Modeling and Analysis of Load-Balancing Based on Base-Station CoMP with Guaranteed QoS

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Abstract

With the explosive deployment of the wireless communications technology, the increased QoS requirement has sparked keen interest in network planning and optimization. As the major players in wireless network optimization, the BS's resource utilization and mobile user's QoS can be improved a lot by the load-balancing technology. In this paper, we propose a load-balancing strategy that uses Coordinated Multiple Points (CoMP) technology among the Base Stations (BS) to effectively extend network coverage and increase edge users signal quality. To use universally, different patterns of load-balancing based on CoMP are modeled and discussed. We define two QoS metrics to be guaranteed during CoMP load balancing: call blocking rate and efficient throughput. The closed-form expressions for these two QoS metrics are derived. The load-balancing capacity and QoS performances with different CoMP patterns are evaluated and analyzed in low-dense and high-dense traffic system. The numerical results present the reasonable CoMP load balancing pattern choice with guaranteed QoS in each system.

Keywords: wireless networks, load balancing, CoMP, call blocking rate, efficient throughput

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1. Introduction

The 4G/5G wireless networks will have a dense Base-Station (BS) distribution to provide higher data-rate services. This trend gives rise in more dynamical of traffic load in both time domain and space domain. However, many realistic wireless cellular networks are designed by assuming a fixed traffic load. Hence satisfying the requirement for varied load with the supply of BS's resources is a basic problem in wireless cellular network. The solution on this problem is always called load balancing, in which make the BS's load distribution reasonable such as guiding the traffic from the high loaded BS to the low loaded BS.

1.1 Related Work

We can simply classify the load balancing ways into several categories: (a) Cell Range Expansion (CRE): [1] and [2] adjust control signals to extend the coverage range to balance neighbor cell's load. [3] and [4] use diverse small cells and pico-cells to achieve CRE. [5] [6] and [7] design the relay stations and femtocells to expand the BS' service to balance the high-load of the macro-cells. Although CRE may be an easy way to deploy in the existed network, it is always not energy-efficient and easy to bring the inter-cell interference. (b) BS and user associations' optimization: [8] and [9] model the association between users and BSs and give the optimal balanced-load association with the guaranteed QoS. [10] presents a relay-assisted load balancing scheme, which dynamically changing the BS-relay station associations. This kind of load-balancing solution faces the challenges of high complexity because of focusing on a large amount of the users in a dynamical sysem. (c) Virtual cell breathing. [11] and [12] control the system handover parameter like Cell Individual Offset (CIO) to form cell breathing virtually in order to extend the coverage and balance the load. However, handover parameters conflicts between cells occur with high probability when having many BSs. (d) Heterogeneous network balance. [13], [14] and [15] transfer the load in the cellular network to other wireless network. But the cost of the multiple networks coordination is always large.(e) Spectrum dynamic assignment. Based on [9], [16] tries to assign the BS's frequency resource more reasonably to the load according to the dynamical varied traffic and QoS requirements. The problem is that spectrum space is finite when providing high bandwidth services so that the network system has not enough spectrum resources to achieve Fractional Frequency Reuse(FFR).

By the above analysis, we can learn CRE is an effective method of load balancing if we can solve the inter-cell interference problem. In this paper, we provide another method of CRE: Coordinated Multiple Points Transmission/Reception (CoMP)[17][18]. Due to the cooperation diversity, CoMP can potentially lead to diminishing of inter-cell interferences. Hence, CoMP is expected to be deployed in wireless cellular systems to improve the performance of cell-edge users [19].

1.2 Our Approach

In this paper, we propose a load balancing strategy for wireless cellular network based on the BS' CoMP to effectively extend the coverage to the areas of the high-loaded BSs we want to balance as shown in **Fig. 1**. From **Fig. 1**, we can see in this standard hexagonal cellular, some cells are high-loaded and other neighbor BSs around these cells are low-loaded. We can use the CoMP by low-loaded BSs to extend the service in order to cover those edge users in the high-loaded cell, which balance the traffic load of the high-loaded BS. Special, we firstly propose three basic CoMP load balancing patterns and extend to the multiple and reused patterns. The load-balancing capacity of each basic and multiple CoMP patterns are analyzed on the base of the hexagonal cell architecture. Then we study the guaranteed QoS from two perspectives: call blocking rate and efficient throughput. We derive and analyze the closed-form expressions for these two QoS metrics. For the call blocking rate, we derive it by Erlang C model and the capacity of CoMP load-balancing. And for the efficient throughput, we derive it by the CoMP channel model and signal service/outage probability. Especially, we present the signal service/outage probability on the worst-case location of each CoMP pattern as an illustration of analysis. As will be shown in this paper, we give two hexagonal cellular areas with different distribution density of the high-loaded BSs as the simulation scenes. Lastly, we simulate our CoMP load-balancing schemes and evaluate the achievable capacity of load-balancing, efficient throughput and call blocking rate performance of the proposed CoMP patterns and compare them with the former non-CoMP operation in these two simulation areas.

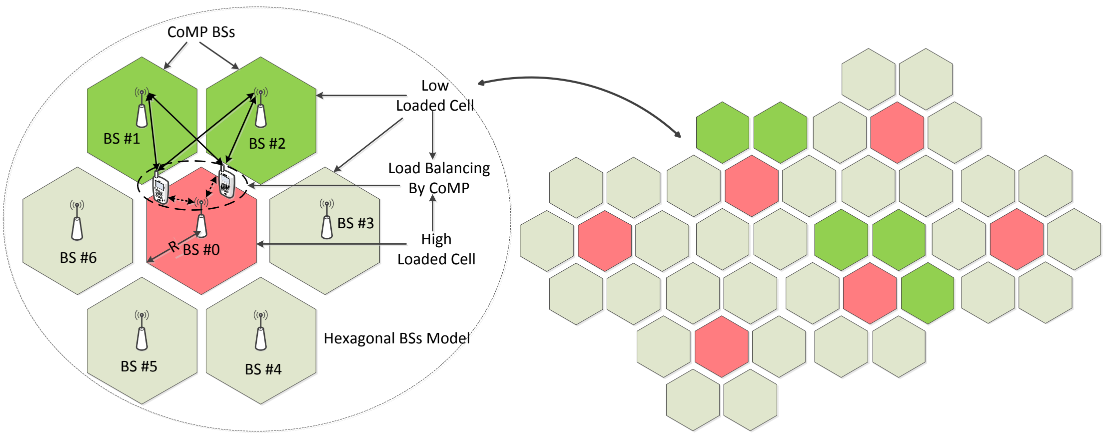


Fig. 1. Illustration of load balancing based on CoMP

The rest of the paper is organized as follows: **Section 2** presents the system model; The CoMP load-balancing patterns are proposed in **Section 3**; **Section 4** gives the closed-form expression of the QoS; Simulated Numerical results are demonstrated in **Section 5**; **Section 6** concludes this work.

2. System Model

Consider a regular mobile cellular network pattern consisting of hexagonal cells with radius *R*. All the BSs are positioned in the center of the cell, as shown in Fig. 1. We assume there is a complete frequency reuse which means all the neighboring cells assigned by same frequency with the central cell. This assumption is similar with real-life network having only the limited bandwidth resource if the cells are homogeneous. In order to analyze the problem easily, the antenna mode between one BS and one UE is assumed to be SISO. Then we introduce the system model in detail by the following 3 parts: traffic model, CoMP channel model and QoS metrics.

2.1 Traffic Model

Let each user in the cell with position (x, y) has the arrival rate $\lambda(x, y, t)$ at time t and the average call remaining time is T that giving the call service rate $\mu = 1/T$. For simplicity, we assume all the users in the cell own the same value of arrival rate and service rate. Then the offered traffic load *A* (Erlangs) of *s*-th BS at time *t* can be given by:

$$A_s(t) = \int_{O_s} \frac{\lambda(x,y,t)}{\mu} dxdy \tag{1}$$

where O_s represents the coverage area of *s*-th BS. Each BS also has *C* channels capacity to support the concurrent UEs. The channel capacity *C* determines the QoS metric, i.e. blocking rate, for different queue length *L* and offered load *A*. In this paper we think $A_s(t)$ follows a Poisson process with average arrival rate $\lambda_s(t)$ and call service rate μ. Each cell has the independent and identically distributed (i.i.d.) arrival rate and same value of the service rate.

