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NETWORK PLANNING AND CAPACITY MANAGEMENT CONSIDERING ADAPTIVE SECTORIZATION IN SURVIVABLE FDMA/CDMA SYSTEMS

Kuo-Chung Chu[†, ‡] *and Frank Yeong-Sung Lin*[†]
[†]Department of Information Management, National Taiwan University
[‡]Department of Information Management, Jin-Wen Institute of Technology
Taipei, Taiwan

ABSTRACT

In this paper, we investigate the integrated problem of survivable CDMA network planning and management. The problem is formulated as a combinatorial optimization formulation in terms of deploying cost minimization. Solution approach to the development algorithm is Lagrangean relaxation. In experiment results, the proposed algorithm is shown to be more effective and achieves up to 25% reduction on the total deployment cost over a simple algorithm. It also takes around 30% expenses to guarantee survivability.

1. INTRODUCTION

Generally, the issues of network planning consist of allocation for mobile telephone switching offices (MTSO), base stations (BS), backbone topology, and system configuration. Since backbone topology is a key factor in the routing problem, the backbone topology and the routing path for each O-D (origination-destination) pair must be jointly considered. Unlike second-generation cellular networks, CDMA system capacity bounded on interferences in both uplink and downlink is another issue of system planning.

To mitigate the interferences in terms of capacity maximization, sectorization is an effective way [1][2]. Denote K the set of sector configurations and S the set of sector candidates, sector candidate $s_{k,i}$ is defined by both sector configuration ($k \in K$) and sector identity (*i*). For simplicity, $s_{k,i}$ is substituted by s, and denote sector$_{js}$ the sector s in BS j ($\forall s \in S_k, j \in B$), where B is the set of base stations. Without loss of generality, the interferences between users can be treated as the interferences between sectors. Besides, combining traditional FDMA to CDMA is an alternative to moderately mitigate interferences. [3] shows that the current frequency reuse factor of 1 is not always optimal. Another study demonstrated that it is possible to increase the cell capacity without deploying additional cells by applying proper FDMA frequency reuse to minimize interference [4].

Although intensive research on different issues of network planning has been conducted, relatively little work attempting to deal with the overall planning and management problem in an integrated and joint manner has been seen in the literature. Previous studies of CDMA planning focused on cell arrangement [5][6]. Chu et al. [7] first developed a mathematical model to the aforementioned overall planning and management problem. However, sectorization and spectrum resource allocation were not considered in their work. In this paper, we investigate CDMA network planning which jointly considers adaptive sectorization and hybrid F/CDMA scheme under QoS/GoS and survivability constraints. The remainder of this paper is organized as follows. In Section 2, hybrid F/CDMA scheme is introduced. Section 3 presents the integrated model of network planning as well as solution approach. Section 4 illustrates the computational experiments. Finally, Section 5 concludes this paper.

2. HYBRID F/CDMA SCHEME

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 (UL) and downlink (DL), which is made up of N_{FU} frequency units (FU) with BW_{FU} =6MHZ, where $N_{FU} = BW_{WHOLE}/BW_{FU}$ =10. Denote M the set of sub-bands in length of frequency segment (FS). By integrating FU, a number of FS in both UL (denote W_{js}^{UL}) and DL (denote W_{js}^{DL}), so-called sub-band, can be separated. FS instead of whole bandwidth (reuse factor of 1) is deployed in sector$_{js}$. The term frequency segment (FS) and sub-band will be used in turn throughout the paper.

Given sector configuration, the interference indicator functions $\Omega_{jsj's'}^{UL}$ and $\Omega_{jsj's'}^{DL}$ for UL and DL from sector$_{js}$ to sector$_{j's'}$, respectively, can be pre-calculated. Let y_{jsm} be the decision variable which is 1 if sector$_{js}$ deploys *m*–th sub-band in both *UL* and *DL*, or 0 otherwise. Thus, bandwidth allocated for uplink

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and downlink is calculated by $W^{UL}_{js} = \sum_{m\in M} y_{jsm} \cdot L_m \cdot BW^{UL}_{FU}$ and $W^{DL}_{js} = \sum_{m\in M} y_{jsm} \cdot L_m \cdot BW^{DL}_{FU}$, respectively, where L_u is the length of m–th sub-band. Sub-bands deployed in any two sector_{js} probably exist overlapping of FU. Furthermore, the interference indicator function $\Psi^{UL}_{m\,m'}$ ($\Psi^{DL}_{m\,m'}$) from m to m' can be pre-calculated.

