Dynamic Multi-stage Energy-Saving Management Mechanism based on Base Station Cooperation

Peng Yu, Wenjing Li, Yulin Su, Xuesong Qiu
State Key Laboratory of Networking and Switching Technology
Beijing University of Posts and Telecommunications
Beijing 100876, China

***Abstract*—A novel dynamic multi-stage ESM (Energy-Saving Management) mechanism based on BS (Base Station) cooperation is proposed. The mechanism firstly introduces a local OP (Opposite Pair) cooperation method taking account of geographic topology and then divides time period into four domains. In time domains, regional dynamic multi-stage algorithms and efficient performance evaluation model for the mechanism is analyzed as well. The mechanism is simulated under a practical LTE BS deployment. Results show that 25.1% of regional energy can be saved at most. Still better coverage, interference, and throughput performance can be obtained comparing to other algorithms.**

Keywords—BS cooperation*; *Multi-stage*; *OP*; *ES algorithm

I. INTRODUCTION

Presently BSs (such as BTS, NodeB, eNodeB) occupy about 50%~60% of the energy consumption in wireless networks [1]. As wireless networks are designed according to predictive peak traffic, when the regional traffic is low, much resource and energy is wasted [2]. Thus saving energy for BS can largely reduce OPEX for telecom operators. ES (Energy Saving) methods require frequent adjustments to wireless parameters (such as BS transmit power, antenna tilt) [3], so traditional manual management is not suitable. And ESM defined in SON (Self-Organized Network) use case is effective [4][5]. ESM solutions mainly adopt BS cooperation to compensate coverage and capacity for switched-off BSs [6], and primarily concentrate on effective ES methods and energy consumption evaluation model.

For ES methods, a simple scheme targeting coverage compensation is introduced in [7]. On account of traffic load and neighbor relationship, a method through cell extension is given in [8]. Traffic variation is profiling as a sinusoidal-function in [9]. Opposite pair and trigonal pair compensation solution for a single BS is analyzed in [10], further modified ES method based on trigonal pair compensation is proposed in [11]. A multi-stage method in [12] takes ES actions in each divided coverage grid. ES solutions are abstracted into an integrated problem with user association and BS operation in [13]. However, these ESM solutions exist following problems: 1) compensation methods are not effective for irregular BS deployment; 2) mathematical model of ES problem is always NP-hard with complex algorithms; 3) most methods lack analysis for performance tradeoff.

Generally, macro-cell/BS is responsible for regional coverage. Other cell/BS with smaller size is mainly deployed for hotspot [14]. As power consumption of macro-BS/cell is fairly higher than smaller one [15], thus research on ESM for macro-BS/cell takes on more significance.

Aiming at above problems, the proposed DM-ESMM-BC (Dynamic Multi-stage Energy-Saving Management Mechanism based on BS Cooperation) in this paper is suitable for heterogeneous network scenarios with multiple types of BSs. Its contributions are followed: 1) it proposes more effective practical OP cooperation method for a single macro BS; 2) it divides time periods based on variation feature of regional traffic; 3) it introduces novel efficient ES trigger and recovery algorithms based on OP with low complexity; 4) it proposes integrated evaluation model which assesses regional performance affect.

II. LOCAL OP COOPERATION AND TIME DIVISION METHOD

A. Local OP cooperation method

Our method firstly determines the OP set, and then selection of effective OP. Notice that this method just aims at macro-BSs.

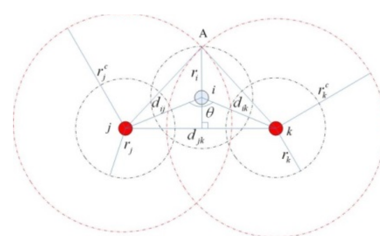


Fig. 1. A opposite pair compensation case for BS i

Assume radius of BS i is r_i, inter-BS distance of BS i and BS j is d_{ij}, and compensation radius of BS k is r^c_k. For BS i requiring compensation, assume its neighbor BS set is $\boldsymbol{S}^i_N$, and $\boldsymbol{S}^i_D = \{j \mid r_i + r_j < d_{ij}\}$ represents set of BSs overlap with BS i. Then candidate compensation BS set $\boldsymbol{S}^i_C = \boldsymbol{S}^i_N \cap \boldsymbol{S}^i_D$. As shown in Fig. 1, when coverage of BS j and k increase and intersect at point A which is just on the coverage edge of BS i, coverage of BS i can be totally compensated. Several Definitions are below.

