Cell Planning in WCDMA Networks for Service Specific Coverage and Load Balancing

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Abstract

Third-generation (3G) Wideband Code Division Multiple Access (WCDMA) network is an evolutionary network which supports services from circuit-based voice service to high and low rate packet-based data services. Unlike the voice oriented second-generation (2G) service, the 3G network is enhanced to support services with different data rate, different asymmetry, and different coverage. We thus need to investigate the coverage of multiple services and the capacity of a cell in cell planning for the advanced network.

Service specific uplink coverage and downlink capacity with load balancing are considered in our cell planning. The problem is formulated as a linear integer programming optimization model. An efficient tabu search heuristic is developed to solve the NP-hard problem. Very promising computational results are demonstrated, where the solution gap from the optimal to the lower bound by CPLEX is within 0.9% in problems to cover all service traffic in the system. It is demonstrated that higher load factor effectively reduces cell sites for multiple service classes. Load balancing among cells is also demonstrated with different coverage ratio.

Keywords

Cell planning, Coverage, Capacity, Load balancing, Tabu search optimization

1. Introduction

WCDMA system is a multiple service radio network that supports high data rate multimedia services as well as low rate voice services. Each service class has different data rate which ranges from 12.2kbps to 2Mbps. It is clear that the 2G radio network could no longer provide the diverse high bit rate services. Moreover, higher rate multimedia services have an asymmetric feature in uplink and downlink. These higher bit rate services which have less processing gain [1] may require higher transmission power than ordinary voice services. Thus, additional base stations will be necessary to cover all kinds of 3G services. Coverage and capacity of a cell thus has to be considered for each service with different data rate requirement.

The purpose of cell planning in the literature is to determine necessary cell sites, base station configuration and the number of network elements to support required services with minimum investment and operating cost. Thus, cell planning for the 2G voice oriented service can be considered as the capacitated maximal covering location problem [2]. The problem considers a facility's workload to consist of all demand points that lie within the maximum coverage distance. The capacitated maximal covering location problem has been mainly studied in spatial representation part and other applications [3, 4].

However, for cell planning in 3G WCDMA network, it is essential to guarantee the quality of service (QoS) of each service class. In the 3G cell planning, we need to consider locations and capacities of base stations to cover various services with different qualities located at the same point. Voice, video, and other multimedia services require different data rate with different service range. The higher the data rate, the smaller the service range. In addition to the service specific coverage, the traffic load in 3G wireless service needs to be balanced among cells in a wireless network. This is for efficient operation of the wireless network with low cost without extra bandwidth or bandwidth borrowing.

Several approaches for cell planning problem have been proposed in the literature mostly based on integrated heuristics [5, 6, 7, 8]. Tran-Gia et al. [9] present an approach to characterize customer demand and incoming traffic using a partitioning algorithm. However, they only consider the traffic

intensity (calls / km^2) of CDMA system. Because the intensity value itself varies with time, the model presented can be considered only as an initial approach to stationary user distribution during the busy hour of a cell.

Observing all uplink and downlink constraints of the cell planning problem, Amaldi et al. [10] solve the problem based on the signal-to-interference ratio (SIR) constraint. They propose discrete optimization models with tabu search algorithms to determine the location of new base stations. These models consider SIR as QoS measure. However, they limit themselves by considering only the symmetric voice service in the uplink and propose a planning algorithm which takes capacity aspect into account.

Base station selection problem in wireless sensor networks is investigated by Hou et al. [5]. The problem is formulated as a mixed integer nonlinear programming which maximizes the network lifetime with energy constraint. They present a heuristic to match each source node to a particular base station and to find an optimal anycast routing where one transmitter is connected to some of the nearest receivers.

In this paper, we examine a cell planning in WCDMA networks. We focus on the coverage of different service classes while satisfying the cell capacity and inter-cell load balancing. With inter-cell load balancing, traffic loads can be evenly distributed among the base stations. The problem is formulated as a linear integer programming which minimizes the base station deployment cost. Uplink coverage and downlink load balancing are considered as constraints. An efficient tabu search heuristic is developed to solve the cell planning problem.

The remainder of this paper is organized as follows. In Section 2, we define service classes in WCDMA network and service demand area (SDA) for cell planning. In Section 3, coverage of each service class, capacity of a cell, and load balancing among cells are discussed. Section 4 provides a mathematical model for the cell planning problem. Section 5 presents an efficient tabu search procedure to solve the problem. Computational results and conclusion are presented in Section 6 and 7, respectively.

2. Service Classes and Service Demand Area

WCDMA network supports various services ranging from low rate voice service to high rate multimedia messaging service. Unlike voice service, many services require different uplink and downlink data rate as shown in Table 1. In this study, we consider four different services ranging from 12.2kbps to 384kbps in downlink.

In cell planning, we assume users with different classes of service are located at each service demand area (SDA). A set $I = \{1,\ldots,m\}$ of SDAs is assumed in the cell planning region. SDA i has its traffic demand DI_i that is represented by demand intensity. The demand intensity in each SDA is a basic measure to predict required resources in the cell planning. It is computed with the number of expected calls and their service data rate as in the following equation.

$$DI_i = \sum_{k=1}^{K} n_i^k R_k, \quad \text{for all } i \in I = \{1,\ldots,m\} \tag{1}$$

where n_i^k is the number of expected calls of service class k in SDA i and R_k is the data rate of service class k. $n_i = \sum_{k=1}^{K} n_i^k$ becomes the total number of expected calls in SDA i.

3. Coverage and Capacity of the WCDMA Network

In WCDMA, the coverage and capacity analysis show very different results in uplink and downlink. Clearly, coverage is limited by the uplink due to the limited mobile transmission power. Capacity, on the other hand, is known to be limited by the downlink[11]. This is because downlink power is shared by all users in a cell. In this study, we thus consider the uplink path loss [1] for the coverage and downlink load factor for the capacity.

3.1. Coverage

Since WCDMA network supports many different services, we need to consider coverage for each service. In this study, we consider the Okumura-Hata model [12] for the propagation which is shown below.

$$L(d_{\max}^k) = 137.4 + 35.2\log(d_{\max}^k) \tag{2}$$

In the propagation model, $L(d_{\max}^{k})$ is the path loss in *dB* and $d_{\max}^{k}$ is the maximum radius from the center of an SDA for service class *k*. Note that the processing gain [1] is obtained from $10\log(W/R_k)$ for fixed chip rate *W*. Thus, higher data rate service has lower processing gain. Since the maximum path loss is dependent on the processing gain, $d_{\max}^{k}$ is different for different service classes.

