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Distributed Simplicial Homology Based Load Balancing Algorithm for Cellular Networks

Ngoc-Khuyen Le, Anaïs Vergne, Philippe Martins and Laurent Decreusefond
LTCI, CNRS, Télécom ParisTech, Université Paris-Saclay, 75013, Paris, France
Email: ngoc-khuyen.le, anais.vergne, philippe.martins, laurent.decreusefond@telecom-paristech.fr

***Abstract*—In this paper, we introduce a distributed load balancing algorithm for cellular networks. Traffic load in cellular networks is sometimes unbalanced. Some cells are overloaded, while others remain free. Simplicial homology is a tool from algebraic topology that allows to compute the coverage of a network by using only simple matrix computations. Our algorithm, which is based on simplicial homology, controls the transmission power of each cell in the network, not only to satisfy the coverage constraint, but also to redirect users from the overloaded cells to the underloaded ones. As a result, the traffic load of the cellular network is more balanced. The simulation results show that this algorithm improves the capacity of the whole network by 2.3% when the user demand is fast varying.**

I. Introduction

Due to user mobility, some cells can be overloaded at some moments while the others are still underloaded at the same time. These underloaded cells have free resources that are not used. In other words, these free resources are wasted. In order to avoid this waste of resources, the traffic load in the network should be balanced for cells. However, cellular networks configurations are traditionally manual and costly as they lack a self-organized method to balance the traffic load between cells in real time.

There exists some load balancing methods. The first method is to borrow the bandwidth from low traffic cells, and give it to overloaded cells. Some bandwidth borrowing algorithms can be found in [12], [15], [16], [26]. However, the bandwidth borrowing may increase interference in the network. When the network is dense and the cell size is small, the interference is becoming hard and degrades strongly the quality of service.

Another method is to force the users to redirect from the overloaded cell to one of its neighbors that is underloaded. It can be done by modifying the hysteresis margin in the handover scheme between the overloaded cells and the underloaded cells, for example in [5], [20]. For more details about the handover scheme and the hysteresis margin, see [1]. Users can be also redirected from the overloaded cells to the underloaded cells by modifying the pilot power of cells. In [6], the underloaded cells attract more users by increasing its pilot power. However, the power of data channels is not changed. Users can be also associated with the underloaded cells by a cooperated resource allocation such as in [17], [23]. However, overload often happens when many users are located in a cell while only a few users are located in another. These methods do not take into account the distance between the redirected users and their target cells. The target cell, which should be a free cell, is one of the overloaded cell's neighbors. Due to the long distance between the redirected users and the base station of their target cells, many redirected users may suffer from a bad connection. In addition, most resource allocation schemes prefer to give access to the users that have better connection [22], therefore, these redirected users can lose their connection. The load balancing should guarantee not only the free resources, but also the coverage for users.

Recently, in [10] authors change the power of antenna beams in the selected directions. The overloaded base stations reduce the antenna beam power in the direction where some users are in outage, while the underloaded base stations increase their beams power. Thanks to the handover process, the users in outage will connect to the underloaded base stations. However, this method requires the full access to the positions of users, which is not always available. In addition, modifying the power of antenna beams changes the shape of cells, but no method to verify the coverage is presented.

In recent researches, simplicial homology is often used to analyze the coverage of wireless networks. The wireless network is represented by a simplicial complex. Then, the information about the topology of the network is obtained via its homology. The Čech complex is the most suitable simplicial complex to represent the wireless network as it captures exactly its topology [8]. The construction of the Čech complex for the wireless network is introduced in [18]. Some applications based on simplicial homology have been proposed. In [14], [7], [9], [25], simplicial homology is used to detect coverage holes. In [24], it is used to turn off redundant cells. And in [19], it is used to save energy for wireless networks.

In this paper, we introduce a distributed load balancing algorithm for cellular networks, which not only solves the overload problem for the base stations but also ensures a strong quality of service for every user. Our algorithm changes the transmission power for each base station in order to redirect some users in the overloaded cells to the underloaded ones via the handover process. Then, the traffic loads in different cells are balanced. We use the simplicial Čech complex [18] to represent the topology of the network. Thanks to simplicial homology theory, the coverage of the network is always computable. This allows us to always ensure the coverage of the network as well as to avoid the interference due to the redundant transmission power. In addition, our algorithm increases the transmission power of the cells that have enough

free resources to allocate to the redirected users. Furthermore, our algorithm does not need any information about the positions of users.

