A Novel Component Carrier Selection Algorithm for LTE-Advanced Heterogeneous Networks

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Abstract—**Carrier aggregation has been proposed in LTE-advanced to support a wider bandwidth up to 100 MHz. The basic aggregated unit is called component carrier (CC). CCs are shared among different devices. Therefore it may cause performance degradation due to severe interference. A good CC assignment mechanism is desired to alleviate the interference problem. In this article, we propose a CC selection algorithm called Interference Management based Component Carrier (IMCC) scheduling to tackle the problem in heterogeneous networking environments of Femto Access Points (FAPs) and Macro-cell base stations. IMCC assigns CCs according to the entire system information, such as, location of FAPs, location of UEs (User Equipments), and the channel quality based on an evolutionary approach. In this way, IMCC mitigates the interference, and improves the system throughput. We construct a simulation environment with some stripes of apartments, which is often used to evaluate the performance of FAPs in prior works. The simulation results indicate the proposed approach outperforms other algorithms and show the effectiveness of IMCC.**

Keywords—**component carrier; carrier aggregation; interference management; LTE-advanced.**

I. INTRODUCTION

Nowadays, the total mobile traffic of the whole world is growing exponentially thanks to the number of mobile users. Mobile users want higher throughput and lower latency while using wireless communication. Long Term Evolution-Advanced is developed to meet the increasing demand. It can support the throughput of 100 Mbps for high mobility users (such as user in the train) and 1 Gbps for low mobility users. Carrier aggregation is proposed as a solution to support a wider bandwidth up to 100 MHz for LTE-Advanced to deliver such a high throughput.

In carrier aggregation, the basic aggregated unit is called component carrier (CC). Carrier aggregation supports a wider bandwidth by aggregating two or more CCs. However, LTE-Advanced standard hasn't specified the way of CC assignment. Many issues remain to be answered in CC assignment. CCs can not only be aggregated to support a wider bandwidth, but also shared among many devices. It is inevitable to produce interference in such a CC-sharing scheme. Despite using carrier aggregation, to shrink the cell size is also a key technique to improve the performance in cellular networks.

Shrinking the cell size may reduce coverage range of a macro cell. On the other hand, users need high data rate and a macro cell may not satisfy all users' demand in the cell. Therefore, femtocell would be a viable solution to handle this situation. However, there are some challenges to deploy femtocells, such as, massive deployment, uncoordinated deployment, and high density [1]. These challenges cause the interference between Femto Access Points (FAPs) [2] to be severe and unpredictable. So, the interference is the main factor affecting the system performance, and CC selection of each FAP is an important topic to be explored.

In this paper, we consider the CC selection of each FAP in a heterogeneous networking environment. The goal of the proposed approach called "IMCC" (Interference Management based Component Carrier scheduling algorithm) is designed to mitigate the interference and achieve the maximum throughput. Since the determination of CC selection can not be solved analytically, IMCC is an evolutionary computation approach based on PSO (Particle Swarm Optimization) mechanism [3]. We devise a discrete computing approach, which is used in IMCC to solve the CC selection problem. One advantage of IMCC is the adaptive capability since IMCC takes the whole system information into consideration, such as, the location of FAPs, the location of UEs (User Equipments), and the channel quality. Therefore, the interaction between deployed FAPs is also considered in IMCC. When the CC selection is determined, IMCC then assigns the appropriate power on each used CC of each FAP.

We construct the simulation environment of a heterogeneous networking environment which consists one marcocell and many FAPs. FAP are deployed in an environment with some stripes of apartments which is a commonly used scenario in prior works to evaluate FAP performance. The performance of IMCC is compared with several existing CC-selection algorithms [1], [4], [5]. From our computer simulations, the results indicate the proposed approach outperforms other algorithms.

The rest of this paper is organized as follows: In Section II, we introduce some related work. The system model is explored in Section III and in Section IV, we describe the proposed algorithm. The simulation results are presented in Section V, and Section VI is our conclusion.