For traffic distribution, denote C the set of traffic classes and $c(o)$ ($c(o) \in C$) the traffic class of OD pair o ($\forall o \in O$), where O is the set of OD pair. If traffic type of OD o belongs to class-c, class-$c(o)$ 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 uplink signal-to-interference ratio (SIR) $SIR^{UL}_{js,c(t)} = \sum_{m\in M}\left[L_m BW^{UL}_{FU}\left(y_{jsm}\left(P^{UL}_{c(t)}+V\right)-\gamma_{jsmt}V\right)\right]/d^{UL}_{c(t)}\left((1-\rho^{UL})I^{UL}_{jst,intra}+I^{UL}_{jst,inter}\right)$, 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). Downlink is similar to uplink, given $SIR^{UL}_{js,c(t)} = \sum_{m\in M}\left[L_m BW^{DL}_{FU}\left(y_{jsm}\left(P^{DL}_{c(t)}+V\right)-\gamma_{jsmt}V\right)\right]/d^{DL}_{c(t)}\left((1-\rho^{DL})I^{DL}_{jst,intra}+I^{DL}_{jst,inter}\right)$. Since we jointly considers effect of inter-sector and inter-FS on inter-cell interference, the coupling of decision variables (y_{jsm}, z_{jst}) and decision variables ($y_{j's'm'}$, y_{jsm}, z_{jst}) results to non-linear form. Here we introduce auxiliary variables $\gamma_{jsmt} = y_{jsm}z_{jst}$ (s.t. $y_{jsm}+z_{jst} \geq 2\cdot\gamma_{jsmt}$, $y_{jsm}+z_{jst}-1 \leq \gamma_{jsmt}$) and $\zeta_{j's'u'jsut'} = \gamma_{j's'u't'}y_{jsu} = y_{j's'u'}z_{j's't'}y_{jsu}$ (s.t. $\gamma_{j's'u't'}+y_{jsu} \geq 2\cdot\zeta_{j's'u't'jsu}$, $\gamma_{j's'u't'}+y_{jsu}-1 \leq \zeta_{j's'u't'jsu}$) so that non-linear form can be reduced to linear form. The detail definition is referred to [8].

3. SYSTEM MODEL

3.1. Mathematical modeling

To better describe the problem, the following subproblems are jointly investigated: (i) base station allocation subproblem; (ii) routing, network topology, and capacity management subproblem; (iii) mobile station homing and channel assignment subproblem; (iv) power transmission radius control subproblem; (v) bandwidth allocation subproblem. Denote L_1, L_2, L_3 the set of links between two MTSO, between MTSO and base station, between base station and mobile station, respectively. Given $L = L_1 \cup L_2 \cup L_3$. If the costs of base station installation, sector configuration, bandwidth allocation, and link connection are given Δ_B, Δ_k, Δ_m, and $\Delta_l(c_l)$ with capacity c_l, respectively, the objective is to minimize total costs in (IP).

$$Z_{IP} = \min$$

$$\sum_{j\in B}\Delta_B a_j + \sum_{j\in B}\sum_{k\in K}\Delta_k b_{jk} + \sum_{j\in B}\sum_{s\in S}\sum_{m\in M}\Delta_m d_{jsm} + \sum_{l\in L}\Delta_l(c_l) \qquad \text{(IP)}$$

$$\left(\frac{E_b}{N_{TOTAL}}\right)^{UL}_{c(t)} \leq SIR^{UL}_{js,c(t)} \qquad \forall j\in B, k\in K, s\in S_k, t\in T, e\in E \quad (1)$$

$$\left(\frac{E_b}{N_{TOTAL}}\right)^{DL}_{c(t)} \leq SIR^{DL}_{js,c(t)} \qquad \forall j\in B, k\in K, s\in S_k, t\in T, e\in E \quad (2)$$

$$\sum_{l\in L_3}\sum_{o\in O}\sum_{p\in P_o} A_{c(o)}x^e_p\delta_{pl}\phi_{ljs} = g^e_{jsc} \qquad \forall j\in B, k\in K, s\in S_k, c\in C, e\in E \quad (3)$$

$$\sum_{l\in L_3}\sum_{o\in O}\sum_{p\in P_o} q_{c(o)}x^e_p\delta_{pl}\phi_{ljs} = q^e_{jsc} \qquad \forall j\in B, k\in K, s\in S_k, c\in C, e\in E \quad (4)$$

