System Performance Comparison of Three Channel Allocation Strategies in Next Generation Mobile Communication Networks with Femtocells

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Abstract— **Femtocell base stations are low power base stations which are able to provide indoor wireless network coverage with high transmission data rate to users. In this paper, three different channel allocation strategies are studied and the corresponding system performances, including SINR and throughput, are compared. We first show that femtocell deployment can improve system performance. We then show that a conservative channel allocation strategy not only provides good signal quality to individual user but also maximizes the total macrocell user throughput. On the other hand, a hybrid strategy that takes advantage of both conservative and aggressive strategies may yield even higher throughput if used in a proper setting.**

I. Introduction

As the wireless communication technology advanced over the years, being able to support not only voice communication but also high speed data transmission and multimedia applications, the users also develop a bigger appetite for more bandwidth. Following the success of IMT-2000, ITU-R subsequently proposed IMT-Advanced with the objective of providing 100Mbps data transmission rate to high mobility users and 1Gbps transmission rate to stationary users [1]. Furthermore, future wireless communication system will use the IP (Internet Protocol) based platform, integrating systems such as 3G, WLAN, and ADSL to provide users "always best connected" anywhere and anytime. Presently, two main standard organizations, 3GPP LTE-advanced and IEEE 802.16m, are developing the system standard for IMT-advanced. The first version focuses on the establishment of basic functions, and more advanced techniques are expected to be presented in later versions.

In order to reduce macrocell coverage holes and improve indoor transmission quality, femtocell is proposed in the IEEE 802.16m SDD technical document [2]. As shown in figure 1, femtocell base stations are low power base stations utilizing licensed frequency band. They are installed indoors and connect to the mobile service provider's network through users' ISP services such as DSL or cable modem.

Within the coverage of a macrocell, there may be hundreds or thousands of femtocells deployed. Given a limited amount of channel resources for macrocells and femtocells to share, how to properly allocate channels to macrocell and femtocells so that their co-channel interferences are minimized while simultaneously maintaining a high system capacity is a critical design issue. We have previously considered a channel allocation strategy ((c, s, n)=(1,3,3), see section III) and built a suburban femtocell simulation model that can analyze how the received signal quality (SINR) is improved as thousands of femtocells are deployed. In this paper, we further consider two other channel allocation strategies and compare their performance under different femtocell deployment densities. We focus on the down link performance, in particular the SINR (signal to interference plus noise ratio) and the throughput.

The research on femtocell issues has been proliferating in recent years. To name a few, [3], [4] study how spectrum/channels are allocated between macrocells and femtocells. But their interference model is simple. They only consider the interference between one macrocell base station and one femtocell base station. [5], [6], [7] study many 3G femtocell related issues. Most of their studies assume overlapping channel assignment between macrocells and femtocells.

The rest of the paper is organized as follows. In section 2, we give a brief background information on femtocells. In section 3, three different channel allocation strategies are described. In section 4, the system model and parameters of a next-generation mobile communication network with femtocells are described. In section 5, we show how the three channel allocation schemes fare with respect to one another in terms of MUE (macrocell user equipment) throughput when femtocells are deployed with different densities. Section 6 is the conclusion.

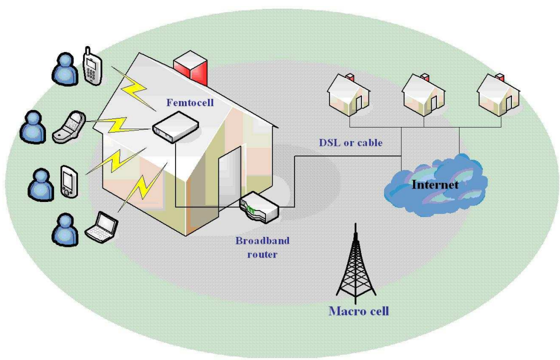

Fig. 1. Femtocell deployment Architecture.

