A Load Balancing Method in Downlink LTE Network based on Load Vector Minimization

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***Abstract*—Load balancing is one of the key target of LTE Self-Optimization Network (SON). In this paper, we propose a load balancing method for LTE downlink network, namely Load Vector Minimization based Load Balancing (LVMLB) method. Load Vector (LV) is a vector whose elements are the load values of cells and sorted in descending order. The order of LVs is defined by the lexicographical order. The smaller the LV is, the higher the balance degree of cells load will be. As the LV has a lower bound with total load fixed, the balance degree of cells load would reach a local optimal. On this basis, we design the LVMLB algorithm, trying to get the optimal solutions to load balancing problems, the proof of being optimal will also be given in this paper. Simulation scenarios are set in a square part of Macro-Pico mixed HetNets. Simulation results show that LVMLB outperforms the Cell Region Expansion (or Bias) scheme, increasing the capacities of Macro and Pico tiers at the same time, and improving balance degree of cells load, only sacrificing a little QoS performance.**

Keywords—cell load vector; lexicographical order; LTE; load balancing.

I. INTRODUCTION

The unbalanced load distribution in wireless communication system is inevitable, because of the randomness of user position and their service status. The evolution of mobile phones bring an explosion of mobile users, which challenges the capacity of the wireless access network and raises higher requirements to load balancing ability. Both of the two aspects are considered in LTE design. The density of base stations is greatly raised so that resources in unit area increase. As a result, the capacity of the whole wireless access network is improved. Besides, HetNets, developed in 3G, are taken as basic parts of LTE radio access network (RAN) architecture. Through the flexible deployment of Low-power Base Stations (LBS), not only the traffic pressure at high-load areas can be relieved, but also the coverage holes at the edges of macro-cells can be easily compensated, without disturbing the current setting of eNodeBs. The capacity of LTE system is further enhanced. To facilitate load balancing, a Cell Individual Offset (CIO) parameter is designed in LTE to affect the handover procedures of users. By adjusting CIO, the actual coverage of LTE RAN will not be greatly influenced, compared with other methods, such as power tuning, or antenna tilting.

To reduce the management complexity and operational cost, the concept of self-organizing network (SON) is introduced in LTE, that the network is autonomously operated to reducing manual intervention. Load balancing is one of the key target of SON [1]. LTE network with SON functions configured will transfer load from high load cells to their low load neighbor cells automatically, when the load status of the network reaches a trigger condition, to maintain a proper load distribution in the network. The use case given in [1] proposed a load balancing method based on CIO adjustment. However, it is not a frozen standard. In order to improve the efficiency and performance of load balancing, the algorithms or methods of load balancing are still worth deep research. New properties of dense small cell and HetNets also raise new requirements to the current LB methods.

Present works on load balancing are shown below. A load balancing method is proposed in [2], aiming at reducing the load of high load cells to certain threshold. S. Yang, et al, in [3], improve the former method by proposing a two-hop scheme to make up the shortcoming that when a cluster of cells are all of high load, the center cell will not be able to transfer its load. Method in [4] is to achieve load balancing by minimizing the load gap between two neighbor cells to certain threshold. However, all the methods above have the limitation that they depends on certain predesign load threshold. These predesign threshold cannot adapt to the load status of the network, so the balance degree cannot be further improved. In addition, the above methods considers little about their applicability under HetNets scenarios. In [5] optimized cell selections are made for mobile users under proportional fairness principle, but it pays no attention to the order of users in traversal process, which affects the performance of LB. In [6] LB problem is transformed into a convex optimization problem, and optimal user-BS associations can be found by solving it. However, this paper focus on the load balancing between different HetNets tiers, rather than the load balancing among all cells. Besides, [5] [6] give merely user-BS associations, lacking the practical implementation procedures.

To overcome the shortcomings of the above LB methods, in this paper we propose a load balancing method whose main idea is the balance degree of network load can be improved the most by minimizing the load vector. We first give the definition of Load Vector (LV) and define a balancing degree function of the load of all cells in the network, and then we prove the value of the function is monotonically increasing with the decrease of LV, which will transform the load balancing problem of minimizing the function value to minimizing LV. Thus, the original load balancing problem is much easier to solve. The QoS of users are guaranteed by handover margin (HOM), which stands for the limit of CIO parameters. Users are not allowed to transfer to neighbor cells, if their RSRP suffer from a loss more than HOM.

The rest of this paper are organized as follows. Section 2 gives the problem formulation, in which the system model and some related concepts are introduced. In Section 3, we describe the LVMLB method, including the basic principle, the detailed procedures, and also the convergence proof of it. Simulation settings and results analysis will be given in section 4, and the whole paper will be concluded in section 5.

