An Adaptive Hot-Spot Operating Scheme for OFDMA Downlink Systems in Vertically Overlaid Cellular Architecture

Nak-Myeong Kim, Hye-Sun Choi, and Hee-Jeong Chung

In vertically overlaid cellular systems, a temporary traffic concentration can occur in a hot-spot area, and this adversely affects overall system capacity. In this paper, we develop an adaptive hot-spot operating scheme (AHOS) to mitigate the negative effects from the nonuniform distribution of user location and the variation in the mixture of QoS requirements in orthogonal frequency division multiple access downlink systems. Here, the base station in a macrocell can control the operation of picocells within the cell, and turns them on or off according to the system overload estimation function. In order to determine whether the set of picocells is turned on or off, we define an AHOS gain index that describes the number of subcarriers saved to the macrocell by turning a specific picocell on. For initiating the picocell OFF procedure, we utilize the changes in traffic concentration and co-channel interference to the neighboring cells. According to computer simulation, the AHOS has been proved to have maximize system throughput while maintaining a very low QoS outage probability under various system scenarios in both a single-cell and multi-cell environments.

Keywords: Hot-spot, OFDM, OFDMA, resource allocation, QoS.

I. Introduction

To accommodate an increasing demand of high data rate transmission among many subscribers, orthogonal frequency division multiple access (OFDMA) is considered as one of the promising multiple access schemes in the next generation mobile communication systems. In order to maximize spectral efficiency in OFDMA systems, some of the subcarriers can be shared among adjacent cells or sectors. In this case, however, co-channel interference (CCI) becomes one of the main reasons of performance degradation. Recently, there have been several investigations for efficient resource allocation algorithms to mitigate CCI among nearby cells [1]-[3].

Adaptive modulation is usually known as a method to maximize system throughput. However, one of the problems with adaptive modulation is that users in a cell boundary will require more resources in the number of subcarriers because of lower channel gain. Therefore, when the users are distributed more around the edges, the overall spectral efficiency decreases a great deal. Abrupt changes in traffic demand according to the concentration of users in a certain area cause further degradation of system capacity. That is, in order to support the quality-of-service (QoS) of such users, more resources are allocated in the cell edge area, so inter-cell interference increases. Yasushi Yamao and others proposed a multi-hop radio access cellular (MRAC) scheme to achieve both high capacity and a good coverage area [4]. By utilizing two kinds of hop stations, a dedicated repeater station, and a user terminal, the transmit power consumption of the mobile stations (MSs) located in the cell edge area is effectively reduced. However, it

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Manuscript received Aug. 18, 2005; revised Mar. 15, 2006.

Nak-Myeong Kim (phone: + 82 2 3277 2802, email: nmkim@ewha.ac.kr) is with Department of Information Electronics Engineering, Ewha Womans University, Seoul, Korea.

Hye-Sun Choi (email: heysun79.choi@samsung.com) and Hee-Jeong Chung (email: heejeong.chung@samsung.com) are with the Department of Telecommunication Network Business, Samsung, Suwon, Korea.

is not easy to designate an optimal user terminal station for a hop station. Besides, the interference reduction effect may be reduced since a dedicated repeater station requires some extra radio resources.

In this paper, we propose an adaptive hot-spot operating scheme (AHOS) to mitigate the negative effects from the nonuniform distribution of user location and the variation in the mixture of QoS requirements in OFDMA downlink systems. In the future mobile multimedia environment, some sort of hot-spot area could occur at a certain place at an unexpected time, and the amount of user traffic will also fluctuate. Since these may cause temporary resource exhaustion, the proposed AHOS tries to solve it by setting up and controlling intelligently several hot-spot access points (AP) within the given cell. When a hot-spot AP is implemented, nearby users can expect much higher channel gain, so they can use higher modulation, which implies that fewer subcarriers are needed to maintain the same data rate. In the proposed scheme, the macrocell base station (BS) continuously estimates the resource utilization and the user outage probability along with the user locations and the traffic characteristics, and then decides if any of the picocells must run. On the other hand, when the traffic concentration near any of the running picocells reduces or the CCI to the neighboring cells becomes excessive, the BS decides to turn some picocells off.

The rest of the paper is organized as follows. In section II, the system model is described. The proposed AHOS is described in section III in detail, and then the performance of the AHOS is discussed in section IV. We conclude in section V.

II. System Description

In the downlink of OFDMA mobile communication systems, adaptively modulated signals on each subcarrier are transmitted through the multipath fading channel. Figure 1(a) shows the adaptive hierarchical cellular architecture of the single cell OFDMA system. A macrocell in the OFDMA system is supposed to serve K users with a carrier containing N subcarriers. Each user requests to transmit information with a satisfactory QoS guarantee, which can be defined as a function of the required minimum data rate and the required bit error rate (BER). Here, we assume that the channel state information (CSI) is perfectly known to BSs and MSs [5], [6]. This assumption might not perfectly represent a practical system, and the performance of the proposed scheme under imperfect knowledge of CSI may have some potential difference from the ideal case. Since the modulation for each subcarrier is adaptive, the number of subcarriers assigned to each user is assumed to be a function of the received signal to interference and noise ratio (SINR) and the user's QoS requirement.