Definition 1: For BS i, if BS pair $\{j, k\}$ satisfied that $j \in \boldsymbol{S}^i_C$, $k \in \boldsymbol{S}^i_C$, and $2\pi/3 < \theta = \angle jik \leqslant \pi$, then we call pair $\{j, k\}$ as a OP of BS i.

Definition 2: For OP=$\{j, k\}$ of BS i, if BS j and BS k intersects at two points, then we call the point near BS i as a CRP (Coverage Reference Point), as point A in Fig.1.

Definition 3: For BS i, if OP=$\{j,k\}$ can totally compensate its coverage, but $r^c_j < d_{ij}+r_i$ and $r^c_k < d_{ik}+r_i$, which means only

BS j or BS k could not cover BS i entirely, then we call this OP as an EOP (Effective OP).

Then we construct the following two-dimension axis for BS i in Fig.2 and obtain Theorem 1.

Theorem 1: For EOP=$\{j, k\}$ of BS i, when CRP slides on coverage of BS i, only one solution exists with $r^c_j/r^c_k = d_{ij}/d_{ik}$.

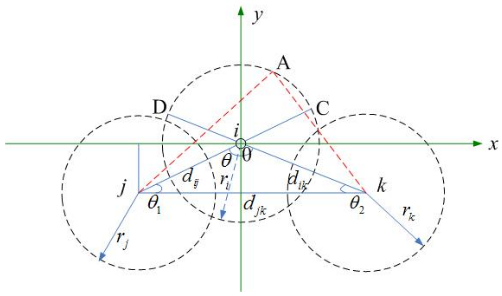


Fig. 2. Analysis of compensation radius for EOP

Proof: as shown in Fig.2, for EOP of BS i, $\alpha \in (\theta_1, \pi\text{-}\theta_2)$. Assume $f(\alpha) = r^c_j(\alpha)/r^c_k(\alpha)$. Then $f(\alpha)$ is monotone decreasing in this domain. Then maximal value of $f(\alpha)$ is obtained when $\alpha=\theta_1$. Similarly, minimal value of $f(\alpha)$ is obtained when $\alpha=\pi\text{-}\theta_2$. Under practical networks, $d_{ij}>r_i$ and $d_{ik}>r_k$. With definition 1 we have $0\leq\theta_1+\theta_2=\pi\text{-}\theta<\pi/3$. Through deviation we can get that $f(\pi\text{-}\theta_2)<d_{ij}/d_{ik}< f(\theta_1)$. As $f(\alpha)$ is monotone, so only one value $\alpha^* \in (\theta_1, \pi\text{-}\theta_2)$ satisfied that $f(\alpha^*)= d_{ij}/d_{ik}$.

Definition 4: For an EOP=$\{j, k\}$ of BS i, when its CRP locates on coverage edge of BS i, and $r^c_j/r^c_k = d_{ij}/d_{ik}$, we call this unique EOP as BOP (Balanced OP) of BS i. r^c_j and r^c_k are corresponding BR (Balanced Radius) separately.

B. Time domain division method

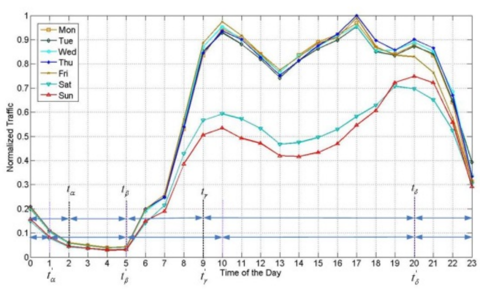


Fig. 3. Normalized traffic variations case for one week

Normalized traffic variations for one week from a district in Beijing are shown in Fig.3. It denotes that basic varying cycle is 24 hours. Still, during midnight, such as from 1:00 to 5:00, traffic is lower than 10% of peak value.

Assume regional traffic load at time t is $Tr(t)$. We firstly determine busy traffic threshold Th_{max} and slight traffic threshold Th_{min} according to empirical value, and then time division method for each day as: 1) Train out integer time points t_α and t_β as shown in Fig.3, which satisfy $t_\alpha<t_\beta$, and for arbitrary $t\in[t_\alpha, t_\beta]$, condition $Tr(t)\geqslant Th_{min}$ is constantly tenable; 2) Train out integer time points t_δ and t_γ as in Fig.3, and these conditions should be satisfied: 1) $t_\delta\leqslant t_\alpha$ and $t_\beta\leqslant t_\gamma$; 2) $Tr(t_\delta)\leqslant Th_{max}$ and $Tr(t_\gamma)\leqslant Th_{max}$; 3) $Tr(t)$ is monotone decreasing in $[t_\delta, t_\alpha]$ and monotone increasing in $[t_\beta, t_\gamma]$.

