CDMA기반 고속 패킷 데이터 전송 시스템을 위한 전력제어가 결합된 스케줄링 알고리즘☆

A Joint Power Allocation and Scheduling Algorithm for CDMA-based High-rate Packet Data Systems

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요 약

고속 데이터 전송 서비스를 지원하는 1xEV-DO와 같은 CDMA 기반 패킷 전송 시스템들에서 각 기지국은 최대 전송 전력을 가지고 시간분할다중화방식을 이용하여 데이터 패킷들을 전송한다. 따라서 특정 시간에 한 사용자만이 시스템 내에서 서비스를 받을 수 있다. 본 논문에서는 1xEV-DO와 같은 CDMA기반 고속 패킷 데이터 전송 시스템을 위한 전력제어가 결합된 스케줄링 알고리즘을 제안한다. 제안된 알고리즘은 하향링크 공동 채널에서 채널 직교성을 이용하는 코드분할다중화전송기법을 채택하여, 스케줄러에 의해 선택된 첫 번째 사용자가 요구하는 서비스를 지원하고 남은 여분의 자원이 있는 경우 이를 활용하여 주어진 시간에 다른 사용자를 지원할 수 있다. 모의실험을 통하여 제안된 방식이 최대전송률 기반 스케줄링 알고리즘과 같은 기존 스케줄링 알고리즘의 성능을 향상 시킬 수 있음을 보였다.

Abstract

In the case of CDMA-based packet data systems such as 1xEV-DO which are designed to support high rate services, BSs transmit data packets with a maximum power based on time multiplexing mode such that only one user can be serviced at a time. In this paper, we propose a joint power allocation and scheduling algorithm for 1xEV-DO-like systems in which we adopt a code division multiplexing (CDM) transmission method in the downlink common channel in order to utilize channel orthogonality such that we can serve more than one user at a time slot especially when there exist remaining resources after serving the firstly selected user by the scheduler. Simulation results demonstrate that the proposed scheme can improve the performances of conventional schemes such as the maximum rate and the proportional fair algorithms.

☞ Keyword : power allocation, scheduling algorithm, High-rate packet data systems

I. Introduction

CDMA-based high-rate packet data systems such as 1x radio transmission technology EVolution high-speed Data Only (1xEV-DO) and High Speed Downlink Packet Access (HSDPA) adopt common shared channels in the forward link in order to provide a high bit rate packet data service and an improved throughput. For example, 1xEV-DO systems adopt the Forward Packet Data CHannel (FPDCH)[1] while HSDPA systems use the High Speed Downlink Shared CHannel (HS-DSCH)[2]. These common shared channels are capable of supporting high bit rate by employing adaptive modulation and coding

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with hybrid automatic request, turbo codes and transmit diversity. One of the most distinct features of these common shared channels however is to adopt rate adaptation and to service multiple packet data users based on time multiplexing mode. In addition, a mix of services with different requirements is expected to be serviced in the context of next generation CDMA systems. In order to support the quality of various services through the common shared channels, efficient Medium Access Control (MAC) protocols are necessary. More specially, it is expected that a scheduling algorithm among MAC protocols plays an important role in the common shared channels since it controls the allocation of the shared resources among users and to a large extent determines the overall behavior of the system.