The remainder of this paper is organized as follows. Section II introduces basic notion about simplicial homology and its applications. Section III is devoted to describe all the details about our load balancing algorithm. The simulation results will be presented in Section IV. Finally, we conclude and discuss our works in Section V.

II. Simplicial homology

In this section, we introduce some notions of algebraic topology. We also explain how these tools can be used to capture and analyze the topology of the network. For more details about algebraic topology, see [21].

A. Simplicial complex

Let $S_k = \{v_0, v_1, \ldots, v_k\}$ be a geometrically independent set of $k+1$ points in $\mathbb{R}^n$, where $n > k$. The convex hull of S is called a k-simplex, denoted s_k. The number k is its dimension and $v_0, v_1, \ldots, v_k$ are its vertices. Thus, a single point is a 0-simplex, an edge is an 1-simplex, a triangle is a 2-simplex, a tetrahedron is a 3-simplex, and on and on. See Figure 1 for some instances.

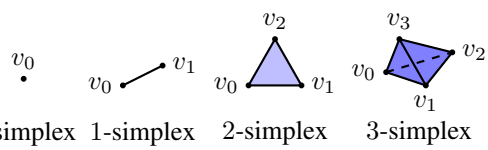


Fig. 1: An example of simplices.

Any subset of S_k is also geometrically independent, therefore the convex hull of this subset is a simplex of a lower dimension. Let l be the dimension of this simplex, this simplex is called a l-face of s_k. An abstract simplicial complex is a collection of simplices such that: every face of a simplex is also in this collection.

B. Homology group

The orientation of a simplex is determined by an ordering of its vertices. A simplex $\{v_0, v_1, \ldots, v_k\}$ together with an ordering of its vertices is denoted as $[v_o, v_1, \ldots, v_k]$. The orientation of a simplex changes into the inverse one if the ordering of its vertices is transformed by an odd permutation. In instance, if two vertices of a simplex are swapped, then the orientation of this simplex changes to the opposite one, denoted by the negative sign as:

$$[v_0, \ldots, v_i, \ldots, v_j, \ldots, v_k] = -[v_0, \ldots, v_j, \ldots, v_i, \ldots, v_k].$$

Let us denote K an abstract simplicial complex, we can define for each k the k-chain group $C_k(K)$ as the vector space spanned by the set of oriented k-simplices of K. Let $[v_0, v_1, \ldots, v_k]$ be a k-simplex, which is viewed as a basic element of C_k. The boundary map ∂_k is defined as the linear transformation $\partial_k : C_k(K) \to C_{k-1}(K)$ which acts on basis elements via:

$$\partial_k[v_0, v_1, \ldots, v_k] = \sum_{i=0}^{k} (-1)^i [v_0, v_1, \ldots, v_{i-1}, v_{i+1}, \ldots, v_k],$$

where $[v_0, v_1, \ldots, v_{i-1}, v_{i+1}, \ldots, v_k]$ is the i-th face obtained by deleting the i-th vertex. This formula tells us that the boundary of a k-simplex is its collection of $(k-1)$-faces. A simple computation shows that $\partial_k \circ \partial_{k+1} = 0$, this means that the boundary of a chain has no boundary. We call a k-chain a k-cycle if its boundary is zero. So, the group of k-cycles, denoted as $Z_k(K)$, is the kernel of $\partial_k : C_k(K) \to C_{k-1}(K)$. Let $B_k(K)$ be the group of k-boundaries, it is the image of $\partial_{k+1} : C_{k+1}(K) \to C_k(K)$. Since $\partial_k \circ \partial_{k+1} = 0$ for each k, it implies that every k-boundary is also a k-cycle. It follows that $B_k(K) \subset Z_k(K)$ for all k. We can now define the k-th homology group of K as the quotient vector space: $H_k(K) = Z_k(K)/B_k(K)$. The dimension of k-th homology group is called the k-th Betti number:

$$\beta_k = \dim H_k = \dim Z_k - \dim B_k. \tag{1}$$

This number has an important meaning in solving coverage problems. Given a simplicial complex that captures the topology of a network, its k-th Betti number β_k counts the k-dimensional holes. For example, the β_0 counts the connected components while the β_1 counts the coverage holes. Therefore, the network is connected if $\beta_0 = 1$, and there is no coverage hole if $\beta_1 = 0$.

