A Dynamic Energy Savings Scheme Based on Enhanced Mobility Load Balancing

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***Abstract*—Nowadays, energy saving in wireless communications has become a hot topic as energy consumption increasingly becomes a global environment problem. In this paper, we formulate an Energy Consumption Rating (ECR) minimization problem in a multi-layer network and provide analysis of its property and complexity. To solve this problem, we propose the Enhanced Mobility Load Balancing (EMLB) firstly. A heuristic and practical algorithm is then introduced, which transfers traffic using EMLB in vertical and horizontal directions and adaptively switches off/on some cells based on traffic load condition. The performance of the proposed algorithm is evaluated by comparing with existing static and dynamic schemes through system level simulations. The simulation results demonstrate that our proposed scheme not only has good system throughput performance, but also achieves significant power saving in typical traffic scenario.**

I. Introduction

The increasing emission of carbon dioxide (CO_2) of Information and Communication Technology (ICT) industry and the sharp rising cost of the energy consumption make the energy consumption a major issue for future mobile systems. As a result, many organizations pay more and more attentions to Energy Saving (ES). ES is introduced to Long Term Evolution (LTE) as an important use case and is currently discussed in 3rd Generation Partnership Project (3GPP) standardization [1]. Besides, the Energy Aware Radio and neTwork tecHnologies (EARTH) project has discussed some promising green network technologies and green radio technologies in [2,3].

In cellular networks, the deployment strategies of Base Stations (BSs), such as cell size, the number and positions of micro cells, have important influences on system power consumption. These impacts have been investigated for particular load scenarios in [4]. Once deployed, the system is difficult to change. However, because of the day-night behavior of User Equipments (UEs), traffic load changes spatially and temporally. For instance, 1) the total load is relatively higher in the daytime than at night; 2) most load is transferred from office areas to residential areas at night and is transferred back during the daytime. Load fluctuations have significant negative effects on system performances. Firstly, the system may suffer from low throughput and high block rate due to the existence of hot cells. Secondly, light load in some cells with excessive power resources brings serious energy waste. Both the above impacts eventually result in low energy efficiency.

To reduce power waste, we can switch off some BSs which are the major power consumptions in the ICT industry when their traffic load is light enough and UE experience is not affected. There have been many switching on/off algorithms proposed recently [5-7]. [5] and [6] proposed that operators switch on and off the fixed BSs at the fixed time, which is not flexible and limits the energy saving extent. [7] introduced a new and flexible technology named zooming out and zooming in. However, it may bring coverage holes and harm UE experience when UEs move to coverage holes or sessions are established in coverage holes.

Mobility Load Balancing (MLB) is an important use case of Self-Organizing Network (SON) in 3GPP [1], whose purpose is to cope with the unequal traffic load and to improve the system capacity. In order to improve the system energy efficiency, we propose the EMLB and integrate it into switching on/off strategy. This can not only transfer some UEs of overloaded BSs out to reduce the block rate to achieve throughput performance gain, but also shift all UEs of BSs with light load away to save energy by switching the BSs off dynamically.

In this paper, we formulate a Energy Consumption Rating (ECR) minimization problem in a multi-layer network. To solve this problem, we propose a heuristic but practical algorithm, called Dynamic Energy Saving scheme based on Enhanced Mobility Load Balancing (DESEMLB). In the algorithm, we transfer traffic using EMLB and adaptively switch off/on some cells according to their traffic load conditions. Simulation results show that the DESEMLB has higher energy efficiency than existing static and dynamic schemes.

The rest of this paper is organized as follows. Section II depicts the system model. In Section III, we present a system energy efficiency formulation in a multi-layer network and analyze the property and complexity. In Section IV, we propose an online algorithm. In Section V, a system level simulation is conducted to evaluate the improvement of energy efficiency by comparing with existing static and dynamic schemes. We conclude this paper in Section VI.

