

RADIO RESOURCE BLOCK ASSIGNMENT FOR 4G-LTE FEMTOCELL NETWORKS IN MULTI-FLOOR BUILDINGS

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Abstract

The requirement of a mobile data rate and ubiquitous network access for an indoor environment has been increasing continuously. A long term evolution allows femtocell base stations as a potential solution which can improve not only indoor coverage but also data rates. However, one of major challenges is the increase of inter-cell interference caused by the neighboring femtocell base stations that share the same radio resource blocks. In this paper, we formulate the optimization problem as a linear programming on radio resource block assignment for 4G-long term evolution femtocell networks in multi-floor buildings. We separate the problem formulation into 2 phases. The first phase aims to assign a user to the optimal femtocell base station in order to maximize a received signal strength for a user in the service area. Then, in the second phase, the objective is to maximize the number of the radio resource blocks that is assigned to each femtocell base station from the first phase's solution. Moreover, the proposed technique can guarantee the quality of services in terms of signal to interference plus noise ratio and signal coverage. The experimental results illustrate that the proposed technique can achieve 100% service coverage throughout the service area. Furthermore, the proposed technique can reduce the inter-cell interference and improve maximum downlink throughput by up to 86.11%.

Keywords: 4G-LTE femtocell network, radio resource assignment, inter-cell interference, linear programming

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Introduction

The popularity of smartphones and tablets has increased widely in recent years due to the availability of mobile data rates and ubiquitous network access that has been increasing continuously. A survey has demonstrated that voice calls and data traffic mainly occur in the indoor environment (Zhang and de la Roche, 2011), such as the home, office, and department store. Due to severe wall penetration losses, the signal from the macro base stations has difficulty in reaching the indoor users. In order to satisfy the requirements of the indoor users, the 4G Long Term Evolution (LTE) offers the femtocell base stations (FBSs) that can improve not only indoor coverage but also data rates. The femtocell is a low-power home base station, which brings advantages to both mobile operators and mobile users, such as infrastructure costs, indoor coverage, and system throughput (Mahmud *et al.*, 2013).

In order to optimize the radio resource utilization, FBSs apply the frequency reuse approach to accomplish high data rates (Ahmed *et al.*, 2014). However, if the FBSs share the same radio resource in the building without careful planning, the FBS user will suffer severe inter-cell interference (ICI). A good approach to mitigate ICI in the femtocell network that uses orthogonal frequency division multiple access (OFDMA) (Holma and Toskala, 2011) as a multiple-access technique is the assignment of a resource block. In addition, a resource block, which consists of several subcarriers, is the smallest radio resource unit of information for OFDMA transmission.

ICI is one of the important problems of femtocell networks. Some works in the literature have considered this issue. In Selim *et al.* (2012), the authors proposed soft and partial frequency reuse schemes for interference management in LTE femtocell networks considering some metrics such as throughput, quality of service, and fairness. In Liu *et al.* (2012), the authors presented a semi-static resource allocation scheme based on fractional frequency reuse using a heuristic algorithm which avoids interference on cell edge users for dense indoor femtocell deployments.

In order to improve the resource utilization in OFDMA networks, resource allocation schemes have been introduced. Saeed *et al.* (2015) presented a technique to solve control and the data channel resource allocation problem for OFDMA heterogeneous networks by using a linear binary integer programming heuristic algorithm in order to provide a high data rate for femtocell users while ensuring the certain level of quality of service for macrocell users. Estrada *et al.* (2013) proposed a joint base station selection and resource allocation model for macro-femtocell networks with interference mitigation that aims to maximize the network throughput by using linear programming. In Ebrahim *et al.* (2016), the authors presented the technique of a resource allocation for distributed and uncoordinated femtocell networks that maximizes cell capacity while avoiding inter-cell interference to neighboring cells. Varghese and Sudha (2015) conducted a joint subchannel and power allocation algorithm with throughput maximization for downlink of an OFDMA-based femtocell network by considering some constraints such as quality of service, data rate, and optimum power. In Liang *et al.* (2012), the authors presented a resource block assignment algorithm which avoids co-channel intercell interference and ensures service quality for femtocell networks by using a heuristic algorithm.

