Analysis of Forward Link Capacity for a DS/CDMA System with Multirate Traffic Sources

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Abstract: In this paper, we derive forward link Erlang capacity reflecting both outage probability and blocking probability of each traffic type in mixed traffics environment. We firstly determine the number of available virtual trunks of the forward link from a circuit switching perspective. Then, capacity sharing model and generalized Erlang model are employed to derive joint Erlang capacity of various traffics types.

I. Introduction

In the FDMA and the TDMA systems, traffic channels are allocated to calls as long as they are available. Incoming calls are blocked when all the channels have been assigned. Therefore, the blocking probability and capacity depend on the number of available trunks which are frequency bands or available time slots in the FDMA or TDMA, respectively. On the other hand, the capacity of the CDMA is soft in that the system performance is gracefully degraded as the number of users increases. The CDMA capacity has been typically estimated based on the outage probability [1]. However, for multimedia traffic sources, traditional methodology of evaluating capacity based on outage probability has some limitations. Calls of multimedia traffics are blocked from the system when the outage probability exceeds the 'same' preset threshold level. In that sense, blocking probability as a different QoS can not be granted for specific types of calls because calls of any types are blocked whenever the outage threshold is reached. The authors of [2] focused on this limitation and proposed a new approach for evaluating reverse link capacity.

However, the study also addressed the reverse link capacity as some other studies [2-4]. This is due to the fact that most believe that the CDMA capacity is mainly limited by reverse link. However, in the future-generation CDMA system including IMT-2000, the forward link can be a limiting link since emerging multimedia services are likely to require higher data rates and capacity in the forward link compared to in the reverse link.

In our previous works [5,6], we derived outage probability of a forward link of a DS/CDMA system with various types of traffics, and evaluated forward link Erlang capacity under outage probability criterion.

In this paper, we extend our previous studies to derive forward link capacity reflecting blocking probabilities of each traffic types. Firstly, we determine the number of available virtual trunks from a circuit switching perspective and then derive forward link Erlang capacity reflecting both outage probability and blocking probability of each traffic types. Capacity sharing model and generalized Erlang model are employed to derive joint Erlang capacity of various types traffics. We take into account the effect of closed loop power control [7] in the analysis.

The rest of this paper is organized as follows: In section II, system model used in this paper is presented. We derive the forward link Erlang capacity reflecting both outage and blocking probabilities of each traffic type in section III. We show some numerical results in section IV. Finally, we draw some conclusive remarks in section V.

II. System Model

In this paper, an equally loaded multiple hexagonal cell structure in which there are K base stations is considered. In the equally loaded multiple cell structure, the numbers of each type call in a cell are the same to those in other cells. We assume that users in each cell are uniformly distributed and there are M traffic types (call types) in each cell.

The path-loss model used in this paper is given by

$$L_m = d_m^{-l} \cdot 10^{\xi_m/10} = d_m^{-l} \cdot \chi_m \tag{1}$$

where d_m is the distance from the m-th base station to the mobile station, l is path loss exponent, typically 3 or 4, and ξ_m is gaussian distributed random variable with zero mean and standard deviation (std.) σ, representing shadow fading. Under power control, the std., σ, reflects a power control error. Typically, σ is 6 ~ 10 dB for the signals from adjacent base stations and is 1.5 ~ 2.5 dB for the singal from home base station, respectivley, since a fast forward closed loop power control scheme is adopted in the 3G CDMA system [8]. χ_m denotes $10^{\xi_m/10}$ and is log-normally distributed random variable.

Then, the same cell interference power at the i th mobile station can be given by

$$I_{sc} = \alpha \cdot P_0 \cdot L_0 \tag{2}$$

where P_0 is total transmitted power from home base station, L_0 is path loss from home base station, and α is an orthogonality factor which represent the fraction of the received power on the forward link that is seen as interference by each of the codes from the same cell. The orthogonality factor reflects an imperfection of code channel orthogonality due to multi-path.

The other cell interference power from adjacent base stations to the i-th mobile station is given by

$$I_{oc} = \sum_{k=1}^{K} P_k \cdot L_k \tag{3}$$

where P_k is total transmitted power from the k th base station and L_k is path loss from the k th base station. We assume that all cells are transmitting at full power. The cell transmit power is actually a function of the number of users served by the cell and thus is a random variable. Therefore, our assumption is a worst case condition.

