수직적으로 겹쳐진 OFDMA 무선 시스템에서의 적응적 Hot-spot 운용 기법

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An Adaptive Hot-spot Operating Scheme in Vertically Overlaid OFDMA Wireless Systems

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요 약

OFDMA 하향링크 시스템에서 단말의 불균등한 위치 분포와 다양한 QoS 요구사항의 변화에 따라 시스템에 끼치는 부정적인 영향을 줄이기 위한 적응적 hot-spot 운용 기법에 대해 제안하였다. 매크로셀의 기지국은 셀 내 피고셀의 운용을 조절하며, 예측된 user outage probability와 AHOS 이득 파라미터 값에 의해 피코셀을 켜고 끄게 된다. 제안된 AHOS 기법은 다양한 시스템 환경에서 QoS outage probability를 유지하면서 시스템의 throughput을 최대화 시키는 이득을 보였다.

Key Words : hot-spot, OFDM, OFDMA, resource allocation, QoS.

ABSTRACT

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 OFDMA downlink systems. The base station in a macrocell can control the operation of picocells within the cell, and turns on or off according to the changes in the estimated user outage probability and the AHOS gain parameter. With the computer simulation, the AHOS has been proved to maximize the system throughput while maintaining the QoS outage probability very low under various system scenarios.

Ⅰ. Introduction

To accommodate an increasing demand of high data rate transmission among many subscribers, the orthogonal frequency division multiple access (OFDMA) is considered as one of the promising 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 researches on efficient resource allocation algorithms to mitigate the CCI among nearby cells[1][2][3][4].

Adaptive modulation is usually known as a meth-

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od to maximize the system throughput. However, one of the problems of 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 spectral efficiency is much reduced. Abrupt changes in traffic demand according to the concentration of users in a certain area cause further degradation of system capacity. In order to support the QoS of the users at the cell edge area, more resources are required, so the inter-cell interference increases. In [8], the Multi-hop Radio Access Cellular (MRAC) scheme is proposed to achieve both the high capacity and the good coverage area. By setting up the two kinds of hop stations which are a dedicated repeater station and a user terminal, the transmit power of the mobile stations located at the cell edge area is effectively reduced. However, it is not easy to find a appropriate mobile station as a hop station, and the fast moving mobile station could not achieve the performance enhancement.

To mitigate negative effects from the nonuniform distribution of user locations and the variation in the mixture of quality of service(QoS) requirements, we propose an adaptive hot-spot operating scheme(AHOS) in OFDMA downlink system. The AHOS addresses a hierarchical cellular system structure, in which the macrocell base stations can control the operations of picocells within the cell area. The macrocell base station(BS) continues to estimate the resource utilization and the user outage probability in addition to the user locations and the traffic characteristics. Then it utilizes such information to turn on and off the access points(AP) serving the picocells.

The rest of the paper is organized as follows. In section II, the system model considered is described. Section III describes the proposed AHOS in detail, and then section IV discusses the performance of the AHOS. 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. Fig. 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 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 is perfectly known to BSs and MSs. 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. Assuming that M-QAM is applied for the adaptive modulation, the BER for each subcarrier can be approximated by.

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

where L is defined as $\sqrt{M}$ [5]. For $b_{k,n} \geq 2$ and $\mathrm{BER} \leq 10^{-3}$, (1) can be further approximated by

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

where $b_{k,n}$ and $\gamma_{k,n}$ are the number of bits and the received SINR for the nth subcarrier of the kth user, respectively[6]. Rearranging this notation, the maximum number of bits to transmit is

$$b_{k,n} = \left\lfloor \log_2\left(1+\frac{\gamma_{k,n}}{\Gamma}\right)\right\rfloor, \quad (3)$$

where $\Gamma = -\ln(5\mathrm{BER})/1.5$. Then, the BS should select a minimal number of subcarriers which can accommodate the required transmission data rate of each user. Therefore, in the OFDMA system the throughput of a given cell can be estimated by the sum of total allocated bits per symbol, that is, the total throughput can be defined as

$$T = \sum_{k=1}^{K}\sum_{n=1}^{N} b_{k,n}. \quad (4)$$

Ⅲ. Adaptive Hot-spot Operating Scheme

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

$$N_{req} = \sum_{k=1}^{K}\sum_{c=1}^{C}\left\lceil \frac{R_k^c}{\bar{b}_k \cdot W_{sub}} \right\rceil, \quad (5)$$

where C and R_k^c are the number of QoS classes and the required data rate of the kth user requesting the cth QoS class, respectively. $\bar{b}_k$ is the average number of loaded bits on a subcarrier for the kth user, and W_{sub} is the bandwidth of a subcarrier.

