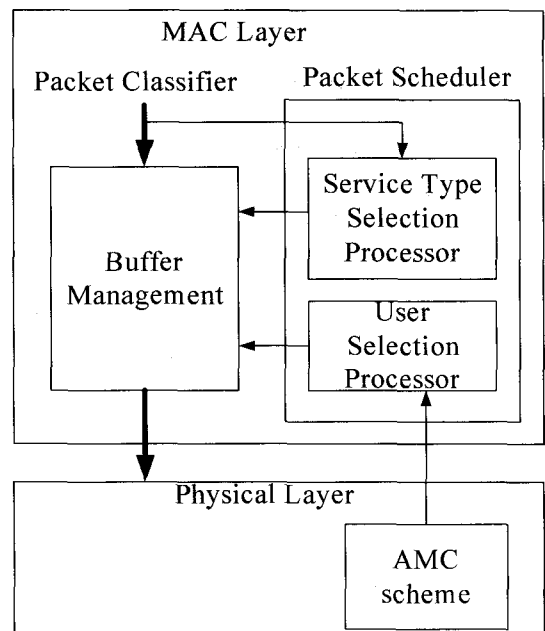

Fig. 1. Simplified MAC architecture.

of packet schedulers. One is to use one priority metric considering channel condition and buffer status without service type such as proportional fair (PF) [8], modified largest weight delay first (M-LWDF) [9], and urgency- and efficiency-based wireless packet scheduling (UEPS) [10]. The other is to use multiple priority metrics based on any specified constraint such as EXP/PF scheme [11] and PLR-MMBR scheme [12]. Each priority metric consists of some constraint like the channel condition and class relative urgency, throughput, and fairness. Once the priority metrics are evaluated individually, a user with the highest value of metric is scheduled for the service, regardless of the service class.

Hence, there are several packet scheduling schemes which perform service type selection processor's role [13,14] such as the service-dependent priority scheme, dynamic channel assignment, and priority reservation with preemptive priority based on the service QoS requirement, which differ depending on the type of services, in order to maximize the number of services satisfying each service's QoS requirements. The simple approach is the PQ scheme which popularly used for the multimedia service applications because of its easy implementation. It is an absolute priority control approach, which prioritizes the RT traffic over the NRT traffic by allocating the remaining resources to the NRT traffics only after processing all the RT traffics.

As a result, because the existing packet scheduler employs only a user selection or independently two different processors for user selection and service type selection, it is increased that the operation complexity such as control signaling overhead and performance degradation in terms of the number of services satisfying the QoS requirements per service due to the employment of two independent processors. Therefore, as it is required to minimize a lot of message exchange cost and to maximize the number of services satisfying the

required QoS parameter, the proposed APQ scheme combines two processors simultaneously, which are user selection processor and service type selection processor, and then share the information between physical layer having adaptive modulation and coding (AMC) scheme due to variable wireless channel information and MAC layer managing the service priority due to the QoS differentiation of multimedia services which generated from IP layer.

3. PROPOSED PACKET SCHEDULING ALGORITHM

In order to enhance the performance of existing packet scheduling algorithm as shown in Section 2, this paper proposes a new downlink APQ scheduling scheme which has user selection processor selecting a specific AMC mode according to received SIR values under the varying channel conditions like the existing algorithms and adopts the PQ scheme as a service selection processor based on amount of data supported by the selected AMC mode for service differentiation in the multimedia services at the same time as shown in Fig. 2.