II. RELATED WORK

The purpose of carrier aggregation is to aggregate multiple CCs to get a wider bandwidth for transmission. LTE-advanced

[2] is an intensive spectrum sharing environment, while many cells aggregate the same CCs to form a wider bandwidth at the same time, which leads to severe interference. Therefore, the interference is an important factor to affect system performance. Interference management inevitably becomes an important topic and many works focus on this issue. The simplest strategy of CC selection is called universal reuse or reuse of factor 1. Universal reuse allows each cell to access each CC without any restriction. A. Simonsson [6] shows us that universal reuse performs best for wideband services. From another aspect, Y. Wang [7] tells us that an appropriate reuse factor leads to an improvement in 5%-outage user throughput in uncoordinated local area deployment. Decentralized Intercell-Cell Interference Coordination (D-ICIC) was proposed by Ellenbeck [8], which parametrized by the amount of channels N that each femtocell can allocate. G. Costa et al. [1] propose a dynamic channel selection algorithm to increase system performance in a femtocell scenario. He shows that dynamic channel selection is better than the static amount of channels.

L. Garcia et al. [4] propose an algorithm called "Autonomous Component Carrier Selection" (AACS) which is a fully distributed and slowly-adaptive algorithm. The CC selection criterion is to estimate the carrier-to-interference ratio to decide which CC can be chosen. The values of this ratio are static in ACCS, so there are some drawbacks in using these static values. Because of the nature of distributed properties, the complexity of ACCS is low, but ACCS may not obtain the optimal solution about CC selection in each cell. On the other hand, ACCS only provides a method of CC selection, it doesn't take transmission power of each CC into consideration. The author improves ACCS with power adaption on each CC in his following work [5].

R. Menon et al. [9] use potential game to provide a work about interference avoidance (IA). Similarly, K. Son et al. [10] also use potential game to formulate distributed IA which focuses on transmission over multiple channels in cellular network scenario. G. Costa et al. [1] propose an algorithm called "Timeout Based Reuse Selection" (TBRS). In his algorithm, each FAP determines its own reuse factor to approach IA in the whole system. He shows the performance of TBRS is better than D-ICIC. Therefore, in this work, we compare IMCC with ACCS, G-ACCS, and TBRS.

III. SYSTEM MODEL AND PROBLEM FORMULATION

In this section, we present the system model, and formulate the CC selection in a heterogeneous networking environment with the system performance. In addition, we give a simple analysis about the complexity of the problem at the end of this section.

A. System Model

We consider an environment with a LTE-advanced macro cell, several LTE-advanced FAPs, and several user equipments (UEs). Suppose that the number of FAPs is N, and the number

of UEs is K. LTE-advanced adopts carrier aggregation, therefore the bandwidth of the communication system is aggregated by L CCs. The macro cell always uses the whole bandwidth to transmit data, and FAPs transmit data by using the selected CCs, which is a subset of L CCs. We apply a full buffer traffic model with infinite data packets in the queue for each FAP. h_{fj} denotes the channel gain between FAP f and user j, and $h_{bs,j}$ is the channel gain between macro cell and user j. $\mathbb{I}$ denotes the CC assignment matrix where an element of $\mathbb{I}$, i_{fl}, equals to 1 if FAP f uses CC l.

Our work is first to focus on component carriers scheduling for each FAPs. Therefore, to simplify the problem, we suppose the transmission power is fixed and denoted by P_f and P_{bs} for each FAP and macro cell respectively. We suppose FAPs and macro cells allocate their power in each used component carrier uniformly. P_{fl} and $P_{bs,l}$ denote the transmission power on component carrier l of FAP f and macro cell respectively. U_f and U_{bs} denote the set of users associated with FAP f and the macro cell. $|U_f|$ and $|U_{bs}|$ are the number of elements of U_f and U_{bs}. An UE can only belong to a FAP or the macro cell, so we can describe the situation using the following equations:

$$\sum_{f=1}^{N} |U_f| + |U_{bs}| = K$$
$$\text{and} \quad U_i \cap U_j = \phi, \forall \ i \neq j \tag{1}$$

Suppose the transmission power of each FAP is P, and the power is uniformly distributed on each selected CCs, therefore P_{fl} can be computed as the follows:

$$P_{fl} = \frac{P_f}{\sum_{b=1}^{L} i_{fl}} \times i_{fl} \tag{2}$$

The modified Shannon formula developed in [11] is used to calculate the system performance. The formula can be depicted as below:

$$S = BW_{eff} log_2(1 + \frac{SINR}{SINR_{eff}}) \tag{3}$$

where B denotes the system bandwidth. W_{eff} and $SINR_{eff}$ adjust the system bandwidth efficiency and the Signal to Noise plus Interference Ratio (SINR) implementation efficiency respectively.