2.2 CoMP Channel Model

Firstly denote $h_{s,k}$ as the total channel loss from *s*-th BS to the *k*-th user. It consists of three parts: the distance-path loss $d_{s,k}^{-\alpha}$, the slow-fading effects $\zeta_{s,k}$, and other fading marginal constant *N*, such as fast-fading and penetration loss margin. The detailed expression is given by

$$h_{s,k} = \frac{d_{s,k}^{-\alpha} 10^{\zeta_{s,k}/10}}{N} \tag{2}$$

where α is the path loss coefficient[20]. $\zeta_{s,k}$ (dB) is a random variables following standard normal distribution with zero mean and σ standard variance, i.e $\zeta_{s,k} \sim (0, \sigma^2)$. Then the received signal strength of *k*-th user for *s*-th BS transmission $S_{s,k}$ can be given by Eq. (3) if the transmission power of *s*-th BS P_s is *P* and the antenna gain G_s is *G*.

$$S_{s,k} = P_s G_s h_{s,k} = \frac{PG}{N} d_{s,k}^{-\alpha} 10^{\zeta_{s,k}/10} \tag{3}$$

Then, we can easily get the expectation and variance of the received signal strength by $\psi = 10^{\zeta/10}$.

$$E(S_{s,k}) = \frac{PG}{N} d_{s,k}^{-\alpha} E(\psi = 10^{\zeta/10}) = \frac{PG}{N_s} d_{s,k}^{-\alpha} \int_{-\infty}^{+\infty} 10^{\frac{z}{10}} \frac{1}{\sqrt{2\pi}\sigma} e^{\frac{z^2}{2\sigma^2}} dz \tag{4}$$

$$Var(S_{s,k}) = (\frac{PG}{N} d_{s,k}^{-\alpha})^2 (E(\psi^2) - (E(\psi))^2) = (\frac{PG}{N} d_{s,k}^{-\alpha})^2 (\int_{-\infty}^{+\infty} 10^{\frac{z}{10} \cdot 2} \frac{1}{\sqrt{2\pi}\sigma} e^{\frac{z^2}{2\sigma^2}} dz - (E(\psi))^2) \tag{5}$$

Our aim is to use the CoMP technology to achieve the load-balancing. So to efficiently extend coverage to the high-loaded BS's serving areas, the neighboring active BSs will use complete joint process of cooperative communications to form the multiple BSs transmission. Multi-BS cooperation can be modeled as MISO channel that the total received signal strength of one user is the sum of received signal strength from the cooperative BSs. We assume the different cooperative BSs have the independent and identically distributed (i.i.d.) slow-fading, i.e. a standard normal distribution with zero mean and σ standard variance, the same BS transmission power *P* and antenna gain *G*. Then the received signal strength of cooperative BSs of *k*-th user Sc_k is:

$$Sc_k = \sum_{s \in Jc} P_s G_s h_{s,k} = \frac{PG}{N} \sum_{s \in Jc} d_{s,k}^{-\alpha} 10^{\zeta_{s,k}/10} \tag{6}$$

where *J*c is the set of all the cooperated BSs. For instance in **Fig. 1**, *J*c contains BS #1 and BS #2. They are the cooperated BS to balancing the load of BS #0.

2.3 Quality of Service

In this paper, we analyze the load-balancing performance based on different CoMP patterns according to the varying offered traffic load. However, the aim of load-balancing makes sense only when the QoS can be guaranteed by a certain requirement. In this paper, we define two QoS metrics: call blocking rate and efficient throughput.

2.3.1 Call Blocking Rate

Call blocking rate is used to evaluate the likelihood of that the UE's request is rejected by a BS due to the limited resources. The definition is given by:

Definition 1. *For any given BS's offered load A and limited BS channel capacity C, the* ***call blocking event*** *happens when the queue length of the BS exceeds the queue limit L when new UE's request arrives. And the probability that this case happens is the* ***call blocking rate****, denoting* $B_s(A,C)$ *for s-th BS.*

One detailed method of how to calculate the call blocking rate is give in the **Section III**.

2.3.2 Efficient Throughput

Efficient throughput is used to evaluate the spectrum effectiveness of 'efficient transmission' for a given received signal strength. To know the meaning of 'efficient transmission', we firstly need to define the signal outage probability and the signal service probability:

Definition 2. *Conditioned on that a UE's request is not blocked, the* ***signal outage probability*** *for this UE is the probability that the signal strength received from BS(s) is below a certain threshold* γ *. Denoting* $P_{out}(S_{s,k}) = \Pr[S_{s,k} < \gamma]$ *for k-th user and s-th BS.*

Definition 3. *Conditioned on that a UE's request is not blocked, the* ***signal service probability*** *for this UE is the probability that the signal strength received from BS(s) is equivalent to or higher than a certain threshold* γ *. Denoting* $P_{serv}(S_{s,k}) = \Pr[S_{s,k} \geq \gamma]$ *for k-th user and s-th BS. And it has:*

$$P_{serv}(S_{s,k}) = 1 - \Pr[S_{s,k} < \gamma] = 1 - P_{out}(S_{s,k}) \tag{7}$$

We have known that the spectrum effectiveness *U* is to investigate the throughput achieved per bandwidth (Hz) without fading channel effect which is given by:

$$U_{s,k} = \log_2(1 + SINR_{s,k}(\zeta = 0)) \tag{8}$$

where *SINR* is the Signal to Interference and Noise Ratio that can be obtained by :

$$SINR_{s,k} = \frac{S_{s,k}}{\sum_{s' \in Jn_s} S_{s',k} + N_T} \tag{9}$$

where N_T is the white noise and Jn_s represents the set consisting of all the neighbor BSs around *s*-th BS. Considering the path loss increases as the distance increasing, for simplicity we limit the set Jn_s consisting of only six nearest neighboring BSs. However, the value of $U_{s,k}$ makes no sense when the *k*-th user is not served by *s*-th BS. So we give a definition of 'efficient throughput' considering both signal service probability and spectrum effectiveness.

Definition 4. *Conditioned on that a UE's request is not blocked, the* ***efficient throughput*** *for this UE is the conditional spectrum effectiveness where the UE's signal strength received from BS(s) is equivalent to and higher than a certain threshold* γ. *Denoting the* ***efficient throughput*** *as* $R(S_{s,k})$ *and having:*

$$R(S_{s,k}) = U_{s,k} \cdot P_{serv}(S_{s,k}) = \log_2(1 + SINR_{s,k}(\zeta = 0)) \cdot (1 - P_{out}(S_{s,k})) \tag{10}$$

The derived closed-form expressions for signal outage/service probability and efficient throughput are given in the **Section IV**.

3. CoMP Load-Balancing Patterns

In this section, we firstly introduce the basic, multiple and reused CoMP load balancing patterns respectively according to different level of offered traffic load.

3.1 Introduction on CoMP Load-Balancing Patterns

3.1.1 Basic Patterns

Considering a standard 7 hexagonal BSs model as shown in **Fig. 1**, the central BS with high traffic load has 6 nearby BSs with low traffic load. The high loaded BS is that we want to balance, so called 'balanced BS' and the nearby low loaded BSs are called by 'balancing BS'. Then this paper analyzes the patterns that choosing some of these nearby BSs to be the cooperative BSs in order to balance the load of the central BS. We only propose 2 or 3 as the number of the cooperative BSs. When we use more than 3 BSs to achieve the cooperation, the CoMP BSs' coverage area extends a lot and much traffic flowed to the each CoMP BS. It seems better from the view point of load decreasing of the balanced BS. However, the load-balancing behavior at this point makes no sense because the balancing BS's loads increase heavily even though the balanced cell's load decreases a lot. The 2 BSs and 3 BSs basic CoMP load balancing patterns are shown in **Fig. 2**. We use the symbol $\omega_{Nc,T}$ to represent these basic patterns for short, where $Nc = 2,3...$ is the number of the cooperative BSs and $T : I, II, III...$ indicates the different type for the same Nc. Patterns $\omega_{2,II}$ and $\omega_{2,III}$ are not suggested because the coverage gain by the cooperative BSs is limited due to the considerably far distance between two cooperative BSs in these patterns. So it cannot balance enough traffic loads and offer an excellent service for the edge users. Hence, we only focus on $\omega_{2,I}$, $\omega_{3,I}$ and $\omega_{3,II}$ as the basic CoMP load-balancing patterns.

