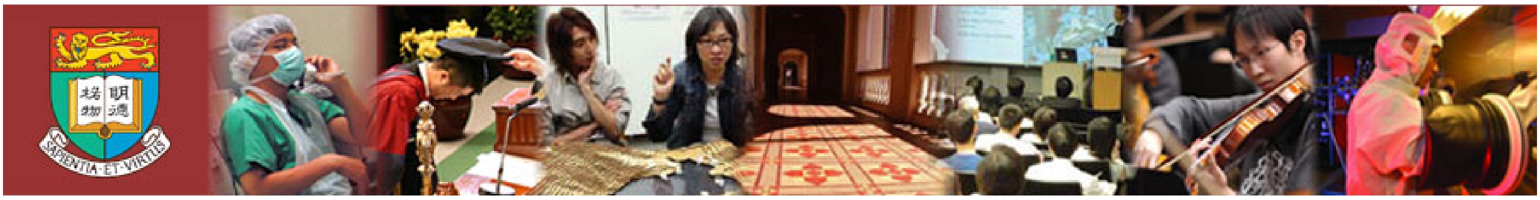

Scheduling Start Time in CDMA Burst Admission

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***Abstract*— Burst transmission protocols have been proposed in the next generation CDMA cellular systems to support short-time high-speed data communications. The existing burst admission algorithm considers only the current interference condition in the system. The burst transmission request will be rejected if the interference in the system will exceed the acceptable level with the burst admitted. In this paper we propose a new burst admission algorithm where a currently-unacceptable burst request can be assigned to start at a later time when the system interference level is lower. The interference prediction is based on the establishing, updating, and exchanging the load and burst scheduling tables among the neighboring cells. Simulations show that our method can reduce the burst blocking probability and improve the system resource utilization.**

I. Introduction

In recent years, there is an increasing need of wireless data services, and new systems and protocols are designed for this purpose, such as the Japanese i-mode system and the Wireless Application Protocol (WAP). Some people even suggest all-packet-data wireless systems where all services are based on packet transmissions, like the current Internet. In this paper we focus on the method of high-speed wireless data transmission proposed in the IS-95-B and cdma2000 standards, where data frames can be transmitted in high-speed *bursts* [1], [2], [3].

Here is a brief description of the burst transmission protocol defined in IS-95-B and cdma2000. (Details of the protocol can be found in [2], [3] or the corresponding standards.) In the reverse link, the user sends to the base station a *supplemental channel request message (SCRM)* to request burst transmission. The base station estimates the increased interference level in the local cell and the neighbor cells from the pilot strength measurements included in the user's SCRM message, and decides to admit the burst request if the interference increase is acceptable, or to reject the burst request otherwise. The decision is transferred to the user as the *supplemental channel assignment message (SCAM)*. In the forward link, the base station may request the user to report pilot strength measurements, then inform the details of the next burst transmission from the base station in the SCAM message.

The burst admission algorithm used in the above protocol is an *instant admission* algorithm in the sense that it uses only the current interference condition to determine burst acceptance. It is possible that a burst request rejected in this way can actually be assigned to start at a later time when the system load is lighter. This requires the prediction of system load into a future time. In fact the burst start time has been included as a parameter in the burst assignment message SCAM, but it can not be assigned by the instant admission algorithm. Appropriate scheduling of burst start time based on load prediction can reduce burst blocking probability and thus improve the system resource utilization, which is the major purpose of this paper.

Before discussing the new burst scheduling algorithm, in the next section we first give a method of estimating the system load and interference level from the number of users and traffic type information. The load prediction and burst scheduling algorithm are introduced in Section III. Section IV gives numerical examples, and the paper is concluded in Section V.

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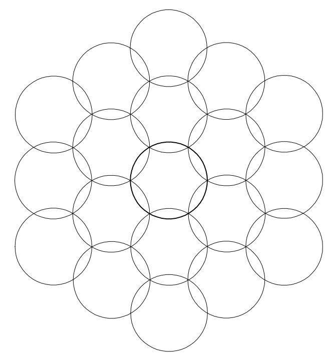

Fig. 1. Cell layout

II. Load Estimation

A. Reverse Link Estimation

Fig. 1 shows the cell layout used in our analysis. We assume circular cells with 60-degree overlap. This is the circular cell layout with the smallest overlapping area while ensuring full coverage. Interference from two tiers of totally 18 neighbor cells is considered in the load estimation.