Recently, many works have been done regarding scheduling algorithm for common shared channels in order to increase total throughput and to guarantee Quality of Service (QoS) requirements of users [3,4,5]. A proportionally fair scheduling algorithm proposed in [3] takes advantage of short-term channel variations while at the same time maintaining almost same long-term throughput among all users such that it can increase system throughput and achieve some degree of fairness among users. As a variant of the proportional fair scheduling algorithm, 4 et. al. suggested an algorithm to provide priority for users by introducing weighting factor [4]. Ofuji et. al. also proposed a new fast packet-scheduling algorithm based on instantaneous received signal-to-interference power ratio with a constraint condition assuring minimum throughput where the maximum Carrier-to- Interference power ratio (CIR) and the proportional fair scheduling methods are combined to overcome the disadvantages of the maximum CIR scheduling method and the proportional fair scheduling simultaneously [5]. The scheduling algorithms [3,4,5], however, basically exploit time-varying channel conditions to make a scheduling decision. That is, the previous works only utilize the data-rates requested by the Mobile Station (MS)s based on the their channel information while ignoring the aspects of queuing by assuming that all buffers are always full. In most cases, the system does not operate at the fully loaded condition, and the traffic load changes time to time. It implies that there are not always enough data packets to send in the queue of each user such that for a certain time, the demanded data rate to transmit current packets in the queue can be less than the feasible data-rate requested by the MS. In this situation, we can waste system resources by allowing more transmission power than the demanded one if we assign the resource only based on the feasible data-rates requested by MSs.

With the motivation of this idea, we in this paper suggest a joint power allocation and scheduling algorithm which utilizes both queueing information of Base Station (BS) and channel information of each MS, and further uses Code Division Multiplexing (CDM) in the downlink common shared channel. In the proposed scheme, if the demanded data rate of the user who is selected by the scheduler is less than the feasible data rate requested by MS (i.e., in aspects of transmission power, it corresponds to the facts that the demanded power is less than the maximum power level of BS), then scheduler enters into the CDM mode where the BS calculates a proper power level to send data packet of the selected user and further selects another user who can utilize the remaining power most efficiently. Finally, the BS will send data packets through CDM transmission and MSs receive their packets from the serving BS.

The rest of the paper is organized as follows. In Section II, we review the operation of conventional 1xEV-DO-like systems. In Section III, we present the proposed algorithm where the scheduling algorithm and power allocation are combined through CDM transmission in the downlink common shared channel. In Section IV, we show simulation results, and finally draw conclusions in Section V.

II. Conventional 1xEV-DO-like Systems

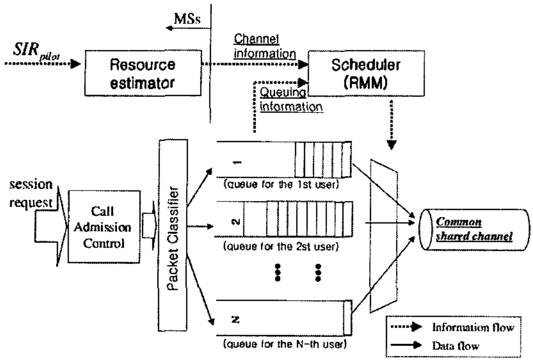
In this paper, we consider the common shared channel of 1xEV-DO system, namely Forward Packet Data CHannel (FPDCH). It consists of a single data channel that is divided into 1.667ms time slots. Two pilot bursts are inserted into each time slot to aid synchronization, Signal to Interference plus noise Ratio (SIR) estimation and coherent demodulation. Control channels and user payload are time-multiplexed onto the forward link.

Pilot burst is transmitted by a constant power from each BS and aids in synchronization and SIR prediction at MSs. Then, each MS measures the pilot-signal SIR, and determines the feasible data-rate that can be supported in the current channel state, based on the quality of the received signals. Channel information such as feasible data-rate and the received SIR level is also reported to BS by each MS through the Data Request Channel (DRC), one of the reverse link channels. For example, Table.1 shows the data-rate of traffic channel under consideration.

On the side of BS, the scheduler makes a decision on which user will be chosen for the next transmission slot by utilizing channel information of each MS as well as queue information of BS. And then, the BS transmits data packets to the selected user with the requested data rate. Fig. 1 shows overall schematic structure of the system being considered.

〈Table 1〉 Lookup table for the required SIR of the pilot signal and corresponding data rate.

Data rate (kbps)	the required SIR [dB] of pilot signal for 1% FER in AWGN
38.4	-12.5
76.8	-9.5
153.6	-6.5
307.2	-4.0
614.4	-1.0
921.6	1.3
1228.8	3.0
1843.2	7.2
2457.6	9.5



〈Figure 1〉 Overall structure of 1xEV-DO-like systems.

