

Determination of Optimal Cell Capacity for Initial Cell Planning in Wireless Cellular Networks

Young Ha Hwang*, Sung-Kee Noh*, and Sang-Ha Kim**

Abstract: In wireless cellular networks, previous researches on admission control policies and resource allocation algorithm considered the QoS (Quality of Service) in terms of CDP (Call Dropping Probability) and CBP (Call Blocking Probability). However, since the QoS was considered only within a predetermined cell capacity, the results indicated a serious overload problem of systems not guaranteeing both CDP and CBP constraints, especially in the hotspot cell. That is why a close inter-relationship between CDP, CBP and cell capacity exists. Thus, it is indispensable to consider optimal cell capacity guaranteeing multiple QoS (CDP and CBP) at the time of initial cell planning for networks deployment. In this paper, we will suggest a distributed determination scheme of optimal cell capacity guaranteeing both CDP and CBP from a long-term perspective for initial cell planning. The cell-provisioning scheme is performed by using both the two-dimensional continuous-time Markov chain and an iterative method called the Gauss-Seidel method. Finally, numerical and simulation results will demonstrate that our scheme successfully determines an optimal cell capacity guaranteeing both CDP and CBP constraints for initial cell planning.

Keywords: QoS, optimal cell capacity, cell planning, wireless cellular networks

1. Introduction

The specification and management of quality of service (QoS) is important in a wireless networks environment, particularly to support multimedia applications. The next generation wireless network is expected to offer a reliable solution to deal with multimedia applications over mobile wireless networks. Limited resource, however, causes an increase of intercell handoffs and rapid changes of traffic conditions in the network [1]. As a result, it leads to non-uniformity among cells in the aspect of channel utilization, CDP, and CBP [2].

Therefore, deployable QoS provisioning schemes must be able to regulate and adapt to variable traffic conditions among neighboring cells so as to ensure the predefined target QoS constraints independent of the non-uniform traffic conditions [3].

In general, CDP of handoff calls has been considered an important QoS metric because dropping an ongoing call is considered to have a more negative impact than blocking a newly originating call in a wireless network. In this context, many call admission control (CAC) schemes have been developed to prioritize handoff calls by applying an adaptive channel reservation policy. In these schemes, a number of channels in a cell are reserved solely for the use of handoff calls, allowing both handoff and new calls to

compete for the remaining channels [4]. Specifically, an admission threshold is set in each cell, and if the number of channels being used exceeds this threshold, an originating new call is blocked and only handoff calls are admitted.

These channel reservation schemes [1], [2], [5] involve two problems: The first is how to determine the admission threshold. In [1], the threshold is calculated as a function of the number of existing service connections and/or the requested channels. Then, after monitoring the hand-off dropping probability, this threshold is adaptively increased or decreased. In [2], the threshold is initially set by the maximum number of channels in a cell. If dropping a handoff call occurs, the system adapts the threshold. Both of these schemes, however, do not propose a minimal threshold that can guarantee QoS adapting variable traffic load conditions in a cell. That is, exact threshold can be known only after both QoS violation and threshold adaptations have repeatedly occurred. As a result, these schemes could potentially suffer from poor channel utilization and/or frequent short-term QoS violation until threshold convergence is adaptively completed [4]. The second is that decrease of CDP by channel reservation may increase CBP. Specially, when the offered load is heavy and incoming handoff rate is high, reservation schemes compensate by sacrificing newly arriving calls.

It is very difficult to achieve this kind of optimum QoS provision, mainly due to limited resources and the dynamic nature of the wireless channel and user mobility. This can cause critical changes to the QoS determined at the connection setup. Previous researches [1]-[17] dealt with resource reservation approaches and CAC schemes only under limited resources in wireless networks. In particular,

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some researches [9]-[17] considering effective cell capacity involved problems to determine effective bandwidth or system capacity for controlling signal quality only under limited resources.

In effective bandwidth-based CAC schemes [9]-[12], the maximum number of admissible users is determined using the effective bandwidth concept. Limiting the number of users per cell is used to ensure the SIR (signal to interference ratio) requirements under limited resources. Thus, the selection of the maximum number of users per cell depends heavily on the interference level [10], [11]. This effective bandwidth is chosen such that it can guarantee the packet loss requirements to each user [9]. The amount of effective bandwidth is usually found by solving the above inequality using approximation approaches [9], [12].

