OFDMA Femtocell Gateway Scheduling Based on Coloring

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Abstract

The deployment of femtocells can effectively improve the capacity of a cellular network without significant increase in the network management costs. However, spectrum allocation policy to reduce the interference is one of the most significant challenges for femtocell deployments. In this paper, we first propose a coloring algorithm to distinguish neighbor femtocell access points (FAPs) with the aid of femtocell gateway. Though neighbor FAPs are colored with different colors, their neighbors result in being colored with the same color with each other. So a coloring algorithm 2 is proposed in this paper to guarantee that FAPs' neighbors are colored with different colors. After the two coloring algorithms have been explored, two subchannel allocation strategies in Long Term Evolution (LTE) are proposed to efficiently schedule resources which only need little overhead and the two strategies are compared with the basic strategy --- that is, randomly allocate an unused subchannel to requesting users. Mathematical derivations and simulation results are given, which confirm the promising performance of our resources scheduling algorithms.

Keywords*: Femtocell Gateway, Access Scheduling, Coloring, System Capacity, Spectrum Allocation*

1. Introduction

Femtocell access points (FAPs), also called “home base station”, are crucial for next generation cellular networks. Femtocells can effectively improve the capacity of a cellular network without significant increase in the network management costs [1-2, 13]. FAPs are usually installed by users and deployed in indoor environments. These low-power base stations provide a limited coverage area and connect to the operators' core networks through digital subscriber line (DSL), cable broadband connection, or even wireless links [3].

The interest in femtocells in the mobile operator community continues to grow, and the commercial deployments have increased to 41 in 23 countries during 2012 [4]. It is estimated by Informa Telecoms & Media that the deployments of small cell market would reach 91.9 million by 2016, with femtocells accounting for more than 80%. It is expected the FAPs would be widely deployed in the near future.

Before its large scale employment, there are some technical challenges that need to be addressed. Perhaps the most significant challenge for femtocell deployments is the possibility of stronger, less predictable, and more varied interference [4]. Meanwhile, as a next generation critical technology, Orthogonal Frequency Division Multiple Access (OFDMA) technique presents us with more flexible and effective access method. Consequently, exploring OFDMA femtocell scheduling technology to combat interference issue is a promising area that will definitely facilitate the development of femtocells.

A problem would occur is that when FAPs are not “isolated” enough; spectrum collisions are bound to happen if there is no policy on spectrum allocation. Thus, a realistic spectrum allocation and access policy should be implemented within FAPs to combat the conflicts. As a result, there are plenty of spectrum allocation and access methods proposed to alleviate the interference between FAPs and provide users with a reasonable amount of resources.

In [5], a distributed femtocell resource allocation strategy is proposed, which does not require any coordination among femtocells, and utilizes distributed hash tables. A cognitive femtocell framework is introduced in [6], where femtocells cognitively recognize the interference signature, and implement an opportunistic channel scheduler in order to avoid interference to/from neighboring femtocells and the macrocell users. In [7], the authors propose an OFDMA subband scheduling strategy that uses feedback to allocate resources to users. The scheduling strategy uses a frequency-domain method that complexity is shown to be pseudo-polynomial. However, the paper is focused on maximum throughout achieved by user rather than cooperative femtocells to reduce interference. In [8] and [9], interference avoidance strategies in OFDMA femtocells are proposed. However, they all need FAPs to sense the subchannel usage of neighbor FAPs, which may be not accurate enough to combat the interference in realist employment.

The femtocell gateway could be used as a control and convergency point of FAPs in a certain area. Rather than complicated “sense” ability implemented within FAPs, which is bound to increase the cost of FAPs and hurdle its business deployment, using femtocell gateway to provide a certain amount of “intelligence” to femtocell technology is necessary and realistic. With the aid of femtocell gateway, different colors for neighbor nodes can be used as an identity to schedule various resources.

In the coloring procedure, FAPs just send nearby FAPs' IDs which the received pilot strength is higher than a specific value to femtocell gateway. Upon collecting the information, femtocell gateway will construct a neighbor graph. The coloring problem is then reduced to node coloring theory in the graph theory. The first coloring algorithm is based on the proof of the node coloring theory and of course, guarantees the colors of neighboring nodes are different. However, it cannot guarantee that the neighbors of FAPs are colored with different colors. In view of this, a second coloring algorithm is proposed which is referred to as coloring algorithm 2 in this paper.