$$\sum_{o\in O}\sum_{p\in P_o} A_{c(o)}x^e_p\delta_{pl} = f_{lc} \qquad \forall l\in L-\{L_3\}, c\in C, e\in E \quad (5)$$

$$\sum_{o\in O}\sum_{p\in P_o} q_{c(o)}x^e_p\delta_{pl} = n_{lc} \qquad \forall l\in L-\{L_3\}, c\in C, e\in E \quad (6)$$

$$SB_{jsc}\left(g^e_{jsc}, m^e_{jsc}\right) \leq \beta^e_{jsc} \qquad \forall j\in B, k\in K, s\in S_k, c\in C, e\in E \quad (7)$$

$$LB_{lc}\left(f_{lc}, n_{lc}\right) \leq \varepsilon_{lc} \qquad \forall l\in L-\{L_3\}, c\in C, e\in E \quad (8)$$

$$\sum_{p\in P_O} x^e_p = 1 \qquad \forall o\in O, e\in E \quad (9)$$

$$\sum_{o\in O}\sum_{p\in P_o} x^e_p\delta_{pl}\phi_{ljs}\rho_{lt} \leq z^e_{jst} \qquad \forall j\in B, k\in K, s\in S_k, l\in L_3, t\in T, e\in E \quad (10)$$

$$z^e_{jst}D_{jt} \leq r^e_{js}\mu^e_{jst} \qquad \forall j\in B, k\in K, s\in S_k, t\in T, e\in E \quad (11)$$

$$0 \leq r^e_{js} \leq R_{js} \qquad \forall j\in B, k\in K, s\in S_k, r^e_{js}\in Y, e\in E \quad (12)$$

$$b^e_{jk} \leq a_j \qquad \forall j\in B, k\in K, e\in E \quad (13)$$

$$d^e_{jsm} \leq a_j \qquad \forall j\in B, k\in K, s\in S_k, e\in E \quad (14)$$

$$\sum_{j\in B}\sum_{k\in K}\sum_{s\in S_k} z^e_{jst} = 1 \qquad \forall t\in T, e\in E \quad (15)$$

$$\sum_{k\in K} b^e_{jk} = 1 \qquad \forall j\in B, e\in E \quad (16)$$

$$\sum_{m\in M} d^e_{jsm} = 1 \qquad \forall j\in B, k\in K, s\in S_k, e\in E \quad (17)$$

$$z^e_{jst} \leq a_j \qquad \forall j\in B, k\in K, s\in S_k, t\in T, e\in E \quad (18)$$

$$2\cdot\gamma^e_{jsmt} \leq y^e_{jsm} + z^e_{jst} \qquad \forall j, \in B, k\in K, s\in S_k, t\in T, m\in M \quad (19)$$

$$y^e_{jsm} + z^e_{jst} - 1 \leq \gamma^e_{jsmt} \qquad \forall j, \in B, k\in K, s\in S_k, t\in T, m\in M \quad (20)$$

$$2\cdot\zeta^e_{j's'm'jsmt'} \leq \gamma^e_{j's'm't'} + y^e_{jsm} \quad \forall j, j'\in B, j\neq j', k\in K, s, s'\in S_k, s\neq s', t'\in T, m, m'\in M \quad (21)$$

$$\gamma^e_{j's'm't'} + y^e_{jsm} - 1 \leq \zeta^e_{j's'm'jsmt'} \quad \forall j, j'\in B, j\neq j', k\in K, s, s'\in S_k, s\neq s', t'\in T, m, m'\in M \quad (22)$$

$$a_j = 0 \text{ or } 1 \qquad \forall j\in B \quad (23)$$

$$b^e_{jk} = 0 \text{ or } 1 \qquad \forall j\in B, k\in K, e\in E \quad (24)$$

$$d^e_{jsm} = 0 \text{ or } 1 \qquad \forall j\in B, k\in K, s\in S_k, m\in M, e\in E \quad (25)$$

$$x^e_p = 0 \text{ or } 1 \qquad \forall o\in O, p\in P_o, e\in E \quad (26)$$

$$z^e_{jst} = 0 \text{ or } 1 \qquad \forall j\in B, k\in K, s\in S_k, t\in T, e\in E \quad (27)$$

$$y^e_{jsm} = 0 \text{ or } 1 \quad \forall j, \in B, k\in K, s\in S_k, t\in T, m\in M, e\in E \quad (28)$$

$$\gamma^e_{jsmt} = 0 \text{ or } 1 \quad \forall j, \in B, k\in K, s\in S_k, t\in T, m\in M, e\in E \quad (29)$$

$$\zeta_{j's'm'jsmt'} = 0 \text{ or } 1$$

$$\forall j, j'\in B, j\neq j', k\in K, s, s'\in S_k, s\neq s', t'\in T, m, m'\in M \quad (30)$$