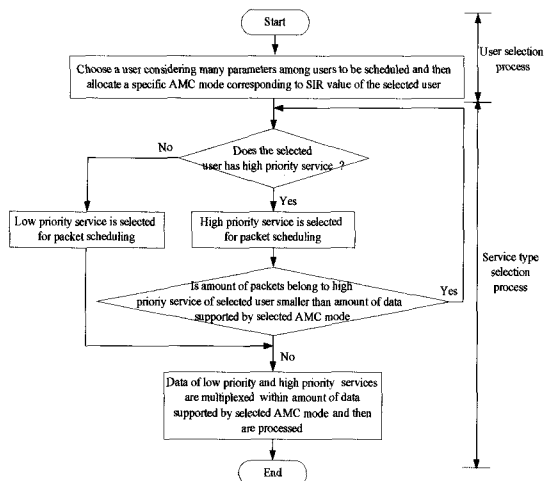Fig. 2 represents the example flowchart of the APQ scheme which combines efficiently the above

Fig. 2. The example flowchart of the APQ scheme.

two selection processors. In Fig. 2, it is shown that the SIR value and AMC mode are used for user selection and the PQ scheme is employed for service type selection. After a user with the selected AMC mode among all users to be scheduled is selected as a user to be scheduled and the packets belonging to the selected user are accumulated at the corresponding buffer, priority order will be set in order according to its service type. In case of service with high priority, its packets are accumulated in the high priority buffer. Also, in case of service with low priority, its packets are sent into the low priority buffer. As shown in Fig. 2, the operation of service type selection is processed. If the amount of packets in the high and low priority buffers is smaller than the amount of data that can be supported by selected AMC mode, it is processed as total service rate corresponding to selected SIR value. And then, high priority service takes precedence over low priority service. As a result, data with low priority and high priority buffers are multiplexed within the range of data rate which can be supported by selected AMC mode and then are processed.

4. NUMERICAL ANALYSIS OF THE APQ SCHEME

In this Section, it is described that the system model for APQ scheduler over a downlink shared channel in a base station (BS). Fig. 3 shows the details of integration of user selection and service type selection processor. Where, it is assumed that the user selection processor selects one transmission user per a fixed time duration. The user selection processor in Fig. 3 selects a user among user k for each service class based on AMC mode according to current wireless channel condition. Also, the service type selection processor services the selected user who belongs to service class with higher priority (more sensitive to delay) over lower priority and then the remaining lower priority

service is serviced only after processing all the higher priority service.

For numerical analysis, user selection processor can be considered as a queuing system with different service rate according to wireless channel condition. Also, service type selection processor can be thought as a queueing system in which high priority service has priority over low priority service in terms of service order such as the PQ scheme. As a result, the APQ scheme can be considered as a queuing system that handles k priority classes of users. Type k users arrive according to a Poisson process of rate λ_k and have service time with the probability distribution function (PDF) $f_{tk}(x)$ and mean τ_k. A separate queue is kept for each priority class, and each time the server becomes available it selects the next user from the highest-priority non-empty queue. This service discipline is often referred to as the "head-of-line priority service". It is assumed that users cannot be preempted once their service has begun [15]. In this paper, for simple numerical analysis, it is supposed that there are two classes of users. Therefore, user selection processor is modeled as a queuing system in which a user with a specific SIR value has exponentially distributed service times with mean
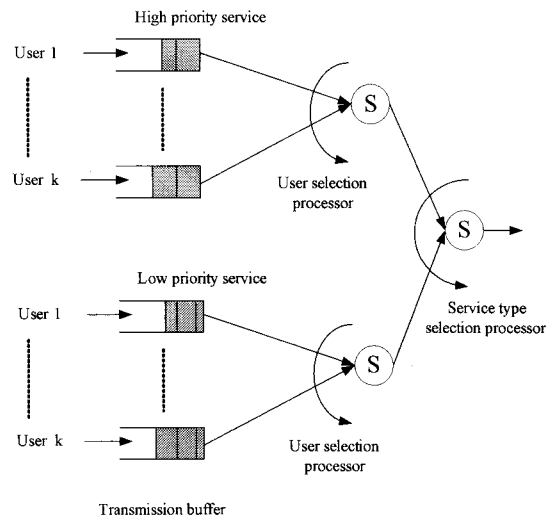

Fig. 3. The system model for APQ scheduler.