In optimum CAC schemes with signal quality constraints under limited resources [13]-[17], the signal quality is controlled by solving as a constrained optimization problem. Such schemes optimize certain objective functions, providing certain constraints on signal quality measures. This approach has been used in [13] to maximize the system capacity while maintaining the upper bound of the outage probability and blocking probability. Modified linear programming techniques are used to solve the optimization problem and find the optimum policy. The same approach is used in [14] to maximize the system capacity in hierarchical cellular structures (consisting of micro/macro cells).

In [15], an optimum CAC policy is employed to minimize the blocking rate of voice calls while maintaining the signal quality in terms of probability of packet error. The CAC policy is based on the Semi-Markovian Decision Process (SMDP). A cost function, which is equal to the number of blocked calls, is minimized using the value-iteration algorithm. This optimum policy is compared with a threshold CAC policy based on the number of users and is called the direct admission algorithm. Similarly, the algorithm proposed in [16] minimizes the blocking probability of one service class while taking the blocking rate requirements of other classes and SIR condition as constraints. The problem is then formulated as a Semi-Markovian Decision Process (SMDP) and solved by linear programming; the SIR constraint takes into account the multi-user detection feature.

The proposed scheme in [17] maximizes a cost function that is equal to the sum (over all cells) of the difference between weighted call admitting probabilities ($1-P_b$) and weighted dropping probabilities. The chosen weights reflect the relative impact of call blocking and dropping. The optimization problem is subject to constraints on maximum blocking probability and minimum SIR for all users in all cells, assuming non-uniform traffic.

However, since the QoS was previously considered only within a pre-determined cell capacity, the results showed a serious overload problem of the system not guaranteeing both CDP and CBP constraints, especially in the hotspot cell. That is why a close inter-relationship between CDP,

CBP and cell capacity exists. In order to overcome this problem, we considered the algorithm to determine the optimal cell capacity guaranteeing multiple QoS in the aspect of initial cell planning for networks deployment.

In this paper, we suggest a distributed optimal cell-provisioning scheme guaranteeing both CDP and CBP from a long-term perspective for initial cell planning. Our proposed scheme is performed by using both the two-dimensional continuous-time Markov chain and an iterative method called the Gauss-Seidel method [18]. Numerical and simulation results demonstrate that our scheme successfully determines an optimal cell capacity guaranteeing both CDP and CBP constraints.

The main contribution of this paper is stated as follows: We propose a novel recursive algorithm to determine the optimal cell capacity for initial cell planning in wireless cellular networks and verify that our algorithm and analysis are effective and suitable by comparing the numerical results with the simulation results.

The remaining segments are organized as follows: The second section illustrates the system model. The third section analyzes the model using the two-dimensional continuous-time Markov chain. In the fourth section, we present the optimal cell-provisioning algorithm guaranteeing both CDP and CBP. In the fifth section, we reveal numerical results along with a simulation analysis and compare both results to each other. Finally, we sum up this study with the conclusion.

2. System Model

Fig. 1 presents the system model of a cell in a distributed wireless networks environment. The basic assumptions included in this model are as follows:

- This model is within a distributed wireless environment.
- Traffic arriving into each cell is heterogeneous.
- The initial cell capacity (C_{in}) has already been determined by previously gathered data.
- A typical dynamic resource allocation scheme is used in this model. (e.g., New call channels, Handoff call channels, and Shared channels)

