Radio Resource Allocation with Power Control for Femto Base Stations in Broadband Mobile Cellular Systems

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Abstract—**The femtocell network has widely been studied as a promising candidate in the next-generation wireless system to improve the radio resource reuse efficiency. The femtocell base stations can be deployed to cover dead zones or to share traffic loads from macrocells. With the large amount of traffic being properly handled by femtocells, the coverage and capacity of macrocells can be enhanced in cellular networks. In this paper, we address the performance evaluations using resource allocation with power control. Two comparison methods are presented are presented to bound the performance for handling the system performance using resource allocation. Moreover, a femtocell station sensitive allocation with power control strategy is provided to enhance system capacity with decreasing outage and drop rates.**

Keywords—**Cellular System, Femtocell, Resource Allocation, System Capacity, and Power Control.**

1. INTRODUCTION

Mobile applications demanding high-quality communications have tremendously increased in recent years. The femtocell network has widely been studied as a promising candidate in the next-generation wireless system to improve the radio resource reuse efficiency. The femtocell base stations can be deployed to cover dead zones or to share traffic loads from macrocells [1-3]. With the large amount of traffic being properly handled by femtocells, the coverage and capacity of macrocells can be enhanced in cellular networks. Moreover, certain studies show that deployment of macrocells can be reduced since 70–80% of traffic can be offloaded from macrocells. Instead of deploying more macrocells, the deployment of femtocells is an economical option due to its low cost and low power consumption.

Based on the Third-Generation Partnership Project (3GPP) specifications, a femtocell architecture is composed of multiple sets of femtocell user equipment (UE), femtocells, and a femtocell management system (FMS). The UEs, e.g., mobile devices or laptops, connect to its associated femtocells through air interface. Femtocells can be deployed in houses, enterprise buildings, or public places. Because femtocells are designed to be deployed by the end users with minimum intervention from the service providers, the femtocell deployment is not well controlled. Numerous femtocells may be randomly distributed in a surrounding area. With the coverage of neighbouring femtocells overlapped, their UEs may interfere with one another[4-6].

Many techniques have been proposed to handle the bandwidth allocation. In an orthogonal system, such as code division multiple access CDMA, it becomes the code-assignment problem [7-11], where more than one code can be used simultaneously in a space (cell) and in non-orthogonal systems, such as frequency division multiple access (FDMA) or time division multiple access (TDMA), it becomes signal-to-interference control problem, where mobile transmit power and base station antenna assignment have to be intelligently managed to control the mutual interference. In this paper, we address the femtocell bandwidth allocation to enhance system capacity with decreasing outage and drop rates.

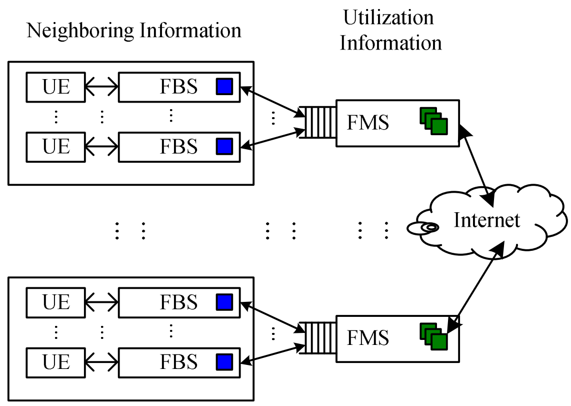


Fig. 1 Network model

2. System Model and Related Works

In this section, we first introduce the system model and accordingly, describe the related strategies. We assume a cellular system with femtocells deployed in the restricted indoor areas, such as home or enterprise environments. The coverage of randomly deployed femtocells may be overlapped. Multiple femtocells are connected to the FMS serving as a controller and a gateway toward the cellular system. The relationships between FMSs and other network components are depicted in Fig. 1, where UEs, femtocells, and FMSs constitute the entire femtocell network. Femtocells logically connected to Internet through broadband wire-line connections. Assume the network contains a set $CC=\{c_1, c_2, \ldots, c_m\}$ of m carrier components, a set $FT=\{f_1, f_2, \ldots, f_n\}$ of n FBSs and a set $UE=\{u_1, u_2, \ldots, u_n\}$ of n UEs, where each FBS f_i serves a corresponding UE u_i. A connection between f_i and u_i can be established if a carrier component c_j can be allocated to this couple (f_i, u_i), which can provide the necessary data transmission rate. Moreover, we also assume that each f_i (or u_i) has the capability to acquire system information, measure the signal power, and do evaluation. Moreover, $SINR(f_i(\text{or } u_i), c_j)$ denote the SINR for f_i(or u_i) according to c_j.