C. Simplicial complex of cellular networks

Definition 1 (Čech complex): Given a collection of cover sets $\mathcal{U}$, the Čech complex of $\mathcal{U}$, denoted as $\check{C}(\mathcal{U})$, is the abstract simplicial complex whose k-simplices correspond to nonempty intersection of $k+1$ distinct elements of $\mathcal{U}$.

If each cover set in the collection $\mathcal{U}$ is a disc that presents the coverage of a cellular cell, then the Čech complex of $\mathcal{U}$ captures exactly the topology of the network [18].

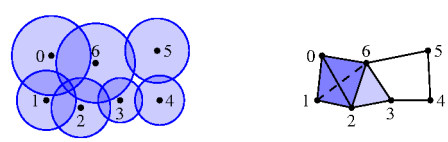


Fig. 2: Cells and their Čech representation.

For example, in Figure 2, the overlapping region of coverage of four cells 0, 1, 2 and 6 is represented by a tetrahedron, which is a 3-simplex. The overlapping region of coverage of three cells 2, 3 and 6 is represented by a triangle, which is a 2-simplex. The coverage hole inside four cells 3, 4, 5 and 6 is represented by an empty space that is bounded by four edges 3-4, 4-5, 5-6 and 6-3, which are a chain of 1-simplices. The number $\beta_0 = 1$ indicates that all cells are connected. The number $\beta_1 = 1$ indicates that there is a coverage hole.

III. Distributed load balancing algorithm

In this section, we entirely describe the details about our load balancing algorithm. We are considering a cellular network with high traffic. We assume that the coverage of the network is satisfied before performing the load balancing algorithm. This means that before applying our load balancing

algorithm, there is no coverage hole in the network. We consider a cellular network that contains a collection of cells: $\mathcal{C} = \{c_i(v_i, r_i) \mid i = 1, 2, \ldots, N\}$, where N is the number of cells, and $c_i(v_i, r_i)$ is the i-th cell centered at the position of its base station v_i and covering the space within a radius r_i.

Let $p_{t,i}$ be the transmission power of the cell c_i and u be a user in this cell. The distance from the user u to the base station c_i is $d_{u,i}$. The path loss from the base station c_i to the position of the user u is $L_{i,u}(d_{u,i})$. To estimate the path loss $L_{i,u}(d_{u,i})$, we use the COST-231 model [4]. Let p_s be the sensitivity of the mobile device, the coverage radius r_i of the i-th cell c_i is the maximum distance $d_{u,i}$ that satisfies $p_{t,i} - L_i(d_{u,i}) \geq p_s$. So, the radius r_i of the cell c_i is controlled by the transmission power $p_{t,i}$.

Each base station c_i periodically computes the requested traffic load, denoted ρ_i, which is generated by its registered users as: $\rho_i = \sum_k \rho_{i,k}/\mu_i$, where $\rho_{i,k}$ is the number of requested resource blocks of the k-th registered user and μ_i is the capacity of the base station c_i. The capacity of a base station is the total number of resource blocks that are available in this base station. Each resource block is a group of 12 consecutive subcarriers, where each subcarrier has a bandwidth of 15kHz. For the details about the resource blocks, see [2]. A base station is called hot, or overloaded if its requested traffic load is greater than one. It is called warm if it is not hot and its requested traffic load is greater than a warm load threshold ρ_w such that $0 < \rho_w < 1$. Otherwise, the base station is called cool, or underloaded.

We assume that all cells are connected by the backhaul network. Each cell c_i can transmit information about its position and its coverage radius to every cell via this backhaul network. We also assume that the cells can cooperate to cancel the interference in the overlapping regions [13]. Therefore, the cells can adjust their transmission power without the interference problem. We say that two cells are neighbors if the coverage of each one intersects with the coverage of the other. Then, each cell c_i can compute its table of neighbors $\mathcal{N}_i$ and sends its requested traffic load ρ_i to its neighbors in $\mathcal{N}_i$. Therefore, each base station knows information about the requested traffic load, the position and the coverage of itself and of all its neighbors.