Let S_{0i} be the received signal power from user i by the base station in the local cell (cell 0), and S_{cj} the received signal power from user j by the base station in a neighbor cell c. When the user signal propagates through the wireless channel, it experiences path loss and shadowing which can be modeled as

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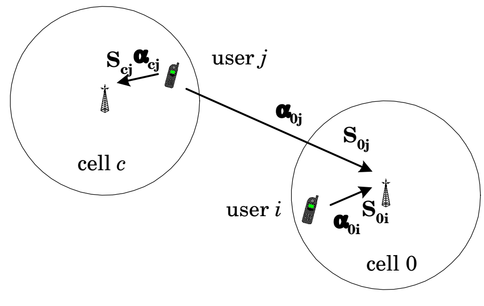
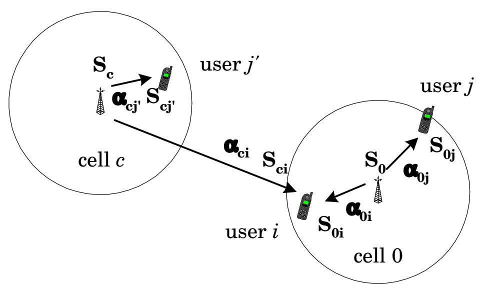


(a) reverse link



(b) forward link

Fig. 2. Power and path loss symbol definitions

[4]

$$\alpha = r^m \epsilon \tag{1}$$

where r is the distance it travels, m the path loss exponent, and ϵ the log-normal shadowing factor with parameters $(0, \sigma_\epsilon^2)$. The interference in the base station of cell 0 from user j in cell c is then equal to (see Fig. 2(a))

$$S_{0j} = S_{cj} \frac{\alpha_{cj}}{\alpha_{0j}} \tag{2}$$

The total interference power received by cell 0, including intra-cell interference, other-cell interference, and thermal noise, can therefore be approximated as[1]

$$I_0 = \sum_{i=1}^{N_0} S_{0i} + \sum_{c=1}^{M} \sum_{j=1}^{N_c} S_{cj} \frac{\alpha_{cj}}{\alpha_{0j}} + n_0 W \tag{3}$$

where N_k is the total number of users in cell k ($k = 0, \ldots, M$), M is the number of neighbor cells in consideration ($M = 18$ in the layout of Fig. 1), n_0 is the thermal noise density, and W is the cell bandwidth.

The limit on the interference power I_0 can be expressed on the ratio of the thermal noise power over I_0 [5]

$$\frac{n_0 W}{I_0} \geq \eta \tag{4}$$

[1] Approximating the total interference power by the total received power is valid when the signal power from any single user is small compared with the total interference.

In order to obtain a constraint on the system traffic from (4), we refer to the bit energy ($E_{b,ki}$) to interference density (i_k) ratio (BIR) parameter of each user i in cell k

$$\gamma_{ki} \triangleq \frac{E_{b,ki}}{i_k} = \frac{S_{ki}}{I_k} \frac{W}{R_{ki}} \quad (i = 1, \ldots, N_k,\ k = 0, \ldots, M) \tag{5}$$

where R_{ki} is the data rate of the user. Note that the interference power I_k and its density $i_k = I_k/W$ are independent of user i. With imperfect fast close-loop power control the BIR of each user deviates from its target value γ_{ki}^* by a log-normal margin [5], or

$$\gamma_{ki} = \gamma_{ki}^* \pi_{ki} \tag{6}$$

where π_{ki} is log-normal with parameter $(0, \sigma_\pi^2)$.