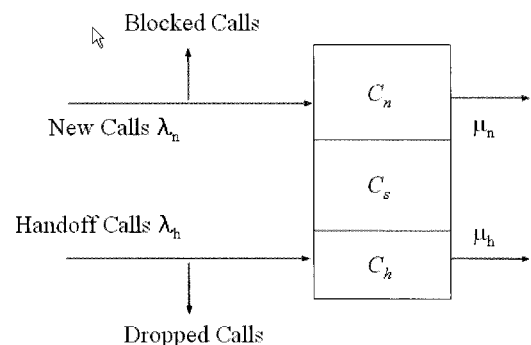


Fig. 1. System model for a cell

There are three types of traffic channels (new call,

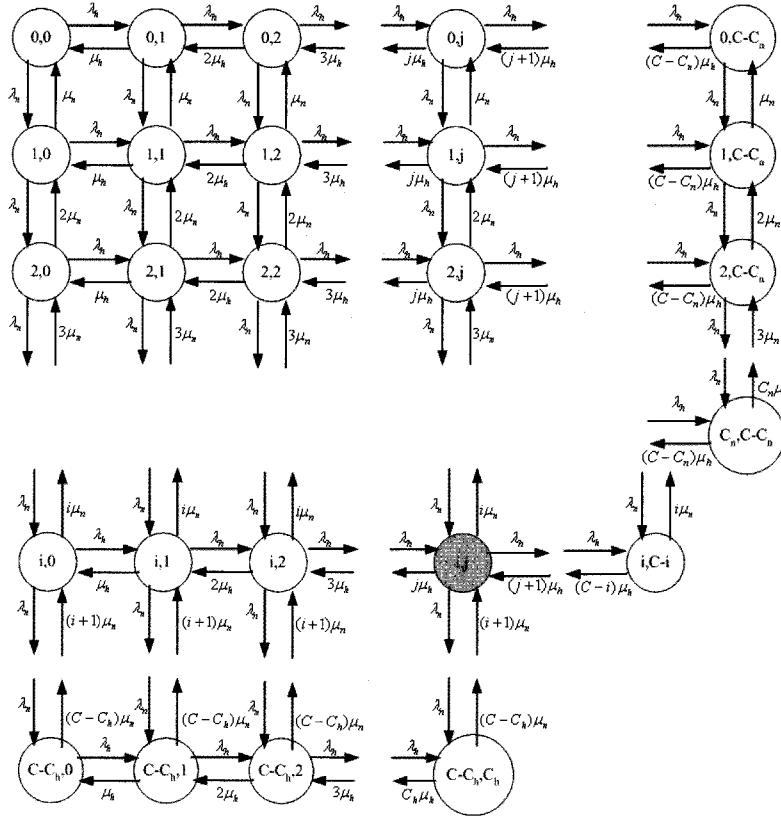


Fig. 2. Two-dimensional state transition diagram

handoff call, and shared) used in a typical dynamic resource allocation scheme adjusted according to the traffic behavior. New call and handoff call channels (C_n and C_h) are designated specifically for new call and handoff call traffic, respectively, while shared channels (C_s) can be used for either type of traffic. The typical admission control policy is based on the following rules: A new call is accepted if new call channels or shared channels are available, and a handoff call is accepted if handoff call channels or shared channels are available.

* Notations

- λ_n, λ_h : Arrival rate of new calls and handoff calls
- μ_n, μ_h : Service rate of new calls and handoff calls
- C_{mi} : Initial cell capacity
- C_n : Channel set used only by new calls
- C_h : Channel set used only by handoff calls
- C_s : Shared channel set used by both new and handoff calls
- C : Channel capacity in the cell ($C=C_n+C_h+C_s$)
- C_{opt} : Optimal cell capacity of the cell determined by our algorithm

3. Performance Analysis

The system model shown in Fig.1 can be described by the two-dimensional continuous-time Markov chain where i and j denote the number of existing new and handoff calls

in a cell, respectively. The state space is $S=\{s(i, j) | 0 \leq i \leq C_n, 0 \leq j \leq C-C_n, \text{ and } C_h \leq j \leq C-C_n, 0 \leq i \leq C-j\}$

State (i, j) changes to $(i+1, j)$ with rate λ_n if the new call and shared channels are available, and to $(i, j+1)$ with rate λ_h if the handoff call and shared channels are available. When one of the channels occupied by j handoff calls is released (with rate $j\mu_h$), the state (i, j) changes to $(i, j-1)$. The release of channels occupied by new calls will contribute to the transition from (i, j) to $(i-1, j)$. Fig.2 shows a two-dimensional state transition diagram.

Let P_{ij} be the steady state probability that there are i new calls and j handoff calls simultaneously in the cell. The corresponding balance equations from Fig.2 are shown as four distinct cases.

- Case 1. If the number of existing new calls in the cell is less than C_n , that is, $0 \leq j \leq C_n-1$, then:

$$[\lambda_n + \lambda_h + i\mu_n + j\mu_h]P_{ij} = \lambda_n P_{i-1,j} + \lambda_n P_{i+1,j} + (i+1)\mu_n P_{i+1,j} + (j+1)\mu_h P_{i,j+1}, \text{ for } 0 \leq j \leq C-C_n-1; \quad (1)$$

$$[\lambda_n + i\mu_n + (C-C_n)\mu_h]P_{ij} = \lambda_n P_{i-1,j} + \lambda_n P_{i+1,j} + (i+1)\mu_n P_{i+1,j}, \text{ for } j = C-C_n. \quad (2)$$