III. A joint power allocation and scheduling algorithm

In order that a scheduler make an appropriate decision on which user to be chosen for the next transmission slot, information on the channel of MSs as well as on the queues of each user at BS is needed as like Fig. 1. The channel information of each MS is the feasible data-rate, which can be supported by each MS under the current channel condition, while the queue information of BS is the number of packets to send and packet delay of respective queue for each user. By using information about individual data steams, together with information about channel characteristics of different MSs, the scheduler makes a plan for the transmission so that the system performance will be maximized while QoS requirements of each user are satisfied. In the previous works[3,4,5], the scheduler only utilized the feasible data-rates requested by MSs while ignoring the aspects of queuing by assuming that all buffers are always full. This approach however can waste system resource by assigning more power than the needed one especially when the demanded data rate is less than the feasible data rate. In this section, we present a scheduling algorithm which utilizes both the queueing information in BS and the channel information of each MS, and further uses code division multiplexing (CDM) in the downlink common shared channel.

A. Feasible data rate

Mobile stations measure the SIR of the pilot signal transmitted from BS. Since the pilot signals are transmitted by the same transmission power at each BS, the SIR of the pilot signal, SIR_{pilot} from the j-th BS at the i-th MS can be expressed as

$$SIR_{pilot}(i) = \frac{P_{pilot} \cdot L(d_{i,j})}{\sum_{k=1,k\neq j}^{K_b} P_{pilot} \cdot L(d_{i,k})} = \frac{L(d_{i,j})}{\sum_{k=1,k\neq j}^{K_b} L(d_{i,k})} \quad (1)$$

where P_{pilot} is the transmission power of the pilot signal, $L(d_{i,j})$ is the path loss from the j-th BS to the i-th MS, and K_b is the number of BSs in the service area. Here we assume that the path loss of forward link between the i-th MS and the j-th BS, $L(d_{i,j})$ is characterized by $d_{i,j}^{-l} \cdot 10^{\xi/10}$ where l is the pass-loss exponent, ξ is a gaussian distributed random variable with zero mean and station deviation σ to consider the effect of shadow fading. Typically, σ takes the value of 6 to 10 [dB] for signals from adjacent BSs and that of 2 to 2.5 [dB] for signals from home BS.

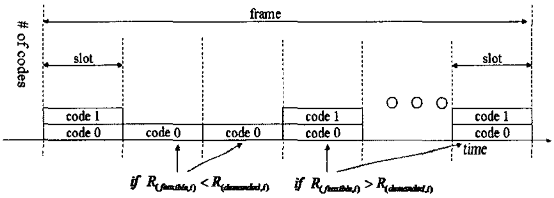
Since 1xEV-DO-like systems basically adopt the rate control scheme, the assigned data rate to a user depends on the received SIR of the pilot signal. The highest data rate is assigned to each user as long as the received SIR of the pilot signal is larger than the required SIR. The required SIR value of the pilot signal $SIR_{plt_{req}}$, which is necessary to meet the target frame error rate (FER). e.g., 1% FER, can be calculated through off-line simulations under AWGN conditions [1,4,7]. Here we adopt the results of [1,7], and summarize the main results in Table. 1. Then, each MS can calculate the required E_b/N_o, $(E_b/N_o)_{req}$ of the common shared channel based on the required SIR value of the pilot signal, $SIR_{plt_{req}}$ and the processing gain. Further, each mobile can estimate the feasible data rates after calculating the received E_b/N_o of the common shared channel by measuring the pilot signal such that the feasible data rate of user i, $R_{feasible,i}$ with the maximum transmission power of BS can be calculated as

$$R_{feasible,i} \leq W \cdot \frac{(SIR)_{pilot}}{(E_b/N_o)_{req}} \tag{2}$$

where $(SIR)_{pilot}$ is the received SIR of the pilot signal, W denotes the spreading bandwidth, and $(E_b/N_o)_{req}$ is the required E_b/N_o of the common shared channel to keep the frame error rate below than the target value.