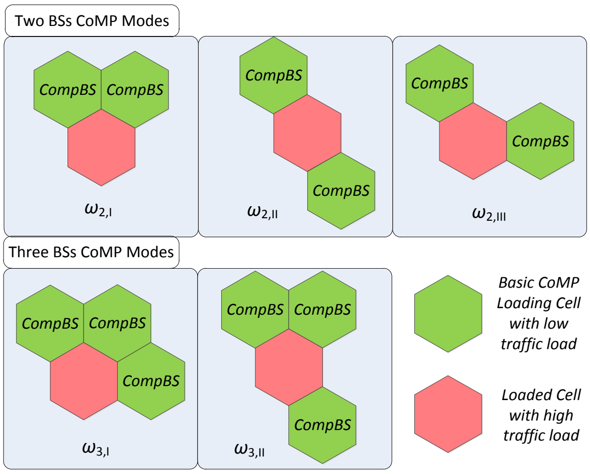


Fig. 2. Basic patterns of load balancing based on CoMP

3.1.2 Multiple and Reused Patterns

In some cases, the basic pattern may not be applied properly. For some cases that having a low-dense distribution of the high traffic loaded BS, it exists sufficient low-loaded BSs that to conduct the load-balancing behavior. So we can adopt the multiple combinations of basic CoMP patterns to increase the utilization ratio of these low loaded BSs. And for some cases that having a high-dense distribution of the high loaded BS, it may not have enough low loaded BSs to achieve balancing. Therefore we need to reuse the whole or part of the cooperative BSs in the basic pattern. For these two cases, we give the extended pattern symbol $\omega_{Nc,T}(Nm, Nr/Nc)$ where Nm is the multiple number of CoMP pairs to balance a central high loaded BS and $Nm=1$ represents no use of multiple CoMP pairs; Nr is the number of the BS to be reused in a certain CoMP set and value $Nr=0$ represents no BS in one CoMP basic pattern is reused.

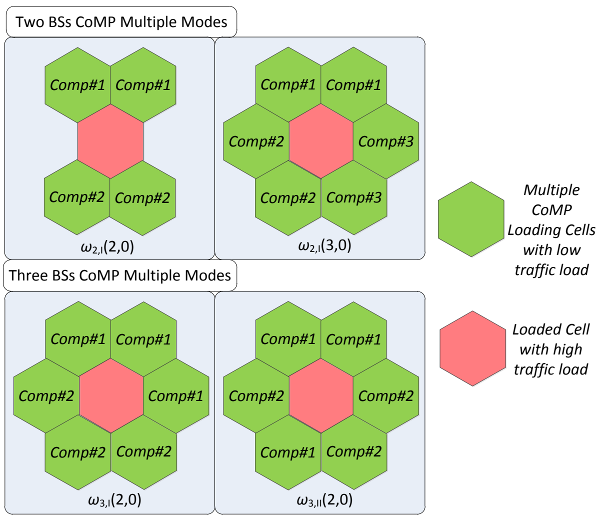


Fig. 3. Multiple patterns of load balancing based on CoMP

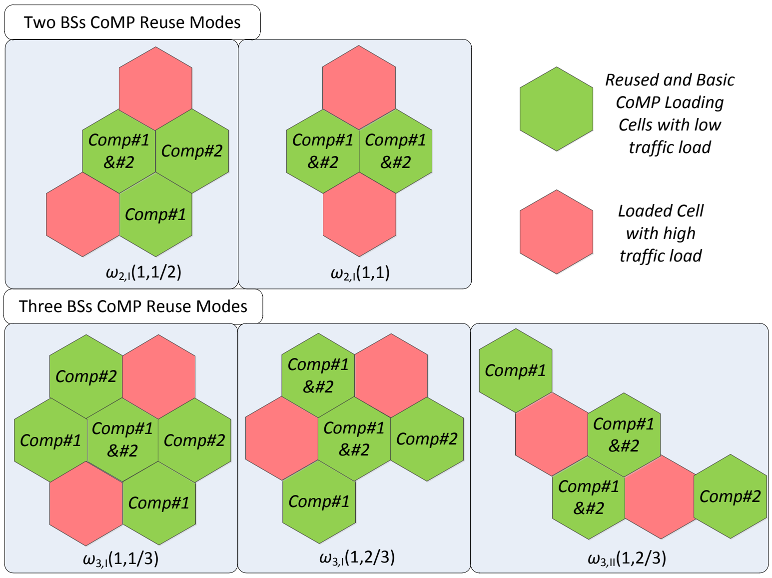


Fig. 4. Reused patterns of load balancing based on CoMP

Fig. 3 shows the multiple mode of the basic $\omega_{2,I}$, $\omega_{3,I}$ and $\omega_{3,II}$ CoMP patterns. We can see one central high loaded BS can be balanced by up to 3 pairs of $\omega_{2,I}$ CoMP pattern or 2 pairs of $\omega_{3,I}$ or $\omega_{3,II}$ CoMP pattern if the six nearby BSs are all low loaded. **Fig. 4** shows some reused modes of the basic $\omega_{2,I}$, $\omega_{3,I}$ and $\omega_{3,II}$ CoMP patterns. All the cooperative BSs in one CoMP basic pattern can be reused when $Nr/Nc = 1$.

3.2 Patterns Determination

The next problem is to determine the pattern of CoMP load-balancing for the areas with different distribution of high loaded BSs. In this paper we give a method that can be used in the area with regular hexagonal cell. **Fig. 5** and **Fig. 6** give the illustration on a low-dense and a high-dense traffic area respectively. From **Fig. 5**, we can see for the low-dense traffic area, the ratio of the number of high loaded BSs Nh to the number of low loaded BSs Nl in the building block is 1:6. Then the rule of determining the CoMP load-balancing patterns is maximizing the utilization of the number of low loaded BSs Nl according to different patterns combined by the basic, reused and multiple patterns. If we limit the number of being reused for one BS is 1, then the optimal solution on this problem can be given by:

$$Nl = ((Nc - Nr) + 0.5 * Nr) * Nm \tag{11}$$

If the combinational pattern $\omega_{Nc,T}(Nm, Nr/Nc)$ satisfies Eq. 11, then we can fully utilize the low loaded BSs to balance the high loaded BS. Therefore the proper CoMP load-balancing patterns for the low-dense traffic area are $\omega_{2,I}(2,0)$, $\omega_{3,I}(2,0)$ and $\omega_{3,II}(2,0)$. **Fig. 6** shows the high-dense traffic area with the ratio Nh/Nl in the building block is 1:2. Similarly we can also get the optimal CoMP load-balancing patterns for this kind of area are $\omega_{2,I}(1,0)$, $\omega_{2,I}(2,1/2)$, $\omega_{3,I}(1,2/3)$ and $\omega_{3,II}(1,2/3)$. We use these two kinds of areas as the simulation instances in **Section V**.