For service specific coverage, we introduce a coverage indicator δ_{ij}^{k} to represent whether service class k in SDA i can be covered by cell site j. δ_{ij}^{k} is expressed as follows.

$$\delta_{ij}^{k} = \begin{cases} 1 & \text{if } d_{ij} \le d_{\max}^{k} \\ 0 & \text{otherwise} \end{cases} \quad \text{for all } i, j \text{ and } k \tag{3}$$

where d_{ij} is Euclidean distance between base station j and SDA i. The constraint $d_{ij} \le d_{\max}^{k}$ is typically referred to as the service standard in the category of location problems. All service classes in an SDA are assumed to be located at the center.

Now, for practical cell planning with the coverage indicator δ_{ij}^{k}, the ratio of traffic covered by base station j to the traffic demand of SDA i can be measured as follows:

$$\rho_{ij} = \frac{\sum_{k=1}^{K} n_i^k R_k \delta_{ij}^k}{\sum_{k=1}^{K} n_i^k R_k}, \quad \text{for all } i \text{ and } j \tag{4}$$

In cell planning, we employ the above service coverage ratio to properly assign each SDA to a base station. SDAs with relatively higher service coverage ratio are prioritized for base station coverage as far as the capacity is allowed.

3.2. Capacity

The capacity of WCDMA system is limited by downlink and measured by the load factor [11]. The load factor is a theoretical spectral efficiency of a cell. It shows how close to the maximum capacity the network is operating at. If the load factor η_j becomes close to one, the system reaches its pole capacity, which is a theoretical maximum capacity by perfect power control.

WCDMA is a wideband Direct-Sequence CDMA (DS-CDMA) system, where user information bits are spread over a wide bandwidth by multiplying the user data with quasi-random bits derived

from CDMA spreading codes. In order to support very high bit rates up to 2 Mbps, the use of a variable spreading factor and multi-code connections is supported. For DS-CDMA, $\eta_j = 0.75$ is recommended[13] for cells in urban area.

To have load factor for multiple service classes, we extend the E_b / N_0 requirement under single service [14] to that under multiple services as follows.

$$(E_b / N_0)_k = \frac{WP_k / L_{j',k}}{R_k(\beta_k P_{j'} / L_{j',k} + P_{j'} \sum_{j=1, j \neq j'}^{l+h} 1 / L_{j,k} + P_N)} \tag{5}$$

In the above equation, $(E_b / N_0)_k$ is the signal energy per bit divided by noise for service class *k* to meet a predefined bit error rate. W and R_k are WCDMA chip rate and data rate of service class *k* respectively as defined in previous sections. P_k is the required transmission power for service class *k* and $P_{j'}$ is the total downlink transmission power of target base station *j*' and P_N is thermal noise power. β_k is the non-orthogonality factor which depends on multipath propagation conditions. $L_{j',k}$ ($L_{j,k}$) is the path loss from target (other) base station *j*' (*j*) to a class *k* user. By solving Equation (5) for $P_{j'}$ we have

$$P_{j'} = \frac{P_N \sum_{k=1}^{K} N_{j'}^k \frac{(E_b / N_0)_k R_k \nu_k}{W} L_{j',k}}{1 - \sum_{k=1}^{K} \left[N_{j'}^k \frac{(E_b / N_0)_k R_k \nu_k}{W} \left(\beta_k + \sum_{j=1, j \neq j'}^{l+h} \frac{L_{j',k}}{L_{j,k}} \right) \right]} \tag{6}$$

In the above equation, $N_{j'}^k$ is the number of calls of service class *k* in cell *j*' and ν_k is the channel activity factor of service class *k* at physical layer which is responsible for bit-level transmission among nodes in a network. From Equation (6), we have the following downlink load factor η_j of base station *j*.

$$\eta_j = \sum_{k=1}^{K} \left[N_j^k \frac{(E_b / N_0)_k R_k \nu_k}{W} (\beta_k + r_k) \right], \quad \text{for all } j \tag{7}$$

In the above equation, $r_k = \sum_{j'=1, j' \neq j}^{l+h} (L_{j,k} / L_{j',k})$ is own-to-other cell interference ratio for service class *k* in downlink. From Equation (7), the downlink load factor η_i of SDA *i* can be represented as follows.

$$\eta_i = \sum_{k=1}^{K} \left[n_i^k \frac{(E_b / N_0)_k R_k \nu_k}{W} (\beta_k + r_k) \right], \quad \text{for all } i \tag{8}$$

In the above equation, n_i^k is the number of calls of service class *k* in SDA *i*. Because the downlink load factor η_j of base station *j* is the summation of the downlink load factor η_i's of SDA *i* satisfying the service coverage ratio, the following equation results.

$$\eta_j = \sum_{i=1}^{m} \rho_{ij} \eta_i, \quad \text{for all } j \tag{9}$$

3.3. Load Balancing

In view of the remarkable growth of cellular subscribers and the limited bandwidth for multiple services, efficient assignment of bandwidth among users is necessary to enhance network performance. In WCDMA, unexpected increase of multimedia traffic may occur in a specific cell. In order to alleviate this kind of traffic overload, reservation of extra bandwidth or bandwidth borrowing can be employed to satisfy the traffic of the heavy loaded cell.

In this paper, to avoid the bandwidth migration between cells and to balance the load, cells are planned based on the service coverage ratio. SDAs with higher service coverage ratio are prioritized for base station coverage. However, to balance the load, an SDA may be assigned to other cell that satisfies the minimum coverage ratio. Load factors η_j are used to balance the load among cells within a limit. Cleary, the load factor η_j has to satisfy reasonable maximum and minimum capacities [15].

4. Formulation of the Cell Planning Problem

The objective of our cell planning in WCDMA networks is to maximize the coverage of different classes of services with minimum base station cost. As discussed in Section 3, since each SDA has different traffic demand of each service class, it is not practical to cover all requirements by SDAs. Therefore, we are interested in minimizing the base station cost while keeping the coverage of traffic demand within a reasonable limit. To cover services of different classes, *h* candidate cell sites are

considered in addition to l existing base stations. The existing base stations are assumed to cover only voice service of class 1 in Table 1.

