The Study of Burst Admission Control in an Integrated Cellular System

Jie Zhou, Yoshikuni Onozato, and Ushio Yamamoto

Dept. of Computer Science, Faculty of Engineering, Gunma University
1-5-1 Tenjin-cho, Kiryu, Gunma, 376-8515 Japan
{zhou, onozato, kansuke}@nztl.cs.gunma-u.ac.jp
http://www.nztl.cs.gunma-u.ac.jp

Abstract. CDMA has been proven to be one of the promising mainstream multiaccessing techniques in the third-generation mobile system. In this paper, we fully investigated the performance of a CDMA system which supports the data users. In the proposed algorithm[1][2], data user's burst admission is permitted based on the load situation of the system. Performance measures obtained included the system capacity, ISR limitation and the constraint set between the load of the system and the allowed maximum data rate. Based on the numerical results, we see the feasibility of integrated services supported in the CDMA system, where the burst admission is available, and what kinds of data services can be supported over the coverage area.

1 Introduction

Code Division Multiple Access (CDMA) has been a mainstream access technique in the third-generation mobile cellular system,[1][2]. The CDMA techniques have been reported to offer attractions such as high link capacity, more efficient spectral utilization, soft capacity and anti-multipath shadow fading[3][4]. In the future CDMA systems, a good variety of narrow-band and wide-band applications is expected to be supported in the same system with sharing the same spreading spectrum.

In this paper, we use the "equivalent load" to address the issues about providing data transmission in the CDMA cellular system shown in Fig.1. When the system wants to support the data rate services, the challenge is to design an admission control mechanism and estimate the impact of shadow fading on the data transmission in order to achieve efficient reuse of bandwidth and allow more users to obtain high data services without affecting the E_b/N_0 for the other different services. Based on the algorithm, where the burst admission is allowed in the coverage area, we investigate how to control the data rate and give the complete and detailed numerical results, especially provide the numerical results about the forward link and its optimization of the distance-based power control scheme. At first, we summarize the analysis of the CDMA system as follows.

In a CDMA system, the quality of transmission is susceptible to the well-known near-far issue. Power control is exercised to reduce such effects. The work

G. Pujolle et al. (Eds.): NETWORKING 2000, LNCS 1815, pp. 908–919, 2000.

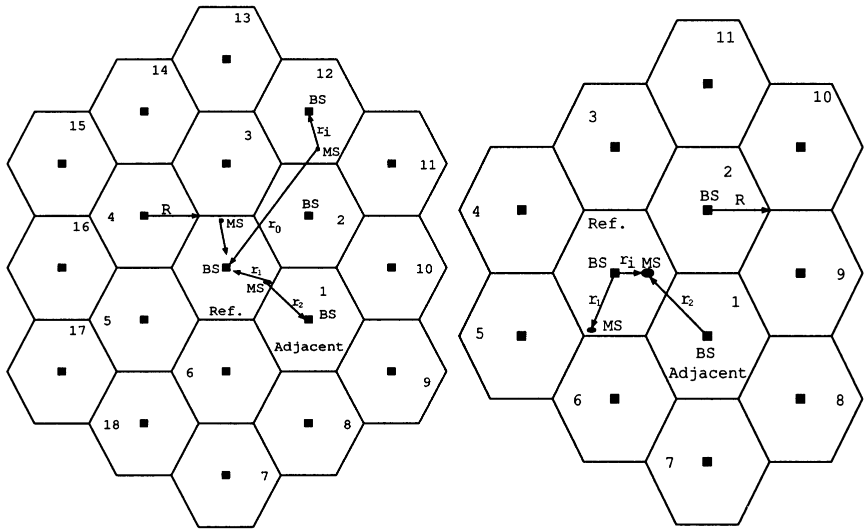

Fig. 1. A typical example of the reverse and the forward links in standard cellular layout

in this paper is to be done under the assumption of perfect power control[8] in the reverse link and the distance-based power control scheme supported in Refs.[5] and [6] for the forward link.