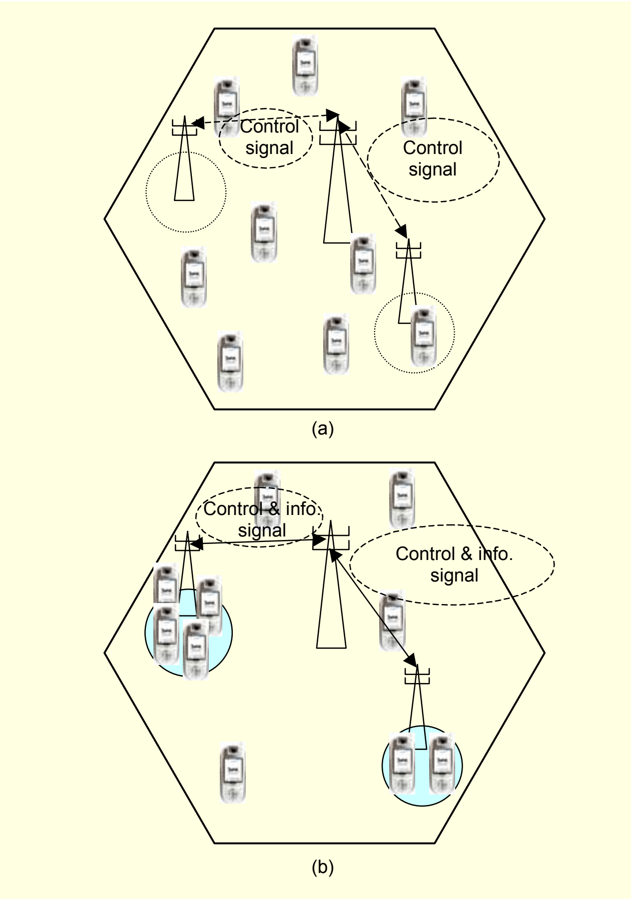

Fig. 1. Adaptive hierarchical cellular architecture with (a) dormant hot-spots and (b) active hot-spots.

Assuming that M-quadrature amplitude modulation (M-QAM) is applied for adaptive modulation, the BER for each subcarrier can be approximated by

$$BER_{MQAM} \approx \frac{2(1-L^{-1})}{\log_2 L} Q\left(\sqrt{\left(\frac{3\log_2 L}{L^2-1}\right)\frac{2E_b}{N_0}}\right), \qquad (1)$$

where L is defined as $\sqrt{M}$ [7]. Suppose that $P_{k,n}$ is the transmission power of the n-th subcarrier for the k-th user, and $H_{k,n}$ is the k-th user's channel gain of the n-th subcarrier including pathloss. Then, the received SINR of the n-th subcarrier for the k-th user can be expressed as

$$\gamma_{k,n} = \frac{P_{k,n} \cdot H_{k,n}}{I_n + \sigma_{k,n}^2}, \qquad (2)$$

where I_n and $\sigma_{k,n}^2$ are the summation of the CCI on the n-th subcarrier from neighboring cells and the power of additive white Gaussian noise, respectively. Let $b_{k,n}$ denote the number of bits per symbol of the n-th subcarrier for the k-th user. Then,

(1) can be further approximated by

$$BER_{MQAM}(\gamma_{k,n}) \approx 0.2\exp\left[\frac{-1.5\gamma_{k,n}}{2^{b_{k,n}}-1}\right], \tag{3}$$

when $b_{k,n} \geq 2$ and BER$\leq 10^{-3}$ [8]. Rearranging this notation, the maximum possible number of bits per symbol can be described as

$$b_{k,n} = \left\lfloor \log_2\left(1+\frac{\gamma_{k,n}}{\Gamma}\right)\right\rfloor, \tag{4}$$

where $\Gamma = -\ln(5 \cdot BER_{MQAM})/1.5$ [9]. Then, the BS now selects a minimal number of subcarriers that can accommodate the required transmission data rate of each user. Therefore, the throughput of a given cell in the OFDMA downlink system can be estimated by the sum of total allocated bits per symbol, that is,

$$T = \sum_{k=1}^{K}\sum_{n=1}^{N} b_{k,n} \cdot \rho_{k,n}, \tag{5}$$

where $\rho_{k,n}$ is the assignment indicator of the n-th subcarrier to the k-th user [10]. That is, $\rho_{k,n}$ is equal to one if the n-th subcarrier is allocated to the k-th user; otherwise, $\rho_{k,n}$ is equal to zero.