Next, we denote C_{fl} be the capacity of FAP f on selected CC l. We calculate the capacity of each user in FAP f, and sum up all of the capacity of user in FAP f to get C_{fl}. The equation is as the follows:

$$C_{fl} = \sum_{u \in U_f} \frac{B}{L|U_f|}$$
$$\times log_2(1 + \frac{P_{fl}h_{fu}}{\frac{BN_0}{L} + \sum_{f'=1, f' \neq f} P_{f'l}h_{f'u} + P_{bs,l}h_{bs,u}}) \times i_{fl} \tag{4}$$

where N_0 is the noise power per hertz, and L is the number of component carriers. Analogously, $C_{bs,l}$ is the capacity of the macro cell on CC l. We calculate the capacity of each user in the macro cell, and sum up all of the capacity of users in the macro cell to get $C_{bs,l}$. The equation is shown below:

$$C_{bs,l} = \sum_{u \in U_{bs}} \frac{B}{L|U_{bs}|} \qquad (5)$$

$$\times log_2(1 + \frac{P_{bs,l}h_{bs,u}}{\frac{BN_0}{L} + \sum_{f'=1}^{F} P_{f'l}h_{f'u}})$$

The total capacity C_{total}, the sum of capacity of FAPs and the macro cell, can be depicted as the follows:

$$C_{total} = \sum_{l=1}^{L}(C_{bs,l} + \sum_{f=1}^{F} C_{fl}) \qquad (6)$$

B. Problem Formulation

The binary assignment matrix $\mathbb{I}$ records the selected CC used by each FAP. For a specific assignment matrix $\mathbb{I}$, the system performance will be calculated according to (6). The goal of the proposed approach is to find a suitable CC assignment matrix $\mathbb{I}$ such that the maximum system throughput can be achieved. Therefore, the problem is depicted as follows:

$$\underset{\mathbb{I}}{\text{Maximize}} \quad C_{total} \qquad (7)$$

Each FAP can choose a CC for transmission or not. The number of CCs is L, so each FAP has 2^L different ways to choose CCs for transmission. The system has N FAPs, so the complexity of this problem becomes $O(2^{NL})$ if the exhausted search mechanism is used to find the optimal solution. The complexity increases exponentially with respect to the number of CCs and FAPs. When the parameter is large, it becomes impractical to use such a mechanism.

IV. PROPOSED ALGORITHM

Our design is based on an evolutionary computation approach called particle swarm optimization to find a suitable CC assignment matrix $\mathbb{I}$. The original PSO algorithm [3] is used in continuous case, but our problem is a discrete case. In this paper, we redefine position and velocity in order to determine the binary assignment matrix.

A. Particle Swarm Optimization

Particle Swarm Optimization is an optimization algorithm developed by James Kennedy and Russell Eberhart in 1995 [3]. In PSO, each candidate solution is seen as a particle. The algorithm is to randomly spread particles in the search space, and assign the position and velocity of each particles. Each particle would move in the search-space according to its position and velocity, and each particle has its own performance. In this way, local and global maximum performance can be defined since we know each particle's performance. The movement of each particle is influenced by these two maxima, namely the particle would move approach to the particle with maximum performance. The behavior of particles at time t is shown as follows:

$$\begin{aligned} V_i(t) &= W \times V_i(t-1) + C_1 \times rand \times (P_{best}(t-1) - X_i(t-1)) \\ &\quad + C_2 \times rand \times (G_{best}(t-1) - X_i(t-1)) \\ X_i(t) &= X_i(t-1) + V_i(t) \end{aligned}$$

$$(8)$$

where $V_i(t)$ is the velocity of particle i at time t, X_i is the position of particle i at time t, and W is the inertial weight. C_1 and C_2 are the positive constant parameters, rand is the random function which takes value in range [0,1], P_{best} is the best position of the particle, and G_{best} is the position of the particle with best performance among all particles.