On the forward link, we consider the cellular system model in Fig.1 and the distance-based power control scheme as

$$P(r_i) = \begin{cases} P_t \ \left(\frac{r_i}{R}\right)^{\tau} & for \ \ qR \le r_i \le R \\ P_t \ \ q^{\tau} & for \ \ 0 \le r_i < qR \end{cases} \tag{1}$$

where r_i is the distance from the reference mobile station (MS) to its base station (BS). P_t is the forward link power required to reach those MS's located at the cell boundary. q is the power control parameter so that any users located at a distance less than qR is assured of receiving a minimum amount of transmitted power.

Based on the interference analysis[1][8][9] for the CDMA cellular system, we can easily obtain the mean of the total interference to the desired signal ratio I_t/S defined with ISR. ISR and variance of it, which is composed of intracellular and intercellular are given by[7]

$$\begin{aligned} ISR = E[I_t/S] &= E[I_{intra}/S] + E[I_{inter}/S] \\ &= E[I_{intra}/S] + \sum_{k=1}^{K} E[I(k, r_s)/S] \end{aligned} \tag{2}$$

$$V[I_t/S] = V[I_{inter}/S] = \sum_{k=1}^{K} V[I(k, r_s)/S] \tag{3}$$

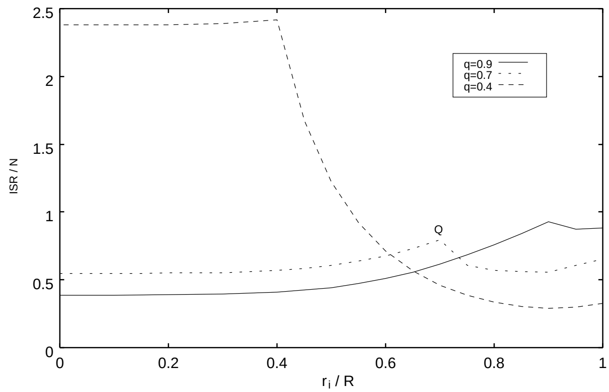

Fig. 2. ISR/N versus distance r_i/R with the distance-based power control scheme[9] ($\tau = 3$, $\sigma = 8dB$)

where,

$$E[\frac{I(k,r_s)}{S}] = \alpha \iint r_s^{\mu} F_1(r_s) \rho dA$$

$$V[\frac{I(k,r_s)}{S}] = \iint r_s^{2\mu} (\alpha H_1(r_s) - \alpha^2 F_1(r_s)) \rho dA$$

$$F_1(r_s) = exp\Big[(\sigma ln10/10)^2\Big]\Big\{1 - Q\Big(\frac{10}{\sqrt{2\sigma^2}} \cdot log\Big(\frac{1}{r_s}\Big)^{\mu} - \sqrt{2\sigma^2}\frac{ln10}{10}\Big)\Big\}$$

$$H_1(r_s) = exp\Big[(\sigma ln10/5)^2\Big]\Big\{1 - Q\Big(\frac{10}{\sqrt{2\sigma^2}} \cdot log\Big(\frac{1}{r_s}\Big)^{\mu} - \sqrt{2\sigma^2}\frac{ln10}{5}\Big)\Big\}$$

where $Q(x) = \frac{1}{\sqrt{2\pi}} \int_x^{\infty} e^{-\frac{y^2}{2}} dy$, and ρ is the density function of users distributed in the cell. $r_s = r_i/r_0$ for the reverse link and $r_s = r_i/r_2$ for the forward link shown in Fig.1. μ is the path loss exponent. σ is the standard deviation of shadow fading. α is the voice activity factor.