III. Adaptive Hot-Spot Operating Scheme

Traffic concentration in certain areas, especially at a cell boundary, leads to the consumption of a chunk of radio resources, resulting in the reduction of system throughput. To address such problems, we propose a novel mechanism to utilize the picocells within a macrocell. Figure 1(b) shows the operation of the proposed AHOS conceptually. The macrocell BS estimates the total required number of subcarriers as

$$N_{req} = \sum_{k=1}^{K}\sum_{c=1}^{C}\left\lceil \frac{R_k^c}{\bar{b}_k \cdot W_{sub}}\right\rceil, \tag{6}$$

where C and R_k^c are the number of QoS classes and the required data rate of the k-th user designating the c-th QoS class, respectively, $\bar{b}_k$ is the average modulation efficiency in bps/Hz for the k-th user, and W_{sub} is the bandwidth of a subcarrier. Modulation efficiency $\bar{b}_k$ is adaptively determined according to the user location. That is, if the k-th user is located in an area where m-QAM is possible at maximum, then $\bar{b}_k$ becomes $\log_2 m$.

If a cell is temporarily overloaded according to the current set of QoS requirements, the number of users who are not provided with enough resources may increase. Here, we define the QoS outage probability, p_{outage}, which represents the probability that the users fail to achieve the required data rate, as

$$p_{outage} = E\left[\frac{1}{K}\cdot\sum_{k=1}^{K}\delta_k\right], \tag{7}$$

where $\delta_k = \begin{cases} 1 & \text{if } r_k < R_k^c, \\ 0 & \text{otherwise,} \end{cases}$

and r_k is the offered data rate to the k-th user.

In order to maintain the system performance regardless of the variation of traffic requests, it is important to estimate this overloaded situation in advance, and to control the picocell APs intelligently. In this paper, we propose to anticipate the overloaded situation by estimating a weighted difference between N_{req} and N, which is a function of the number of insufficient subcarriers. By dividing this estimate by the mean number of requested subcarriers per user, the number of possible outage users can be estimated. Accordingly, we further define the system overload estimate function for the picocell ON/OFF procedure as

$$D(N_{req}) = \left[\frac{1}{K}\cdot\left(\frac{N_{req}-\lambda N}{v_{avg}}\right)\right]^{+}, \tag{8}$$

where $[x]^{+}$ is defined as $\max\{x,0\}$, and ν_{avg} represents the mean number of requested subcarriers per user. Parameter λ is a sensitivity parameter in the range of [0, 1] to control the frequencies of the picocell ON/OFF procedures. With a smaller λ, $D(N_{req})$ becomes positive with smaller traffic concentration, so the picocell ON/OFF procedure tends to be operated more frequently to maintain system performance.

The QoS outage probability can sharply increase when the users are unexpectedly concentrated in a certain area, or many users at the boundary region request higher data rates. In order to mitigate such QoS outage probability even in the overloaded situation, the proposed AHOS can be operated as follows. We first define two thresholds, the upper threshold, ρ_{ON}, and the lower threshold, ρ_{OFF}, to control the AHOS, which can be optimized system by system by the designer. In real situations, however, these two parameters may be determined according to the target service quality of the service provider since the responsiveness of the system depends on the values. The AHOS is composed of two alternate procedures: a picocell ON procedure and picocell OFF procedure. If $D(N_{req})$ becomes larger than ρ_{ON} while increasing, the macrocell BS initiates the picocell ON procedure. On the other hand, if $D(N_{req})$ becomes smaller than ρ_{OFF} while decreasing, the BS activates the picocell OFF procedure. By designing an appropriate gap between the upper threshold and the lower threshold, the ping-pong effect between the picocell ON and OFF procedures can be avoided with an inherent hysteresis feature.

1. Picocell ON Procedure

In a case in which the traffic concentrates at a cell edge area, the macrocell BS needs to assign more subcarriers to support the same QoS since the channel gains of the users in the cell boundary are low. This results in an increase of the QoS outage probability. In this case, if the picocell APs at the cell boundary are turned on, nearby users expect higher channel gains, which enable a higher modulation level, so they need fewer subcarriers to get the same QoS. The number of subcarriers saved by turning on the picocell APs can now be assigned to the outage users, and this leads to the decrease of the QoS outage probability.

For the picocell ON procedure, the BS in the macrocell periodically estimates the system overload estimation function, $D(N_{req})$. If the estimate is larger than the given system upper threshold, the BS initiates the picocell ON procedure as follows.

A. Choosing the Picocells

In this step, the BS determines the set of picocells that should be turned on to maximize the system capacity. In order to choose the proper set of picocells, we define the AHOS gain index for each picocell, G_i, which indicates the number of subcarriers that can be saved to the macrocell by operating the i-th picocell as

$$G_i = u_i \cdot (v_{i,\max} - v_{i,\min}), \tag{9}$$

where u_i is the number of users in the i-th picocell, and $v_{i,max}$ and $v_{i,min}$ are the mean numbers of necessary subcarriers per user when the i-th picocell is dormant and when the i-th picocell is active, respectively.

