行政院國家科學委員會專題研究計畫　成果報告

第三代無線通訊系統之整合式網路規劃、資源管理、與效能最佳化

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Abstract—CDMA-based 3G networks, especially in DS-CDMA (direct sequence CDMA), provide more capacity than FDMA/TDMA ones. However, 3G network planning is also far more complex than before. Besides, to provisioning a certain level of QoS, survivability is an important issue for ever-growing user demands. In this report, we jointly investigate the problems of both planning and survivability on the design of DS-CDMA networks. The problem is modeled as mathematical optimization formulation in terms of deploying cost minimization. We apply Lagrangean relaxation as a solution approach. Several algorithms are proposed to solve the complicated problem. Based on computational experiments, proposed algorithms are calculated with much more improvements than other primal heuristics. This report concludes that survivability is time-consuming as well as expensive factor. It is suggested separating survivability from planning problem is appropriate, and developing another survivable only model while it is needed.

Keywords—DS-CDMA, Lagrangean relaxation, Mathematical programming, Network survivability, Nonlinear programming, Optimizataion, Planning & capacity management.

I. INTRODUCTION

Wireless and mobile communications have been highly improved, thus the diffusion and demand of mobile communication services are growing rapidly. The system planning for the GSM has reached nearly perfect results [6] [8]. However, the evolution of third-generation (3G) communications networks has nominated a variety of user requirements, e.g. higher data rate, multimedia data services, mobility as well as quality of service (QoS). To fulfill ever-growing user demands, provides no upper limit of available channels, which is the standard of 3G broadband wireless communications. A core technique of CDMA is direct sequence CDMA (DS-CDMA) [13], in which the capacity is bounded by interferences. The interference, in the uplink, comprise of inter-cellular, intra-cellular interferences, and background noises [1] [5]. Based upon the analysis [7], this report takes uplink into account only since the capacity limit of DS-CDMA is uplink.

For the sake of forthcoming demands and deployments on CDMA communications networks, network design and planning is interesting for system providers. Issues for network planning consist of allocation for mobile telephone switching offices (MTSO), base stations, networks topology, and system configuration in terms of set up costs. Routing problem in network planning stage is also considered. Since backbone topology is a key factor in the routing problem, we determine the routing path for each O-D pair and the backbone topology of the network at the same time. For network planning, we build a more generic model instead of both regular cell system, that is a perfect situation using unique of cell size as well as effective transmission radius.

Besides, reliable and survivable environment is another important issue to provisioning uninterrupted services [6] [11]. When any base station fails, system should dynamically re-allocate resources to provide adequate services. Finally, in system operators' point of view, the major disbursals are just the cost of building the wireless communication network. A good network design will save a lot of money for the company and also will fulfill some system requirements [6] [8]. This report investigates the problem of the 3G wireless communications network planning under survivability constraints. The planning problem is deciding the suitable positions of communication devices, network topology, and base station power control, etc. In the CDMA network, there are some differences from the GSM system, including interference model, channel assignment, handoff procedure, etc. We jointly take into account of network design, as well as capacity management problem for DS-CDMA networks.

The remainder of this report is organized as follows. In Section II, the problem of network planning and capacity management for DS-CDMA is described, mathematical problem formulation of survivable networks is proposed as well. Section III presents a solution approach to the problem based on Lagrangean relaxation. In Section IV, heuristic is developed to calculate good primal feasible solutions. Section V illustrates the computational experiments. Finally, Section VI concludes this report.

II. NETWORK PLANNING AND CAPACITY MANAGEMENT PROBLEM

A. Assumptions

The problem considered in this report is summarized below. A model of integrated planning and capacity management for survivable DS-CDMA networks is proposed that is based on a number of assumptions, 1) the interference situation of each base station is under general conditions; 2) the same frequency band is reused in every cell; 3) considering only uplink spectrums, but not downlink; 4) the reverse link is perfectly separated from the forward link; 5) every mobile terminal is under perfect reverse link power control; 6) multi-path fading and mobility are not considered; 7) only voice traffic is considered.

