Cell Configuration Strategy for OFDMA Based Hierarchical Cell Structure

Eunsung Oh
Department of Electronics Engineering, Hanseo University, Korea, 360-706
(e-mail: esoh@hanseo.ac.kr)

Abstract. This paper presents cell configuration strategies for orthogonal frequency division multiple access (OFDMA) based hierarchical cell structure (HCS) downlink systems. It is considered that HCS systems are used to extend the data rate coverage. The cell configuration strategy problem is formulated with spectral reuse planning and channel allocation constraints, and is proposed the solution. The numerical results show that the proposed algorithm can enhance the system performance of HCS systems.

Keywords: Cell configuration, hierarchical cell structure, orthogonal frequency division multiple access, resource allocation.

1 Introduction

Wireless communication systems recently provide multimedia services such as voice, video streaming and high-speed Internet access, etc. These services require high data rate wireless communications. To provide various high data rates services in the same location, it is preferable that some macro-cells overlay other microcells [1]. This cellular structure is called the overlaid cell structure or hierarchical cell structure (HCS) [2].

In HCS systems, UEs with different characteristics (i.e., mobility, required traffic, etc.) are initialized at different cells. Therefore, to enhance the system performance, the efficient cell configuration strategy is required in HCS systems [3].

It has been researched about the cell configuration algorithms [4] and the frequency planning [5] in HCS systems. Prior works have shown that the HCS system can enhance the system capacity. However, proposed strategies are based on the heuristic approach. In addition, most of the schemes are proposed based on the coordinated cell configuration across cells with several practical challenges.

In this paper, the cell configuration strategy is established for the total transmitted data rate maximization in HCS downlink systems. Firstly, the optimization problem for maximizing the total transmitted data rate is formulated. Using some assumptions, the optimal cell configuration strategy is proposed for the total transmitted data rate maximization. The control strategy is researched with partial channel state information (CSI).
2 System Model and Problem Formulation

2.1 System model

It is considered a system that its service area is divided into hexagonal macro-cells of equal size with the base station (BS) at the center of each macro-cell, and micro-cells are overlaid on each macro-cell service area. Macro/micro-cells use same frequency assignment (FA). The subcarrier space is divided into successive groups. A subchannel has one element from each group allocated. Subchannels are randomly allocated to each UE. It is assumed partial CSI at the BS and perfect CSI at the UE. The best serving cell selection is considered that each UE is served by the BS which has the maximum signal strength. Let the sets of macro/micro BSs be $B_1$ and $B_2$, and the UEs served by macro-cells and micro-cells is presented as $U_1$ and $U_2$, respectively.

2.1 Problem formulation

Assuming the homogeneous system, the objective function for the total transmitted data rate is calculated as

$$f(R) = \sum_{u \in U_1} R_u + \sum_{u \in U_2} R_u$$

where $R_u$ [bits/sec] is the transmitted data rate of a UE $u$. The transmitted data rate is modeled by the Shannon capacity as,

$$R_u = BW \log_2 \left(1 + \frac{g_u}{n_u} \right)$$

where $n_u$ is the number of subchannel allocated to a UE $u$, $BW$ is the system bandwidth, and $g_u$ is the transmitted SIR of a UE $u$, which is calculated as

$$g_u = \frac{G_u P_{\text{Tx}}}{{\sum_{i \in B_1} G_{ub} P_{i1}} + \sum_{i \in B_2} G_{ub} P_{i2}}$$

for $u \in \{U_1, U_2\}$ and $i \in \{1, 2\}$.

where $G_{ub}$ is the channel power from BS $b$ to UE $u$, $P_{i1}$ and $P_{i2}$ are the transmitted power at macro/micro BS, and $a_{ij}$ is the channel orthogonal factor between cell $j$ and cell $i$ [6].

The optimization problem for maximizing the total transmitted data rate is formulated as
3 Cell Configuration Strategy

One of the important usage models of HCS is the coverage extension. In this case, it is assumed that UEs are uniformly distributed. Therefore, we assume that the spectral reuse planning for macro-cell and micro-cell are equally controlled.

Based on the above assumption, the transmitted SIRs of (3) are calculated as

\[
\gamma_u = \frac{G_{ub}p_1}{G_{ub}p_1 + G_{ub}p_2} = \frac{1}{2} \frac{\tau_s}{u} \text{ for } u \in U_i
\]

(5)

Using this model, the optimization problem of (4) is reformulated as

\[
\max_{u} \left( R_u + R_u \right) \quad \text{s.t. } \begin{array}{ll}
R_u & u \in \{U_1, U_2\} \\
0 & i, i \{1,2\}
\end{array}
\]

(6)

where \( \hat{R}_u = \frac{BW}{N} n_u \log_2(1 + \frac{\gamma_u}{\tau_i}) \). The object function with \( \hat{R}_u \) is monotonic decreasing in \( \gamma_u \). Thus, the second constraint for the spectral reuse planning in (4) is modified as the second and third constraints in (6). The optimization problem of (6) is the convex optimization problem because the constraints are satisfied the convexity and the object function is concave [7].