On the basis of the discussion in Section 3, the cell planning problem is introduced as the following linear integer programming.

$$\text{Minimize} \quad \sum_{j=1}^{l} a_j x_j + \sum_{j=l+1}^{l+h} b_j x_j \tag{10}$$

$$\text{s.t.} \quad x_j = 1 \qquad \text{for all} \quad j \in A \tag{11}$$

$$\sum_{j=1}^{l+h} y_{ij} = 1 \qquad \text{for all} \quad i \in I \tag{12}$$

$$y_{ij} \le x_j \qquad \text{for all} \quad i \in I \quad \text{and} \quad j \in A \cup B \tag{13}$$

$$(\rho_{ij} - \alpha) y_{ij} \ge 0 \qquad \text{for all} \quad i \in I \quad \text{and} \quad j \in A \cup C \tag{14}$$

$$\eta_{\min} x_j \le \sum_{i=1}^{m} \rho_{ij} \eta_i y_{ij} \le \eta_{\max} x_j \qquad \text{for all} \quad j \in A \cup B \tag{15}$$

$$x_j, y_{ij} \in \{0,1\} \qquad \text{for all} \quad i \in I \quad \text{and} \quad j \in A \cup B \tag{16}$$

In the formulation, $x_j = 1$, when site j is selected for a base station. Clearly, all existing base stations in set $A = \{1, \cdots, l\}$ have $x_j = 1$. Then, our objective is to minimize the sum of updating cost a_j of existing base station j, and deploying cost b_j of new base station as in Equation (10).

Let $y_{ij} = 1$, if SDA i is assigned to base station j. To support wireless service, each SDA has to be covered by only one base station as in Equation (12). For an SDA to be covered by a base station, the base station has to be selected as shown in Equation (13). In the equation $A = \{1, \cdots, l\}$ and $B = \{l+1, \cdots, l+h\}$.

For each SDA which has different class of service requirements, we need to guarantee certain level of the traffic demand. In other words, an SDA has to be assigned to a base station that satisfies minimum coverage ratio α as in Equation (14). In the equation, α is set to a value between zero and one.

Finally, to balance the load among cells we need to keep the load factor η_j within a certain limit as in Section 3.3. By applying lower and upper bounds of the load factor, we have a constraint as in Equation (15).

Note that the well known facility location problem which is a special case of above cell planning is NP-hard [10, 16]. This implies that any known algorithm cannot find good approximation solutions in a reasonable time. Thus, such an algorithm is unusable in most cases for real-world size problems. As encouraging results on NP-hardness problems, we propose a tabu search heuristic to obtain near optimal cell planning in WCDMA networks.

5. Tabu Search Optimization

Tabu search [17] is a meta-heuristic procedure for solving optimization problems. It is designed to guide other methods to overcome the trap of local optimality. The main concepts of tabu search includes: 1) tabu lists and tabu list size, 2) tabu restrictions and aspiration criteria and 3) intensification and diversification strategies. In this study, the following three steps are considered to obtain the cell planning in WCDMA networks.

1) Selection of initial base stations

2) Intensification with a Short-Term Memory

3) Diversification with a Long-Term Memory

The role of a short-term memory is to prohibit moves from recently visited solutions in the intensification process. Recently visited solutions are stored in a tabu list and forbidden from cycling. Since the short-term memory may fail to discover good solutions, a long-term memory is introduced. The long-term memory is employed to diversify the search, thus enhance the algorithm's effectiveness for finding improved solutions. The diversification explores a large solution space while intensification strategy provides an elite solution in a restricted search space.

5.1. Initial Base Stations

We assume that the location of any SDA can be a candidate of a cell site. Thus, initial Candidate_

List is a set of all SDAs. To obtain an initial feasible solution, we need a set of cell sites that covers SDAs with balanced load.

An SDA having the largest demand intensity DI_i is first selected from the Candidate_ List. From the selected cell site j', service coverage ratio $\rho_{ij'}$ of each SDA is computed. Base station j' then covers SDAs in non-increasing order of their service coverage ratios as far as the minimum coverage constraint $\rho_{ij'} \geq \alpha$ and the lower bound of load factor $\eta_{\min}$ is satisfied by the base station. The cell site j' is then moved to Active_List. The base station selection process for the next cell site is continued by taking an SDA with the largest demand intensity which is not yet covered. If the lower bound of load factor $\eta_{\min}$ is not satisfied, the process continues by selecting next cell site from the Candidate_ List. After covering all SDAs with base stations, some base stations may not satisfy the minimum load factor $\eta_{\min}$. In this case, the initial base station selection procedure is terminated and the tabu intensification process continues. The load factor feasibility is expected to be satisfied in the intensification process.

5.2. Intensification with Short-Term Memory

After we obtain an initial feasible solution, we need to improve it while maintaining the feasibility. To have better solution, we apply “Drop Move” and “Add Move” for base stations to be newly deployed.

In a Drop Move, a base station which has the smallest total demand intensity is selected from Active_List of current base stations. By dropping the selected cell site from the Active_List, it is possible to decrease the number of base stations and improve the objective function value of the problem in Section 4. After the Drop Move, SDAs which were covered by the dropped base station need to be reassigned to other base stations. Each SDA which satisfies the service coverage ratio $\rho_{ij_2} \geq \alpha$ is moved from the dropped base station j_1 to base station j_2 as far as it satisfies the load factor $\eta_{j_2} \leq \eta_{\max}$. If all SDAs are covered by the neighboring base stations, the current solution is updated. Otherwise, an Add Move is performed to handle the uncovered SDAs.

In an Add Move, an SDA j' which has the largest demand intensity among the uncovered SDAs

is selected from Candidate_ List. The service coverage ratio $\rho_{ij'}$ of all SDAs from the added cell site j' is updated. SDAs are covered by the base station j' in non-increasing order of the service coverage ratio as far as the minimum coverage constraint $\rho_{ij'} \geq \alpha$ and the lower bound of load factor $\eta_{\min}$ is satisfied by the base station. If there exists any uncovered SDA by the base station j', another ADD Move is performed. In this process, a base station may not satisfy the minimum load factor $\eta_{\min}$. In this case, SDAs satisfying the service coverage constraint $\rho_{ij_2} \geq \alpha$ are moved from current base station j_1 to base station j_2 such that $\eta_{j_1} \geq \eta_{\min}$ and $\eta_{j_2} \geq \eta_{\min}$.