B. Problem Formulation

For the convenience of the reader, a legend of the notation used in the proposed mathematical formulation is given as follows, related definition of notation illustrated in Table I. The following is the problem formulation of the optimization problem [12].

$$Z_{IP} = \min \sum_{j\in B} \Delta_j^B h_j + \sum_{l\in L} \Delta_l^L (c_l) + \Delta^W (w_i) \qquad \text{(IP)}$$

subject to:

(1) $$\left(\frac{E_b}{N_{total}}\right)_{req} \le \frac{\frac{S}{N_0} a_j^e + (1-a_j^e)V}{1 + \frac{1}{G_i}\alpha \frac{S}{N_0}(\hat{c}_j^e - 1)a_j^e + \frac{1}{G_i}\alpha \frac{S}{N_0} \sum_{\substack{j'\in B \\ j'\neq j}} \left(\frac{r_{j'}^e/2}{Max(D_{jj'} - r_{j'}^e/2, \varpi)}\right)^{\tau} \hat{c}_{j'}^e a_{j'}^e} \qquad \forall j\in B, e\in E$$

(2) $$\sum_{l\in L_5} \sum_{o\in O} \sum_{p\in P_o} k_o x_p^e \delta_{pl} \phi_{lj} \le g_j^e \qquad \forall j\in B, e\in E$$

(3) $$\theta(g_j^e, \beta_j^e) \le \hat{c}_j^e a_j^e \qquad \forall j\in B, e\in E$$

(4) $$A^e \le \frac{\sum_{o\in O} \sum_{p\in P_o} k_o x_p^e}{\sum_{o\in O} k_o} \qquad \forall e\in E$$

(5) $$D_{jt} z_{jt}^e \le r_j^e \mu_{jt}^e \qquad \forall j\in B, t\in T, e\in E$$

(6) $$0 \le r_j^e \le R_j \qquad \forall j\in B, e\in E, r_j \in Y_j$$

(7) $$\sum_{p\in P_o} x_p^e \le 1 \qquad \forall o\in O, e\in E$$

(8) $$\sum_{j\in B} z_{jt}^e = 1 \qquad \forall t\in T, e\in E$$

(9) $$\hat{c}_j^e \le M \qquad \forall j\in B, e\in E$$

(10) $$\sum_{o\in O} \sum_{p\in P_o} k_o x_p^e \delta_{pl} \le \varepsilon(c_l, \sigma_l^e) \qquad \forall l\in L - \{L_5\}, e\in E$$

(11) $$\sum_{o\in O} \sum_{p\in P_o} x_p^e \delta_{pl} \phi_{lj} \rho_{lt} \le z_{jt}^e \qquad \forall j\in B, t\in T, l\in L_5, e\in E$$

(12) $$G_i = \frac{w_i}{K_R} \qquad \forall w_i \in W$$

(13) $$a_j^e \le h_j \qquad \forall j\in B, e\in E$$

(14) $$x_p^e = 0 \text{ or } 1 \qquad \forall o\in O, p\in P_O, e\in E$$

(15) $$z_{jt}^e = 0 \text{ or } 1 \qquad \forall j\in B, t\in T, e\in E$$

(16) $$h_j = 0 \text{ or } 1 \qquad \forall j\in B$$

(17) $$a_j^e = 0 \text{ or } 1 \qquad \forall j\in B, e\in E$$

(18) $$c_l \in Q_1 \qquad \forall l\in L_1$$

(19) $$c_l \in Q_2 \qquad \forall l\in L_2$$

(20) $$c_l \in Q_3 \qquad \forall l\in L_3$$

(21) $$c_l \in Q_4 \qquad \forall l\in L_4$$

The objective function is to minimize the total cost of the following items: (1) the first term means the fixed cost of base station j, including installation, operation, maintenance, and equipment cost, and (2) the second term means the cost of links, including connections among MTSO's and their slave base stations, and the cost related with MTSOs (MTSO is modeled as a link in the formulation), and (3) the third term means the spectrum licensing cost. These items are the major costs involved in configuring a cellular network. The following is an interpretation of constraints in our model. Constraint (1): to ensure that every connection in any base station is serviced with the required QoS. The left of this inequality means the SIR (Signal-to-Interference Ratio) that each connection required; and the right means the really value of SIR. There are three terms in the denominator of this inequality's right part, and they mean the total interference value, including white noise, the intra-cell interference, and inter-cell interference. We want this formulation to be more generic, so we don't consider the multi-user detection here. This will be discussed in next few sections. Constraints (2)-(3): to ensure that any base station can serve its slave mobile terminal under certain call blocking rate. Constraint (4): to ensure that the coverage ratio in every system state is fulfilled. We take the percentage of the aggregate flow we can serve as the coverage ratio. Constraint (5): to ensure that the any base station only can serve those mobile terminals that are in its coverage area of effective radius. Constraint (6): to ensure that the transmission radius of each base station ranges between 0 and R_j, and it is in a giving integer, discrete set. Constraint (7): to ensure that each O-D pair would be transmitted at most on one path, because system would not have enough capacity to provide services on some failure state e. Constraint (8): to ensure that each mobile terminal can be homed to only one base station. Constraint (9): to ensure that the number of users who can be active at the same time in a base station would not exceed the base station's upper bound. Constraint (10): the capacity constraints of link l. Like Constraint (3), it is also calculated with Erlangs B Formula. Constraint (11): to ensure that if a base station does not provide service to a mobile terminal, the link between them cannot be selected as a part of routing path. Constraint (12): the CDMA processing gain formula. Constraint (13): to ensure that if a base station is not installed it cannot be active. Constraints (14)-(17): to ensure the integer property of the decision variables. Constraints (18)-(21): to ensure the capacity of each type of links belongs to some given sets.

