

Spectrum Sharing and Inter Cell Interference Mitigation in Wireless Cellular Networks

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Abstract

Objective: Spectrum shortage and Inter Cell Interference (ICI) are two factors which limits the performance of wireless cellular networks. **Methods/Analysis:** One of the popular methods is Soft Frequency Reuse which effectively controls the spectrum management and reduces the ICI for wireless networks. In conventional static Soft Frequency Reuse (SFR) scheme, transmission power in cell and allocation of subcarriers are fixed during the system deployment, which affects the performance of system. **Findings:** This paper focuses Intercell Resource Allocation algorithm, which is dynamic in nature and optimizes both subcarrier and transmission power for cellular network. **Novelty/Improvement:** Intercell Resource Allocation algorithm result in greater improvement in data rate and system capacity.

Keywords: Intercell Interference (ICI), Long-Term Evolution (LTE), LTE-Advanced (LTE-A), Soft Frequency Reuse (SFR), Spectrum Management

1. Introduction

The enormous and ever increasing growth of mobile subscribers and their demand for increase in data rate indirectly increases demand of the spectrum size^{1,2}, but unfortunately the wireless spectrum allotted to each radio systems are limited and further they are costly^{3,4}. Therefore higher system capacity and data rate requirement are the two main designing constraints for new and upcoming wireless cellular networks like LTE⁵ and LTE-Advanced (LTE-A)⁶. All these new wireless cellular technologies are focusing on making the frequency reuse factor as one, instead of conventional frequency reuse factor of three or seven, which means utilizing whole available spectrum in each individual cell. If signals are transmitted on same frequency from neighboring cells there is possibilities of ICI for cell edge user i.e. users located at boundaries of cells. Therefore there exist need to find optimization technique that will encounter the ICI and will give a new path for spectrum management⁷. There are two different approaches have been examined Fractional Frequency

Reuse (FFR)⁸ and SFR⁹ to enhance the spectrum efficiency and to reduce ICI. Both the methods physically divides the entire cell region into cell center and cell edge area, due to frequency reuse of one there exist ICI which is then mitigated by assigning different power values for cell edge and cell center region subcarrier frequency groups for each user. Furthermore, it has been examined that SFR scheme gives better spectrum efficiency when compared with FFR¹⁰. In static versions of FFR and SFR schemes, subcarrier frequency groups and their transmission power for each cell is fixed, therefore these methods are not significantly used to vary users mobility and data rate^{11,12}. Dynamic version of these schemes have been proposed in for FFR¹³⁻¹⁷ and for SFR¹⁷⁻²⁰. Further, the system capacity can be improved by optimization of both subcarrier and power in SFR schemes^{19,20}. The objective of this paper is to enhance the system throughput by dynamically assigning both subcarriers and power within cell center and cell edge regions. Adaptive second tier soft frequency reuse method works by dividing multicell resource allocation to single cell resource allocation with the help of message

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transfer between adjacent base stations (BS). Resource allocation method is continued till system target data rate is reached to its saturated value. The rest of the paper is organized as follows: section 2 represents the proposed system model, section 3 describes adaptive second tier soft frequency reuse algorithm, section 4 gives simulation results and section 5 concludes our results.

2. System Model

To control ICI with enhancing the system data rate, the combined optimization of subcarrier and power allocation for SFR is considered. To increase the system throughput the following steps are to be followed.

- According to system traffic and user mobility, we dynamically optimize subcarrier frequencies and power by varying number of minor and major subcarriers and their power for each cell.
- Cell center target data rate of each cell will remain constant even if adjacent cell's cell center and cell edge minimum rate requirement is not fully satisfied this will ensure that system target is not decreasing and procedure converges to solution.
- Further scheme will work in distributed manner where each cell will determines its own resources allocation with sharing of limited information with its adjacent cells. This will reduce computational complexity.