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II. PROBLEM FORMULATION

In this section, we give the system model and basic concepts of LV, and describe the original load balancing problem with a balancing degree function derived from Jain's fairness index formula [7]. By analyzing the function, it is easy to know that the function value monotonically increases with the decrease of LV. Therefore, we naturally get the main idea of LVMLB.

A. System Model

Consider a Macro-Pico cell mixed HetNets scenario, as illustrated in figure 1. N cells in the network forms a set B, which consists of N_1 Macro cells in B_1 and N_2 Pico cells B_2. $N_1 + N_2 = N$. M mobile users forms the set U. Mobile users access cells with best RSRP signals by default. For simplicity, we assume a cell generates a Unit Load (UL), when a user access the network through it. Due to the restriction of resource blocks, the capacity of each cell has an upper bound ρ_{max}. If the load of BS $i \in B$ reaches the bound, new users cannot be admitted to it and thus be blocked. The default user access scheme, MaxRSRP, can be described in formula 1 as follows.

$$CellID_{serv}(j) = \arg\max_{i \in B}\{RSRP_{ij}\} \quad (1)$$

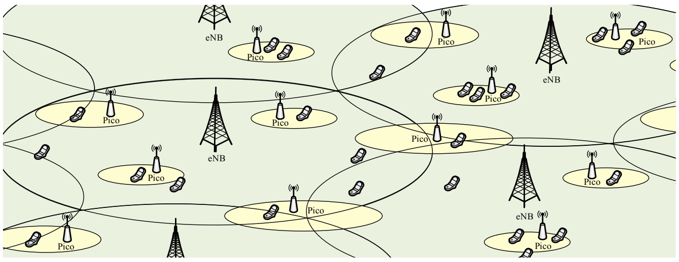


Fig. 1 Illustration of Macro-Pico Mixed HetNets.

In LTE Macro-Pico mixed HetNets, Macro BS and Pico BS differ in the transmit power and the size of them [8], so in this paper we assume all BSs have the same load capacity. However, because the transmit power of Macro BS is about 100 times (20dB) of that of Pico BS [9], the default cell selection scheme will bring about the coverage disparity of Macro and Pico cells, causing the unbalanced load distribution between different kinds of cells. Range expansion (Bias) scheme is proposed to deal with it [7], that the RSPR of LBSs are biased up so that more users are tend to access LBSs. In HetNets with Bias scheme deployed, cell selections of users are made according to formula 2.

$$CellID_{serv}(j) = \arg\max_{i \in B}\{RSRP_{ij} + Bias_i\} \quad (2)$$

However, Bias scheme can't balancing the load among cells in the same tier. So other schemes are needed.

B. Problem Formulation

The function in formula 3, derived from Jain's fairness index, is widely used to evaluate the balance degree of cells load. Wherein, the ρ_i stands for the load of BS i, and N is the number of base stations. The load of a UL is represented by e, and x_{ij} indicates whether there is an association between user j and BS i. $x_{ij} = 1$ is for yes, and 0 for no. The value of the function is in the range of $[1/N,1]$, and the bigger value means the load of cells is more balanced.

$$f(\vec{\rho}) = \frac{(\sum_{i \in B} \rho_i)^2}{|N|(\sum_{i \in B} \rho_i^2)} \quad (3)$$

$$s.t. \rho_i = e \sum_j x_{ij}$$

$$x_{ij} = \begin{cases} 1 & \text{user } j \text{ is serving by BS } i \\ 0 & \text{user } j \text{ is not serving by BS } i \end{cases}$$

Load vector indicates the load of all cells in descending order. With the help of neighbor cell information, a possible target cell in each iteration of load balancing can be easily specified. User j in BS i_1, for instance, wants to handover to neighbor cell BS i_2 should satisfy the following simplified requirement [10].

$$RSRP_{i_2 j} + CIO_{i_1 i_2} > RSRP_{i_1,j} \quad (4)$$

Here for simplicity we omit the hysteresis and fixed offset. The difference of $RSPR_{i_1 j}$ and $SRP_{i_2 j}$, denoted as $Pcost_{i_1 i_2 j}$, can be expressed as $Pcost_{i_1 i_2 j} = RSRP_{i_1 j} - RSRP_{i_2 j}$, which indicates the RSRP sacrifice after handover and the minimum value the CIO parameter should be adjusted to. Users in cell i_1 can be sorted on $Pcost_{i_1 i_2 j}$, and smaller value means the corresponding user j is closer to the target neighbor cell i_2 and is more likely to be handed over. Moreover, only users who meet the requirement in formula 4, which also means the $Pcost$ should be less than the current CIO value, can be handed over to their target cell. So the CIO parameter should be adjusted according to $Pcost$.

A large CIO value may lead to severe QoS deterioration, as the RSPR drops too much for the user of big $Pcost$ value. So an upper bound of CIO, denoted as Handover Margin (HOM) is set. Users whose $Pcost$ value exceed HOM will not be allowed to hand over and CIO will never be set a value bigger than HOM.