If the base station c_i is hot, then it needs to reduce its requested traffic load. One solution is to redirect some of its currently registered users to its neighbors via handovers. Handovers would happen automatically when a cool neighbor cell increases its coverage radius, while a hot cell decreases one. In order to do that, a hot cell chooses a neighbor cell which has a lot of free resource blocks, i.e. a cool cell and requests it to help. The neighbor that is chosen is called a helper. A neighbor that is warm can not be chosen to be a helper. This will prevent a helper from becoming hot after having received the redirected users from the hot base station. The helper of the cell c_i is defined as the neighbor c_h that has the lowest traffic load: $c_h = \arg\min_{c_j \in \mathcal{N}_i} \rho_j$ such that $\rho_j \leq \rho_w$. If there is no available helper, the cell c_i redoes the process in the next time frame. To attract users via handover, helper cells not only need free resource blocks but also a stronger signal. However, the redirected users in outage that are currently in the hot cell c_i can be outside the coverage of the helper c_h. The helper c_h needs to increase its transmission power by a power step Δp_h. At the same time, the helper c_h transmits its new coverage radius to other cells. It also requests its neighbors to reduce their transmission power if possible. However, a fast reduction of transmission power may create a coverage hole. Each neighbor of the helper c_h, denoted c_k, computes the coverage with a transmission power decreased by $\Delta p_k/2$, where Δp_k is the power step of the cell c_k. If this reduction does not create any coverage hole, the base station c_k reduces its transmission power by $\Delta p_k/2$ and sends its new coverage radius to other cells. If a coverage hole appears, this cell must keep its transmission power as the original value. If a neighbor is the helper of another cell, it will ignore the request to reduce transmission power. To verify if a coverage hole appears, the shrunk cell constructs a Čech complex for a local region that includes itself and its neighbors. For the details about the construction of the Čech complex, we refer to [18]. Then the information about the coverage can be tractable through the computation of Betti numbers (1) of this Čech complex. If no coverage hole appears after the reduction, the Betti numbers must be $\beta_0 = 1$ and $\beta_1 = 0$. Otherwise, a coverage hole appears. To verify the coverage of the network, we need to compute only β_0 and β_1. Therefore, the Čech complex is only computed up to dimension two. The verification of the coverage of the network is summarized as in the Algorithm 1.

Algorithm 1 Verification of coverage holes

Input: c_i the shrunk cell and its neighbors set $\mathcal{N}_i$;
Output: **true** $\iff$ a coverage hole appears;
  compute $\check{\mathbf{C}}$ = the Čech complex of $c_i \cup \mathcal{N}_i$;
  compute β_0 and β_1 of $\check{\mathbf{C}}$;
  verification = false;
  if $\beta_0 \neq 1$ or $\beta_1 \neq 0$ **then**
    verification = **true**;
  end if
  return verification;

We should note that, a coverage hole may appear due to an outdated information about coverage radius. Therefore, whenever a cell tries to reduce its coverage radius, it firstly sends a "pause" signal to its neighbors. Then, it obtains the information from neighbors and processes the reduction. When it finishes the reduction, it sends a "continue" message to its neighbors to indicate them that they can continue. If a cell receives a "pause" signal, it pauses the balancing process and waits until a "continue" signal is received. To avoid an infinite wait in a special case that two neighbors send "pause" at the same time, and both of them receive the "pause", if one cell sends the "pause" and receives another "pause" before it sends a "continue", it waits in a random period of time then tries to send "pause" again.

Let us consider a special case where small cells are deployed, such as: pico and micro cells. The transmission power of macro cells is much higher than the one of small cells. If a small cell is hot, and it chooses a macro cell to be a helper, then it does not send a help request to the macro cell. The small cell directly reduces its transmission power if the verification of the coverage allows it as in the Algorithm 1, and broadcasts the new information to other cells. This prevents the unnecessary modification of macro cells transmission power that would affect many other small cells inside the macro cells.