Denote E the set of network state. SIR constraint for uplink and downlink is (1) and (2), respectively, in state $e \in E$. Denote δ_{pl} the indicator function which is 1 if link l belongs to path p and 0 otherwise, and denote ϕ_{ljs} the indicator function which is 1 if sector s in BS j is one end of link l and 0 otherwise. Given traffic intensity A_o of OD pair $o \in O$ and routing decision variable x_p^e, which is 1 if path p is selected at state e, the aggregate traffic (in Erlangs) in sector_{js} and in link l is given $g_{js}^e = \sum_{c \in C} g_{jsc}^e$ and $f_l = \sum_{c \in C} f_{lc}$, where g_{jsc}^e and f_{lc} is the aggregate intensity of class-c defined in (3) and (5). Denote $q_{js} = \sum_{c \in C} q_{jsc}$ ($n_l = \sum_{c \in C} n_{lc}$) the number of total channels allocated in sector_{js} (link l), where q_{jsc} and n_l is the number of channels required for traffic class-c defined in (4) and (6). Constraint (7) and (8) requires that a blocking in sector and link is under predefined threshold (β_{jsc}^e and ε_{lc}) of probability, respectively, where sector blocking $SB(\cdot)$ and link blocking $LB(\cdot)$ is the model developed by Kaufman [9]. Constraint (9) ensures that each O-D pair would be transmitted on one path. Constraint (10) is to guarantee that if a base station does not provide service to a mobile station, the link between them cannot be selected as a part of routing path.

Denote μ_{jst}^e indication function is 1 if MS t is covered by sector s of MS j at state e or 0 otherwise. MS can be serviced in the coverage of BS by (11), where r_{js}^e and D_{jt} is the power transmission radius and the distance to MS. Constraint (12) is to ensure that the transmission radius of each base station ranges from 0 to R_j. The following constraints are associated with bandwidth allocation. Constraint (13) ensures that sectorization is not deployed without base station installation, while (14) requires that the bandwidth is assigned only if the base station is installed. Constraint (15) guarantees that each mobile station is serviced. Constraint (16) requires only one sector configuration is deployed for each base station. A sector in any network state is allocated by one bandwidth in (17). If base station is not installed, no mobile station can be serviced by (18). Since two auxiliary decision variables are introduced, a number of constraints are listed from (19) to (22). (23)-(30) are integer properties of the decision variables.

3.2. Solution approach

To solving the complicated mathematical optimization model, Lagrangean relaxation method is applied [10]. Problem (IP) is transferred to be a dual problem by relaxing nine complicating constraints (1)(2)(10)(11) (13) (14)(18)(19)(20), then multiply the relaxed constraints with corresponding Lagrangean multipliers vector $V=(v_1, v_2, v_3, v_4, v_5, v_6, v_7, v_8, v_9)$ and add them to the primal objective function. We get Lagrangean relaxation (LR) problem, which is further decomposed into five independent subproblems with respect to decision variables. 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 of Z_{IP}. Thus, the dual problem $Z_D = \max Z_D(V)$ is constructed to calculate the tightest lower bound by adjusting multipliers subject to $V \geq 0$. Then, subgradient method is used to solving the dual problem. Let the vector S is 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 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]. In order to prove the efficiency of proposed Lagrangean relaxation (LR) algorithms, a simple algorithm[3] (SA) is also implemented.

4. EXPERIMENT RESULTS

In this work, we consider voice (v) and data (d) traffics, $v, d \in C$. Number of OD pairs is half of total number of MS ($|O| = |T|/2$). Each OD pair belongs to only one traffic type, either voice or data, and the number of voice-data traffics is 50-50 in all OD pairs. The traffic distribution among OD pairs is randomly generated. The experiment environment is given $|B|$=15, $|K|$=2 (omni-directional antenna and three uniform sectors). Associated GoS/QoS parameters are given ε_{lv}=0.01, $\varepsilon_{ld} = \beta_{jsv}^e$=0.03, β_{jsd}^e=0.05, the required bit energy-to-noise density for voice (v) and data (d) traffics $(E_b/N_{TOTAL})_v^{UL} = (E_b/N_{TOTAL})_v^{UL}$=7dB and $(E_b/N_{TOTAL})_d^{UL} = (E_b/N_{TOTAL})_d^{UL}$=10dB, respectively. Activity factor of α_v and α_d in both links are all given 0.5. Assigning the unit costs Δ_B=5,000,000, Δ_k=800,000, Δ_m=200,000, and Δ_l=50 per channel. Information rate $d_v^{UL} = d_v^{DL}$=9.6bps, $d_d^{UL} = d_d^{DL}$=38.4bps. Number of channel required q_v=1, q_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.