Bigger HOM means more users can be reallocated in load balancing, so the load in the network can be more balanced. But the QoS of users after load balancing may not be guaranteed. HOM is a tradeoff between the two factors, and the value of HOM should be carefully designed. Related works have given empirical range of it. In this paper, we adopt the value derived from simulations.

C. Definitions

To facilitate the explanation of LVMLB, some relative terms are defined here.

Definition 1. Cell Load Vector (CLV) is a vector consisting of the load values of all cells in descending order, denoted as $\vec{\rho} = (\rho_1, \rho_2, \ldots, \rho_N)$.

Definition 2. Lexicographical Order (LO). Two vectors, $\overrightarrow{W_1} = (a_1, a_2, \ldots, a_n)$ and $\overrightarrow{W_2} = (b_1, b_2, \ldots, b_n)$, if $\exists i \in \{i | i < n, i \in \mathbb{Z}^+\}$ indicates the index of the first element that $a_i \neq b_i$, then $a_i > b_i$ means $\overrightarrow{W_1} > \overrightarrow{W_2}$; $a_i < b_i$ means $\overrightarrow{W_1} < \overrightarrow{W_2}$. If no such i exists, $\overrightarrow{W_1} = \overrightarrow{W_2}$.

The order of CLV can be defined as the lexicographical order. $\mathrm{LO}(\overrightarrow{\rho_1}) < \mathrm{LO}(\overrightarrow{\rho_2})$ means $\overrightarrow{\rho_1} < \overrightarrow{\rho_2}$. If $\mathrm{LO}(\overrightarrow{\rho_1}) = \mathrm{LO}(\overrightarrow{\rho_2})$, $\overrightarrow{\rho_1} = \overrightarrow{\rho_2}$. A property of CLV is noticeable that a CLV has a lower bound, and the ideal lower bound is a vector consist of elements being the average load value. So it is intuitive to try to achieve load balance by minimizing CLV, especially when it is proved that the balance degree function monotonically increases with the decrease of CLV. So we get the main idea of LVMLB. The details of it will be depicted in next section.

III. LVMLB ALGORITHM

In this section, we give the basic principle of LVMLB, and later we prove it will converge to a local optimal. The detailed procedures of LVMLB are given later in this section.

A. Basic Principle of LVMLB

Principle of LVMLB: Search the elements of CLV in turn to find a cell that can transfer a UL to a low load neighbor cell, until no such cell can be found. If such a cell is found, update the user-BS association, the BS load and CLV, and then search the CLV from beginning again.

High load cell i_1 can transfer a UL to a low load neighbor cell i_2 based on two conditions.

1) $\rho_{i_1} > \rho_{i_2}$ and $\exists j \in U, Pcost_{i_1 i_2 j} \le HOM$;

2) The UL to be transferred will not bring about a loop of target cells.

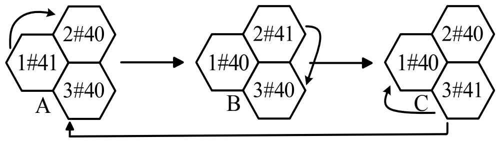


Fig. 2 Illustration of UL-transfer cell loop.

The example of a load-transfer cell loop is illustrated in Fig. 2. In state A, BS1 has the highest load, so it transfer a unit load to neighbor BS2 and BS2 turns to be the BS of the highest load. Then in state B, BS2 transfers a unit load to BS3. BS3 transfers a unit load to BS1 in state C, where it goes back to state A. To avoid the endless load-transfer loop, condition 2 is necessary.

The first condition is easy to check, while the second seems not apparent. In fact, it includes two situations. Situation 1,$\rho_i - \rho_j > e$, no loop will occur. Situation 2, $\rho_i - \rho_j = e$, LVM try to guarantee no loop occurs by the following rule.

It is easy to know that the loop occurs only when $\rho_i - \rho_j = e$, which also means the cells with their load higher than ρ_i, cannot have their load transferred according to the principle of VLMLB. Assuming cell i is selected to transfer a unit load to neighbor cell j, whose load is as low as possible among all neighbor cells, and ρ_i and ρ_j satisfy $\rho_i - \rho_j = e$ in an iteration, we can use a Broad First Search (BFS) algorithm to search all the neighbor cells of cell i, with load being ρ_j, to find a cell k being the neighbor of neighbor cells of cell i, that satisfy $\rho_j > \rho_k$. BFS will continue to search multilayer cells until a cell k is found or all the possible searches are tried.

If such a cell k is found, BFS will return a path to transfer a UL from cell i to cell k. If not, BFS will keep all the cells it searched in a set S_{tmp}, because these cells can't transfer any UL to their neighbor cells. They will be appended to the set S_{DSC}, the cells in which will not be considered in the following iteration.