When the users are unexpectedly concentrated in a certain area or users at the boundary region request a high data rate, the AHOS tries to locate appropriate picocell APs to serve the specific area. On the other hand, if any concentrated area has been recovered or the CCI from the neighboring cells makes it hard to maintain high performance at the active picocells, the BS tries to turn them off. We define the QoS outage estimation function, $D(N_{req})$, as

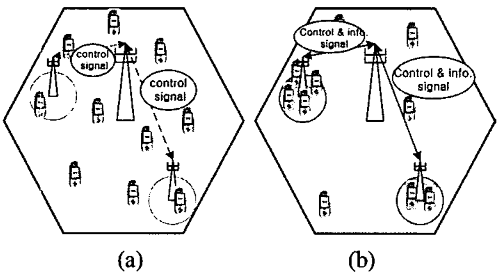

Fig. 1. Adaptive hierarchical cellular architecture; (a) with dormant hot-spot; (b) with active hot-spot

$$D(N_{req}) = \frac{N_{req} - \lambda N}{K \cdot v_{avg}}, \quad (6)$$

where λ is a control parameter, and v_{avg} represents the mean number of requested subcarriers per user. We further define two thresholds, the upper threshold ρ_{on} and the lower threshold ρ_{off}, to control the anticipated QoS outage probability. If $D(N_{req})$ is larger than ρ_{on}, the macrocell BS initiates the picocell ON procedure, which is described below. On the other hand, if $D(N_{req})$ becomes less than ρ_{off}, the BS activates the picocell OFF procedure.

3.1 Picocell ON procedure

The QoS outage probability which the BS in the macrocell periodically estimates is defined as the probability that users do not get the required minimum data rate. If the estimated user outage probability is larger than the given system upper threshold, the BS initiates the picocell ON procedure as follows.

3.1.1 Choosing the picocells

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

$$G_i = u_i \cdot v_{\max} - u_i \cdot v_{\min}, \quad (7)$$

where u_i is the number of users in the ith picocell, and v_{max} and v_{min} are the mean numbers of necessary subcarriers per user, when the picocell is dormant and when the 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, and d_i and $d_{k,i}$ are the radius of the ith picocell and the distance from the ith AP to the kth user, respectively. $P_{s,i}$ represents the current status of the picocell, and $\tilde{P}_{s,i}$ is the suggested next status of the picocell.

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

3.1.2 Resource allocation between the macrocell and the picocells

The BS in the macrocell informs the chosen picocells of the users' information and the subcarrier indices that they should control. With theses information the picocells allocate the resources to the user. In the AHOS, two types of subcarrier allocation methods between the macrocell and the picocells are considered.

Fig. 2 represents these methods. In an optimal allocation method which is fully centralized, the BS in the macrocell receives the channel state information of the picocell users. The macrocell BS coordinates with the picocell APs to assign the resource to the users in the macrocell and the picocells, so the entire range of subcarriers can be used by the picocells. It means that spectral diversity can be fully achieved. Another one is a suboptimal allocation method which is semi-centralized. The macrocell BS only informs the picocell APs of a fixed number of contiguous subcarriers they can use. The resources for the picocell users are assigned within the allocated part of subcarriers, so multiuser diversity is limited.

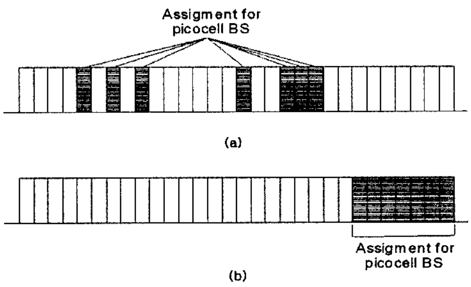

Fig. 2. Subcarrier assignment methods in the proposed scheme; (a) optimal allocation; (b) sub-optimal allocation

After allocating resources for each user, the QoS outage probability can be calculated. The QoS outage probability, P_{out}, which is the probability that users do not get the required data rate, is defined as

$$P_{out} = \Pr[r_k < R_k^c], \quad (8)$$

where r_k is the offered data rate for the kth user.