The proposed system model considers LTE/LTE-A type of network with C_1 number of cells in its 1-tier adjacent cells and C_2 number of cells in 2-tier adjacent cells. SFR scheme is adopted as frequency allocation scheme with downlink transmission. The available spectrum is then divided into set of L subcarriers, where $L = \{1, 2, \dots, L\}$. Each cell in the system is physically divided into two geographical areas, cell center and cell edge area depending upon distance from serving base station as in. For each cell let us denote L_j^{minor} and L_j^{major} subcarriers as its minor and major subcarrier groups and p_j^{minor} and p_j^{major} as minor and major subcarrier powers respectively for j^{th} cell. Let us assume that there are total K_j users in cell such that K_j^V and K_j^C are users

in cell exterior region and cell interior region respectively which follows $K_j = K_j^V + K_j^C$. The minimum data rate requirement for cell user in j^{th} cell is $d_{j,k}^{min}$. Let channel gain for each user located j^{th} cell on all subcarrier by BS has $u_{j,h,k}$. Let us assume virtual cell center user and virtual cell edge user having worst channel gain among the cell interior and cell edge users respectively are given as in equations (1a) and (1b);

$$k_{j,VC} = \{k \mid \min \{u_{j,j,k_j^C-1}, u_{j,j,k_j^C-2}, \dots, u_{j,j,k_j^C}\}\} \tag{1a}$$

$$k_{j,VE} = \{k \mid \min \{u_{j,j,1}, u_{j,j,2}, \dots, u_{j,j,k_j^C}\}\} \tag{1b}$$

Then each virtual user have lower bound data rate which is sum of rate requirement for the each user in that specific cell region, as

$$D_j^{VCmin} = \sum_{k \in K_j^C} d_{j,k}^{min} \tag{2a}$$

$$D_j^{VEmin} = \sum_{k \in K_j^E} d_{j,k}^{min} \tag{2b}$$

Equations (2a) and (2b) are data rate requirement of virtual users and minimum data rate requirement of all users to be satisfied. As SFR scheme is deployed then it can be assumed that interference mainly contributed from adjacent cells, therefore for virtual user in j^{th} cell signal to interference plus noise ratio is as follows as,

$$SINR_{v_j}^j = \frac{p_j^i u_{j,j,v_j}}{\sum_{h \in C_{1adj}^j} (p_h^i u_{j,h,v_j}) + \sum_{h \in C_{2adj}^j} (p_h^i u_{j,h,v_j}) + N_o B_{sub}} \tag{3}$$

where p_j^i is transmission power on subcarrier 'i' in cell j, C_{1adj}^j is interfering 1-tier base stations adjacent to cell j similarly, C_{2adj}^j is interfering 2-tier base stations adjacent to cell j, N_o is noise thermal power density and B_{sub} is the subcarrier bandwidth. For cell exterior user interference on major subcarriers in each cell mainly comes from adjacent minor subcarrier i. Shannon capacity theorem is used²¹, to find data rate of virtual cell edge user in j cell as,

$$D_j^{VE} = \sum_{i \in N} y_{j,i} B_{sub} \log_2 (1 + SINR_{k_{j,VE}}^j)$$

$$D_j^{VE} = L_j^{major} B_{sub} \log_2 \left(1 + \frac{p_i^{major} \cdot u_{i,i,k_{j,VE}}}{\sum_{h \in C_{1adj}^j} p_h^{minor} \cdot u_{j,j,k_{j,VE}} + \sum_{h \in C_{2adj}^j} p_h^{major} \cdot u_{j,j,k_{j,VE}} + N_o B_{sub}} \right) \tag{4}$$

$$D_j^{VC} = \sum_{i \in N} (1 - y_{j,i}) B_{sub} \log_2 (1 + SINR_{k,VC}^i)$$

$$D_j^{VE} = L_j^{major} B_{sub} \log_2 \left(1 + \frac{p_i^{major} \cdot u_{i,i,k_i,VE}}{\sum_{h \in C_{1adj}^j} p_h^{minor} \cdot u_{j,j,k_j,VE} + \sum_{h \in C_{2adj}^j} p_h^{major} \cdot u_{j,j,k_j,VE} + N_o B_{sub}} \right) \quad (5)$$

Here, $y_{j,i}$ is subcarrier allocation variable, its value can be 1 or 0. Similarly interference exist on virtual cell center user on minor subcarrier i by major subcarrier i of adjacent base stations. The data rate of virtual cell center user in cell j can be found out as,