Based on the coloring result, two subchannel access strategies are proposed, which are referred to as scheme 2 and scheme 3 in this paper. Comparisons are drawn among the two schemes and the basic scheme 1, in which FAPs just allocate an unused subchannel to the requesting user. In scheme 2, the femtocell gateway is of no use when the coloring procedure is completed. As for a node, which is colored with one color, say green, there are no differences that the neighbors are colored with blue or red, as long as the colors are differed. In scheme 3, the femtocell gateway is occasionally accessed and different colors are taken as flags for corresponding scheduling strategies.

The paper is organised as follows: in Section 2, the system model is given to illustrate issues such as coloring procedure and subchannel scheduling strategies. In Section 3, performance analysis is made, with the mathematical derivation. In section 4, simulation scenarios are presented and results are drawn. At last, we conclude this paper in Section 5.

2. System Model

The configuration of FAPs and femtocell gateway is depicted in Figure 1. It is obvious from the figure that if there is no coordination between FAPs, then spectrum collisions probability will be high due to the stochastic characteristic of FAPs. Consequently, a policy on resources scheduling such as subchannels in LTE should be considered. Even though there are already plenty of femtocell gateway scheduling policies that achieve reasonable performance gain, they tend to computation-overwhelming and thus power-hungry, which are not appropriate for current technology development level. In following parts of this section, we propose procedures that differentiate neighboring FAPs with the aid of femtocell gateway and call the procedure “coloring”.

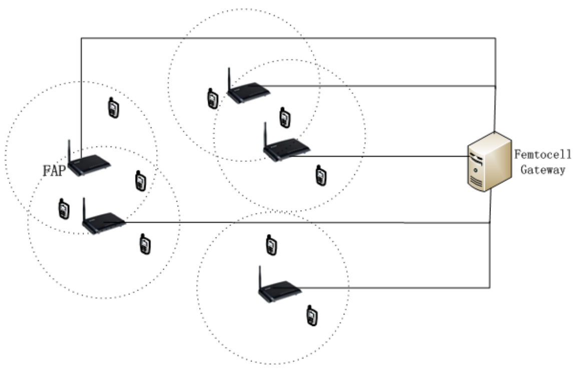
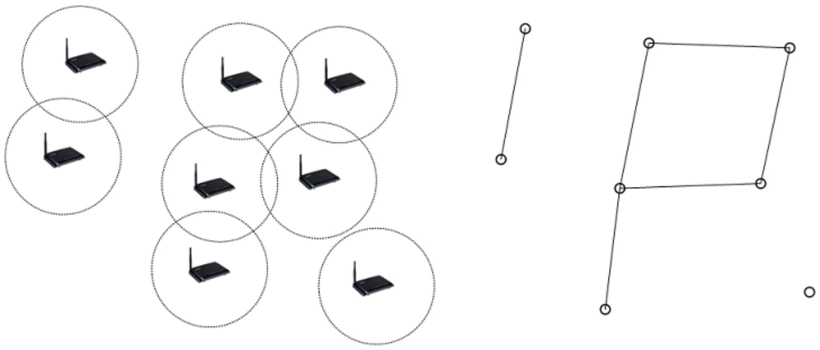


Figure 1. The femtocells are connected to a femtocell gateway that handles the resource management.

2.1. Coloring Procedure

First, we will illustrate the general node coloring procedure what we call it algorithm 1. Next, algorithm 2 is proposed which is the improved version of algorithm 1.

With the aid of femtocell gateway, neighbor FAPs can be differentiated. In this paper, we refer neighbor FAPs to the femtocell access points that the received pilot signal strength from each other is higher than a specified value. If FAPs are regarded as nodes, there is an edge connecting two nodes if they are neighbors. Consequently, the differentiation of nearby FAPs can be reduced to the coloring in the graph theory. The illustration is depicted in Figure 2. Femtocell network configuration and its corresponding abstraction is shown in Figure 2(a) and Figure 2(b) respectively. Theorem 1 guarantees the existence of the basic coloring.



(a) Femtocell configuration. (b) Resulting abstraction.

Figure 2. The femtocell configuration and its resulting abstraction. For clarity, when two circles centered at FAPs overlap, we regard them as neighbors.

The neighboring nodes are colored with different colors to distinguish neighbors and its corresponding procedure is called node coloring in graph theory.