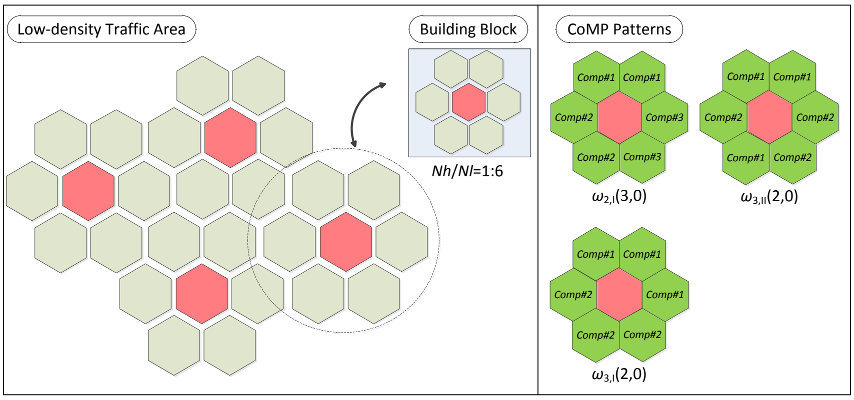


Fig. 5. CoMP load balancing patterns in low-dense traffic area

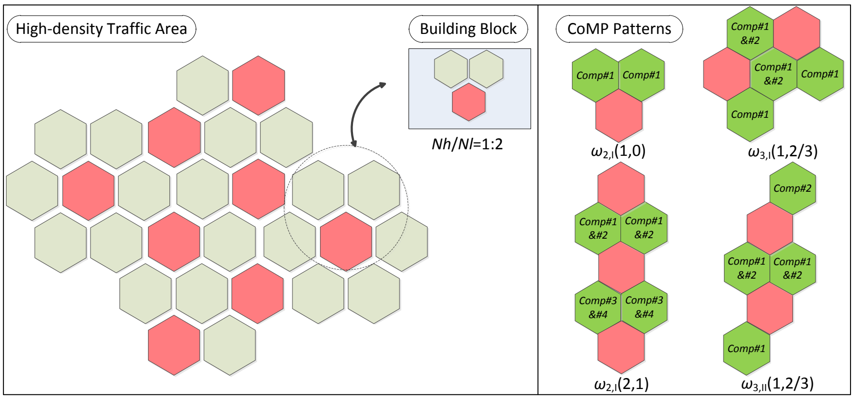


Fig. 6. CoMP load balancing patterns in high-dense traffic area

4. Call Blocking Rate and Efficient Throughput

In this section, we derive the closed-form expressions for two QoS metrics to be guaranteed during the CoMP load-balancing: call blocking rate and efficient throughput.

4.1 Call Blocking Rate

4.1.1 Capability of CoMP Load-Balancing

To analyze the performance of call blocking rate, we firstly need to know the volume of traffic load that can be balanced by each CoMP pattern. The evaluation method to identify which BS that a user is associated with follows the signal strength rule specified in [21].

$$S_{a,k} - S_{b,k} \geq S_{Th} \tag{12}$$

This rule shows the k-th user is associated with a-th BS if the received signal strength $S_{a,k}$ from a-th BS exceeds the received signal strength $S_{b,k}$ from b-th BS than a strength threshold S_{Th}. According to this basic rule, we can extend it to the received signal strength comparison between a set of CoMP BSs and a single BS. For one hexagonal cellular building block as shown in **Fig. 1**, the single BS is the central high loaded BS that we want to balance by CoMP.

We denote it as 0-th BS. The received signal strength of k-th user from this BS is $S_{0,k}$. And the received signal strength from the CoMP BSs is given in Eq. 6. Then Eq. 12 becomes

$$Sc_k - S_{0,k} \geq S_{Th} \tag{13}$$

If we use this rule, we can get the CoMP extended coverage area for basic and multiple patterns which are shown in **Fig. 7**. We assign α to 1.5 because it is most similar with the distance path-loss in COST-Hata model. The CoMP extended coverage area, denoted as $O_{Jc} \in O_0$, is the serving area provided by cooperative BSs in CoMP set instead of by the original central BS.

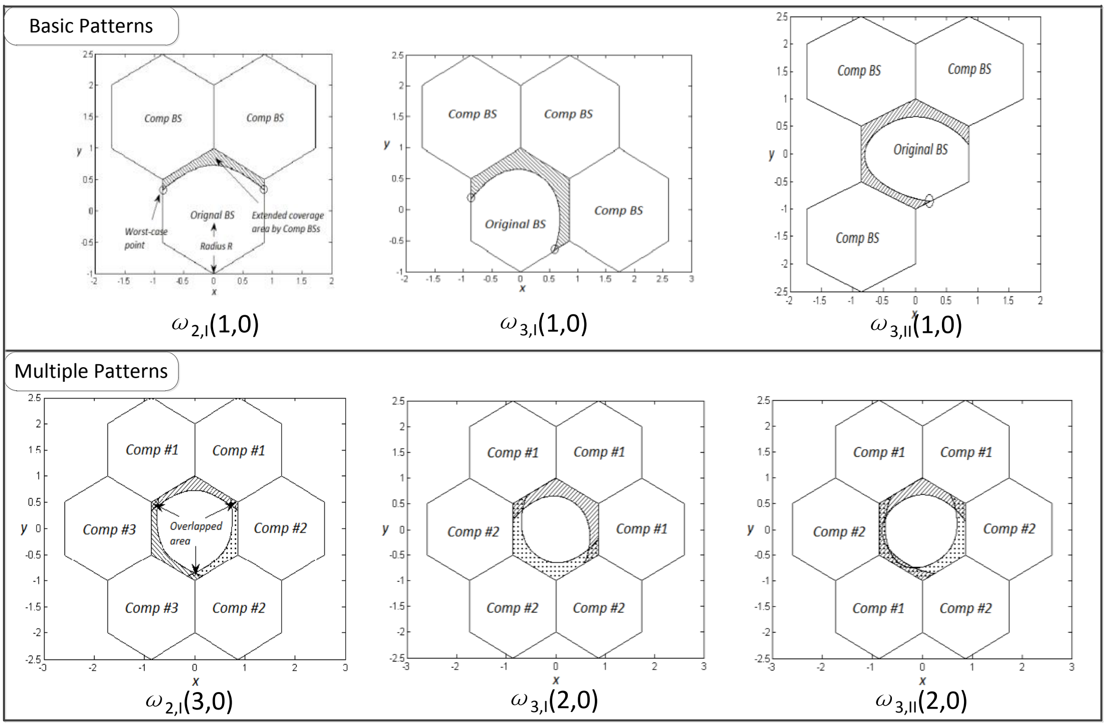


Fig. 7. CoMP extended coverage area for basic and multiple patterns

It should be noticed that it has the overlapped area among the extended coverage areas provided by different CoMP BSs pair if we use the multiple patterns. So we also need the rule in Eq. 12 and Eq. 13 to judge which pair of CoMP BSs the user is served when the user is in the overlapped area. We denote the extended coverage area of each CoMP pattern as $O_{Jc}(\omega_{Nc,T}(Nm, Nr/Nc))$. Then we can give the following definition of the capacity of CoMP load-balancing.

Definition 5. ***Capability of CoMP Load-Balancing*** *is the traffic that generated by all the users with position* $(x, y) \in O_{Jc}$ *in the extended coverage area at some certain time t. Denoting the* ***Capability of CoMP Load-Balancing*** *as* $Ac(t)$ *and having*

$$Ac(t) = \int_{O_{Jc}(\omega_{Nc,T}(Nm, Nr/Nc))} \frac{\lambda(x, y, t)}{\mu} dxdy \tag{14}$$

4.1.2 Call Blocking Rate for Balanced and Balancing BS

Firstly we need to know the traffic change in the balanced and balancing BSs after load balancing, which is important to find the call blocking rate for each BS. From Eq. 14, we can easily find the remaining traffic $A_0'(t)$ of the central high loaded 0-th BS after CoMP load-balancing:

$$A_0'(t) = A_0(t) - Ac(t) = \int_{O_0 - O_{Jc}(\omega_{Nc,T}(Nm, Nr/Nc))} \frac{\lambda(x,y,t)}{\mu} dxdy \tag{15}$$

The new traffic $A_s'(t)$ of the nearby s-th low loaded BS belonging to CoMP set Jc after load-balancing is determined by whether this BS is reused or not.

$$A_s'(t) = A_s(t) + (1 + Ir_s)Ac(t) \quad \begin{cases} Ir_s = 1, & \text{if } s\text{-th BS is reused} \\ Ir_s = 0, & \text{otherwise} \end{cases} \tag{16}$$