The above intensification procedure is based on a short-term memory which systematically controls the two tabu lists: Active_List and Candidate_List. The short-term memory, embodied in two tabu lists, is implemented with tabu tenure as Candidate_Tabu_Time(j) := Current_Iteration + TC and Active_Tabu_Time(j) := Current_Iteration + TA. The tabu tenure TC (TA) represents the number of iterations during which a base station is not allowed to be moved. This is to prevent reselecting a base station in Candidate_List (Active_List) back to Active_List (Candidate_List) before a certain tabu period. Intensification procedure is continued until no solution improvement is obtained consecutively for N_Max iterations.

5.3. Diversification with Long-Term Memory

The purpose of diversification is to drive the search space into new solution space by escaping from local optimality. It is initiated when solution improvement is not obtained during N_Max consecutive iterations of intensification process. To start the tabu search in new solution space, the Active_Frequency(j) count is employed. The frequency count of a base station represents how often the base station is considered as a solution in the previous pass of the tabu search. Base stations with relatively lower Active_Frequency(j) are selected as a starting solution in each diversification. That is, base stations are deployed by selecting SDAs with relatively lower frequencies. Then the intensification procedure is continued. When the number of diversifications is equal to D_Max, the tabu search is terminated.

6. Computational Results

In this section, we present our simulation results of the proposed tabu search algorithm for cell planning with service specific coverage and load balancing. The proposed tabu search algorithm was programmed in Visual C++, and ran on a 2.4GHz Intel Pentium 4 based personal computer with 1Gbyte of memory under Windows XP. The integer programming problem was solved by CPLEX [18].

Three types of service regions: $5km \times 5km$, $7km \times 7km$ and $10km \times 10km$ are considered. The size of an SDA is given by $500m \times 500m$. In each SDA, calls are generated uniformly over [6, 12]. These calls are distributed to four service classes such that the average portion of 12.2kbps, 64kbps, 144kbps and 384kbps are 70%, 15%, 10% and 5% respectively. The cost ratio of new deployment to updating is given by 1 : 0.1.

For each service, different link budget [11] is applied to compute the uplink coverage. Maximum allowed path loss is given by 154.2, 151.0, 148.0, and 144.0 dB for 12.2kbps, 64kbps, 144kbps, and 384kbps services respectively. The coverage indicator δ_{ij}^{k} of Section 3.1 is then computed. To compute the downlink capacity and balance the load at each cell, the load factor is computed with parameters in Holma and Toskala [11]. E_b / N_0 requirement considered for each service is 5.0dB for 12.2kbps, 2.0dB for 64kbps, 1.5dB for 144kbps and 1.0dB for 384kbps. Service activity factor for 12.2kbps is set to 0.58 and those for other services to 0.5. The orthogonality factor and interference ratio are set to $\beta = 0.5$ and $r = 0.55$[19].

Now, to solve the cell planning problem with tabu search, we need to optimize the tabu parameters: tabu tenure size, N_Max for the intensification and D_Max for the diversification procedure. Tabu tenure size represents the number of iterations during which a target SDA is forbidden to be adopted in move operation. Experiments are performed by generating problems with 196 SDAs. Three different cases of minimum service coverage ratio, i.e., α = 0.7, 0.9 and 1.0, are considered each with five problems. The load factor considered in the test is $\eta_{\min}$ = 0.5 and $\eta_{\max}$ = 0.8. Figure 1, 2 and 3 show the result of tabu tenure size. From the figures, it is reasonable to set (TA, TC) = (10, 15) for α = 0.7 and (TA, TC) = (5, 10) for α = 0.9 and 1.0, where the number of new base stations are minimized.

Test for N_Max is performed as in Figure 4. The figure shows that N_Max = 3, 2, and 1 is appropriate for the minimum coverage ratio α = 0.7, 0.9, and 1.0, respectively. This shows that problems with lower coverage ratio have more diverse solution combination than those with higher coverage ratio. By assuming that the value of N_Max is proportional to the total number *m* of SDAs, N_Max = 0.015*m* for α = 0.7, 0.010*m* for α = 0.9 and 0.005*m* for α = 1.0 are applied.

The number of diversifications in tabu search is deeply related to the solution quality. Test for D_Max is performed as in Figure 5. For each service coverage ratio, the portion of problems that gives no further improvement is plotted in the figure. The number of diversifications increases as the coverage ratio α decreases. This result is consistent with that by the N_Max and shows that problems with lower coverage ratio have a more complex solution space. From the figure, it seems reasonable to apply D_Max = 2 for α = 0.7 and 1 for α = 0.9 and 1.0.

With the parameters adjusted in the experiments, cell planning problems with 100, 196 and 400 SDAs are solved each with 10 different problems. The first five problems in each case are solved only with new base stations. The rest of the problems include existing base stations. CPLEX is employed to compare the performance of the proposed tabu search. From Table 2, 3, and 4, it is clear that the performance of the proposed tabu search is very promising. The average gap from the optimal solution or the lower bound by CPLEX is within 1.5% even in the most complex solution space with α = 0.7. CPLEX, on the other hand, fails to obtain the optimal solutions in 10,000 seconds for almost all problems due to the exponential growth of branches in the solution process. From the tables, it is clear that the solution gap decreases as the minimum coverage ratio α increases. In problems with 196 and 400 SDAs, the average gap is within 0.6% for α = 0.9 and 1.0.

A sample solution of cell planning with the problem number 1 of 196 SDAs is shown in Figure 6. The minimum service coverage ratio is set to α =0.7 with base station load factor $[\eta_{\min}, \eta_{\max}] = [0.5, 0.8]$. The number in each SDA shows the service coverage ratio ρ_{ij} between the selected base station j and SDA i. With cell planning, it is clear that all calls generated in most of all SDAs are covered by the base stations. Calls of high data rate service have the tendency of not being covered in cells which are relatively far away from the base stations.

The effect of different load factors is experimented with problems of 196 SDAs. Three different $\eta_{\max}$ values are tested with $\eta_{\min}$ = 0.5. Figure 7 shows reduced number of base stations to cover traffics with higher per base station load factor. With $\eta_{\max}$ = 0.8, the base station reduction effect is about 30% compared to $\eta_{\max}$ = 0.6.

Finally, we consider the load balancing in our cell planning problem. Experiments are performed with the problem number 1 of 196 SDAs. Figure 8 shows the load factor at each base station. As shown in the figure the load factor of all base stations are within $[\eta_{\min}, \eta_{\max}] = [0.5, 0.8]$. Moreover, the load in each base station is more evenly distributed as α increases, which show the effect of load balancing to cover the traffic in the system.

