The 2004 IEEE Asia-Pacific Conference on
Circuits and Systems, December 6-9, 2004

EFFECT OF NON-UNIFORM TRAFFIC DISTRIBUTIONS ON LOAD BALANCING IN CELLULAR CDMA SYSTEMS

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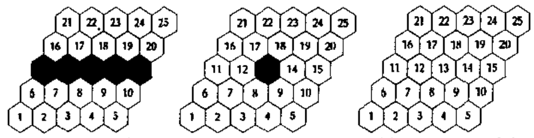
ABSTRACT

This paper presents a load balancing model to investigate the effect of non-uniform traffic distributions on load balancing in CDMA system. Applying two traffic models on non-uniform traffic distributions, the impact of traffic non-uniformity on system load balancing is compared with uniform distributions. To evaluate the model, we define both load balancing factor (LBF) and load balancing coefficient (LBC). Results indicate that the more offered traffic is easier to achieving load balancing than the less offered traffic.

1. INTRODUCTION

CDMA has been proposed as a technique for third generation wireless communication systems. An intrinsic feature of CDMA that claims to accommodate a very large number of users per cell for a given bandwidth is the reuse of all frequency resources in every cell. There have been many studies evaluating the capacity of CDMA systems. Most of them [1][2] assume uniform spatial traffic distribution, which best fits CDMA characteristics to have all signals sharing the whole spectral resource. Nevertheless, the uniform offered traffics between cells (equal cells load) is very uncommon. For example, the whole bandwidth is assigned to each cell, so that the heaviest loaded cells have at their disposal the same frequency resources of any other cell. Especially in an urban environment, this traffic distribution can result very far from the actual situation. The traffic non-uniformity will decrease the system capacity.

Though planned with sufficient capacity, uneven/non-uniform (two terms are used in turn hereafter) traffic distribution in a cellular system may occur, creating a "hot spot", exceeding the pre-determined capacity, and introducing large blocking probability. Besides "hot spot", considering linear distribution as in highway is another scenario. For non-uniform traffic distributions, sectorization is an effective way to maximize the network capacity [3][4]. Power control enforced soft handoff has been proposed as a possible solution to local traffic unbalancing among cells [5].



(a) linear model (b) hot spot (c) uniform model

FIGURE 1 SCENARIOS OF TRAFFIC DISTRIBUTIONS

If there is distribution deviation, the communications quality expressed by signal-to-interference ratio (SIR) differs between cells, and thus, the variance in communications quality degrades the spectrum reuse efficiency in the whole system. Previous work [6] on non-uniform traffic in CDMA dealt with the unbalance of load levels among cells. When non-uniform traffic distribution occurs it is desirable to re-allocate the radio resources to allow all cells to carry the desired amount of traffic. Since the possibility to accommodate the expected growth of traffic and broadband service is limited by the scare radio spectrum, it is of interest to design more spectral efficient technique, such as spectrum resource management. Capacity analysis in multi-band overlaid CDMA is proposed, and maximum spectrum utilization is obtained [7][8]. Especially, the multi-band spectrum is to provisioning heterogeneous services requirements with sub-bands.

In this paper, we investigate the effect of non-uniform traffic distributions on load balancing so that sub-spectrum can be effectively allocated in cell/sector in multi-band system. Two different non-uniform traffic distributions are considered in the structure of 5×5 two-dimensional array with hexagonal cells, and their impact on system load balancing is compared with uniform distribution between cells/sectors, in Figure 1, where shadow cell means uneven load, it is either heavily or lightly loaded than normal cells (without shadow). The user density is assumed to be uniform inside cell. An analytical model of load balancing is presented in section 2, in which CDMA interference and performance indicator are described. Section 3 is the numerical results. Section 4 concludes this paper.