3.2 Picocell OFF procedure

Since the distribution of user location and the mixture of QoS requirements are varying, some of the running picocells would rather be turned off under certain conditions. There are three sources to do so; 1) the AHOS gain parameter G_i is zero, which implies that no one is in the hot-spot, 2) the users are uniformly distributed in the entire macrocell, so $D(N_{req})$ is less than the lower system threshold, ρ_{off}, and 3) the performance improvement by operating picocells is not expected anymore due to the significant CCI from neighboring cells. The algorithm for the picocell OFF procedure is described below. In the algorithm, T_i represents the CCI from the ith picocell, and T_{CCI} denotes the CCI threshold.

Initialize : $I_{ON}=\{i \mid P_{s,i} \neq 0\}$ and $\tilde{P}_{s,i}=P_{s,i},\ i=1,\ldots,P$
for $i=1:P$
  if $P_{s,i} \neq 0$
    if $T_i > T_{CCI}$, then $\tilde{P}_{s,i}=0$ // picocell OFF
    else if $G_i = 0$, then $\tilde{P}_{s,i}=0$ // picocell OFF
    else if $D(N_{req}) < \rho_{OFF}$
      $i_{\min} = \arg\min_{i \in I_{ON}} G_i$
      $\tilde{P}_{s,i_{\min}} = 0$ // picocell OFF

$\tilde{N}_{req} = N_{req} + u_{i_{\min}}(v_{\max} - v_{\min})$
$D(N_{req}) = D(\tilde{N}_{req})$
$I'_{ON} = I_{ON} - \{i_{\min}\}$
if $D(N_{req}) > \rho_{ON}$, then $\tilde{P}_{s,i_{\min}} = 1$
end
end
end
$P_{s,i} := \tilde{P}_{s,i}$

Ⅳ. Performance Evaluation

The performance of the AHOS has been evaluated with an OFDMA downlink system having 128 subcarriers. We assume the frequency reuse factor is 1, and there are three picocells in one macrocell. For the adaptive modulation, QPSK, 16QAM and 64QAM are applied. Two types of QoS classes are assumed. In type1, the data rate is 60kbps and the required BER is 10^{-3}. Type2 requires 200kbps and BER of 10^{-4}. The simulation was performed under a multipath fading channel described in Pedestrian A model in [7]. In the figures, the traffic concentration in hot-spot as the horizontal axis means that how many subcarriers are utilized in the hot-spot.

Fig. 3 shows the QoS outage probabilities according to the different tuning parameter values. The tuning parameter, λ, affects the frequency of the ON/OFF operations. With smaller λ, the ON/OFF operations happen more frequently. If the picocell ON/OFF procedures operates too early or too late, the users both in the macrocell and in the picocells can not be guaranteed the QoS.

Fig. 4 describes the QoS outage probabilities in various senarios. Even if the users tend to conglomerate in several hot-spots, the AHOS can adapt the situation and maintains almost same QoS outage probabilities. On the other hand, with the conventional algorithm, the QoS outage probability increasesas the traffic concentration goes on. With the proposed AHOS, the picocells which 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.

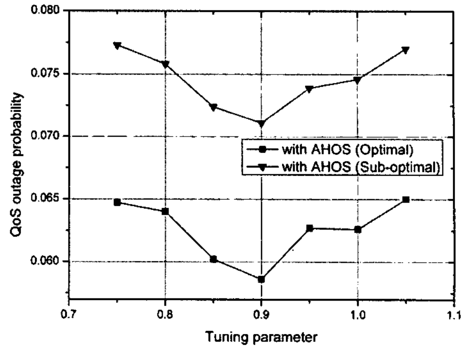

Fig. 3. The QoS outage probabilities with the various tuning parameter values when K=35, $Wsub$=10kHz and ρon=0.1

