On Stochastic Cell Association Scheme Over Carrier Aggregated Heterogenous Networks

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Abstract— **Triggered by the ever growing demand of wireless data rate, modern cellular network is in the middle of a paradigm shift. By deploying small cells underlaying current macrocells, a heterogeneous network (HetNet) architecture is formed with great potentials to improve system capacity and reduce overall energy consumption in the mean time. However, such layout is challenged by the co-tier and cross-tier interference and uneven traffic loads due to the massive deployment of small cells. In this work, a cell association scheme based on stochastic control theory is explored to attain improved network performance in carrier aggregated HetNets. Simulation results have shown the advantages of the proposed scheme under different kinds of carrier deployments across multiple tiers.**

Index Terms— **HetNets, cell association, carrier aggregation, stochastic control**

I. INTRODUCTION

TYPICAL/approaches are loosing the abilities to fulfill the gap between the ever growing demand for wireless data rate and the system capacity in practical cellular networks. Paradigm shifted changes must be taken to the mobile cellular network to cope with the upcoming "data shower" for future wireless connections.

As a new cellular paradigm, HetNets have been considered as one of the most promising technologies for engaging better mobile coverage and higher cellular network capacity, which are developed by the Third Generation Partnership Project Long Term Evolution - Advanced (3GPP LTE-A) [1].

Transmitting nodes characterized by graded coverage abilities are categorized into multiple tiers to reinforce the service quality of mobile communications under a heterogeneous way. Thus, increasing attentions have been paid for heterogeneous cellular network architecture design from both industrial and academic world.

With low power small cells underlaying conventional macrocells, the deployment of multi-tier HetNets is considered as a new cellular network constructions. However, the coverage disparities of the HetNets would cause uneven traffic loads across different tiers, which makes the users within the network more sensitive to the cell association policies [2]. Massive small cell deployment would benefit the network by offloading the traffic from the overloaded macrocells into small cells .

The layout of HetNets have pushed the network throughput into a much higher level attributing to the enhanced spectral efficiency in space. However, extra interference [3], [4] occurs either among or across different tiers according to the specific access control mode of the base stations (BS), which would jeopardize the improvement of network spectral efficiency improvement with such dense deployments. Intelligent and dynamic cell association policies are needed [5]- [7].

In [8], cell association policies are designed, for example by biasing, to solve such problems by pushing the traffic load from the overloaded marco BSs onto the under-loaded small cells. As soon as the traffic is offloaded from the macro BS, a much lower transmit power could offer a more satisfying QoS for its serving users because the distance for transmission is much shorter apparently. In addition, the active small cell nodes require much less transmit power and they could play a prominent role in achieving higher energy efficiency in HetNets. Apparently, the total energy consumption in the whole network is deduced by cell association, which makes the HetNets a green [9] network layout.

An overview of LTE-A Carrier Aggregation (CA) deployment scenarios for the Fourth Generation (4G) communications is presented in [10], where the users are within overlapped areas of interference-limited cells. With proper deployment of component carriers, besides the wide-banded data rate improvement, the interference could be delicately coordinated for both homogeneous and heterogeneous networks.

In particular for HetNets, a very recent research [11] proposes a tractable multi-band multi-tier model for carrier aggregation, where base station positions in each tier follow an independent Poisson Point Process (PPP). With this model, analytical results are derived to express the dependency of the network metrics on the data off-loading to small cells and band deployment configuration. The per area spectral efficiency is improved significantly by the CA-enabled small cells as expected.

As the one of the main features of LTE-A, CA increases the transmission bandwidths by aggregating multiple component carriers in HetNets to offer the most desirable spectral efficiency enhancement. However, given such

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aggregated bandwidths, a well-deployed heterogeneous network still needs association strategies on the optimal network coverage and overall throughput.

As for the random deployment of HetNets, the cell association scheme of carrier aggregated heterogeneous network need to be more flexible and more adaptive. In this work, a highly stochastic cell association scheme is discussed in multi-tier heterogeneous cellular networks.

The rest of this paper is organized as follows, the carrier aggregated HetNets layout is introduced in section II with system model demonstration, followed by the user and cell association strategies by means of stochastic control theory in section III. To further investigate the performance of the proposed scheme, simulations are carried out in section IV under all kinds of carrier deployments across different tiers. Finally, conclusions are revealed in the last section.

Throughout this paper, matrices and column vectors are demonstrated by bold upper and lower case letters, respectively.