***Theorem 1*:** In an undirected graph G, the node chromatic number $\chi(G) \le \Delta+1$, where Δ is the degree of G.

The proof is simple and can be reasoned as follows: Get node $v \in V(G)$, color it with one of the $\Delta+1$ colors. Get uncolored node $u \in V(G)$, color it with the color which is differed from its neighboring colored nodes. Since the degree of $u \le \Delta$, the colors occupied by its neighbors at most Δ kinds. There is at least one kind of $\Delta+1$ colors that can be used to color u. As the procedure goes on, it is obvious that all nodes in G can be colored with $\Delta+1$ colors.

The procedures of the two coloring algorithm proposed by the paper are accomplished with the aid of the femtocell gateway.

2.1.1. Algorithm 1 of coloring

When a FAP boots (or at an interval basis), it scans for nearby FAPs and regards them as neighbors if the received pilot strengths are higher than a specific value. Next, the FAP sends the information about its ID and neighbors' IDs to femtocell gateway to construct the neighbor graph. Once the graph is constructed, the femtocell gateway will enforce the algorithm 1.

In algorithm 1, neighbors are given different colors, and the color can be used to indentify different resources. When coloring procedure is finished, the femtocell gateway will push its own color and neighbor colors to each FAP. Figure 3 shows a snapshot according to algorithm 1. But it can be seen from the figure that many neighbors of one node are colored with the same color (depicted by big circle). There are 16 nodes out of 40, which are shown in Figure 3. Consequently, we improve the preceding algorithm and propose algorithm 2 of coloring.

2.1.2. Algorithm 2 of coloring

The basic idea of algorithm 2 is coloring neighbors of one node and considering different colors for neighbors at the same time, and then recursively color the nodes that are not colored. The algorithm is illustrated at below and the result is depicted in Figure 4. It can be seen from the figure that no neighbors of one node are colored with the same color. The complexity of the algorithm is polynomial, and since the algorithm is targeted at each connected branch, a parallel computation is available.

Algorithm 1 coloring algorithm 1

for each node i in graph **do**
  initial color pool of node i equals the complete color pool
  for each neighbor node j of node i **do**
    if the node j has allocated color c_j **then**
      clear the color c_j from the color pool of node i
    end if
  end for
  randomly choose one color from the color pool of node i
end for

Algorithm 2 coloring algorithm 2

for each connected branch of the graph **do**
  randomly take one node i as first node and color it with c_i
  the available color pool P_i of c_i is the complete pool minus c_i
  the neighbors colored by node i is C_i, and $C_i = empty$
  for each neighbor node j of node i **do**
    temporary color pool T_j of node j is P_i
    for each neighbor node z of node j **do**
      if the node z has allocated color c_z **then**
        clear the color c_z from the color pool T_j
      end if
    end for
    randomly pick a color from T_j to node j
    clear the chosen color from P_i
    add node j to C_i
  end for
  repeat
    for each node w in C_i **do**
      enforce the preceding algorithm for node w
    end for
  until C is empty for all nodes in the branch
end for

2.2. Downlink Subchannel Scheduling

Based on the above coloring procedures, two subchannel scheduling strategies are proposed. Our main focus is on LTE/OFDMA. In LTE, a minimum of 72 subcarriers must be supported, and 12 subcarriers (occupying a total of 180kHz) are grouped into a subchannel. Thus a minimum of 6 subchannels must be supported for each FAP. Since FAPs are installed by users rather than operators, adaptively subchannel scheduling ability is required for each FAP. Rather than randomly assign subchannels to users, which is bound to cause severe conflicts, or assign a part of subchannels to each FAP, which wastes the available spectrum, we propose two downlink subchannel scheduling algorithms that will combat these two problems.

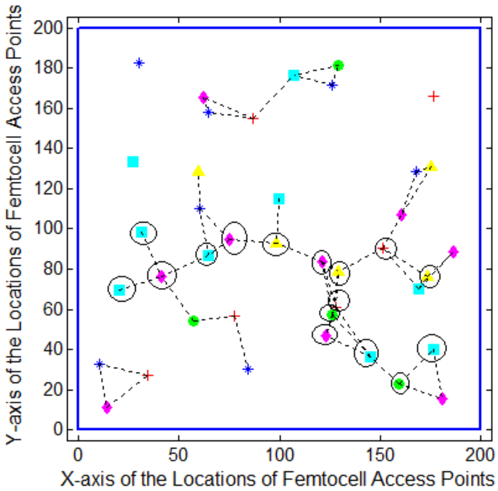


Figure 3. Simulation result of algorithm 1.

