AN EFFICIENT SCHEDULING ALGORITHM FOR QOS IN WIRELESS PACKET DATA TRANSMISSION

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Abstract - In this paper, we proposed an efficient packet scheduling scheme, where the tradeoff of channel condition and QoS(quality of service) is factored according to the user traffic. It can be performed by adding the exponent term to the part of DRC(data rate control) which indicates the channel condition, in the proportional fair algorithm. With measuring the current level of supporting the QoS and controlling the DRC exponent, the proposed scheme can enhance the overall throughput without violating the QoS threshold.

Keywords - DRC exponent rule, packet scheduling, proportional fair, QoS

I. INTRODUCTION

In wireless data transmission systems, efficient use of forward link gets more attention realizing that asymmetric properties of data. One of the key issues for better utilization of scarce radio resources is an appropriate scheduling of users in order to enhance the throughput. A good scheduling algorithm may guarantee the fairness or the QoS of each service with considering the time-varying channel condition of each user. Several such algorithms are suggested and investigated on their usefulness in the wireless networks. In such systems as HDR (High Data Rate, also known as 1xEV-DO) [1] or HSDPA (High Speed Downlink Packet Access) [2], rate control and time-division scheduling algorithms are used in forward link packet data transmission to utilize the radio resource effectively and support the high transmission rate. Other than the simple RR (round robin) scheme and max CIR(carrier-to-interference ratio) scheme, which focus on one side of the fairbe shown ness and channel condition, respectively, a proportional fair algorithm is suggested by considering the channel condition and the fairness effectively where a user with better channel condition and less frequent service can be selected [3]. Also, various methods, adequate for the new classes of applications that require the QoS assurance are suggested. For example, M-LWDF (modified largest weighted delay first) algorithm considering both the proportional fairness and the QoS is proposed [4].

However, there has been no discussion about the QoS margin, the surplus value in QoS requirement, and its usefulness. Provided current level of QoS is higher than that of required one for all users, that is the Qos margin is positive for all users, by increasing the weighting factor of channel condition, overall system throughput can be increased. In this paper, we proposed an efficient packet scheduling scheme, where the tradeoff of channel condition and QoS is factored according to the user traffic. Thereby, overall throughput can be increased with the graceful QoS degradation of users under severe channel condition. It can be performed by adding the exponent term to the part of DRC which indicate the channel condition, in the proportional fair algorithm.

The paper is organized as follows. In Section II, we briefly review the proportional fair algorithm and suggest the proposed DRC exponent rule with the asymptotic analysis of the DRC exponent rule describing the effect of the exponent value to the system throughput. Section III presents an algorithm, a version of DRC exponent rule in the real-time service that the QoS should be assure. In Section IV, system throughput of the proposed scheme is investigated with various QoS's and environments. Concluding remarks are given in Section V.

II. A MODIFIED PROPORTIONAL FAIR ALGORITHM (DRC EXPONENT RULE)

A. Proportional Fair Algorithm

The max CIR rule, an algorithm based on priority given just by the CIR, would schedule the user whose channel can support the largest data rate. Though the rule can be the best solution to maximize the system throughput, the problem of the fairness can arise. In HDR system, to balance the system throughput and fairness effectively, proportional fair algorithm is suggested [5],[6]. We can consider a version of this rule, given by

$$j = \text{arg max}_i \frac{DRC_i(t)}{R_i(t)}, \quad i = 1, ..., N, \tag{1}$$

where j is the selected user for the next slot, N is the number of the users, $DRC_i(t)$ is the DRC at slot t for user i and $R_i(t)$ is the average received rate updated at slot t. This algorithm gives equal allocation time to users who only differ in the mean path loss, their fading characteristics being the same provided the equal power is transmitted. Also it takes advantage of channel variations by selecting with the higher probability when the channel condition is relatively better than the average value for each user.

This work was supported by the grant from SK Telecom, Korea.

B. *DRC Exponent Rule*

Proportional fair algorithm can make a good comprise between the throughput and the fairness, where the weighting factors of the throughput and the fairness are the same as in (1). Now let consider the parameter which can control the weighting factor. The system could be operated more efficiently by changing the parameter. In this paper, a modified scheduling scheme is proposed, named as 'DRC exponent rule', which is given by

$$j = \text{arg max}_i \frac{DRC_i^n(t)}{R_i(t)}, i = 1, ..., N, \tag{2}$$

where n is the control parameter. If n is lower than 1, the allocated time to the users of better channel quality decreases and for each user, relatively bad channel condition is allocated compared with the proportional fair algorithm. So, it can be undesirable in the system operation with the value of n lower than 1 and we consider the case when n is equal to or higher than 1 in this paper.