Divide both sides of (3) by I_0, then apply (4) and (5),

$$1 - \eta \geq \sum_{i=1}^{N_0} \frac{R_{0i}\gamma_{0i}}{W} + \sum_{c=1}^{M} \sum_{j=1}^{N_c} \frac{R_{cj}\gamma_{cj}}{W} \frac{I_c}{I_0} \frac{\alpha_{cj}}{\alpha_{0j}} \tag{7}$$

Because the amount of the system resource is assumed to be the same in every cell, for the purpose of high resource utilization it is beneficial to keep the interference level approximately the same among the neighboring cells, i. e. $I_c \approx I_0$ for all c. With this assumption and the definition of

$$\omega \triangleq \sum_{i=1}^{N_0} \frac{R_{0i}\gamma_{0i}}{W} + \sum_{c=1}^{M} \sum_{j=1}^{N_c} \frac{R_{cj}\gamma_{cj}}{W} l_{cj} \tag{8}$$

(7) is simplified as

$$\omega \leq 1 - \eta \quad \text{or} \quad \omega W \leq (1 - \eta) W \tag{9}$$

In (8) $l_{cj} = \alpha_{cj}/\alpha_{0j}$ is the path loss ratio for user i in cell c (as seen from cell 0). ω is a good index of the system load because it includes all the local traffic from the N_0 users in the local cell, and the load on the local base station from all the $\sum_{c=1}^{M} N_c$ users in the neighbor cells. It also contains the quality-of-service (QoS) parameter (BIR γ_{ki}) of different traffic types. We name ω the *virtual bandwidth utilization* of the cell since in (9) ω can be thought as the fraction of cell bandwidth "virtually utilized" by local and neighbor users (although signals from all users are spread over the full bandwidth), and at least a fraction η of the bandwidth has to be left with the thermal noise.

Considering the variable imperfect power control factor π_{ki} (included in γ_{ki}) and path loss ratio l_{ci}, it is more accurate to define a statistical limit for the interference I_0 (in replace of (4))

$$\Pr\left\{\frac{n_0 W}{I_0} < \eta\right\} \leq \delta \tag{10}$$

and hence

$$\Pr\{\omega > 1 - \eta\} \leq \delta \tag{11}$$

in replace of (9). δ is a system parameter called the *outage probability* limit.

To obtain a deterministic constraint from (11), we approximate ω by linearly scaling and shifting the shadowing variable ϵ (included in the path loss ratio l) to produce a new log-normal random variable with the same mean and variance as ω. We have shown in [6], [7] that this log-normal approximation has satisfactory accuracy in approximating the sum and scaling of log-normal random variables such as the shadowing variable. Specifically,

$$\omega \approx m_\omega + (\epsilon - m_\epsilon)\sqrt{\frac{v_\omega}{v_\epsilon}} \tag{12}$$

where m_x and v_x stand for mean and variance of x, respectively, and

$$\begin{aligned} m_\omega &= \sum_{i=1}^{N_0} \frac{R_{0i}\gamma_{0i}^*}{W} m_\pi + \sum_{c=1}^{M}\sum_{j=1}^{N_c} \frac{R_{cj}\gamma_{cj}^*}{W} m_{(l_c\cdot\pi)} \\ v_\omega &= \sum_{i=1}^{N_0}\left(\frac{R_{0i}\gamma_{0i}^*}{W}\right)^2 v_\pi + \sum_{c=1}^{M}\sum_{j=1}^{N_c}\left(\frac{R_{cj}\gamma_{cj}^*}{W}\right)^2 v_{(l_c\cdot\pi)} \end{aligned} \tag{13}$$

The product $(l_c \cdot \pi)$ results in a new random variable, whose moments can be calculated from the moments of l_c and π. Uniform user distribution in the cell is assumed for deriving the moments of the path loss ratio l_c. When soft handoff is considered, l_c has a more complex format than just the division of two path loss variables. The method of finding the mean and variance of l_c is similar to what we did in [7]. Details are skipped to avoid over-length of this paper.

The load constraint is then proved to be

$$u_\omega \triangleq m_\omega + (\tau - m_\epsilon)\sqrt{\frac{v_\omega}{v_\epsilon}} \leq 1 - \eta \tag{14}$$

where

$$\tau = \exp\left[\tfrac{\ln 10}{10}\sigma_\epsilon Q^{-1}(\delta)\right] \tag{15}$$

and $Q^{-1}(x)$ is the inverse function of $Q(x) = \frac{1}{\sqrt{2\pi}}\int_x^\infty e^{\frac{t^2}{2}}dt$.

u_ω is actually the point where the probability of ω exceeding $1-\eta$ is equal to δ. Unlike ω, u_ω has a deterministic value, and is therefore more convenient to be used as the system load index.