II. Background

Femtocell base stations are low power and user deployed wireless access base stations. They connect to the core network by cable, DSL, optical cable or similar backhaul technology. [8]. Femtocells utilize licensed frequency band and lower transmission power compared to macrocells. The coverage of femtocells is between 30 meters to 100 meters. Moreover, femtocells are not required to provide large storage capacity to save user data, and complex backhaul network management mechanism is not necessary either. As a result, femtocells are suitable for wide deployment since they are simple, low cost, and easy to install.

Deploying femtocells in next generation wireless communication networks can enhance transmission quality. The main advantages of femtocells are described as follow:

1) Improve indoor signal quality: One of the most significant purposes of femtocells is to overcome the indoor signal degradation. According to [9], 32 % of users use wireless communication in indoor environment. The high frequency bands used in existing wireless wide band technology, such as 3G or WIMAX, do not allow signals to penetrate walls well. Therefore, femtocell is the best solution for solving the indoor signal degradation problem[10].

2) Enhance system coverage and performance: Femtocell base stations not only effectively improve signal degradation caused by walls, but also extend macrocell coverage and enhance cell edge service. Moreover, since femtocell base stations are near the femtocell users, the received signal strength can be maintained at a high level so that the users are able to obtain higher SINR which enhances the system performance.

3) Relieve the loading of macrocell base stations: Generally, a macrocell covers an area of 1 to 5km in radius and serves hundreds or even thousands of users. As mentioned in [11], because of the limitation of available bandwidth, the amount of simultaneously serviceable users is restricted. However, if femtocells are deployed and reuse the frequency band of macrocells, the traffic loads of macrocells can be mitigated and system throughput can be increased.

4) Low system deployment cost: Since femtocell base stations are devices required to be simple and easy to deploy without complex data processing and operation ability, the cost of hardware is much lower than that of macrocell base stations. According to [10], $200 femtocell base stations are commercially available, which is about the same price as that of a WiFi AP. Furthermore, the backhaul of femtocells to access the core network is a widely available wired access network. It enables network service providers to economize their deployment cost [12].

III. Channel Allocation Strategies

We study three different channel allocation strategies, including channel assignment (c, s, n) = (1,3,1), channel assignment (c, s, n) = (1,3,3), and FFR (Fractional Frequency Reuse). Different channel allocation strategies for macrocells have been conveniently distinguished by the (c, s, n) notation. The first symbol c is the cluster size, which is also called the frequency reuse factor, representing the number of macrocells that form a cluster to coordinate the reuse of frequency (or channels). For example, if c is one, it means that all macrocells reuse the same channel resources. The second symbol s is the number of sectors that divide a macrocell. When s is three, a macrocell is divided into three sectors and each sector spans 120 degrees. The third symbol n represents how many sectors are able to share the channel resource within a macrocell. For example, when n is three, each sector can utilize one third of channels allocated to a macrocell. FFR is a hybrid spectrum allocation strategy that mixes the use of different (c, s, n) strategies in a macrocell.

For femtocells, their channel allocation strategies have to accommodate what the overlapped mocrocell's channel allocation strategy is. The main consideration is to avoid co-channel interference with the macrocell. Given a macrocell channel allocation strategy, the femtocell is left with limited choices of its channel allocation strategies. In what follows, we use the macrocell channel allocation strategy to distinguish the three macrocell/femtocell channel allocation strategies.

A. Channel assignment (1,3,3)

If a macrocell utilizes channel allocation strategy (c, s, n) = (1,3,3), as shown in figure 2, and for example, sector 1 uses channel set w1, sector 2 uses channel set w2, and sector 3 uses channel set w3, then a femtocell within the macrocell can use the channel sets that are different from the one used in the sector where the femtocell locates. For example, the femtocells in sector 1 shall use channel sets w2 and w3 to avoid co-channel interference with the macrocell.

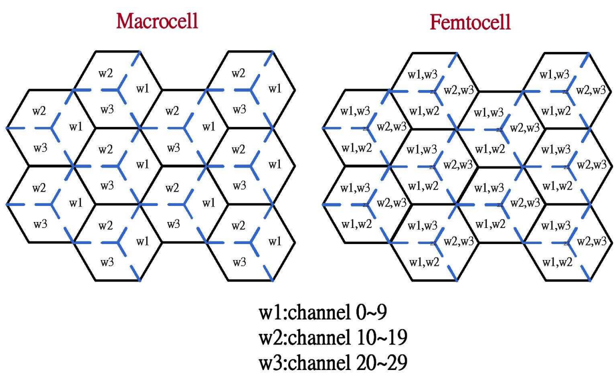

Fig. 2. Channel assignment (1,3,3).