B. IMCC

In our problem, a particle represents a specific assignment matrix which represents component carriers selected by femto cells. Suppose that the communication environment has K users, N FAPs, and L CCs. Each user links to the nearest FAPs or macro cell, which means the user would receive the largest signal power. Each particle is an $N \times L$ matrix to represent an assignment method for FAPs. We suppose there are P particles in the proposed algorithm, denoted by $\{Particle_1, Particle_2, ..., Particle_p\}$, and $Partcile_i(j, k)$ is the element in row j and column k of the particle i. $Particle_i(j, k)$ equals to 1 if FAP j use CC k in particle i, otherwise, it equals to 0.

Then, the performance of each particle can be computed according to 6. Rec_i is denoted as the best score of the $Particle_i$ from the beginning to the current iteration and $recParticle_i$ is the assignment matrix of this best score. This best score is referred to the P_{best} in the original PSO algorithm. The initial values of Rec_i and the elements of $recParticle_i$ are all zero for $i \in \{1, 2, ..., p\}$. New C_{total} of 6 is computed in each iteration, and Rec_i is updated accordingly. Let Opt be the global maximum matrix among all Rec_i, and

$$Opt = \arg\max_i\{Rec_i\}, i \in \{1, 2, ..., p\} \qquad (9)$$

Rec_{opt} is referred to G_{best} in the original PSO algorithm and $recParticle_{opt}$ is its assignment matrix.

Before we define the movement operation of the assignment matrix to approach closer to P_{best} or G_{best}, we need to define the distance $D(P_1, P_2)$ between two particles of P_1 and P_2. The definition is shown below:

Definition: The distance between matrices $\mathbb{A}$ and $\mathbb{B}$ ($\mathbb{A}$ and $\mathbb{B}$ are both N by M matrices) is

$$D(\mathbb{A}, \mathbb{B}) = \sum_{i=1}^{N} \sum_{j=1}^{M} a_{ij} \oplus b_{ij} \qquad (10)$$

where a_{ij} and b_{ij} are the element of ith row and jth column of matrix $\mathbb{A}$ and $\mathbb{B}$ respectively, and notation $\oplus$ represent XOR operation.

The goal of the movement is to approach either the local maximum or the global maximum, namely to decrease the

distance between particle and P_{best} or G_{best}. The particle usually can get a higher score with this movement. Two moving operations are defined as:

Definition: The move operation $Move_{\mathbb{G}}(\mathbb{P})$ and $Move_{\mathbb{L}}(\mathbb{P})$ are defined as follows:

$$Move_{\mathbb{G}}(\mathbb{P}) \quad : \quad p_i^t = g_i^t, i = randi(1, M)$$
$$Move_{\mathbb{L}}(\mathbb{P}) \quad : \quad p_i^t = l_i^t, i = randi(1, M)$$

where $\mathbb{P}$, $\mathbb{G}$, $\mathbb{L}$ are $M \times N$ matrix, and $\mathbb{P} = [p_1^t p_2^t ... p_M^t]^t$, $\mathbb{G} = [g_1^t g_2^t ... g_M^t]^t$, $\mathbb{L} = [l_1^t l_2^t ... l_M^t]$. $randi(a, b)$ returns a random integer between a and b. $\mathbb{G}$ is referred to the global maximum assignment matrix $recParticle_{opt}$, and $\mathbb{L}$ is referred to the local maximum assignment matrix $recParticle_i$ mentioned before. While doing $Move_{\mathbb{G}}(\mathbb{P})$ operation, we arbitrarily change a row of $particle_i$ to the same row of $recPartcile_i$ to move closer to P_{best}, and $Move_{\mathbb{L}}(\mathbb{P})$ operation is similar.

Proposition: The action $Move_{\mathbb{G}}(\mathbb{P})$ and $Move_{\mathbb{L}}(\mathbb{P})$ can decrease $D(\mathbb{P}, \mathbb{G}_{best})$ and $D(\mathbb{P}, \mathbb{P}_{best})$ respectively.