III. Problem Solution

A. Lagrangean Relaxatrion Approach

By using the Lagrangean relaxation method, we can transform the primal problem (IP) into the following Lagrangean relaxation problem (LR) where Constraints (1)-(5), (10), and (11) are relaxed. For a vector of non-negative Lagrangean multipliers, a Lagrangean relaxation problem of IP is given by

Optimization problem (LR):

$$Z_D\left(v_{jei}^1, v_{je}^2, v_{je}^3, v_e^4, v_{jte}^5, v_{le}^6, v_{jtle}^7\right) =$$
$$\min \sum_{j\in B} \Delta_j^B h_j + \sum_{l\in L} \Delta_l^L (c_l) + \Delta^W (w_i)$$

$$+\sum_{j\in B}\sum_{e\in E} v_{je}^{1}\Bigg((\frac{E_b}{N_{total}})_{req} + (\frac{E_b}{N_{total}})_{req}\frac{1}{G_i}\alpha\frac{S}{N_0}((\hat{c}_j^e - 1)a_j^e$$

$$+\sum_{\substack{j'\in B\\ j'\neq j}}(\frac{r_{j'}^e/2}{Max((D_{jj'}^e - r_{j'}^e/2),\varpi)})^{\tau}\hat{c}_{j'}^e a_{j'}^e) - \frac{S}{N_0}a_j^e - (1-a_j^e)V_j^e)\Bigg)$$

$$+\sum_{j\in B}\sum_{e\in E} v_{je}^{2}(\sum_{l\in L_5}\sum_{o\in O}\sum_{p\in P_o}k_o x_p^e \delta_{pl}\phi_{lj} - g_j^e)$$

$$+\sum_{j\in B}\sum_{e\in E} v_{je}^{3}(\theta(g_j^e,\beta_j^e) - \hat{c}_j^e a_j^e) \qquad +\sum_{e\in E} v_e^4 (A^e - \frac{\sum_{o\in O}\sum_{p\in P_o}k_o x_p^e}{\sum_{o\in O}k_o})$$

$$+\sum_{t\in T}\sum_{j\in B}\sum_{e\in E} v_{jte}^{5}(D_{jt}z_{jt}^e - r_j^e \mu_{jt}^e)$$

$$+\sum_{l\in L-L_5}\sum_{e\in E} v_{le}^{6}(\sum_{o\in O}\sum_{p\in P_o}k_o x_p^e \delta_{pl} - \varepsilon(c_l,\sigma_l^e))$$

$$+\sum_{l\in L_5}\sum_{t\in T}\sum_{j\in B}\sum_{e\in E} v_{jtle}^{7}(\sum_{o\in O}\sum_{p\in P_o}x_p^e \delta_{pl}\phi_{lj}\rho_{lt} - z_{jt}^e)$$

subject to: (6)-(9), (12)-(21).

where $v_{je}^1, v_{je}^2, v_{je}^3, v_e^4, v_{jte}^5, v_{le}^6, v_{jtle}^7$ are Lagrange multipliers. To solve (LR), we can decompose (LR) into the following five independent and easily solvable optimization subproblems

