Adaptive Load Balancing of Cellular CDMA Systems Considering Non-uniform Traffic Distributions

Kuo-Chung Chu[1, 2] and Frank Yeong-Sung Lin[1]

[1] Department of Information Management, National Taiwan University,
[2] Department of Information Management,
Jin-Wen Institute of Technology, Taipei, Taiwan
d5725003@im.ntu.edu.tw

Abstract. In this paper, we investigate the load balancing problem by jointly considering sectorization and hybrid F/CDMA scheme in the scenario of non-uniform traffic distributions. The problem is formulated as a mathematical optimization model, and is solved by Lagrangean relaxation approach. The model objective is to minimize weighted blocking probability in terms of distribution diversity. To evaluate the model, performance analysis of adaptive load balancing is conducted by proposed bandwidth segmentation scheme; it is denoted adaptive scheme (AS). Non-adaptive (NA) approach by common power control scheme is compared. Combining sectorization and bandwidth segmentation scheme provides novel adaptive load balancing. Performance improvement that proposed adaptive scheme outperforms common power control scheme is about 50%.

1 Introduction

Code-division multiple access (CDMA) technique has been a promising technique for next generation wireless communication systems since the same bandwidth is shared by all users in the system, i.e. reuse of unity, soft channel capacity, and so forth. Users transmitting in the same frequency band are identified by user-specific code. For the sake of imperfect code orthogonality, interferences are incurred. In a multi-cellular environment, whenever a particular CDMA cell becomes increasingly loaded and the user increases, it will unavoidably affect all users in the system, not only the users in the home cell but also those in neighboring cells, especially in the scenario of hot spot and non-uniform traffic distributions. Hence, the system performance decreases as the number of active users increases.

Generally, a solution to the interference problem is power control mechanism for uniform traffic distribution environment, which attempts to achieve constant received mean power from each mobile within a cell [1]. However, with hot-spot cell, powering up all users in the cell to accommodate more users will result in excessive interference to users in neighboring cells to maintain sufficient signal-to- interference ratio (SIR) levels at their cell sites. Considering linear distribution, as in highway, power control may not be appropriate approach in the scenario. For non-uniform traffic distribution, sectorization is an effective way to maximize the network capacity

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[2][3]. The goal of dynamic sectorization is similar to load balancing in previous studies [4][5]. Adaptive load-shedding scheme combines the power control and soft handoff functionality to enforce some users farthest away from cell/base station (two terms are used in turn hereafter) enter forced soft handoffs, and transfer to neighboring cells that are lightly loaded. In such a way, heavily loaded cells dynamically down size their coverage area in order to serve traffics, while adjacent cells that are less heavily loaded increase their coverage to accommodate the extra traffics.

A hybrid F/CDMA scheme has been proposed to moderately mitigate interferences [6]. In consideration of F/CDMA, capacity analysis in multi-band overlaid CDMA is proposed, and maximum bandwidth utilization is obtained [7][8]. Especially, the multi-band spectrum is to provisioning heterogeneous services requirements with sub-bands [8]. In this paper, we investigate the load balancing to maximize system capacity by jointly considering sectorization and allocating appropriate sub-spectrum in a cell. CDMA background is given in section 2. Section 3 presents the model of adaptive load balancing as well as solution approach. Section 4 illustrates the computational experiments. Finally, Section 5 concludes this paper.

2 CDMA Background

2.1 Sectorization and Hybrid F/CDMA Scheme

The common way to reducing the interference between users is sectorization using directional antennas. Sectorization utilizes the spatial domain to introduce orthogonalization [2][3] to the system. Since only a subset of the users is received at each antenna, the interference that each user incurs is less compared to a single antenna system. Without loss of generality, the interferences between users can be treated as the interferences between sectors. If the interference indicator function between sectors is pre-calculated, the interference from other users/cells is easily analyzed.