LVMLB will converge to local optimal solutions, which will be proved through the following several theorems.

B. Convergence of LVMLB

Theorem 1. CLV is non-increasing in each iteration of LVMLB.

Proof: The CLV is $\overrightarrow{\rho_t}$ after the *t*-th iteration, and $\overrightarrow{\rho_{t+1}}$ after (*t*+1)-th iteration. A UL is transferred from cell of index i in $\overrightarrow{\rho_t}$ to cell of index j in $\overrightarrow{\rho_t}$. Then the original proposition equals to prove $\overrightarrow{\rho_t} \ge \overrightarrow{\rho_{t+1}}$. As the order of two equal elements in $\overrightarrow{\rho_t}$ will not affect LO, so the elements of $\overrightarrow{\rho_t}$ can be adjusted to satisfy the condition, $\rho_{it} > \rho_{(i+1)t}$. There are two cases to be discussed.

1) $\rho_{it} > \rho_{jt} + e$. It means $\rho_{it} > max\{(\rho_{jt} + e), \rho_{kt}(k > i)\}$ in $\overrightarrow{\rho_t}$, and $\rho_{i(t+1)} = max\{(\rho_{jt} + e), \rho_{kt}(k > i)\}$ in $\overrightarrow{\rho_{t+1}}$. So $\rho_{it} > \rho_{i(t+1)}$ and therefore $\overrightarrow{\rho_t} > \overrightarrow{\rho_{t+1}}$.

2) $\rho_{it} = \rho_{jt} + e$. If a target cells k is found by BFS algorithm, it is easy to know that $\overrightarrow{\rho_t} > \overrightarrow{\rho_{t+1}}$, for the same reason as in case 1. If no target cell is found, $\overrightarrow{\rho_t} = \overrightarrow{\rho_{t+1}}$ is sure to be true.

So we conclude that $\overrightarrow{\rho_t} \ge \overrightarrow{\rho_{t+1}}$, after each *t*-th iteration.

Theorem 2. If $\overrightarrow{\rho_t} \ge \overrightarrow{\rho_{t+1}}$ then $f(\overrightarrow{\rho_t}) \le f(\overrightarrow{\rho_{t+1}})$.

Proof: If $\overrightarrow{\rho_t} = \overrightarrow{\rho_{t+1}}$, according to the property of elementary functions, $f(\overrightarrow{\rho_t}) = f(\overrightarrow{\rho_{t+1}})$.

If $\overrightarrow{\rho_t} > \overrightarrow{\rho_{t+1}}$, and a UL is to be transferred from cell i to cell j, we can get $\rho_{it} \ge \rho_{jt} + 2e$ from the proof of theorem 1. So the inequality $\rho_{it} > \rho_{it} - e \ge \rho_{jt} + e > \rho_{jt}$ stands. Rewrite it as $a > b \ge c > d$ for simplicity and $a + d = b + c$ stands.

Let $F(\overrightarrow{\rho_t}, \overrightarrow{\rho_{t+1}}) = f(\overrightarrow{\rho_t}) - f(\overrightarrow{\rho_{t+1}})$, then $F(\overrightarrow{\rho_t}, \overrightarrow{\rho_{t+1}})$

$$= \frac{(\sum_{i\in B} \rho_{ti})^2 (\sum_{i\in B} \rho_{(t+1)j}^2) - \left(\sum_{i\in B} \rho_{(t+1)j}\right)^2 (\sum_{i\in B} \rho_{tj}^2)}{|N| (\sum_{i\in B} \rho_{ti}^2)(\sum_{j\in B} \rho_{(t+1)j}^2)}$$

$$= \frac{(a+d+A)^2 (b^2 + c^2 + B) - (c+d+A)^2 (a^2 + d^2 + B)}{|N| (\sum_{i\in B} \rho_{ti}^2)(\sum_{j\in B} \rho_{(t+1)j}^2)}$$

$$= \frac{(a+d+A)^2 (b^2 + c^2 - a^2 - d^2)}{|N| (\sum_{i\in B} \rho_{ti}^2)(\sum_{j\in B} \rho_{(t+1)j}^2)}$$

$$= \frac{\frac{1}{2}(a+d+A)^2 [(b-c)^2 - (a-d)^2]}{|N| (\sum_{i\in B} \rho_{ti}^2)(\sum_{j\in B} \rho_{(t+1)j}^2)} < 0$$

Wherein $A = \sum_{i\in B} \rho_{ti} - a - d$, and $B = \sum_{i\in B} \rho_{tj}^2 - a^2 - d^2$. Thus, $f(\overrightarrow{\rho_t}) > f(\overrightarrow{\rho_{t+1}})$ is proved.