C. *Asymptotic Analysis*

To have simple interpretation of the algorithm, let's take the following assumptions which are similar to those in [5].

- DRC of user i is $a_i b_i(t)$, where a_i is average DRC and $b_i(t)$ is the variant component of the DRC of each user, is iid's from slot to slot. The pdf of $b_i(t)$ is assumed to be chi-square, so the pdf of $DRC_i(t)$ is given by,

$$p_x(X) = \frac{1}{2a'_i} e^{-\frac{x}{2a'_i}}. \tag{3}$$

- Scheduling and transmission is performed at every slot, and once transmitted, the data can be correctly recovered.
- Throughput of user k is stationary (with the throughput window of infinite length).

For the simple expansion, users are classified as the two groups in [5].

$$\begin{aligned} DRC_{1,j}(t) &= a'_1 b_{i,j}(t), j = 1, .., N_1 \\ DRC_{2,j}(t) &= a'_2 b_{2,j}(t), j = 1, .., N_2. \end{aligned} \tag{4}$$

Because the users in the class has the same independent distribution, the stationary throughput converged to the same value. Let the values be T_1 and T_2 for each class and r be the ratio (T_1/T_2). Then the ratio of the total class throughputs are represented as

$$\frac{T_1 N_1}{T_2 N_2} = \frac{P\{X_1 > r^n X_2\} E[X_1 | X_1 > r^n X_2]}{P\{X_2 > r^{-n} X_1\} E[X_2 | X_2 > r^{-n} X_1]}, \tag{5}$$

where

$$X_1 = max_j\{a'_1 b_1, j(t)\}, j = 1, ..., N_1$$
$$X_2 = max_j\{a'_2 b_2, j(t)\}, j = 1, ..., N_1.$$

The pdf of the X_1 and X_2 can be obtained as

$$\begin{aligned} f_{x_i}(X_i) &= \frac{d\left(F_{x_i}^{N_i}(X)\right)}{dx} \\ &= -a_i \sum_{k=1}^{N_i} A_k e^{-k a_1 x}, \end{aligned} \tag{6}$$

where $F_{x_i}(X)$ is the cdf of DRC of the users in class i, A_k is ${}_{N_1}C_k(-1)^k$ and a_i is $2a'_i$. Equation (5) is a fixed point equation $r = f(r)$ and there is a unique fixed point for positive r [7]. Then the numerator of $f(r)$ is evaluated as

$$\begin{aligned} N &= N_2 \int_0^\infty a_2 \sum_{l=1}^{N_2} A_l e^{-l a_2 x_2} \\ &\quad \int_{r^{\frac{1}{n}} x_2}^\infty x_1 a_1 \sum_{k=1}^{N_1} A_k e^{-k a_1 x_1} dx_1 dx_2 \\ &= a_2 N_2 \sum_{k=1}^{N_1} \sum_{l=1}^{N_2} A_k A_l l \left[\frac{2 a_1 k r^{\frac{1}{n}} + a_2 l}{a_1 k \left(a_1 l r^{\frac{1}{n}} + a_2 l \right)^2} \right] \end{aligned} \tag{7}$$

By the similar manner, the denominator is represented as

$$D = a_1 N_1 \sum_{k=1}^{N_1} \sum_{l=1}^{N_2} A_k A_l k \left[\frac{2 a_2 l r^{-\frac{1}{n}} + a_1 k}{a_2 l \left(a_2 l r^{-\frac{1}{n}} + a_1 k \right)^2} \right] \tag{8}$$

And the ratio r is derived as the following equation.

$$r = \frac{a_2 N_2 \sum_{i=1}^{N_1} \sum_{j=1}^{N_2} A_i A_j j \left[\frac{2 a_1 i r^{\frac{1}{n}} + a_2 j}{a_1 i \left(a_1 i r^{\frac{1}{n}} + a_2 j \right)^2} \right]}{a_1 N_1 \sum_{i=1}^{N_1} \sum_{j=1}^{N_2} A_i A_j i \left[\frac{2 a_2 j r^{\frac{1}{n}} + a_1 i}{a_2 j \left(a_2 j r^{\frac{1}{n}} + a_1 i \right)^2} \right]} \tag{9}$$