B. Channel assignment (1,3,1)

As shown in figure 3, in (c, s, n)=(1,3,1), each sector of a macrocell uses the same channel set w, where w is the union of w1, w2, and w3. Accordingly, since this is an aggressive reuse of the channel resources and there is no orthogonal channels left for the femtocells to use, femtocells are allowed to use the same channel set w.

(c, s, n)=(1,3,1) is an aggressive channel reuse strategy to serve more users. However, for macrocell users at the cell edge, the received signal quality may be severely degraded due to serious co-channel interference. Similarly, because femtocells are forced to use the same channel set as that of the macrocell, femtocell users may experience a high interference too. Whether aggressive channel reuse will result in higher system capacity/throughput is one of the questions we would like to answer.

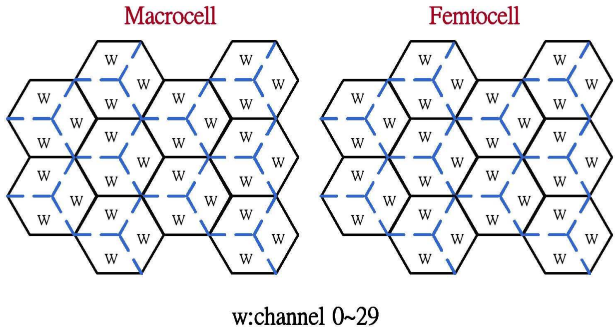

Fig. 3. Channel assignment (1,3,1).

C. Fractional frequency reuse

In the fractional frequency reuse channel allocation strategy, separate channel sets are allocated to the inner region and the outer region of a macrocell. The left-hand side of figure 4 shows the channel allocation for macrocells. We divide the available channel resources into 4 channel sets. In the inner region, all three sectors use the same channel set w1. In the outer region, sector 1 uses channel set w2, sector 2 uses channel set w3, and sector 3 uses channel set w4.

In addition, we adopt orthogonal channel allocation between femtocells and macrocells as shown on the right-hand side of figure 4. In the outer region, femtocells in sector 1 use channel sets w1, w3, and w4; femtocells in sector2 use channel sets w1, w2, w4; femtocells in sector 3 use channel sets w1, w2, w3. Meanwhile, in the inner region, femtocells in sector 1 use channel sets w3 and w4; femtocells in sector 2 use channel sets w2 and w4; femtocells in sector 3 use channel sets w2 and w3. Furthermore, the number of channels in the inner region and that in the outer region are determined based on the area ratio of the inner region to the outer region. For example, in figure 4, when the area ratio of the inner region to the outer region is one, both inner region and outer region are allocated the same number of channels.

In summary, (1,3,3) is a conservative channel allocation strategy in that it emphasize minimizing the interference at the expense of less channels for use per sector. (1,3,1) is an aggressive channel allocation strategy in that each sectors reuse all channels. The drawback is the strong interference at the cell edge as well as the stronger cross-tier (macro-femto) interference. FFR is a compromise between the two.

IV. System Model

A. Cell architecture

We consider a femtocell deployment model in a suburban area as shown in Figure 5 [13]. There are 19 macrocells,

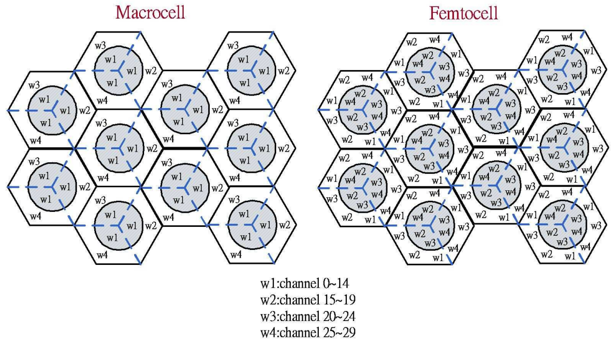

Fig. 4. Fractional Frequency Reuse (Area ratio: inner area:outer area = 1:1).