7. Conclusion

Cell planning with four different service classes are examined for 3G services. The coverage and capacity analysis [11] in WCDMA is applied to support services with different data rates, different asymmetry and different coverage. Uplink coverage is considered with different link budget for each service by employing coverage indicator δ_{ij}^{k} to cover service class *k* at SDA *i* with base station *j*. The capacity of a cell is measured by load factor by expanding the E_b / N_0 requirement to multiple service classes. To balance the load at each base station, minimum and maximum load factor $\eta_{\min}$ and $\eta_{\max}$ are considered to evenly distribute the traffic in the system.

The above cell planning problem is formulated as a linear integer programming to minimize the base station deployment cost. An efficient tabu search procedure is developed to solve our cell planning problem. Intensification by dropping and adding base stations is considered by starting from initial deployment. Frequency based diversification is adopted to improve the solution from local optima.

Computational experiments of the proposed tabu search are performed for WCDMA network with 100, 196 and 400 SDAs. An outstanding performance is illustrated by the proposed tabu search. The average gap from the optimal solution or the lower bound by the CPLEX is within 1.5% for all

problems. The effect of load factor with higher $\eta_{\max}$ shows reduced cell sites for multiple service classes. Load balancing among cells is also demonstrated with different coverage ratio.

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Table 1. Representative Service and Data rate for each service class

Service class (k)	Representative Services	Data Rate (Uplink/Downlink)
1	AMR codec voice	12.2kbps / 12.2kbps
2	Video Telephony	64kbps / 64kbps
3	Web document	64kbps / 144kbps
4	VOD (Video on Demand)	64kbps / 384kbps
5	MMS (Multimedia Messaging Service)	64kbps / 2Mbps

Table 2. Computational Results with 100 SDAs

Problem Number	Total Number of Simultaneous Calls	α=0.7			α=0.9			α=1.0		
		Tabu Search	CPLEX	Gap†	Tabu Search	CPLEX	Gap†	Tabu Search	CPLEX	Gap†
1	897	19 (23.21)	19 (833.06)	0.00	22 (17.15)	22 (10,000*)	0.00	22 (15.33)	22 (220.27)	0.00
2	904	19 (22.81)	19 (866.73)	0.00	23 (21.04)	23 (10,000*)	0.00	22 (14.63)	22 (10,000*)	0.00
3	952	22 (25.35)	21 (711.06)	0.05	25 (19.91)	24 (10,000*)	0.04	24 (16.59)	23 (10,000*)	0.00
4	899	19 (26.05)	19 (836.43)	0.00	25 (17.54)	25 (10,000*)	0.00	24 (18.85)	25 (10,000*)	0.04
5	920	20 (21.07)	20 (756.81)	0.00	23 (25.06)	23 (10,000*)	0.00	24 (13.72)	23 (10,000*)	0.00
6	918	14+[6] (21.53)	14+[6] (822.05)	0.00	18+[6] (26.45)	17+[6] (10,000*)	0.04	17+[6] (20.36)	17+[6] (10,000*)	0.00
7	905	13+[6] (25.95)	13+[6] (727.48)	0.00	17+[6] (23.22)	17+[6] (10,000*)	0.00	17+[6] (20.05)	17+[6] (10,000*)	0.00
8	934	14+[6] (26.09)	13+[6] (719.33)	0.05	19+[6] (27.02)	19+[6] (10,000*)	0.00	19+[6] (19.82)	19+[6] (10,000*)	0.00
9	896	14+[6] (23.88)	13+[6] (816.21)	0.05	17+[6] (22.56)	16+[6] (10,000*)	0.05	17+[6] (21.20)	16+[6] (10,000*)	0.05
10	881	13+[6] (26.09)	13+[6] (820.59)	0.00	17+[6] (21.71)	17+[6] (10,000*)	0.00	17+[6] (20.11)	17+[6] (10,000*)	0.00

* Terminated by time limit

† Gap = |Tabu Search – CPLEX|/CPLEX

[6] The number of existing base stations

The numbers in parenthesis represent the CPU seconds

Table 3. Computational Results with 196 SDAs

Problem Number	Total Number of Simultaneous Calls	α=0.7			α=0.9			α=1.0		
		Tabu Search	CPLEX	Gap†	Tabu Search	CPLEX	Gap†	Tabu Search	CPLEX	Gap†
1	1750	39 (1054.06)	38 (10,000*)	0.03	44 (947.71)	44 (10,000*)	0.00	47 (56.73)	47 (10,000*)	0.00
2	1752	38 (970.02)	38 (10,000*)	0.00	43 (903.07)	43 (10,000*)	0.00	47 (54.41)	46 (10,000*)	0.02
3	1785	41 (996.11)	40 (10,000*)	0.03	46 (887.12)	45 (10,000*)	0.02	48 (55.05)	48 (10,000*)	0.00
4	1758	39 (1072.32)	39 (10,000*)	0.00	44 (954.68)	44 (10,000*)	0.00	47 (55.01)	47 (10,000*)	0.00
5	1773	40 (963.03)	41 (10,000*)	0.02	46 (872.32)	46 (10,000*)	0.00	49 (58.18)	49 (10,000*)	0.00
6	1743	24+[12] (1106.51)	23+[12] (10,000*)	0.03	28+[12] (909.47)	28+[12] (10,000*)	0.00	34+[12] (52.12)	34+[12] (10,000*)	0.00
7	1796	27+[12] (982.40)	26+[12] (10,000*)	0.03	31+[12] (826.04)	31+[12] (10,000*)	0.00	37+[12] (54.19)	37+[12] (10,000*)	0.00
8	1809	28+[12] (997.11)	27+[12] (10,000*)	0.03	33+[12] (820.31)	32+[12] (10,000*)	0.02	39+[12] (52.83)	38+[12] (10,000*)	0.02
9	1780	22+[12] (1023.59)	22+[12] (10,000*)	0.00	27+[12] (935.19)	27+[12] (10,000*)	0.00	33+[12] (55.10)	33+[12] (10,000*)	0.00
10	1807	27+[12] (989.26)	27+[12] (10,000*)	0.00	32+[12] (974.29)	32+[12] (10,000*)	0.00	38+[12] (54.40)	38+[12] (10,000*)	0.00