III. Capacity Analysis

Using (2) and (3), the received E_b / N_t at the mobile station can be obtained as

$$\gamma = \frac{W}{R} \frac{\psi \cdot \phi_i \cdot P_0 \cdot L_0}{\sum_{k=1}^{K} P_k \cdot L_k + \alpha \cdot P_0 \cdot L_0 + N_0 W} \tag{4}$$

where ψ is a fraction of base station power assinged to traffic channels, ϕ_i is a relative power allocation for the i th mobile station, N_0 is a power spectral density of backgroud noise, W is the spreading bandwidth of the CDMA system, and R is the transmit data rate.

Generally, in (4), the background noise will be negligilbe compared to the total signal power (including all users' signals) received from all base stations. Hence, the received E_b / N_t at the mobile station can be given by

$$\gamma \approx \frac{W \cdot \psi}{R} \cdot \frac{\phi_i}{\frac{I_{oc}}{S_0} + \alpha} \tag{5}$$

where $S_0 (= P_0 \cdot L_0)$ denotes total received power at the mobile stataion from home base station in the absence of interference.

For the worst case, i.e., MS is at cell the average ratio of other cell interference power to received power at the mobile station from the home cell power , I_{oc} / S_0 can be approximated as a log-normally distributed random variable with a mean dB value m_y and a standard deviation of dB value σ_y [6].

From (5) we can find that the received E_b / N_t at mobile station is different as type of traffic. Hence, if d_i, $i = 1, \cdots, M$ denote traffic types, then the received E_b / N_t values of d_i-traffic type is

$$\gamma_{d_i} \approx \frac{W \psi}{R_{d_i}} \cdot \frac{\phi_i^{(d_i)}}{I_{oc} / S_0 + \alpha}. \tag{6}$$

Then, the relative power allocation for the i th user, $\phi_i^{(d_1)}, \cdots, \phi_i^{(d_M)}$ can be derived as follows,

$$\phi_i^{(d_i)} = \frac{\gamma_{d_i} \cdot R_{d_i}}{W \psi} \cdot \left(\frac{I_{oc}}{S_0} + \alpha \right) = \frac{\gamma_{d_i} \cdot R_{d_i}}{W \psi} \cdot y_i \tag{7}$$

where, $y_i (= I_{oc} / S_0 + \alpha)$ is log-normally distributed random variable with a mean $E[I_{oc} / S_0] + \alpha$ and a standard deviation of $Var[I_{oc} / S_0]$.

The forward link outage probability in homogeneous traffic environment (only d_i traffic type exist) is given by

$$P_{out} = \Pr[\frac{\gamma_{d_i} R_{d_i}}{W} \sum_{i=1}^{N_{d_i}^{\max}} \rho_i^{(d_i)} y_i > \frac{\psi}{\eta}] \tag{8}$$

where $N_{d_i}^{\max}$ and $\rho_i^{(d_i)}$ are the available maximum number of calls without exceeding a given outage probability and the activity factor of the d_i traffic type respectively. Since we have derived $y_i (= I_{oc} / S_0 + \alpha)$ for the worst case, we introduced an average forward power factor η to the forward link outage condition to take into account the fact that most of the mobile users are not located at the cell edge. If all users are uniformly distributed at each cell and 4-th power law and perfect power control are assumed, $\eta \approx 0.42$ [6]. The average forward link traffic channel power is about η times the traffic channel power needed to serve mobiles at the edge of the cell.

In (8), let Z denote $\frac{\gamma_{d_i} R_{d_i}}{W} \sum_{i=1}^{N_{d_i}^{\max}} \rho_i^{(d_i)} y_i$. Z can be approximated as lognormal random variable since y_i's ($i = 1, 2, \cdots, N_{d_i}^{\max}$) are i.i.d. lognormal random variables [4]. The mean and variance of Z is given by

$$E[Z] = \frac{\gamma_{d_i} \cdot R_{d_i}}{W} \cdot N_{d_i}^{\max} \cdot \rho^{(d_i)} \cdot f(m_{y_i}, \sigma_{y_i}) \tag{9}$$

$$Var(Z) = \left(\frac{\gamma_{d_i} \cdot R_{d_i}}{W} \right)^2 N_{d_i}^{\max} \cdot \rho^{(d_i)} \cdot h(m_{y_i}, \sigma_{y_i}) \tag{10}$$

where $f(a, b) = \exp\{\beta a + \beta^2 b^2 / 2\}$ $\beta = \ln(10)/10$, and $h(a, b) = \exp\{2\beta a + \beta^2 b^2\} \cdot (\exp\{\beta^2 b^2\} - 1)$.