To do so, sector candidates probably configured in base station (BS) must be defined. Denote K the set of sector configurations. Denote S the set of sector candidates, each sector candidate $s_{k,i}$ is defined by both sector configuration (k) and sector identity (i). Denote B the set of BSs, in this paper, two configurations are given at base station ($|K|$=2), they includes one sector (360° with omni-directional antenna) and three sectors (120° per sector), and assign k =1, 2, respectively. For simplicity, $s_{k,i}$ is substituted by s, and denote sector_{js} the sector s in BS j ($\forall s_{k,i} \in S$, $j \in B$), where B is the set of base stations.

In hybrid F/CDMA scheme, the available wideband spectrum is divided into a number of sub-bands with smaller bandwidths. Each sub-band employs direct sequence (DS) spreading with reduced processing gain and is transmitted in one and only one sub-band. The capacity of this F/CDMA system is calculated as the sum of the capacities of the sub-band. Given the whole bandwidth BW_{WHOLE} 60MHZ in both uplink and downlink (in both $W^{DL}_{js_{k,i}}$ and $W^{UL}_{js_{k,i}}$), which is made up of N_{FU} frequency units (FU) with BW_{FU} =6MHZ, where $N_{FU} = BW_{WHOLE} / BW_{FU}$ =10. By integrating FU a number of frequency segments (FS), so-called sub-band, can be separated. FS instead of whole bandwidth is deployed in sector_{js}. The term frequency segment and sub-band will be used in turn throughout the paper.

We investigate the load balancing by jointly considering sectorization and hybrid F/CDMA scheme in the scenario of non-uniform environment. If there are four frequency segments (FS0, FS1, FS2, and FS3) to be assigned in a cell/sector, for each of traffic distributions in Fig. 1 where shadow cell means heavy loads, the probable assignment would be different. Since the nature of non-uniform traffic distribution, the bandwidth requirement in each cell to satisfying SIR would be varied. The proposed scheme is called "adaptive load balancing" to optimally assigning FS with respect to traffic loads, the interferences between cells/sectors can be mitigated by bandwidth segmentation. For example, if BW_{WHOLE} allocated in downlink connection is decomposed into five FUs, $N_{FU} = |FU| = BW_{WHOLE} / BW_{FU}$ =5, the frequency segments (FS) that combined consecutively from FU are categorized into five groups of FS length. Thus, the set FU ={ 1, 2, 3, 4, 5 }, the set FS ={ (1), (2), (3), (4), (5), (1,2), (2,3), (3,4), (4,5), (1,2,3), (2,3,4), (3,4,5), (1,2,3,4), (2,3,4,5), (1,2,3,4,5) }. The total number of FS, $N_{FS} = |FS| = N^{DL}_{FU} \times (N^{DL}_{FU} + 1)/2 = 5 \times 6/2 = 15$.

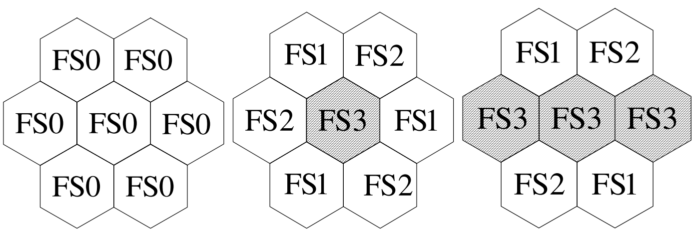

Fig. 1. Scenarios of F/CDMA scheme applied in distribution diversity

2.2 Interference Model

Given sector configuration, 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. Denote FS^{UL} and FS^{DL} the FS set in *UL* and *DL*, respectively. Applying bandwidth segmentation scheme, let x_{jsu} (y_{jsd}) be the decision variable which is 1 if sector_{js} deploys frequency segment $u \in FS^{UL}$ ($d \in FS^{DL}$) or 0 otherwise. Thus, bandwidth allocated for uplink and downlink is calculated by $\mathrm{W}^{UL}_{js} = \sum_{u \in FS^{UL}} x_{jsu} \cdot L_u \cdot BW^{UL}_{FU}$ and $\mathrm{W}^{DL}_{js} = \sum_{d \in F^{DL}} y_{jsd} \cdot L_d \cdot BW^{DL}_{FU}$, respectively, where L_u (L_d) is the length of $u\,(d\,)$. Frequency segments deployed in any two sector_{js} probably exists overlapping of FUs. Furthermore, the interference indicator function $\Psi^{UL}_{u\,u'}$ from u to u' can be pre-calculated, and the indicator function $\Psi^{DL}_{d\,d'}$ is similar to $\Psi^{UL}_{u\,u'}$.