The system throughput optimization is constraint to lower bound of minimum data rate and maximum transmit power of each base station, the mathematical formulation can be concluded as,

$$\max_{p_j^{major}, p_j^{minor}} \sum_{j \in C} (D_j^{VC} + D_j^{VE}) \quad (6a)$$

With respect to,

$$D_j^{VC} \geq D_j^{VC_{min}} \quad (6b)$$

$$D_j^{VE} \geq D_j^{VE_{min}} \quad (6c)$$

$$p_j^{total} \leq P_{max} \quad (6d)$$

$$L_j^{major} + L_j^{minor} = L \quad (6e)$$

$$L_j^{major} = \sum_{i \in N} y_{j,i} \quad (6f)$$

$$\sum_{k \in Y(m)} y_{k,i} \leq 1 \quad (6g)$$

Where constraints (6b) and (6c) represents lower bound data rate constraint, (6d) constraint limits the transmit power used in each cell.

$$p_j^{total} = L_j^{minor} p_j^{minor} + L_j^{major} p_j^{major} \quad (7)$$

Condition (6g) ensures the no interfering SFR major subcarrier condition according to. $Y(m)$ represents m term in Y_j where Y_j is set of adjacent cells that fulfills orthogonality condition set by SFR scheme.

3. Adaptive Second Tier Soft Frequency Reuse Resource Allocation Algorithm

3.1 Single-Cell Resource Allocation Algorithm

Single cell resource allocation is to maximize cell's throughput by finding major and minor subcarrier and their power with prerequisite of resource allocation information in adjacent cells. In first step, find the minimum transmit power that can be used to satisfy the virtual user's data rate requirement, in second step reallocate remaining power in such a way that cell throughput is increased and these steps are repeated until cell's throughput achieves constant rate. In first step, determine the optimum number of major and minor subcarriers and their respective transmit power to minimize the total base station transmit power, subject to the target data rate constraints of the virtual cell interior and cell edge users. The formulation can be written as,

$$\min (L_1^{minor} p_1^{minor} + L_1^{major} p_1^{major}) \quad (8a)$$

$$D_j^{VC} \geq D_j^{VC_{min}} \quad (8b)$$

$$D_j^{VE} \geq D_j^{VE_{min}} \quad (8c)$$

$$L_1^{major} + L_1^{minor} = L \quad (8d)$$

$$L_1^{major} \leq L_{max} \quad (8e)$$

Constraint (8e) guarantees that major subcarriers for a given cell are non overlapping with its adjacent cells. Here, we define the maximum possible number of major subcarriers for the single cell as L_1^{max} which can be derived through,

$$L_1^{max} = L - \max \left\{ \sum_{k \in V_{1,h}, k=1} L_1^{major} \right\} \quad (9)$$

Equation (9) can be rewritten as to find, p_1^{major} and p_1^{minor} are given,

$$L_1^{minor} = L - L_1^{major} \quad (10)$$

$$p_1^{major} = \left(2^{\frac{D_1^{V_{tar}}}{L_1^{major} B_{sub}}} - 1 \right) \cdot \left(\frac{\sum_{h \in C_{1,adj}} [(p)_h^{minor} u_{1,h,k_1,VE}]}{+ \sum_{h \in C_{1,adj}} p_h^{major} \cdot u_{j,j,k_1,VE} + N_0 B_{sub}} \right) \quad (11)$$

$$p_1^{minor} = \left(2^{\frac{D_1^{V_{tar}}}{L_1^{minor} B_{sub}}} - 1 \right) \cdot \left(\frac{\sum_{h \in C_{1,adj}} [(p)_h^{major} u_{1,h,k_1,VC}] + \sum_{h \in C_{1,adj}} p_h^{minor} \cdot u_{j,j,k_1,VC} + N_0 B_{sub}}{u_{1,1,k_1,VC}} \right) \quad (12)$$

Now perform an exhaustive search among all possible $(L_1^{minor}, L_1^{major})$ that can give lowest possible transmit power, we note this power value as P_{min} . In resource allocation, the minimum transmit power P_{min} , is found using equations (11) and (12). If it is less than the maximum available transmission power, then the remaining power $(p_{max} - p_{min})$ can be used for major subcarriers in cell exterior region. Thus, now major subcarriers can transmit with additional power than that used in the initial allocation step. As a result, now decrease the number of major subcarriers that assigned in the initial allocation step which are required to satisfy cell exterior users for data rate requirement. The available major subcarriers are then assigned as minor subcarriers for cell interior users.