Theorem 3. If $\overrightarrow{\rho_s}$ and $\overrightarrow{\rho_t}$ are two CLVs from a same original state and $\overrightarrow{\rho_s} \ge \overrightarrow{\rho_t}$, then $\overrightarrow{\rho_s}$ can turn into $\overrightarrow{\rho_t}$, through a series of CLVs $\{\overrightarrow{\rho_\alpha}(\alpha \in \{1,2,\dots,n\})\}$, in which two adjacent CLVs have only one UL transferred, and $\overrightarrow{\rho_s} \ge \overrightarrow{\rho_1} \ge \overrightarrow{\rho_2} \ge \cdots \ge \overrightarrow{\rho_n} \ge \overrightarrow{\rho_t}$.

Proof: A serial of $\{\overrightarrow{\rho_\alpha}(\alpha \in \{1,2,\dots,n\})\}$ can be constructed the following way. The index of first different element in the same position of $\overrightarrow{\rho_s}$ and $\overrightarrow{\rho_t}$ is i, and the last is j. $\rho_i \ge \rho_j$. A unit load is transferred from cell i to cell j. Update the CLV, we can get $\overrightarrow{\rho_1}$. Substitute $\overrightarrow{\rho_1}$ for $\overrightarrow{\rho_s}$, and go on the process, we can get $\overrightarrow{\rho_2}$. Repeat the process, we will get a series of $\overrightarrow{\rho_\alpha}(\alpha \in \{1,2,\dots,n\})$, in which $\overrightarrow{\rho_n}$ has only two elements different from $\overrightarrow{\rho_t}$, and after one more iteration, it would turn into $\overrightarrow{\rho_t}$. There must be such a $\overrightarrow{\rho_n}$.

(Proof by contradiction). If such a $\overrightarrow{\rho_n}$ doesn't exist, there must be a $\overrightarrow{\rho_x}$, which has the fewest elements that different from elements in $\overrightarrow{\rho_t}$. So the number of different elements between $\overrightarrow{\rho_x}$ and $\overrightarrow{\rho_n}$ should be 1. However, we have known it is impossible. So there must be such a $\overrightarrow{\rho_n}$, and the theorem is proved.

Here the proof of theorem 3 only care about the property of CLV and doesn't concern about the actual handover events.

Corollary 1. $\overrightarrow{\rho_s}$ and $\overrightarrow{\rho_t}$ are two CLVs that the load of the network can be adjusted to, if $\overrightarrow{\rho_s} \ge \overrightarrow{\rho_t}$, $f(\overrightarrow{\rho_s}) \ge f(\overrightarrow{\rho_t})$.

Proof: According to the principle of LVMLB, there must be a serial of $\{\overrightarrow{\rho_\alpha}(\alpha \in \{1,2,\dots,n\})\}$ that satisfies $\overrightarrow{\rho_s} \ge \overrightarrow{\rho_1} \ge \overrightarrow{\rho_2} \ge \cdots \ge \overrightarrow{\rho_n} \ge \overrightarrow{\rho_t}$. And according to theorem 2, $f(\overrightarrow{\rho_s}) \ge f(\overrightarrow{\rho_1}) \ge f(\overrightarrow{\rho_2}) \ge \cdots \ge f(\overrightarrow{\rho_n}) \ge f(\overrightarrow{\rho_t})$. So $f(\overrightarrow{\rho_s}) \ge f(\overrightarrow{\rho_t})$.

Theorem 3. If $\overrightarrow{\rho_m}$ is the result CLV of LVMLB, no other CLVs will be small than it on the given conditions.

Proof: (by contradiction) assuming there exists a $\overrightarrow{\rho_n}$, $\overrightarrow{\rho_n} < \overrightarrow{\rho_m}$, there must be at least two elements in $\overrightarrow{\rho_n}$ different from elements in $\overrightarrow{\rho_m}$. Because if there is only one different element, the total load of $\overrightarrow{\rho_n}$ and $\overrightarrow{\rho_m}$ will be different. It is impossible, because they are from the same original state and the total load of $\overrightarrow{\rho_n}$ and $\overrightarrow{\rho_m}$

should be the same. If there is a cell i whose load satisfies $\rho_{mi} > \rho_{ni}$, it means the LVMLB is not finished, so it is contradiction that $\overrightarrow{\rho_m}$ is the final result of LVMLB. Therefore, the assumption doesn't stands, and the original proposition is proved.

Corollary 2: LVMLB get the local optimal of original load balancing problem.

Proof: LVMLB get the smallest CLV, according to theorem 3. It is easy to know the result CLV corresponds to the biggest $f(\vec{\rho})$. Thus, we get the local optimal resolution of original load balancing problem.

C. Details of LVMLB procedures

LVMLB includes the following procedures.

Pretreatments:

1) Each BS gets reports from users it serves and monitors the load status of itselft;

2) Each BS judges whether the load status of its own reach a trigger threshold. If it reaches, inform other BSs to step into the main procedure.