From above steps we can divide each day into four time domains, which are $T_1=[t_\delta, t_\alpha]$, $T_2= (t_\alpha, t_\beta)$, $T_3=[t_\beta, t_\gamma)$ and $T_4=[t_\gamma, t_\delta+24]$ separately. Different ES action should be executed for each time domain: 1) During T_1, traffic load gradually decreases, so dynamic multi-stage ES trigger algorithm will be executed at the beginning of each hour; 2) During T_2, regional traffic is fairly low and may be fluctuant, so states of each BS will keep on the status at time point t_α; 3) During T_3, traffic load gradually increases, so dynamic multi-stage ES recovery algorithm will be executed at the beginning of each hour; 4) At time point t_γ, all the BS will be recovered to normal states, and keep on active in T_4.

III. Dynamic multi-stage ES algorithms and Evaluation model

A. ES trigger algorithm

Algorithm 1: Dynamic Multi-stage ES trigger algorithm

Input: $\boldsymbol{B}, \boldsymbol{D}, \boldsymbol{TR}, \boldsymbol{S}, \boldsymbol{S}_{op}, \boldsymbol{R}$

Output: $\boldsymbol{S}, \boldsymbol{R}'$

for each $i\in \boldsymbol{B}$, *set* $tr_i'(t)=tr(t)$, $r_i'(t)=r(t)$, *and* $\boldsymbol{OPB}_i=\varnothing$

while $\boldsymbol{B} \neq\varnothing$, *for* $i=\arg_j \min\{tr_j'(t) \mid j\in \boldsymbol{B}\}$ *with* $s_i(t)=0$ **do**

  while $\boldsymbol{S}^i_{op}\neq\varnothing$, **do**

    for $\forall op_{ij}=\{k,l\}\in \boldsymbol{S}^i_{op}$, *get* n_{ij}, o_{ij} *and* c_{ij}

  $\Delta tr_{ip}(t)=Tr_{\max}-\lambda_p\cdot tr_i'-tr_p'$, $\Delta Tr_i(t)=\sum\Delta tr_p^2(t),\ p=k,l$

    if $o_{ij}=0$, $\Delta tr_k(t)>0\,\&\&\Delta tr_l(t)>0$, **then** $\boldsymbol{OPB}_i=\boldsymbol{OPB}_i+op_{ij}$, **end if**

    $\boldsymbol{S}^i_{op}=\boldsymbol{S}^i_{op}-op_{ij}$

  end while

  if $\boldsymbol{OPB}_i\neq\varnothing$, **then** $\boldsymbol{S}^i_m=\varnothing$

    for each $op_{ik}\in \boldsymbol{S}^i_{op}$ *with* $\max\{c_{ij}\}$, $\boldsymbol{S}^i_m=\boldsymbol{S}^i_m\cup op_{ik}$

    $op_{iJ}=\{K,L\}\leftarrow\arg\max\{\Delta Tr_i(t), op_{ij}\in \boldsymbol{S}^i_m\}$

    find BOP *for* op_{iJ} *and its* BR *as* $r^c_K(t)$ *and* $r^c_L(t)$

    $tr_p'(t)=tr_p'(t)+\lambda_p\cdot tr_i'(t)$, $r_p'(t)=\max\{r_p'(t), r^c_p(t)\}\quad p=K,L$

    set $s_i(t)$=1, $s_p(t)$=2, $p=K,L$

  end if

  $\boldsymbol{B}=\boldsymbol{B}-i$

end while, *for each* $i\in\boldsymbol{B}$, $r_i(t)=r_i'(t), tr_i(t)=tr_i'(t)$

if exist BS i and j, $s_i(t)$=0, $s_j(t)\neq0$, $r_i+d_{ij}\leq r_j\ \&\&tr_i(t)+tr_j(t)<Tr_{\max}$,**then**