Since it is assumed that the traffic arrival process is a Poisson process, we can use the Erlang B or Erlang C formula [22] to calculate the call blocking rate for each balanced or balancing BS. In this paper, we use Erlang C model because it has been proved more exact for the data service which has become the primary service of telecom operator. The call blocking rate in Erlang C model is the probability of that the queue is fully occupied. According to **Definition 1**, if the queue length limit is L and the channel capacity is C for one BS, then we can get the probability of that we have n users in the queue:

$$Pc(A,n) = \frac{C^{C-n}}{C!} A^n Pc(A,0) \tag{17}$$

where $Pc(A,0) = [\sum_{n=0}^{C-1} \frac{C^n}{n!}\rho^n + \frac{C^C}{C!}\frac{\rho^C - \rho^{L-1}}{1-\rho}]^{-1}$ and $A = \lambda / \mu$. Then the call blocking rate is the probability when $n = L$:

$$B(A,C) = Pc(A,L) = \frac{C^{C-L}}{C!} A^L Pc(A,0) \tag{18}$$

Then by Eq. 15 and Eq. 16, we can find the call blocking rate for balanced and balancing BSs after CoMP load-balancing:

$$B_s(A_s', C) = Pc(A_s', L) \quad \begin{cases} s = 0 & \text{central balanced BS with high load} \\ s = 1,2...6 & \text{nearby balancing BS with low load} \end{cases} \tag{19}$$

4.2 Efficient Throughput

4.2.1 Signal service/Outage Probability

To analyze the efficient throughput, we firstly need to discuss the signal outage or service probability in the extended coverage provided by each CoMP pattern according to **Definition**

4. We can take the worst-case point to show our method. Set the position coordinates to the original serving BS, CoMP BSs and UE: Original Serving BS: $BS_0(x_0, y_0)$; UE: $UE(x, y)$; CoMP BSs: $BS_1(x_1, \mathrm{y}_1), BS_2(x_2, \mathrm{y}_2)...BS_M(x_M, \mathrm{y}_M)$, M is the total number of CoMP BSs and $BS_1, BS_2...BS_M$ belong to the CoMP set Jc. Then the path loss on distance $d_{s,k}^{-\alpha}$ is

$$d_{s,k}^{-\alpha} = ((x - x_s)^2 - (\mathrm{y} - y_s)^2)^{-\alpha/2} \tag{20}$$

The UE's signal strength expectation received from the single original BS $E(S_{0,k})$ and CoMP BSs $E(Sc_k)$ can be written as

$$E(S_{0,k}) = PGh_{0,k} = \frac{PG}{N} E(10^{\frac{\zeta_{0,k}}{10}})((x - x_0)^2 - (y - y_0)^2)^{-\alpha/2} \tag{21}$$

$$E(Sc_k) = \frac{PG}{N} \sum_{s=1}^{M} E(10^{\frac{\zeta_{s,k}}{10}}) d_{s,k}^{-\alpha/2} = \frac{PG}{N} \sum_{s=1}^{M} E(10^{\frac{\zeta_{s,k}}{10}})((x - x_s)^2 - (\mathrm{y} - y_s)^2)^{-\alpha/2} \tag{22}$$

We have assumed all the channels follow the i.i.d. slow fading. So $E(10^{\zeta_{0,k}/10}) = E(10^{\zeta_{1,k}/10})$ $... = E(10^{\zeta_{M,k}/10})$. By applying Eq. 13, finding position of the worst-case point is equivalent to getting the solution on the minimization problem below:

$$\begin{aligned} \min \quad & f(x, y) = \sum_{s=1}^{J} ((x - x_s)^2 - (\mathrm{y} - y_s)^2)^{-\alpha/2}) - (x - x_0)^2 - (\mathrm{y} - y_0)^2)^{-\alpha/2} - \frac{S_{Th} N}{PG} \\ s.t. \quad & |x| + \sqrt{3}|y| \le \sqrt{3}R \\ & |x| \le \frac{\sqrt{3}}{2} R \end{aligned} \tag{23}$$

From Eq. 23, we can see it is an inequality constraint problem and both the objective function and the constrained conditions are continuously differentiable. Hence we can use KKT conditions to easily find the solution (x^*, y^*) if we have a geological symmetrical distribution of BSs. Hence, the solution (x^*, y^*) should satisfy

$$\nabla f(x^*, y^*) - \left((u_1 - u_2) \begin{bmatrix} 1 \\ \sqrt{3} \end{bmatrix} + (u_3 - u_4) \begin{bmatrix} -1 \\ \sqrt{3} \end{bmatrix} + (u_5 - u_6) \begin{bmatrix} 1 \\ 0 \end{bmatrix} \right) \tag{24}$$

where

$$\nabla f(x, y) = \begin{bmatrix} \frac{\partial}{\partial x} f(x, y) \\ \frac{\partial}{\partial y} f(x, y) \end{bmatrix} = \begin{bmatrix} -\alpha(\sum_{s=1}^{J} (x - x_s) \cdot ((x - x_s)^2 - (\mathrm{y} - y_s)^2)^{-\frac{\alpha}{2} - 1}) - (x - x_0) \cdot ((x - x_0)^2 - (\mathrm{y} - y_0)^2)^{-\frac{\alpha}{2} - 1}) \\ -\alpha(\sum_{s=1}^{J} (y - y_s) \cdot ((x - x_s)^2 - (\mathrm{y} - y_s)^2)^{-\frac{\alpha}{2} - 1}) - (y - y_0) \cdot ((x - x_0)^2 - (\mathrm{y} - y_0)^2)^{-\frac{\alpha}{2} - 1}) \end{bmatrix}$$

And (x^*, y^*) should also satisfy the Complementary Slackness Conditions.

$$\begin{cases} u_1(x^*+\sqrt{3}y^*+\sqrt{3}R)=0; \quad u_2(x^*+\sqrt{3}y^*-\sqrt{3}R)=0; \\ u_3(x^*-\sqrt{3}y^*-\sqrt{3}R)=0; \quad u_4(x^*-\sqrt{3}y^*+\sqrt{3}R)=0; \\ u_5(x^*+\frac{\sqrt{3}}{2}R)=0; \quad u_6(x^*-\frac{\sqrt{3}}{2}R)=0; \end{cases} \tag{25}$$

Then we can get the position of the worst-case point. The ellipse-marker points in **Fig. 7** are the worst case point location of the basic CoMP load-balancing patterns: $\omega_{2,I}$, $\omega_{3,I}$ and $\omega_{3,II}$.

This paper takes these worst-case points as instances to show the performance of the received signal outage/service probability for each basic CoMP pattern. Assuming BS#1, BS#2,…, BS#*J* are the cooperative BSs with the i.i.d. slow-fading, the same transmission power *P* and antenna gain *G*, then we can extend the **Definition 2** and **Definition 3** to the CoMP mode. Hence, Eq. 7 can be rewritten by

$$P_{serv} = \Pr[Sc_k \geq \gamma] = 1 - \Pr[Sc_k < \gamma] = 1 - \iint\limits_{\sum_{s=1}^{J} d_{s,k}^{-\alpha} 10^{\frac{z_s}{10}} = \gamma N/PG} \frac{1}{(\sqrt{2\pi}\sigma)^J} e^{-\frac{\sum_{s=1}^{J} z_s^2}{2\sigma^2}} dz_1 dz_2 ... dz_J \tag{26}$$

This is the signal service probability of the *J* BSs' CoMP pattern. However, it is difficult to find the solution of Eq. 26 when $J \geq 3$ because of the mathematical complexity. Therefore, we use a mathematical approximation proposed in [23] to solve this problem. We firstly approximate *k*-th user's received signal strength from CoMP BSs Sc_k as another random variable $\vartheta = \delta 10^{\zeta/10}$ where δ is a scaling factor that we want to find and ζ is also a random variables following standard normal distribution with zero mean and ζ standard variance, i.e. $\zeta \sim (0, \sigma^2)$. Then we get the expectation of Sc_k :

$$E(Sc_k) = \delta E(10^{\frac{\zeta}{10}}) = \frac{PG}{N}(d_{1,k}^{-\alpha} E(\psi_1 = 10^{\frac{\zeta_1}{10}}) + d_{2,k}^{-\alpha} E(\psi_2 = 10^{\frac{\zeta_2}{10}}) ... + d_{J,k}^{-\alpha} E(\psi_J = 10^{\frac{\zeta_J}{10}})) \tag{27}$$