A short summary for the above single cell resource allocation algorithm is described as follows:

- Initialization:** Let $D_1^{V_{tar}}(\mathbf{0}) = D_1^{V_{min}}$, $D_1^{V_{tar}}(\mathbf{0}) = D_1^{V_{min}}$ and repetition count $n=0$
- For each pair of subcarriers that fulfills (8e) and (8d), find the respective major and minor subcarrier power according to (12) and (11) that satisfy $D_1^{V_{tar}}(n)$ and $D_1^{V_{tar}}(n)$.
 - Next step is to evaluate total power P_1 for each subcarrier pair by using (7) and require to find $P_{min(n)} = \min(P_1)$
 - If $P_{min(n)} < P_{max}$, go to step 6,
 - If $P_{min(n)} = P_{max}$, go to step 7,
 - If $P_{min(n)} > P_{max}$, terminate the algorithm.

- This is resource allocation step, where $P_{min(n)} < P_{max}$. $P_{min(n)} < P_{max}$ we need to set $L_1^{major} \leftarrow L_1^{major} - 1$, $L_1^{major} \leftarrow L_1^{major} - 1$, then reassign major subcarrier's power and finally set $L_1^{minor} \leftarrow L - L_1^{major}$, $L_1^{minor} \leftarrow L - L_1^{major}$ repeat this step until condition $L_1^{minor} p_1^{minor} + L_1^{major} p_1^{major} > P_{max}$ to be achieved.
- Calculate cell interior data rate and reassign cell interior data rate requirement.
- Increase the repetition count by 1, furthermore we need to follow step 1-7 until cell data rate maintains constant value.

3.2 Second Tier Multi Cell Resource Allocation Algorithm

We will extend the single cell solution to solve multicell resource allocation problem as stated in (6), this part of algorithm works by decomposing multicell resource allocation into several single cell resource allocation problem and then passing this calculated and assigned values to adjacent base stations. Here, the another term to be considered as system data rate which is sum of data rates of virtual users in all executed cells, formulated as,

$$D_{SUM}^{tar} = \sum_{j \in C} (D_j^{V_{tar}} + D_j^{VE_{tar}}), \text{ for } j \text{ cell. Summary for}$$

multicell resource allocation is as follows:

Initialization: For each cell, $i \in C$, set $D_i^{V_{tar}}(\mathbf{0}) = D_i^{V_{min}}$, $D_j^{V_{tar}}(\mathbf{0}) = D_j^{V_{min}}$, $L_j^{minor}(\mathbf{0}) = L$ and repetition count $n = 0$, start from any random cell by having major and minor subcarrier and their transmit power as an initial seeding to algorithm.

- For each cell, consider single source allocation, to find minimum power $P_{min(n)}$ that satisfies $D_j^{V_{tar}}(n)$ and $D_j^{VE_{tar}}(n)$ by applying initial allocation step as per single cell resource allocation algorithm.
- If $P_{min(n)} < P_{max}$, allocate remaining power to cell exterior area and manage the subcarrier assigning by using resource allocation step as per single cell resource allocation algorithm.
- If $P_{min(n)} > P_{max}$, perform reallocation of the power and subcarrier in cell j by following steps from 4 to 8.
- For each L_j^{major} that satisfies (8e), find respective major subcarrier power according to (11), then calculate total power in cell exterior area.
- In next step find out subset τ of L_j^{major} where
- If τ set is not empty, for each subcarrier in τ . Assign

additional power to cell interior, $L_j^{minor} \leftarrow L - L_j^{major}$, $p_j^{minor} = \lfloor (P_{max} - p_j^{VE}) / L_j^{minor} \rfloor$ and obtain cell

center rate.