Proof: Let the $\acute{P}$ be the particle after particle P did operation $Move_{\mathbb{G}}(\mathbb{P})$. Without loss of generality, we suppose the kth row of $\mathbb{P}$ is chosen to be changed to the kth row of $\mathbb{G}_{best}$. From Eq.10, we know the distance between $\mathbb{P}$ and $\mathbb{G}_{best}$ is:

$$D(P, G_{best}) = \sum_{i=1}^{N} \sum_{j=1}^{M} p_{ij} \oplus g_{ij} \tag{11}$$
$$= \sum_{i=1, i \neq k}^{N} \sum_{j=1}^{M} p_{ij} \oplus g_{ij} + \sum_{j=1}^{M} p_{kj} \oplus g_{kj}$$

The only difference between $\mathbb{P}$ and $\acute{\mathbb{P}}$ is the kth row, so we have

$$\sum_{i=1, i \neq k}^{N} \sum_{j=1}^{M} p'_{ij} \oplus g_{ij} = \sum_{i=1, i \neq k}^{N} \sum_{j=1}^{M} p_{ij} \oplus g_{ij} \tag{12}$$

Since the kth row of $\acute{P}$ and G_{best} are the same

$$\sum_{j=1}^{M} \acute{p} \oplus g_{kj} = \sum_{j=1}^{M} g_{kj} \oplus g_{kj} = 0 \leq \sum_{j=1}^{M} p_{ij} \oplus g_{kj} \tag{13}$$

Therefore, we have

$$\sum_{i=1}^{N} \sum_{j=1}^{M} \acute{p}_{ij} \oplus g_{ij} \leq \sum_{i=1}^{N} \sum_{j=1}^{M} p_{ij} \oplus g_{ij}$$
$$\Rightarrow \qquad D(\acute{\mathbb{P}}, \mathbb{G}_{best}) \leq D(\mathbb{P}, \mathbb{G}_{best}) \tag{14}$$

■

In our design, there is a probability that $Particle_i$ does not get close to local maximum nor global maximum. The purpose is letting particles find more, possibly better solutions, in the solution space. So, we define an operation called "Row-Addition" as below.

Random Movement: Row-Addition RA($\mathbb{P}$)

Algorithm 1 The procedure of CC selection in IMCC

Initialization: $P(k), k = 1, ..., N$, denote N particles, and the algorithm runs i iterations.
repeat
  repeat
    $temp$ = score of $P(k)$
    if $temp < rec(n)$ **then**
      $Move_{\mathbb{G}}(P(k))$
      $Move_{\mathbb{L}}(P(k))$
    else if $temp > rec(k)$ **then**
      $rec(k) \leftarrow temp$
      $recParticle(k) \leftarrow P(k)$
    else if $temp > opt$ **then**
      $opt \leftarrow temp$
      $recParticle_{opt} \leftarrow P(k)$
    end if
    if $rand < \delta$ **then**
      $P(k) \leftarrow RA(P(k))$
    end if
    $k \leftarrow k + 1$
  until $k = N$
  $k \leftarrow 1$
  $i \leftarrow i - 1$
until $i = 0$

RA(P) means to do row-addition on particle P. The row-addition is operated in a random row of $\mathbb{P}$. If row j of particle P is chosen, we regards this row as a binary number and add this row by 1 ($mod\ F$), where F is equal to $2^L - 1$. Because the maximum value of each row is $2^L - 1$, the mod operation is to be sure that this binary number wouldn't exceed this value. For example, the row j of $Particle_i$ is [0 1 0 1], which is 5 in binary, and it is changed to [0 1 1 0] by adding 1 to it.

So, the movement of our algorithm is defined. We would repeat these operations, namely evaluation, record, and movement, iteratively. For simplicity, each user chooses the FAP with maximum channel gain for transmission. The final solution to the problem is $recParticle_{Opt}$. The pseudo code of CC selection procedure in IMCC is shown in Algorithm 1.