Subproblem 1: (related to $\hat{c}_j^e$, h_j, a_j^e, r_j^e and w_i)

$$= \min \sum_{j\in B}\Bigg\{ \Delta_j^B h_j + \sum_{e\in E}\Bigg[a_j^e \Bigg(((\frac{E_b}{N_{total}})_{req}\frac{1}{G_i}\alpha\frac{S}{N_0})$$

$$(\hat{c}_j^e v_{je}^1 - v_{je}^1 + \sum_{\substack{j'\in B\\ j'\neq j}} v_{j'e}^1 (\frac{r_j^e/2}{Max(D_{j'j}^e - r_j^e/2,\varpi)})^{\tau} c_j^e) \qquad - v_{je}^1\frac{S}{N_0} + v_{je}^1 V_j^e - v_{je}^3\hat{c}_j^e \Bigg)$$

$$+((\frac{E_b}{N_{total}})_{req} - V_j^e)v_{je}^1 - r_j^e\sum_{t\in T}v_{jte}^5\mu_{jt}^e \Bigg]\Bigg\} + \Delta^W(w_i) \qquad \text{(SUB 1)}$$

subject to: (6), (9), (12), (13), (17), and

$LB \le \hat{c}_j^e \le UB \;\; \forall j\in B, e\in E$ (22)

Base on past experience, we intend to find the lower bound and upper bound of $\hat{c}_j^e$ to improve the efficiency of the subproblem solution, and the gap between the dual

TABLE I. DESCRIPTION OF NOTATIONS

Notation	Description	Notation	Description
G_i	The processing gain in the bandwidth state *i*	W	The set of total bandwidth
K_R	Data bit rate	E_b	The energy BS received
N_0	The background noise	N_{total}	Total noise
α	Voice activity	R	Upper bound of radius of base station *j*
Y_j	The set of radius of base station *j*	ϖ	A small number
$\theta(g_j^e,\beta_j^e)$	Minimum number of channels for traffic demand g_j^e such that the call blocking probability shall not exceed β_j^e	$\varepsilon(c_l,\sigma_l^e)$	Maximum traffic that can be supported by c_l trunks such that the call blocking probability shall not exceed σ_l^e
		β_j^e	Call blocking probability of base station *j* at state *e*
μ_{jt}	Indicator function which is 1 if mobile terminal *t* can be served by base station *j* and 0 otherwise	S	The power that a base station received from the mobile terminal that is homing to it with perfect power control
B	The set of candidate location for a base station	T	The set of mobile terminals
E	The set of network states (In this report, we only consider the failing possibility of some base stations. One of the states is that all network components are working.)	σ_l^e	Call blocking probability of link *l* required by users
O	The set of OD pairs	A^e	Acceptable coverage ratio on network state *e*
ρ_{lt}	Indicator function which is 1 if mobile terminal *t* is one end of link *l*	δ_{pl}	Indicator function which is 1 if link *l* belongs to path *p* and 0 otherwise
$\Delta_l^L(c_l)$	Cost function of link *l* with capacity c_l	$\Delta_j^B(n)$	Cost function of base station *j* with capacity *n*
$\Delta^W(w)$	Spectrum w licensing cost	ϕ_{lj}	Indicator function which is 1 if base station *j* is one end of link *l*
M	Upper bound on number of users that can be handled by a base station	P_o	The set of paths which can support the requirement of OD pair *o*
V_j^e	An arbitrarily large number.	τ	Attenuation factor
h_j	Decision variable which is 1 if base station *j* is decided to build and 0 otherwise	r_j^e	Decision variable of transmission radius of base station *j* at network state *e*
a_j^e	Decision variable which is 1 if base station *j* is decided to be activated at network state *e* and 0 otherwise	$\hat{c}_j^e$	Decision variable of number of users who can be active at the same time in the base station *j* at network state e
z_{jt}^e	Decision variable which is 1 if mobile terminal *t* is serviced by base station *j* and 0 otherwise at network state *e*	δ_{ot}	Indicator function which is 1 if mobile terminal *t* belongs to OD pair *o* and 0 otherwise
I_j	The intracell interference	$I_{jj'}$	The interference from base station *j'* to *j*
k_o	User demand of O-D pair o (in Erlangs)	$D_{jj'}$	Distance between base station *j* and *j'*
D_{jt}	Distance between base station *j* and mobile terminal *t*	x_p^e	Routing decision variable which is 1 if path *p* is selected at network state *e*.
g_j^e	Decision variable of aggregate flow in base station *j* on network state *e* (in Erlangs)	c_l	Decision variable of capacity assigned for link *l*.
L_1	The set of links which is between two MTSO	w_i	The total bandwidth in the bandwidth state *i*
L_2	The set of links which is between an MTSO and other systems	L_3	The set of links which is between an MTSO and other ISPs
L_4	The set of links which is between a base station and an MTSO	L_5	The set of links which is between a mobile terminal and a base station