Two conditions must be considered for doing resource allocation. The first one is outage condition. The outage condition is that a carrier component c is allocated to a couple (f, u). The SINR value between (f, u) is not enough to provide the necessary data rate of (f, u). The other is drop condition. The drop condition is that connection (f, u) is established with the available date rate. However, some established connections are been interfered (co-channel interference) and cause the original connections cannot have the necessary date rates. Therefore, these connections will be dropped.

In previous studies, a Maximal SINR strategy and a drop-free strategy are presented to do carrier component allocation to UEs and FMSs. The principle of Maximal SINR strategy is to select a carrier component whose SINR value is maximal for all carrier components. As shown in (1), when a FBS f_i is powered on, f_i evaluates the SINR values of each carrier component in CC and chooses the carrier component c_T having maximal SINR value to establish its connection.

$$c_T = \arg_{c_T \in CC} \left\{ \begin{array}{l} Max(SINR(u_i, c_1), SINR(u_i, c_2), \ldots, \\ SINR(u_i, c_m)) \end{array} \right\} \quad (1)$$

In drop-free allocation strategy, each UE u_i must dynamically maintain a NI_i table, i.e., a Neighborhood Information table. As shown in Fig. 2, in table NI_i, a UE u_i needs to record the received signal power (S), the received noise power (N), the used carrier component (C), and the identification (ID) of the neighboring couples. The NI_i table record the effective area that u_i has the probability that the signal interferes with other connection (f_k, u_k). The worst case, a f_i is powered on and a carrier component c is assigned to couple (f_i, u_i). The assignment interferes other connection using same c to be dropped. The principle of drop-free allocation strategy must guarantee an allocation of c to couple (f_i, u_i) cannot drop other connections. Therefore, the drop-free allocation strategy must satisfy the following two conditions to allocate c_T to (f_i, u_i), where r_{req} is the necessary SINR value that can maintain the necessary transmission data rate.

1. $SINR(u_i, c_T) \geq r_{req}$
2. After c_T is allocated to (f_i, u_i), for each ID k in table NI_i, $SINR(u_k, c_T) \geq r_{req}$

To ensure these conditions can be satisfied, each UE must dynamically maintain its NI table that need to do message exchanges with other UE u_k in NIi. Therefore, drop-free allocation can be termed as UE sensitive allocation strategy. However, the dynamic information collection server-degree work, in real system, it is difficult to handle by UE-degree devices.