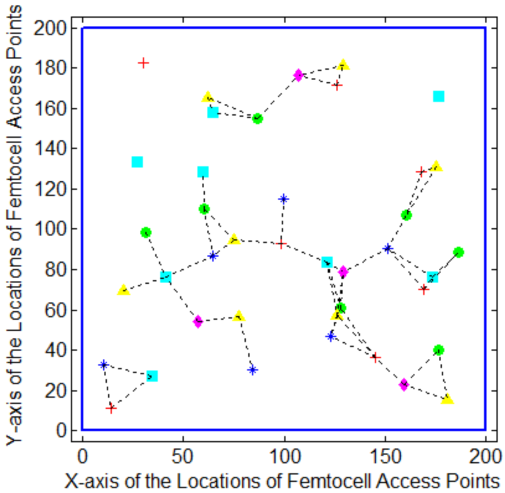


Figure 4. Simulation result of algorithm 2.

2.3. Downlink Resources Scheduling Schemes

In this subsection, we will propose two scheduling schemes, namely, scheme 2 and scheme 3, and compare their performance with the basis scheme, which is named scheme 1 in this paper.

After all FAPs were colored, the color can be taken as a token for resources. For clarity, we define the color pool size as the same size of subchannels supported by the femtocell network. Hence, a one-to-one projection between colors and subchannels can be achieved. Other kinds of projections can also be constructed.

For simplicity, we numbered each color. We denote the number of FAPs as N. The color of node i is c_i. The color pool of neighbors of FAP i is $\Omega(i)$. The downlink subchannel scheduling policy of FAP i is described as follows.

2.3.1. Scheme 1

In this basic scheme, coloring is not adopted. When a user requests a subchannel, the FAP merely allocates an unused subchannel to the user. It is obvious that the collision probability in this scheme is high and needs more effective subchannel allocation algorithm.

2.3.2. Scheme 2

Using the result of coloring proposed in the preceding section. In scheme 2, when a user in femtocell i requests a subchannel, the FAP i first checks whether it has allocated the c_i^{th} subchannel; if hasn't, gives the user the c_i^{th} subchannel; if it has already been allocated, it checks whether there is subchannel available that is not in $\Omega(i)$; if it is, randomly pick up one to the user; if not, it randomly chooses a subchannels in $\Omega(i)$. The flow chart of accessing the subchannels in scheme 2 is shown in Figure 5.

The effectiveness of the scheme 2 can be explained as follows: the c_i^{th} subchannel of FAP i is not polluted at the maximum probability since a collision in this subchannel occurs only if the neighbors have used up all his subchannels. The same is applicable to neighbor FAP because the FAP i will not use the neighbors' $color^{th}$ subchannels unless the FAP has no other available subchannels. As for the subchannels that not belong to the neighboring FAPs' $color^{th}$ subchannels, there may be collision if more than two nearby FAPs use it.

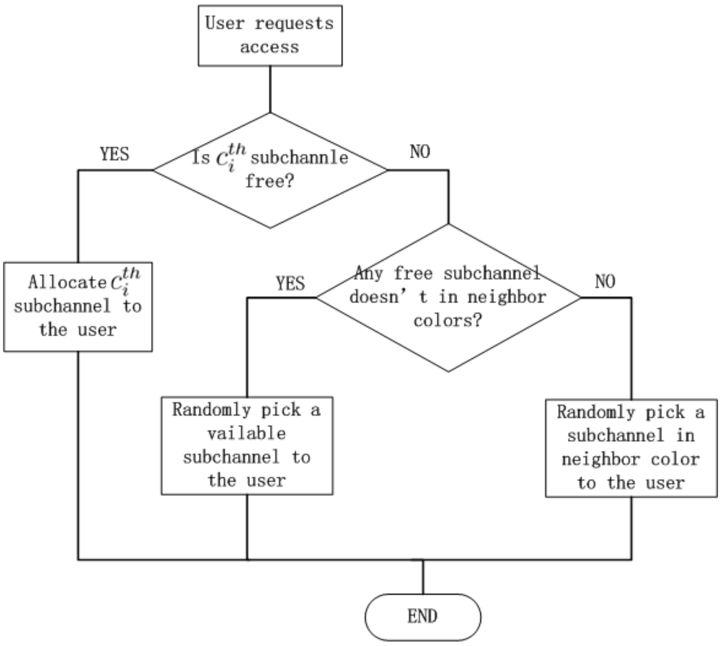


Figure 5. The flow chart of user accessing subchannel in scheme 2.