solution and primal feasible solution. So, we get Constraint (22). We can assume that only one base station is active and its power radius is maximized. Under this situation, the number of mobile terminals that are covered by the active base station is just the UB if it is smaller than M, the capacity limitation of the equipment. Also, we can assume that all of the base stations are active but one. Under this situation, the number of mobile terminals that are not covered by active base stations and can be covered by the inactive base station is just the LB. First, we can decompose this into |B| independent subproblems. In each subproblem we can decompose this into |E| subproblems again. We can solve these subproblems with the decision tree process.

Subproblem 2: (related to decision variable z_{jt}^{e})

$$\min \sum_{t\in T}\sum_{j\in B}\sum_{e\in E} v_{jte}^{5} D_{jt} z_{jt}^{e} - \sum_{l\in L_5}\sum_{t\in T}\sum_{j\in B}\sum_{e\in E} v_{jtle}^{7} z_{jt}^{e} \quad \text{(SUB 2)}$$

subject to: (8), (15), and $\sum_{j\in B}\sum_{s\in S} z_{jst}^{e} = 1$, if $A[e]$ = 1 $\forall t\in T, e\in E$ (23)

Like SUB 1, we add a redundant constraint (23) to improve the dual solution's quality. It means that we must find a base station to serve each mobile terminal under the condition that the coverage ratio equals 1. To rewrite (SUB 2), we can get

$$\sum_{t\in T}\sum_{j\in B}\sum_{e\in E} v_{jte}^{5} D_{jt} z_{jt}^{e} - \sum_{l\in L_5}\sum_{t\in T}\sum_{j\in B}\sum_{e\in E} v_{jtle}^{7} z_{jt}^{e} = \sum_{t\in T}\sum_{j\in B}\sum_{e\in E} z_{jt}^{e}(v_{jte}^{5} D_{jt} - \sum_{l\in L_5} v_{jtle}^{7}).$$

Subproblem 3: (related to decision variable x_p)

$$\min \sum_{j\in B}\sum_{e\in E} v_{je}^{2} \sum_{l\in L_5}\sum_{o\in O}\sum_{p\in P_o} k_o x_p^{e} \delta_{pl}\phi_{lj} + \sum_{e\in E} v_e^{4}\Big(A^{e} - \frac{\sum_{o\in O}\sum_{p\in P_o} k_o x_p^{e}}{\sum_{o\in O} k_o}\Big)$$
$$+ \sum_{l\in L-L_5}\sum_{e\in E} v_{le}^{6} \sum_{o\in O}\sum_{p\in P_o} k_o x_p^{e} \delta_{pl} + \sum_{l\in L_5}\sum_{t\in T}\sum_{j\in B}\sum_{e\in E} v_{jtle}^{7} \sum_{o\in O}\sum_{p\in P_o} x_p^{e}\delta_{pl}\phi_{lj}\rho_{lt} \quad \text{(SUB 3)}$$

subject to: (7)(14) and $\sum_{p\in P_o} x_p^{e} = 1$, if $A[e]$ = 1 $\forall o\in O, e\in E$. (24).

Like SUB 2, we add a redundant constraint (24) to improve the dual solution's quality. It means that we must find a route for route each OD-pair under the condition that the coverage ratio equals 1.To rewrite SUB 3, we can get

$$\sum_{e\in E}\sum_{o\in O}\sum_{p\in P_o} x_p^{e}\Bigg[\sum_{l\in L_5}\sum_{j\in B}(v_{je}^{2} k_o \delta_{pl}\phi_{lj} + \sum_{t\in T} v_{jtle}^{7}\delta_{pl}\phi_{lj}\rho_{lt})$$
$$+ \sum_{l\in L-L_5} v_{le}^{6} k_o \delta_{pl} - \frac{v_e^{4} k_o}{\sum_{o\in O} k_o}\Bigg] + \sum_{e\in E} v_e^{4} A^{e}$$

Subproblem 4: (related to decision variable c_l)

$$\min \sum_{l\in L-L_5} \Delta_l^{L}(c_l) - \sum_{l\in L-L_5}\sum_{e\in E} v_{le}^{6}\varepsilon(c_l, \sigma_l^{e}) \quad \text{(SUB 4)}$$

subject to: (18)-(21).