Algorithm 2 Load balancing algorithm applied to each cell c_i

Input: c_i the i-th cell, and ρ_w the warm load threshold;
Output: balanced traffic load for the cell c_i;
  for each time frame **do**
    send position and coverage radius to every cell;
    compute the requested traffic load ρ_i;
    collect position and coverage radius of other cells;
    build the neighbors set $\mathcal{N}_i$ of c_i;
    send requested traffic load ρ_i to neighbors in $\mathcal{N}_i$;
    collect requested traffic load of neighbors in $\mathcal{N}_i$;
    if $\rho_i > 1$ **then**
      helper cell $c_h = \arg\min_{c_j \in \mathcal{N}_i} \rho_j$ such that $\rho_j < \rho_w$;
      if $c_h \neq$ **null then**
        if c_i is not macro cell **and** c_h is macro cell **then**
          obtain coverage radius of neighbors;
          $p_{t,i} = p_{t,i} - \Delta p_{t,i}/2$;
          if a coverage hole appears **then**
            $p_{t,i} = p_{t,i} + \Delta p_{t,i}/2$;
          else
            send new radius to every cell;
          end if
        else
          send request to increase power to c_h;
        end if
      end if
    end if
    if c_i is the helper **then**
      $p_{t,i} = p_{t,i} + \Delta p_{t,i}$;
      send new radius to every cell;
      send request to reduce the transmission power to neighbors of c_i;
    else
      if c_i received a reduce power request message **then**
        obtain information from neighbors;
        $p_{t,i} = p_{t,i} - \Delta p_{t,i}/2$;
        if a coverage hole appears **then**
          $p_{t,i} = p_{t,i} + \Delta p_{t,i}/2$;
        else
          send new radius to every cell;
        end if
      end if
    end if
  end for
  return

The procedure to balance the traffic load for each base station, which is described in the Algorithm 2, is repeated in every radio time frame. In this procedure, the "pause" message is automatically sent before a base station tries to reduce its transmission power. Similarly, the "continue" message is also automatically sent after a reduction. In the description of this algorithm, we do not insert the "pause" and "continue" messages for a smooth reading.

In the load balancing algorithm, the requested traffic load can be computed in an instant, while the coverage verification is still needed for only the local region. We recall that the local region is comprised of the cell which reduces its coverage and its neighbors. This verification needs the computation of the Čech complex for this local region and its Betti numbers β_0, β_1. In the worst case where every cell is neighbor of the others, the complexity of the Čech complex is still $\mathcal{O}(N^3)$, where N is the number of cells in the network [18]. In this case, there are $m_1 = C_N^2$ 1-simplices and at most $m_2 = C_N^3$ 2-simplices in the Čech complex. Following [11], the complexity to compute β_0 is $\mathcal{O}(m_1)$, and the complexity to compute β_1 is equivalent to the computation time of the rank of a matrix that has m_2 columns and m_2 rows. The complexity to compute this rank by SVD method is $\mathcal{O}(m_2^3)$ [3]. Therefore, the complexity to compute the Čech complex and its Betti numbers β_0, β_1 is $\mathcal{O}(N^9)$, which is only polynomial time. As a result, the load balancing algorithm has the complexity of polynomial time.

IV. Simulation results

A. Network deployment

We deploy the macro cells according to the hexagonal model. In each macro cell, we deploy two micro cells, which are placed randomly following a uniform law in the coverage of macro cells. The parameters about the macro cells and the micro cells are summarized in Table I and Table II. However, micro cells are often deployed in the rear side of macro cells to increase the coverage at cell edge. In addition, if a micro cell is deployed too close to a macro cell's base station, due to the much stronger signal from the base station of the macro cell, the users will connect to the macro cell even when they are very close to the micro cell's base station. In our simulations, the macro cells and the micro cells are separated by a distance greater than two thirds of the macro cell coverage radius.