  set $tr_j(t)=tr_i(t)+tr_j(t), s_i(t)=1, s_j(t)=2$

end if

ES trigger algorithm is executed in each hour of T_1, and make sure each BS is slept at most once. Assume set of BS is $\boldsymbol{B}=\{i\}$, distance matrix is $\boldsymbol{D}=\{d_{ij}\}$ and regional traffic vector at t time is $\boldsymbol{TR}=(tr_1(t), tr_2(t),\ldots, tr_N(t))$. N is regional BS number. Regional OP set vector, BS state vector and BS radius vector are $\boldsymbol{S}_{op}=(\boldsymbol{S}^1_{op}, \boldsymbol{S}^2_{op},\ldots,\boldsymbol{S}^N_{op})$, $\boldsymbol{S}=(s_1(t), s_2(t), \ldots, s_N(t))$ and $\boldsymbol{R}=(r_1(t), r_2(t), \ldots, r_N(t))$ separately. $s_i(t) = 0, 1, 2$ denote normal state, switched-off state and compensation state separately. The procedure is in Algorithm 1.

When one BS is under normal state, only OP=$\{j,k\}$ satisfies the following conditions can be put into $\boldsymbol{OPB}_i$:1) None of BS j and k is under switched-off states; and 2) traffic of BS i can be accommodated, so $\Delta tr_j(t)>0$ and $\Delta tr_k(t)>0$. λ_p is the traffic load distribution ratio, defined as below:

$$\lambda_p = d_{ip}^2 / \sum d_{ip}^2,\ p = k, l \tag{1}$$

n_{ij}, o_{ij} *and* c_{ij} means number of normal, sleep and compensation BS in op_{ij}. To maximize compensation efficiency, candidate OP in $\boldsymbol{OPB}_i$ with maximal c_{ij} should be considered. These OPs are put into $\boldsymbol{S}^i_m$. Tr_{max} is the capacity for each BS. Moreover, we should prevent the traffic of compensation BS from overload, so $op_{iJ}=\{J, K\}$ in $\boldsymbol{S}^i_m$ with maximal $\Delta Tr_i(t)$ will be selected. For op_{iJ}, we then find it BOP and BR through definition 4.

After execute effective OP compensation for BS under normal state, we should next consider the probability that one micro BS which can be absorbed by a macro BS. As shown in the end of Algorithm 1, when traffic accommodation requirement is satisfied, micro BS *i* can be switched off as well.

B. ES recovery algorithm

Algorithm 2: Dynamic Multi-stage ES recovery algorithm

Input: $\boldsymbol{B}, \boldsymbol{D}, \boldsymbol{TR}, \boldsymbol{TR}^0, \boldsymbol{S}, \boldsymbol{R}, \{\boldsymbol{AS}_i\}, \{\boldsymbol{CS}_i\}$

Output: $\boldsymbol{S}, \boldsymbol{R}'$

for each $i \in \boldsymbol{B}$, *set* $tr_i'(t) = tr(t)$, $r_i'(t) = r(t)$, *sort* $\boldsymbol{CS}_i$ with $\downarrow tr_k^0(t)$, $k \in \boldsymbol{CS}_i$

while $\boldsymbol{B} \neq \varnothing$, *for* $i = \arg_j \max\{tr_j'(t) \mid j \in \boldsymbol{B}\}$ *with* $s_i(t) = 2$ **do**

  if $tr_i'(t) \geq Tr_{\max}$

    if *exist* BS j, $s_j(t)=1$, $r_j^0(t) + d_{ij} \leq r_i'(t)$, $tr_i'(t) - tr_j^0(t) < Tr_{\max}$, **then**

      set $tr_i'(t) = tr_i'(t) - tr_j^0(t), \boldsymbol{CS}_i = \boldsymbol{CS}_i - j, s_i(t) = 0, r_j'(t) = r_j^0(t)$

    else *get minimal* $\boldsymbol{PS}_i \subseteq \boldsymbol{CS}_i, tr_i'(t) - \sum \lambda_k \cdot tr_k^0(t) < Tr_{\max}, k \in \boldsymbol{PS}_i$

      while $\boldsymbol{PS}_i \neq \varnothing$, *for each* $k \in \boldsymbol{PS}_i$, $j \leftarrow \boldsymbol{AS}_k - i$ **do**

        $tr_p'(t) = tr_p'(t) - \sum \lambda_p \cdot tr_k^0(t), AS_k = AS_k - p, p = i, j$

        $\boldsymbol{CS}_p = \boldsymbol{CS}_p - k, r_p'(t) = \max\{BR_q \mid q \in \boldsymbol{CS}_P - i\}, p = i, j$