Because the value of c_l is limited and discrete, we can decompose this into |*L*| subproblems. To get the optimum solution, we must exhaustively search for all possible c_l.

Subproblem 5: (related to decision variable g_j)

$$\min - \sum_{j\in B}\sum_{e\in E} v_{je}^{2} g_j^{e} + \sum_{j\in B}\sum_{e\in E} v_{je}^{3}\theta(g_j^{e}, \beta_j^{e}) \quad \text{(SUB 5)}$$

subject to: $\theta(g_j^{e}, \beta_j^{e}) \le M \ \forall j\in B, e\in E$. (25)

Constraints (3) and (9) imply Constraint (25). Because the value of $\theta(g_j^{e}, \beta_j^{e})$ is an integer and is limited, we can decompose this into |*E*|×|*B*| subproblems. To get an optimal solution, we must exhaustively search for all possible $\theta(g_j^{e}, \beta_j^{e})$.

B. *Duality of Planning and Capacity Management Problem*

According to the weak Lagrangean duality theorem [2], for any v_{je}^{1}, v_{je}^{2}, v_{je}^{3}, v_e^{4}, v_{jte}^{5}, v_{le}^{6}, v_{jtle}^{7} ≥ 0, Z_D(v_{je}^{1}, v_{je}^{2}, v_{je}^{3}, v_e^{4}, v_{jte}^{5}, v_{le}^{6}, v_{jtle}^{7}) is a lower bound on Z_{IP}. The following dual problem (D) is then constructed to calculate the tightest lower bound.

$$Z_D = \max Z_D\left(v_{je}^{1}, v_{je}^{2}, v_{je}^{3}, v_e^{4}, v_{jte}^{5}, v_{le}^{6}, v_{jtle}^{7}\right) \quad \text{(D)}$$

subject to: $v_{je}^{1}, v_{je}^{2}, v_{je}^{3}, v_e^{4}, v_{jte}^{5}, v_{le}^{6}, v_{jtle}^{7} \ge 0$.

The most common method for solving the dual problem is the subgradient method [3]. Let *g* be a subgradient of $Z_D(v_{je}^{1}, v_{je}^{2}, v_{je}^{3}, v_e^{4}, v_{jte}^{5}, v_{le}^{6}, v_{jtle}^{7})$. Then, in iteration *k* of the subgradient optimization procedure, the multiplier vector $\pi = (v_{je}^{1}, v_{je}^{2}, v_{je}^{3}, v_e^{4}, v_{jte}^{5}, v_{le}^{6}, v_{jtle}^{7})$ is updated by $\pi^{k+1} = \pi^{k} + t^{k} g^{k}$. The step size t^{k} is determined by $t^{k} = \delta\left(Z_{IP}^{h} - Z_D(\pi_k)/\|g^{k}\|^{2}\right)$. Z_{IP}^{h} is the primal objective function value for a heuristic solution.

IV. GETTING PRIMAL FEASIBLE SOLUTIONS

By using Lagrangean relaxation and the subgradient method as our tools to solve these problems, we can get not only a theoretical lower bound of primal feasible solution, but also some hints to help us get our primal feasible solution under each solving dual problem iteration [6] [8] [12]. If the decision variables calculated happen to satisfy the relaxed constraints, then a primal feasible solution is found. Otherwise, the modification on such infeasible primal solutions can be made to obtain primal feasible solutions; for instance, drop-and-add heuristics. To simplify the process of getting primal feasible solutions, a divide-and-conquer strategy is proposed. We can divide this network design problem into two parts: (1) the mobile terminals homing subproblem and base station configuration subproblem, including the base station should be built or not, and it should be active in every error state or not power control and capacity assignment; (2) the backbone network topology design subproblem and capacity assignment subproblem. In each subproblem, we provide some heuristics to get a primal feasible solution.

A. Heuristics for the Homing and Base Station Configuration Subproblem

To improve our primal feasible solution, we need to find some heuristics to help us. In this part, we try to solve the homing subproblem and the base station configuration subproblem. Base on past experiments, when considering a network design problem with a single component failure state, we can make some decisions about some decision variables in the initialization stage. Taking this problem, for example, for each mobile terminal we can pre-calculate how many base stations can provide service to it without violating the service radius constraint. If there is any mobile terminal only served by "two" base stations, the two base stations must be built.