TABLE I: Macro cell parameters

Parameters	Assumptions
Carrier Frequency	1800MHz
Number of resource blocks	50 resource blocks
Distribution of base station	hexagonal
Users	uniformly distributed
Maximum transmission power	46 dBm
Initial transmission power	42 dBm
Antenna gain	18 dBi
Cable loss	2 dB
Number of macro cells	91 cells

We assume that the number of requested resource blocks of each user follows a Poisson law. In average, each user

TABLE II: Micro cell parameters

Parameters	Assumptions
Carrier Frequency	1800MHz
Number of resource blocks	15 resource blocks
Distribution of base station	uniformly distributed
Users	uniformly distributed
Maximum transmission power	30 dBm
Initial transmission power	24 dBm
Antenna gain	18 dBi
Cable loss	2 dB
Number of micro cells	182 cells

requests two resource blocks. We denote R_{total} the total number of requested resource blocks, which is generated by all users in the network. And, we denote C_{total} the total capacity of all cells in the network, where the capacity of each cell is the total number of available resource blocks in this cell. The traffic load T of the network is: $T = R_{\text{total}}/C_{\text{total}}$. In our simulations, we analyze the performance of the algorithm with a given traffic load T. We generate the total number of requested resource blocks R_{total} according to the Poisson point process of intensity $T \times C_{\text{total}}$.

We assume that the total number of requested resource blocks in the micro cells and the macro cells are proportional to their capacity. The number of requested resource blocks in the micro cells is $R_{\text{micro}} = R_{\text{total}} \times \frac{C_{\text{micro}}}{C_{\text{mico}}+C_{\text{macro}}}$. We then generate the users in the micro cells first. The users positions are uniformly distributed in coverage of all micro cells. The number of requested resource blocks of each user is generated following a Poisson law with intensity of two resource blocks. When the accumulated number of requested resource blocks in all micro cells reaches the number R_{micro}, we stop the process of generating the users in the micro cells. Similarly, we generate the users in the macro cells until the total number of requested resource blocks in the network reaches R_{total}.

We assume the COST-231 model for the radio propagation [4] with the correction $c = 3$ for urban areas. The sensitivity of the terminal is -104 dBm. The body loss at user mobile is 3 dB. The load balancing algorithm is performed for each cell in each time frame, which is assumed to be 10 ms.

B. Performance with varying traffic load

In this subsection, we consider the performance of the load balancing algorithm when the users change their number of requested resource blocks frequently. We assume that each user changes its demand of resource blocks every 10 time frames. In each time frame, each cell applies the load balancing algorithm one time.

We assume that the average requested traffic load in the network is 0.9, it means the total number of requested resource blocks is 90% of the total capacity of the network in average. Although the average requested traffic load is less than one, the number of resource blocks demanded by each user is random. Some cells in network are overloaded while others are free. We define the outage of each cell as the number of requested resource blocks in this cell that are not serviced. The outage of the network is the accumulated outage of every cell.

In this simulation, the warm load threshold ρ_w is set to 0.9 and the power step Δp is set to 1dB for every cell. We perform the simulation in 250 time frames and record the outage of network in two cases: without load balancing applied and with load balancing applied. We show one example of simulation in Figure 3. The outage of system in the case that the load balancing is not applied is drawn as the red line. The outage of system in the case that the load balancing is applied is drawn as the blue line. Because the users change their demand of resource blocks every 10 time frames, the outage of system when the load balancing is not applied is also changed every 10 time frames. The blue line is under the red line, this shows that by using the load balancing, the outage of system is reduced. The number of reduced resource blocks in outage is the capacity gain of system. In the Figure 3, the difference between the red line and the blue line describes the capacity gain of the load balancing algorithm. The simulation is repeated 1000 times. In average, this load balancing algorithm reduces the number of resource blocks in outage by 25.7%, and gains 2.3% of the capacity of the whole system.

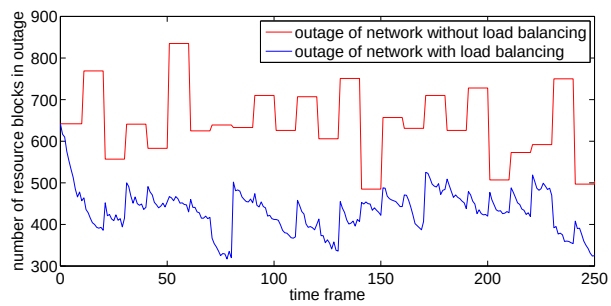


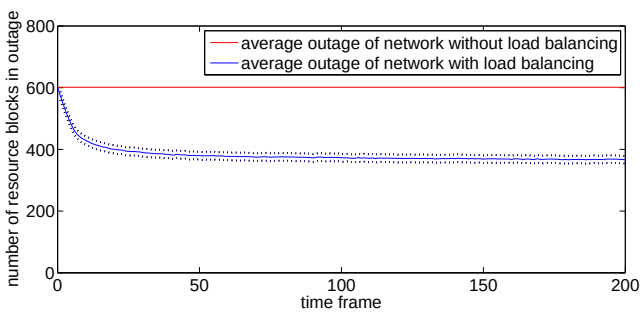
Fig. 3: An instance of total outage of a varying traffic network with and without load balancing on the same scenario: base stations, users positions and user requests are identical in both cases.