After determining the binary assignment matrix, IMCC further adjust power using the original PSO algorithm. Therefore, IMCC can also perform power adaption on each FAP. The procedure of IMCC is to determine the CC assignment matrix at first. The next step is to applied the original PSO to allocate power on each selected CC of each FAP.

V. SIMULATION RESULTS

A. Simulation set-up

Several experiments are performed to evaluate the performance of the proposed algorithms and other algorithms. In our simulation environments, we set the maximum power of the base station and FAPs to 43dBm and 13dBm, respectively. The bandwidth of component carrier is 20MHz for each CC. The deployment of carrier aggregation is that each CC is on the same or little frequency separation spectrum. We consider a layout of 1-tier 7 hexagonal cells with 3 identical sectors in each cell. The simulation scenario and indoor path loss modeling are the same as in the literature [12] for the evaluation of femtocells. We suppose the temperature of the

environment is 300K, therefore the noise of the system is -174 dBm/Hz. We compare the performance of IMCC, ACCS [4], G-ACCS [5], and TBRS [1]. The PCC threshold is 10dB and the SCC threshold is 8dB, which are the same as described in [4]. The parameters of TBRS are TBRS(2,10) which lead to the best average performance while the FAPs are crowded [1]. δ in IMCC is set to 0.3. The number of iterations, i, is set to 500, which can obtain a nearly optimal solution in our experiments. Therefore, the computation time of IMCC is a few seconds in a computer with Matlab R2009 and Intel(R) Core(TM) i5 CPU k655.

Fig. 2.   The topology of 5 FAPs in an apartment with two stripes.

Fig. 3.   The throughput v.s. distance of all algorithms.
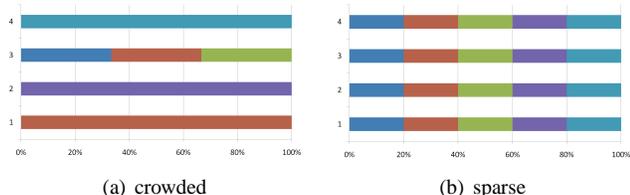
Fig. 1.   The CC allocation of 4 FAPs. (a) is the crowded topology, and (b) is the sparse topology. 5 different colors are used to denote different CCs.

B. Crowded and sparse environments

The design of the simulation is to evaluate how the selected CCs are determined by the proposed IMCC algorithm. Two simple topologies are considered: crowded and sparse distribution of FAPs. When FAPs are placed in a crowded environment, the selected CCs should show the orthogonal characteristics to avoid severe interference between each other in order to deliver the maximum system performance. On the other hand, if FAPs are placed in a sparse environment, they should use the whole bandwidth because the interference between each other is negligible.

In both topologies, the BS is placed at location (0,0), and there are 20 users. The users are randomly distributed in a 40m×40m square with center 800m far from the base station which is on the cell edge. Four FAPs are distributed circularly with the same center as users, the radius of crowded and sparse topology are 5m and 20m respectively.

Figure 1 shows the selected CCs for the four FAPs in both topologies. In Figure 1, there are five colors in each figure, and each color stands for a CC. Subfigure (a) in Fugure 1 shows the CC allocation of the crowded case. The interference is serve among FAPs, so FAPs trend to using the different CCs for transmission. The neighboring FAPs use different CCs, and a CC is shared by FAP 1 and FAP 3. This is because that the distance between FAP 1 and FAP 3 is far enough such that the interference is light. Sharing the same CC can improve the system performance. Subfigure (b) in Figure 1 shows each FAP has five colors. That means every FAP uses the whole bandwidth for transmission. The interference is too light to be ignored while the distance between FAPs is large. In our intuition, using the whole bandwidth leads to the highest aggregate throughput.
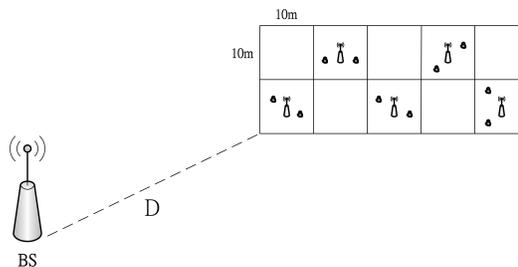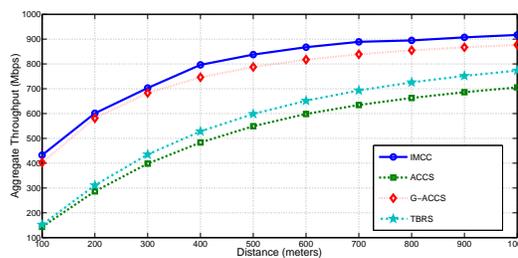
C. Two stripes of apartments