Power control strategy is not only used for decreasing interference to the other systems, but also for achieving the balance of the forward link user capacity. In the power control strategy used in this paper, it is important issue to choose the power control parameter for the highest possible user capacity and make *ISR* versus r_i/R curves shown in Fig.2 as flat as possible, that means[2][6][9]

$$\min_{0 \le q \le 1} \Big\{ \max_{0 \le r_i \le 1} \; ISR \Big\} \tag{4}$$

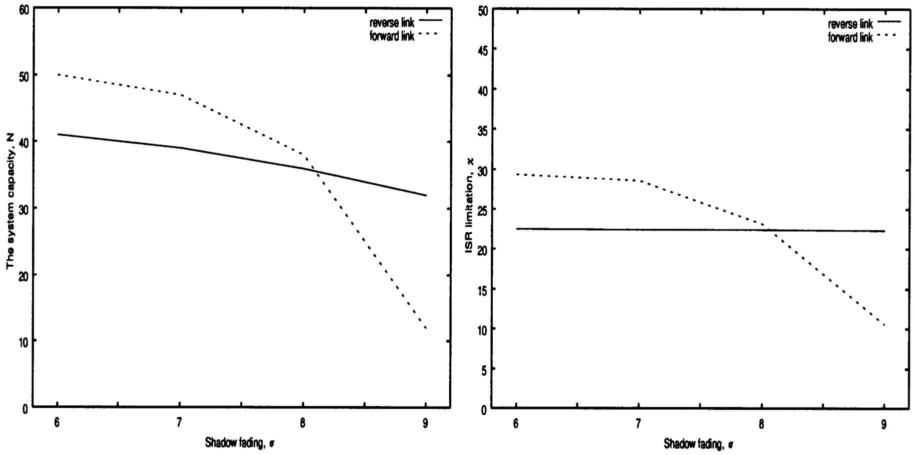

Fig. 3. The system capacity, N and the ISR limitation, χ versus shadow fading, σ ($W = 1.25MHz$, $R_b = 8kbps$, $\mu = 4$, $\alpha = 3/8$)

We must minimize the maximun of Eq.(4), i.e., it is the optimal issue of the forward link power control scheme. Eq.(4) was evaluated numerically for the forward link. The worst case is termed as 'hole' (Q) shown in Fig.2[6][9] in the presence of shadow fading which is assumed as the Gaussian random variable[1][7].

Outage probability P_{out} for the reference MS in the analysis of the forward link or P_{out} for the reference BS in the analysis of the reverese link is defined as the probability that the bit error ratio, BER exceeds the certain level, such as 10^{-3} for the voice user. Adequate performance $(BER \leq 10^{-3})$ is achievable on the reverse link with the required $(E_b/N_0)_v$=7 dB and the forward link, 5 dB[3][4]. Gilhousen[8] and Ref.[9] proposed models for estimating the reverse link and forward link capacity, respectively. P_{out} is given by

$$P_{out} = \sum_{k=1}^{N-1} \left\{ \binom{N-1}{k} \alpha^x (1-\alpha)^{N-k-1} \right\} EQ\left(\frac{\kappa - \psi k - E[I_{inter}/S]}{\sqrt{V[I_{inter}/S]}} \right) \tag{5}$$

In Eq.(5), $Q(x) = \frac{1}{\sqrt{2\pi}} \int_x^\infty e^{-\frac{y^2}{2}} dy$. $\kappa = \frac{W}{R_b}\left(\frac{N_0}{E_b}\right)_v$. ψ is the weight coefficient of intracellular interference. which is calculated for the reverse and forward links, respectively. R_b is the information rate of the voice user. W is the spread bandwidth of the system. N is the system capacity defined as the maximun number of active users in one cell when the outage probability is equal to 0.01[7][8][9]. So the maximum ISR limitation of the CDMA cellular system, χ is

$$\chi = \alpha\psi(N-1) + \alpha\eta_1 N \tag{6}$$

where, η_1 is the equivalent intercellular interference coefficient according to the calculation of $E[I_{inter}/S]$. The numerical results of the CDMA cellular system with the voice users under IS-95-B protocol are depicted in Fig.3.