- Case 2. If the number of existing new calls in the cell is equal to C_n , that is, $i = C_n$, then:

$$[\lambda_n + \lambda_h + i\mu_n + j\mu_h]P_{ij} = \lambda_n P_{i-1,j} + \lambda_n P_{i+1,j}$$

$$+(i+1)\mu_n P_{i+1j} + (j+1)\mu_h P_{ij+1}, \text{ for } 0 \leq j \leq C-C_n-1; \quad (3)$$

$$[C_n \mu_n + (C-C_n) \mu_h] P_{ij} = \lambda_h P_{ij-1} + \lambda_n P_{i-1j},$$

for $j=C-C_n$. (4)

- Case 3. If the number of existing new calls in the cell exceeds C_n but is less than $C-C_h$, that is, $C_n+1 \leq i \leq C-C_h-1$, then:

$$[\lambda_n + \lambda_h + i\mu_n + j\mu_h] P_{ij} = \lambda_h P_{ij-1} + \lambda_n P_{i-1j}$$

$$+ (i+1)\mu_n P_{i+1j} + (j+1)\mu_h P_{ij+1}, \text{ for } 0 \leq j \leq C-i-1; \quad (5)$$

$$[i\mu_n + (C-i)\mu_h] P_{ij} = \lambda_h P_{ij-1} + \lambda_n P_{i-1j},$$

for $j=C-i$. (6)

- Case 4. If the number of existing new calls in the cell is equal to $C-C_h$, that is, $i=C-C_h$, then:

$$[\lambda_n + (C-C_h)\mu_n + j\mu_h] P_{ij} = \lambda_h P_{ij-1} + \lambda_n P_{i-1j}$$

$$+ (j+1)\mu_h P_{ij+1}, \text{ for } 0 \leq j \leq C_h-1; \quad (7)$$

$$[(C-C_h)\mu_n + C_h\mu_h] P_{ij} = \lambda_h P_{ij-1} + \lambda_n P_{i-1j},$$

for $j=C_h$. (8)

The steady state probabilities satisfy the following normalization condition:

$$\sum_{i=0}^{C-1} \sum_{j=0}^{C-C_n} P_{ij} + \sum_{i=C_n}^{C-C_h} \sum_{j=0}^{C-i} P_{ij} = 1 \quad (9)$$

Also, these steady state probabilities can be solved by using a classical iterative method called the Gauss-Seidel method [18]. Both the arrival and departure rate of handoff and new calls can be presented for each state (i, j) . By using both the normalization condition and the iterative procedure for steady state probability, we can achieve the converged values of steady state probability (P_{ij}) .

The new call blocking and handoff dropping probability can be estimated by these steady state probabilities. Consider new call blocking probability under normal conditions. A new call is accepted if the number of existing new calls is less than C_n . However, when the number of existing new calls is greater than or equal to C_n , a new call is admitted only when the channel occupancy in the cell is smaller than the $C-C_h$. Therefore, the new call blocking probability (CBP) is given by:

$$CBP = 1 - \left[\sum_{i=0}^{C_n-1} \sum_{j=0}^{C-C_n} P_{ij} + \sum_{i=C_n}^{C-C_h-1} \sum_{j=0}^{C-i} P_{ij} \right] \quad (10)$$

In the same manner, a handoff call is accepted if the channel occupancy is smaller than $C-C_n$. Thus, the dropping probability of handoff calls (CDP) is given by:

$$CDP = 1 - \left[\sum_{j=0}^{C_n-1} \sum_{i=0}^{C-C_h} P_{ij} + \sum_{j=C_n}^{C-C_h-1} \sum_{i=0}^{C-j} P_{ij} \right] \quad (11)$$

4. The Algorithm

This section proposes an iterative algorithm (Fig.3) to discover the optimal cell capacity. The required minimum channel capacity (C_n , C_h , and C_s) determined by our algorithm guarantees that the new call blocking and handoff call dropping probabilities satisfy the predetermined constraints. Initially, we must determine the steady state probability (P_{ij}) using equations (1)-(9) and the Gauss-Seidel method. Then, we can calculate the new call blocking probability and the handoff call dropping probability using equations (10) and (11). Finally, the required minimum channel capacity (C_n , C_h , and C_s) guaranteeing CBP and CDP constraints (α and β) is determined. As shown in Fig.3, the value of C_n and C_h can be initially started with $C_h=1$, $C_n=C-C_h$, respectively. Then, whenever CBP and/or CDP calculated by equations (10) and (11) violate constraints, the size of C_n and C_h are iteratively increased or decreased by one until multiple QoS constraints are satisfied.