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. Let $d^{UL}_{c(t)}$ ($d^{DL}_{c(t)}$) be the information rate in uplink (downlink). Denote z_{jst} the decision variable which is 1 if MS t is granted 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-$c(t)$. Denote $P^{UL}_{c(t)}$ ($P^{DL}_{c(t)}$) the received uplink (downlink) power signal, the signal-to-interference ratio (SIR) $SIR^{UL}_{js,c(t)}$ in uplink, which consists of processing gain and intra-inter cell/sector interferences, is defined as $SIR^{UL}_{js,c(t)}=\frac{W^{UL}_{js}}{d^{UL}_{c(t)}}\cdot\frac{P^{UL}_{c(t)}+(1-z_{jst})V}{(1-\rho^{UL})I^{UL}_{jst,intra}+I^{UL}_{jst,inter}}$, where ρ^{UL} is the uplink orthogonality factor, $\alpha^{UL}_{c(t)}$ is uplink activity factor. 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 is $I^{UL}_{jst,intra}=\sum_{t'\in T, t'\neq t}\alpha^{UL}_{c(t')}P^{UL}_{c(t')}z_{jst'}$ and inter-cell $I^{UL}_{jst,inter}$ in uplink can be expressed by (1). Equation (1) jointly considers effect of inter-sector and inter-FS on inter-cell interference.

Linear model is a best form to efficiently solve the integer programming problem. Unfortunately, the coupling of decision variables (x_{jsu}, z_{jst}) and decision variables ($x_{j's'u'}$, x_{jsu}, z_{jst}) results to non-linear form in $SIR^{UL}_{js,c(t)}$ and (1), respectively. Here we introduce auxiliary variable $\gamma_{jsut}=x_{jsu}z_{jst}$ (s.t. $x_{jsu}+z_{jst}\geq 2\cdot\gamma_{jsut}$, $x_{jsu}+z_{jst}-1\leq\gamma_{jsut}$) so that non-linear form can be reduced to linear form. Applying auxiliary variable γ_{jsut}, $SIR^{UL}_{js,c(t)}$ can be rewritten as (2). Based upon γ_{jsut}, another auxiliary variable $\zeta_{j's'u'jsut'}=\gamma_{j's'u't'}x_{jsu}=x_{j's'u'}z_{j's't'}x_{jsu}$ is also employed (s.t. $\gamma_{j's'u't'}+x_{jsu}\geq 2\cdot\zeta_{j's'u't'jsu}$, $\gamma_{j's'u't'}+x_{jsu}-1\leq\zeta_{j's'u't'jsu}$). Applying auxiliary variable $\zeta_{j's'u'jsut'}$, (1) can be rewritten as (3).

$$I^{UL}_{jst,inter}=\sum_{\substack{j'\in B\\ j'\neq j}}\sum_{\substack{s'\in S\\ s'\neq s}}\sum_{\substack{t'\in T\\ t'\neq t}}\Omega^{UL}_{j's'js}\,\alpha^{UL}_{c(t')}P^{UL}_{c(t')}\left(\frac{D_{j't'}}{D_{jt'}}\right)^{\tau} z_{j's't'}\sum_{u\in FS^{UL}}\sum_{u'\in FS^{UL}}\left(\Psi^{UL}_{u'u}\,x_{j's'u'}x_{jsu}\right) \quad (1)$$