II. System Model

As shown in Fig. 1, there are three layers in our system: LTE micro cell layer, LTE macro cell layer and GSM macro cell layer. Different layers use different carrier frequency and have the same system bandwidth W. There are many BSs and UEs in each layer. $\mathbf{B}$ and $\mathbf{U}$ denote the sets of total BSs and total UEs, respectively. Each UE is only served by one BS

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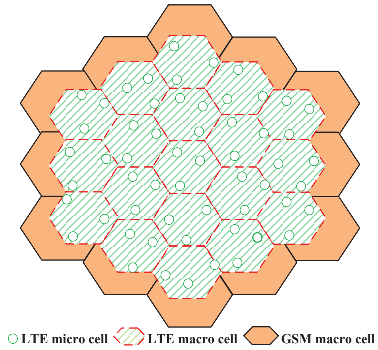


Fig. 1. Multi-layer Coverage Network

at any time. Assignment indicator variable $X_{i,k}(t)$ is defined, which is equal to 1 when UE k is served by BS i at time t, and 0 otherwise.

A. Link model

With pilot detection, each UE can measure the instantaneous signal strength from each BS. And the measurement results are sent to its serving BS within uplink data transmission or by periodical report. The received signal to noise and interference ratio (SINR) at time t for UE k from BS i can be written as:

$$\gamma_{i,k}(t) = \frac{g_{i,k}(t)Pt_i(t)}{N_0 + \sum_{j\in\mathbf{B},L_i=L_j,i\neq j} g_{j,k}(t)Pt_j(t)} \quad (1)$$

where

- $g_{i,k}(t)Pt_i(t)$ is the signal strength received by the UE k from BS i at time t with $Pt_i(t)$ and $g_{i,k}(t)$ representing the transmitting power of BS i and channel gain between BS i and UE k. The channel gain takes into account the path loss, log-normal shadowing and fast fading.
- $L_i = L_j$ represents that BS i and BS j are in the same layer where co-channel interference exists because of the same carrier frequency.
- N_0 is the additive white Gaussian noise.

Given $\gamma_{i,k}(t)$, the instantaneous achievable bandwidth efficiency of UE k from BS i at time t is:

$$r_{i,k}(t) = log_2(1+\gamma_{i,k}(t)) \quad (2)$$

For UE k, its service model [8] determines its demanded data rate θ_k. In order to achieve θ_k from BS i at time t, the required bandwidth is $w_{i,k}(t) = \frac{\theta_k}{r_{i,k}(t)}$. The load of BS i can be represented by $\rho_i(t) = \sum_{k\in\mathbf{U}} X_{i,k}(t)\frac{w_{i,k}(t)}{W}$, which is the ratio of used bandwidth. When new UE k wants to access BS i, BS i will reject UE k if BS i could not provide $w_{i,k}$ bandwidth for UE k, which means UE k is blocked. Thus, the throughput of UE k from BS i can be calculated as follows:

$$\overline{r}_{i,k}(t) = \begin{cases} \theta_k & \rho_i(t)W + w_{i,k}(t) \leq W \\ 0 & \rho_i(t)W + w_{i,k}(t) > W \end{cases} \quad (3)$$

The system throughput $R(t)$ is the sum of all UEs' throughput at time t, i.e.,

$$R(t) = \sum_{k\in\mathbf{U}}\sum_{i\in\mathbf{B}} X_{i,k}(t)\overline{r}_{i,k}(t) \quad (4)$$

B. Power model

In order to quantify the energy need of a cellular system, we refer [9] to build BS power model, which considers the power consumption of Power Amplifier (PA), signal processing, A/D converter, antenna, cooling, power supply loss and battery backup. The detail formula of macro BS's power consumption is specified as follows (Micro BS is similar):

$$P_{BS} = N_{PApS}(\frac{Pt}{\mu_{PA}} + P_{SP})(1+C_C)(1+C_{PB}) \quad (5)$$

where, N_{PApS} is the number of PAs, Pt is the transmitting power, μ_{PA} is PA efficiency, P_{SP} is signal processing overhead, C_C is cooling loss, and C_{PB} is battery backup and power supply loss. Therefore, the power consumption of BS i at time slot t can be written as $P_i(t) = a_i \cdot Pt_i(t) + b_i$, where, $a_i = \frac{N_{PApS}(1+C_C)(1+C_{PB})}{\mu_{PA}}$ and $b_i = N_{PApS}P_{SP}(1+C_C)(1+C_{PB})$ depend on the type of BS i. The term a_i accounts for power consumption that scales with the average radiated power due to amplifier and feeder losses as well as cooling. The coefficient b_i models an offset of power which is consumed by signal processing, battery backup, as well as cell cooling. If there is no UE in BS i, we can switch off BS i to be asleep. By switching it off, we can save the power consumption of part $a_i \cdot Pt_i$. However, the power consumption of part b_i still exists. Thus, we can rewrite formula (5) as:

$$P_i(t) = \begin{cases} a_i \cdot Pt_i + b_i & \sum_{k\in\mathbf{U}} X_{i,k}(t) > 0 \\ b_i & \sum_{k\in\mathbf{U}} X_{i,k}(t) = 0 \end{cases} \quad (6)$$

For simplicity, the backhaul power consumption has been ignored in this paper. Therefore, the total system power consumption can be calculated by $P_{total}(t) = \sum_{i\in\mathbf{B}} P_i(t)$.

III. PROBLEM FORMULATION

The definition of energy efficiency varies according to measured objects [10]. We use ECR to evaluate the system energy efficiency, which is written as:

$$ECR(t) = \frac{P_{total}(t)}{R(t)} = \frac{\sum_{i\in\mathbf{B}} P_i(t)}{\sum_{k\in\mathbf{U}}\sum_{i\in\mathbf{B}} X_{i,k}(t)\overline{r}_{i,k}(t)} \quad (7)$$

The physical meaning of ECR is how much watts the system should spend in transmitting per bit per second. Obviously, the smaller ECR value is, the higher energy efficiency system has.

Since $R(t)$ and $P_{total}(t)$ are both determined by the assignment between UEs and BSs, the problem is to find the optimal assignment that minimizes $ECR(t)$ for the current time t. Denoting the assignment by assignment matrix $\mathbf{X}(t) = (X_{i,k}(t) : i \in \mathbf{B}, k \in \mathbf{U})$, the problem is thus equivalent to the following minimization problem with $\mathbf{X}(t)$:

$$\min_{\mathbf{X}(t)} ECR(t) \quad (8)$$

s.t.

$$\sum_{i\in\mathbf{B}} X_{i,k}(t) = 1, \forall k \in \mathbf{U} \quad (9)$$

$$\sum_{k\in\mathbf{U}} w_{i,k}(t)X_{i,k}(t) \leq W, \forall i \in \mathbf{B} \quad (10)$$

$$X_{i,k}(t) \in \{0,1\}, \forall k \in \mathbf{U}, \forall i \in \mathbf{B}, \forall t \quad (11)$$

There are two constraints: the unique association constraint (9) and the total bandwidth constraint (10). The first constraint is used to make sure that a UE can only be assigned to one BS. The second constraint means that the occupied resource of a BS by all UEs could not exceed the total resource limit. We can use exhaustive search method, whose computational cost is huge, to achieve the optimal solution theoretically. Besides, to the best of our knowledge, there is no effective or realistic algorithm available to solve such a problem for the following reasons:

- A central controller which collects the information about load of each BS and data rate between each UE and each BS is required. LTE does not have a central controlling unit, not to mention a central controller of multi-layers.
- Information sent to the controller is too much, which accordingly leads to excessive overhead.
- The computational cost is huge due to the large number of UEs and BSs.

To solve the problem, we will introduce a practical algorithm in next section which could be dynamically executed in a distributed manner with low overhead based on realtime load condition. More importantly, it is easy to implement on the basis of the improvement of existing standards.

IV. PRACTICAL ALGORITHM

A. EMLB

MLB is an important use case in SON in 3GPP [1], whose purpose is to cope with the unequal traffic load and to achieve the load balancing and improve the system capacity. It monitors the load periodically. When the load value of one BS exceeds the overload threshold Th_o, it adjusts its load value to middle level Th_m through transferring load to its light load neighbor BSs. We enhance MLB from two aspects. Firstly, we make load transferring begin to work when BS load value is below ES threshold Th_E. Secondly, if load transferring fails when all the neighboring BSs cannot accept the load of the BS any more, the BS will request one of its neighboring BSs to transfer load out. After these enhancements, load transferring can be triggered by the following three cases.