B. Forward Link Estimation

In the forward link, a user receives all the signals from the neighboring base stations. The maximum transmission power of a base station can be assumed to be a given value P_{max}. Among this power P_{max} usually a fixed portion β is used for transmitting common control signals for pilot, paging, and synchronization purposes. The remaining part $(1-\beta)P_{max}$ is then used for user signals. In [7] we performed the forward link capacity analysis assuming the same traffic distribution among the cells. In the following we will extend this work by analyzing the forward link capacity and interference with a more general traffic distribution.

Suppose a user i in the local cell 0 receives a power S_{0i} from the local base station, and S_{ci} from the base station in a neighbor cell c (see Fig. 2(b)). Owing to the synchronous and orthogonal properties of the forward link, only partial power $(1-f_o)S_{0i}$ from the local base station acts as interference, where f_o is the *orthogonality factor* [8]. The total interference received by user i is therefore

$$I_{0i} = (1-f_o)S_{0i} + \sum_{c=1}^{M} S_{ci} \tag{16}$$

Here we have ignored the thermal noise since it is small compared with the total received power in the forward link.

Let ϕ_{0i} be the fraction of P_{max} for user i's *transmission* signal. Since the total *transmission* power S_0 at the base station of cell 0 is approximately equal to P_{max} when the capacity is reached, ϕ_{0i} is approximately the fraction of the *received* power S_{0i} for user i's signal. The BIR of user i is then

$$\gamma_{0i} = \frac{\phi_{0i}S_{0i}}{I_{0i}}\frac{W}{R_{0i}} = \frac{\phi_{0i}}{(1-f_o) + \sum_{c=1}^{M} S_{ci}/S_{0i}}\frac{W}{R_{0i}} \tag{17}$$

Hence,

$$\phi_{0i} = \frac{R_{0i}\gamma_{0i}}{W}\left(1 - f_o + \sum_{c=1}^{M}\frac{S_c}{S_0}\frac{\alpha_{0i}}{\alpha_{ci}}\right) \tag{18}$$

where S_c is the total *transmission* power in cell c, α_{ki} is the path loss from base station k to user i. In the forward link we can assume perfect power control since the BIR variation is very small especially with the adoption of fast close-loop power control in the new wideband CDMA standards [8]. γ_{ki} here can therefore be considered as equal to its target value γ_{ki}^*.

Adding up ϕ_{0i} for all users in the local cell, after some calculations we can arrive at the following expression

$$\Phi \triangleq \sum_{i=1}^{N_0}\phi_{i0} \approx \sum_{i=1}^{N_0}\frac{R_{0i}\gamma_{0i}}{W}\left(1 - f_o + \frac{\sum_{c=1}^{M}\frac{1}{\alpha_{ci}}\sum_{j'=1}^{N_c}R_{cj'}\gamma_{cj'}}{\frac{1}{\alpha_{0i}}\sum_{j=1}^{N_0}R_{0j}\gamma_{0j}}\right) \tag{19}$$

As in the reverse link, here we have assumed $S_c \approx S_0$ for all c. (Note that this does not necessarily require the same amount of traffic of each type in every cell.)

The mean and variance of Φ are

$$\begin{aligned} m_\Phi &= \sum_{i=1}^{N_0}\frac{R_{0i}\gamma_{0i}}{W}(1-f_o) + \sum_{c=1}^{M}\sum_{j=1}^{N_c}\frac{R_{cj}\gamma_{cj}}{W}m_{l_c} \\ v_\Phi &= \sum_{c=1}^{M}\sum_{j=1}^{N_c}\left(\frac{R_{cj}\gamma_{cj}}{W}\right)^2 v_{l_c} \end{aligned} \tag{20}$$

where we have defined the path loss ratio $l_{ci} = \alpha_{0i}/\alpha_{ci}$ (note that its mean and variance are independent of i).

In the forward link the constraint lies in the total base station power used for transmitting user signals. The limit for the forward link *outage probability* is defined as

$$\Pr\{\Phi > 1 - \beta\} \leq \delta \tag{21}$$

As in the reverse link, this constraint can be reformatted into a bound on the system load (using the log-normal approximation)

$$u_\Phi \triangleq m_\Phi + (\tau - m_\epsilon)\sqrt{\frac{v_\Phi}{v_\epsilon}} \leq 1 - \beta \tag{22}$$

where ϵ is again the shadowing variable.