$$SIR^{UL}_{js,c(t)}=\frac{\sum_{u\in F^{UL}}\left[L_u BW^{UL}_{FU}\left(x_{jsu}\left(P^{UL}_{c(t)}+V\right)-\gamma_{jsut}V\right)\right]}{d^{UL}_{c(t)}\left((1-\rho^{UL})I^{UL}_{jst,intra}+I^{UL}_{jst,inter}\right)} \quad (2)$$

$$I_{jst,inter}^{UL} = \sum_{\substack{j'\in B \\ j'\neq j}} \sum_{\substack{s'\in S \\ s'\neq s}} \sum_{\substack{t'\in T \\ t'\neq t}} \Omega_{j's'js}^{UL} \left(\frac{D_{j't'}}{D_{jt'}} \right)^{\tau} \sum_{u\in FS^{UL}} \sum_{u'\in FS^{UL}} \Psi_{u'u}^{UL} \zeta_{j's'u't'jsu} \alpha_{c(t')}^{UL} P_{c(t')}^{UL} \tag{3}$$

In downlink connection, it is similar to uplink except that the interference of intra-cell is more complicated. Auxiliary variables $\eta_{jsdt} = y_{jsd} z_{jst}$ and $\xi_{j's'd'jsdt'} = \eta_{j's'd't'} y_{jsd} = y_{j's'd'} z_{j's't'} y_{jsd}$ are introduced that subject to ($y_{jsd} + z_{jst} \geq 2 \cdot \eta_{jsdt}$, $y_{jsd} + z_{jst} - 1 \leq \eta_{jsdt}$) and ($\eta_{j's'd't'} + y_{jsd} \geq 2 \cdot \xi_{j's'd't'jsd}$, $\eta_{j's'd't'} + y_{jsd} - 1 \leq \xi_{j's'd't'jsd}$), respectively. Associated models are expressed in (4)-(6).

$$I_{jst,intra}^{DL} = \sum_{\substack{t'\in T \\ t'\neq t}} \alpha_{c(t')}^{DL} P_{c(t')}^{DL} \left(\frac{D_{jt'}}{D_{jt}} \right)^{\tau} z_{jst'} \tag{4}$$

$$I_{jst,inter}^{DL} = \sum_{\substack{j'\in B \\ j'\neq j}} \sum_{\substack{s'\in S \\ s'\neq s}} \sum_{\substack{t'\in T \\ t'\neq t}} \Omega_{j's'js}^{DL} \left(\frac{D_{j't'}}{D_{j't}} \right)^{\tau} \sum_{d\in FS^{DL}} \sum_{d'\in FS^{DL}} \Psi_{d'd}^{DL} \xi_{j's'd't'jsd} \alpha_{c(t')}^{DL} P_{c(t')}^{DL} \tag{5}$$

$$SIR_{js,c(t)}^{DL} = \frac{\sum_{d\in FS^{DL}} \left[L_d BW_{FU}^{DL} \left(y_{jsd} \left(P_{c(t)}^{DL} + V \right) - \eta_{jsdt} V \right) \right]}{d_{c(t)}^{DL} \left((1-\rho^{DL}) I_{jst,intra}^{DL} + I_{jst,inter}^{DL} \right)} \tag{6}$$

3 Adaptive Load Balancing Model

3.1 Performance Measure

In this paper, we consider multiple traffic classes in adaptive load balancing. 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 μ_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 $B^c(a,b) = \sum_{i=0}^{b_c-1} q(|M| - i)$, where the distribution of $q(\bullet)$, the number of channels occupied for the complete sharing policy, satisfies the equation $\sum_{c\in C} a_c b_c q(j - b_c) = jq(j)$, $j = 0, 1, ..., M$, and $q(x) = 0$ for $x < 0$ and $\sum_{j=0}^{M} q(x) = 1$.