and each macrocell may contain hundreds or thousands of femtocells. Furthermore, the entire area is filled with housing blocks and streets. Houses are located within each block, and when users (or user equipment, UE) are inside a house, they are considered indoors. On the contrary, UEs are in the outdoor environment when they are on streets or in-between houses but within the block. UEs are randomly placed in the area, and then based on the location of the UEs, interferences from 18 surrounding macrocells and neighbor femtocells are calculated. Finally, signal quality and system performance are determined according to the propagation loss model and co-channel interference.

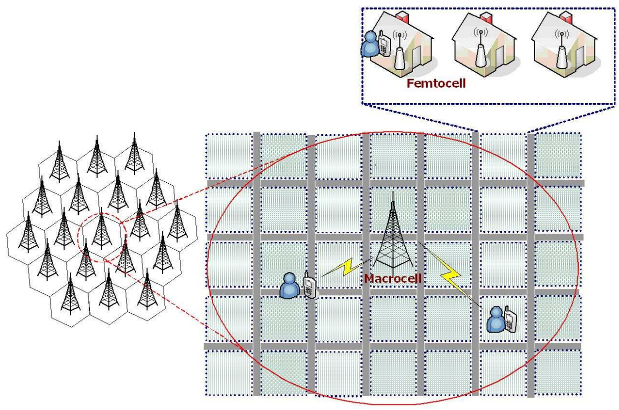

Fig. 5. System Environment.

The detailed model for one macrocell area is shown in figure 6. Each block is a 200 by 200 squared meter area, which is further divided into 100 (20mx20m) lots. There is exactly one house in each lot. The house is modeled by a 14m by 14m square, centered in the lot with a 3-meter space to the border of the lot on each side. In other words, there is a 6-meter separation between houses. Blocks are separated by 30-meter wide streets. Based on the given femtocell density, a house is randomly chosen to deploy a femtocell base station. If a house is required to place a femtocell base station, the femtocell base station is placed in the center of the house.

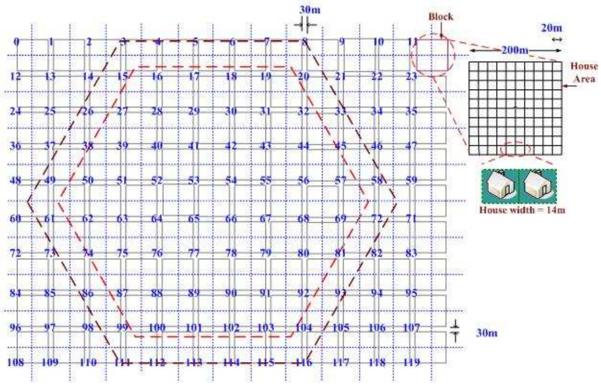

Fig. 6. Relationship between streets and blocks.

TABLE I
COMMUNICATION SYSTEM PARAMETERS.

Parameter	Value
Macrocell Transmit Power [dBm]	46.532 (45W)
Femtocell Transmit Power [dBm]	12.3 /16.7 / 20.3
Macrocell Coverage Range [m]	1000
Femtocell Coverage Range [m]	30 / 40 /50
Macrocell Antenna Height [m]	12.5
Back-off [dB]	5
UE Noise Figure [dB]	7
Noise Power Density [dBm]	-169.93

B. System parameters

To calculate SINR at the UE, we need to have the received signal strength (RSS), interference strength, and noise power. The first two are calculated by adding antenna gain G_{ant} (assuming to be 0 dB here) and deducting back-off (BO), and path loss (PL) from the transmitter power (P_T).

$$RSS(dBm) = P_T - BO + G_{ant} - PL.$$

The values of transmission power, antenna height, transmitter side back-off, and receiver side noise figure used in our study are listed in Table 1. The parameters of the OFDMA system are listed in Table 2. They are all chosen based on the IEEE802.16m Evaluation Methodology Document (EMD) [8], IEEE802.16-2004 [14], and IEEE 802.16m System Requirements Document (SRD) [15]. Note that the term "channel" used in the paper is equivalent to the "subchannel" in an OFDMA system. We will use the two terms interchangeably.