2.3.3. Scheme 3

Intuitively, scheme 2 is a promising subchannel allocation strategy. However, there is no difference for red node that its neighbor's color is green or blue. All it concerns is that they are different colors. Consequently, scheme 3 is proposed that utilizes different colors as an identity to allocate subchannels. The procedure of scheme 3 is detailed in following.

First, femtocell gateway constructs the color-subchannel relation table. One of the color-subchannel tables for the size of color pool 6 and 8 can be constructed as in Fig. 6. For instance, when 6 subchannels are supported by each FAP and if a FAP is colored with the 5^{th} color, it will initially allocate the subchannel 3 and subchannel 5 according to the left figure in Figure 6. It can be seen from Figure 6 that different colors' subchannels allocations conflict at most one subchannel allocated to one other colors. When a FAP is colored, it will get its color and corresponding two subchannels. For instance, when a FAP is colored with the 5^{th} color, it will previously be given subchannel 3 and subchannel 5 in the left figure when the color size is 6.

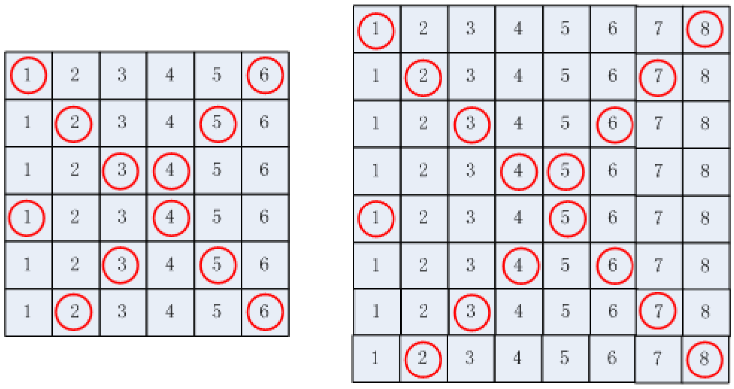


Figure 6. The color-subchannel relation table. The figures in the left and right are the corresponding relationships when the size of color pool is 6 and 8, respectively.

Secondly, when a FAP used up its allocated subchannels, it will enquire the femtoell gateway to find out whether there are colors not to be allocated; if so, it requests the color's two subchannels from Figure 6 to the FAP; otherwise, the FAP will randomly assign a subchannel to the user. After the coloring and color-subchannel projection have finished, the flow chart of user accessing the subchannel in scheme 3 is depicted in Figure 7.

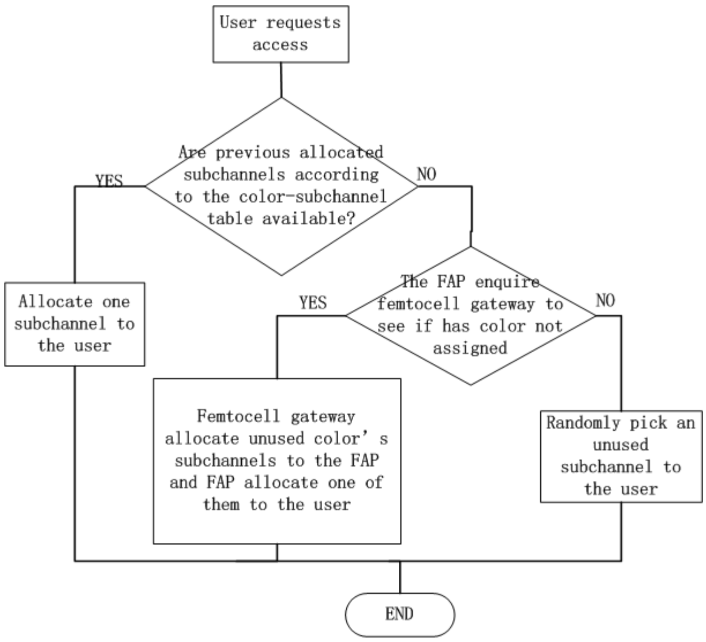


Figure 7. The flow chart of user accessing subchannel in scheme 3.