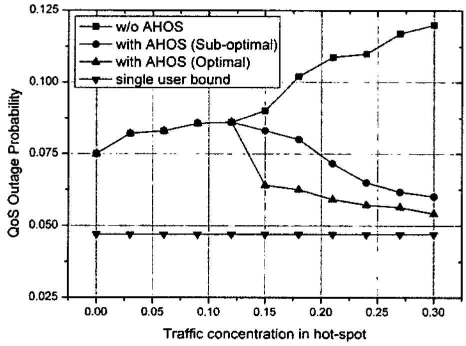

Fig. 4. Comparison of the QoS outage probabilities when K=35, $Wsub$=10kHz and ρon=0.1

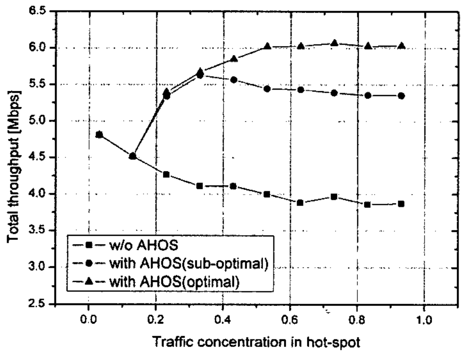

Fig. 5. Comparison of the total system throughput when K=35, $Wsub$=10kHz and ρon=0.1

Fig. 5 depicts the improvement of the total system throughput by the AHOS system. As the level of traffic concentration in hot-spot increases, the system throughput by the AHOS increases to the limit whereas the throughput by the conventional algorithm decreases. In this case, the main contribution comes from the picocell ON procedure which extends the efficiency of subcarrier utilizations at unexpected concentration of users. The performance of the suboptimal allocation method falls a little short of the performance of the optimal allocation method, it still gives enough gain over the conventional method with the advantage of less complexity.

Fig. 6 presents the performance improvement with the variation in the mixture of QoS requirements. p_1 and p_2 describes the ratio of the QoS class type1 and type2, respectively. The QoS outage probabilities of the AHOS are decreased at p_2=0.2 and then increased again as the ratio of the service class type2 is growing. But the outage probability with the optimal AHOS and that with the suboptimal AHOS is less than the upper threshold, ρ_{on}, until p_2=0.7 and 0.55, respectively.

Fig. 7 shows the QoS outage probability as the traffic concentration in the hot-spot is reduced. Continuously operating picocells in spite of the reduced traffic concentration in the hot-spot causes

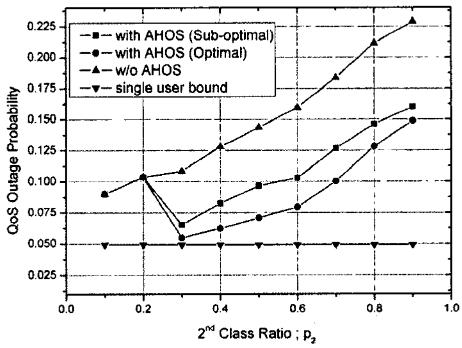

Fig. 6. QoS outage probabilities of the proposed schemes versus the ratio of service class type2 when K=35, $Wsub$=10kHz and ρ_{on}=0.1

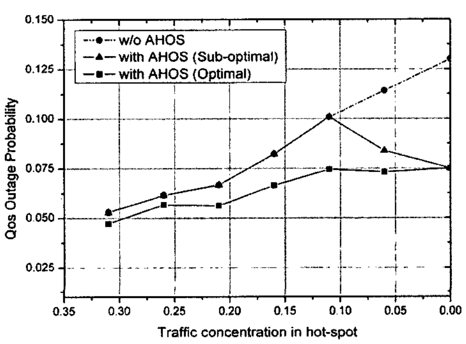

Fig. 7. QoS outage probabilities of the proposed schemes with the picocell OFF procedure when K=35, ρ_{off}=0.08 and p_1=0.7

system performance degradation. The macrocell user cannot have enough subcarriers because the picocells capture a certain amount of subcarriers. With the AHOS, the QoS outage probabilities start getting lower by initiating the picocell OFF procedure when the traffic concentration in the hot-spot is 0.1. However, the outage probability without the AHOS becomes deteriorated.