$1/_{A\mu}$ where A is a kind of weighting factor having a different value according to the received SIR value. Similarly, service type selection processor is modeled as a queuing system with priority given to high priority service. In summary, the APQ scheme can be assumed as two-priority M/G/1 system in which the user has exponentially distributed service time with mean $1/_{A\mu}$ according to the measured SIR value and the high priority and low priority services have the arrival rate of λ_{high} and λ_{low} of Poisson distribution, respectively. If the selected user has a total service rate $A\mu$ corresponding to received SIR value, the mean waiting times for high priority and low priority services of the APQ scheme are as follows. First, the first two moments of the service time are as follows [16].

$$E[\tau] = \frac{\lambda_{high} E[\tau_{high}]}{\lambda_{high} + \lambda_{low}} + \frac{\lambda_{high} E[\tau_{low}]}{\lambda_{high} + \lambda_{low}} = \frac{1}{A\mu} \tag{1}$$

$$E[\tau^2] = \frac{\lambda_{high} E[\tau_{high}^2]}{\lambda_{high} + \lambda_{low}} + \frac{\lambda_{high} E[\tau_{low}^2]}{\lambda_{high} + \lambda_{low}} = 2\left(\frac{1}{A\mu}\right)^2 \tag{2}$$

The traffic intensity for each service class and the total traffic intensity are as follows.

$$\rho_{high} = \lambda_{high} E[\tau_{high}] = \frac{\lambda_{high}}{A\mu} \tag{3}$$

$$\rho_{low} = \lambda_{low} E[\tau_{low}] = \frac{\lambda_{low}}{A\mu} \tag{4}$$

$$\rho_{total} = \lambda_{high} E[\tau_{high}] + \lambda_{low} E[\tau_{low}] = \frac{1}{A\mu}\left(\lambda_{high} + \lambda_{low}\right) \tag{5}$$

The mean residual service time is as follows.

$$E[R] = \frac{\lambda_{total} E[\tau^2]}{2} = \left(\frac{1}{A\mu}\right)^2 \left(\lambda_{high} + \lambda_{low}\right) \tag{6}$$

The mean waiting times for high priority and low priority services of the APQ scheme which is M/G/1 system with priority service discipline are as follows.

$$E[W_{high,APQ}] = \frac{E[R]}{1 - \rho_{high}} = \left(\frac{1}{A\mu}\right)^2 \left(\frac{\lambda_{high} + \lambda_{low}}{1 - \lambda_{high} \frac{1}{A\mu}}\right) \tag{7}$$

$$E[W_{low,APQ}] = \frac{E[R]}{\left(1 - \rho_{high}\right)\left(1 - \rho_{high} - \rho_{low}\right)} = \left(\frac{1}{A\mu}\right)^2$$

$$\left(\frac{\lambda_{high} + \lambda_{low}}{\left(1 - \lambda_{high} \frac{1}{A\mu}\right)\left(1 - \lambda_{high} \frac{1}{A\mu} - \lambda_{low} \frac{1}{A\mu}\right)}\right) \tag{8}$$

where $E[W_{high,APQ}]$ is the mean waiting time for the high priority service and $E[W_{low,APQ}]$ is the mean waiting time for the low priority service.

The mean waiting time of the packet scheduler which has only user selection processor considering AMC scheme and dose not consider the service type selection processor, $(E[W_{withAMC}])$, is as follows.

$$E[W_{withAMC}] = \frac{E[R]}{1 - \rho_{total}} = \frac{\left(\frac{1}{A\mu}\right)^2 \lambda_{high} + \lambda_{low}}{1 - \frac{1}{A\mu}\left(\lambda_{high} + \lambda_{low}\right)} \tag{9}$$

Also, the mean waiting time of the packet scheduler which has only user selection processor without AMC scheme and dose not consider the service type selection processor, $(E[W_{withoutAMC}])$, is as follows.

$$E[W_{withoutAMC}] = \frac{E[R]}{1 - \rho_{total}} = \frac{\left(\frac{1}{\mu}\right)^2 \lambda_{high} + \lambda_{low}}{1 - \frac{1}{\mu}\left(\lambda_{high} + \lambda_{low}\right)} \tag{10}$$

In this paper, because the packet scheduler which has only user selection processor with AMC scheme or without AMC scheme dose not consider the service type selection processor, the mean waiting times for the high priority and low priority services are same.