1) Load transferring triggered by high load condition

BS s whose load satisfies the following formula is overloaded:

$$\sum_{k\in\mathbf{U}} X_{s,k}(t)\frac{w_{s,k}(t)}{W} > Th_o \tag{12}$$

In this case, BS s cannot be switched off because of high traffic, which means we can not reduce $P_{total}(t)$ significantly. However, we can be transfer enough load out to make sure BS s is not overloaded to ensure that new arrival UEs will not be blocked. It can increase total system throughput $R(t)$ by accommodating more UEs. Thus, $ECR(t)$ can be decreased because of the fixed $P_{total}(t)$ and the increased $R(t)$.

2) Load transferring triggered by light load condition

When the load of BS s satisfies the following formula:

$$\sum_{k\in\mathbf{U}} X_{s,k}(t)\frac{w_{s,k}(t)}{W} < Th_E \tag{13}$$

we can reassign its UEs to other BSs. In this case, BS s can be switched off to reduce $P_{total}(t)$ after all its UEs are taken over by its neighboring BSs. In addition, $R(t)$ would be maintained for the existing UEs set $\mathbf{U}$ and would not make neighboring BSs overloaded through load transferring, only if neighboring BSs have enough free bandwidth. Therefore, $ECR(t)$ can be decreased because of the fixed $R(t)$ and the decreased $P_{total}(t)$.

3) Load transferring requested by neighboring BS

If one BS's load transferring fails because all its neighboring BSs cannot accept its load any more to avoid overload, it will request one of its neighboring BSs to transfer some UEs out. It can solve the problem that no neighboring BS can take over the load of the overloaded BS. Therefore, the system can increase total system throughput $R(t)$ to decrease $ECR(t)$ by accommodating more UEs, which is similar to situation one.

B. Methods of Load Transferring

There are many ways to transfer load, such as adjusting cell reselection/handover parameters and redirection. The detail algorithms, which are outside the scope of this paper, have been discussed in many research studies [11,12].

Each BS maintains a neighbor relationship table including vertical and horizontal neighboring BSs. It can transfer traffic in either vertical or horizontal directions. Switching one UE to neighboring BSs may bring bad channel quality and may affect other UEs and BSs. However, the demand throughput of θ can be maintained with fixed transmit power Pt, if only neighboring BSs have enough free bandwidth. BSs need to update their load and reject other BSs' load after their load reaches middle threshold Th_m in order to avoid overload.

As described in previous subsection, three cases can trigger load transfer: high load condition, light load condition and requests from neighboring BSs. Each case has an expected value V_e that the load value should be less than or equal to after load transferring. In case 1 and case 3, $V_e = Th_m$, which makes sure BS not be overloaded. In case 2, $V_e = 0$, which ensures BS has no UEs and can be asleep.

C. Dynamic Energy Saving algorithm based on EMLB

With EMLB, DESEMLB can work dynamically and efficiently. This subsection depicts how DESEMLB works.

Every BS monitors and evaluates its load condition. DESEMLB consists of three parts as illustrated in Fig. 2, which correspond to three cases of EMLB. Case 1, BS's load exceeds Th_o, which means the BS is overloaded and needs load balancing. In this case, load transferring begins to work to ensure that the BS will be not overloaded. If it fails, the overloaded BS will check whether there are neighboring BSs in sleep mode. If there are neighboring BSs in sleep mode, we choose one of them to wake up, which is of great benefit to load balancing next time; otherwise, the BS requests one of its awake neighbors to transfer load out. Case 2, BS's load is lower than Th_E. In this case, load transferring begins to try its best to shift all its UEs away. If it successes, the corresponding BS is switched off; otherwise, it requests one of its awake neighbors to transfer load out. Case 3, BS receives the request message from its neighboring BSs. In this case, DESEMLB works as the same with case 1. In order to avoid the coverage holes problem, we enforce that the BSs in bottom layer should not be switched off to be asleep.