We continue the solving process with the value of decision variable z_{jte} of each mobile terminal, which is calculated when getting dual solution. With the values of z_{jte}, we can determine the approximate aggregate traffic of each built base station, and we can use these values of approximate aggregate traffic to process the following LR algorithm.

[Algorithm LR]

Step 0. In each failure state, we arrange the built base stations in descending order of the approximate aggregate traffic.

Step 1. Starting with the base station that has the highest value of the approximate aggregate traffic, we turn it on in this failure state with the maximum power radius. In the mean time, we turn off the base stations that may violate QoS constraint.

Step 2. We assign all mobile terminals, which are under the coverage of current base station with such degree of radius and are not assigned yet, to this base station.

Step 3. Then, we consider the other built base stations that have not been turned off with step 1 and 2.

Step 4. Rearrange the base stations that have not been built yet in descending order of the approximate aggregate traffic.

Step 5. We decide to build the base station that has the highest value of the approximate aggregate traffic and turn it on with the maximum power radius in this failure state. In the mean time, we turn off the base stations that may violate QoS constraint.

Step 6. We assign all mobile terminals, which are under the coverage of current base station with such degree of radius and are not assigned yet, to this base station.

Step 7. Repeat step 4, 5, and 6 until all mobile terminals have homed to a base station that is built and active in this failure state. If the program gets into an infinite loop and a few mobile terminals are left (the number of mobile terminals / the left mobile terminal > 2), we home them to the base station that has shortest distance between them.

Step 8. Rehome the mobile terminals that are not homed to a nearest active base station.

Step 9. For each base station, we find the maximum distance between this base station and its slave mobile terminals. Then we take this value to fit the degree of radius.

Step 10. For each base station, we calculate the actually aggregate traffic and assign enough capacity.

TABLE II. GIVEN PARAMETER FOR EXPERIMENTS

Notation	Value
S/N_0	7 db
Eb/N_{total}	6.58 db
σ_l^e	0.01
β_j^e	0.03
M_j	120
α	0.5
MTSO fixed cost	30,000,000 units
Unit connection cost	300,000 units/km
BS fixed cost	5,000,000 units
Voice communication bit rate	9.6 Kbps

TABLE III. EXPERIMENTAL SCENARIOS

Error State	Case	MTSO	BS	MT	O-D Pair	Traffic demand*
0/1	1	3	15	40	20	0.1
	2	3	15	40	20	1.5
	3	3	15	40	20	3.0
0 only	A	3	15	40	20	1.5
	B	3	30	40	20	1.5
	C	3	40	40	20	1.5

* in Erlangs

Step 11. Check the QoS requirement (constraint 1), if it violates then we give up this iteration.

B. Heuristics for the Tolopogy Design and Capaqcity Assignment Subproblem

In this part, we intend to consider $\sum_{e\in E} v_{le}^6$ and its length for each link as its weight. Then we use minimum cost spanning tree algorithm to select enough L_1 links to build a tree for routing. Then for each base station j, we choose the L_4 link, which has the minimum cost, as its candidate link. Then we can calculate the routing path for all OD-pairs on each scenario. According to the aggregate traffic of each link, we assign proper capacity to it under the call blocking rate constraint. Repeat the above processes, consider all network states, to get several values of each link. We choose the maximum volume of capacity of each link, which is calculated on each network state, as our primal solution.

V. COMPUTATIONAL EXPERIMENTS

A. Experiment Environment

Because of the complexity of this network design problem, we cannot get a tighter lower bound by solving the Lagrangean relaxation problem iteration by iteration. Although we cannot get a tighter lower bound, this powerful methodology provides a lot of hints to help us get a primal feasible solution. In order to demonstrate that our heuristics are good enough, we also implement a simple algorithm (denote SA) to compare with our heuristics.

B. *Experimental Parameters and Results*

The parameters referring to previous works of Um [4], Lin [6], Wu [8], and Lee [12] are listed in Table II. Table III specifies a number of experimental scenarios. All experiments are coded in Java and performed on a dual Pentium III 1G MHz PC running Microsoft Windows 2000 Advance Server with 2GB DRAM. Results analysis of all experimental scenarios is also enumerated in Table IV, in which Case 1 and 2 take around 1-1.5 hours for 1000 iterations. If we ignore the consideration of error states, i.e. only considering the error state 0, the time complexity is considerably decreased. Case A, B, and C only take around 3, 13, and 20 minutes, respectively, for 1000 iterations in experiments. The statistic of approximated computational time is reported in Table V.