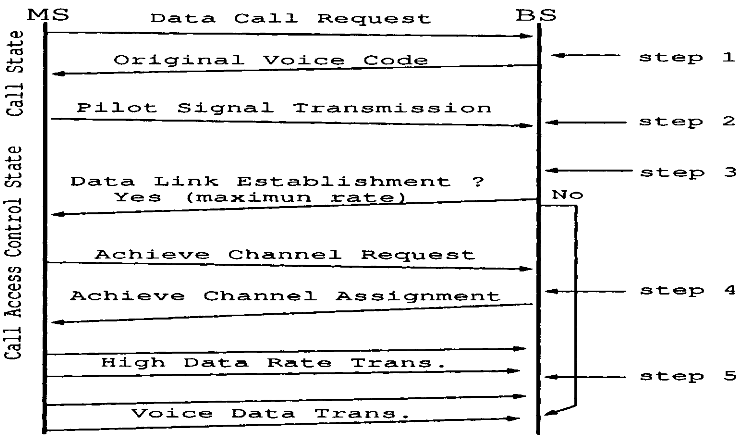

Fig. 4. Burst Admission Control Algorithm

In Section 2, the burst admission control algorithm is explained. The analytical methodologies are provided in Section 3. According to the burst admission control algorithm, we give the numerical results for the system designers in Section 4. Finally, the conclusions are given in Section 5.

2 Burst Admission Control Algorithm

The static analysis[3][10], concluded that the data rate permitted to the users who need data services is a function of its current path loss, shadow fading loss and the current load of the system. Because the load, traffic distribution and the current interference change dynamically due to the user mobility. The static analysis does not capture the relations among the voice users and effects of the data user due to the data user's burst admission, the user mobility and the load variation. Here, we summarize the burst admission control algorithm[1][2].

In the CDMA cellular system, to provide a smooth migration path to serve burst data traffic, we follow the admission control scheme that accounts for the interference, load and soft-handoff in making the access and *QOS* in the system, which protects voice isochronous users, but can accommodate peak rate user's admission as the interference and load on the assignment channel permits. It is important to derive a burst admission control algorithm in order to achieve the sharing of the same channel between the voice and data users, that both services are possible in the system without serious situations of outage probability and throughput occurred in the system.

In current CDMA cellular system employing mobile assisted soft handoff, BS provides the mobile with a neighbor list of pilot signal levels[1][2]. MS periodically detects the pilot signal levels and transmits them to its BS. These pilot signal strengths may be used for determining the data user's admission as shown in Fig.4 which shows each voice user has a unique primary code. Then an active data user is assigned a fundamental code channel on the origination. According to all the pilot signal levels which are related to the interference, the load and the soft-handoff, its BS autonomously dertermines the maximum values of data rate or sets the user to maintain the origination. In particular, the data user will be granted a burst admission only if this burst admission will not affect the original voice users and data users.

In the burst admission algorithm, because the reuse in CDMA cellular system is based on the average interference, its calculation is important whether the load and interference-based demand assignment (LIDA)[1][2] and interference-based channel allocation (ICA)[11] schemes are used in the system. The burst admission from MS contains the data rate and required E_b/N_0. From the system management, the burst admission contains R_{max} and the area where the burst admission is allowed in the coverage area. They are important problems for system designers. For this purpose to achieve the most important step 3 of the burst admission control algorithm in Fig.4, we provide detail numerical results for the design of the reverse and forward links, respectively.

3 Analysis of Performance

3.1 R_{max} and the Constraint Set

In the CDMA cellular system, let us now consider the interference change when a data user is introduced in the CDMA system. The intracellular and intercellular interference are critical in determining R_{max}. The ISR constraint inequality for the reference cell is modified from Eq.(2), using "equivalent load" $\phi(l)$ as

$$ISR = E[I_{intra}/S] + E[I_{inter}/S] + \phi(l) \leq \chi \tag{7}$$

where

$$\phi(l) = \frac{\left(\frac{E_b}{N_0}\right)_l / \left(P_{G_l} + \left(\frac{E_b}{N_0}\right)_l\right)}{\left(\frac{E_b}{N_0}\right)_v / \left(P_{G_v} + \left(\frac{E_b}{N_0}\right)_v\right)} \tag{8}$$

$\phi(l)$ is the "equivalent load" of one data user. It is considered that an active data user with data rate, R_l and required $(E_b/I_0)_l$ consumes $\phi(l)$ times greater equivalent resources of voice users if the data user is introduced in the system. In Eq.(8), $P_{G_v} = W/R_b$ and $P_{G_l} = W/R_l$.