Since $\widetilde{Z} = \ln(Z)$ is a Gaussian random variable with mean $E[\widetilde{Z}]$ and variance $Var(\widetilde{Z})$, the outage probability can be derived in closed form as

$$P_{out} = \Pr\left[\tilde{Z} = \ln(Z) > \ln\frac{\psi}{\eta}\right] = Q\left(\frac{\ln(\psi/\eta) - E[\tilde{Z}]}{\sqrt{Var(\tilde{Z})}}\right) \tag{11}$$

The relationships for evaluateing $E[\tilde{Z}]$ and $Var(\tilde{Z})$ are given as [9]

$$E[Z] = \exp\left\{ E[\tilde{Z}] + \frac{1}{2}Var(\tilde{Z}) \right\} \tag{12}$$

$$Var(\tilde{Z}) = \ln\left(\frac{Var(Z)}{E^2[Z]} + 1\right) \tag{13}$$

In the mixed traffic environment, the capacity will be given with the pair of available number of calls for each traffic type. Let $(N_{d_1}, N_{d_2}, \cdots, N_{d_M})$ pair denote the available number of calls of each type in mixed traffic environment. Each type of traffic shares the capacity of the system in the various traffics environment. Capacity may be completely shared, or certain customer may have exclusive use of portion of the resource with the excess commonly shared obviously, the resource sharing policy has a strong effect on the blocking experienced by different customer. In this paper, we assume that the users completely share the resource. So, the capacity sharing algorithm [10] can be employed. From the capacity sharing algorithm, the system can support each $(N_{d_1}, N_{d_2}, \cdots, N_{d_M})$ pair satisfying the following equation

$$\sum_{i=1}^{M} \frac{N_{d_i}}{N_{d_i}^{\max}} < 1 \tag{14}$$

The Erlang capacity can be easily found for each type of call by applying the generalized Erlang B model to each valid $(N_{d_1}, N_{d_2}, \cdots, N_{d_M})$ pair. The $(N_{d_1}, N_{d_2}, \cdots, N_{d_M})$ pair means the available number of trunks of each type of call in circuit switching perspective. The trunks that we are alluding to, are not physical trunks, but rather virtual ones. When a call arrives, it gets blocked if it doesn't find an idle trunk. Then, the forward link Erlang capacity of each type of calls can obtained from

$$P_{d_i,block} = \frac{(C_{d_i})^{N_{d_i}} / N_{d_i}!}{\sum_{k=0}^{N_{d_i}} (C_{d_i})^k / k!} \tag{15}$$

where $P_{d_i,block}$ and C_{d_i} are the blocking probability and the Erlang capacity of the d_i type call, respectively.

IV. Numerical Results

In this section, the forward link Erlang capacity in mixed traffics environment is presented. We consider 3G-1x system and 3G-3x system so that the spreading bandwidth, W, is 1.2288 Mcps and 3.6864 Mcps, respectively. It is assumed that the path loss exponent is 4 and a fraction of base station power assigned to traffic channels, ψ, is 0.8. The standard deviation of lognormal shadow fading, the forward link power control error, and the power control factor are assumed as 8 dB and 2.5 dB, 0.42, respectively.

In figure 1, we show the Erlang capacity of 1x system in mult-path channel. The orthogonality factor reflecting the severity of multi-path, α, is assumed as 0.2. We consider only three types of traffics in this figure due to lack of computing power. One is 9.6 kbps voice traffic. The average required E_b/N_t of voice traffic is 3 dB and the voice activity is 0.5. The target blocking probability for voice traffics is 1%. Another is 76.8 kbps real time data traffic. The average required E_b/N_t of the 76.8 kbps data traffic is assumed as 3.5 dB and the data activity is 1 because the real time traffics need continuous data transmission. The target blocking probability for the real time traffics is 2%. The third is 153.6 kbps web browsing traffic. The average required E_b/N_t of the web traffic is also assuemd as 2.0 dB and average file size transmitted during a burst is assumed as 13.9 kbyte and mean OFF period is assumed as 10.5 sec. [11]. The target blocking probability of the web traffics is 2.5%. The target outage probabilities of the three traffic are same as 1%. The Erlang capacity is determined by the 3 dimensional surface in this figure. The system can support any Erlang pairs below the 3 dimensional surface.

We show Erlang capacity of 1x system according to the orthogonality factors in figure 2. Two kinds of traffics, that is, 9.6 kbps voice and 76.8 kbps real time traffic, are considered. The average required E_b/N_t's of the traffics are assumed as 3.5 dB and 2.5 dB, respectively. All other conditions are the same as those of figure 1.

In figure 3, the Erlang capacity of 3x system with three kinds of traffics. All conditions are the same as those of figure 1 except data rate. The real time traffic has 153.6 kbps and the web traffic has 307.2 kbps.