In a femtocell network, the signal to interference plus noise ratio (SINR) is important in defining the modulation technique for the user. However, the previous works have not considered the SINR requirement guarantee in an indoor scenario. Consequently, this paper aims to propose a radio resource block assignment for femtocell networks in multi-floor buildings. We formulate the optimization problem as the linear programming (LP) on radio resource block assignment. Our objective is to maximize the number of the radio resource blocks (RRBs) that is assigned to each FBS. To improve network performance, we consider the quality of services in terms of the signal coverage and the SINR requirement. Additionally, the user network throughput is also considered.

Method

We propose the LP (Winston and Goldberg, 2004) model to solve the radio resource block assignment problem (RRBAP) for 4G-LTE femtocell networks in multi-floor buildings. This work is divided into 2 phases. The first phase aims to assign a user to the optimal FBS in order to maximize the received signal strength for the user in the service area. Then, in the second phase, we aim to assign the total available RRB for all FBSs with an objective to maximize the number of the RRBs that is assigned to each FBS under the signal coverage and the SINR constraints. For the network performance analysis, we compare our technique with the graph coloring problem (GCP) technique presented in Liu *et al.* (2012).

RRBAP Technique

Phase 1: The Maximization of the Received Signal Strength Level

To improve the network performance, we need to find the optimal FBS that can provide

the maximum received signal strength for a signal test point (STP). Therefore, the objective of the first phase is to maximize the summation of the received signal strength at all STPs. This can be written as the objective function, as shown in Equation (1). Equations (2) and (3) are the model constraints. In addition, Table 1 shows the notation used in the model.

$$\text{Maximize } \sum_{h=1}^S \sum_{i=1}^B P_r(h, i) y_{hi} \quad (1)$$

Constraints:

$$\sum_{i=1}^B y_{hi} = 1, \forall h \in S \quad (2)$$

$$y_{hi} (P_r(h, i) - P_{rt}) \geq 0, \forall h \in S, \forall i \in B \quad (3)$$

Constraint (2) ensures that each h^{th} STP can have only 1 serving i^{th} FBS, but each i^{th} FBS can support multiple h^{th} STPs. Constraint (3) ensures that the received signal strength received at the h^{th} STP from the i^{th} FBS must be greater than the received signal strength threshold P_{rt} .

Table 1. Notations

Sets:	
B	A set of femtocell base stations (FBSs)
S	A set of signal test points (STPs)
R	A set of radio resource blocks (RRBs)
Decision variables:	
y_{hi}	A binary {0,1} variable that equals 1 if the STP h is assigned to FBS i , $h \in S$, and $i \in B$; 0 otherwise
α_{ik}	A binary {0,1} variable that equals 1 if the RRB k is assigned to FBS i , $k \in R$, and $i \in B$; 0 otherwise
x_{ik}^h	A binary {0,1} variable that equals 1 if RRB k is assigned to STP h in FBS i , $k \in R$, $h \in S$, and $i \in B$; 0 otherwise
Constant parameters:	
$P_r(h, i)$	The signal strength that a STP h receives from FBS i , $h \in S$, and $i \in B$
$P_r(h, i, k)$	The signal strength that a STP h receives from FBS i at RRB k , $h \in S$, $i \in B$, and $k \in R$
P_{rt}	The received signal strength threshold
γ_t	The SINR threshold
N_r	The number of RRBs
N_0	Thermal noise density
B	Bandwidth
Inf	Infinity

Phase 2: The Maximization of the Assigned RRBs

In order to mitigate ICI, the RRB may not be assigned to adjacent FBSs. Therefore, the goal of this phase is to explore the optimal assignment of the RRB for the FBSs from the first phase's solution. The objective of the second phase is to maximize the number of the RRBs that is assigned to each FBS. This can be written as the objective function, as shown in Equation (4).

$$\text{Maximize } \sum_{k=1}^R \sum_{i=1}^B \alpha_{ik} \quad (4)$$

Equational conditions can be divided into 3 sets of constraints, denoted as S1, S2, and S3. The S1 consists of the constraint that guarantees the upper bound of RRB assignment, as shown in Equation (5) while the S2 consists of constraints that ensure the signal coverage in the service area, as shown in Equations (6) to (8). In addition, the S3 consists of a constraint that ensures the SINR requirement in the service area, as shown in Equation (9).