For the case of $N_1 = N_2 = 1$, the following result can be obtained.

$$r = \frac{a_2}{a_1} \left[\frac{2 a_1 a_2 r^{1/n} + a_2^2}{2 a_1 a_2 r^{1/n} + a_1^2 r^{2/n}} \right] \tag{10}$$

which become the following value when n goes to the infinite.

$$r = \frac{a_2^2 (2a_1 + a_2)}{a_1^2 (2a_2 + a_1)} \tag{11}$$

The existence of the upper bound of the ratio means that the DRC exponent rule practically cannot approaches to the max CIR rule with increase of n. So the minimum throughput for the users of worse channel condition can be reserved, though it is lower than that in the case of proportional fair rule.

Fig.1 shows the relationship between the throughput ratio, r and the DRC exponet, n. If $a_1 = a_2$, where the pdfs of the DRC for the users are the same, r and system throughput are not changed regardless of the value of n. But except the case, With the increase of n, the user of better channel quality is selected more and r increases the the increasing slope decreases. Also, it can be noticed that the slope relatively high when a_1 is large. By increasing n, also the better system throughput, defined by $(T_1N_1 + T_2N_2)/(N_1 + N_2)$ can be obtained. In Fig.2, it can be shown that the system throughput is increased with the increase of n except for the case when $a_1 = a_2$. Also the larger the slope of the total throughput, the larger a_1 and n. Fig.3 shows the throughput ratio with different N_1 when $n = 3$. If N_1 increases, the effect of user diversity increases and throughput increase in the users of class 1 also increases, which means the probability that the user in class 1 is selected increases. In Fig.4, the total throughput with variant N_1 is shown with the same condition in Fig.3. As N_1 increases, the total system throughput increases because the probability of selecting the user in the better channel quality increases.

III. DRC EXPONENT RULE WITH QOS MEASUREMENTS

The proportional fair algorithm described in section II is one of the options for the best effort data traffic which utilizes asynchronous channel variation to improve the overall system throughput with considering the fairness. However, this algorithm is not adequate for the real-time services which requires minimum throughput or delay bounds, by which the QoS of each service should be concerned. So the algorithms considering the requirements are suggested and investigated on their usefulness in the wireless networks whose the forms are represented in general as

$$j = \arg\max_i \frac{DRC_i(t)}{R_i(t)} f_Q\left(QoS_{req_i}, QoS_{cur_i}\right), i = 1, ..., N, \quad (12)$$

where QoS_{req_i} and QoS_{cur_i} denote the required QoS and currently serviced QoS for user i, respectively and $f_QoS(.)$ is the monotonically increasing function as the level of the QoS requirements. In (12), the part of the proportional fair and the QoS are contained with equal priority. If we modify the rule by the same manner form (1) to (2), inserting the control parameter in DRC, the rule becomes

$$j = \arg\max_i \frac{DRC_i^n(t)}{R_i(t)} f_Q\left(QoS_{req_i}, QoS_{cur_i}\right), i = 1, ..., N, \quad (13)$$

Now we have the problem of how the value of n can be changed more effectively. One of the desirable ways is to increase the system throughput with guaranteeing the QoS of each user. In (13), n can control the relative weighting factor of DRC, which increase the system throughput with unavoidable decreasing the throughput of the users in bad channel quality.

If QoS margin denotes the level of the QoS requirements. The suggested scheme can be described as following.

- Measure the QoS margin of each user
- If QoS margin's are positive for all users, increase n by the step size. Else, set n to 1
- n has the maximum value.

The step size and maximum values of n are given so that avoid rapid degradation in the QoS margin and unstable operation. If there is at least one user whose QoS margin is lower than 1, the rule operate as the conventional scheme with setting n to 1.