C. Path loss modeling

IEEE 802.16m EMD standard document also provides various path loss models. In our study, according to the location of UE and the type of serving base station (macrocell or femtocell), the path loss can be categorized as follows.

- Outdoor macrocell UE path loss model

$$PL[dB] = 38\log_{10}(d) + 21\log_{10}(f) + 62.26$$

- Indoor macrocell UE path loss model

$$PL[dB] = PL_b + PL_{tw} + PL_{in},$$

TABLE II
OFDMA PARAMETERS.

Parameter	Value
Carrier frequency [GHz]	2.5
Channel bandwidth [MHz]	10
FFT size	1024
Frame duration [ms]	5
OFDMA symbol duration [gs]	102.86
Number of subchannels	30
Total symbol number	47 (23UL, 23DL)
Number of subcarriers	28
Number of subchannels per UE	2

where

$$\begin{aligned} PL_b &= 32.4418 + 20\log_{10}(f) + 20\log_{10}(d) \\ &+ 0.0174d + 20\log_{10}(max(0.013d/f), 1), \\ PL_{tw} &= 14 + 15(1-\cos(\theta))^2, \\ PL_{in} &= 0.5d_{in} \end{aligned}$$

- Indoor femtocell UE path loss model

$$PL(dB) = 46.4 + 20\log_{10}(d) + 20\log_{10}(f/5.0) + 12n_w$$

- Outdoor femtocell UE path loss model

$$PL[dB] = 43.8 + 36.8\log_{10}(d) + 20\log_{10}(f/5.0) + 12n_w$$

In the above, d is the distance between the base station and the UE, f is the carrier frequency, n_w is the number of walls that the signal has to penetrate, and θ is the angle between the signal incident line and the line perpendicular to the wall of the house.

V. PERFORMANCE COMPARISONS

We wrote a C++ simulation software to evaluate the downlink performance of users (or UE). The SINR and throughput that a UE will experience is heavily dependent on its location relative to the base stations (BS). To obtain the distributions of SINR and throughput, we repeat 3000 times of independently placing a UE uniformly in the macrocell area. For statistical significance, the above process is repeated 10 times for a given femtocell deployment density. In each UE placement, the signal strength from the serving base station and interferences from the co-channel macrocells and femtocells are calculated. We assume that all the deployed femtocells are active, which means that each femtocell has one stationary UE (subscriber) communicating with the femtocell base station. In other words, as soon as a femtocell is placed in the system, one subchannel is allocated to the stationary user. Afterwards, when a new UE becomes active, macrocell BS or femtocell BS will be chosen to be connected with based on the RSSI (received signal strength indication) level. After connecting to either a macrocell BS or a femtocell BS, the UE is allocated with one available subchannel according to the underlying channel allocation strategy.

Once the SINR is calculated, we adopt the mutual information equivalent SINR mapping (MIESM) method [8] to derive

TABLE III

SYSTEM PERFORMANCE OF CHANNEL ASSIGNMENT (c, s, n) = (1,3,3).

Density	Avg. SINR (dB)	Avg. MUE SINR (dB)	Avg. FUE SINR (dB)	Total MUE TP (Mbps)	Per UE avg. TP
0	9.30	9.30	N/A	10.56	0.35
0.1	11.10	10.62	13.14	11.63	0.37
0.5	18.04	14.21	20.74	14.62	0.44
0.9	24.78	15.72	27.66	15.91	0.49

TABLE IV

SYSTEM PERFORMANCE OF CHANNEL ASSIGNMENT (c, s, n) = (1,3,1).