To solve the problem, the second and third constraints are relaxed using the Lagrangian relaxation,
\[ L(n, x, l, m) = \bar{R}_n + (1 + x) + (1 + x) + (1 + x) \]  

(7)

From (7), the problem is decomposed into two parts. The first part is the problem of the global spectral reuse planning, \( x \),

\[ \max_x \left( x_1 + x_2 \right) x + \]  

(8)

Considering the slackness condition and the dual values, the solution of (8) is determined as

\[ x = \min \left( 1, r_1, r_2 \right) \]  

(9)

It is said that the system is not limited by CCI when \( x = 1 \). However, if \( r_1 = 1 \) or \( r_2 = 1 \) then the system is restricted by CCI effected to the macro- or the micro-cell.

The problem of the second part is constructed by the residual part of (7) with the first and fourth constraints. It is decomposed to the independent problem per each cell.

Similar to solve the first part, the first and fourth constraints in (7) is relaxed using the Lagrangian relaxation,

\[ L(n, l, m) = \bar{R}_n U + l + m \]  

(10)

From KKT, slackness condition and the characteristic of dual variables, \( u^*_i > 0 \), it is expressed as

\[ s = \frac{N}{BW} \log_2 \left( 1 + \frac{\nu}{r_i} \right) \]  

(11)

Considering the dual problem, \( u^*_i \) is calculated as

\[ u^*_i = \frac{BW}{N} \log_2 \left( 1 + \frac{\nu}{r_i} \right) \]  

(12)

where \( u^*_i = \arg \max \left( \frac{\nu}{r_i} \right) \).

The channel for each UE except UE \( u^*_i \) is allocated as

\[ n_u = \frac{N \nu / r_i \log_2 \left( 1 + \frac{\nu}{r_i} \right)}{BW} \]  

(13)

It means that the minimum channel satisfied the minimum required data rate is allocated to UEs without UE, which has the best CSI. For the best CSI UE the channel is allocated to satisfying the follow condition,

\[ n_u = \frac{N \nu / r_i \log_2 \left( 1 + \frac{\nu}{r_i} \right)}{BW} \]  

(14)
4 Simulation results

In our simulation, the system considered subchannelized OFDMA with 1024 subcarriers. The number of subchannel sets is 30 subchannels. The cellular system being simulated consists of 19 two-tier hexagonal cells. In order to avoid the boundary effect, the results from the center hexagonal cell are used. The simulation values were chosen for urban environments [8]. To fairly compare, it is calculated the spectral efficiency per a macro-cell area, i.e., one macro-cell plus microcells. In figures, \( d \) means the distance from a macro-cell BS to a micro-cell BS.

![Figure 1](image)

Fig. 1. Spectral efficiency versus number of micro-cell and UE with \( v = 256 [kbps/sec] \)

Spectral efficiencies verse number of UEs is shown in Fig. 2. Spectral efficiency without micro-cells is increased in low traffic region, but that is decreased in medium and high traffic region. That is why in low traffic case the system can be obtained the multi-user diversity when the number of UEs are increased, but CCI constraints the spectral efficiency in medium and high traffic region [12]. However, spectral efficiencies with micro-cells are maintained in medium and high traffic region. It means that HCS systems can be enhanced the system stability in high traffic region. And, the spectral efficiency is improved when the number of micro-cell is increasing and the distance between the macro-cell BS and the micro-cell BS becomes far off. It is shown that HCS systems are obtained the performance enhancement by spreading the traffic. Without loss of generality, when the micro-cell is posited at the macro-cell edge, the enhancement is maximized in medium and high traffic region. In low traffic region, the switching-off BS without serving UE is occurred. Therefore, the spectral efficiency has the maximum value when the micro-cell is posited near the macro-cell BS.
4 Conclusions

In this paper, it is proposed a cell configuration strategies for OFDMA based HCS downlink systems. First, the optimization problem is formulated with spectral reuse planning and channel allocation constraints, and obtained the optimum solution using the Lagrangian relaxation because the optimization problem is the convex problem. The proposed solutions are only required partial CSI and are able to be distributed cell configuration. Results shown that HCS systems can enhance the system stability and improve the system performance.

Acknowledgment. This research was supported by Basic Science Research Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Science, ICT & Future Planning (No. 2013R1A1A1009526).

References

8. IEEE 802.16m Evaluation Methodology Document (EMD), IEEE Std. 802.16m, 2009.