3. Performance Analysis

In this section, we will compare the performance of the three schemes. For mathematically tractable, we just compare the situation that only one neighbor is considered. We also assume that the number of users in each femtocell follows Poisson distribution with parameter λ. In the following content, we denote N is the number of subchannels, and EN is the mean number of collision subchannels. X_i denotes the event that the i^{th} subchannel is in collision. Thus, we have

$$X_i = \begin{cases} 1, \text{ the } i^{th} \text{ subchannel conflicts} \\ 0, \text{ otherwise} \end{cases}, \tag{1}$$

$$EN = E[\sum_{i=1}^{N} X_i] \cdot \tag{2}$$

3.1. Performance of the Basic Scheme: Scheme 1

Since each subchannel is equally chosen in scheme 1, the collision probability of the $i^{th} (1 \le i \le N)$ subchannel is equal, and is given as:

$$\begin{aligned} P\{X_i = 1\} = P\{X_j = 1\} &= \frac{\lambda^2}{N^2} \cdot \Phi^2(N-2;\lambda) + 2 \cdot \frac{\lambda}{N} \cdot \Phi(N-2;\lambda) \cdot [1 - \Phi(N-1;\lambda)] \\ &+ [1 - \Phi(N-1;\lambda)]^2 \qquad (1 \le i, j \le N) \end{aligned}, \tag{3}$$

where $\Phi(n;\lambda) = \sum_{k=1}^{n} \frac{\lambda^k}{k!} e^{-\lambda}$, that is, the Poisson cumulative distribution function taken value at n; and the mean number of collision subchannels EN satisfies the following relation:

$$EN = N \times P\{X_i = 1\}. \tag{4}$$

3.2. Performance of the Proposed Scheme: Scheme 2

For clarity, we suppose that the two FAPs considered are colored 1 and N. The corresponding collision probability is:

$$P\{X_1 = 1\} = P\{X_N = 1\} = [1 - \Phi(0;\lambda)] \cdot [1 - \Phi(N-1;\lambda)]. \tag{5}$$

The other subchannels suffer more collisions and their collision probabilities are:

$$\begin{aligned} P\{X_i = 1\} &= \sum_{k_1=0}^{\infty} \sum_{k_2=0}^{\infty} P\{X_i = 1, X_A = k_1, X_B = k_2\} = \sum_{k_1=0}^{N-1} \sum_{k_2=0}^{N-1} P\{X_i = 1, X_A = k_1, X_B = k_2\} \\ &+ 2 \cdot \sum_{k_1=N}^{\infty} \sum_{k_2=0}^{N-1} P\{X_i = 1, X_A = k_1, X_B = k_2\} + \sum_{k_1=N}^{\infty} \sum_{k_2=N}^{\infty} P\{X_i = 1, X_A = k_1, X_B = k_2\}. \end{aligned} \tag{6}$$

Calculating each item in the preceding equations comes

$$\begin{aligned} P\{X_i = 1\} &= \frac{1}{(N-2)^2} \cdot \{\lambda[\Phi(N-3;\lambda) - \Phi(0;\lambda)] - [\Phi(N-2;\lambda) - \Phi(1;\lambda)]\}^2 \\ &+ \frac{2}{N-2} \cdot [1 - \Phi(N-2;\lambda)] \cdot \{\lambda[\Phi(N-3;\lambda) - \Phi(0;\lambda)] - [\Phi(N-2;\lambda) - \Phi(1;\lambda)]\} \\ &+ [1 - \Phi(N-2;\lambda)]^2 \quad (\mathrm{i} \ne 1, \mathrm{N}). \end{aligned} \tag{7}$$

Thus, the corresponding mean number of collision subchannels is:

$$EN = 2 \times P\{X_1 = 1\} + (N-2) \times P\{X_i = 1\}. \tag{8}$$

3.3. Performance of the Proposed Scheme: Scheme 3

Accurate expressions for collision probability in each subchannel and its mean number are too involved in scheme 3. Thus a proximate equation is given. We are just concerned about one neighbor, which is corresponding to sparse deployment environment. Thus we just consider the pre-allocated subchannels and let the other suchannels identical, we have

$$\begin{aligned} P\{X_i = 1\} &= \sum_{k_2=1}^{\infty} P\{N_i = 1, X_A = 1, X_B = k_2\} + \sum_{k_1=2}^{\infty} \sum_{k_2=1}^{\infty} P\{N_i = 1, X_A = k_1, X_B = k_2\} \\ &= \frac{1}{N-1} \cdot (\frac{1}{2} \lambda e^{-\lambda} + 1 - \Phi(1;\lambda))^2. \end{aligned} \tag{9}$$

The corresponding mean number of collision subchannels EN is:

$$EN = N \times P\{X_i = 1\}. \tag{10}$$

3.4. Comparisons and Analysis among the Three Schemes

First, we are concerned about the expected number of collision subchannels in each of the three schemes. According to the Equation (4), (8) and (10), the result is drawn in Figure 8. λ is only concerned in the interval of 1 to ceil(number of subchannels / 2). It can be seen from Figure 8 that the number of collision subchannels in scheme 2 is about 0.5 subchannel lower than in scheme 1, whereas the mean number of collision subchannels in scheme 3 is more gradual than all the other two schemes.

