Link Capacity Improvement by Utilizing Overlaid Bandwidth and Region Division

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Abstract—A cell planning and resource allocation scheme for improving channel capacity and for maintaining QoS (quality of service) over a downlink OFDMA (Orthogonal Frequency Division Multiple Access) system is proposed. The frequency overlay is applied to improve link capacity and the sectorization is reduce the influence of carrier collision. This consideration enhances link capacity of system with a proper outage probability.

I. INTRODUCTION

For ever-increasing demand of wireless multimedia services, an efficient use of radio resources for the maximization of channel capacity remains a major issue for the system design. An effort to increase channel capacity, a FRF (frequency reuse factor) of 1 is typically used for OFDMA (orthogonal frequency division multiple Access)-based wireless networks. However, even if the link capacity is greatly improved near the BSs (base stations), the influence of ICI (intercell interference) become larger in the vicinity of the cell boundary so that the system performance can be severely degraded in the cell border region [1]. Therefore, it is necessary to develop cell planning and resource coordination techniques for guaranteeing the QoS (quality of service) at the cell boundary.

As a strategy in multi-cell environments, inter-cell coordination schemes have been presented by using power allocation, sectorization and reuse partitioning. The power allocation scheme assigns a power to each subcarrier or subband for OFDMA-based wireless networks in order to reduce the amount of ICI and to maximize SINR (Signal to Interference plus Noise Ratio) [2]. The sectorization scheme assigns a subband into each sector using the directional antennas in order to reduce ICI. This scheme has been widely used for maintaining the QoS, especially at the cell boundary due to a decrease in the number of interferers [3]. In the reuse partitioning scheme, each cell is divided into two regions (inner and outer), and a subband is then allocated to each region by designing frequency pattern over multi-cell environments [4]. In an effort to increase link capacity and to reduce ICI, recently studies incorporates the advantages of those schemes.

In this paper, we suggest a technique that would allow a better QoS and a higher link capacity by combining power allocation, sectorization and reuse partitioning. To improve link capacity, an FRF of 1 is used for the system. The cell is divided into the inner and outer regions and resource allocation is then performed for each region to increase the frequency efficiency based on reuse partitioning. The proposed resource allocation technique would permit enhanced link capacity with maintaining the QoS under limited resource conditions.

II. THE PROPOSED SCHEME

A. Description of the Proposed Scheme

The proposed scheme would allow an improved throughput using reuse partitioning, power allocation and sectorization under limited resource conditions. We design the system...
with an FRF of 1 to improve link capacity. In addition, the mitigation of ICI is issued to guarantee the QoS.

As shown in Fig. 1 (a) and (b), the cell is first divided into the inner and outer regions according to the distance from the BS. Each region has a different resource allocation strategy due to sensitivity to the ICI. As shown in Fig. 1 (c), the separated frequency bands, inner and outer bands, assigned to each region. The inner band with the half power is assigned to the users of the inner region because the attenuation by the distance is lower. However, the users at the cell border are assigned the outer band with a full power due to more attenuation by the distance. The dynamic power allocation can improve channel capacity using an adaptive power allocation to each user though the complexity and load of the system is increased by collecting the channel information. Thus, with fixed power allocation, a different power is allocated to only the inner and outer regions without increasing the complexity of the system.

The inner region is divided into 6 sectors in Fig. 1 (a). Each sector is allocated to the sub-bands A1, A2, \ldots, C2 of the inner band. In addition, the outer region is divided into 3 sectors and the sub-bands α, β, γ of the outer band are assigned into each outer sector. The number of the interferers is decreased by the sectorization.

We can improve the link capacity of the system using the surplus power that is an unused part for the inner band because the inner band supports the service with the half power band. In this paper, this scheme is defined by the frequency overlay. The surplus resource of the inner band is called by the overlaid band.

The signal power of the overlaid band hardly reaches the user of the cell boundary due to its lower power that is remains of the inner band. Thus, the proper use of the overlaid band is assigned to the user near to the BS. The overlaid band is divided into 6 sectors, a1, a2, \ldots, c2, like as the inner band in Fig. 2 (b) and then allocated into each sector of the inner region in Fig. 2 (a). The inner band of A1 uses the same band with the overlaid band of a1. The capitals, as A, B and C, stand for the inner band while the small letters, as a, b, and c, represent the overlaid band.