In this simulation, the scenario we apply is that a floor with two stripes of apartments, each stripe having 5 apartments. The size of each apartment is 10m×10m, and we set FAPs in the center of this square. We suppose each FAP serves two users which are randomly distributed in the apartment. The distribution topology is shown in Figure 2, where D is the distance between FAPs and BS. The purpose of this scenario is to investigate performance in a LTE-advanced cellular network. We change the distance between the stripes and the BS from 100 meters to 1000 meters. The performance results are shown in Figure 3 for different algorithms.

While the distance is short, the interference caused by BS is very severe. In this condition, IMCC and G-ACCS is better than other two algorithms as seen in Figure 3. The reason is that G-ACCS and IMCC change the power allocation for each CC while ACCS, and TBRS just use uniform power allocation and use the maximum power on each used CC. Therefore, the interference is more severe than G-ACCS and IMCC. The severe interference makes the performance lower. However, the gap between these algorithms becomes smaller while the
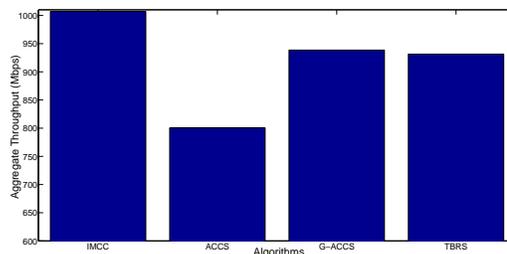

Fig. 4.   The throughput of all algorithms when the distance between Marco BS is large.
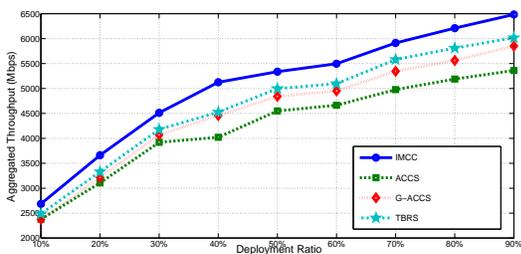
Fig. 5.   The aggregate throughput with different deployment ratio in all algorithms.
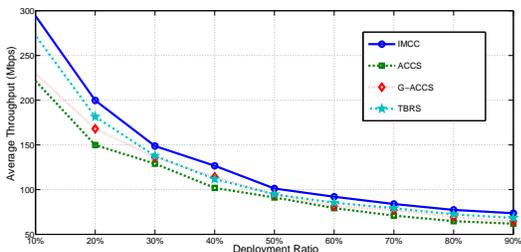
Fig. 6.   The average throughput of FAPs with different deployment ratio in all algorithms.

distance gets larger because the interference from BS becomes smaller while D becomes larger.

If the distance is far enough, the interference caused by BS can be ignored, which is the same as the situation where there is no BS. Under such a circumstance, Figure 4 shows IMCC is still the best among all algorithms. Although G-ACCS performs power adaption and TBRS uses only uniform power allocation, the performance of G-ACCS and TBRS are almost the same. These results clearly indicate that an appropriate CC allocation is more important than power adaption. While managing interference among FAPs, the CC assignment is important and should be determined first.

D. Different Deployment Ratio

In this experiment, we construct a scenario with 100 apartments in a square and the size of each apartment is 10m×10m. If there is a FAP in an apartment, it would be put in the center of the apartment, and two users are randomly distributed in the apartment. We vary the FAP deployment ratio of each apartment from 10% to 90%. The distance between these apartments and the BS is very large. Therefore we can ignore the interference caused by BS. We perform the experiment several times, and average these results.