Since ζ and $\zeta_1, \zeta_2, ...\zeta_J$ follows i.i.d. Then we can solve the scaling factor δ and find the signal service probability by:

$$P_{serv}(Sc_k) = 1 - \Pr[Sc_k < \gamma] = 1 - \int_{-\infty}^{10*\log\frac{\gamma}{\delta}} \frac{1}{\sqrt{2\pi}\sigma} e^{\frac{z^2}{2\sigma^2}} dz \tag{28}$$

where $\delta = \frac{PG}{N}\sum_{s=1}^{J} d_{s,k}^{-\alpha}$. **Fig. 8** gives the received signal service probability of the worst-case location for the basic patterns versus the times of normalized radius *R* of the hexagonal cell. *R* is initially normalized to 1Km. The essential determination of *R* is the different transmission parameters such as transmission power *P* and antenna Gain *G*, or the received signal quality requirement γ , or the different channel environment α and *N*. And the solid-square-marker and dot-square-marker lines are the signal service probability of the basic two BSs CoMP pattern solved by exact method by Eq. 26 and approximate method by Eq. 28 respectively. We can see the accuracy error of the approximation is higher than 5% when R exceeds 1.35. And the best performance of the service probability is provided by the pattern $\omega_{3,I}$ rather than $\omega_{3,II}$ because the average distance between three CoMP BSs in this pattern is shortest. We can also see the decreasing of service probability is likely linear with R when R is higher than 1.4. Hence, we can think the proper requirement on R is from 1.0-1.35 according to both the accuracy error requirement and signal service probability performance.

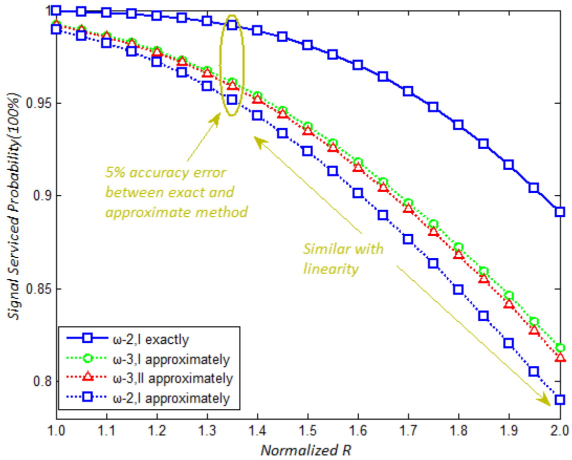


Fig. 8. Signal service probability of the worst-case point in each basic CoMP pattern

4.2.2 Efficient Throughput

By **Definition 4**, we can easily find the average efficient throughput by Eq. 29 if we assume the distribution of users in the extended coverage area is uniform:

$$R_{avg}(t) = \frac{\int_{O_{Jc}(\omega_{Nc,T}(Nm,Nr/Nc))} Uc_k(x,y)\cdot P_{serv}(Sc_k(x,y))dxdy}{O_{Jc}(\omega_{Nc,T}(Nm,Nr/Nc))}$$
$$= \frac{\int_{O_{Jc}(\omega_{Nc,T}(Nm,Nr/Nc))} \log_2(1+ScINR_k(x,y)(\zeta=0))\cdot(1-P_{out}(Sc_k(x,y)))dxdy}{O_{Jc}(\omega_{Nc,T}(Nm,Nr/Nc))} \quad (29)$$

where Uc_k is the spectrum effectiveness of the kth user whose service is provided by the CoMP BSs and given by $Uc_k = \log_2(1+ScINR_k(\zeta=0))$ where $ScINR = Sc_k / (\sum_{s'\in Jn_0/Jc} S_{s',k} + N_T)$ is the received Signal with CoMP to Interference and Noise Ratio. The interference signal is from all neighbor BSs of central 0-th BS except for the BSs in the CoMP set Jc.

5. Numerical Result Analysis

In this section, we give some numerical results to show the load-balancing effects and QoS performances of our proposed CoMP load-balancing patterns. We work on two scenes: a) Low-Dense Traffic Area as shown in **Fig. 5** and b) High-Dense Traffic Area as shown in **Fig.**

6. The simulation system parameters are shown in **Table 1**. Notice that we distinguish the high loaded BS and low loaded BS by the offered load *A* and 0.5*A*.

Table 1. Simulation System Parameters

Path-loss exponent α	1.5
Other Fading Marginal Constant N	-114dB
BS Coverage Radius R	Normalized to 1Km
BS's Transmitting Power P	20W
Antenna Gain G	17.5dBi
Channel Capacity C	50
Offered Traffic for high-loaded BS A	[30:0.1:70]Erlangs
Offered Traffic for low-loaded BS (0.5A)	[15:0.1:35]Erlangs
Grade of QoS(GoS): Call Blocking Probability	2%
Queue length limit L	50
Strength Hysteresis for User Association Determination S_{Th}	0mW
Received Signal Power Threshold γ	-95dBm
Slow Fading Standard Variance σ	3dB

5.1 The Low-Dense Traffic Area

We firstly analyze the area with low-dense distribution of high loaded BS as shown in **Fig. 5**. The ratio of the number of high loaded BSs Nh to the number of low loaded BSs Nl is 1:6. The determined CoMP load balancing patterns to maximally use the low loaded BSs can be obtained by Eq. 5, which are $\omega_{2,I}(2,0)$, $\omega_{3,I}(2,0)$ and $\omega_{3,II}(2,0)$. The QoS performances are discussed from the metrics we have defined above: efficient throughput and call blocking rate.

5.1.1 Efficient Throughput

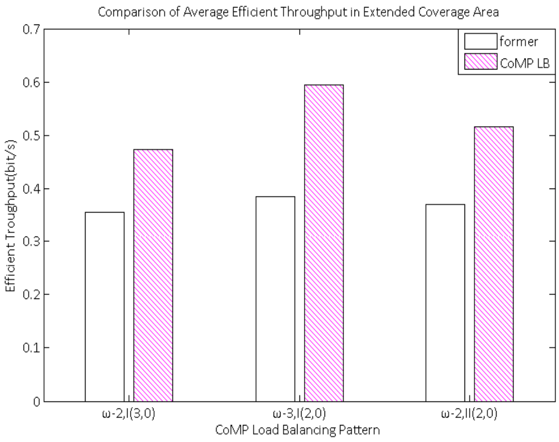


Fig. 9. Comparison of average efficient throughput for low-dense traffic area

We firstly consider the efficient throughput and investigate the performance obtained purely by the proposed CoMP load balancing method. **Fig. 9** shows the average efficient throughput before and after CoMP load balancing with different CoMP patterns. We only focus on the users in the extended coverage area as shown in **Fig. 7**. The reason is only the user's efficient throughput in this area changes after CoMP if we assume BSs have enough resources to allocate. As expected, the efficient throughput with the patterns $\omega_{2,I}(2,0)$, $\omega_{3,I}(2,0)$ and

$\omega_{3,II}(2,0)$ are all higher than the performances before CoMP load balancing. The improvement derives from that CoMP can essential improve the edge user's SINR [17][18] in order to increase the throughput per bandwidth. The best performance is provided by pattern $\omega_{3,I}(2,0)$ that increasing by 54.8%. This is because we have worked out that $\omega_{3,I}$ has higher channel service probability in **Section 4.2**. Hence, $\omega_{3,I}(2,0)$ owns higher likelihood to overcome the fading channel than non-CoMP and other CoMP modes.