The ISR constraint inequality for the adjacent cell is

$$ISR = E[I_{intra}/S] + E[I_{inter}/S] + \phi(l)E[I_d(r_1, r_2, \sigma)] \leq \chi \tag{9}$$

where, $E[I_d(r_1, r_2, \sigma)]$ is the normalized means of interference ratio between the path losses of r_1 and r_2 shown in Fig.1.

The data transmission is permitted to the users who require the data services depending on the locations of the user and the load of the system. According to

Eq.(9), R_{max} for the number of the voice users in the reference cell, N_v can be obtained as

$$R_{max} \leq \frac{W}{\left(\frac{E_b}{N_0}\right)_l} \cdot \frac{E[I_d(r_1, r_2, \sigma)] \cdot \left(P_{G_v} + \left(\frac{E_b}{N_0}\right)_v\right)}{\left(\chi - \alpha(\psi N_v + \eta_1 N)\right) \cdot \left(\frac{E_b}{N_0}\right)_v} - \left(\frac{E_b}{N_0}\right)_l \tag{10}$$

According to Eqs.(7) and (9), the ISR constraint inequality for the reference cell is

$$N_v \leq \frac{\chi - \alpha\eta_1 N - \phi(l)}{\alpha\psi} \tag{11}$$

and the ISR constraint inequality for the adjacent cell becomes

$$N_v \leq \frac{\chi - \alpha(\psi + \eta_2)N - \phi(l)E[I_d(r_1, r_2, \sigma)]}{\alpha(\eta_1 - \eta_2)}. \tag{12}$$

where η_2 is the equivalent coefficient of total intercellular interference to the nearest adjacent cell, from all cells except for the reference cell as shown in Fig.1 for the reverse and forward links, respectively.

3.2 Reverse Link Assignment Analysis

Based on the standard propagation models[4][6], we obtain

$$E[I_d(r_1, r_2, \sigma)] = \left(\frac{r_1}{r_2}\right)^{\mu} F_1\left(\frac{r_1}{r_2}\right) \tag{13}$$

and $V[I_d(r_1, r_2, \sigma)]$ as

$$V[I_d(r_1, r_2, \sigma)] = \left(\frac{r_1}{r_2}\right)^{2\mu} \left[H_1\left(\frac{r_1}{r_2}\right) - F_1\left(\frac{r_1}{r_2}\right)\right] \tag{14}$$

3.3 Forward Link Assignment Analysis

Based on the distance-based power control scheme, the location of the data user is composed of two areas, such as, $qR \leq r_1 \leq R$ and $0 \leq r_1 < qR$, respectively. When the data user is located in $qR \leq r_1 \leq R$, we obtain $E[I_d(r_1, r_2, \sigma)]$ as[4][9]

$$E[I_d(r_1, r_2, \sigma)] = \left(\frac{r_1}{R}\right)^{\tau} \frac{1}{q^{\tau}} r_s^{\mu} F_2(r_s) \tag{15}$$

and $V[I_d(r_1, r_2, \sigma)]$ as

$$V[I_d(r_1, r_2, \sigma)] = \left(\frac{r_1}{R}\right)^{2\tau} \frac{1}{q^{2\tau}} r_s^{2\mu} \cdot \left[H_2(r_s) - F_2(r_s)\right] \tag{16}$$

where in Eqs.(15) and (16), the explicit functions of $F_2(r_s)$ and $H_2(r_s)$ are expressed as

$$F_2(r_s) = exp\left[(\sigma ln10/10)^2\right]\left\{1 - Q\left(\frac{10}{\sqrt{2\sigma^2}} \cdot log\left(\frac{1}{r_s}\right)^{\mu}\left(\frac{qR}{r_1}\right)^{\tau} - \sqrt{2\sigma^2}\frac{ln10}{10}\right)\right\}$$