3.2 Problem Formulation and Solution Approach

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. Appropriately allocating FS in a sector/cell to mitigate interference is considerable in the environment with heterogeneous traffics. The aim of the model is to investigate the load balancing among all cells/sectors in terms of blocking probability. Performance measure, B_{js}^{c} the call blocking probability of traffic class-*c* in sector_{js}, developed by Kaufman is applied. Denote $g_{js}=\sum_{c\in C} g_{js}^{c}$ the aggregate traffic (in Erlangs) in sector_{js}, where g_{js}^{c} is the aggregate intensity of class-c, and denote $m_{js} = \sum_{t\in T} z_{jst} m^{c(t)}$ 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 weighted factor w_{js} is expressed by $w_{js}=\sum_{c\in C} g_{js}^{c} \Big/ \sum_{j\in B}\sum_{s\in S}\sum_{c\in C} g_{js}^{c}$. To objective function (IP) is to minimize weighted blocking probability, in which K^{c} is the balancing coefficient (BLC) 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.

$$Z_{IP} = \min \sum_{c\in C} K^{c} \sum_{j\in B}\sum_{s\in S} w_{js} B_{js}^{c}\left(g_{js}, m_{js}\right) \qquad \text{(IP)}$$

$$\left(\frac{E_b}{N_{TOTAL}}\right)_{c(t)}^{UL} \le \frac{\sum_{u\in F^{UL}}\left[L_u BW_{FU}^{UL}\left(x_{jsu}\left(P_{c(t)}^{UL}+V\right)-\gamma_{jsut}V\right)\right]}{d_{c(t)}^{UL}\left((1-\rho^{UL})I_{jst,intra}^{UL}+I_{jst,inter}^{UL}\right)} \qquad \forall j\in B, s\in S, t\in T \quad (7)$$

$$\left(\frac{E_b}{N_{TOTAL}}\right)_{c(t)}^{DL} \le \frac{\sum_{d\in F^{DL}}\left[L_d BW_{FU}^{DL}\left(y_{jsd}\left(P_{c(t)}^{DL}+V\right)-\eta_{jsdt}V\right)\right]}{d_{c(t)}^{DL}\left((1-\rho^{DL})I_{jst,intra}^{DL}+I_{jst,inter}^{DL}\right)} \qquad \forall j\in B, s\in S, t\in T \quad (8)$$

$$\sum_{t\in T} z_{jst}\lambda_{c(t)}\mu_{c(t)} = g_{js}^{c} \qquad \forall j\in B, s\in S, c\in C \quad (9)$$

$$\sum_{t\in T} z_{jst} m^{c(t)} = m_{js} \qquad \forall j\in B, s\in S \quad (10)$$

$$z_{jst} D_{jt} \le R_{js}\delta_{jst} \qquad \forall j\in B, s\in S, c\in C \quad (11)$$

$$\sum_{j\in B}\sum_{s\in S} z_{jst} \le 1 \qquad \forall t\in T \quad (12)$$

$$2\cdot\gamma_{jsut} \le x_{jsu} + z_{jst} \qquad \forall j,\in B, s\in S, t\in T, u\in FS^{UL} \quad (13)$$

$$x_{jsu} + z_{jst} - 1 \le \gamma_{jsut} \qquad \forall j,\in B, s\in S, t\in T, u\in FS^{UL} \quad (14)$$

$$2\cdot\zeta_{j's'u'jsut'} \le \gamma_{j's'u't'} + x_{jsu} \qquad \forall j, j'\in B, j\ne j', s, s'\in S, s\ne s', t'\in T, u, u'\in FS^{UL} \quad (15)$$

$$\gamma_{j's'u't'} + x_{jsu} - 1 \le \zeta_{j's'u'jsut'} \qquad \forall j, j'\in B, j\ne j', s, s'\in S, s\ne s', t'\in T, u, u'\in FS^{UL} \quad (16)$$

$$2\cdot\eta_{jsdt} \le y_{jsd} + z_{jst} \qquad \forall j,\in B, s\in S, t\in T, d\in FS^{DL} \quad (17)$$

$$y_{jsd} + z_{jst} - 1 \le \eta_{jsdt} \qquad \forall j,\in B, s\in S, t\in T, d\in FS^{DL} \quad (18)$$