B. Demanded data rate

The demanded data rate of each MS, $R_{demanded}$ depends on the amount of the packets to send in each respective queue. For example, if there are two packets with packet length of 1024 bits in the queue of the i-th user, then the demanded data rate of the i-th user is about 1.2288M *bps* when one time slot duration is 1.667 ms. In a certain time, the demanded data rate could be less than the feasible data rate according to the number of packets in the respective queues.



〈Figure 2〉 Code division multiplexing transmission in the common shared channel.

C. The proposed algorithm

In the proposed scheme, if the demanded data rate of the user who is selected by scheduler is less than the data-rate requested by the MS (i.e., in aspects of the power, it corresponds to the case that the demanded power is less than the maximum transmission power of BS), then the BS calculates a proper power level to send data packets of the selected user successfully and the remaining power will be assigned to another user who can utilize the remaining power most efficiently. Finally, the BS will send data packets by CDM and MSs receive their packets from the serving BS. Fig. 2 shows an example of the code division multiplexing transmission in the common shared channel. The main procedure of the proposed scheme also can be described as following:

- With the information on both the channel of each MS and the queue of BS, the scheduler selects the user, $\hat{i}$ for the next transmission who can maximize the objective function of the scheduler, δ_i. That is, $\hat{i}=\arg\{\max(\delta_i)\}$. The objective function, δ_i can be various according to the scheduling algorithm employed in BS.

- If the feasible data-rate of the selected user $\hat{i}$ is smaller than the demanded data-rate, then the BS transmits data packets of the user $\hat{i}$ with the maximum power as like the operation of conventional 1xEV-DO-like systems. Otherwise, the scheduler enters into the CDM mode in which BS calculates the power fraction of user $\hat{i}$ and the left power $(1-\phi(\hat{i}))$ will be allocated to another user who can utilize the remaining power most efficiently. More detailed description for the CDM mode is also as following:

- In the CDM mode, we calculate the proper power level to send the data packets of user $\hat{i}$ successfully. When the radio channel is static during a frame, the E_b/N_o of the packet that will be received in the following time slot from the BS j at the $\hat{i}$-th MS, $E_b/N_o(\hat{i},j)$ can be expressed by

$$E_b/N_o(\hat{i},j)=\frac{\phi_A(\hat{i})P_{total}(j)L(d_{\hat{i},j})\frac{W}{\min(R_{feasible,\hat{i}},R_{demanded,\hat{i}})}}{\left((1-\overline{F_o})(1-\phi_A(\hat{i}))P_{total}(j)L(d_{\hat{i},j})+\sum_{k=1,k\neq j}^{K}P_{total}(k)L(d_{\hat{i},k})\right)} \quad (5)$$

where $P_{total}(j)$ is the total transmission power at the j-th BS, $\phi_A(\hat{i})$ is a ratio of transmission power for the $\hat{i}$-th MS to the total transmission power $P_{total}(j)$, and $\overline{F_o}$ is an average orthogonality factor defined as the fraction of total received power that will be experienced as intra-cell interference due to the multi-path propagation. The $\overline{F_o}$ is 1 for perfect orthogonality and 0 for non-orthogonality. Here we can assume that $P_{total}(j)$ is the same for all BSs. Then, $E_b/N_o(\hat{i},j)$ can be estimated by using the following equation:

$$E_b/N_o(\hat{i},j)=\frac{W}{\min(R_{feasible,\hat{i}},R_{demanded,\hat{i}})}\cdot\frac{\phi_A(\hat{i})SIR_{pilot}(\hat{i})}{(1-\overline{F_o})(1-\phi_A(\hat{i}))SIR_{pilot}(\hat{i})+1} \quad (4)$$