- Next step is to find out power and subcarrier allocation from all combination and select that pair which will maximize the cell data rate.
- If τ set is empty, assign all power to cell exterior area only, $p_j^{minor} = 0$, $p_j^{major} = P_{max} / L_j^{major}$
- If $P_{min(n)} = P_{max}$, go to step 10.
- Randomly select non overlapping subcarriers for cell interiors that fulfills (6i), reassign cell interior and exterior data rates determined by using steps 1-7 and assign value to rate indicator.
- Perform information broadcasting of major subcarrier, minor subcarrier and their transmission power along with rate indicator to interfering neighboring cells.
- Increment repetition counter by 1, go to step 1 to perform all steps until saturation for system data rate is obtained.

4. Simulation Results

The simulation parameters used are given in Table 1. Figure 1 compares FFR and SFR schemes with cell system having 48 sub bands. Further, it show that for 0.5 value of cell interior radius to total cell radius ratio, sub band assigned for SFR are 22% more than FFR scheme which ensures improved data rate. In addition, soft frequency reuse scheme provides better spectrum management over FFR scheme. Figure 2 shows the performance analysis of Multi Cell Resource Allocation Maximized System Data Rate. To analyze the adaptive second tier soft frequency reuse scheme, average number of 10 users per cell is considered. The system data rate, subcarrier and power allocation during iterative process is continuously monitored. It can be observed that the system data rate formulated in second tier scheme in multicell resource algorithm keep increasing and saturates before adaptive soft frequency reuse algorithm. Once saturation of system data rate is achieved, major and minor subcarriers and their respective power also saturates to their corresponding values.

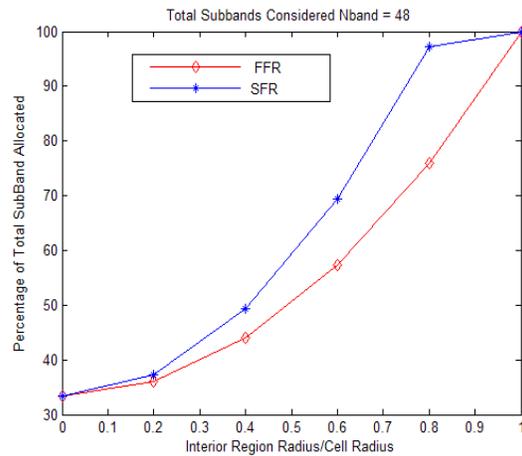


Figure 1. Performance comparison between FFR and SFR.

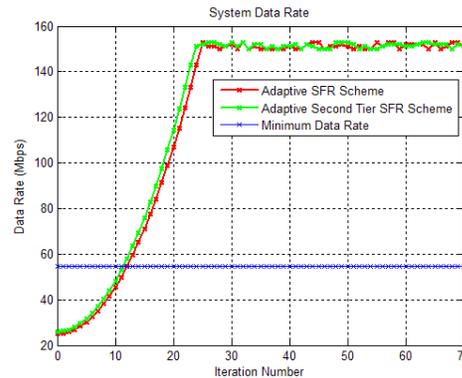


Figure 2. Multi Cell Resource Allocation Maximized System Data Rate.

Table 1. Simulation Parameters

Parameters	Specification
Subcarrier Bandwidth	180 KHz
Number and Type of Cells	7, Hexagonal and Wraparound
Thermal Noise Power Density	-174dBm/Hz
Max. Base Station Transmit Power	46dBm
Minimum Data Rate requirement	500-600 Kbps
Number of users per cell/ Bandwidth	10/10 MHZ

5. Conclusion

The proposed adaptive second tier soft frequency reuse algorithm works in physical layer by iteratively optimizing

subcarriers count and power allocation. In each cell by search and evaluate method the information is passed to its adjacent cells on X2 interface of LTE and LTE-A systems. The proposed algorithm is practically feasible as per state of the art of LTE/LTE- Advanced system architecture. In this paper, existing adaptive soft frequency reuse scheme is extended to next level of interfering neighboring cells as in LTE are focusing on frequency reuse factor of 1. Combined optimization of both subcarriers and their transmission power in distributed fashion in SFR, which is under constraints of data rate requirement in each individual cell regions to enhance the system data rate with system capacity.

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