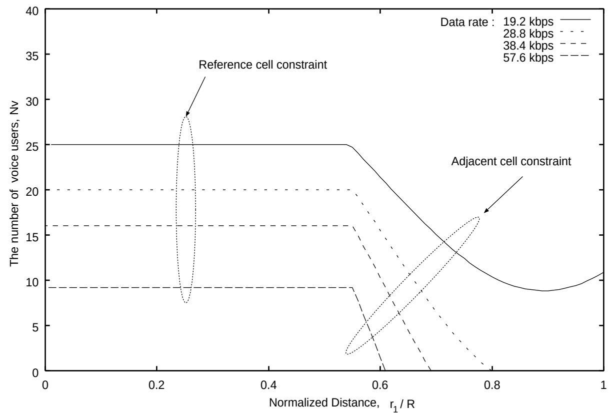

Fig. 5. N_v versus the position of the data user, r_1/R about the reverse link (σ=8 dB, α=3/8, μ=4, $(\frac{E_b}{N_0})_v$=7 dB, $(\frac{E_b}{N_0})_l$=10 dB)

and

$$H_2(r_s) = exp\Big[(\sigma ln10/5)^2\Big]\Big\{1 - Q\Big(\frac{10}{\sqrt{2\sigma^2}} \cdot log\Big(\frac{1}{r_s}\Big)^{\mu}\Big(\frac{qR}{r_1}\Big)^{\tau} - \sqrt{2\sigma^2}\frac{ln10}{5}\Big)\Big\}$$

In the other case, when the data user is located in $0 \le r_1 < qR$, we obtain $E[I_d(r_1, r_2, \sigma)]$ as

$$E[I_d(r_1, r_2, \sigma)] = r_s^{\mu} F_1(r_s) \qquad (17)$$

and $V[I_d(r_1, r_2, \sigma)]$ as

$$V[I_d(r_1, r_2, \sigma)] = r_s^{2\mu}\Big[H_1(r_s) - F_1(r_s)\Big] \qquad (18)$$

For the forward link, we will focus our analysis on the reference MS located at the 'hole' [5][6][9].

4 Numerical Results and Discussions

4.1 System Capacity and χ

Figure 3 shows the system capacity and χ for the CDMA cellular system to various shadow fading environments. In Fig.3, we obtain the CDMA system capacity is equal to 36 users/cell for the reverse link, 38 users/cell under $\sigma = 8dB$. According to those results and Eq.(6), we can obtain the ISR limitation of the system as $\chi = 22.39$ for the reverse link and $\chi = 23.14$ for the forward link, respectively. We can also see the situations when σ is changed from 6 dB to 9 dB. The system capacity and χ decrease rapidly for the forward link. That means the effect of the shadow fading is more significant on the forward link, which should be carefully designed and managed.

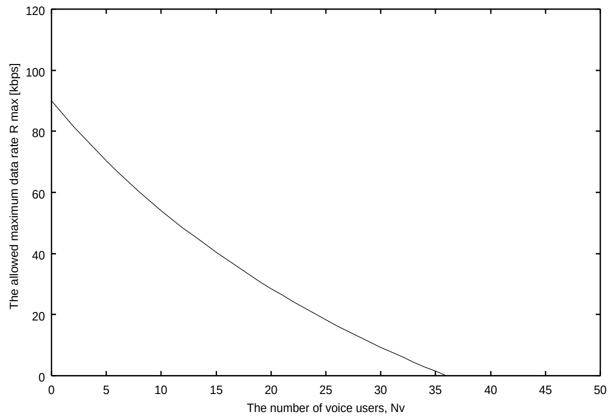

Fig. 6. R_{max} versus N_v about the reverse link (σ=8 dB, α=3/8, μ=4, $(\frac{E_b}{N_0})_v$=7 dB, $(\frac{E_b}{N_0})_l$=10 dB)

4.2 Effects of Burst Admission and R_{max}

Figures 5 and 6 show the impact of one high data user's burst admission on the CDMA system reverse link. Notice that the curves in Fig.5 consist of two portions, i.e., the flat part and the rapid drop part. The first part is where the reference cell constraint dominates. The second part near the cell boundary is where the adjacent cell constraint becomes dominant. According to the figure, the important points are shown at near $r_1/R = 0.55$, we see if the data user with R_l is located at $0 \leq r_1/R \leq 0.55$, N_v can be maintained as the same. when the data user is located at $0.55 \leq r_1/R \leq 1$, the locations of the data user greatly affect the system capacity, then should be managed carefully. From this part, the data services should not be permitted to any users when $R_l \geq 38.4kbps$. Based on the results, the high data transmission is available over a fraction of the cell coverage area as shown in Fig.5. It may be desirable to expand the coverage area for the high data transmission or at least to guarantee the minimum data rate.