2. LOAD BALANCING

2.1. CDMA Interference

As we described in previous section, the capacity of each cell/sector is calculated subject to SIR requirement. Probably, the cell that is lightly loaded is incurred more interference from the heavily loaded cell, it results to increasing blocking probability in lightly loaded cell. Denote B and S the set of base stations (BSs) and sector candidates, respectively. Generally speaking, BS configuration is uniformly sectorized in one sector (with omni-directional antenna), three sectors (120° per sector), and six sector (60° per sector). Denote sector_{js} the sector s in BS j ($\forall s \in S$, $j \in B$). The interference indicator functions $\Omega^{UL}_{js\,j's'}$ and $\Omega^{DL}_{js\,j's'}$ for uplink (UL) and downlink (DL) from sector_{js} to $\text{sector}_{j's'}$, respectively, can be pre-calculated. For traffic distribution, denote C the set of traffic classes and $c(t)$ ($c(t) \in C$) the traffic class of call request from mobile station (MS) t ($\forall t \in T$), where T is the set of mobile stations. If call type of MS t belongs to class- c , class- $c(t)$ is equivalent to class- c . Denote z_{jst} the decision variable which is 1 if MS t is granted subject to SIR requirement by sector_{js} or 0 otherwise. Assuming both link powers are perfectly controlled, it ensures the received power at sector_{js} from MS t with constant value in same traffic class- $c(t)$.

Let $d^{UL}_{c(t)}$ ($d^{DL}_{c(t)}$) be the information rate in uplink (downlink), and denote $P^{UL}_{c(t)}$ ($P^{DL}_{c(t)}$) the received uplink (downlink) power signal. The signal-to-interference ratio (SIR) $SIR^{UL}_{js,c(t)}$ and $SIR^{DL}_{js,c(t)}$ in uplink and downlink is defined as (1) and (2), respectively, where ρ^{UL} (ρ^{DL}) is the uplink (downlink) orthogonality factor, $\alpha^{UL}_{c(t)}$ ($\alpha^{DL}_{c(t)}$) is uplink (downlink) activity factor, and W^{UL} (W^{DL}) is spectrum allocated in uplink (downlink). A very large constant value V in numerator is to satisfy constraint requirement if MS t is rejected (z_{jst} =0). Denote D_{jt} the distance from MS t to sector_{js} , and given attenuation factor τ =4, the intra-cell interference in uplink and downlink is given in (3) and (4), respectively. Inter-cell interference in uplink and downlink is expressed by (5) and (6), respectively.

$$SIR^{UL}_{js,c(t)} = \frac{W^{UL}}{d^{UL}_{c(t)}} \cdot \frac{P^{UL}_{c(t)} + (1 - z_{jst})V}{(1-\rho^{UL}) I^{UL}_{jst,intra} + I^{UL}_{jst,inter}} \quad (1)$$

$$SIR^{DL}_{js,c(t)} = \frac{W^{DL}}{d^{DL}_{c(t)}} \cdot \frac{P^{DL}_{c(t)} + (1 - z_{jst})V}{(1-\rho^{DL}) I^{DL}_{jst,intra} + I^{DL}_{jst,inter}} \quad (2)$$

$$I^{UL}_{jst,intra} = \sum_{\substack{t' \in T \\ t' \neq t}} \alpha^{UL}_{c(t')} P^{UL}_{c(t')} z_{jst'} \quad (3)$$

$$I^{DL}_{jst,intra} = \sum_{\substack{t' \in T \\ t' \neq t}} \alpha^{DL}_{c(t')} P^{DL}_{c(t')} \left(\frac{D_{jt'}}{D_{jt}} \right)^{\tau} z_{jst'} \quad (4)$$

$$I^{UL}_{jst,inter} = \sum_{\substack{j' \in B \\ j' \neq j}} \sum_{\substack{s' \in S \\ s' \neq s}} \sum_{\substack{t' \in T \\ t' \neq t}} \Omega^{UL}_{j's'js} \, \alpha^{UL}_{c(t')} P^{UL}_{c(t')} \left(\frac{D_{j't'}}{D_{jt'}} \right)^{\tau} z_{j's't'} \quad (5)$$

$$I^{DL}_{jst,inter} = \sum_{\substack{j' \in B \\ j' \neq j}} \sum_{\substack{s' \in S \\ s' \neq s}} \sum_{\substack{t' \in T \\ t' \neq t}} \Omega^{DL}_{j's'js} \, \alpha^{DL}_{c(t')} P^{DL}_{c(t')} \left(\frac{D_{j't'}}{D_{j't}} \right)^{\tau} z_{j's't'} \quad (6)$$