$C_h = 1; C_n = C - C_h;$

REPEAT

Calculate P_{ij} using (1)-(9), and Gauss-Seidel method;

Calculate CBP and CDP using (10) and (11);

CASE

$CDP > \beta$ and $CBP \leq \alpha$: $C_n = C_n - 1$; $C_h = C_h + 1$;

$CDP > \beta$ and $CBP > \alpha$: $C_n = C_n + 1$; $C_h = C_h + 1$;

$CDP \leq \beta$ and $CBP > \alpha$: $C_n = C_n + 1$; $C_h = C_h - 1$;

$CDP \leq \beta$ and $CBP \leq \alpha$: 'Multiple QoS guaranteed';

UNTIL Num = QoS guaranteed

IF $(C_n + C_h) \geq C$ THEN $C_s = 0$; $C_{opt} = C_n + C_h + C_s$;

ELSE $C_s = C - C_n - C_h$; $C_{opt} = C_n + C_h + C_s$;

Fig. 3. Algorithm to determine optimal cell capacity

5. Numerical and Simulation Results

This section presents the numerical results and simulation results of our algorithm.

Fig.4 shows the results of the optimal cell capacity determined by our algorithm under normal traffic conditions, where $\rho_n = \lambda_n / \mu_n = 40/20$ for new call and $\rho_h = \lambda_h / \mu_h = 50/10$ for handoff call, given $C_{ini} = 15$, $\alpha = 0.3$, $\beta = 0.01$. As shown in Fig.4, the initial value of C_h and C_n is 1 and 14, respectively, and is changed by the iteration of algorithm. Our iterative algorithm ceases if multiple QoSs (CBP and CDP) are satisfied. After our algorithm to determine the optimal cell capacity completes, we can obtain the values of C_n , C_h , and $C_s (= C - C_n - C_h)$ to be 11, 3, and 1, respectively. That is, the optimal cell capacity (C_{opt}) is 15.

Fig.5 shows the results of the optimal cell capacity in an

overloaded hotspot cell where the call arrival rates are high ($\rho_n = \lambda_n / \mu_n = 110/20$, $\rho_h = \lambda_h / \mu_h = 80/10$, $C_{ini} = 15$, $\alpha = 0.3$, $\beta = 0.01$). The initial value of C_h and C_n is the same as Fig.4. However, after many iterations of our algorithm the values of C_n , C_h , C_s , and C_{opt} are 17, 6, 0, and 23, respectively. According to this result, a high traffic load overloads the initial cell capacity and the final optimal cell capacity (C_{opt}) has 23 channels. That is, since the initial cell capacity ($C_{ini} = 15$) cannot guarantee multiple QoS (CDP and CBP) in the hotspot cell, additional cell capacity (8 channels) is required. Thus, the final cell capacity (23 channels) determined by our algorithm is an optimal minimum cell capacity that guarantees both CDP and CBP simultaneously in the hotspot cell.