II. PROBLEM STATEMENT

The key issue of the heterogeneous network layout is to keep the existing macrocell topology unchanged and overlaid with more smaller cells. Unlike the delicately pre-arranged macro base stations, smaller base stations with lower transmitting power, such as picos, femtos and relays, are scatting within the original cellular network in a stochastic manner. Different transmitting power levels and other distinguish characteristics make all of the afore mentioned base stations automatically clustered into different " tiers ", each tier of which accounts for different Quality of Services (QoS) due to their coverage abilities. Compared to the traditional cellular network, the multi-tier HetNets are expected to be paradigm shifted in a number of ways in the recent developed literatures. One of the most promising topics is using the random deployment of smaller cells to perform cell association for traffic load balancing among different tiers.

In this section, a heterogeneous network layout is stated, followed by a detailed introduction of the system model and signal model. The problem of cell association is formulated at last.

A. Network Overview

To get an clear insight on the random deployments of multi-tier HetNets, the components and architecture should be illustrated first. The small cells with lower transmit power nodes are underlaid in the same area with the macrocells aiming at a higher network spectrum efficiency through denser spacial deployment. Due to different coverage regions and QoS requirements, the low power nodes are clustered into different tiers named picocells, femtocells [12] and relay networks, as illustrated in Table I.

Due to the co-deployed small cells with various types, active numbers and unpredictable locations, the traditional fully planed cellular paradigm is generally shifting into a randomness dominated decentralized HetNets, which also brings both opportunities and challenges for researchers in these field.

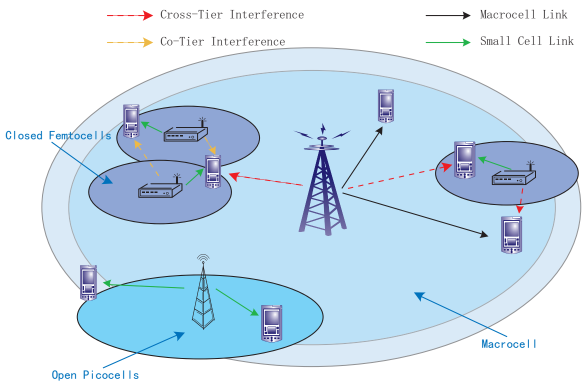


Figure 1. Heterogenous Networks.

To solve the complicated interference problems illustrated in Fig. 1, carrier aggregation in heterogeneous networks draws attentions from both industry and academic world. Carrier aggregation is brought up by the 3GPP in LTE-Advanced to support higher data rate requirements with wider bandwidths, where multiple component carriers of smaller bandwidth are aggregated for transmission. Unlike the multi-carrier transmission technologies, like OFDM, CA prepares individual physical modulation and coding schemes for each component carrier. By aggregating such carrier bands, interference could be mitigated through carefully cross-carrier scheduling schemes.

In this paper, a stochastic cell association scheme is proposed for the problem of traffic load balancing among different tiers and different carriers of the HetNet.

B. System and Signal Model

A downlink HetNet scenario is considered with N available carrier bands denoted as a set $\mathcal{N} = \{1, ..., N\}$ for carrier aggregation, and the bandwidth is B^n for each carrier band $n \in \mathcal{N}$. It is assumed that K base stations are normally scattered into T different tiers, each of which is composed of a single type of base stations. In this paper, one macrocell overlaid with multiple femtocells network structure is assumed, which makes $T = 2$. And a total M users are normally distributed within the network among different tiers.

When user $m \in \mathcal{M} = \{1, ..., M\}$ is served by BS $k \in \mathcal{K} = \{1, ..., K\}$ on carrier $n \in \mathcal{N}$, the received signal could be formulated as

$$y^n_{k,m} = H^n_{k,m} x^n_k + \sum_{j=1, j\neq k}^{K} H^n_{j,m} x^n_j + \sigma_{n,m} \quad , \qquad (1)$$

where the intended signal, co-channel interferences among different cells and the additive white Gaussian noise with zero mean and variance N_0 are demonstrated respectively. x^n_k is the transmitted symbol for the scheduled user in cell k on carrier band n with power level $p^n_k = \mathbb{E}\{| x^n_k |^2\}$. $H^n_{k,m}$ denotes the complex channel state

TABLE I.
SPECIFICATION OF HETNETS

Nodes	Power Level	Coverage	Access Mode	Deployment Environment
Mcrocell	$40W$	$1-10Km$	Open	Out-door
Picocell	$1W-2W$	$<100m$	Open/Closed	Out-door/In-door
Femtocell	$\leq 100mW$	$<50m$	Open/Closed/Hybrid	In-door
Ralay	$250mW-2W$	$300m$	Open	Out-door

information from BS k to user m on carrier band n, which captures both large and small scale fading characteristics.