$$2\cdot\xi_{j's'd'jsdt'} \le \eta_{j's'd't'} + y_{jsd} \quad \forall j,j'\in B, j\ne j', s,s'\in S, s\ne s', t'\in T, d,d'\in FS^{DL} \quad (19)$$

$$\eta_{j's'd't'} + y_{jsd} - 1 \le \xi_{j's'd'jsdt'} \quad \forall j,j'\in B, j\ne j', s,s'\in S, s\ne s', t'\in T, d,d'\in FS^{DL} \quad (20)$$

$$\Phi_{js}^{c} \le \frac{\sum_{t\in T} z_{jsc(t)}}{\sum_{t\in T} \delta_{jsc(t)}} \quad \forall j\in B, s\in S, c\in C \quad (21)$$

$$\sum_{u\in FS^{UL}} x_{jsu} = 1 \quad \forall j\in B, s\in S \quad (22)$$

$$\sum_{d\in FS^{DL}} y_{jsd} = 1 \quad \forall j\in B, s\in S \quad (23)$$

$$z_{jst} = 0 \text{ or } 1 \quad \forall j\in B, s\in S, t\in T \quad (24)$$

$$x_{jsu} = 0 \text{ or } 1 \quad u\in FS^{UL} \quad (25)$$

$$y_{jsd} = 0 \text{ or } 1 \quad d\in FS^{DL} \quad (26)$$

$$\gamma_{jsut} = 0 \text{ or } 1 \quad \forall j,\in B, s\in S, t\in T, u\in FS^{UL} \quad (27)$$

$$\eta_{jsdt} = 0 \text{ or } 1 \quad \forall j,\in B, s\in S, t\in T, d\in FS^{DL} \quad (28)$$

$$\zeta_{j's'u'jsut'} = 0 \text{ or } 1 \quad \forall j,j'\in B, j\ne j', s,s'\in S, s\ne s', t'\in T, u,u'\in FS^{UL} \quad (29)$$

$$\xi_{j's'd'jsdt'} = 0 \text{ or } 1 \quad \forall j,j'\in B, j\ne j', s,s'\in S, s\ne s', t'\in T, d,d'\in FS^{DL} \quad (30)$$

Denote $(E_b/N_{TOTAL})_{c(t)}^{UL}$ and $(E_b/N_{TOTAL})_{c(t)}^{DL}$ the QoS requirement of admission control, then SIR constraint for uplink and downlink is expressed by (7) and (8), respectively. Traffic intensity of class-c in sector_{js} is calculated in (9), where $\lambda_{c(t)}$ is mean arrival rate for class-$c(t)$. The number of channels allocated is constrained by (10). Denote δ_{jst} indication function which is 1 if MS t is covered by sector_{js} or 0 otherwise. MS t can be serviced in the coverage of sector_{js} by (11), where R_{js} is the power transmission radius and D_{jt} is the distance from sector_{js} to MS t. Constraint (12) requires that each mobile user can be homed to only one base station. We do not take soft handoff into account. Since four auxiliary decision variables are introduced, a number of constraints are listed from (13) to (20). A pre-defined service rate Φ_{js}^{c} for class-c is given in (21). Using bandwidth segmentation scheme, only one FS can be deployed in uplink and downlink by constraint (22) and (23), respectively. Constraints (24)-(30) are integer properties of the decision variables.