The BS then selects the set of picocells in the descending order of the AHOS gains until ρ_{ON} is guaranteed. The following algorithm describes in detail the procedure for choosing the set of picocells to turn on. In the algorithm, P represents the number of picocells in a macrocell, d_i and $d_{k,i}$ are the radius of the i-th picocell and the distance from the i-th AP to the k-th user, respectively, $P_{s,i}$ represents the current status of the i-th picocell, $\tilde{P}_{s,i}$ is the suggested next status of the i-th picocell, and I_{OFF} is a set of picocells that are turned off.

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initialize: $I_{OFF} = \{i \mid P_{s,i} \neq 1\}$, and
        $\tilde{P}_{s,i} = P_{s,i}$, for all $i = 1, \cdots, P$
while $D(N_{req}) > \rho_{ON}$, and $I_{OFF} \neq null$,
    $U_i = null$, for all $i = 1, \cdots, P$
    for $i = 1:P$,
        for $k = 1:K$,
            $k' = \arg(d_{k,i} < d_i)$
            $U_i = U_i \cup \{k'\}$
        end
        $G_i = u_i \cdot (v_{i,\max} - v_{i,\min})$
        // $u_i = \|U_i\|$, the number of elements
    end
    $i_{\max} = \arg\max_{i \in I_{OFF}} G_i$
    $\tilde{P}_{s,i_{\max}} = 1$   //picocell ON
    $\tilde{N}_{req} = N_{req} - u_{i_{\max}}(v_{i_{\max},\max} - v_{i_{\max},\min})$
    $D(N_{req}) = D(\tilde{N}_{req})$
    $I_{OFF} = I_{OFF} - \{i_{\max}\}$
    $P_{s,i_{\max}} = \tilde{P}_{s,i_{\max}}$
end.
```

B. Resource Allocation between the Macrocell and the Picocells

The BS in the macrocell informs the chosen picocell APs of the users' information and the subcarrier indices that they should control. With this information, the picocells allocate the resources to the users. In the AHOS, two types of subcarrier allocation methods between the macrocell and the picocells are considered. Figure 2 represents these methods. In the optimal allocation method, which is fully centralized, the BS in the macrocell collects the channel state information and QoS requirements from all users, including the picocell users near the picocell APs. Then, the macrocell BS optimally allocates the subcarriers and informs each picocell AP of its own

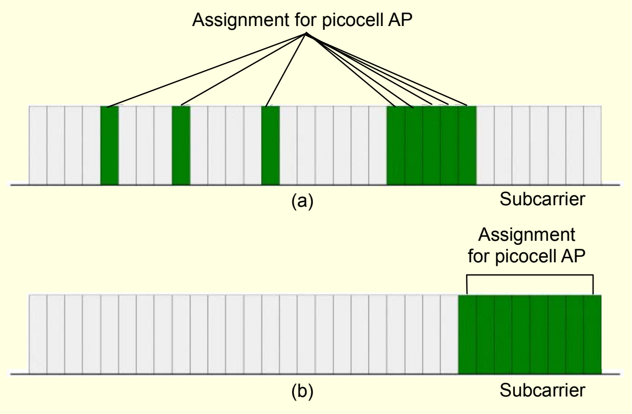

Fig. 2. Subcarrier assignment methods in the proposed scheme: (a) optimal allocation and (b) suboptimal allocation.

allocation table. Therefore, the entire range of subcarriers can be utilized by both the macrocell BS and the picocell APs, so that an optimal SINR can be obtained by each mobile station under the given CCI. The other method is a suboptimal allocation method that is semi-centralized. That is, the macrocell BS allocates a fixed chunk of contiguous subcarriers to the picocell APs, and then each picocell AP allocates subcarriers to the users within its own coverage, so the spectral diversity is limited.

For both the optimal allocation method and the suboptimal allocation method, the intracell interference between the macrocell BS and the picocell APs is negligible since the macrocell BS and the picocell APs share the subcarriers owned by the macrocell BS mutually and exclusively. The remaining interference still affecting the macrocell BS and the picocell APs in the downlink OFDMA system is the CCI from the neighboring cells.

2. Picocell OFF Procedure

Since the distribution of user locations and the mixture of QoS requirements are varying, some of the running picocells would rather be turned off under certain conditions. There are three cases to do so: 1) when the AHOS gain index, G_i, is zero, which implies that no one is in the hot-spot or that $v_{i,max}$ is equal to $v_{i,min}$, 2) when the user traffic is no longer concentrated at the cell edge area, so $D(N_{req})$ is smaller than the lower system threshold, ρ_{OFF}, and 3) when the picocell causes a significant CCI to the neighboring cells. Indeed, when a picocell is turned on near the edge of neighboring cells, it causes an additional interference for them. That is, the SINR in the neighboring cells are affected by the operating picocells in the edge of the reference cell. Then, the SINR of the n-th subcarrier for the k-th user in a neighboring cell can be described as

$$\gamma_{k,n} = \frac{P_{k,n} \cdot H_{k,n}}{I_{M,n} + I_{P,n} + \sigma_{k,n}^2}, \qquad (10)$$

where $I_{M,n}$ and $I_{P,n}$ are the aggregate interference from the neighboring macrocells to the n-th subcarrier and that from the nearby picocells, respectively. From (10), when $I_{P,n}$ becomes large, the performance is degraded because of the reduced SINR. In order to alleviate this problem, we add another procedure to turn off a picocell if the CCI resulting from the picocell is larger than a certain CCI threshold, T_{CCI}.

The algorithm for the picocell OFF procedure is described below. In the algorithm, T_i represents the CCI from the i-th picocell, and I_{ON} denotes a set of picocells that are turned on.