2.2. Performance Measure

In this paper, we consider the traffics with multiple classes. Kaufman model [9] is used as a performance measure to effectively analyze blocking probability for each traffic class. Assuming M channels are shared by all traffic requirements. For each traffic class- c ($\forall c \in C$) with distinct resource requirements, the traffic arrival is a stationary Poisson process with mean rate λ . The channel requirement b is an arbitrary discrete random variable ($P\{b = b_c\} = q_c$, $\forall c \in C$). A call request with channel requirement b_c has holding time with mean $1/\mu_c$. Thus, traffics with channel requirement b_c generate in Poisson arrival process with mean rate $\lambda_c = \lambda q_c$ and the class- c offered load $a_c = \lambda_c / \mu_c$. The blocking probability of traffic class- c is defined as (7), where the distribution of $q(\cdot)$ that is the number of channels occupied for the complete sharing policy satisfies the equation (8), and $q(x) = 0$ for $x < 0$ and $\sum_{j=0}^{M} q(x) = 1$.

$$B^c(a,b) = \sum_{i=0}^{b_c - 1} q(|M| - i) \qquad \forall c \in C \quad (7)$$

$$\sum_{c \in C} a_c b_c q(j - b_c) = j q(j) \qquad j = 0, 1, \ldots, M \quad (8)$$

2.3. The Model

Since the traffic variation, at best we can seek load balancing in the average sense [10]. To analyzing the experiment results, we derived the differences in call blocking probability among cells/sectors. These differences have certain distributions. The more balanced traffics keep the differences as small as possible. The deviation of these differences should approach zero. This proximity is measured by the standard deviations in the distributions of the blocking differences. The smaller the standard deviation is, the better the balancing results are. If $g_{js} = \sum_{c \in C} g^c_{js}$ is the aggregate traffics (in Erlangs) in sector_{js} where $g^c_{js} = \sum_{t \in T} z_{jst} / \mu_{c(t)}$ is the traffic intensity of class- c , and m_{js} = $\sum_{t \in T} z_{jst} m^{c(t)}$ is the number of total channels allocated in sector_{js} where $m^{c(t)}$ is the number of channels required for traffic class- $c(t)$, the performance measure B^c_{js} (call blocking probability of traffic class-c in sector$_{js}$) as in (7) is calculated. To investigate the load balancing of multiple classes traffic in terms of standard deviation in difference of call blocking probability, denote F_{LB} the load balancing factor (LBF), the load balancing model is formulated as (9), where $SD\left(B^c_{js}\right)$ is a the standard deviation function of B^c_{js}.

$$F_{LB} = \sum_{c\in C} K^c SD\left(B^c_{js}\right) \qquad \forall j\in B, s\in S \quad (9)$$

Furthermore, to study the impact of traffic type on load balancing, denote K^c the load balancing coefficient (LBC) where $\sum_{c\in C} K^c = 1$. If $K^{c1} > K^{c2}$, it claims that class-$c1$ is more concerned than class-$c2$ about traffic load balancing.

3. NUMERICAL RESULTS

3.1. Parameter

The structure of 5×5 two-dimensional array with hexagonal cells is deployed with 3 sectors ($|S|$=3) in each cell, and given R_{js}=5.0 km. The required bit energy-to-noise densities (QoS) for voice (v) and data (d) traffic are given $(E_b/N_{TOTAL})^{UL}_v$ = $(E_b/N_{TOTAL})^{DL}_v$ =7dB and $(E_b/N_{TOTAL})^{UL}_d$ = $(E_b/N_{TOTAL})^{DL}_d$ =10 dB, respectively. The information rates d^{UL}_v = d^{DL}_v =9.6bps, d^{UL}_d =19.2bps, d^{DL}_d =38.4bps, and activity factors $\alpha^{UL}_v = \alpha^{DL}_v = \alpha^{UL}_d$ = α^{UL}_d =0.5 are also given. Number of channel required is m^v=1, m^d=4, and orthogonality factor is ρ^{UL}=0.9, ρ^{DL}=0.7. Power is perfectly controlled by P^{UL}_v=10dB, P^{DL}_v=15 dB, P^{UL}_d=15 dB, P^{DL}_d=20 dB. Assigning service rate to be $\Phi^v_{js} = \Phi^d_{js}$=0.1.