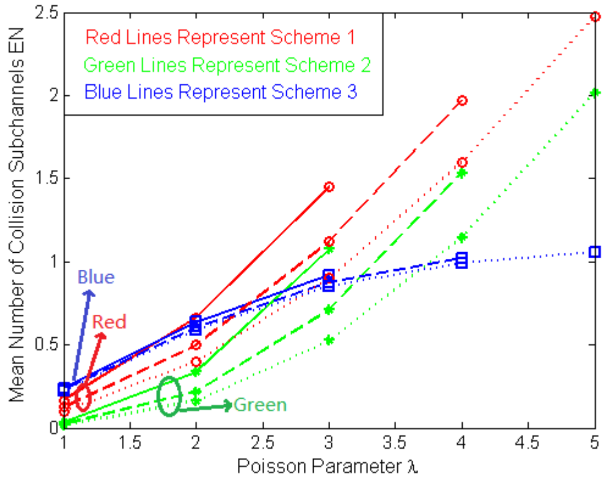


Figure 8. Mean number of collision subchannels. The abscissa is the poisson parameter λ. The red, green and blue lines represent the scheme 1, scheme 2 and scheme 3, respectively.

Next, we will compare the collision probability in each subchannel. Since there is no difference among the subchannels in scheme 1 and scheme 3, the collision probability is equal in each subchannel. However, in scheme 2, there exits difference and the c_i^{th} subchannel in femtocell i will endure much less collisions. Equation (3), (5), (7) and (9) are the mathematical expressions. In Figure 9, we only draw the probability in the cases of N = 6 and 10.

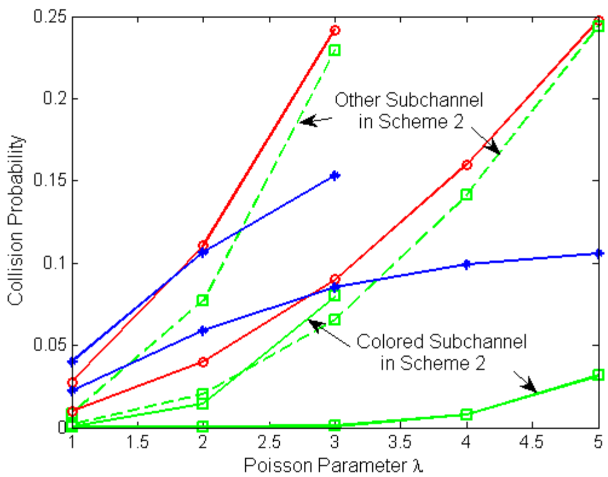


Figure 9. The collision probability in each subchannel in the three schemes. The red, green and blue lines represent scheme 1, scheme 2 and scheme 3, respectively.

It can be seen from Figure 9 that in scheme 2, the collision probability is always lower than scheme 1. Especially the c_i^{th} subchannel with the collision rarely occurs. And again, this is due to the property that neighbors of the FAP are most unlikely to use this subchannel. This high quality subchannel can be used for differential services. For instance, it can be dedicated to FAP owners or to the high priority services. In the case of scheme 3, the change of probability is more gradual, this is because we just consider one neighbor here, and thus the organized method is less likely to result in collisions.

4. Simulation Results

In preceding sections, we are focused on the theoretical analysis, especially in the case of just one neighbor. In this section, simulation results will be given.

4.1 Simulation Parameters

An area of 200×200 square meters is considered and there are 50 FAPs randomly distributed among this area. Each femtocell has a radius of 10 meters. We adopt the wireless propagation model proposed in [11]. For clarity, we omit the log-normal shadowing and the channel model can be reduced to L = 37 + 40lgR. In addition, there are two walls between each femtocell and a 10 dB loss is added for each wall. The Shannon Formula is used to compute system capacity. In order to comply with the LTE standard, an adaptive modulation and coding is adopted for each user, as shown in Table 1 [11]. Advanced signal processing technologies are omitted here and readers can refer to [12, 14] for further information.