IV. SIMULATION MODEL AND RESULTS

The QoS of a data can be defined in different ways. In this paper, for the simple investigation, one constraint that the average throughput R_i provided to user i be not less than some predefined value Q_i is concerned and let f_Q be Q_i/R_i. The DRC of user i is $a_i'(t)b_i(t)$ as (3), while $a_i(t)'$s are given as following.

$$a_i'(t) = i + \frac{ratio - 1}{N}, i = 1, ..., N \quad (14)$$

where N is the number of total users and $ratio$ is a'_N/a'_1, that is the ratio of the best averaged channel condition to the worst one. a_1 is 1 and with one increase of user index, a_i is increased by $\frac{ratio-1}{N}$. If ratio is 1, a_i's are all the same as 1. Also, three QoS requirement cases (linear, equal, inversely proportional) are considered. With different ratios and QoS requirement cases in Table I, variant environments can be investigated. Following figures show the results without n (can be considered as conventional scheme), and with variant n (proposed scheme, with step size : 1 dB and maximum of n : 10). In Fig.5, throughput of each user of linear case is provided when Q_1 is set to 0.1 with variant $ratio$. Fig.5 indicates the performance difference cannot be shown between the schemes when the capacity cannot cover the QoS requirements ($ratio$ is 1 or 3). But there are some overall throughput increase with the degradation of QoS in the users of bad channel when the capacity covers the QoS requirements ($ratio$ is 5 or 7) while the QoS requirements are still guaranteed. In Fig.6, overall throughput vs. $ratio$ is shown with adopting the three rate request cases (in all cases, the capacity covers the requirements) and it can be noticed that the proposed scheme always give the better performance.

Table 1
QoS requirements cases

cases	QoS requirements
linear case	$Q_1 \cdot i$
inversely linear case	Q_1/i
equal case	Q_1

V. CONCLUSIONS

With the modified rule containing the DRC exponent, the proposed scheme can utilize the channel condition more effectively while guaranteeing the QoS. The effect of the exponent and the number of users are analyzed asymptotically with some assumptions. Simulation results show that overall throughput can be increased by the proposed scheme when there exists some margin in QoS.

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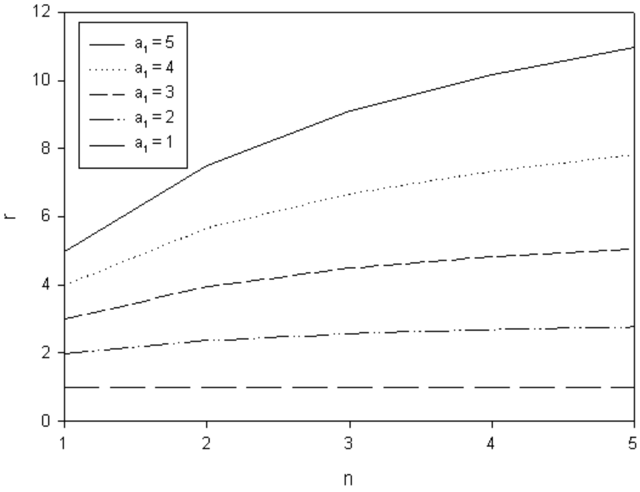

Fig. 1. Throughput ratio(r) vs. n when $N_1 = N_2 = 1$ and $a_2 = 1$.

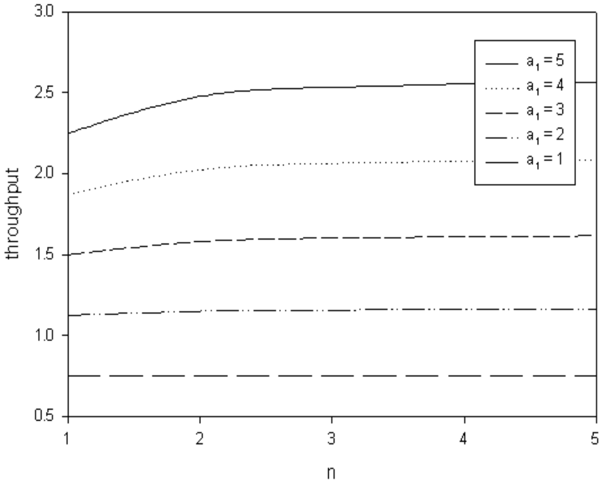

Fig. 2. Total throughput when $N_1 = N_2 = 1$ and $a_2 = 1$.