Density	Avg. SINR (dB)	Avg. MUE SINR (dB)	Avg. FUE SINR (dB)	Total MUE TP (Mbps)	Per UE avg. TP
0	-1.75	-1.75	N/A	8.76	0.097
0.1	0.20	-1.03	5.38	9.96	0.120
0.5	7.27	0.76	11.86	13.18	0.208
0.9	14.13	1.50	18.14	14.55	0.300

the block error rate (BLER). The method considers different levels of signal degradation over the constituent sub-carriers in a subchannel. It also considers the adaptive modulation in an OFDMA system to map the SINR to the received bit mutual information rate (RBIR). Once the BLER is calculated, we can derive the successful data rate, or the throughput.

Since there are a large amount of femtocells close to each other, when femtocells allocate subchannels to UEs, a proper interference-aware channel assignment mechanism is adopted to avoid allocating the same subchannels already used by nearby femtocells. The mechanism assumes that all the femtocells are capable of scanning the entire frequency spectrum, and then each femtocell chooses the subchannel that has the lowest carrier strength [13].

A. SINR and throughput

1) (1,3,3) vs. (1,3,1): The SINR and throughput of (c, s, n)=(1,3,3) and (c, s, n)=(1,3,1) channel allocation strategies are shown in tables III-IV. First, we observe improved SINR and throughput as more femtocells are deployed in both strategies. (c, s, n) = (1,3,3) has significantly better SINR (more than 10 dB) than (c, s, n)=(1,3,1). The per UE average throughput of (1,3,3) is at least three times better than that of (1,3,1) when no femtocells are deployed. But as more femtocells are deployed, the per UE throughput difference becomes smaller. In terms of total MUE throughput, which accounts for the number of UEs that a macrocell can serve (30 for (1,3,3) and 90 for (1,3,1)), (1,3,3) edges out (1,3,1) by more than 10 percent. The results show that a strategy that avoids intra-cell and inter-cell interferences at the expense of reduced number of served UEs is advantageous in terms of overall system capacity.

2) FFR: For FFR, as more femtocells are deployed, the SINR and throughput are also improved. Here, we show only two femtocell deployment cases: density = 0 and 0.5, in Tables V and VI, respectively. In each case, we also show how different values of the FFR radius that defines the inner/outer regions can influence the SINR and throughput.

With a small FFR radius, FFR behaves very much like the (c, s, n)=(1,3,3). As the radius increase, FFR becomes more like the (c, s, n)=(1,3,1). When no femtocells are deployed and the FFR radius is smaller than 0.6km, the total MUE throughput of FFR is higher than that of (c, s, n)=(1,3,3). When femtocell density is 0.5, the FFR radius has to be less than 0.3km so that it can achieve higher throughput than (1,3,3). Therefore, when the FFR radius is properly set at a relatively small value, FFR makes sense because it provides more channels to inner region MUEs (merit of (1,3,1)), and at the same time, the MUEs in the outer region suffer less degree of interferences (merit of (1,3,3)).

TABLE V

SYSTEM PERFORMANCE OF FFR (NO FEMTOCELL).

Radius km)	Avg. MUE SINR (dB)	Avg. FUE SINR (dB)	Total MUE TP	Per UE avg. TP
0.1	8.82	N/A	11.76	0.347
0.2	7.85	N/A	11.50	0.332
0.3	6.64	N/A	12.33	0.306
0.4	5.41	N/A	11.18	0.270
0.5	4.17	N/A	12.41	0.228
0.6	2.93	N/A	11.71	0.191
0.7	1.63	N/A	10.20	0.150
0.8	0.23	N/A	9.69	0.120
0.9	-1.35	N/A	8.52	0.102

TABLE VI

SYSTEM PERFORMANCE OF FFR (FEMTOCELL DENSITY = 0.5).