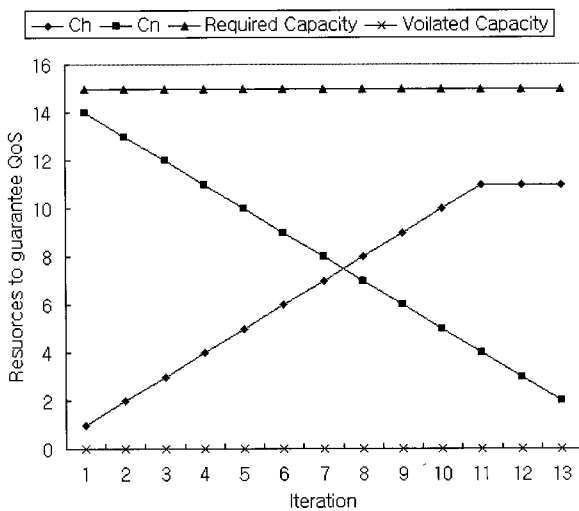


Fig. 4. Optimal cell capacity in a normal cell

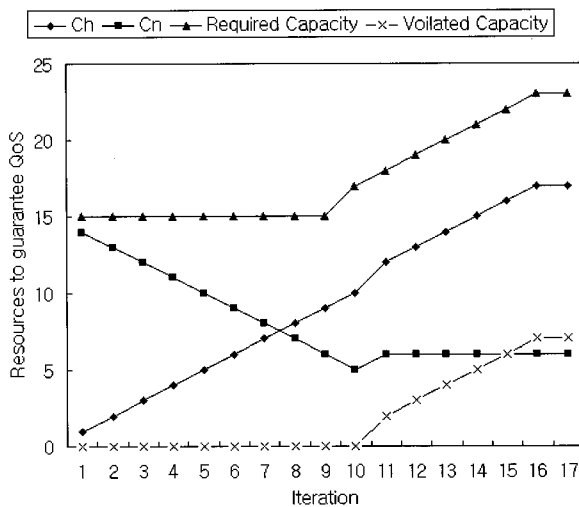


Fig. 5. Optimal cell capacity in a hotspot cell

Table 1 presents numerical and simulation results performed by our algorithm according to variable traffic conditions, given $\alpha = 0.3$, $\beta = 0.01$, $\mu_n = 20$, $\mu_h = 10$, and $C_{ini} = 15$. AweSim (Visual SLAM [19]) was used as a simulation tool. There is a little difference in the results of the numerical and simulation analyses. That is why the

numerical analysis was ceased if CBP and CDP were satisfied, while the simulation analysis was continued during one million run-times to obtain the results in a steady-state, even though the CBP and CDP were satisfied and the optimal cell capacity was determined. Thus, on the whole, the values of CBP and CDP in the simulation results were lower than those in the numerical results. However, the results of optimal channel capacity (C_n , C_h , C_s) determined by both analyses were the same. In accordance with the compared results of the numerical and simulation analyses, we believe there is no significant difference between both results.

Table 1. Results of numerical and simulation

(λ_n, λ_h)	Numerical Results		Simulation Results	
	(CBP,CDP)	(C_n, C_h, C_s)	(CBP,CDP)	(C_n, C_h, C_s)
(110, 80)	(0.26,0.006)	(6, 17, 0)	(0.23,0.002)	(6, 17, 0)
(60, 100)	(0.20,0.009)	(4, 19, 0)	(0.20,0.004)	(4, 19, 0)
(80, 40)	(0.20,0.007)	(5, 10, 0)	(0.20,0.005)	(5, 10, 0)
(40, 50)	(0.28,0.004)	(3, 11, 1)	(0.21,0.004)	(3, 11, 1)

Table 2 presents an optimal cell capacity (C_{opt}) determined by our algorithm according to variable traffic conditions. For example, when traffic condition (λ_n, λ_h) in a cell changes from (40, 50) to (110, 80), the required optimal cell capacity and channel region (C_n , C_h , C_s) for QoS provisioning must be increased from 15 to 23 and from (3, 11, 1) to (6, 17, 0), respectively.

Table 2. Optimal cell capacity according to traffic conditions

(λ_n, λ_h)	(C_n, C_h, C_s)	C_{opt}
(110, 80)	(6, 17, 0)	23
(60, 100)	(4, 19, 0)	23
(80, 40)	(5, 10, 0)	15
(40, 50)	(3, 11, 1)	15

6. Discussions and Conclusion

Our final goal including this work is to optimally determine the total cell capacity of wireless cellular networks consisting of many independent cells with heterogeneous traffic under a distributed environment. If all networks consist of n cells, we can obtain their total capacity by summation of each independent cell capacity with heterogeneous traffic. That is, the total capacity, C_{total} , is $C_1 + C_2 + \dots + C_n$. In this paper, we obtained an optimal cell capacity (C_1, C_2, \dots, C_n) for each independent cell by our proposed algorithm. Of course, there may be some additional QoS problems such as intercell fairness, signal interference, and cost in the case of multi-cells. We consider these problems as subject matter for further works.

In previous researches, adaptive channel reservation and call admission control schemes aimed to reduce CDP and CBP in a wireless network. Since they, however, considered QoS only within limited cell capacity, a serious QoS violation problem can occur, especially in the hotspot cell. Additionally, because they did not plan the required

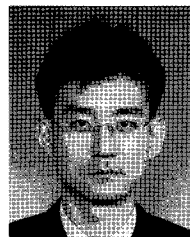
optimal cell capacity to guarantee QoS in advance, it resulted in a QoS-violation problem.

In order to solve these problems, this paper proposed the algorithm to discover the optimal cell capacity to guarantee multiple QoS (CBP and CDP) in each independent cell with variable traffic. In accordance with the compared results of the numerical and the simulation analyses, we can conclude that our algorithm and method to determine optimal cell capacity is suitable and useful for initial cell planning in designing appropriate wireless cellular networks.

As further study, we can consider the algorithm to determine the optimal cell capacity of multi-cells instead of a single cell in wireless cellular networks.

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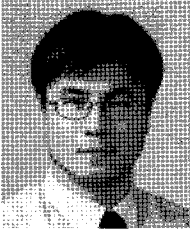
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