5.1.2 Call Blocking Rate

In this part, we show the numerical results of the capability of CoMP load balancing and call blocking rate defined and analyzed in **Section 4.1**. From **Definition 5**, we use how much the traffic of the high loaded BS can be balanced to evaluate the capacity of CoMP load balancing. **Fig. 10** gives the variant of the average traffic per BS with different CoMP load balancing patterns. From **Fig. 10**, we can see for the balanced high loaded BS with initial traffic *A*, after CoMP load balancing the average traffic per high loaded BS decreases to 0.697*A*, 0.562*A* and 0.615*A* with $\omega_{2,I}(2,0)$, $\omega_{3,I}(2,0)$ and $\omega_{3,II}(2,0)$ respectively. This is as same as our analyzed results in **Section 4.1.1**. We have assumed all the users have the same arrival rate and service rate. So the balanced traffic is determined by the CoMP extended coverage range. From **Fig. 7** we have known $\omega_{3,I}(2,0)$ has the largest CoMP extended coverage range except for the overlapped area resulted by the multiple pairs of CoMP BSs. However, the negative effect of the CoMP load balancing is that all the CoMP BSs will bear the same total balanced traffic. Therefore we cannot ignore the increment of the traffic for those balancing CoMP BSs. **Fig. 10** also shows the traffic of the balancing BSs. We can see the traffic per CoMP BS with $\omega_{3,I}(2,0)$ reaches 0.724*A* after load balancing if the initial traffic of these low loaded BSs is 0.5*A*. This is acceptable for 2% grade of call blocking rate if *A* is 50 Erlangs and the number of BS's channel is 40. However, if *A* is more than 50 Erlangs, the 2% grade of call blocking rate cannot be satisfied by CoMP pattern $\omega_{3,I}(2,0)$. We go to analyze this performance specifically in the following.

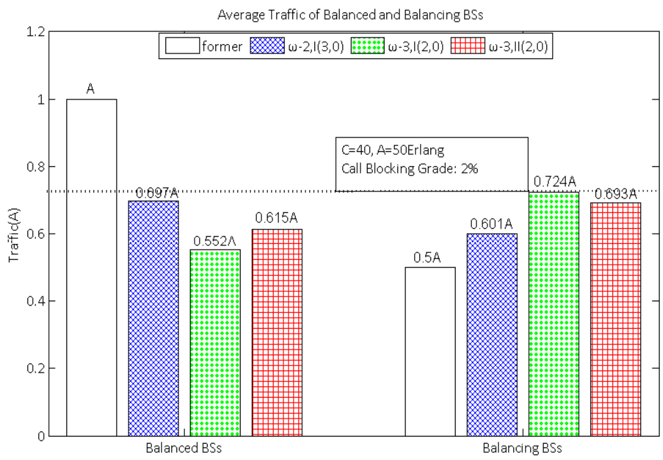
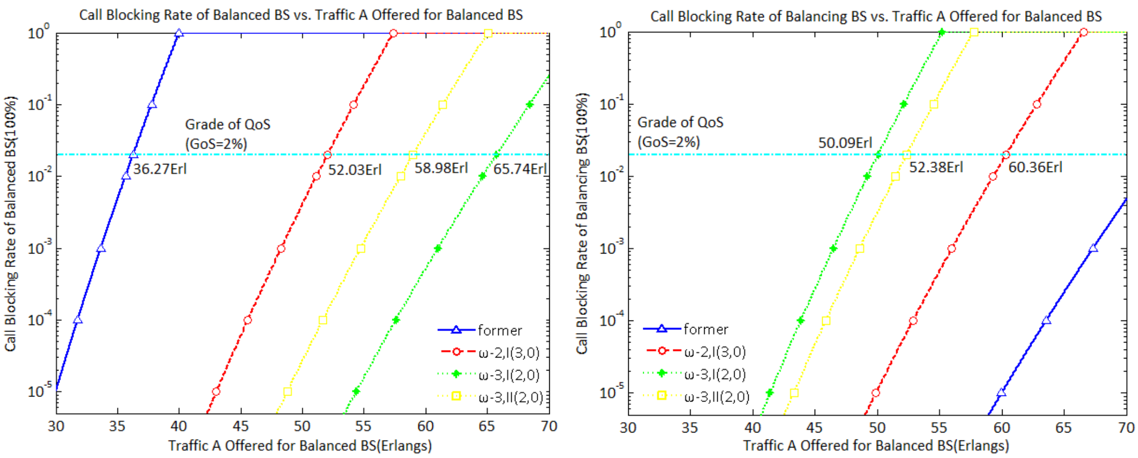


Fig. 10. Average traffic of balanced and balancing BSs before and after CoMP load balancing in low-dense traffic area

Fig. 11 show the call blocking rate per balanced BS and per balancing BS of all the patterns in low-dense traffic area with varying traffic loads *A*. From **Fig. 11(a)**, when channel capacity per BS *C*=40 and the initial traffic of high-loaded BS we want to balance is *A*, to achieve a call blocking rate of 0.2%, the high-loaded BS can only maximally bear *A*=36.27 Erlangs without CoMP load balancing. After CoMP load-balancing, for the same QoS requirement, the high loaded balanced BS can maximally bear *A*=52.03 Erlangs with $\omega_{2,I}(2,0)$, *A*=58.98 Erlangs with $\omega_{3,II}(2,0)$, and *A*=65.74 Erlangs with $\omega_{3,I}(2,0)$. However, as analyzed above, we also need to pay attention to the call blocking rate of the balancing CoMP BSs. From **Fig .11(b)**, when the initial traffic of low loaded BSs we want to use as the CoMP BSs is 0.5*A*, for the same QoS requirement, the high loaded balanced BS can only maximally bear *A*=60.36 Erlangs with $\omega_{3,I}(2,0)$, *A*=50.09 with $\omega_{3,I}(2,0)$ and *A*=52.38 Erlangs with $\omega_{3,II}(2,0)$, which is a conflict of lowering than balanced BS a lot. When *A* is high, If we want both high loaded balanced BSs and low loaded balancing BSs to achieve a good performance of call blocking rate, $\omega_{2,I}(2,0)$ and $\omega_{3,II}(2,0)$ are better choices than $\omega_{3,I}(2,0)$.



(a) Balanced BS **(b)** Balancing BS

Fig. 11. Call Blocking Rate per balanced and balancing BS in low-dense traffic area

5.2 The High-Dense Traffic Area

In our second simulation run we consider the system with high-dense distribution of high loaded BSs as shown in **Fig. 6**. The ratio of the number of high loaded BS Nh to the number of low loaded BS Nl is 1:2. The determined CoMP load balancing patterns to maximally use the low-loaded BSs can also be obtained by Eq. 5, which are $\omega_{2,I}(1,0)$, $\omega_{2,I}(2,1/2)$, $\omega_{3,I}(1,2/3)$ and $\omega_{3,II}(1,2/3)$.

5.2.1 Efficient Throughput

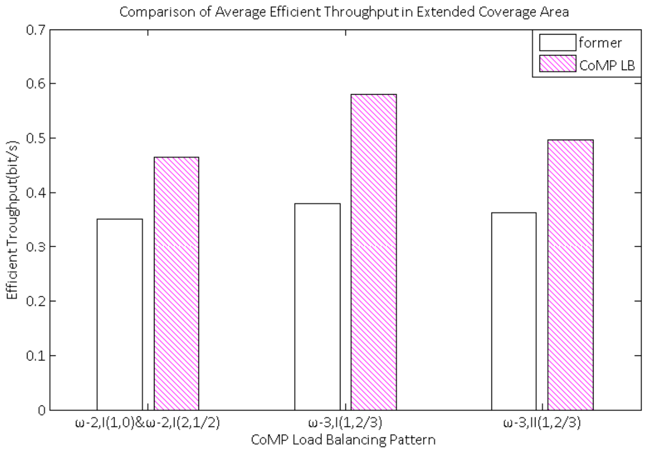


Fig. 12. Comparison of average efficient throughput in high-dense traffic area

Fig. 12 presents the average efficient throughput before and after CoMP load balancing with different CoMP patterns. $\omega_{2,I}(1,0)$ and $\omega_{2,I}(2,1/2)$ have the same numerical results because the user's received signal power is independent with whether the CoMP BSs are reused. As expected, $\omega_{2,I}(1,0)$, $\omega_{2,I}(2,1/2)$, $\omega_{3,I}(1,2/3)$ and $\omega_{3,II}(1,2/3)$ also improve the efficient throughput because of the characteristic of CoMP. And $\omega_{3,I}(1,2/3)$, as a type of basic pattern $\omega_{3,I}$, gives the best performance of efficient throughput.