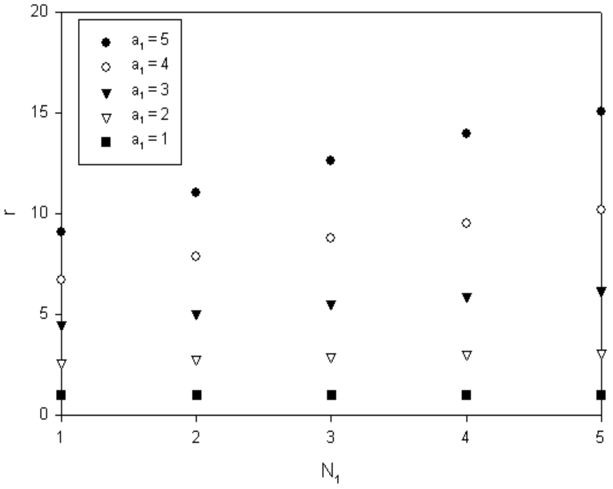

Fig. 3. Throughput ratio(r) vs. N_1 when n=3, $N_2 = 1$ and $a_2 = 1$.

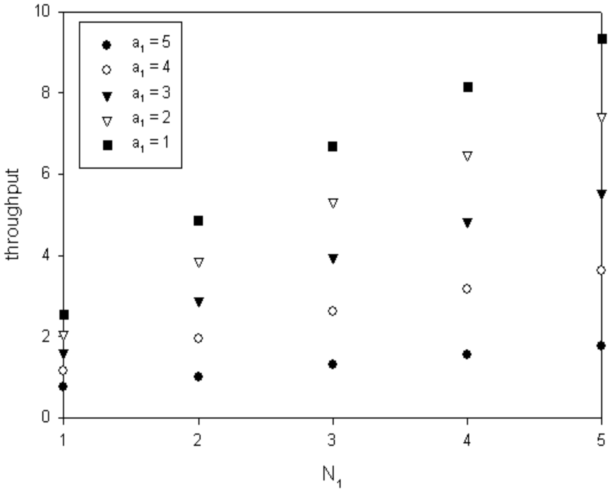

Fig. 4. Total throughput vs. N_1 when n=3, $N_2 = 1$ and $a_2 = 1$.

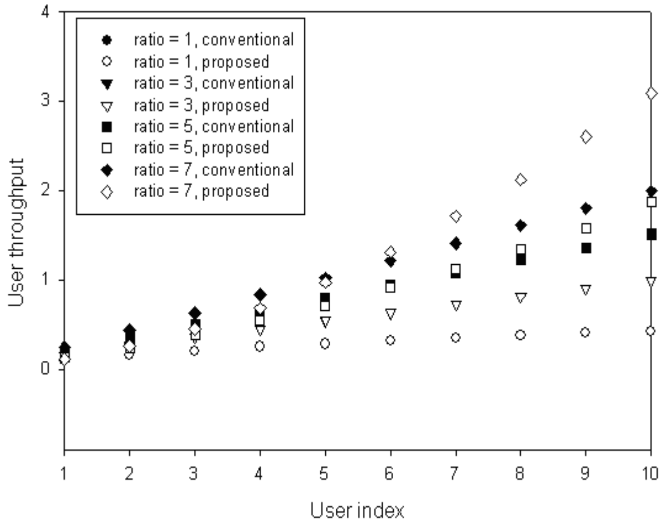

Fig. 5. User throughput vs. user index with linear rate requirement case

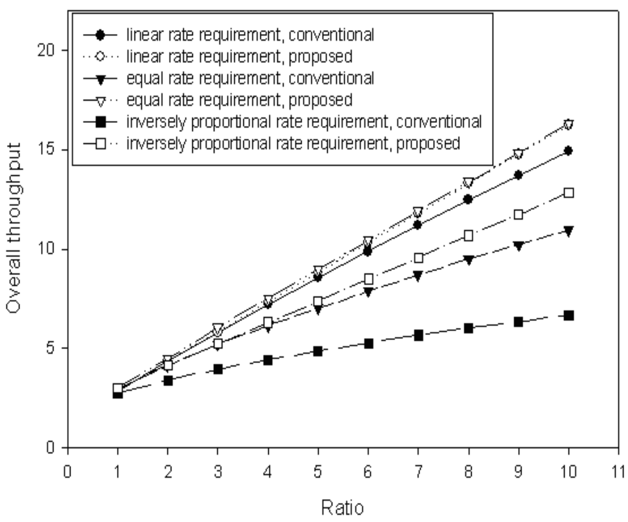

Fig. 6. Overall throughput vs. $ratio$ with different QoS requirement cases