```
initialize: $I_{ON} = \{i \mid P_{s,i} \neq 0\}$, and
        $\tilde{P}_{s,i} = P_{s,i}$, for all $i = 1,\cdots,P$
for $i = 1:P$,
  if $P_{s,i} \neq 0$,
    if $G_i = 0$,
      $\tilde{P}_{s,i} = 0$ // picocell OFF
    else if $T_i > T_{CCI,}$
      $\tilde{P}_{s,i} = 0$ // picocell OFF
    end
    $P_{s,i} = \tilde{P}_{s,i}$
  end
end
while $D(N_{req}) < \rho_{OFF}$, and $I_{ON} \neq null$,
  $i_{\max} = \arg \max_{i \in I_{ON}} G_i$
  $i_{\min} = \arg \min_{i \in I_{ON}} G_i$
  $\tilde{P}_{s,i_{\min}} = 0$ //picocell OFF
  $\tilde{N}_{req} = N_{req} + u_{i_{\min}} (v_{i_{\min},\max} - v_{i_{\min},\min})$
  $D(N_{req}) = D(\tilde{N}_{req})$
  $I_{ON} = I_{ON} - \{i_{\min}\}$
  if $D(N_{req}) > \rho_{ON}$,
    $\tilde{P}_{s,i_{\min}} = 1$
    $\tilde{N}_{req} = N_{req} - u_{i_{\min}} (v_{i_{\min},\max} - v_{i_{\min},\min})$
    $D(N_{req}) = D(\tilde{N}_{req})$
  end
  $P_{s,i_{\min}} = \tilde{P}_{s,i_{\min}}$
  if $i_{\min} = i_{\max}$,
    break // to avoid infinite loop
  end
end.
```

A flow chart providing the description of the proposed AHOS is shown in Fig. 3. The overloaded situation is first estimated with the given QoS requirements and the information about the users. Comparing the thresholds with the overload estimation function, the proposed AHOS is adaptively operated according to the variation of the QoS requirements and the traffic distribution.

IV. Performance Evaluation

The performance of the AHOS has been evaluated with a typical OFDMA downlink system under a multipath fading channel described in the Pedestrian A model in [11]. We used MATLAB for the simulation on Pentium-IV personal computers with a Windows XP operating system. The developed software ran for about ten hours for each scenario. We have assumed that calls are randomly generated and that the mixture of service classes is continuously varying. Table 1 shows the simulation parameters in detail. In the table, the radii of the available region for the *m*-QAM such as d_{64QAM}, d_{16QAM} and d_{QPSK} are determined by the computer simulation. In this paper, we assume that there are three picocells in a macrocell. In the real world, the picocell APs are implemented in the places where users tend to concentrate. In order to evaluate the efficiency of the proposed algorithm, we compare it with a conventional algorithm that is defined as a general downlink OFDMA system without operating any picocell APs. This is denoted by 'w/o AHOS' in the figures.

Table 1. Simulation parameters.

FFT size		128
Number of picocells in a macrocell		3
Frequency reuse factor		1
Bandwidth per subcarrier		10 kHz
Modulation level		QPSK, 16QAM, 64QAM
Cell radius	Macrocell	1000 m
	Picocell	200 m
Sensitivity parameter, λ		0.9
Number of users		35
Transmit power (macrocell, picocell)		43 dBm, 33 dBm
Upper threshold, ρ_{ON}		0.1
Lower threshold, ρ_{OFF}		0.08