Constraints:

S1: Upper Bound of RRB Assignment

$$1 \leq \sum_{k=1}^R \alpha_{ik} \leq N_r, \quad \forall i \in B \quad (5)$$

The constraint in Equation (5) ensures that the number of assigned k^{th} RRBs per i^{th} FBS must be at least 1 but no more than the maximum capacity of the RRB.

S2: Signal Coverage

$$\sum_{k=1}^R \sum_{i=1}^B x_{ik}^h \geq 1, \quad \forall h \in S \quad (6)$$

$$x_{ik}^h \leq y_{hi}, \quad \forall h \in S, \forall i \in B, \forall k \in R \quad (7)$$

$$x_{ik}^h \leq \alpha_{ik}, \quad \forall h \in S, \forall i \in B, \forall k \in R \quad (8)$$

The constraint in Equation (6) ensures that each h^{th} STP connects to at least 1 i^{th} FBS and receives at least 1 k^{th} RRB. The constraint in Equation (7) specifies that the h^{th} STP can connect to the i^{th} FBS if the i^{th} FBS is selected

in the first phase. The constraint in Equation (8) specifies that the h^{th} STP can connect to the i^{th} FBS if the i^{th} FBS is selected in the RRB assignment.

S3: SINR Requirement Guarantee

$$\begin{aligned} & \ln f * (1 - x_{ik}^h) + \alpha_{ik} 10^{\left(\frac{P_r(h,i,k)}{10}\right)} \\ & \geq \gamma_t N_0 B + \gamma_t \sum_{\substack{a=1 \\ a \neq i}}^B \alpha_{ak} 10^{\left(\frac{P_r(h,a,k)}{10}\right)} \\ & , \forall h \in S, \forall i \in B, \forall k \in R \end{aligned} \quad (9)$$

The constraint in Equation (9) ensures that the SINR at the h^{th} STP from the i^{th} FBS at the k^{th} RRB must be greater than the SINR threshold γ_t .

GCP Technique

The graph coloring algorithm is a simple algorithm that finds the number of sub-bands for a femtocell in the in-building scenario. First, we construct the interference graph that can indicate the interference between 2 FBSs. In the interference graph, each node relates to a FBS and the edge connects 2 nodes representing the interference between 2 FBSs. Then, the graph coloring algorithm colors the nodes of the interference graph with the number of colors. Each node must choose a different color if there is an edge between them. As a result, it is expected that 2 FBSs that have an edge between them are not permitted to use the same sub-band in order to mitigate the ICI. However, the drawback of this technique is ineffective resource utilization.

Experimental Setup

In this section, we first explain the model of the building and parameters used in a numerical experiment. The path loss model used in this work will be discussed in Section B. Section C will introduce the SINR calculation used for the experimental results discussed in this work. Finally, the user throughput calculation will be discussed in Section C.

Description

Our experiments were set up in a 2-story building with each floor having dimensions of 75×75 m. Each floor has a different wall structure, as illustrated in Figures 1 and 2. The number of FBSs on the first and the second floor is 7 and 6, respectively. The STPs' granularity of 5 meters is considered in the service area to evaluate the received signal quality such as received signal strength, SINR, and user network throughput. There are a total of 392 STPs, with 196 STPs on each floor as represented by a plus symbol in Figures 1 and 2. Table 2 shows the parameters used in the numerical studies (European Telecommunications Standards Institute, 2011). Moreover, Table 3 presents the relationship between modulation techniques and the SINR threshold (Abdelhay *et al.*, 2015).