In Fig. 8, 9 and 10, we extend our proposed scheme to the multicell environment. In the multicell environment, since the influence of the co-channel interferers is large, the criterion of QoS outage probability is also changed. In the simulation, the macrocell is sectorized into three to alleviate the CCI.

Fig. 8 compares the QoS outage probabilities with the AHOS and that without the AHOS in the multicell OFDMA system. The outage probabilities with both the optimal AHOS and the suboptimal AHOS outperform that without the AHOS. It is verified that our proposed scheme is not only working in a single cell, but also applicable in the multi-cell environment.

In fig. 9, the total throughput under the existence of the neighboring cells generating CCI is considered. The total throughput decreases with the increase of the CCI cell load, but there are the improvement of the throughput by the AHOS system. With the influence of the CCI, the total throughput under the multicell environment is less than the that under the single cell environment.

In the multicell environment, the picocells in the neighboring cells act as additional interferers.

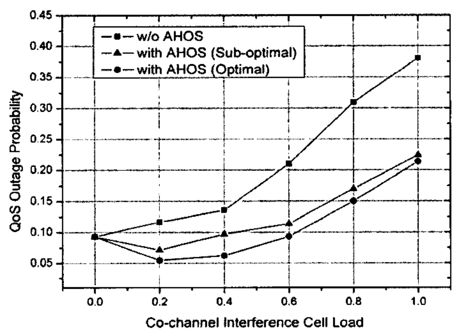

Fig. 8. The QoS outage probabilities with the various tuning parameter values when K=35, $Wsub$=10kHz and ρ_{on}=0.1

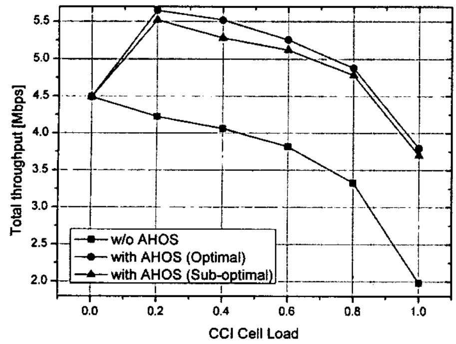

Fig. 9. Comparison of the total system throughput when K=35, $Wsub$=10kHz and pon=0.1

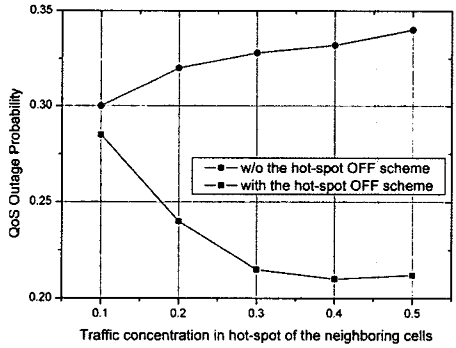

Fig. 10. QoS outage probabilities between with the hot-spot OFF procedure and without the hot-spot OFF procedure in the multicell OFDMA system when load=1 and p_l=0.7

Sometimes the performance improvement is not expected by operating picocells in the reference cell due to the severe CCI from the picocells in neighboring cells. In that case, operating the picocell OFF procedure is better choice to avoid the performance deterioration. Fig. 10 shows the performance evaluation under this situation. The solid line is the QoS outage probability when the picocell is turned off according to the amount of CCI. And the dotted line indicates that the picocells in the reference cell are continuously turned on even though CCI is considerable. The solid line is much better than the dotted line.

This is why the picocells ON/OFF schemes are adaptively working instead of always turning the picocells on.

V. Conclusion

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 define the determination function to turn the picocells on and off. If the value of the determination 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, the macrocell BS decides to turn any of the picocells off. With the AHOS gain parameter, the BS in the macrocell can choose which picocell should be turned on and off to maximize the performance improvement. According to the computer simulation, the AHOS has been proved to maximize the system throughput while maintaining the QoS outage probability very low under various system scenarios in both a single cell environment and the multicell environment. In the comparison the QoS outage probabilities and the throughput between with the AHOS and without the AHOS, it is verified that the proposed AHOS offers better performance

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