C. Performance with constant traffic load

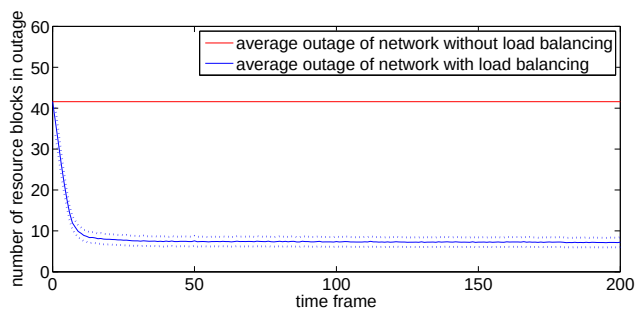
In this subsection, we consider the performance of the load balancing algorithm when the traffic load is kept constant. Indeed, the demand of resource blocks of each user is unchanged during the simulation. Some properties of the load balancing algorithm such as: capacity gain, convergence speed and stability are considered at different requested traffic load T of the network from the low one to the high one. When the requested traffic load of the network is low, it is also necessary to analyze the performance of the load balancing algorithm. Due to the mobility of users, some cells may be overloaded while others are not.

The total requested traffic load of network T varies from 0.5 (low) to 0.9 (high). We perform the load balancing algorithm with different values of warm load threshold ρ_w and power step Δp. The simulation is performed in 200 time frames. Each time we change the value of one of these parameters, we repeat the simulation 100 times. The warm load threshold ρ_w and the power step Δp are assumed to be the same for every cell.

First, we consider the performance of the load balancing algorithm when the network is high loaded $T = 0.9$ in Figure 4a and when the network is low loaded $T = 0.5$ in Figure 4b. The warm load threshold ρ_w is set to 0.9 and the power step Δp is 1 dB for all cell. The users do not change their demand of resource blocks in each simulation, then the outage of network when the load balancing is not applied is the same in every time frame and is drawn by a red line. The blue line draws the average outage of network when the load balancing is applied. The dotted line shows the upper bound and lower bound of the 95% confidence interval of the average outage of the balanced network. The outage of the balanced network is quickly reduced. When $T = 0.9$, the outage of the network is reduced by 34% within 28 time frames. When $T = 0.5$, the outage of the network is reduced by 80% during 16 time frames.



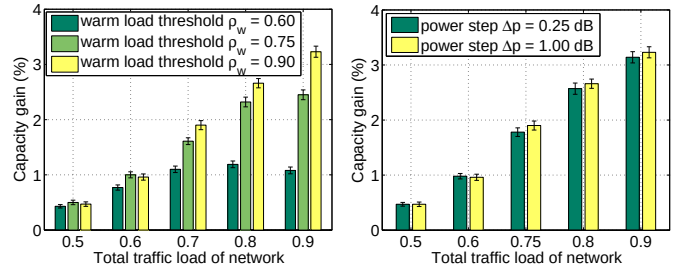
(a) $T = 0.9$, $\Delta p = 1$ dB, $\rho_w = 0.9$



(b) $T = 0.5$, $\Delta p = 1$ dB, $\rho_w = 0.9$

Fig. 4: Average outage of the constant traffic load network

We should note again that the number of reduced requested resource blocks in outage is the capacity gain of the network. The capacity gain is recorded at the last time frame of simulation, the 200-th time frame. The Figure 5a compare the capacity gain of network at different requested traffic loads T when the load balancing is applied with different warm load thresholds ρ_w. The power step Δp is set to 1 dB. When the requested traffic load of the network is high, the higher warm load threshold ρ_w is, the higher capacity gain is. In Figure 5b, the capacity gain is compared when the load balancing is applied with different power steps $\Delta p = 1$ dB and $\Delta p = 0.25$ dB. The warm load threshold ρ_w is set to 0.9. At each requested traffic load T, the capacity gains in long term with different power steps Δp are almost equal.