We consider the user located at $0 \leq r_1/R \leq 0.55$ who is desiring to obtain the data services as shown in Fig.5, where in Fig.6 we investigated R_{max} versus the load situation, N_v. It means keeping the value of N_v, we now determine R_{max} which may be allowed to any one user located in this area, who want to obtain the correspondent data services. For example, the numerical results show R_{max} with the required E_b/N_0 = 10dB can reach 90 kbps when N_v=0. When N_v=18, half load of the system, R_{max} reaches 35 kbps as $\sigma = 8dB$.

For the forward link, the reference cell constraint is dominant wherever the burst admission of the data user occurs in the reference cell shown in Fig.7. We also notice that the curves consist of two portions, i.e., the flat part and the smoothly decreasing part. The transmission of each data rate analyzed in this paper is available over whole cell coverage area, but it gives significant effects

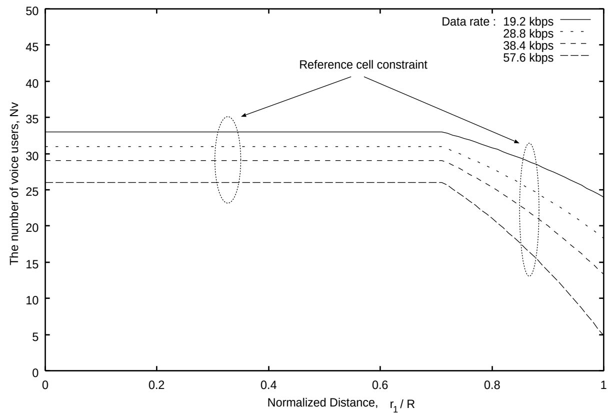

Fig. 7. N_v based the reference cell constraint versus the position of the data user, r_1/R about the forward link (σ=8 dB, α=3/8, μ=4, $(\frac{E_b}{N_0})_v$=5 dB, $(\frac{E_b}{N_0})_l$=10 dB, $\tau = 3$, $q = 0.7$)

on the system when the data user is located in $\frac{r_1}{R} \geq 0.7$. It is also desirable to expand the coverage area for the high data rate transmission. When the user located in $\frac{r_1}{R} \geq 0.7$ is to obtain high data rate services, the allowed data rate needs to be carefully controlled and managed.

When investigate R_{max} of the forward link, we assumed the data user is located at the boundary between cells. According to the distance-based power control scheme, its allocated transmitting power is greatest. R_{max} was estimated in Fig.8, in which R_{max} can reach 70 kbps when N_v=0 and near 30 kbps as the load is in the half of the system for $\sigma = 8dB$. When the data user moves from the boundary to its BS, R_{max} increases gradually.

5 Conclusion

In this paper, we have proposed a solution employing "equivalent load" to the performance of the CDMA cellular system with the integrated services in IS-95-B. Analysis is performed for the case when the burst admission of the data user occurs in the system. Especially, we estimated the characteristics of the forward link under the distance-based power control scheme and its optimal issue. Based on the numerical results, we can obtain our findings as follows:

1) Data users generate significant effects on the system because of its higher required E_b/N_0 and its higher data rate, which means with lower processing gain in the same spreading bandwidth. If the data rate or the required E_b/N_0 increases, the number of allowable voice users in the system decreases rapidly.