Service class (rate, BER)	Type 1 (c_1)	60 kbps, 10^{-3}
	Type 2 (c_2)	200 kbps, 10^{-4}
d_{64QAM}, d_{16QAM}, d_{QPSK}		350 m, 450 m, 1000 m

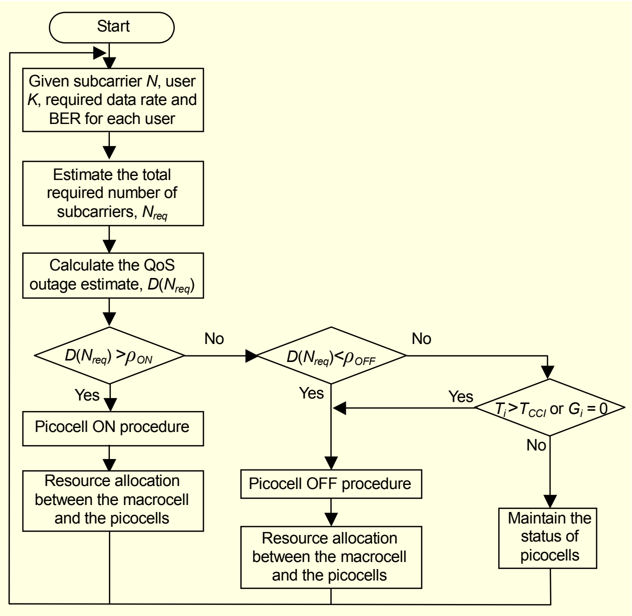

Fig. 3. Flow chart of adaptive hot-spot operating scheme.

Figure 4 shows the QoS outage probabilities according to the different sensitivity parameter values. The sensitivity parameter λ is related to how often the picocell ON/OFF procedures operate. With a smaller λ, the ON/OFF procedures are activated more frequently. If the picocell ON/OFF procedures operate too early, a significant bunch of subcarriers is allocated to the underutilized picocell APs, so the overall throughput decreases. If the picocell ON/OFF procedures operate too late, the users in both the macrocell and the picocells cannot be guaranteed with the required QoS.

Figure 5 describes the QoS outage probabilities in various scenarios. In the figure, the traffic concentration in the hot-spot regions represents the ratio of the aggregate data rate required by the users in picocells to the aggregate data rate required by

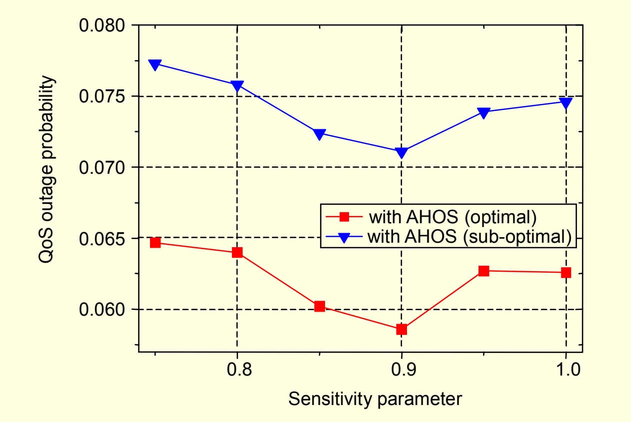

Fig. 4. QoS outage probability with various sensitivity parameter values.

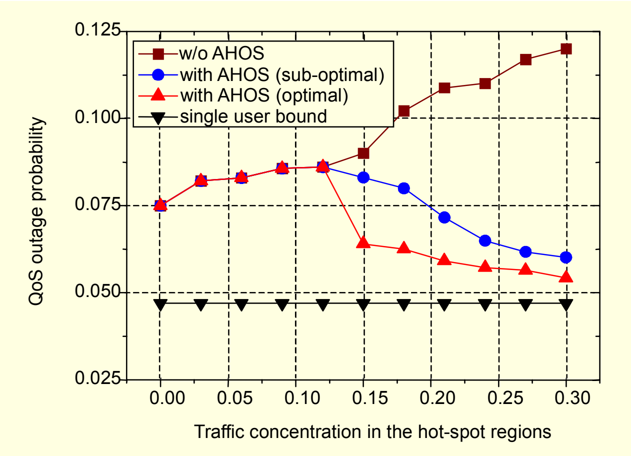

Fig. 5. Performance comparison of the QoS outage probabilities in a single cell environment.

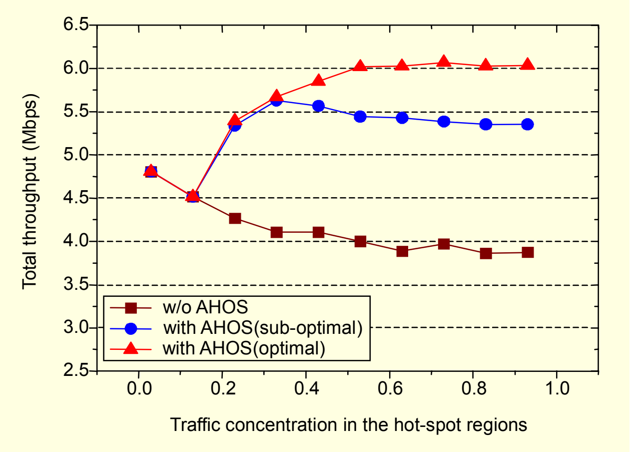

Fig. 6. Performance comparison of the system throughput in a single cell environment.

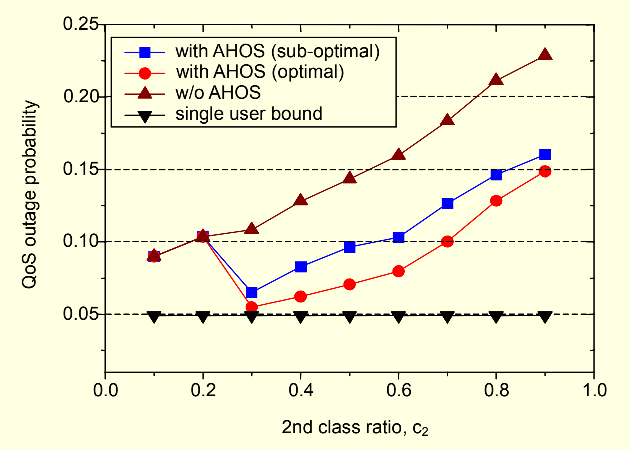

Fig. 7. Performance comparison of the QoS outage probability with various ratios of the QoS class type 2.

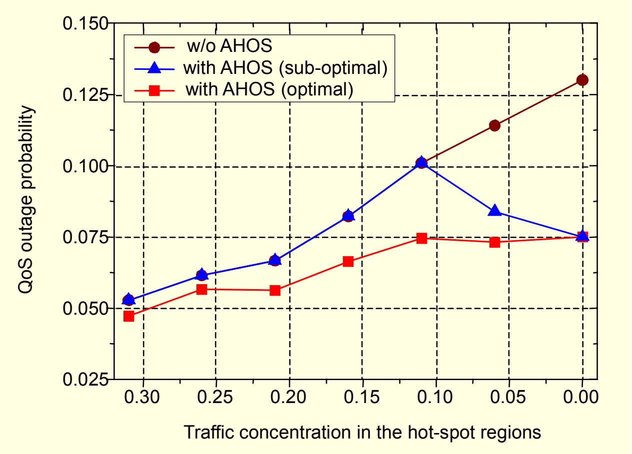

Fig. 8. Performance comparison of the QoS outage probability with the picocell OFF procedure in a single cell environment.

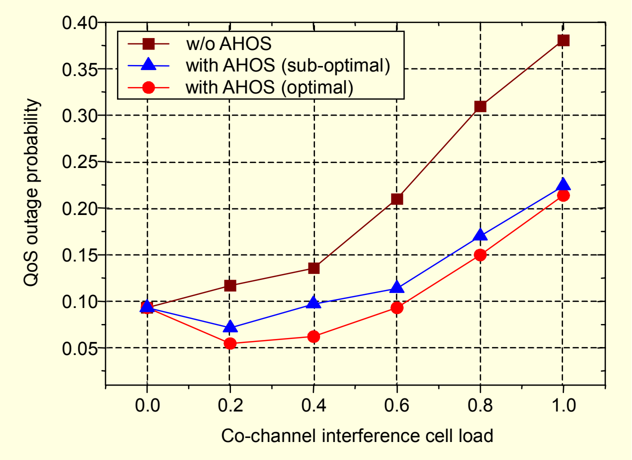

Fig. 9. Performance comparison of the QoS outage probabilities in a multicell environment.

total users. Even if the users tend to conglomerate in several hot-spots, the AHOS can adapt to the situation and maintains almost the same QoS outage probabilities. On the other hand, with a conventional algorithm, the QoS outage probability increases as the traffic concentration goes on. With the proposed AHOS, the picocells that are turned on take over the nearby users, so the required QoS of the users can be maintained. This means that the effective capacity of the system can be increased as much.

Figure 6 describes the improvement of the total system throughput by the AHOS system. As the level of traffic concentration in the hot-spots increases, the system throughput by the AHOS tends to increase while the throughput by the conventional algorithm decreases. In this case, the main contribution comes from the picocell ON procedure that extends the efficiency of subcarrier utilizations at an unexpected concentration of users. The performance of the suboptimal allocation method falls a little short of the performance of the optimal allocation method. However, it still gives enough gain over the conventional method with the advantage of lower complexity.