Radius km)	Avg. MUE SINR (dB)	Avg. FUE SINR (dB)	Total MUE TP	Per UE avg. TP
0.1	13.35	19.44	15.35	0.422
0.2	11.39	19.46	14.96	0.412
0.3	9.26	18.25	15.25	0.383
0.4	7.18	18.45	13.72	0.358
0.5	5.46	17.08	14.05	0.311
0.6	4.04	17.39	13.44	0.296
0.7	2.90	18.03	12.37	0.282
0.8	2.10	18.20	13.16	0.280
0.9	1.13	14.38	12.98	0.240

B. System throughput vs. number of UEs

In this section, we study how the system throughput varies as the number of UEs that request connection service increases. The system throughput is the sum of the macrocell throughput and the femtocell throughput. In figure 7, we first present the system throughput when no femtocells are deployed. For FFR, we use the set of data corresponding to FFR radius equal to 0.5 km. Without femtocells, the number of served UEs is bounded. Channel assignment (c, s, n)=(1,3,1) is capable of serving 90 UEs, with maximum throughput at 8.76 Mbps; channel assignment (c, s, n)=(1,3,3) is capable of serving 30 UEs, with maximum throughput at 10.56 Mbps; FFR is capable of serving 54 UEs, with maximum throughput at 12.41 Mbps. Therefore, as shown in figure 7, each curve has a reflection point representing when the maximum number of serviceable UEs has been reached. After this point, if UEs continue entering the system, no increase of system throughput is possible. Note that there are two reflection points in FFR, the first one indicating when one of the regions is saturated and the second one indicating when both regions are saturated. The slope of the curve becomes smaller after the first reflection point because some newly arrived UEs may situate in the region where the channels are saturated while other regions still have available channels.

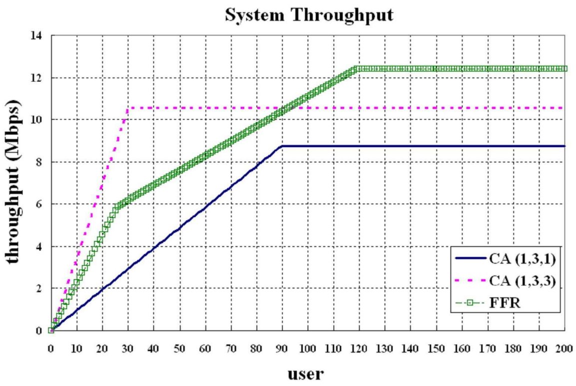

Fig. 7. System throughput (no femtocell).

In figure 8, the system throughput is plotted against the number of UEs when the femtocell deployment density is 0.5. When femtocells are deployed, the number of serviceable UEs and the system throughput can keep on increasing as long as there are sufficient femtocells in the system. There is also a reflection point in each curve. Beyond the reflection point, the increase of system throughput slows down because the macrocell has been saturated. The system throughput increases only when newly arrived UE connects to the femtocell. Note that the FFR is close to but not as good as (1,3,3). This is in agreement with the results in the previous subsection where we show FFR brings advantage at a smaller FFR radius as femtocell density increases.

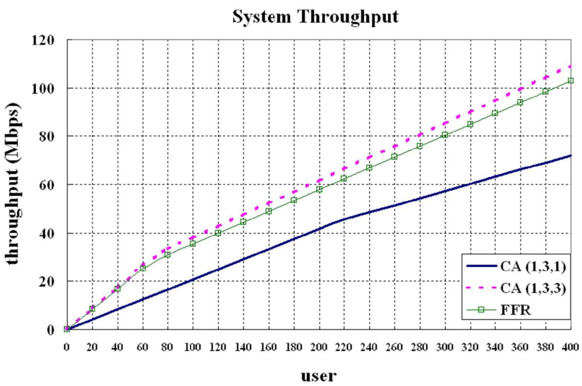

Fig. 8. System throughput (Density = 0.5).

VI. Conclusion

We study three channel allocation strategies for a next generation mobile communication network with femtocells. We show that the SINR and throughput improve as more femtocells are deployed. Under the same femtocell deployment condition, the conservative (in terms of channel reuse) strategy, (c, s, n)=(1,3,3), is shown to provide higher SINR, per user throughput, and total macrocell user throughput than the aggressive (c, s, n)=(1,3,1) strategy, though (1,3,1) is able to support more users with degraded throughput. The FFR (Fractional Frequency Reuse) is a hybrid strategy that aims to take advantage of the merit of both (1,3,3) and (1,3,1). We show that FFR is able to provide higher throughput than (1,3,3) when the FFR radius is less than half of the macrocell radius. As more femtocells are deployed, the advantage of FFR diminishes.

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