Path Loss Model

In order to compute the accurate received signal strength at STPs for the aforementioned building settings where the FBSs are deployed, we use the path loss model to calculate the attenuation of the signal. Therefore, this work uses the path loss model that has been recommended by the 3GPP (The 3rd Generation

Partnership Project) (Vardhan *et al.*, 2014). The path loss model is given in Equation (10).

$$PL = 40.7412 + 20\log_{10}(R) + 0.7d_{2d,indoor} + 18.3\frac{(n+2)(n+1)-0.46}{n} + qL_{iw} \quad (10)$$

where R is the distance between the STP and FBS, $d_{2d,indoor}$ is a wall thickness, n is the number of the building's floors, q is the number of wall separations of STP and FBS, and L_{iw} is the building wall penetration loss. Table 4 illustrates the typical value of wall loss (L_{iw}) (Zulkefly *et al.*, 2015).

SINR Calculation

Our goal is to ensure the SINR requirement while mitigating ICI in the service area. Furthermore, each STP is interfered by the neighboring FBSs which use the same RRBs. The downlink SINR of a STP from the i^{th} FBS at the k^{th} RRB is given by

$$SINR_{STP} = \frac{P_r(h,i,k)}{N_0B + \sum_{a=1, a \neq i}^{N_B} P_r(h,a,k)} \quad (11)$$

where $P_r(h,i,k)$ is the received signal strength of the h^{th} STP from the i^{th} FBS at the k^{th} RRB, N_0 is the thermal noise density, B is the bandwidth of each RRB, N_B is the number of

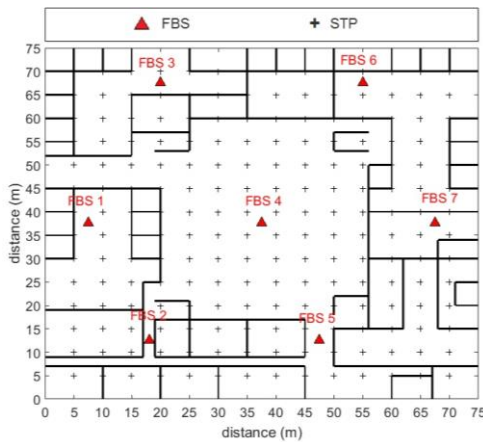


Figure 1. 1st floor of the building

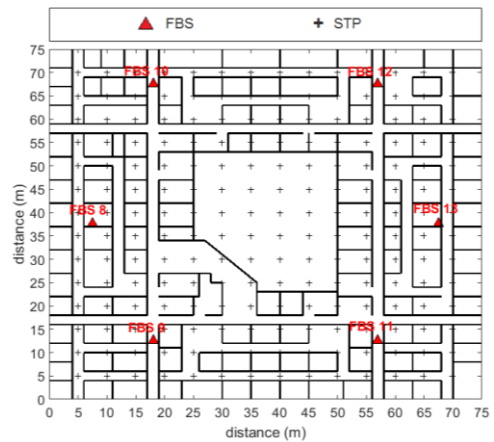


Figure 2. 2nd floor of the building

FBSs, and $P_r(h, a, k)$ is the received signal strength of the h^{th} STP from interfering the a^{th} FBS using the same k^{th} RRB. The received signal strength P_r is calculated from the formula as follows:

$$P_r \text{ (dBm)} = P_t \text{ (dBm)} - PL \text{ (dB)} \quad (12)$$

where P_t is the FBS transmission power in dBm and PL is the path loss in dB.

User Throughput Calculation

In our study, we evaluate the network performance in terms of the SINR and the user throughput. Therefore, the Shannon formula (Mogensen *et al.*, 2007) is adopted to estimate the user throughput in our study, as shown in Equation (13).