Figure 5 shows the aggregate throughput of FAPs and Figure 6 is the average throughput of each FAP. Both figures show that IMCC has the best performance no matter if the deployment ratio is low or high. The results show that IMCC can work efficiently whether in light or severe interference environments. On the other hand, it can be shown that TBRS, which only determines the CC assignment, has performance better than G-ACCS. The results, again, show the appropriate CC assignment can obtain more performance gain.

VI. CONCLUSION

In this article, we propose a CC selection algorithm called IMCC (Interference Management based Component Carrier scheduling) to tackle the problem in heterogeneous networking environments of Femto Access Points (FAPs) and Macrocell base stations. IMCC assigns CCs according to the entire system information, such as, location of FAPs, location of UEs (User Equipments), and the channel quality based on an evolutionary approach. The approach is based on a devised discrete-type optimization mechanism. After the selected CCs are determined, the power on each CC can be further adjusted accordingly. Several simulation topologies are performed to compare the performance with existing algorithms. The simulation results indicate the proposed approach outperforms existing algorithms.

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REFERENCES

[1] G. Costa, A. Cattoni, I. Kovacs, and P. Mogensen, "A fully distributed method for dynamic spectrum sharing in femtocells," in *IEEE Wireless Communications and Networking Conference Workshops (WCNCW)*, pp. 87 –92, April 2012.

[2] T. Zahir, K. Arshad, A. Nakata, and K. Moessner, "Interference management in femtocells," *Communications Surveys & Tutorials, IEEE*, vol. 15, no. 1, pp. 293–311, 2013.

[3] J. Kennedy and R. Eberhart, "Particle Swarm Optimization," in *IEEE International Conference on Neural Networks*, vol. 4, pp. 1942 – 1948, 1995.

[4] L. G. U. Garcia, K. I. Pedersen, and P. E. Mogensen, "Autonomous Component Carrier Selection: Interference Management in Local Area Environments for LTE-Advanced," *IEEE Communications Magazine*, vol. 47, pp. 110 – 116, September 2009.

[5] L. G. U. Garcia, I. Z. Kovacs, K. I. Pedersen, G. W. O. da Costa, and P. E. Mogensen, "Autonomous Component Carrier Selection for 4G Femtocells - A fresh look at an old problem," *IEEE Journal on Selected Areas in Communications*, vol. 30, pp. 525 – 537, 2012.

[6] A. Simonsson, "Frequency Reuse and Intercell Interference Co-Ordination In E-UTRA," in *IEEE 65th Vehicular Technology Conference (VTC Spring)*, pp. 3091 –3095, April 2007.

[7] Y. Wang, S. Kumar, L. Garcia, K. Pedersen, I. Kovacs, S. Frattasi, N. Marchetti, and P. Mogensen, "Fixed Frequency Reuse for LTE-Advanced Systems in Local Area Scenarios," in *IEEE 69th Vehicular Technology Conference*, pp. 1 –5, April 2009.

[8] J. Ellenbeck, C. Hartmann, and L. Berlemann, "Decentralized inter-cell interference coordination by autonomous spectral reuse decisions," in *14th European Wireless Conference*, pp. 1 –7, June 2008.

[9] R. Menon, A. MacKenzie, R. Buehrer, and J. Reed, "A Game-Theoretic Framework for Interference Avoidance in Ad hoc Networks," in *IEEE Global Telecommunications Conference (GlobeCom)*, pp. pp.1 –6, December 2006.

[10] K. Son, S. Lee, Y. Yi, and S. Chong, "REFIM: A practical interference management in heterogeneous wireless access networks," *IEEE Journal on selected areas in communications*, vol. 29, pp. 1260 – 1272, June 2011.

[11] P. Mogensen, W. Na, I. Kovacs, F. Frederiksen, A. Pokhariyal, K. Pedersen, T. Kolding, K. Hugl, and M. Kuusela, "LTE Capacity Compared to the Shannon Bound," in *IEEE 65th Vehicular Technology Conference (VTC Spring)*, pp. 1234 –1238, April 2007.

[12] 3GPP TR 36.814, "Further Advancements for E-UTRA: Physical Layer Aspects," *Technical Specification Group Radio Access Network*, June 2009.