Accordingly, the Signal to Interference plus Noise Ratio (SINR) and the most achievable rate for the scheduled user should be

$$SINR_{k,m}^{n}=\frac{p_k^n G_{k,m}^{n}}{N_0B^n+\sum\limits_{j=1,j\neq k}^{K} p_j^n G_{j,m}^{n}} \qquad (2)$$

and

$$C_{k,m}^{n}=B^n\log_2(1+SINR_{k,m}^{n}) \qquad (3)$$

respectively, where $G_{k,m}^{n}=\mid H_{k,m}^{n}\mid^2$ is the corresponded channel power gain. The small scale Rayleigh fading effects in $G_{k,m}^{n}$ is captured by a random variable with zero mean and unit variance. And path-loss effect [13], [14] is modeled as as a function of distance

$$PL(d)=C_n(\frac{d_0}{d})^{\gamma}, \qquad (4)$$

where d_0 is a reference distance for the antenna far field, γ is the path-loss exponent, and C_n is a carrier frequency depended constant assumed as $C_n=(\lambda_n/4\pi d_0)^2$. λ_n denotes the wavelength of radio carrier $n\in\mathcal{N}$.

For traffic load balancing among different tiers in the carrier aggregated HetNets, the cell association schemes involves determining the user scheduling policy with indicators $\psi_{k,m}^{n}$, where $\psi_{k,m}^{n}=1$ indicates user m is associated with BS k on band n, and otherwise $\psi_{k,m}^{n}=0$. Therefore, the traffic load in each BS k on carrier band n could be defined as

$$L_k^n=\sum_{m=1}^{M}\psi_{k,m}^{n} \quad \forall k,n. \qquad (5)$$

C. Problem Formulation

Since the radio resources are shared by users served by the same BS, the ergodic rate of user m served by BS k on carrier band n should be

$$r_{k,m}^{n}=\psi_{k,m}^{n}\frac{C_{k,m}^{n}}{L_k^n}, \qquad (6)$$

where equal orthogonal resource allocation is assumed among different users in each BS k on carrier n, and there is no interference among users in the same cell.

To maximize the network throughput, users are always connected to the best Signal to Interference plus Noise Ratio (SINR) supplier, which in this case may be the macro BS attributing to its maximum power level in HetNets. However, under such strategies, the cell edge users could be totally shut down for the poor reception. Most importantly, due to their coverage abilities, the traffic load will be extremely uneven among different tiers, causing the fully loaded macrocells and the lightly loaded small cells otherwise.

The load balanced cell association schemes are designed to determine the optimal user scheduling policy to maximize the network utility function

$$\begin{aligned}\max_{\boldsymbol{\Psi},\boldsymbol{L}} \quad & \sum_{n=1}^{N}\sum_{k=1}^{K}\sum_{m=1}^{M} r_{k,m}^{n}\\ \text{s.t.} \quad & \sum_{k=1}^{K}\sum_{n=1}^{N}\psi_{k,m}^{n}=1,\quad \forall m,\\ & L_k^n=\sum_{m=1}^{M}\psi_{k,m}^{n}\leq M,\quad \forall k,n,\\ & \psi_{k,m}^{n}\in\{0,1\},\quad \forall k,n,m,\end{aligned} \qquad (7)$$

where $\boldsymbol{\Psi}=(\psi_{k,m}^{n})_{k\in\mathcal{K},m\in\mathcal{M}}^{n\in\mathcal{N}}$ and $\boldsymbol{L}=(L_k^n)_{k\in\mathcal{K}}^{n\in\mathcal{N}}$.

This optimization problem is a nonlinear non-convex combinatorial problem which is different to solve and unpractical to search for a global solution. In this paper, a stochastic cell association scheme is proposed on the basis of carrier aggregation, where he stochastic control based [15] user scheduling is performed for single flow carrier aggregation with users associated with no more than one BS on one carrier.

III. STOCHASTIC CELL ASSOCIATION SCHEME FOR CARRIER AGGREGATION

In this section, the cell association problem is offered a discrete solution based on the stochastic control theory, which is to perform CA dynamically by the users all over the two layer HetNets.