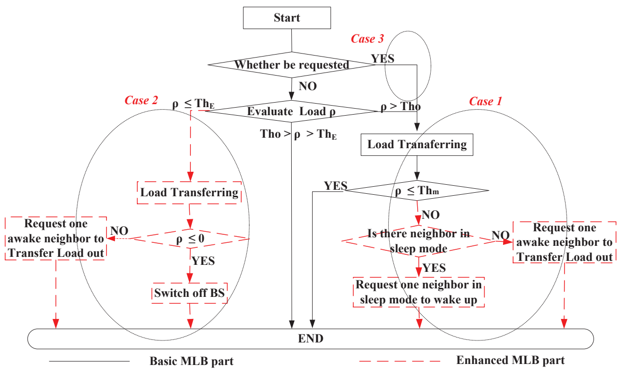


Fig. 2. The process of DESEMLB

V. Performance Evaluation

A. Simulation Setup

A three-layer network composed of 19 hexagonal GSM cells in the bottom layer, 19 hexagonal LTE macro cells in the middle layer and 57 circular LTE micro cells in the top layer shown in Fig. 1 is considered. There are three LTE micro BSs distributed in each LTE macro cell uniformly and randomly. A fixed number of UEs are active and the number of active UEs depends on the system traffic model. Two kinds of system traffic model is considered:

- System traffic is a step function in the time domain. The total number of active UEs is 150 in the first half of the simulation period, which simulates sparse night. The total number of active UEs is 550 in the last half of the simulation period, which simulates dense daytime.
- The number of active UEs is fixed during each simulation. We change it from 205 to 605 to study the system performance with different intensity of system traffic.

The call length depends on UEs' service model [8]. Five kinds of service models are considered: Fullbuffer, VoIP, PSS, HTTP and FTP. The number of active UEs of each kind of service model is one-fifth of total number of UEs. Manhattan Mobility Model is used for UEs and wrap-around technique is used to avoid the edge effect in the Manhattan scenario [13]. BSs in the bottom layer can not be off during simulation. The other simulation assumptions and parameters, such as channel parameters and MLB parameters, are according to the 3GPP specification and are similar to that in [14]. Only the most important and relevant ones are listed in Table I.

B. Results and Discussions

The following four schemes are evaluated to figure out four types of system performance: average block rate, average throughput, total system power consumption and ECR.

1) *REF*: Reference scheme without any ES mechanism.

TABLE I
Simulation Parameters [14]

Parameters	Assumption
Carrier bandwidth W	5 MHz
Tx power of LTE/GSM macro BS	43 dBm
Inter-site distance of LTE/GSM macro BS	1732 m
Cell Radius of LTE micro BS	50 m
Path Loss	$128.1 + 37.6\log_{10}d$
Noise Power	-174 dBm/Hz
Shadowing standard deviation	10 dB
Correlation distance of Shadowing	10 m
Overload Threshold Th_o	0.8
Middle load Threshold Th_m	0.5
Energy Saving Threshold Th_E	0.15
UE speeds	8 m/s
Simulation time	240 s

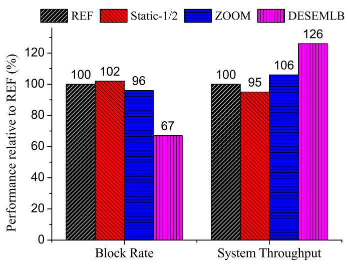
2) *Static-1/2*: The static switching on/off algorithms in [6], which switches off 1/2 of all the BSs at night.
3) *ZOOM*: The cell zooming algorithms in [7].
4) *DESEMLB*: Our proposed algorithm.

The simulation results can be found in Fig. 3 and Fig. 4.

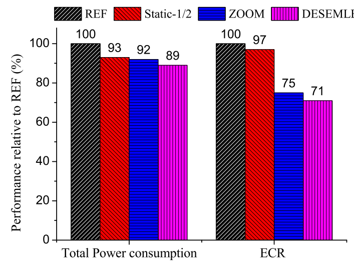
Fig. 3 shows the performance of the system using different ES schemes with step function traffic model. It is obvious that DESEMLB not only has lowest block rate which brings highest system throughput, but also has best energy efficiency performance. Due to load balancing function and considering UEs' experience, DESEMLB has a 33% block rate performance gain and 26% system throughput gain comparing to REF. In addition, it consumes the least energy and has a 29% energy efficiency gain because of two enhancements of EMLB. The first one is using EMLB to transfer load out when cell load is below Th_E. The other one is that EMLB solves the problem that no neighboring BS can take over the load of the overloaded BSs. Both of these enhancements can provide a higher probability of switching off BSs with light load and make system more balancing to accommodate more UEs. Compared with DESEMLB, Static-1/2 has only 3% energy efficiency gain and ZOOM has 25% energy efficiency gain relative to REF. The reason is that switching off 1/2 of BSs brings 2% increase of block rate and 5% decrease of system throughput comparing to REF. ZOOM redirects UEs of BSs with light load to other BSs without considering UEs' experience. Therefore, it has higher block rate and lower system throughput comparing to DESEMLB, which leads to that its energy efficiency is 4% lower than DESEMLB.