Main procedures:

Initialization: assign big enough value to $\vec{\rho}'$, and clear S_{tmp}, S_{DSC};

Step 1: update CLV $\vec{\rho}$ and the corresponding cell ID list L_{BS};

Step 2: search for a BS in L_{BS} that is not in S_{DSC} and satisfies condition 1. If such a BS is found, go to step 3. If no such BS is found, the whole process ends;

Step 3: if BS i has a low load neighbor BS j and follows case 1, come to step 4. If it follows case 2, use BFS to search a target BS k (in multilayer cells) that satisfies $\rho_i - \rho_k > e$, and a UL can be transferred from i to j through a series of BSs. If such a BS k is found, save the path (a series of BSs) into S_{tmp} and go to step 4; else save all the BSs searched into S_{DSC}, and back to step 1;

Step 4: update corresponding user-BS associations and CIO parameters and go back to step 1.

Pseudo codes are as follows.

Input: $\vec{\rho}$, L_{BSNeib}, U_{BSNeib}, $L_{UsrtoBS}$

S
S_{DSC}=[ ]; $\overrightarrow{\rho'}$ = Inf × $(1,1,\dots,1)_{1,N}$;
while $\vec{\rho} \le \overrightarrow{\rho'}$ && $S_{DSC} \subset S_{BS}$
    $f_1 = 0$; $f_2 = 0$; $\overrightarrow{\rho'} = \vec{\rho}$;
    for i in L_{BS}
        sort $\{j \mid j \in L_{BSNeib}(i)\}$ on ρ_j in ascending order;
        for j in $\{j\}$
        if $U_{i,j}$ is empty // no user can be transferred in BS i
            continue;
        else if $\rho_i > \rho_j + 1$
            $f_1 = 1$;break;
        else //$\rho_i = \rho_j + 1$, perform *BFS*
            $[S_{tmp}, f_2] = \boldsymbol{BFS}(i)$
            if $f_2 = 1$ // find cell k
                $f_1 = 1$; break;
            else // $f_2 = 0$, can't find cell k
                $S_{DSC} = S_{DSC} \cup S_{tmp}$
            end
        if f_1==1; break; end;
    end
    if $f_1 == 0$; continue;
    else if $f_2 == 0$
        distribute load unit from i to j;
    else //$f_2 == 1$
        distribute load unit according to S_{tmp};
        $S_{tmp} = [\,]$;
    update $\vec{\rho}$, $L_{UsrtoNeib}$ and U_{BSNeib}
end

Output: $\vec{\rho}$, U_{BSNeib}, $L_{UsrtoBS}$

As Broad First Search (BSF) is a common strategy for searching and the space is limited, the details of BFS is omitted.

IV. SIMULATION

Simulation scenario settings and results will be given in this section.

A. Simulation scenario and settings

The simulation is performed in an irregular HetNets scenario, as illustrated in figure 3 below. The scenario is set according to [9]. This part of network covers a 5000m × 5000m square area. Two kinds of base stations are included, Macro BS (eNodeB) and Pico BS. A blue triangle stands for an eNodeB which serves a wide area of the network, and cyan triangle stands for a Pico BS, which serves only a small area. The ratio of the two types of BSs are 1:5 and there are 30 eNodeBs, which means a total of 180 BSs are in the simulation scenario. The transmitting powers of the two types of BSs are 46dBm and 26dBm respectively. Because it is suggested in [9] that the transmitting power of an eNodeB is about 100 times of that of a Pico BS.

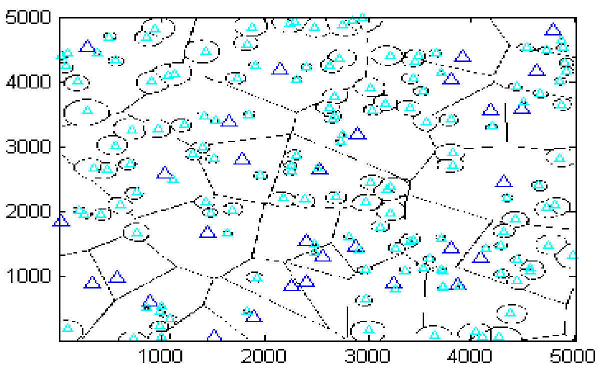


Fig. 3 Illustration of simulation scenario.

Users in the simulation are uniformly distributed. However, as BSs are randomly distributed, the coverage of cells will differ, so it is with the load. So load balancing is necessary. The initial user-BS associations are built according to best RSRP with no resource restrictions considered, different to MaxRSRP.

Other simulation assumptions are outlined in table 1.