III. Load Prediction and Burst Scheduling

Here we use the reverse link to describe our burst admission schemes. The burst admission in the forward link is very similar to the reverse link since their capacity formulas are in the similar format.

Suppose the local base station has the knowledge of the number of users in each service class in all the neighbor cells. Let R_b and γ_b^* be the data rate and BIR requirement of the data burst waiting for admission. The base station can then easily calculate the m_ω and v_ω in (14) after admitting the burst according to

$$m'_\omega = m_\omega + \frac{R_b\gamma_b^*}{W}m_\pi, \qquad v'_\omega = v_\omega + \left(\frac{R_b\gamma_b^*}{W}\right)^2 v_\pi \tag{23}$$

In addition, if the neighboring base stations also exchange information of their load index $u_{\omega,c}$ (subscript c is the base station identifier) in the format of $(m_{\omega,c},\, v_{\omega,c})$, the local base station can also estimate the load update for its neighbor cells by calculating

$$m'_{\omega,c} = m_{\omega,c} + \frac{R_b\gamma_b^*}{W}m_{(l_c\cdot\pi)}, \quad v'_{\omega,c} = v_{\omega,c} + \left(\frac{R_b\gamma_b^*}{W}\right)^2 v_{(l_c\cdot\pi)} \tag{24}$$

Specifically, the neighboring base stations need to exchange the following information:

(a) For non-bursty traffic, the currently-admitted number of users in each traffic type and the characteristic parameters of all traffic types (data rate, activity factor, BIR, etc.) in the local cell. The means and variances of the data rates of these traffic types are used in the calculation of the load index u_ω, or simply the average data rate is used if the data rate variance is not large.

(b) The *burst scheduling table* containing the information of the burst transmissions that have been scheduled in the local cell, including the burst start time, burst length, data rate, BIR, etc.

(c) The load estimate $(m_\omega,\, v_\omega)$ until a certain time point in the future. This load prediction should be long enough to accommodate the admission deadline of all burst types. Although the load estimate is continuous in time, the exchanged values should be those on discrete time points (with fixed interval, for example), and the time points (or sequence numbers) need to be transmitted together with the load estimate.

The above load and scheduling information needs to be transferred whenever there is a change on the current load or schedule in the local cell, e. g. admission of a burst or non-bursty traffic, termination of a non-bursty traffic, or any load change in the neighbor cells which affects the load prediction in the local cell. The load and scheduling information can also be exchanged as periodic updates.

The admission decision steps are the following.

Step 1 — Upon receiving the burst request, the local base station calculate the load estimate (14) for the local cell *and* the first-tier (six) neighbor cells to check if the outage probability limit in these cells is still guaranteed after admitting the burst. The calculation should be performed for *every* time points with fixed interval from the current time until the burst completes. The calculation is a simple update as (23) for the local cell and (24) for the neighbor cells.

When considering soft handoff, the load estimate for the neighbor cells in soft handoff with the user should be based on (23) instead of (24). Soft handoff information is obtained from the handoff message exchange among the base stations and the user [8]. If some neighbor base stations in the soft handoff can not support the burst request but can tolerate the indirect other-cell interference caused by the burst, the burst can still be admitted with less direct communication links. Under this consideration both (23) and (24) may need to be evaluated for a base station in soft handoff.

Step 2 — If the admission check in the first step fails, restart the check from the next time point following the time point of checking failure. This step is repeated until a check is successful, or the checking time point reaches the delay deadline of the burst.

Step 3 — If in Step 1 or Step 2 a start time of the burst can be scheduled, respond to the user issuing the burst request with the burst assignment message including the burst start time. Otherwise send a burst assignment message with rejection information (e.g. burst start time or allocated code is equal to zero). This step is the same as the existing instant burst admission algorithm.

The forward link burst scheduling is almost the same as the reverse link. However, in the forward link the burst start time should be assigned as ensuring the transmission orthogonality with the Walsh codes, and the queueing limit in the base station may need to be considered.