Figure 4 shows the relation ship between the Erlang capacity and the orthogonality factor. Two kinds of traffics, that is, 9.6 kbps voice and 153.6 kbps real time traffic, are considered. The average required E_b/N_t's of the traffics are assumed as 3.5 dB and 2.5 dB, respectively. All other conditions are the same as those of figure 1.

V. Conclusions

In this paper, we derived forward link Erlang capacity in the closed form reflecting both outage probability and blocking probability of each traffic type. In the mixed traffic environment, a blocking probability can be used as an important OoS parameter.

The results in this paper can be applied to the design of IMT-2000 system supporting wireless multimedia services.

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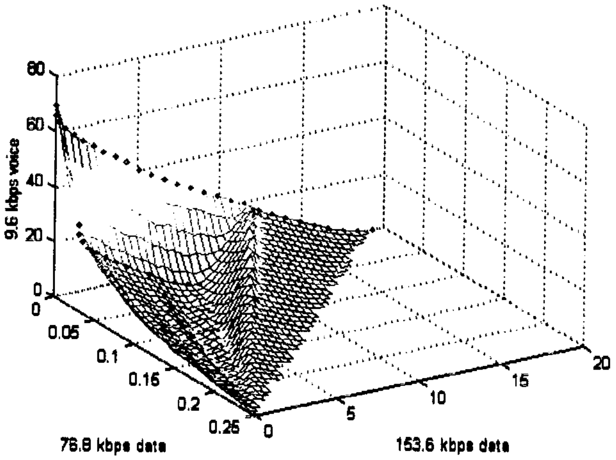

Figure 1. Forward link Erlang capacity of 3G-1x system in mixed traffics with different QoS.

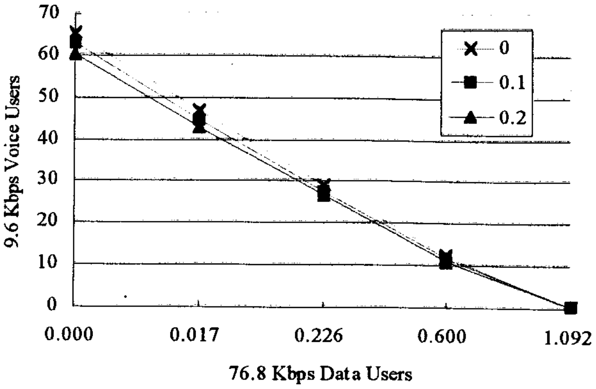

Figure 2. Forward link Erlang capacity of 3G-1x system according to orthogonality factor.

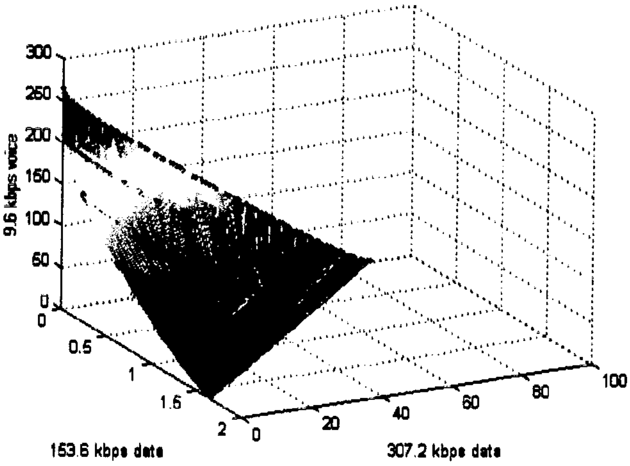

Figure 3. Forward link Erlang capacity of 3G-3x system in mixed traffics with different QoS

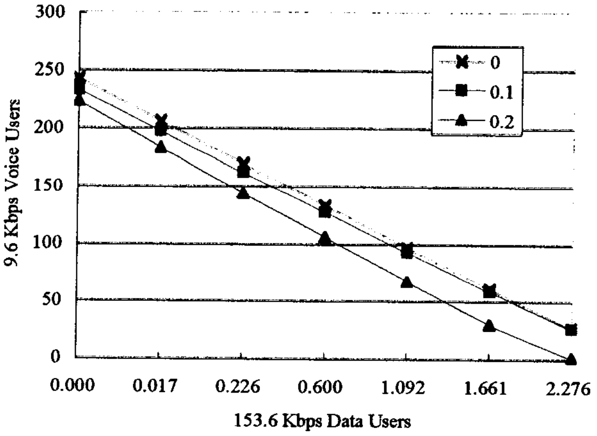

Figure 4. Forward link Erlang capacity of 3G-1x system according to orthogonality factor.