* Terminated by time limit

† Gap = |Tabu Search – CPLEX|/CPLEX

[12] The number of existing base stations

The numbers in parenthesis represent the CPU seconds

Table 4. Computational Results with 400 SDAs

Problem Number	Total Number of Simultaneous Calls	α=0.7			α=0.9			α=1.0		
		Tabu Search	CPLEX	Gap†	Tabu Search	CPLEX	Gap†	Tabu Search	CPLEX	Gap†
1	3583	84 (5591.02)	83 (10,000*)	0.01	90 (2313.06)	90 (10,000*)	0.00	96 (1508.11)	95 (10,000*)	0.01
2	3617	85 (5244.17)	85 (10,000*)	0.00	92 (2411.47)	92 (10,000*)	0.00	97 (1532.01)	97 (10,000*)	0.00
3	3557	83 (5438.20)	82 (10,000*)	0.01	90 (2330.66)	89 (10,000*)	0.01	95 (1538.20)	94 (10,000*)	0.01
4	3620	86 (5169.22)	85 (10,000*)	0.01	93 (2439.42)	92 (10,000*)	0.01	97 (1554.11)	97 (10,000*)	0.00
5	3612	84 (5204.06)	84 (10,000*)	0.00	92 (2588.64)	91 (10,000*)	0.00	96 (1588.37)	96 (10,000*)	0.00
6	3640	55+[24] (5591.33)	55+[24] (10,000*)	0.00	63+[24] (2779.08)	63+[24] (10,000*)	0.00	77+[24] (1602.31)	77+[24] (10,000*)	0.00
7	3616	54+[24] (5674.17)	54+[24] (10,000*)	0.00	62+[24] (2645.06)	62+[24] (10,000*)	0.00	77+[24] (1502.16)	76+[24] (10,000*)	0.01
8	3607	53+[24] (5701.06)	52+[24] (10,000*)	0.01	61+[24] (2703.11)	60+[24] (10,000*)	0.01	74+[24] (1523.47)	74+[24] (10,000*)	0.00
9	3582	51+[24] (5935.10)	51+[24] (10,000*)	0.00	60+[24] (2899.15)	59+[24] (10,000*)	0.01	73+[24] (1487.62)	73+[24] (10,000*)	0.00
10	3610	54+[24] (5842.09)	53+[24] (10,000*)	0.01	61+[24] (2755.49)	61+[24] (10,000*)	0.00	76+[24] (1530.30)	75+[24] (10,000*)	0.01