A. Ergodic Rate Analysis

To solve the problem in (7), the long term data rate of each scheduled user needs to be formulated first. As equal resources allocation assumed in this paper, the $SINR_{k,m}^{n}$ in (2) should be reformed as

$$SINR_{k,m}^{n}=\frac{\frac{p_k^n}{L_k^n}G_{k,m}^{n}}{N_0B^n/L_k^n+\sum\limits_{j=1,j\neq k}^{K}\frac{p_j^n}{L_k^n}G_{j,m}^{n}}, \qquad (8)$$

where the power and bandwidth are shared equally among users associated with the same BS on the same carrier band.

According to (8), and (6), the ergodic rate of user m served by BS k on carrier band n should be

$$r^n_{k,m} = \psi^n_{k,m}\frac{B^n}{L^n_k}\log_2\Big(1+\frac{p^n_k G^n_{k,m}}{N_0 B^n + \sum\limits_{j=1,j\neq k}^{K} p^n_j G^n_{j,m}}\Big). \tag{9}$$

In the two tier carrier aggregated HetNets, the ergodic rate of $r^n_{k,m}$ not only depends on the $SINR^n_{k,m}$ condition which leads to its spectral efficiency, but also the total number of actual users that associated with the same BS on the same carrier band at the same time.

B. Stochastic Control Based Cell Association

Consider the uncertainty of the massive deployment of small cells, searching for the optimal resolution of such dynamic communications is unpractical [16]. At least for practical considerations, the proposed problem (7) may need a more proper and near optimal solution instead.

It could be infered from (9) that each time a user get permissions to access a BS on a particular carrier band, the pre-accessed users are forced to share their resources. Thereby, the ergodic rate changes dynamically with the access control policies, which forms a stochastic process with dynamic inputs and measurements results. And the proposed problem becomes a Knapsack problem, which is NP complete.

Stochastic control theory solves problems where the decisions are made step by step, and the outcomes of such decisions are uncertain and only could be anticipated in each step [17]. Stochastic control theory has shown great potentials in solving such multi-decision problems either to get the minimum cost of the undesired outcomes, or to get the maximum utility of the desired outcomes [18].

In this section, a multiple decision problem is formulated in order to offer (7) with a near optimal solution. The desired utility could be formulated as the sum rate of a group of users that has not been access yet starting with user m_0 as

$$J(m) = \max\sum_{m_0}^{M}\sum_{n=1}^{N}\sum_{k=1}^{K} r^n_{k,m_0}, \tag{10}$$

where $J(M) = \max\sum_{n=1}^{N}\sum_{k=1}^{K} r^n_{k,M}$. The decisions at each step are made by taking all the non accessed users into account.

The Stochastic Control based cell association problem could be formulated as

$$\begin{aligned}
\max_{\boldsymbol{\Psi}(m_0),\boldsymbol{L}(m_0)} \quad & \sum_{m=m_0}^{M}\sum_{n=1}^{N}\sum_{k=1}^{K}\psi^n_{k,m}\frac{B^n}{L^n_k}\log_2(1+SINR^n_{k,m}) \\
\text{s.t.} \quad & \sum_{k=1}^{K}\sum_{n=1}^{N}\psi^n_{k,m}=1, \quad \forall m\in\{m_0,...,M\}, \\
& L^n_k = \sum_{m=m_0}^{M}\psi^n_{k,m} \leq M-m_0, \quad \forall k,n, \\
& \psi^n_{k,m}\in\{0,1\}, \quad \forall k,n,m\in\{m_0,...,M\},
\end{aligned} \tag{11}$$

where $\boldsymbol{\Psi}(m_0) = (\psi^n_{k,m})^{n\in\mathcal{N}}_{k\in\mathcal{K},m\in\{m_0,...,M\}}$ and $\boldsymbol{L}(m_0) = (\sum_{m=m_0}^{M}\psi^n_{k,m})^{n\in\mathcal{N}}_{k\in\mathcal{K}}$.

The decision is made each time when a user tries to access the network, and the constraints are updated on the basis of each successful admission. A dynamic adaptation is formed to move towards solutions with the maximized network throughput, which is to adjust user association step by step based on the changes of the stochastic behavior of HetNets.

C. Summary

The pseudo code of the proposed Stochastic cell association scheme with single flow CA is summarized as in **Algorithm 1**.