To evaluate the performance of survivability issue, network states of both normal case (N-no base station failure) and failure case (F) are taken into account. All experiments are coded in C++ and running on INTELTM P4-1.6GHZ CPU with 256 MB RAM. For

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[1,2,3] Detailed algorithms are omitted due to the length limitation of the paper. A complete version of the paper is available upon request.

each case, Z_{IP} is solved with maximum number of 1000 iterations. The improvement counter is given 25. Average time consumed in normal case and failure case is up to 3800 (sec) and 420 (sec), respectively. The error gap defined by (UB-LB)/LB*100% is calculated near 45% in all cases. Given 1 and 3 Erlangs for voice and data OD pair, respectively, Fig. 1 illustrates the cost analysis as a function of number of mobile stations. No matter what scenario is considered, it takes around 30% expenses to guarantee survivability. Unavoidably, increasing cost is needed to considering survivable network planning.

The effect of traffic intensity on planning cost is also compared with respect to a number of offered Erlangs. Fig. 2 compares the cost analysis as a function of data intensity with given constant voice intensity 1.0 Erlangs, while cost analysis as a function of voice intensity with given constant data intensity 3 Erlangs is depicted in Fig. 3. Those results indicate traffic intensity affects significantly cost expenses in overall system planning; data traffic is more costly than voice traffic especially. In average, the proposed algorithm is shown to be more effective and achieves up to 25% reduction on the total deployment cost over a simple algorithm.

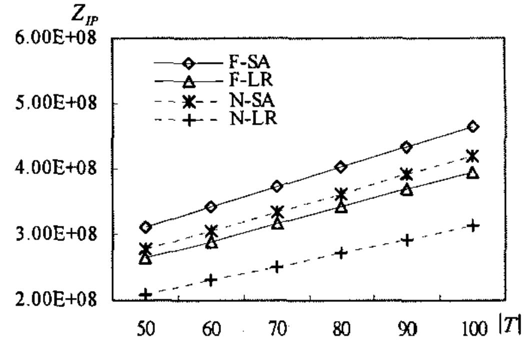

Fig. 1. Planning cost as a function of MS number with respect to algorithms and network states.

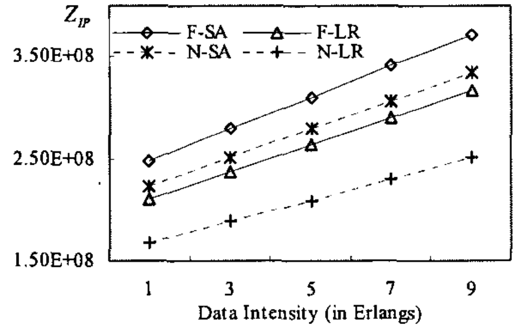

Fig. 2. Planning cost as a function of data traffic intensity with respect to algorithms and network states, given voice intensity 1 Erlangs and |T|=50.

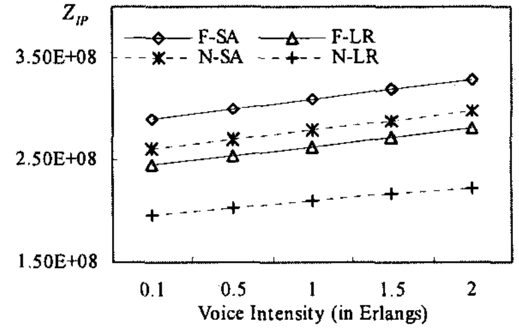

Fig. 3. Planning cost as a function of voice traffic intensity with respect to algorithms and network states, given data intensity 3 Erlangs and |T|=50.

5. CONCLUSION

Due to the ever-growing user demands and the advances of technology, CDMA has been received increasing attention. However, it still remains a challenge for system planners, managers and administrators, to plan and manage such complex systems in an efficient and effective way. In this paper, the integrated model for survivable CDMA network planning is proposed. We express our achievements in terms of formulation and performance. This research proposes a generic modeling for CDMA network planning.

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