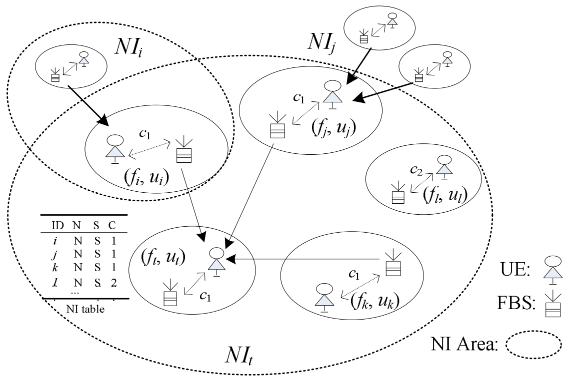


Fig. 2 Profile of UE-sensitive allocation

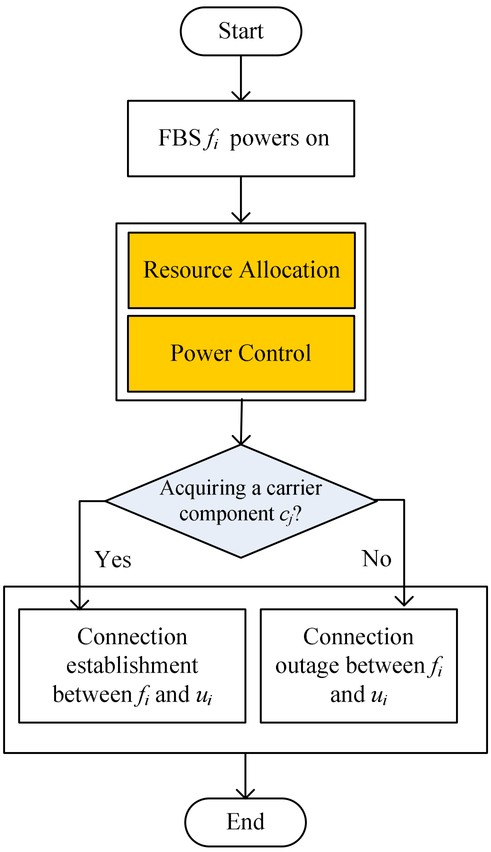


Fig. 3 Overview of Subject Strategy

3. SUBJECT STRATEGY

Overview of the subject strategy is depicted in Fig. 3. When a FBS f_i is powered on, a resource allocation with power control algorithm is performed to determine a carrier component c_j. If a carrier component c_j can be acquired, the connection between f_i and u_i will be established. Otherwise, f_i and u_i will be a connection outage.

In the subject strategy, each FBS f_i needs to maintain a NI table similar to the table of drop-free strategy. When FBS f_i is powered on, f_i broadcasts the power-on information with the power strength *ps*. When the corresponding UE u_i received the message, u_i detects its received power strength and measures the noise strength and sent back to f_i. When the other FBS f_k received the power-on message from f_i, f_k sends its current signal strength, noise strength, and its used carrier component, and the received power strength from f_i. Accordingly, f_i establishes its NI_i table. The NI table for our strategy as shown in Table 1, is similar to the table for UE-sensitive allocation as shown in Fig. 2. The difference is a received power strength (P) of f_k from f_i is recorded into NI_i.

TABLE 1 NI FORMAT

ID	N	S	C	P
i	$N(i)$	$S(i)$	$C(i)$	$P(i)$
j	$N(j)$	$S(j)$	$C(j)$	$P(j)$
k	$N(k)$	$S(k)$	$C(k)$	$P(k)$
…	…	…	…	…

The subject strategy can be described as following.

Part A. Resource Allocation

Step 1: Measure the carrier component set CC_T, $CC_T=\{c \mid c \in CC \text{ and } SINR(f_i, c) \geq r_{req}\}$ and then perform Step 2.

Step 2: When $CC_T \neq \emptyset$, f_i performs the following operations:

i. Select a $c \in CC_T$ and evaluate SINR(c, f_k) using NI_i table.

ii. For each $k \in NI_i$ and $C(k) = c$, if all SINR(c, f_k) $\geq r_{req}$, c is allocated to (f_i, u_i). Otherwise, perform Step 3.

Step 3: Perform $CC_T = CC_T - \{c\}$ and go to Step 2.

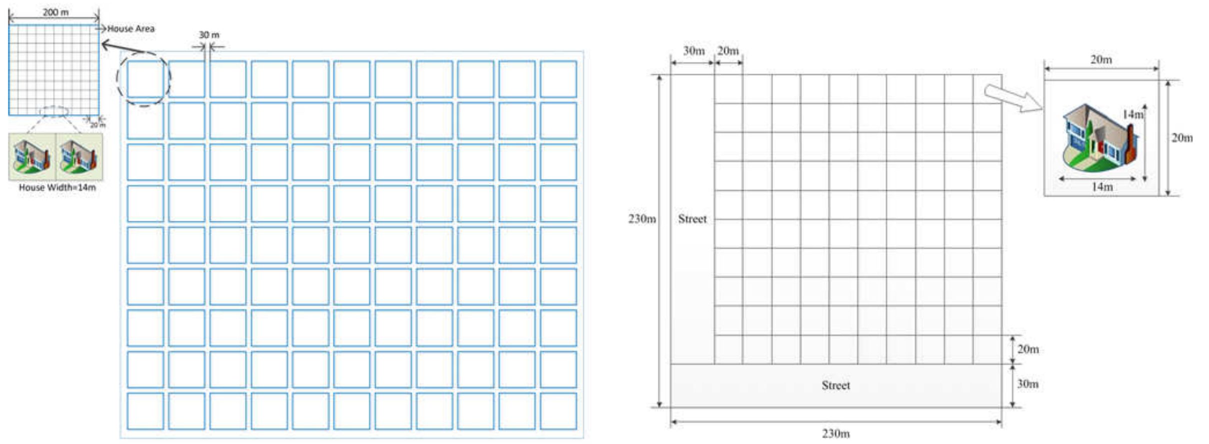
When a FBS f_i performed Part A cannot acquire the carrier component to establish the connection. Part B is then been performed.