TABLE I. SIMULATION PARAMETERS

Items(unit)	Values
Number of BSs	(Macro) 30, (Pico) 150
System bandwidth(MHz)	20
Path loss(dB)	$L(d) = 34 + 40\log(d)$[a]
Shadowing	Lognormal shadowing with a standard deviation $\sigma_s = 8$dB
Transmission power(dBm)	(Macro)46, (Pico)26
Thermal noise power(dBm)	-104
Trigger LB threshold	0.9
RSRP Bias(dB)	6

a. referring to [6].

As HOM is the upper bound of CIO, which is a tradeoff between load balancing performance and user QoS, it should be carefully set. So in this paper a proper HOM value will be chosen for LVMLB by simulations.

B. HOM value setting

1) *HOM affects Balancing Performance.*

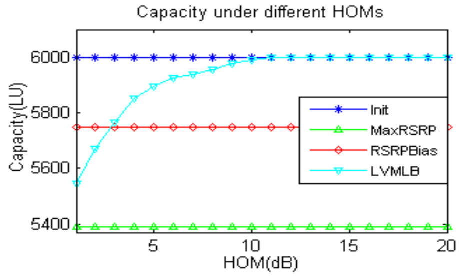


Fig. 4 System capacity of different HOM

Figure 4 shows the system capacities of different schemes for load balancing under different HOM settings and the number of users is fixed at a total of 6000 in the network, while the HOM varies from 1dB to 20dB. When HOM is small, the number of users allowed to transfer is greatly limited, so LVMLB has poor capacity. With the increase of HOM, the capacity of LVMLB has an apparent growth until it reaches the fixed limit of total capacity given by Init scheme at 11dB. From 1dB, it improves the capacity of the default MaxRSRP scheme and from 3dB it outperforms the RSRPBias scheme.

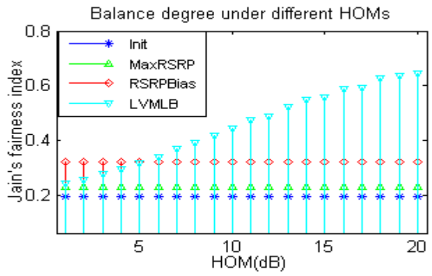


Fig. 5 Balance degree of different HOM'

Figure 5 shows the balance degree of all BSs under different HOM settings. The balance degree increases with the rising of HOM. Low HOM means only a small limited number of users can be transferred, which affects the balance degree greatly and leads to the poor balancing performance. The RSRP bias factor of RSRPBias scheme is 6dB. However, as LVMLB will balance load among all cells rather than only different tiers, it performs almost the same as the bias scheme, when HOM is just 5dB, and outperforms the bias scheme when HOM is 6dB.

2) *HOM affects user Qos*

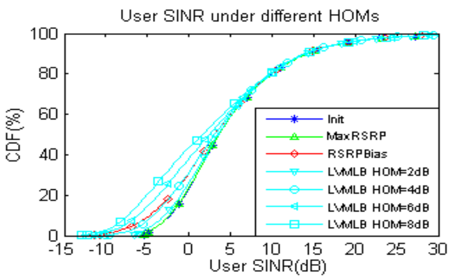


Fig. 6 Balance degree of different HOM

Figure 6 plots the cumulative distribution function (CDF) of user SINR. MaxRSRP and RSRPBias schemes are for contrast. It can be seen from the figure that, with the increase of HOM, SINR performance deteriorates. When HOM is 4dB, the SINR performances of LVMLB and RSRPBias are almost the same. However, when HOM is 6dB, the SINR performance of LVMLB becomes worse than RSRPBias. Because more users are transferred among cells to achieve a more balanced load state in LVMLB.

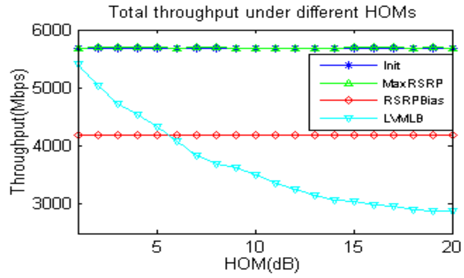


Fig. 7 Balance degree of different HOM

Figure 7 depicts the total throughput under different HOMs. With the increase of HOM, more users are transferred into low load cells in which free resources is possibly enough, but the SINR performances deteriorates too much to achieve any throughput gain. So the throughput decreases with the raising of HOM.

After the above analysis, we simply choose the 6dB as the value of HOM in LVMLB, which also equals to the value of RSRP factor of the RSRPBias scheme. Because it is enough for the capacity and balance gain, while at the same time the user QoS performances will not be sacrificed too much.

C. Performance under different user density

1) *Load balancing performance.*

Here in this paper, the term user density stands for the number of users averaged to all macro cells rather than all cells, denoted as average user number (AUN). Because the Macro cells provide the basic network coverage and Pico cells serve only at spots in the network, which can be treated as supplement to the homogeneous macro-cell network. Assuming a cell (both Macro and Pico) holds at most 200 users, so the range of user density can be set from 20 to 400. Because 400 is double the capacity of a macro cell, and it is extremely high load for a macro cell, even with some Pico cells providing load relief.