Algorithm 1 Stochastic Cell Association Scheme for Single Flow CA.

```
1:  Initiate the HetNets Layout.
2:  for $m = 1$ to $M$ do
3:      for $k = 1$ to $K$ do
4:          for $n = 1$ to $N$ do
5:              Observe Current ergodic rate of (9) as prior knowledge.
6:              Update (9) by admitting user $m$ by BS $k$ on carrier $n$ as posterior estimation information.
7:              Obtain the difference gap between step 5 and step 6.
8:          end for
9:      end for
10:     Obtain the best association policy by (10).
11:     Apply the result of step 7 and step 10 for the next association step.
12:     Refresh the total user number constraint in (11).
13: end for
```

IV. PERFORMANCE ANALYSIS

A. Simulation Configuration

In this section, simulation results are demonstrated to evaluate the proposed stochastic control based cell association scheme.

A typical two layer CA based Heterogenous Network is set with one high frequency (2.5GHz) carrier band C_1 and one low frequency (800MHz) carrier band C_2. The simulation parameters are summarized in Table II unless stated otherwise.

The carrier bands deployments are denoted by a binary matrix between different network tiers and different carrier frequencies as $[\alpha_{11}\ \alpha_{12}; \alpha_{21}\ \alpha_{22}]$, where $\alpha_{i_1 i_2} = 1$ denotes that carrier i_2 is deployed on HetNet tier i_1, while $\alpha_{i_1 i_2} = 0$ denotes otherwise. For example, a deployment of [1 1;1 1] means both two tiers are co-deployed with two carrier bands C_1 and C_2. In this simulation set-ups, the first tier is macrocell tier, and the second is femtocell tier.

All of the simulation results are obtained through at least 1000 Monte Carlo channel realizations. And For

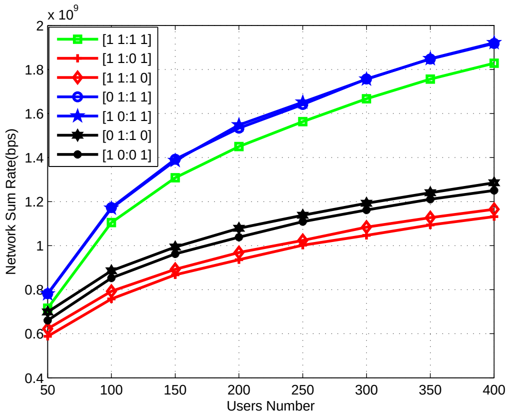
TABLE II.
SIMULATION PARAMETERS

Macro Transmit Power	46dBm
Femto Transmit Power	20dBm
Macro coverage Radius	500m
Femto coverage Radius	50m
AWGN	-174dBm/Hz
Total Users	M = 200
Bandwidth B^1 of C_1	10MHz
Bandwidth B^2 of C_2	10MHz
Wavelength λ_1 of C_1	0.125m
Wavelength λ_2 of C_2	0.375m
Path Loss Exponent γ^1 of Macrocell	4
Path Loss Exponent γ^2 of Femtocell	3
Macro ref distance d_0	10m
Femto ref distance d_0	1m

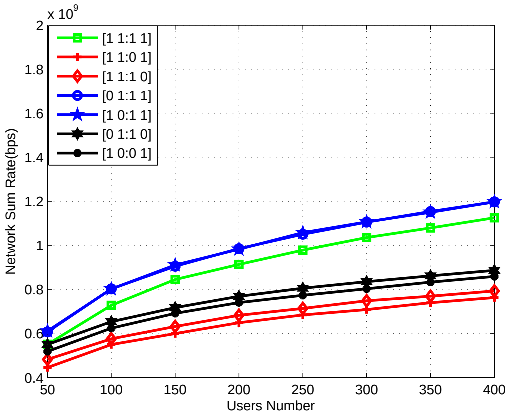
comparison, the traditional max-SINR cell association strategy, in which users are always associated with the BS providing the maximum SINR performance, is considered as a benchmark in the simulation results.

B. Numerical Results and Discussion

Simulation results are demonstrated in this part under such network layout and settled parameters.