Assuming that data packet is successfully received at MS when its received $E_b/N_o(\hat{i})$ is greater than the required E_b/N_o, $(E_b/N_0)_{req}$, we can calculate the condition of $\phi_A(\hat{i})$ in order to correctly receive packets at MS such that

$$\phi_A(\hat{i})\geq\frac{(E_b/N_o)_{req}(SIR_{pilot}(\hat{i})(1-\overline{F_o})+1)}{SIR_{pilot}(\hat{i})((E_b/N_o)_{req}(1-\overline{F_o})+\frac{W}{\min(R_{feasible,\hat{i}},R_{demanded,\hat{i}})})} \quad (5)$$

Hence, the required transmission power $P_{req}(\hat{i})$ for the $\hat{i}$-th MS at the j-th BS can be estimated by using the following equation:

$$P_{req}(\hat{i}) = \phi_A(\hat{i}) \cdot P_{total}(j) \quad (6)$$

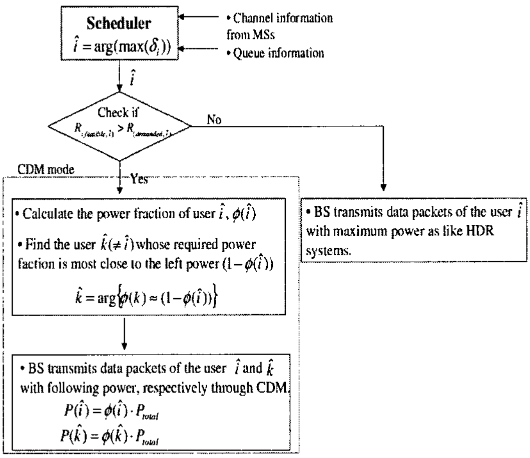
- After that, we find the user $\hat{k}$ ($\hat{k} \neq \hat{i}$) who can fully utilize the remaining power of the j-th BS, $(1-\phi_A(\hat{i})) \cdot P_{total}(j)$. That is, the scheduler selects the user $\hat{k}$ whose required power fraction is most close to the power fraction $(1-\phi_A(\hat{i}))$ such that

$$\hat{k} = \arg\{\phi(k) \approx (1-\phi_A(\hat{i}))\} \quad (7)$$

- Finally, BS transmits the data packets of user $\hat{i}$ and $\hat{k}$ with the following power, respectively.

$$P(\hat{i}) = \phi_A(\hat{i}) \cdot P_{total}(j) \quad (8)$$

$$P(\hat{k}) = \phi_A(\hat{k}) \cdot P_{total}(j) \quad (9)$$

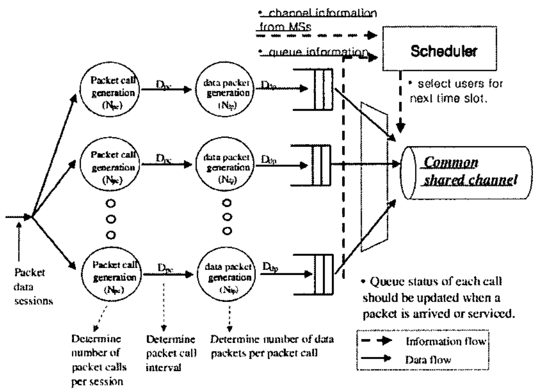


〈Figure 3〉 The flow-chart of the proposed scheme.

In Fig. 3, we show the flow-chart of the proposed scheme. Here it is noteworthy that in the case of CDMA-based high-rate packet data systems such as 1xEV-DO system, the base station transmits the signal of the common shared channel with the maximum power assigned to the common shared channel continuously, without adopting any power control mechanism. The proposed scheme basically shares the maximum power allocated to the common shared channel by the CDM method. Subsequently, it is expected that the effect of the other-cell interference on the system capacity with consideration of the proposed scheme will be similar to that without consideration of the proposed scheme.

IV. Simulation and Results

Fig. 4 shows the schematic of overall simulation environment. As like the figure, multiple sessions are given to the FPDCH.