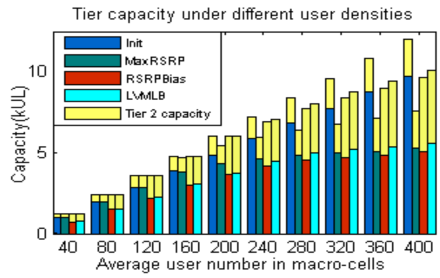


Fig. 8 System capacity under different load densities

Figure 8 shows the system capacities under different user densities. The 'Init' data give an upper bound of the system capacity, it means the total loads available under current user density condition. It is clear that the total capacity increases with the rising of AUN, assuming LB is always triggered. However, the capacities of different schemes differ. When AUN is below 160, LVMLB and RSRPBias scheme have almost the same capacity, and both give remarkable tier capacity gain. When AUN goes to or beyond 160, LVMLB and RSRPBias have almost the same capacity gain from Pico cells, while the LVMLB achieves more capacity gain from Macro cells.

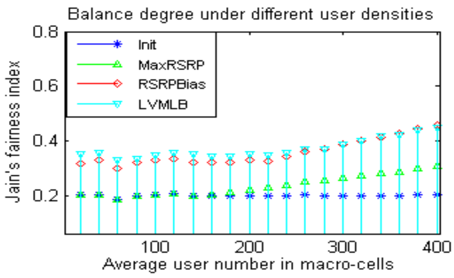
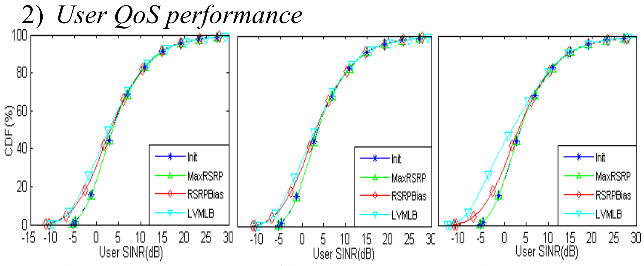


Fig. 9 Balance degree under different load densities

Figure 9 shows the balance degrees under different load densities. It is obvious that the LVMLB has bigger load balance degree than RSRPBias scheme. With the rising of load density, the balance degree gap between the two schemes is narrowed and finally eliminated. This is because the macro cells finally reach their load limit and thus have the same load, and at the same time Pico cells in the two schemes have almost the same load because of the same value of bias factor and HOM, so the gap is eliminated. However this extreme case will seldom occur.

2) *User QoS performance*



(a)AUN = 20 (b)AUN=50 (c)AUN=80

Fig. 10 Balance degree under different user densities

Figure 10(a), 10(b) and 10(c) plot the CDF of user SINR under different user densities with AUN being 20, 50 and 80 respectively. Compared with LVMLB, the RSRPBias scheme has better SINR performance, because of fewer LB handovers. And the SINR performance of both schemes are worse than that in the original state.

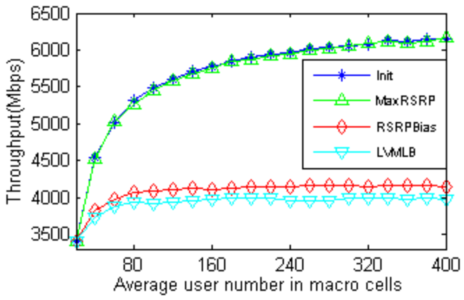


Fig. 11 Balance degree of different user densities

Figure 11 shows the total throughput under different user densities. LVMLB has lower throughput than the RSRPBias scheme. And the throughput of both schemes are lower than that of the original state. Together with figure 10, it is obvious that all load balancing schemes will suffer from QoS performance loss. And it is a tradeoff, between load balancing performance and user QoS requirement.

From the simulation results above, we can conclude that, LVMLB has good load balance performance in improving the balancing degree of all cells and the capacity of the system, both in Macro tier and Pico tier, compared with RSRPBias scheme, only on the expense of a little more QoS loss.

V. Conclusion

The proposed LVMLB in this paper, can achieve the goal of improving the balance degree among all cells, including both Macro and Pico cells, by minimizing cell load vector, rather than merely draining load from Macro cells to Pico cells. It also provides a handover scheme for users, which is implemented by updating CIO parameters in the process. At the same time, HOM parameter, which defines the range for CIO variation, can be adjusted to make a proper tradeoff between QoS requirement and load balancing performance gain. Simulation results show LVMLB has extraordinary performance gain in system capacity and load balance degree, compared with the RSRPbias scheme at the expense of a little more QoS loss.

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