To solving the complicated optimization model, Lagrangean relaxation method is applied [10]. Problem (IP) is transferred to be a dual problem $Z_D = \max Z_D(V)$ by relaxing ten constraints (7), (8), (13)-(20), then multiply the relaxed constraints with corresponding Lagrangean multipliers vector $V=(v_1, v_2, v_3, v_4, v_5, v_6, v_7, v_8, v_9, v_{10})$, and add them to the primal objective function. We then get Lagrangean relaxation (LR) problem, which is further decomposed into three independent subproblems, including admission control subproblem related to z_{jst}, uplink bandwidth allocation subproblem related to x_{jsu}, γ_{jsut}, $\zeta_{j's'u'jsut'}$, and downlink bandwidth allocation subproblem related to y_{jsu}, η_{jsut}, $\xi_{j's'u'jsut'}$. All of them can be optimally solved efficiently by proposed algorithms[1]. According to the weak Lagrangean duality theorem, for any $V \geq 0$, the objective value of $Z_D(V)$ is a lower bound (LB) of Z_{IP}. Thus, the dual problem (D) $Z_D = \max Z_D(V)$ subject to $V \geq 0$ is constructed to calculate the tightest lower bound by adjusting multipliers. Subgradient method is used to solving the dual problem. Let the vector S be a subgradient of $Z_D(V)$ at $V \geq 0$. In iteration k of subgradient optimization procedure, the multiplier vector π is updated by $\pi^{k+1} = \pi^k + t^k S^k$, in which t^k is a step size determined by $t^k = \lambda\left(Z_{IP}^* - Z_D(\pi^k)\right) / \left\|S^k\right\|^2$, where Z_{IP}^* is an upper bound (UB) on the primal objective function value after iteration k, and λ is a constant where $0 \leq \lambda \leq 2$. To calculate upper bound of (IP), the algorithm of getting primal feasible solutions is also proposed [2].

4 Computational Experiments

4.1 Environment and Parameter

The structure of 5×5 two-dimensional array with hexagonal cells is deployed, and given R_{js}=5.0km. The required bit energy-to-noise density (QoS) for voice (v) and data (d) traffics $(E_b/N_{TOTAL})_v^{UL} = (E_b/N_{TOTAL})_v^{UL}$ =7dB and $(E_b/N_{TOTAL})_d^{UL} = (E_b/N_{TOTAL})_d^{UL}$ =10 dB, respectively, and the information rate $d_v^{UL} = d_v^{DL}$=9.6bps, d_d^{UL}=19.2bps, d_d^{DL}=38.4bps. Activity factor $\alpha_v^{UL} = \alpha_v^{DL} = \alpha_d^{UL} = \alpha_d^{UL}$=0.5. Number of channel required m^v=1, m^d=4. Orthogonality factor ρ^{UL}=0.9, ρ^{DL}=0.7. Power is perfectly controlled by P_v^{UL}=10dB, P_v^{DL}=15 dB, P_d^{UL}=15 dB, P_d^{DL}=20 dB. Service rate $\Phi_{js}^v = \Phi_{js}^d$=0.1. Call requests for voice and data are generated in Poisson arrival process with λ_v and λ_d, respectively. The mean call holding time is given μ_v=180(sec), μ_d=600(sec). Traffic intensity generated in heavy loaded cells of non-uniform distribution is multiple of five in uniform distribution.

For each case of distributions, Z_{IP} is solved with maximum number of 1000 iterations. The improvement counter is given 25. Time consumed in each case is up to 370 (sec). The error gap defined by (UB-LB)/LB*100% is calculated less than 30% in all cases. For the purpose of statistic analysis, 100 tests are experimented in each case. Performance analysis is based on the average of 100 tests.

[1, 2] Detailed algorithms are omitted due to the length limitation of the paper. A complete version of the paper is available upon request.

4.2 Performance Analysis

Traffic distributions including uniform (U), linear (L), as well as hop spot (H) models as shown in Fig. 1 are considered, performance analysis of adaptive load balancing is manipulated by proposed bandwidth segmentation scheme; it is denoted adaptive scheme (AS). For the comparison purpose, non-adaptive (NA) approach by common power control scheme [4][5] is implemented. Besides, sectorization is also taken into account. We analyze the weighted blocking