5. RESULT AND DISCUSSION

In this paper, it is assumed that all users always have multimedia services with high priority such as RT traffic and with low priority such as NRT traffic, and high priority service users are given non-preemptive priority in the APQ scheme. Also, this paper deals with performance improvement not in control signaling overhead but in the number

of services satisfying the QoS requirements per service due to the employment of two processors at the same time.

Table 1 shows an AMC mode used as an example for numerical analysis. In this table, the total service rate can be calculated as the ratio of A values due to received SIR value is 1:2:3:4 and service rate μ is always fixed at 1 in this paper. For example, if received SIR value is high such as state 3 and the ratio of A values is 1:2:3:4, the total service rate will be 3. Hence, if received SIR value is high and the ratio of A values is 1:3:6:9, the total service rate will be 6. As a result, in this paper, to reflect the characteristic of AMC scheme having different service rate according to AMC mode, the ratio of total service rates of the AMC mode 2, AMC mode 3, and AMC mode 4 based on normalized total service rate of AMC mode 1 is defined such as 1:2:3:4 or 1:3:6:9. Therefore, according to the received SIR value, all users can choose corresponding AMC mode. Through the above process, user selection processor is accomplished. In this numerical analysis, it is supposed that all users, regardless of service type, arrive at each queue according to the Poisson process of the same rate ($\lambda = \lambda_{high} = \lambda_{low}$).

For exact performance analysis of Fig. 4, Fig. 5, Fig. 6 and Fig. 7, let us assume that the required mean waiting time for high priority and low priority services is 0.2 and 0.4 because high priority service such as RT traffic generally requires less mean waiting time than low priority service such

Table 1. The AMC mode used as an example for numerical analysis when service rate (μ) is 1

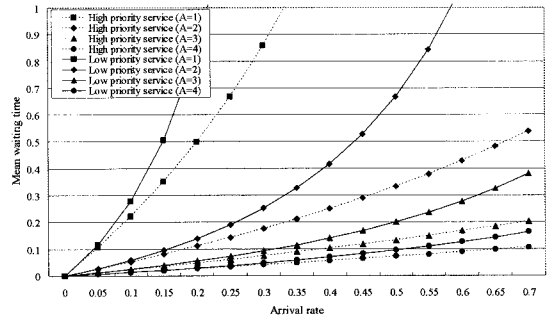| AMC mode	Received SIR (dB)	Total Service Rate ($A\mu$)	
		The ratio of A is 1:2:3:4	The ratio of A is 1:3:6:9
State1	Very low	1	1
State2	Low	2	3
State3	High	3	6
State4	Very high	4	9

Fig. 4. Mean waiting time vs. arrival rate when the ratio of weighting factor A values is 1:2:3:4 and service rate (μ) is fixed at 1.

as NRT traffic. Fig. 4 shows the relation between per-class mean waiting time and arrival rate when received SIR is changed from very high to very low, in other words, when weighting factors are $A=1$, $A=2$, $A=3$, and $A=4$. From Fig. 4, it is observed that the total arrival rate satisfying the required mean waiting time is about 0.21 (0.085 for high priority service and 0.125 for low priority service) in case of $A=1$, about 0.725 (0.325 for high priority service and 0.4 for low priority service) in case of $A=2$, and about 1.35 (0.65 for high priority service and 0.7 for low priority service) in case of $A=3$. Therefore, it is found that the total arrival rate, which means the number of RT and NRT services, satisfying the required mean waiting, increases as A value increases. As a result, Fig. 4 shows that the larger the weighting factor reflecting wireless channel condition is, the smaller the mean waiting time is.