〈Figure 4〉 Schematic of overall simulation environment.

When data packets of a packet call in each session arrive at a BS, these data packets are buffered in respective queues at BS. According to the scheduling algorithm employed in BS, the service turn for each user is determined and the data packets are packaged as "encoder packet" according to the service rate, after that they are transmitted through the FPDCH. The receiver of each session receives the signals from the FPDCH, and picks up the encoder packet for himself by detecting the preamble sub-channel of the FPDCH. Here we consider the following simulation conditions; • the number of connected sessions are fixed 20, • the buffer size of each queue for each session is 100, • the maximum delay requirement is given 0.1 s, • the average inter-arrival time of packet calls is 15 ms, • the average number of data packets per a packet call varies in order to change the traffic load.

In order to investigate the combined effects of scheduling algorithms with the proposed transmission scheme, we consider two scheduling algorithms; the maximum rate rule and the proportional fair rule [6]. The maximum rate (MR) rule schedules the user whose channel condition can support the largest data rate among users in the next slot such that the scheduler selects the user j who satisfies the following condition

$$j = \arg\{\max_i(\min(R_{feasible,i}, R_{demanded,i}))\} \quad (10)$$

by using the channel information as well as queuing information. The proportional fair (PF) rule proposed for 1xEV-DO[3,6] takes advantage of the short term channel variations while at the same time maintaining almost same long term throughput among all users by taking channel information of each user into account such that it can provide some degree of fairness. More specifically, the PF-based scheduler gives the rights to send data to the user who has the highest $\delta_i(t)$ on each decision epoch.

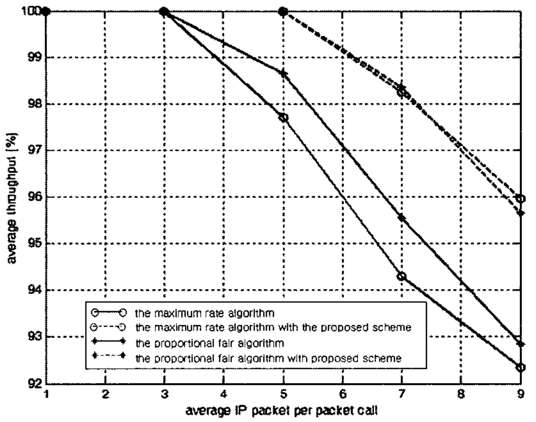
$$\delta_i(t) = \frac{DRC_i(t)}{R_i(t)} \quad (11)$$

where $DRC_i(t)$ is the feasible data rate of the i-th mobile station in a given time slot t, and $R_i(t)$ is the average data rate experienced by the i-th mobile station over a certain window time, t_c and it is updated with following equation.

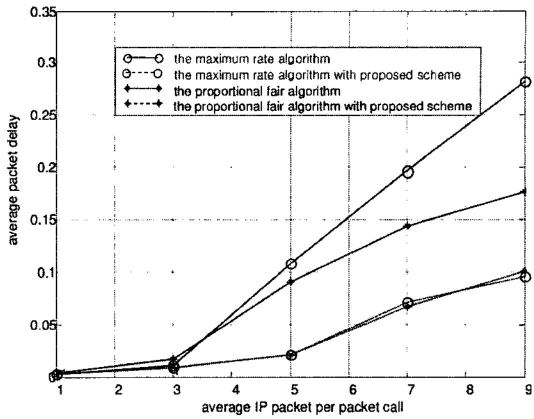
$$R_i(t+1) = (1 - \frac{1}{t_c})R_i(t) + \frac{1}{t_c}r_i(t) \quad (12)$$

where $r_i(t)$ is the current transmission rate of the i-th mobile station and t_c is time constant whose typical value used by the scheduling algorithm is 1000 slots (1.6667 seconds) [6]. The scheduler updates the average transmission rate on each time slot for each mobile station, and a mobile station who is not currently receiving service has 0 for his current rate of transmission.