3.2. Traffic Model

For each cell, call requests of voice and data service are generated in Poisson arrival process with λ_v and λ_d, respectively. The mean call holding time is given $1/\mu_v$ =180 (sec), $1/\mu_d$ =600 (sec). Denote $(E_b/N_{TOTAL})^{UL}_{c(t)} \le SIR^{UL}_{js,c(t)}$ and $(E_b/N_{TOTAL})^{DL}_{c(t)} \le SIR^{DL}_{js,c(t)}$ the QoS requirements for uplink and downlink, respectively. All traffics calculated in g_{js} satisfies QoS requirements and condition $z_{jst}D_{jt} \le R_{js}\delta_{jst}$, where δ_{jst} is the indicator if MS t is in the coverage of sector$_{js}$. Power is perfectly controlled in both uplink and downlink, and soft handoff is not taken into account. Traffics distributed in this work includes uniform (U), hop spot (H), as well as linear (L), shown in Figure 1. As we described in section 1, uneven cells in two different non-uniform distributions are either heavily or lightly loaded than normal cells in uniform distribution. To evaluate non-uniform scenario, we introduce two traffic models in Table 1. Denote M1 the heavily loaded traffics in uneven cells, while M2 the lightly loaded traffics in uneven cells. If normal cell is given traffic arrivals λ_c for traffic class-c, arrivals in uneven cells is assigned to 200% of λ_c in M1, while 50% of λ_c in M2. Accordingly, the level of load balancing can be effectively evaluated in near-realistic environment for the traffics with multiple classes.

TABLE 1 TRAFFIC MODEL IN DISTRIBUTIONS

Model	Traffic Distributions		
	Uniform	Hot Spot*	Linear*
M1	λ_c	200% of λ_c	200% of λ_c
M2	λ_c	50% of λ_c	50% of λ_c

* offered traffics in uneven cells/sectors

3.3. Analysis

Without loss of generality, the level of load balancing is represented in logarithmic form $\log(F_{LB})$. If a smaller value of $\log(F_{LB})$ is calculated, a better level of load balancing is achieved. In Figure 2 (a), no matter what distributions (linear, hot spot, and uniform) and offered voice arrivals λ_v are, $\log(F_{LB})$ is a decreasing function of BLC K^v. This implies that load balancing is easily achieved for voice only traffic than for data only traffic. Given K^v=0 for all distributions, $\log(F_{LB})$ is calculated with near -1.75 if only data traffic is considered, while $\log(F_{LB})$ is near -2.4 if voice traffic only is considered.

Concerning about the effect of traffic intensity on load balancing, the more offered voice traffic is easier to achieving load balancing than the less offered traffic if other things being equal. For example, given K^v= 0.5 in Figure 2 (a) with λ_d=6, $\log(F_{LB})$ calculates with near (-1.2, -1.6, -1.9) in arrivals (λ_v=12, 30, 48). Again given λ_v=12 in Figure 2 (a), $\log(F_{LB})$ is in the range from -1.15 to -1.4 in Figure 2(a), while $\log(F_{LB})$ is in the range from -1.7 to -1.75 in Figure 2(b) with λ_d=24.

In consideration of traffic model (M1 vs. M2), there is no significant difference on load balancing with both λ_v=12 and λ_d=6, in Figure 2(a) and Figure 3(a). However, given λ_d=6 in Figure 3(a), the level of load balancing is varied in heavily loaded voice traffic (λ_v=30, 48). The other case, given λ_d=24 in Figure 3(b), it calculates same results on load balancing variation. Analysis concludes that level of load balancing is more stable in M1 than M2 model. Better scheme is needed in the case of uneven cells with lightly loaded traffics to take care of load balancing.

4. CONCLUSION

Considering ever-increasing non-uniform distributions in mobile wireless communication systems, a load balancing model is proposed. We have studied the effect of non-uniform traffic distributions on load balancing. Numerical results indicate that the level of load balancing is affected by the spatial traffic distributions, lightly loaded in uneven cells especially. To achieving load balancing as well as capacity maximization in the system with non-uniform distributions, hybrid F/CDMA scheme can be utilized to moderately mitigate interferences, by allocating appropriate sub-spectrum in a cell. Results in this work are useful for network planning.

5. REFERENCES

[1] J.-S. Wu and J.-K. Chung, "Analysis of uplink and downlink capacities for two-tier cellular system," *IEEE Proc.-Commun.*, vol. 144, no. 6, 1997, pp. 405-411.

[2] J. C. Liberti, T. S. Rappaport, "Analytical Results for Capacity Improvements in CDMA," *IEEE Trans. Veh. Technol.*, vol. 43, pp. 680-690, Sep. 1994.

[3] C. U. Saraydar and A. Yener, "Adaptive cell sectorization for CDMA systems," *IEEE J. Select. Areas Commun.*, vol. 19, pp. 1041-1051, June 2001.