Table 2. Parameters used in numerical experiments

Parameters	Value
Height of FBSs	2 m
Height of STPs	0.8 m
Transmitted power	5 dBm
Carrier frequency	2.6 GHz
Antenna pattern	omnidirectional
Bandwidth	15 MHz
Number of RRBs	75
Thermal noise density	-174 dBm/Hz
SINR threshold	6 dB

Table 3. The relation between modulation techniques and SINR threshold

CQI	Modulation	Code rate	SINR threshold (dB)
1	QPSK	1/8	-6
2	QPSK	1/5	-4
3	QPSK	1/4	-2.1
4	QPSK	1/3	0
5	QPSK	1/2	2.1
6	QPSK	2/3	3.8
7	QPSK	4/5	6
8	16QAM	1/2	7.8
9	16QAM	2/3	9.9
10	16QAM	4/5	12.6
11	16QAM	2/3	15

Table 4. Relative permittivity of materials

Description	Value (dB)
Wood	1.99
Plasterboard	2.94
Brick	3.75
Concrete	5.31
Glass	6.27

$$C_{STP} = B \log_2(1 + SINR_{STP}) \quad (13)$$

where B is the bandwidth of each RRB and $SINR_{STP}$ is the signal to interference plus noise ratio.

Results and Analysis

For the evaluation of the radio resource block assignment in our study, we compare our proposed technique with the existing technique in terms of the number of assigned RRBs for each FBS, a maximum downlink throughput, an outage probability, an average downlink SINR, and an average downlink throughput. Simulation results were conducted using: (1) MATLAB R2015b and (2) IBM ILOG CPLEX 12.7. Computations are performed on an Intel Core i5-6600 3.30 GHz 64-bit Operating System and 16 GB of RAM.

Table 5 shows the number of assigned RRBs for each FBS. The results of the RRBAP technique are achieved from the CPLEX optimization solver. In the RRBAP technique, FBS 1, 2, 3, 4, 5, 6, 7, and 12 obtain 71 RRBs. Besides, FBS 8, 9, 10, 11, and 13 obtain 72 RRBs. The GCP technique provides 10 assigned RRBs

for each FBS. We can observe that the RRBAP technique can improve the number of assigned RRBs for each FBS by up to 81.34% compared to the GCP technique utilized at FBS 1, 2, 3, 4, 5, 6, 7, and 12. Moreover, this technique can improve the number of assigned RRBs for each FBS by up to 82.67% compared to the GCP technique utilized at FBS 8, 9, 10, 11, and 13.

Figure 3 presents the maximum downlink throughput of each FBS. The RRBAP technique provides the maximum downlink throughput up to 33.18 Mbps, but the GCP technique provides the maximum downlink throughput only up to 4.61 Mbps. Furthermore, we can see that the RRBAP technique can increase the maximum downlink throughput by up to 86.11% compared to the GCP technique due to the FBSs of the RRBAP technique obtaining the number of the RRBs higher than the GCP technique.

Figure 4 shows the outage probability of STPs against the SINR threshold. The SINR threshold is varied from -6 dB to 15 dB with steps of 3 dB. The outage probability of the RRBAP technique is zero until the SINR is 6 dB because the SINR threshold of our proposed technique is 6 dB. Obviously, we can observe that the RRBAP technique can achieve 100% service coverage throughout the service area

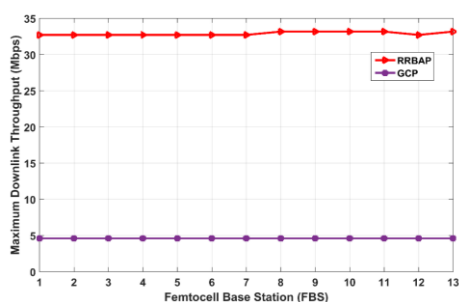


Figure 3. Maximum downlink throughput (Mbps) at FBS

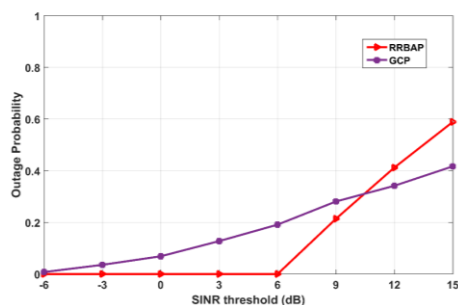


Figure 4. Outage probability vs. SINR threshold

Table 5. The number of assigned RRBs per FBS[illegible]

and can guarantee the value of the SINR for all STPs that is greater than or equal to 6 dB. Moreover, the RRBAP technique can improve the service coverage by up to 19.14% compared to the GCP technique.