Figure 7 presents the QoS outage performance comparison according to the variation in the mixture of QoS requirements. As the ratio of the service class type 2 grows, the QoS outage probabilities increase. However, even though users who request higher data rate services increase, the QoS outage performance with the AHOS is maintained up to a certain point by operating the picocell ON procedure.

Figure 8 shows the QoS outage probability as the traffic concentration in the hot-spot is reduced. Picocells that are continuously operating in spite of the reduced traffic concentration near the area cause the system performance degradation. A macrocell user cannot have enough subcarriers because the operating picocells capture a certain amount of subcarriers. With the AHOS, however, since the picocell APs are adaptively turned off according to the traffic distribution,

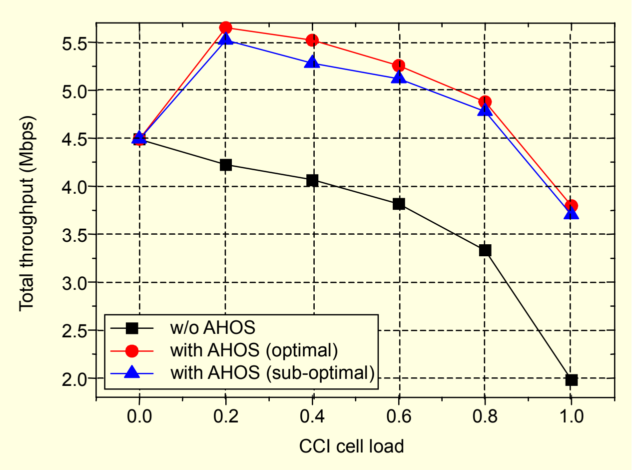

Fig. 10. Performance comparison of the system throughput in a multicell environment.

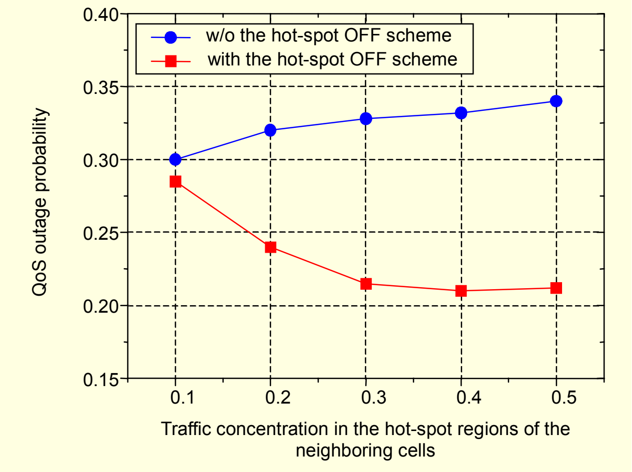

Fig. 11. Performance comparison of the QoS outage probability with the picocell OFF procedure in a multicell environment.

the QoS outage probability can be reduced under the system threshold.

In Figs. 9, 10 and 11, we extend our proposed scheme to a multi-cell environment. It is assumed that there are seven macrocells, and each macrocell is divided into three sectors.

Figure 9 shows the QoS outage probabilities by applying the AHOS in a multi-cell OFDMA system. In the multi-cell environment, the proposed AHOS can support the required QoS performance in the presence of the CCI. In Fig. 10, the total throughput under the existence of the CCI is evaluated. As the load in a neighboring CCI cell increases, the total throughput in the reference cell decreases, but quite an improvement in the total system throughput can still be achieved by applying the AHOS in the multi-cell environment.

In the multi-cell environment, picocells can become additional interferers. Sometimes the performance improvement in the reference cell can be reduced due to the severe CCI from the picocells in the neighboring cells. Figure 11 shows a performance evaluation under the situation in which a picocell in the reference cell is close to a picocell in a heavily loaded neighboring cell. The upper line indicates the QoS outage probability when the picocell in the neighboring cell is continuously turned on, and the lower line indicates the QoS outage probability when the picocell in the neighboring cell is turned off. In this case, the application of the picocell OFF procedure contributes to avoiding the performance degradation in the reference cell under heavy CCI interference from neighboring cells.