* Terminated by time limit

† Gap = |Tabu Search – CPLEX|/CPLEX

[24] The number of existing base stations

The numbers in parenthesis represent the CPU seconds

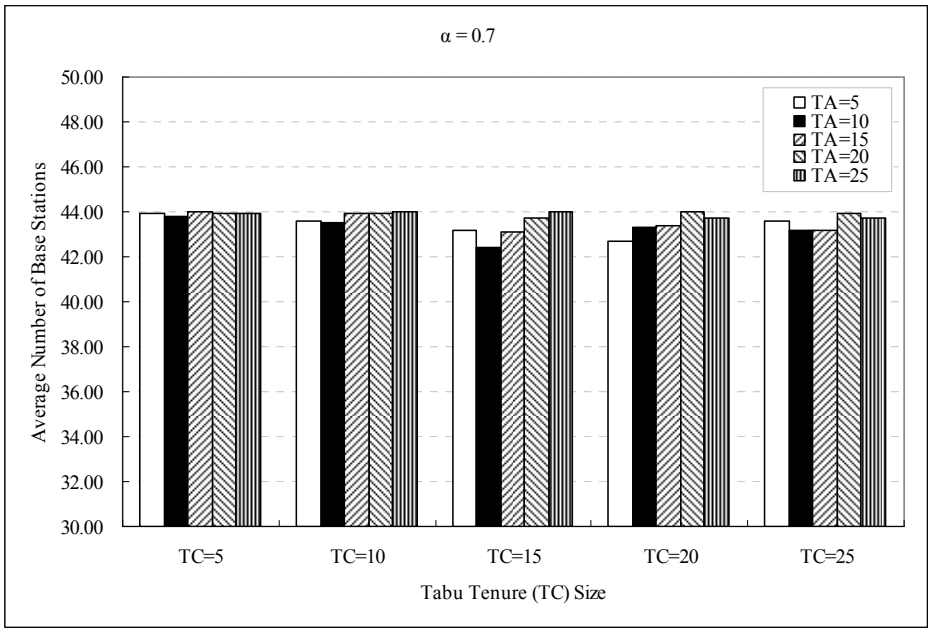

Figure 1. Test of tabu tenure TA (TC) size for $\alpha = 0.7$

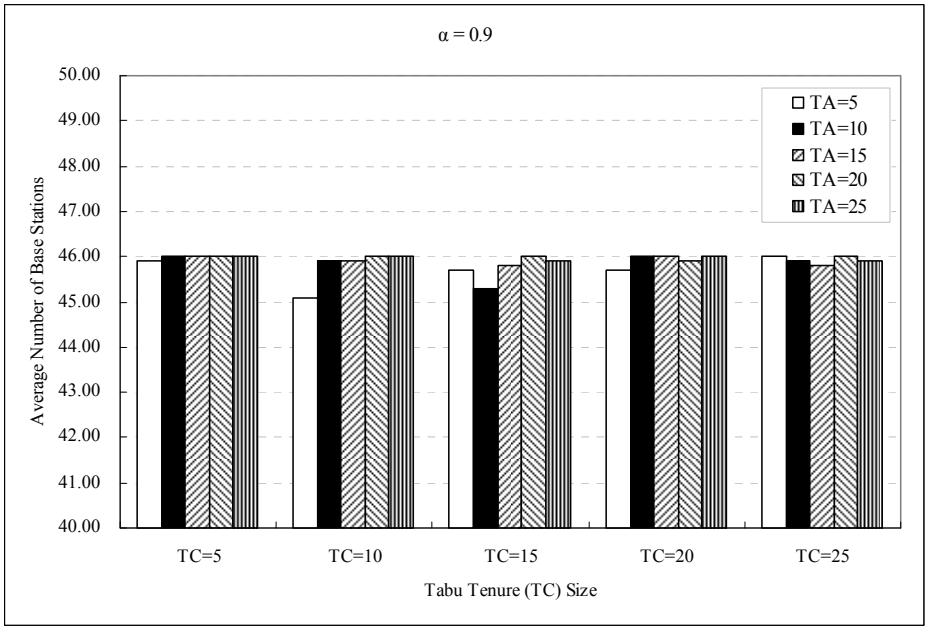

Figure 2. Test of tabu tenure TA (TC) size for $\alpha = 0.9$

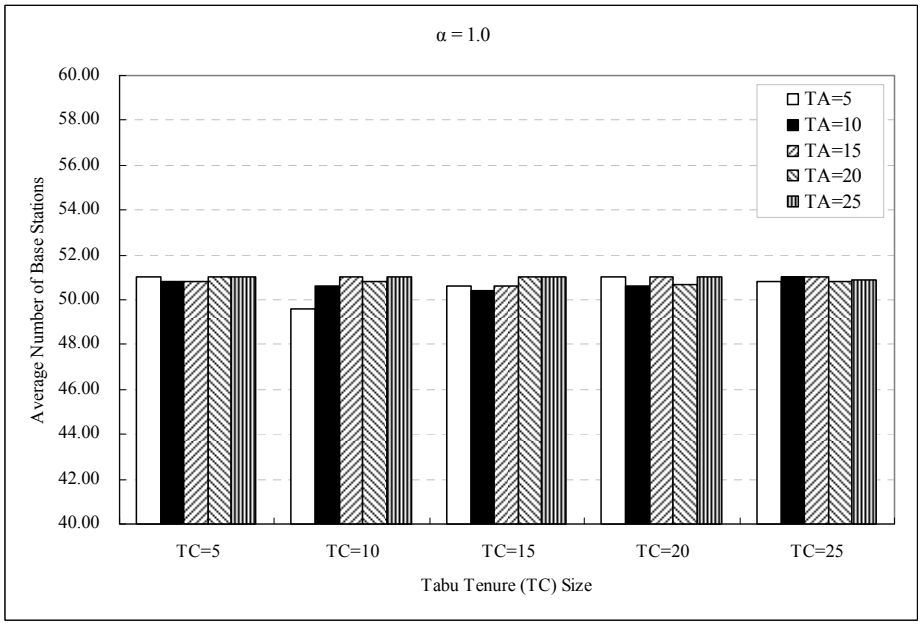