Part B. Power Control

Step 1: FBS f_i downs the power strength as ps', where $ps' < ps$. Then f_i performs Step 2.

Step 2: FBS f_i uses the new power strength ps' to evaluate values in NI_i table. Then, FBS f_i performs the operations of Part A.

Notably, in the subject strategy, the information collection is only when FBS f_i is powered on. In part B, the new NI_i can be evaluated from the old NI_i. since the path loss between f_i and other FBS of NI_i can be acquired



(a) block architecture (b) house architecture

Fig. 4 Manhattan Deployment Scenario

from previous operations to construct the original NI_i table.

3. Numerical Results

The simulation environment is constructed following IEEE 802.16m Evaluation Methodology Document [12]. The total bandwidth f is 100MHz, where each carrier component contains 20MHz. The house deployment is similar to Manhattan deployment scenario and is shown as Fig. 4. This area is divided into 9×11 blocks, where each block contains the 100 houses, uniformly. Each house contains a FBS in the center and each base station serves a UE.

TABLE 2 Link Budget

Transmitter (Femtocell Base Station)		
Max. Transmit power for each Femtocell[dBm]	10 (10 mW)	a
Femtocell Antenna Gain [dBi]	3	b
Back off [dB]	5	c
EIRP Per Femtocell [dBm]	8	d=a+b-c
Bandwidth [MHz]	20	
Receiver (Mobile Station, MS)		
Thermal Noise Density [dBm/Hz]=KT	-174	e
Noise Figure [dB]	6	f
Receiver Noise Density [dBm/Hz]	-168	g=e+f
Receiver Noise Power [dBm]	-94.9897	h
Receiver Interference Power [dBm]	-84.9897	i
Total Receiver Noise & Interference Power[dBm]	-84.5758	j
Required SINR [dB]	3	k
Mobile Antenna Gain [dBi]	0	
Required Received Signal Power [dBm]	-81.5758	l=j+k
Max. Allowable Propagation Loss [dB]	89.5758	m=d-l
Coverage Probability [%]	90	
Log Normal Fading Margin [dB]	10	n
Allowed Path Loss for Cell Range [dB]	79.5758	o=m-n
Corresponding Cell Radius [m]	60	

The link budget used in this study is shown in Table 2. The back off of equipments of a base station is 5dB.

For each UE, the SINR is evaluated according to (2), where P is signal power, I is interference power and N is noise power.

$$SINR = \frac{P}{I + N_0} \qquad (2)$$

Moreover, the FBS is deployed at the center of a house. The signals power P in dBm of a UE received from a femtocell base station is evaluated according to (3), where t_f is the transmission power of a femtocell base station, G_f is the antenna gain, B_o is the back off of the system.

$$P = t_f + G_f - B_o - PL \qquad (3)$$

The path loss is evaluated as (4), where d and n_w respectively are the distance and the number of walls between the femtocell base station with the corresponding user equipment.

$$PL = 46.4 + 20\log_{10}(d) + 5n_w + 20\log_{10}(f/5) \qquad (4)$$

The setup of threshold γ_{req} is to consider the physical modulations and code rates is shown as Table 3. The transmission power of a FBS is 10dBm(10mw) with 3dBi antenna gain. The back off of equipments of a base station is 5dB. Moreover, the FBS is deployed at the center of a house.