IV. Numerical Example

For illustration purpose we consider a simple reverse-link example where there are a fixed number of 100 voice users in every cell of the layout shown in Fig. 1, and burst requests of the same type are generated only in the central cell. We perform burst scheduling in the central cell using the algorithm de-

TABLE I

SIMULATION PARAMETERS (REVERSE LINK)

Item	Symbol	Value
System bandwidth	W	10 MHz
Path loss exponent	m	4
Soft handoff margin	Δ	6 dB
Noise to interference ratio	η	0.1
Outage probability	δ	0.01
Shadowing deviation	σ_ϵ	6 dB
Imperfect power control deviation	σ_π	2 dB
Simulation length	T	1000 s
Checking interval	Δ_T	10 ms
Voice rate	R_v	9.6 kbps
Voice activity factor	ρ_v	0.35
Voice BIR	γ_v^*	4 dB
Average talk spurt	T_v	0.7 s
Number of voice users	N_v	100
Burst rate	R_b	144 kbps
Burst BIR	γ_b^*	6 dB
Average burst length	T_b	200 ms
Maximum burst length	$T_{b,max}$	2 s
Burst delay deadline	D_b	100 ms
Burst arrival rate (per 10 ms)	λ_b	0.1 – 2

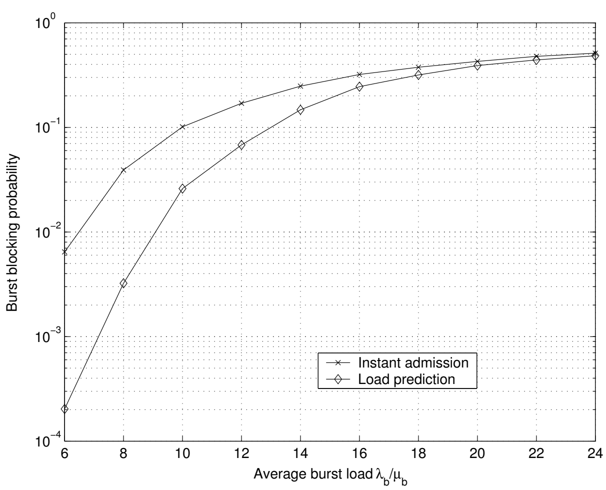


Fig. 3. Blocking probability under different burst scheduling algorithms

scribed in the last section, except that here only the admission check for the local cell is needed.

The simulation parameters are listed in Table I. Voice traffic is modeled as a on-off source with exponentially distributed talk and silent spurts. The average data rate of $R_v \rho_v$ is used in the load estimation for voice. The data burst arrivals follow a Poisson process with rate λ_b. The length of data bursts is also exponentially distributed. Two-way soft handoff with a hysteric margin of 6 dB is assumed for estimating the path loss ratio l.

Fig. 3 and 4 show the comparison of the instant admission algorithm and our burst scheduling algorithm with load estimation, where the average burst load is calculated as the burst arrival rate over the average burst completion rate ($\lambda_b/\mu_b = \lambda_b T_b$). It can be seen that our burst scheduling algorithm has lower

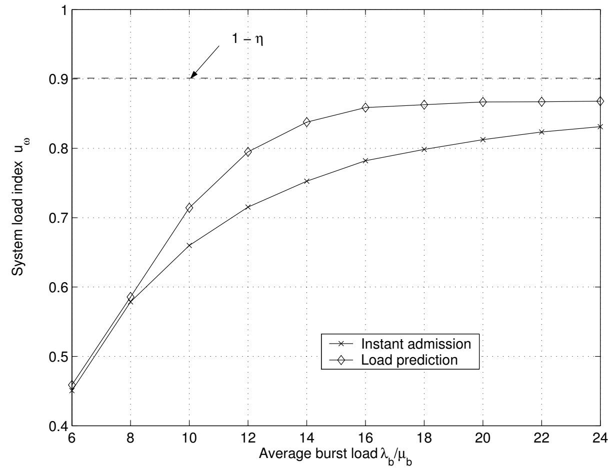


Fig. 4. Virtual bandwidth utilization under different burst scheduling algorithms

blocking probability (unless the cell is heavily loaded, where no algorithm can possibly reduce the blocking probability), and provides higher system resource utilization in terms of u_ω (14).

V. CONCLUSIONS

In this paper we have provided a method for load estimation under homogeneous interference distribution in cellular CDMA systems. Based on this estimation we have designed a burst scheduling algorithm making use of load prediction information. We have shown by simulations that our algorithm is able to achieve lower blocking probability and higher resource utilization than the existing burst admission algorithm.

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