(a) K=40

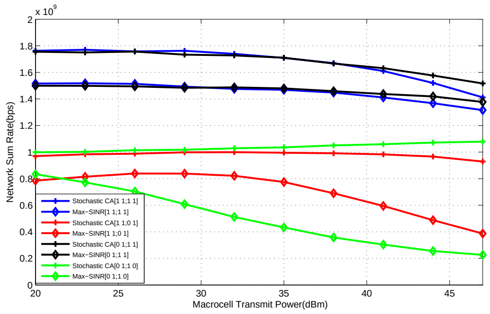


(b) K=20

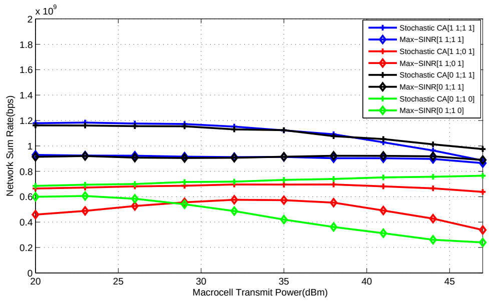
Figure 2. Network Sum Rate against User Number.

In Fig. 2, under different kinds of carrier deployment situations, performance of the network sum rate against total user number is evaluated for two cases. One is when the total BS number K is 40, and the other is when $K = 20$, which states different density of small cells. It could be seen that, for all kinds of carrier deployments, the proposed stochastic cell association schemes are proved to have better performance than the max-SINR scheme due to dynamic control. The results also agree with the fact that as the user density grows in the network, multi-user diversity brings up the performances for both two association schemes.

As for the carrier deployment, comparing Fig. 2(a) and Fig. 2(b), denser small cell deployment also brings much better performances. It seems that the best deployment is the ones where only macrocell is deployed with single carrier, while the worst performance is where femto tier is deployed with single carrier. Therefore, the random deployment of small cells with carrier aggregation have shown the promised performance improvement.



(a) K=40

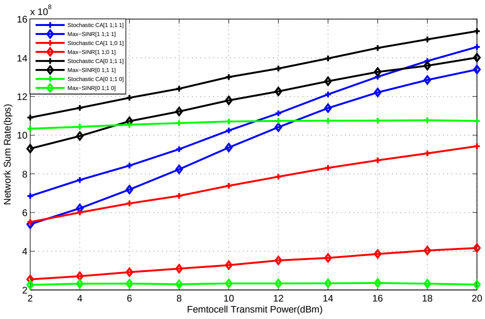


(b) K=20

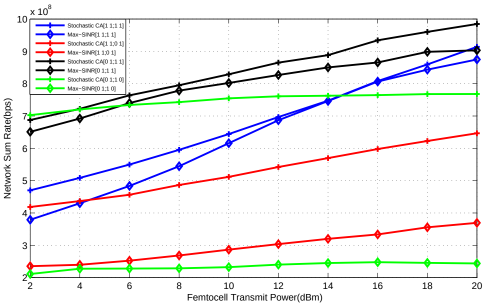
Figure 3. Network Sum Rate against Macro Transmit Power.

Fig. 3 evaluates the influences of the macro BS transmit power on the network performance under different CA deployment. As it is shown, the proposed stochastic scheme still holds advantages over the other scheme under each carrier deployment. However, for both femto densities, the system performance dose not improve along with transmit power of macro BS, which is because strong interference is brought up by higher transmit power of macrocell. Thus, the power allocation strategies need reconsideration when massive small cells are deployed, especially with carrier aggregation across different network tiers.

Fig. 4 shows the performance of network sum rate over growing power levels of the second tier femtocells.



(a) K=40



(b) K=20

Figure 4. Network Sum Rate against Femto Transmit Power.

Either for $K = 40$ or for $K = 20$, besides the expected advantages of the stochastic control based scheme, the overall performances of the demonstrated carrier deployments improve along with the transmit power of femto BS. The reason is that massive deployment of small cells hold the most traffic load of the whole network, and due to its power level the interference caused by femto is nearly negligible for the other BSs compared to macrocell. However, under circumstances as orthogonal deployments, such as [0 1;1 0], the performance do not change because the femtocells do not accomplish most of the network sum rate due to their lack of coverage abilities.

V. CONCLUSIONS

HetNets have pushed the current cellular networking into a new paradigm shift with outstanding performances and much better coverage. In this work, both profits and problems in HetNets attribute to mass deployment of small cells underlaying original macrocells are explored. A stochastic control based cell association scheme is proposed for the user scheduling problems under different aggregated carrier deployments. The performances of the proposed scheme is proved promising for the massive small cell deployment strategies in HetNets through simulation results.

For future work, cognitive ability will be investigated for the femtocells in the carrier aggregated HetNets for cross-tier interference avoidance to further approve the network performances.

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