Figures 5 and 6 illustrate the cumulative distribution function (CDF) of the average downlink SINR and the CDF of the average downlink throughput at the STP, respectively. In Figure 5, considering the average downlink SINR 6 dB, the RRBAP technique can increase the average downlink SINR by up to 19.14% compared to the GCP technique. In order to achieve a 16-quadrature amplitude modulation (16QAM) modulation with a code rate of 2/3 that is the maximum modulation technique in Table 3, the SINR of the STP must be higher than or equal to 15 dB. We can observe that the number of STPs that can achieve 16QAM modulation with a code rate of 2/3 in the RRBAP technique and the GCP technique is 45% and 60% of all STPs, respectively. Although the GCP technique can obtain more numbers of STPs than the RRBAP technique by up to 15%, in this work the higher SINR may not be necessary

as we need the SINR of just 6 dB for a quadrature phase-shift keying (QPSK) modulation with a code rate of 4/5. In Figure 6, considering the cumulative probability 0.1, the average downlink throughput of the RRBAP technique (2.65 bps/Hz) is better than the GCP technique (1.25 bps/Hz).

Table 6 shows an average, a standard deviation (SD), and the guarantee service coverage of each technique. It can obviously be seen that the average of the average downlink SINR and the average downlink throughput from the GCP technique is greater than the RRBAP technique. Conversely, the standard deviation of the average downlink SINR and the average downlink throughput from the RRBAP technique is lower than the GCP technique. However, the GCP technique has the higher variance of the average downlink SINR and the average downlink throughput compared to our RRBAP technique. So, this leads to poor signal quality in some service areas. Furthermore, the RRBAP technique can provide 100% service coverage, which is higher than the GCP technique by up to 19.14%.

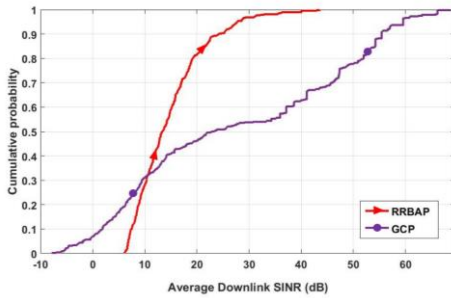


Figure 5. CDF of average downlink SINR at STP

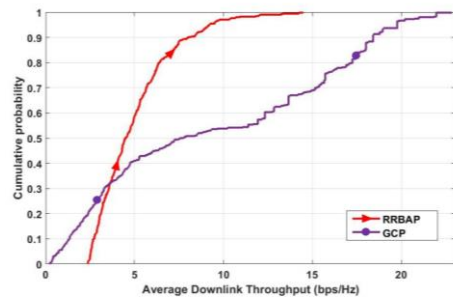


Figure 6. CDF of average downlink throughput at STP

Table 6. Performance comparison of 2 techniques

Technique	Average downlink SINR (dB)		Average downlink throughput (Mbps)		Guarantee service coverage
	Average	SD	Average	SD	
RRBAP	14.80	6.82	5.01	2.19	100%
GCP	27.61	21.44	9.40	6.84	80.86%

Conclusions

In this paper, we have manipulated the ICI issue caused by the FBSs sharing the same RRBs. Furthermore, this issue degenerates the performance of mobile femtocell networks in an indoor environment. Therefore, we have proposed the radio resource block assignment for 4G-LTE femtocell networks in multi-floor buildings. We have formulated the problem as a LP problem. The objective is to maximize the number of the RRBs that is assigned to each FBS. In addition, our proposed technique can guarantee the quality of services in terms of the SINR and the signal coverage, and it can improve the user network throughput. Our experimental results have demonstrated that our proposed technique can solve the problem with constraints better than the GCP technique. Specifically, the proposed technique can achieve 100% service coverage throughout the service area. Moreover, this proposed technique can reduce the ICI and increase the maximum downlink throughput at FBS by up to 86.11% compared to the GCP technique.

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