Table 1. Downlink SINR requirement for LTE UE [15]. IM is short for Implementation Margin.

System	Modulation	Code rate	SINR+IM (dB)
LTE UE	QPSK	1/8	-2.6
		1/5	-0.4
		1/4	0.8
		1/3	1.5
		1/2	4.5
		2/3	6.8
		3/4	8.0
		4/5	8.7
	16QAM	1/2	10.9
		2/3	14.3
		3/4	15.2
		4/5	15.8
	64QAM	2/3	19.3
		3/4	21.5
		4/5	22.6

The system capacity gain is achieved by comparing the capacity of scheme 2 and scheme 3 with scheme 1 using two coloring algorithms proposed in the preceding sections. Results are depicted in Figure 10 and Figure 11 (We only draw the results when the size of subchannels is 6 and 10). It can be seen from both figures that scheme 2 and scheme 3 are promising subchannel allocation strategies. From these figures we can draw the conclusion that scheme 2 is more suitable for the situation when the number of user in each femtocell is small, while scheme 3 is preferable in crowded situations. It is interesting to notice that the performance of coloring algorithm 2 is inferior to that of algorithm 1. It can be explained that in our simulation deployment (which is a little dense, with 50 FAPs in the area of 200×200 square meters), coloring one's neighbors with different color tends to reduce the scheme 2 and scheme 3 to the scheme 1. Consequently, more researches should be conducted.

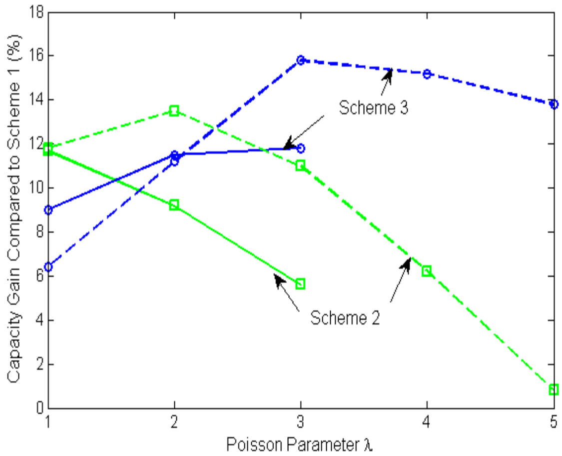


Figure 10. The capacity gain of scheme 2 and scheme 3 compared with scheme 1 based on our simulation scenario when using coloring algorithm 1.

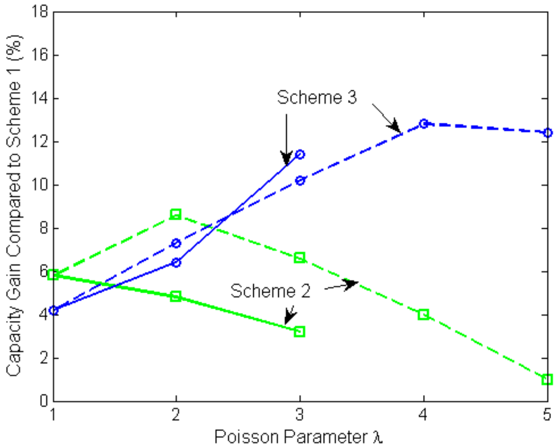


Figure 11. The capacity gain of scheme 2 and scheme 3 compared with scheme 1 based on our simulation scenario when using coloring algorithm 2.

5. Conclusion

The deployment of femtocells can effectively improve the capacity of a cellular network without significant increase in the network management costs. However, spectrum allocation policy to reduce the interference is one of the most significant challenges for femtocell deployments. Before its large scale deployment, there are technical challenges that need to be addressed. Effective subchannel allocation policy in LTE is a crucial one.

In this paper, femtocell gateway is used to color neighbor FAPs. Two coloring algorithms are proposed, which the first algorithm is based on the proof procedure of node coloring in graph theory but can't guarantee the neighbors of a FAP are colored with differed colors, while the algorithm 2 of coloring does. Upon the coloring, two subchannel allocation strategies are given and their performance are compared with the basic scheme, that is, randomly allocate an unused subchannel to the requesting user. The mathematical equations and simulation results have shown that our proposed schemes achieve much more capacity than that of scheme 1. The applicability of scheme 2 and scheme 3 are different: scheme 2 is more suitable for the situations that the number of users in each femtocell is small, whereas scheme 3 is preferable in crowded situations.

7. Acknowledgment

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