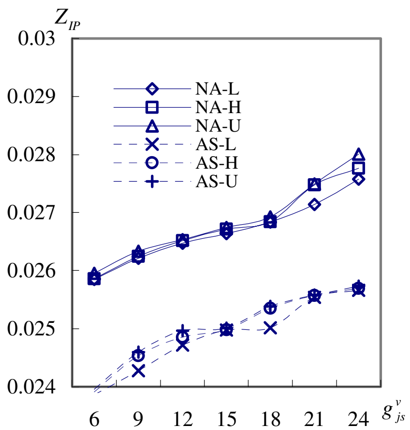

Fig. 2. Blocking as a function of voice traffics with g^d_{js} =30 and $|S|$=1

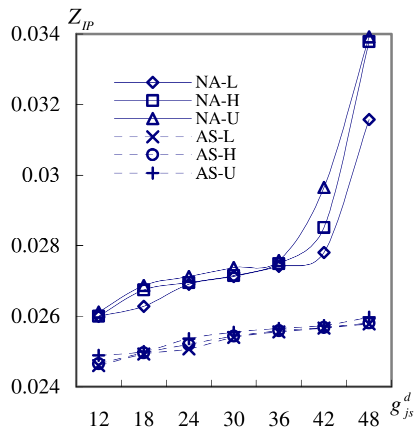

Fig. 3. Blocking as a function of data traffics with g^v_{js} =15 and $|S|$=1

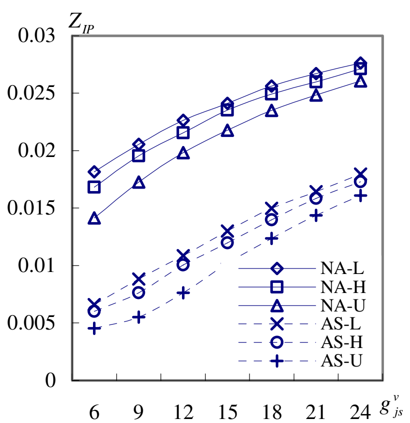

Fig. 4. Blocking as a function of voice traffics with g^d_{js} =30 and $|S|$=3

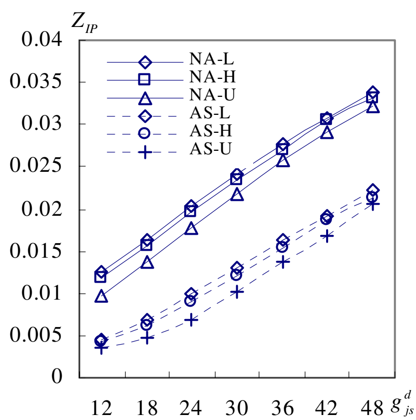

Fig. 5. Blocking as a function of data traffics with g^v_{js} =15 and $|S|$=3

probability (Z_{IP}) as a function of voice (data) traffic intensity with constant data (voice) traffic, in which load balancing scheme v.s. traffic distribution is compared. BLC ratio of K^v vs. K^d (0.5 vs. 0.5) is given.

First of all, without sectorization ($|S|$=1) and given g_{js}^d=30, Z_{IP} is a function of voice traffic in Fig. 2, while Z_{IP} is a function of data traffic in Fig. 3 with g_{js}^v=15. In the case of voice intensity g_{js}^v=15 in Fig. 2, no matter which distribution is considered, proposed AS scheme reduces blocking percentage of (0.0265-0.025)/0.0265*100% = 56.6%. In Fig. 3, much more blocking (up to 0.034) is incurred in case of data intensity g_{js}^d=48 with NA scheme. Considering sectorization with $|S|$=3, Z_{IP} is harmonically increasing function of data and voice traffics intensity in Fig. 4, and Fig. 5, respectively. This implies that combining sectorization and bandwidth segmentation approaches provides novel adaptive load balancing scheme. In summary, performance improvement that proposed adaptive scheme outperforms power control scheme is about 50%.

5 Conclusion

To maximize entire system capacity in ever-increasing non-uniform distribution, we propose the load balancing mechanism by jointly considering sectorization and hybrid F/CDMA scheme. Experiments show the mechanism is outstanding for performance management. For more practical, further experiments can be conducted, such as more generic cell planning rather than hexagonal cell structure, a great diversity of non-uniform distributions, a lot of BLC combinations.

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