Fig. 5 represents the relation between arrival rate and average value of mean waiting times when total service rate $A\mu$ is 1, 2, 3, and 4 in the proposed APQ scheme, existing packet scheduler having only user selection scheme with AMC scheme, and existing packet scheduler having only user selection processor without AMC scheme. Where, the average value of mean waiting time of high priority and low priority services is defined as the average value of mean waiting times which can be calculated by all modes with the ratio of
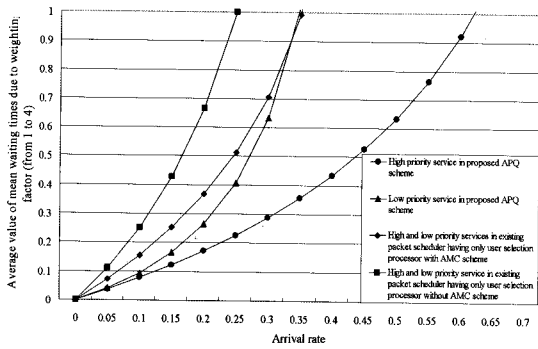
Fig. 5. Arrival rate vs. average value of mean waiting times when total service rate (Aμ) is 1, 2, 3 and 4 (when the ratio of weighting factor A values is 1:2:3:4 and service rate (μ) is fixed at 1) in the proposed APQ and existing packet scheduler which has only user selection processor.

Fig. 6. Arrival rate vs. average value of mean waiting times when total service rate (Aμ) is 1, 3, 6 and 9 (when the ratio of weighting factor A is 1:3:6:9 and service rate (μ) is fixed at 1) in the proposed APQ and existing packet scheduler which has only user selection processor.

1:2:3:4 based on a normalized AMC mode 1 as shown in Table 1. For example, if the required mean waiting time for high priority and low priority services is 0.2 and 0.4, respectively, from Fig. 5, it is found that the total arrival rate satisfying the required mean waiting time is about 0.47 (0.22 for high priority service and 0.25 for low priority service) in case of the APQ scheme, 0.32 (0.12 for high priority service and 0.2 for low priority service) in case of only user selection scheme with AMC scheme, and 0.22 (0.07 for high priority service and 0.15 for low priority service) in case of packet scheduler having only user selection scheme without AMC scheme, respectively. As a result, in terms of the number of RT and NRT services satisfying the required mean waiting time per each service, it is found that the proposed APQ scheme has better performance than the existing packet scheduler having only user selection scheme. Also, it is known that the packet scheduler having only user selection scheme with AMC scheme has better performance than the packet scheduler having only user selection scheme without AMC scheme.