TABLE 3 Maximum Spectral Efficiency of different MCS's

Modulation and Code Rate	SINR (dB)	γ_{req} Maximal Spectrum Efficiency (bps/Hz)
QPSK R1/2	0-6	1
QPSK R3/4	6-8.5	1.5
16QAM R1/2	8.5-12	2
16QAM R3/4	12-13	3
64QAM R1/2	13-16	3

Tables 4-9 demonstrate the performance for γ_{req} = 1, 2, and 3 bps/Hz with the available carrier components |CC|=1, 2, 3, 4, and 5. The simulation demonstrated the performance of subject strategy is better than the performance of maximal SINR strategy. The drop-free strategy presented better performance the subject strategy. However, the drop-free strategy is very difficult to be implemented in real system. However, the subject strategy can be implemented in real system.

Table 4 Outage and Drop rates for γ_{req} = 1 bps/Hz

Density / Method	10%			50%			100%		
	|CC|	P_{outage}	P_{drop}	|CC|	P_{outage}	P_{drop}	|CC|	P_{outage}	P_{drop}
MAX SINR	1	2.20	2.05	1	12.54	12.26	1	23.30	21.91
	2	0.04	0.22	2	1.20	3.65	2	4.45	10.51
	3	0.00	0.01	3	0.11	1.25	3	0.79	4.90
	4	0.00	0.00	4	0.00	0.33	4	0.00	2.28
	5	0.00	0.00	5	0.00	0.00	5	0.00	0.98
Drop-Free Strategy	1	4.16	0.00	1	22.68	0.00	1	40.16	0.00
	2	0.09	0.00	2	2.41	0.00	2	9.32	0.00
	3	0.00	0.00	3	0.17	0.00	3	1.46	0.00
	4	0.00	0.00	4	0.01	0.00	4	0.12	0.00
	5	0.00	0.00	5	0.00	0.00	5	0.00	0.00
Subject Strategy Without Power Control	1	2.26	1.98	1	14.96	10.93	1	32.05	18.32
	2	0.03	0.19	2	1.21	3.72	2	5.08	10.2
	3	0.00	0.02	3	0.09	1.22	3	0.85	4.89
	4	0.00	0.00	4	0.00	0.36	4	0	2.23
	5	0.00	0.00	5	0.00	0.08	5	0	0.93
Subject Strategy With Power Control	1	2.18	2.00	1	13.39	11.30	1	27.95	18.79
	2	0.03	0.19	2	1.19	3.72	2	4.91	10.24
	3	0.00	0.01	3	0.09	1.22	3	0.83	4.90
	4	0.00	0.00	4	0.00	0.36	4	0.00	2.24
	5	0.00	0.00	5	0.00	0.08	5	0.00	0.93

Table 5 System Throughput for γ_{req} = 1 bps/Hz

Density / Method	10%		50%		100%	
	|CC|	Throughput(bps)	|CC|	Throughput(bps)	|CC|	Throughput(bps)
MAX SINR	1	4.4381E+03	1	1.4718E+04	1	2.2564E+04
	2	5.1466E+03	2	2.0150E+04	2	3.2005E+04
	3	5.2876E+03	3	2.3126E+04	3	3.8642E+04
	4	5.3059E+03	4	2.4812E+04	4	4.3583E+04
	5	5.3076E+03	5	2.5686E+04	5	4.6725E+04
Drop-Free Strategy	1	4.4500E+03	1	1.4608E+04	1	2.1212E+04
	2	5.1522E+03	2	2.0550E+04	2	3.3603E+04
	3	5.2878E+03	3	2.3316E+04	3	3.9947E+04
	4	5.3059E+03	4	2.4866E+04	4	4.4246E+04
	5	5.3076E+03	5	2.5704E+04	5	4.7051E+04
Subject Strategy Without Power Control	1	4.4372E+03	1	1.4657E+04	1	2.0565E+04
	2	5.1499E+03	2	2.0144E+04	2	3.1850E+04
	3	5.2877E+03	3	2.3155E+04	3	3.8573E+04
	4	5.3062E+03	4	2.4809E+04	4	4.3573E+04
	5	5.3075E+03	5	2.5694E+04	5	4.6789E+04
Subject Strategy With Power Control	1	4.4392E+03	1	1.4656E+04	1	2.1549E+04
	2	5.1499E+03	2	2.0146E+04	2	3.1881E+04
	3	5.2877E+03	3	2.3155E+04	3	3.8576E+04
	4	5.3062E+03	4	2.4809E+04	4	4.3574E+04
	5	5.3075E+03	5	2.5694E+04	5	4.6789E+04