Obviously, in Table V, it is more time-consuming if we take into survivability account in network planning. Be more efficiently, it is suggested that in the stage of network planning and design, the normal condition (without considering failure states) is appropriate. Furthermore, a new model jointly considering survivability and capacity management can be developed when it is needed.

Generally speaking, a basic approach to provisioning survivable services is duplication of base stations. This implies that it requires double expenses for constructing a survivable network. By using proposed approach of modeling survivable network, as we can see the comparison of case 2 and case A in Table VI, it takes around more 36.194% cost to guarantee survivability rather than 100%.

VI. CONCLUSIONS

In this report, we present an approach to designing and managing a DS-CDMA wireless communication network. We can express our achievements in terms of formulation and performance. In terms of formulation, we model a mathematical expression to describe the overall DS-CDMA wireless communication network design and management problem. We consider both non-regular size cell and non-uniform traffic demand to make this report more generic. An average interference model is discussed. In terms of performance, our Lagrangean relaxation based solution has more significant improvement than other intentional algorithms. Besides, the following subjects may deserve future investigation. First, sectorization is widely used in wireless communication system. Second, to cover both uplink and downlink is another topic worth further investigation. Third, a new frequency planning strategy should be designed to improve the system performance. Adding a new frequency planning strategy into our model would be an interesting work. Fourth, since many applications will be developed in the future, how to transfer our model to fit the other traffic models would be an important task.

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TABLE IV. EXPERIMENTAL RESULTS

Case	Run #	0	1	2	3	4	5	6	7	8	9
1	SA	111236	95594	96236	96236	100836	83932	96236	101236	95421	106236
	LR	91225	80244	79610	84312	85345	73679	84795	84963	79080	85124
	Improvement*	21.94	19.13	20.88	14.14	18.15	13.92	13.49	19.15	20.66	24.80
2	SA	189788	134870	155150	174788	159750	162484	155150	179788	134697	145512
	LR	150139	124642	125236	149440	141620	113281	124833	169740	110525	130742
	Improvement*	26.41	8.21	23.89	16.96	12.80	43.43	24.29	5.92	21.87	11.30
3	SA	266325	253718	254289	219768	259450	265706	259859	254206	248586	265958
	LR	209225	214321	208280	215297	253492	214857	253818	220861	247714	220583
	Improvement*	27.29	18.38	22.09	2.08	2.35	23.67	2.38	15.10	0.35	20.57
A	SA	168008	102771	111756	118317	122871	111809	127650	121529	141646	148528
	LR	102743	97737	92917	116599	117324	103678	107771	62940	107291	122382
	Improvement*	63.52	5.15	20.28	1.47	4.73	7.84	18.45	93.09	32.02	21.36
B	SA	150367	133874	138979	145304	138567	143923	139650	145408	132061	152584
	LR	114226	107707	119195	130932	113202	131834	125286	122129	119357	119278
	Improvement*	31.64	24.29	16.60	10.98	22.41	9.17	11.43	19.6	10.64	27.92
C	SA	137022	166651	153366	134896	150605	149550	131183	106415	177044	153736
	LR	123371	129127	122902	120389	118885	121683	106904	92112	143080	106724
	Improvement*	11.06	29.60	24.79	12.50	26.68	22.90	22.71	15.53	23.74	44.05

*Improvement is expressed by (SA-LR)/LR*100%

TABLE V. COMPARISON OF COMPUTATION TIME (SEC)

Case	1	2	3	A	B	C
SUB 1	30	30	30	1	16	16
SUB 2	300	300	300	16	30	47
SUB 3	700	700	700	47	100	140
SUB 4	1	1	1	1	1	1
SUB 5	1	1	1	1	1	1
Subgradient	3300	3370	3200	235	600	890
Solving Primal	16	16	24	1	16	16
Iteration	1000	1000	1000	1000	1000	1000

TABLE VI COST COMPARISON OF CONSIDERING SURVIVABLE FACTOR OR NOT

Run #	0	1	2	3	4	5	6	7	8	9
LR of Case 2	150139	124642	125236	149440	141620	113281	124833	169740	110525	130742
LR of Case A	102743	97737	92917	116599	117324	103678	107771	62940	107291	122382
More cost (%)	46.13	27.53	34.78	28.17	20.71	9.26	15.83	169.69	3.01	6.83
Average (%)	36.194									