Figure 3. Test of tabu tenure TA (TC) size for $\alpha = 1.0$

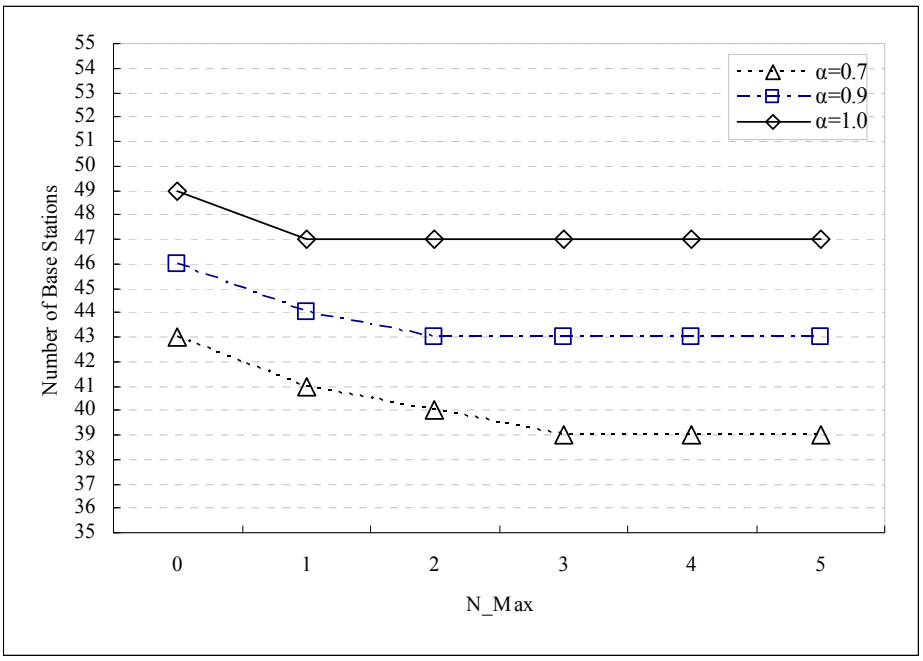

Figure 4. Test of N_Max

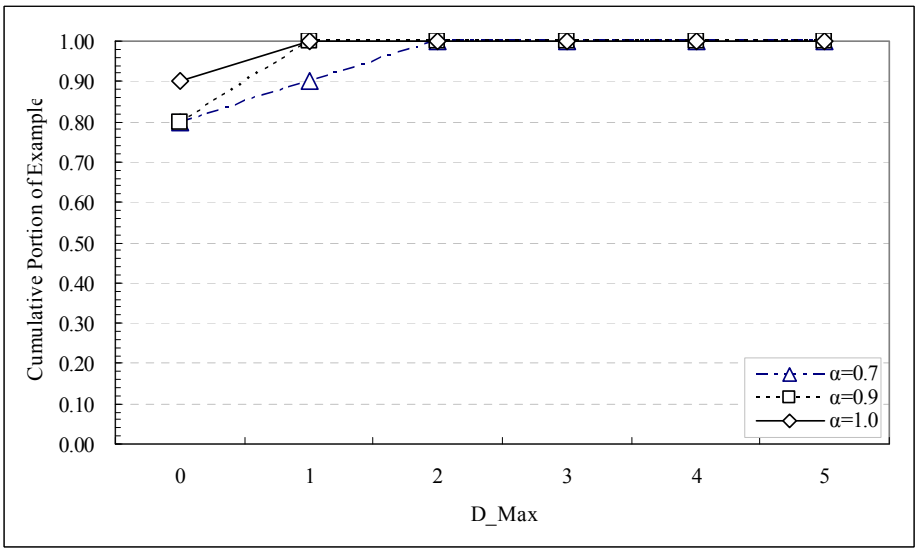

Figure 5. Test of D_Max

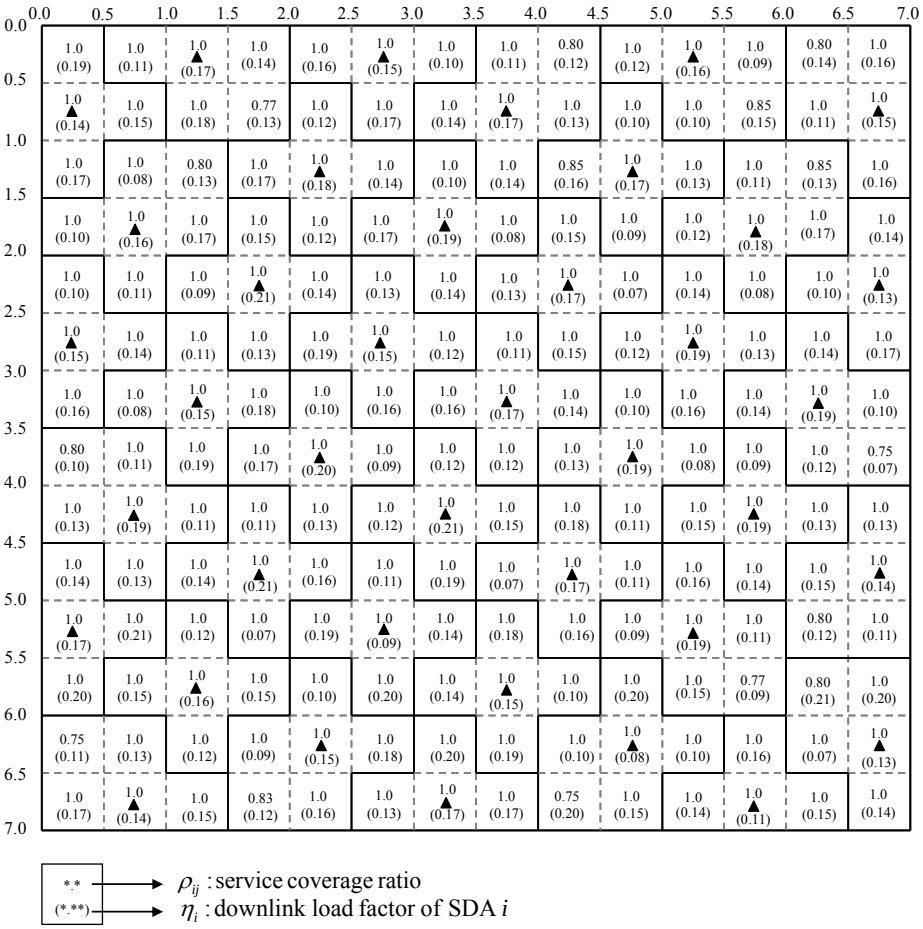

Figure 6. Cell planning with 196 SDAs (▲: Base Station Site)

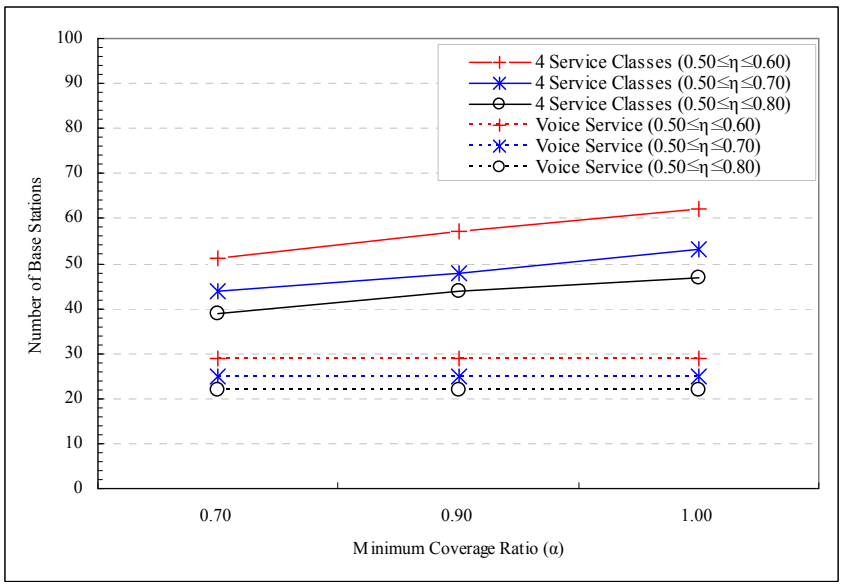

Figure 7. Effect of load factor

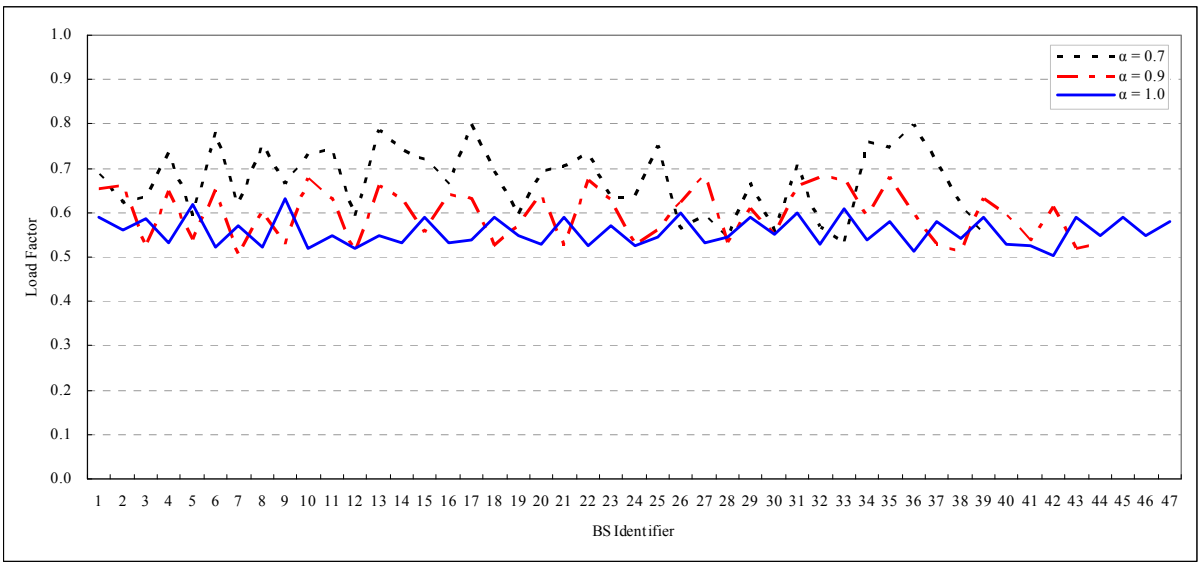

Figure 8. Effect of load balancing