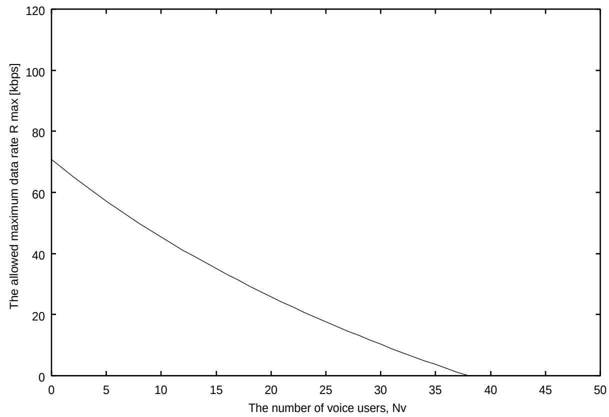

Fig. 8. R_{max} versus N_v about the forward link when the high rate data user is located at the boundary between cells (σ=8 dB, α=3/8, μ=4, $(\frac{E_b}{N_0})_v$=5 dB, $(\frac{E_b}{N_0})_l$=10 dB), $\tau = 3$, $q = 0.7$)

2) Based on the analytical results for the reverse and forward links, we suggest R_{max} is less than 50 kbps in the reverse link and 100 kbps in the forward link, because the near half area of the cell is not available for the data transmission.

3) For wide band CDMA systems of the third-generation cellular system all over the world in the future, our results can be directly proportional to the times of increased spread bandwidth.

4) The "equivalent load" proposed in this paper makes it possible to analyze various systems with a good variety of lower data rate, lower required E_b/N_0 and higher data rate, higher required E_b/N_0.

Our studies demonstrate the feasibility of data users introduced in the CDMA cellular system. We have addressed several issues in some depth, such as R_{max} studies, admission method and the constraint set of the system. The analytical method depicted in this paper could be easily extended to treat much additional performance works such as outage probability and throughput because the complete formulas have been given in this paper.

References

1. S.Kumar and S.Nanda, "High Data-Rate Packet Communications for Cellular Networks Using CDMA: Algorithms and Performance", *IEEE J. Select. Areas Commun.*, Vol.17, No.3, pp.472-492, March 1999.
2. C-L.I and S.Nanda, "Load and Interference Based on Demand Assignment for Wireless CDMA network", in *Proc. IEEE Globecom*, pp.235-241, 1996, Westminster, London.
3. H.G.Jeon, S.K.Kwon and C.E.Kang, "Reverse Link Capacity Analysis of a DS-CDMA Cellular System with Mixed Rate Traffic", *IEICE Trans. Commun.*, Vol.E81-B, No.6, pp1280-1284, June 1998.

4. J.S.Evans and D.Everitt, "On the Teletraffic Capacity of CDMA Cellular Networks", *IEEE Trans. on Veh. Technol.*, Vol.48, No.1, pp.135-165, Jan. 1999.
5. W.C.Y.Lee, "Overview of Cellular CDMA", *IEEE Trans. on Veh. Technol.*, Vol.40, No.2, pp.290-302, May 1991.
6. R.R.Gejji, "Forward-Link-Power Control in CDMA Cellular System", *IEEE Trans. on Veh. Technol.*, Vol.41, No.4, pp.532-536, Nov. 1992.
7. R.Prasad, *CDMA for Wireless Personal Communication*, Boston, MA: Artech, 1995.
8. K.S.Gilhousen, I.M.Jacobs, R.Padovani and A.J.Viterbi, L.A.Weaver, C.E.Wheatley, "On the Capacity of a Cellular CDMA System", *IEEE Trans. on Veh. Technol.*, Vol.40,No. 2, pp.303-311, May. 1991.
9. J.Zhou, Y.Onozato and U.Yamamoto, "Effect of Forward Link Power Control Strategy and Its Optimum Issue on Cellular Mobile System", submitted to *IEEE Trans. on Veh. Technol.*
10. J.Zhou, Y.Onozato and U.Yamamoto, "Throughput and Capacity Analysis of a DS-CDMA System with Integrated Services", Technical Report of IEICE, Vol.99, No.366, pp.1-6, Oct. 1999.
11. S.M.Shin, C.H.Cho and D.K.Sung "Interference-Based Channel Assignment for DS-CDMA Cellular System", *IEEE Trans. on Veh. Technol.*, Vol.48, No.1, pp.233-239, Jan. 1999.