As illustrated in Fig. 3 (c), DESEMLB and ZOOM can switch off/on BSs based on the real-time load during simulation automatically. It can well reflect the dynamic nature of ZOOM and DESEMLB. On the contrary, REF always works with all BSs resources planned initially. And Static-1/2 only switches off 1/2 of BSs at night ($0 \sim 120s$). That is, it switches a fixed number of BSs off at fixed times. This is a major reason why DESEMLB and ZOOM have higher energy efficiency.

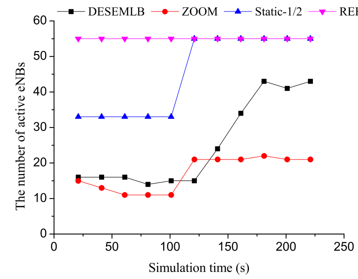
At last, we present simulation results of the schemes with different number of active UEs in Fig. 4 to further prove that our proposed scheme has best energy efficiency performance. All the result data is normalized to the max value, which



(a) Throughput performance relative to REF

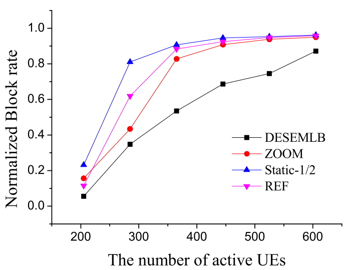


(b) Energy performance relative to REF

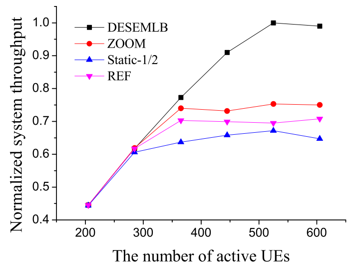


(c) The number of active eNBs

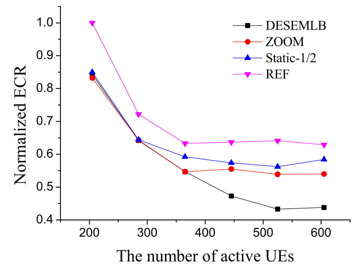
Fig. 3. Performance results relative to REF with step function traffic model



(a) Normalized System Average Block Rate



(b) Normalized System Average Throughput



(c) Normalized System Average ECR

Fig. 4. Normalized performance results of system level simulation with different system load

is suitable to observe the gain. It is obvious that with the growth of the number of active UEs, the block rate, system throughput and energy efficiency rise in both schemes. It is obvious to view two features in Fig. 4. The first one is that all the ES mechanisms have greatly improved energy efficiency comparing to REF. The second one is that DESEMLB has best system performance, especially when the system load is high.

In sum, in contrast with REF, Static-1/2 and ZOOM, our proposed scheme can achieve best energy efficiency performance with high system throughput.

VI. Conclusion

In this paper, we formulate a ECR minimization problem in a multi-layer network. The property and complexity of the problem is analyzed. To solve this problem, we enhance MLB from two aspects and integrate it into ES to design a heuristic but practical algorithm, namely DESEMLB. On the one hand, the two enhancements of EMLB can provide a higher probability of switching off BSs with light load. On the other hand, they can reduce the overloaded BSs' load, which can increase total system throughput by accommodating more UEs. The performance of the proposed algorithm is evaluated by comparing with existing static and dynamic schemes through simulations and the results demonstrate that the scheme not only has good system throughput performance, but also achieves significant power saving. To summarize, DESEMLB offers an energy efficiency performance enhancement.

Acknowledgment

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