Fig. 5 shows the average throughput performance as a function of the offered traffic load. Here, the average throughput is defined as the ratio of the number of successfully transmitted data packets to total number of generated data packets. Without considering the proposed transmission scheme, the proportional fair scheduling scheme



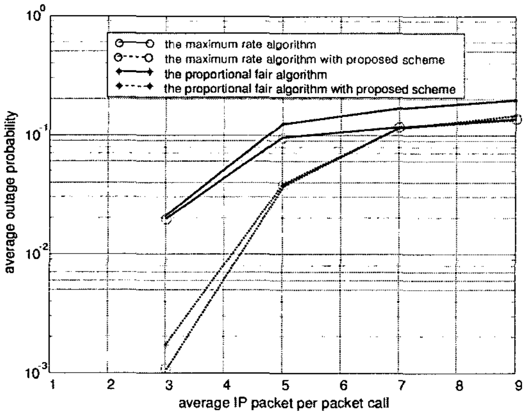
〈Figure 5〉 Average throughput according to the traffic load.



〈Figure 6〉 Average packet delay according to the traffic load.

outperforms the maximum rate scheduling algorithm. By combining the proposed transmission scheme with the employed scheduling algorithm, we can improve average throughput in all cases. In addition, there is a performance gap between the maximum rate algorithm and the proportional fair before the proposed scheme is adopted, but the performance gap becomes small when the proposed scheme is combined, which means that we can reduce the effect of the employed scheduling algorithm on the average throughput performance by fully utilizing the remaining system resource through the proposed transmission scheme.

Fig. 6 shows the average packet delay as a function of the offered traffic load. The average packet delay is defined as the service time that a data packet experiences from the time to arrive at BS to the time when the packet is successfully transmitted to the user. It is also observed that the proportional fair algorithm outperforms the maximum rate algorithm, and that we can improve average packet delay through the proposed transmission scheme. Fig. 6 also shows that the proposed scheme can reduce the effect of the employed scheduling algorithm on average packet delay. It looks unexpected that the proposed scheme can both improve throughput and reduce the packet delay simultaneously since the throughput and packet delay are two contradictory objectives, which needs a trade-off design issue. The reason why the proposed scheme has such nice properties is that the proposed scheme serves another user with the CDM method if the demanded data rate of the firstly selected user by the scheduler is less than the feasible data rate such that the proposed scheme can utilize the remaining system resource fully, and eventually it can improve both throughput and reduce the packet delay simultaneously. On the other hand, the scheduler which does not adopt the proposed scheme, allocates the full resource to the firstly selected user even if its demanded data rate is less than the feasible data rate such that it wastes the system resource. It is however noteworthy that the benefit comes from the more complicated controls in the resource management since the proposed scheme requires a procedure to calculate the remaining resource each time slot, and to find a proper user who can utilize the remaining resource fully.



〈Figure 7〉 Average delay-outage probability according to the traffic load.

Finally, Fig. 7 shows the delay-outage probability according to the traffic load, which is defined as the probability that the delay experienced by a data packet exceeds the maximum delay requirement. In this case, the maximum rate algorithm slightly outperforms the proportional fair algorithm. From Fig. 7, we also know that we can improve the average outage probability for all cases by combining the proposed transmission scheme with the employed scheduling algorithm.

V. Conclusions

In this paper, we have proposed a joint power allocation and scheduling algorithm for CDMA-based high-rate packet data systems. To show the combined effect of the proposed scheme and the scheduling algorithms, we considered the maximum rate and proportional fair algorithms. Simulation results have showed that we can improve the performances of the maximum rate and the proportional fair algorithms by adopting the proposed algorithm. However, the benefits come from the more complicated control in the resource management since the proposed scheme requires a procedure to calculate the remaining resource each time slot, and to find a proper user who can utilize the remaining resource fully. It is also noteworthy that we will get similar performance gains for any kind of scheduling algorithms by combining the proposed scheme as like the cases of the maximum rate and proportional fair algorithms.

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