If each sector of the inner region uses the same frequency sub-band of the overlaid band as the sub-band of the inner band, the intra-cell interference would be produced. Thus, the sub-band of the overlaid band is assigned to the sector with the other frequency sub-band of the inner band. The increase of the ICI with the intra-cell interference is controlled through assigning an overlaid sub-band to each sector that is unused the same frequency sub-band. As shown in Fig. 3, this band allocation pattern avoids an increase in the ICI by controlling the number of interferers. The proposed system gets the enhancement effect of the link capacity using the overlaid band.

B. Problem Definition

Region division is accomplished as a function of the radius $r$. For band division, let $W$ is the entire bandwidth and $\psi$ is the ratio of the outer band for entire band as shown in Fig. 1(c). The optimal radius $r^*$ and outer band ratio $\psi^*$ are obtained using the maximum value of $r$, $\psi$ form the perspective of maximum throughput. Thus, for a given target outage probability $P_{\text{out},t}$, the optimal $r^*$ and $\psi^*$ are obtained by using a joint-optimization problem for maximizing the spectral efficiency subject to outage constraint.

$$\max_{r, \psi} \sum_x C(r, \psi) \quad (1)$$

subject to

$$0 \leq r \leq 1, \quad 0 \leq \psi \leq 1, \quad P_{\text{out}} \leq P_{\text{out},t}$$

where $C(r, \psi)$ is the link capacity with $r$ and $\psi$, and $P_{\text{out}}$ is the average outage probability at position $x$.

III. MATHEMATICAL ANALYSIS

A. Loading factor Definition

Let $N^i$ is the total number of subcarriers, $N^u$ is the number of subcarriers allocated to a single user, $N_j$ is the number of users assigned to $j^{th}$ cell. The loading factor of the $j^{th}$ cell can be expressed by

$$\rho_j = \frac{N^u N_j}{N^i} \quad (2)$$

Since the loading factor of each cell is mutually independent, the collision probability between the $i^{th}$ and the $j^{th}$ cell can be expressed by

$$\rho_{ij} = \rho_i \rho_j \quad (3)$$

B. Interference calculation

The path-loss between an MS located in an “$x$” position of the $i^{th}$ BS, i.e., the home BS, and an $j^{th}$ adjacent BS of the $i^{th}$ BS is given by

$$L(i,x;j) = d_{(i,x;j)}^{-l} 10^{\xi(i,x;j)} / 10 = d_{(i,x;j)}^{-l} \chi(i,x;j)$$

where $l$ is the path-loss exponent (typically 3 to 4), $d_{(i,x;j)}$ is the distance between $x$ in the $i^{th}$ BS and $j^{th}$ BS, $\xi(i,x;j)$ is a Gaussian distributed random variable with a zero mean and a standard deviation representing the shadowing and $\chi(i,x;j)$ is a lognormally distributed random variable. Typically, the standard deviation of $\xi$ is in the range of 6-10 dB (2-2.5dB) for signals from adjacent (home) BSs.
Two cases are considered rely on the distance between the home BS and the MS. If the MS is closer than the inner radius \( r_1 \), it is belong to the inner region. However, if it is not, the MS is belong to the outer region. The inner radius \( r \) and the outer band ratio \( \psi \) are decided with the outage constraint. Denote \( J^P \) as the index set of the interferer for region \( p \) (\( p \) is \( \text{in} \) or \( \text{out} \)). \( E_b/N_0 \) of the MS on \( x \) in region \( p \) of \( i^{th} \) cell is given by

\[
\left( \frac{E_b}{I_0} \right)_{i,p,x} = \frac{S_p \cdot L(i,x,i) \cdot \rho_{ij}}{\sum_{j \in J^P} S_p \cdot L(i,x,j) \cdot \rho_{ij}} \cdot \frac{W_b}{R} \tag{4}
\]

where \( S_p \) is the transmit power for a user assigned to the region \( p \), \( N_0 \) is the power spectral density of AWGN (Additive White Gaussian Noise), \( W_b \) is is the bandwidth and \( R \) is the data rate. Here, the noise density is negligible if the interference power is significantly greater than \( N_0 \).