5.2.2 Call Blocking Rate

Fig. 13 presents the variant of the average traffic per BS with different CoMP load balancing patterns in high-dense traffic area. From **Fig. 13**, we can see the average traffic per high loaded BS decreases to 0.819*A*, 0.783*A*, 0.752*A* and 0.746*A* with $\omega_{2,I}(1,0)$, $\omega_{2,I}(2,1/2)$, $\omega_{3,I}(1,2/3)$ and $\omega_{3,II}(1,2/3)$ respectively through CoMP load balancing. $\omega_{3,I}(1,2/3)$ and $\omega_{3,II}(1,2/3)$ are higher than two types of $\omega_{2,I}$, i.e. $\omega_{2,I}(1,0)$ and $\omega_{2,I}(2,1/2)$, because $\omega_{3,I}$ and $\omega_{3,II}$ have larger CoMP coverage extended areas than $\omega_{2,I}$ as shown in **Fig. 7**. And in further $\omega_{2,I}(2,1/2)$ is better than $\omega_{2,I}(1,0)$ due to the multiple uses of CoMP low loaded BSs. On the other hand, the average traffic of the balancing CoMP BSs increases to 0.609*A* with $\omega_{2,I}(1,0)$, 0.717*A* with $\omega_{2,I}(2,1/2)$, 0.913*A* with $\omega_{3,I}(1,2/3)$ and 0.924*A* with $\omega_{3,II}(1,2/3)$. We can see $\omega_{3,I}(1,2/3)$ and $\omega_{3,II}(1,2/3)$ bring heavy costs with amount of traffic increments. When *A* is more than 40 Erlangs, the CoMP balancing BSs with $\omega_{3,I}(1,2/3)$ and $\omega_{3,II}(1,2/3)$ cannot satisfy the 2% grade of call blocking rate. In addition, we can learn $\omega_{2,I}(2,1/2)$ has a same amount of traffic variation in balanced and balancing BS.

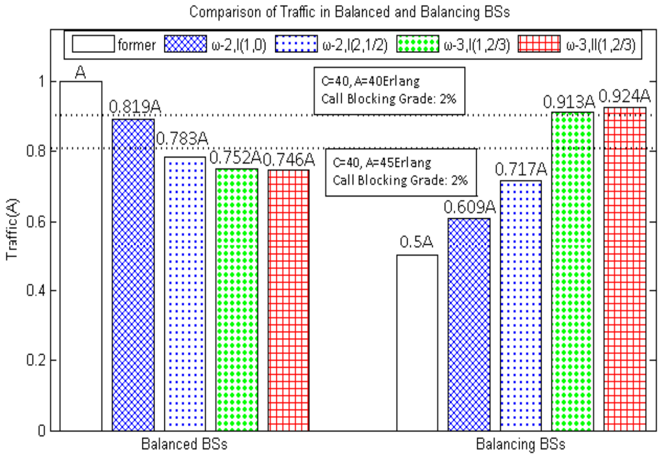
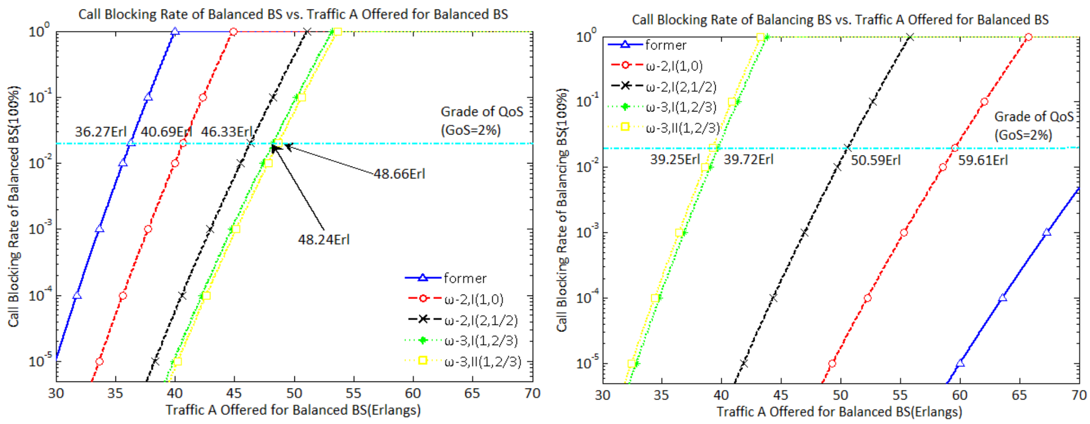


Fig. 13. Average traffic of balanced and balancing BSs before and after CoMP load balancing in high-dense traffic area

As same as **Fig. 11** in the low-dense traffic area, **Fig. 14** also present the call blocking rate per balanced BS and per balancing BS of all the patterns with different traffic load A in the high-dense traffic area. From **Fig. 14(a)**, to satisfy a 2% call blocking rate, the high loaded balanced BS can maximally bear A=40.69 Erlangs with $\omega_{2,I}(1,0)$, A=46.33 Erlangs with $\omega_{2,I}(2,1/2)$, A=48.24 Erlangs with $\omega_{3,I}(1,2/3)$ and A=48.66 Erlangs with $\omega_{3,II}(1,2/3)$. In **Fig. 14(b)**, in the condition of the same QoS requirement for the low loaded balancing BSs after CoMP load balancing, the high loaded balanced BS can only maximally bear A=59.61 Erlangs with $\omega_{2,I}(1,0)$, A=50.59Erlangs with $\omega_{2,I}(2,1/2)$, A=39.72 Erlangs with $\omega_{3,I}(1,2/3)$ and A=39.25 Erlangs with $\omega_{3,II}(1,2/3)$. As expected from the analyzing above, $\omega_{2,I}(2,1/2)$ is the best fitting pattern if we want to obtain an excellent call blocking performance trade-off between balanced and balancing BSs.



(a) Balanced BS **(b)** Balancing BS

Fig .14. Call blocking rate per balanced and balancing BS in high-dense traffic area

6. Conclusion

In this paper, we propose a load-balancing method in which some BSs are used as the CoMP BSs to effectively extend coverage area with guaranteed call blocking rate and efficient throughput. We analyze the basic CoMP load-balancing patterns and extend to the multiple and reused patterns. We consider the call blocking rate based on the capacity of CoMP load balancing and the efficient throughput based on the extended coverage area of CoMP load balancing provided by different CoMP patterns. We give two different types of high loaded BSs distribution areas based on the standard hexagonal cellular model to analyze the CoMP load-balancing performance. The numerical results exhibit significant throughput efficient potential of the proposed idea of using BSs cooperative coverage to balance the load. The capacity of load-balancing and call blocking rate are evaluated and analyzed in order to give the proper CoMP load-balancing pattern in different simulation areas.

Several contributions of this work can be useful to practical cellular networks. First, load balancing between high loaded BS and low loaded BS according to some CoMP patterns is effective with low complexity. CoMP has been made available in recent standards such as LTE-advanced/5G because CoMP is an efficient and energy-saving way to extend the coverage without a lot of power cost and computation complexity. Second, CoMP load balancing scheme brings a high efficient throughput potential instead of the traditional power increasing manner with a strong interference from the balancing BS. Lastly, given the guaranteed QoS and load-balancing capacity by the theoretical model, it can be valuable to investigate the other potential cost of these CoMP load balancing patterns such as handovers. And whether is suitable for 4G /B4G the given Erlang C model is still an open issue. The self-similarity traffic model can also be used to calculate the blocking metric[24] which will be interesting in the future research.

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