Table 6 Outage and Drop rates for γ_{req} = 2 bps/Hz

Density / Method	10%			50%			100%		
	|CC|	P_{outage}	P_{drop}	|CC|	P_{outage}	P_{drop}	|CC|	P_{outage}	P_{drop}
MAX SINR	1	5.52	4.35	1	22.36	17.31	1	33.44	21.19
	2	0.29	0.70	2	6.15	9.15	2	16.35	16.35
	3	0.01	0.05	3	0.86	4.03	3	5.61	12.19
	4	0.00	0.00	4	0.03	1.36	4	0.41	6.91
	5	0.00	0.00	5	0.00	0.38	5	0.00	3.40
Drop-Free Strategy	1	9.55	0.00	1	36.11	0.00	1	51.52	0.00
	2	6.00	0.00	2	10.17	0.00	2	24.20	0.00
	3	0.02	0.00	3	2.03	0.00	3	9.54	0.00
	4	0.00	0.00	4	0.26	0.00	4	2.33	0.00
	5	0.00	0.00	5	0.02	0.00	5	0.37	0.00
Subject Strategy Without Power Control	1	8.38	1.29	1	34.57	4.21	1	50.95	5.43
	2	0.47	0.26	2	9.11	2.88	2	23.20	4.96
	3	0.02	0.02	3	1.66	1.55	3	8.70	3.86
	4	0.00	0.00	4	0.16	0.68	4	1.88	2.56
	5	0.00	0.00	5	0.01	0.24	5	0.21	1.55
Subject Strategy With Power Control	1	5.95	1.60	1	29.75	5.66	1	47.13	7.57
	2	0.30	0.28	2	7.35	3.12	2	20.93	5.43
	3	0.01	0.02	3	1.12	1.61	3	7.45	4.01
	4	0.00	0.00	4	0.05	0.69	4	1.17	2.65
	5	0.00	0.00	5	0.00	0.24	5	0.06	1.58

Table 7 System Throughput for γ_{req} = 2 bps/Hz

Density / Method	10%		50%		100%	
	|CC|	Throughput(bps)	|CC|	Throughput(bps)	|CC|	Throughput(bps)
MAX SINR	1	4.3362E+03	1	1.3460E+04	1	2.1141E+04
	2	5.1320E+03	2	1.9098E+04	2	2.8405E+04
	3	5.2872E+03	3	2.2709E+04	3	3.6089E+04
	4	5.3063E+03	4	2.4672E+04	4	4.2233E+04
	5	5.3092E+03	5	2.5661E+04	5	4.6151E+04
Drop-Free Strategy	1	4.3611E+03	1	1.3433E+04	1	1.9473E+04
	2	5.1499E+03	2	2.0043E+04	2	3.1451E+04
	3	5.2888E+03	3	2.3290E+04	3	3.9097E+04
	4	5.3065E+03	4	2.4901E+04	4	4.4209E+04
	5	5.3092E+03	5	2.5736E+04	5	4.7327E+04
Subject Strategy Without Power Control	1	4.3484E+03	1	1.3180E+04	1	1.8695E+04
	2	5.1430E+03	2	1.9699E+04	2	3.0377E+04
	3	5.2853E+03	3	2.3044E+04	3	3.7981E+04
	4	5.3067E+03	4	2.4785E+04	4	4.3376E+04
	5	5.3076E+03	5	2.5678E+04	5	4.6736E+04
Subject Strategy With Power Control	1	4.3976E+03	1	1.3660E+04	1	1.9370E+04
	2	5.1458E+03	2	1.9861E+04	2	3.0784E+04
	3	5.2856E+03	3	2.3089E+04	3	3.8187E+04
	4	5.3067E+03	4	2.4793E+04	4	4.3488E+04
	5	5.3076E+03	5	2.5679E+04	5	4.6759E+04