From (4), the ISR (Interference to Signal Ratio) at the \( x \) in the \( i^{th} \) cell are

\[
\hat{I}_{i,p,x} = \sum_{j \in J^P} \frac{S_p \cdot L(i,x,j) \cdot \rho_{ij}}{S_p \cdot L(i,x,i)} = \sum_{j \in J^P} \left( \frac{r_{i,x,j}}{r_{i,x,i}} \right)^4 \cdot 10^{\hat{I}_{i,x,j}/10} \cdot \rho_{ij} \tag{5}
\]

\[ C. \text{ Outage Probability} \]

The outage probability at the position is defined by

\[
P_{\text{out}}(i,p,x) = P \left( \frac{E_b}{I_0} \right)_{i,p,x} < \delta \]  \[ \tag{6}\]

where \( \delta \) is the target \( E_b/N_0 \).

Using (4), (5) and (6) becomes

\[
P_{\text{out}}(i,p,x) = P \left( \hat{I}_{i,p,x} > \frac{W_b}{\delta R} \right) \tag{7}\]

where \( v_{th} = \frac{W_b}{\delta R} \) for the MS at \( x \) assigned to the region \( p \).

The cdf (cumulative distribution function) of \( \hat{I}_{i,p,x} \) can be approximately obtained by using the Wilkcinson approximation where the sum of lognormal random variables becomes a lognormal random variable [5].

Using the derivation in [6], the outage probability can be represented by

\[
P_{\text{out}}(i,p,x) = \frac{1}{\sqrt{2\pi \sigma_z}} \int_{v_{th}}^{\infty} \frac{1}{t} \cdot e^{-\left( \ln t - m_z \right)^2/2\sigma_z^2} dt \tag{8}\]

where \( \sigma_z^2 \) and \( m_z \) are the variance and mean of \( \hat{I}_{i,p,x} \).

To analyze the capacity of the OFDMA system, the formula of Shannon capacity is used. Using Jensen’s inequality, the upper bound of the capacity is given by

\[
\hat{C}_{i,p,x} = N_W \cdot W_b \cdot \rho_i \cdot \log \left( 1 + \frac{1}{E \left[ \hat{I}_{i,p,x} \right]} \right) \tag{9}\]

IV. NUMERICAL RESULT

For the performance analysis, it is assumed that all MSs are uniformly distributed over the network, the frequency reuse factor is 1. And the each user is connected to the closest BS. The total number of subcarriers is 1024 and the number of users is 40. The number of subcarriers assigned to each user is 32 or 16 according to the inner or outer region. The target SINR is 4dB. The optimal pair of the radius and the band ratio is obtained by maximizing the sum capacity by (1) subject to the target outage probability of 0.10. The optimal pair is \( r^* = 0.70 \) and \( \psi^* = 0.60 \) under constraints. Using these parameters, an optimal cell region and band division can be achieved.

In Fig. 4, the link capacity between the proposed system and the 3-sectorized system is compared according to the normalized distance. The proposed system accomplishes a higher link capacity than the 3-sectorized system at the inner region. The enhancement of the link capacity is attributed to an increase of subcarrier by reuse of surplus resource at the inner region. However, the link capacity is the same with the 3-sectorized system because the frequency overlay is not applied to the outer region.

As shown in Fig. 5, the outage probability of the proposed
system is lower than the target outage probability over the outer region although that of the proposed system is higher than that of the 3-sectorized system at the vicinity of the inner region boundary. The collision probability of the outer region on the proposed system is 0.18 while that of the 3-sectorized system is 0.39. Because the proposed system uses the 3-sectorization on the outer region with a lower collision probability, the proposed system maintains a relatively lower outage probability for users of the cell boundary. Thus, the QoS of the proposed system is guaranteed with a low outage probability. In general, the proposed system effectively improves the link capacity with constrained interference by using an unequal resource allocation strategy according to the region of an user.

V. CONCLUSION

In this paper, the proposed link capacity enhancement technique is presented by the frequency overlay based on power allocation, especially in the inner region. In order to maintain QoS, sectorization is combined with reuse partitioning based on the frequency overlay. For the performance analysis, this paper introduces a mathematical approach for the link capacity and the outage probability of OFDMA system over multicell environment. The optimal radius for the region partition and the band ratio for resource allocation is obtained using mathematical approach. Due to effective resource allocation, the proposed scheme technique achieved an improved channel capacity with overcoming the influence of the ICI.

REFERENCES