[4] C. Y. Lee, H. G. Kang, and T. Park, "A dynamic sectorization of microcells for balanced traffic in CDMA: genetic algorithms approach," *IEEE Trans. Veh. Technol.*, vol. 51, pp. 63-72, Jan. 2002.

[5] X.H. Chen, "Adaptive traffic-load shedding and its capacity gain in CDMA cellular systems," in *Proc. IEE Communications*, 1995, pp. 186-192.

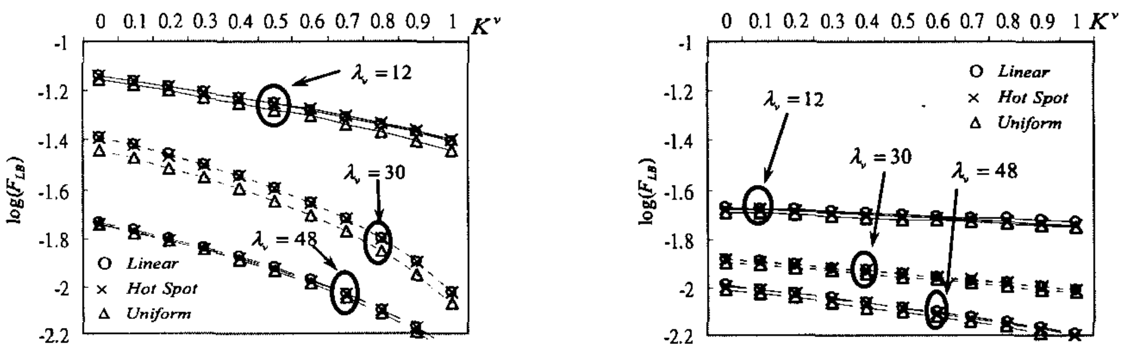
[6] K. Takeo, S. Sato, A. Ogawa, "A base station selection technique for up/downlink in CDMA system," in *Proc. VTC*, 1999, pp. 1804-1808.

[7] L. Zhuge and V. O. K. Li, "Reverse-link capacity of multiband overlaid DS-CDMA systems," *Mobile Networks and Applications*, vol. 7, pp. 101-113, 2002.

[8] L. Zhuge and V. O. K. Li, "Overlaying CDMA systems with interference differentials," *Mobile Networks and Applications*, vol. 8, pp. 269-278, 2003.

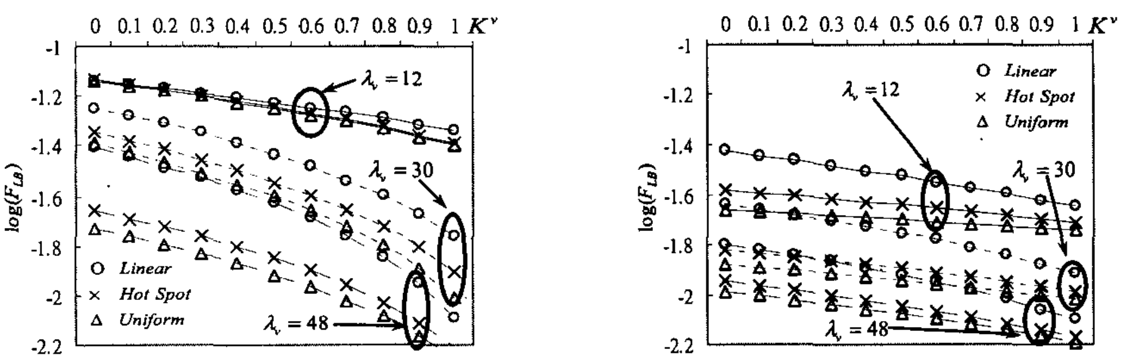
[9] J. S. Kaufman, "Blocking in a shared resource environment," *IEEE Trans. Commun.*, vol. 29, pp. 1474-1481, 1981.

[10] A. He, "Performance comparison of load balancing methods in multiple carrier CDMA systems," in *Proc. IEEE PIMRC*, 2000, pp. 113-118.



(A) λ_d =6 (B) λ_d =24

FIGURE 2 BLF AS A FUNCTION OF BLC K^v WITH RESPECT TO λ_v, GIVEN TRAFFIC MODEL M1 AND $|S|$=3



(A) λ_d =6 (B) λ_d =24

FIGURE 3 BLF AS A FUNCTION OF BLC K^v WITH RESPECT TO λ_v, GIVEN TRAFFIC MODEL M2 AND $|S|$=3