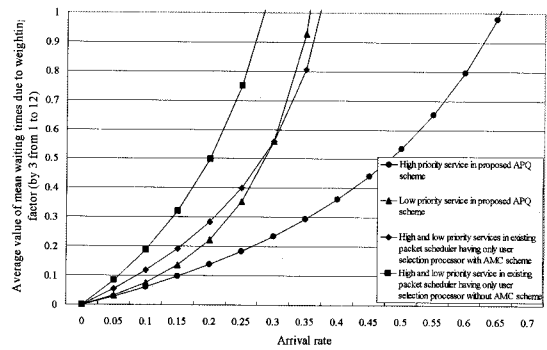Like Fig. 5, Fig. 6 shows the mean waiting time of low priority and high priority services in the proposed APQ scheme and existing packet scheduler having only user selection processor when total service rate (Aμ) is 1, 3, 6 and 9, in other words, the ratio of weighting factor A values is 1:3:6:9 and service rate (μ) is fixed at 1. If the required mean waiting time for high priority and low priority services is 0.2 and 0.4, respectively, the arrival rates meeting the requirements are 0.52 (0.15 for high priority service and 0.24 for low priority service) in the proposed APQ scheme and 0.39 (0.15 for high priority service and 0.24 for low priority service) in case of existing packet scheduler having only user selection processor with AMC scheme, respectively. In terms of the number of high priority and low priority services satisfying the required mean waiting time, like Fig. 5, Fig. 6 represents that the proposed APQ scheme has better performance than the existing packet scheduler having only user selection processor. Also, it is found that the difference of total arrival rate of high priority and low priority services satisfying the required mean waiting time increases as an increasing rate compared with the previous descending AMC mode based on normalized AMC mode 1 increases. More detailed explanation will be introduced at Fig. 7.
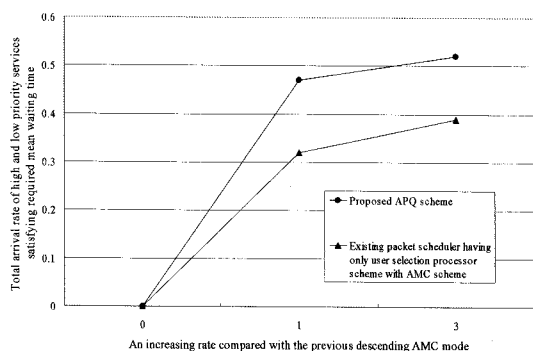
Fig. 7. The total arrival rate of high priority and low priority services satisfying the required mean waiting time (0.2 for high priority service and 0.4 for low priority service) vs. an increasing rate compared with the previous descending AMC mode ("1" means the ratio of weighting factor A is 1:2:3:4 and "3" means that the ratio of weighting factor A is 1:3:6:9) in the proposed APQ scheme and the existing packet scheduler having only user selection processor with AMC scheme.

The results of Fig. 5 and Fig. 6 can be summarized as Fig. 7 in terms of total arrival rate of high and low priority services when the ratio of total service rates of the AMC mode 2, AMC mode 3, and AMC mode 4 based on normalized AMC mode 1 is 1:2:3:4 and 1:3:6:9 respectively, in other words, an increasing rate of 1 (1:2:3:4) and 3 (1:3:6:9) compared with the previous descending AMC mode. From Fig. 5 and Fig. 6, if the required mean waiting time for high priority and low priority services is 0.2 and 0.4, respectively, the arrival rates meeting the requirements are 0.47 for the proposed APQ scheme and 0.32 for the existing packet scheduler having only user selection processor with AMC scheme in case of an increasing rate of 1 compared with the previous descending AMC mode and 0.52 for the proposed APQ scheme and 0.39 for the existing packet scheduler having only user selection processor with AMC scheme in case of an increasing rate of 3, respectively. Thus, Fig. 7 shows that the increasing rate of the arrival rate satisfying the required mean waiting time per each service increases as increasing rate compared with the pre-

vious descending AMC mode increases from 1 to 3. As a result, it means that the proposed APQ scheme has better performance than the existing packet scheduler having only user selection processor scheme with AMC scheme in terms of total arrival rate (the number of services) satisfying the required mean waiting time.

6. CONCLUSIONS

In wireless network supporting multimedia applications, packet scheduling algorithm requires considering both user selection process in variable wireless channel and service type selection process in multimedia services at the same time. This paper introduces the numerical analysis about the downlink proposed AMC-based priority queuing (APQ) scheme which enables multimedia services to be processed on the basis of both user selection by different SIR value per user and service selection by differentiated priority per each service. As a result, the proposed APQ packet scheduling scheme considers the PQ scheme and the adaptive modulation and coding (AMC) scheme at the same time. Particularly, the result of numerical analysis shows that the APQ scheme can secure the reduction in the mean waiting time regarding the high priority services such as real-time (RT) traffic that is sensitive to delay. Therefore, the APQ scheme increases the number of services satisfying the QoS requirements per each service.

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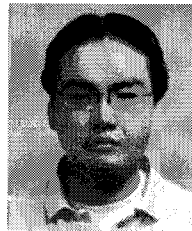
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