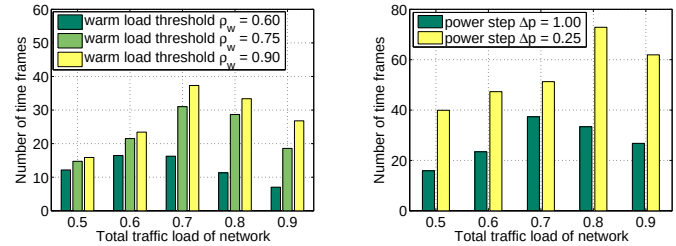


(a) different ρ_w and $\Delta p = 1$ dB (b) different Δp and $\rho_w = 0.9$

Fig. 5: Capacity gain of system

The different values of the warm load threshold ρ_w and the power step Δp may also affect other properties of performance such as: convergence speed and stability. We consider that the outage of the balanced network approaches the stability value within the first 100 time frames. Then, we compute the mean value of the outage of balanced network in the last 100 time frames. We denote this mean by M. When the outage of the balanced network goes below the value $1.05 \times M$, we say the network converged at the current time frame t. The duration from starting point to this current time frame t is defined as the convergence time of the network.

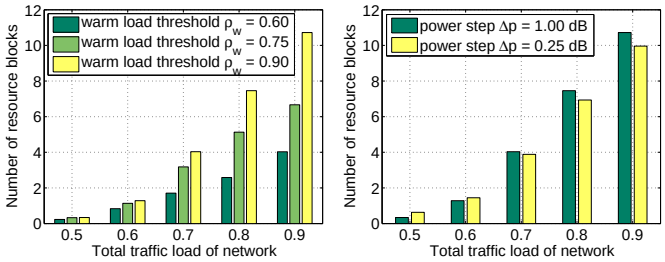
The convergence time is shown in Figure 6a with different warm load thresholds ρ_w, and in Figure 6b with different power steps Δp. With higher warm load threshold ρ_w, there are more available helpers, so more requests to help can be satisfied. Therefore, the process of requests and helps are longer. As a result, the convergence time is higher. The convergence time increases if the power step Δp is reduced. A significant increase of convergence time is shown when the power step is reduced in Figure 6b. As shown in Figure 5b, the capacity gains with different power steps Δp are almost the same. This shows that a smaller Δp reduces the speed of convergence but does not change the capacity gain in long term. In varying traffic load network, we should not choose a so small power step Δp because of the slow convergence speed.



(a) different ρ_w and $\Delta p = 1$ dB (b) different Δp and $\rho_w = 0.9$

Fig. 6: Convergence time

We use the standard deviation of the outage of the balanced network from the mean value M, denoted as σ, as the measurement for the stability of the network. The Figure 7a and Figure 7b show values of σ with different ρ_w and Δp. The higher warm load threshold is, the lower stability of the system is. In addition, reducing the power step can increase a little the stability of the system.



(a) different ρ_w and $\Delta p = 1$ dB (b) different Δp and $\rho_w = 0.9$

Fig. 7: Standard deviation of the outage of balanced network

V. Conclusion and Discussion

In this paper, we introduce a distributed load balancing algorithm for self organized cellular networks. This algorithm does not need information about the position of users, nor to modify the handover process. Our algorithm provides sufficient power and resources to allocate to users, and also guarantees the coverage of the network. This algorithm improves by 2.3% the capacity of the whole network when the user demand is varying very fast.

The simulations show that the value of the warm load threshold ρ_w and the power step Δp should be carefully selected for each cell to keep the best performance and stability for the network. The higher value of the warm load threshold ρ_w gives the higher capacity gain. However, it makes the network less stable. In contrast, the lower value of ρ_w increases the convergence speed and stability of the network, but it gives the lower capacity gain. The power step Δp should be much smaller than the transmission power of the base station. However, a too small value of Δp reduces the convergence speed of the network and therefore reduces the capacity gain of the load balancing algorithm when the traffic load requested by users are fast varying.

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