Table 8 Outage and Drop rates for γ_{req} = 3 bps/Hz

Density / Method	10%			50%			100%		
	|CC|	P_{outage}	P_{drop}	|CC|	P_{outage}	P_{drop}	|CC|	P_{outage}	P_{drop}
MAX SINR	1	6.81	5.54	1	26.72	21.40	1	39.97	29.68
	2	0.45	0.94	2	8.21	11.23	2	20.62	23.42
	3	0.01	0.12	3	1.40	5.20	3	8.27	15.13
	4	0.00	0.01	4	0.08	2.07	4	1.33	9.00
	5	0.00	0.00	5	0.00	0.61	5	0.00	4.51
Drop-Free Strategy	1	11.80	0.00	1	41.61	0.00	1	59.22	0.00
	2	0.92	0.00	2	13.32	0.00	2	30.39	0.00
	3	0.03	0.00	3	3.10	0.00	3	13.23	0.00
	4	0.00	0.00	4	0.55	0.00	4	4.07	0.00
	5	0.00	0.00	5	0.05	0.00	5	0.72	0.00
Subject Strategy Without Power Control	1	11.61	0.24	1	43.11	1.24	1	61.35	2.74
	2	0.82	0.04	2	13.65	0.57	2	32.47	1.42
	3	0.03	0.00	3	3.13	0.24	3	14.21	0.73
	4	0.00	0.00	4	0.50	0.09	4	4.36	0.39
	5	0.00	0.00	5	0.05	0.02	5	0.84	0.21
Subject Strategy With Power Control	1	10.45	0.29	1	40.90	1.63	1	59.25	3.45
	2	0.70	0.04	2	12.80	0.63	2	31.05	1.65
	3	0.02	0.00	3	2.90	0.24	3	13.50	0.79
	4	0.00	0.00	4	0.45	0.09	4	4.11	0.41
	5	0.00	0.00	5	0.04	0.02	5	0.77	0.21

Table 9 System Throughput for γ_{req} = 3 bps/Hz

Density / Method	10%		50%		100%	
	|CC|	Throughput(bps)	|CC|	Throughput(bps)	|CC|	Throughput(bps)
MAX SINR	1	4.2589E+03	1	1.2394E+04	1	1.7706E+04
	2	5.1176E+03	2	1.8540E+04	2	2.6239E+04
	3	5.2842E+03	3	2.2444E+04	3	3.4562E+04
	4	5.3066E+03	4	2.4549E+04	4	4.1322E+04
	5	5.3084E+03	5	2.5609E+04	5	4.5752E+04
Drop-Free Strategy	1	4.2906E+03	1	1.2623E+04	1	1.7051E+04
	2	5.1397E+03	2	1.9653E+04	2	2.9743E+04
	3	5.2883E+03	3	2.3181E+04	3	3.8201E+04
	4	5.3070E+03	4	2.4890E+04	4	4.3868E+04
	5	5.3084E+03	5	2.5727E+04	5	4.7306E+04
Subject Strategy Without Power Control	1	4.2877E+03	1	1.2194E+04	1	1.5834E+04
	2	5.1435E+03	2	1.9479E+04	2	2.8557E+04
	3	5.2881E+03	3	2.3133E+04	3	3.7560E+04
	4	5.3072E+03	4	2.4873E+04	4	4.3596E+04
	5	5.3076E+03	5	2.5726E+04	5	4.7161E+04
Subject Strategy With Power Control	1	4.3236E+03	1	1.2552E+04	1	1.6501E+04
	2	5.1471E+03	2	1.9611E+04	2	2.9011E+04
	3	5.2882E+03	3	2.3164E+04	3	3.7784E+04
	4	5.3072E+03	4	2.4880E+04	4	4.3671E+04
	5	5.3076E+03	5	2.5727E+04	5	4.7179E+04

4. CONCLUSIONS

In this paper, we addressed the femtocell resource allocation to enhance system capacity with decreasing outage and drop rates. In future, we will consider the fault-tolerance problem. When there are variations in traffic, our strategy can adapt the system bandwidth to the traffic loads among femtocells. When a femtocell fails to provide wireless communication service, its occupied channels cannot be used to provide services. Our strategy can revoke the occupied channels of the failed BS and reallocate to other BSs used to provide services. The reduction of the system capacity when BSs fails to provide services will be light.

ACKNOWLEDGMENTS

The financial support of this research by the National Science Council of the R.O.C., under grant no. NSC 99-2632-E-324-001-MY3 is greatly appreciated.

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