V. Conclusions

In this paper, we have developed the AHOS to mitigate the negative effects from the nonuniform distribution of user location and the variation in the mixture of QoS requirements in OFDMA downlink systems. In particular, we have defined the system overload estimation function to activate the picocells' ON/OFF procedures. If the value of the system overload estimation function is larger than the given upper threshold, the macrocell BS decides to operate any of the picocells. On the other hand, if it is smaller than the given lower threshold, or if the CCI to the neighboring cells by the operating picocell APs increases, the macrocell BS decides to turn some of the picocells off. With the AHOS gain indices, the BS in the macrocell can choose which picocell should be turned on or off to maximize the performance improvement. According to computer simulation, the AHOS has been proved to maximize system throughput while maintaining a very low QoS outage probability under various system scenarios in both single-cell and multi-cell environments.

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Nak-Myeong Kim received the BS degree in electronics engineering from Seoul National University, the MS degree in electrical engineering from Korea Advanced Institute of Science and Technology, and the PhD degree in electrical engineering from Cornell University in 1980, 1982, and 1990, respectively. From 1990 to 1996, he was a Principal Researcher at the Central Research Institute in LG Information and Communications, Inc. In 1996, he joined Ewha Womans University, Seoul, Korea, and he is currently an Associate Professor at the Department of Information Electronics Engineering. From 2003 to 2004 he was on leave as a visiting scholar at Samsung Advanced Institute of Technology, Kiheung, Korea. His research interests include 4G mobile communications, MIMO-OFDM systems, hybrid multiple access technologies, and cross-layer optimization. He is a member of IEEE, KICS, and IEICE.

Hye-Sun Choi received the BS and MS degrees in information electronics engineering from Ewha Womans University, Seoul, Korea in 2003 and 2005. She is currently an assistant engineer at Samsung Electronics Inc., Suwon, Korea. Her research interests include OFDMA resource allocation, hierarchical cellular networks, and 4G communication systems.

Hee-Jeong Chung received the BS and MS degrees in information electronics engineering from Ewha Womans University, Seoul, Korea, in 2004 and 2006. She is currently an assistant engineer at Samsung Electronics Inc., Suwon, Korea. Her research interests include hybrid division duplexing, OFDMA resource allocation, and time slot allocation in TDD systems.