        $s_k(t) = 1, r_k'(t) = r_k^0(t), \boldsymbol{PS}_i = \boldsymbol{PS}_i - k$

      end while

    end if

  end if

  $\boldsymbol{B} = \boldsymbol{B} - i$

end while, *for each* $i \in \boldsymbol{B}$, $r_i(t) = r_i'(t), tr_i(t) = tr_i'(t)$

for each $\boldsymbol{CS}_i$, **if** $\boldsymbol{CS}_i = \varnothing$, **then**

  $s_i(t) = 1, r_i(t) = r_i^0(t)$

end if

ES recovery algorithm is the inverse process of ES trigger algorithm. This algorithm is executed in each our of T_3. For each BS under switched-off state, once it's recovered, its state will not change. Assume $\boldsymbol{TR}^0$ and $\boldsymbol{R}^0$ represent the traffic vector and radius vector initially. $\boldsymbol{AS}_i$ is compensation BS set for switched-off BS *i*, and $\boldsymbol{CS}_i$ is compensated BS set of compensation BS *j*. And then ES recovery procedure is below.

In Algorithm 2, we firstly find the BS *i* with heaviest traffic. And switched-off micro BS under BS *i* is considered then. For macro BS scenario, we get the minimal BS set $\boldsymbol{PS}_i$ which can decrease the load of BS *i* under Tr_{max}. Then we update traffic of compensation BS *i*, *j* and recover BS $k \in \boldsymbol{PS}_i$ to normal state. For compensation radius, only the remain BS in $\boldsymbol{CS}_i$ will be guaranteed. So coverage requirement is still satisfied.

We can easy find that complexity of Algorithm 1 is $O(N \cdot \max\{|\boldsymbol{S}^i_{op}|\})$. Based on analysis in section II, we know that $O(N \cdot \max\{|\boldsymbol{S}^i_{op}|\}) \approx O(N)$, which means complexity is linear. For similarly complexity of Algorithm 2 is $O(N)$ as well.

C. Efficiency Evaluation model

We should model the traffic firstly. A consecutive traffic density model in [13] is adopted. Assume ES region is L, $x \in L$ denotes the location, then coverage area of BS i is L_i. For location x, the poisson arrival rate is $\delta(x;t)$, and the data flow length is independent distribution with average $1/\mu(x;t)$. Then traffic density at x is $T(x;t) = \delta(x;t)/\mu(x;t)$, and $tr_i(t)$ is in (2):

$$tr_i(t) = \int \{T(x;t) \mid x \in L_i\} dx \tag{2}$$

Based on Shannon theorem, throughput at x location under BS i, denoted as $c_i(x;t)$ is shown below:

$$c_i(x;t) = T(x;t) \cdot B_W \cdot \log(1 + \varphi_i(x;t)) / M \tag{3}$$

M and B_W are data length and bandwidth for each physical resource unit. $\varphi_i(x;t)$ is the received signal-to-interference ratio from BS i, which is shown in (4).

$$\varphi_i(x;t) = g_i(x;t) \cdot p_\alpha^i(t) / \left(\sum_{k \neq j, k \in \boldsymbol{B}} g_k(x;t) \cdot p_\alpha^k(t) + \sigma^2 \right) \tag{4}$$

$g_i(x;t)$ is the channel gain from BS i, which is obtained from down link budget. $p^i_\alpha(t)$ is the transmit power of BS i and σ^2 denotes the average power noise. Then $p^i_r(x;t) = g_i(x;t) \cdot p^i_\alpha(t)$ denotes the received signal strength from BS i at location x. As ES mechanism is a tradeoff among ES gain and coverage, interference and throughput, so CDF (Cumulative Distribution Function) of $p^i_r(x;t)$, $\varphi_i(x;t)$ and $c_i(x;t)$ will be evaluated as performance metrics. Moreover, energy efficiency evaluation will refer to the model in [11].

IV. Simulation and Discussion

A. Simulation Scenario

In our simulation BS topology obtained from a practical LTE network. There are 135 BS with BS density as 2.25 /km^2. height of BS is between 10m~30m, and antenna tilt is between 11.4 and 14.8 degree. Maximal transmit power, antenna gain, PDCCH power and allowed uplink power is 46 dBm, 15 dBi, 29 dBm and -101.5dBm. PRB of macro and micro BS are 100 and 50. For UE, average antenna height, maximal transmit power, antenna gain and allowed downlink power are 1.5m, 23dBm, 1dBi and -120 dBm. Okumura-Hata propagation model is used for uplink and downlink budget.

Moreover, Th_{max} and Th_{min} are 0.9 and 0.1, for macro BS, average of p^i_β and p^i_γ are 201W and 305W, and ψ_i is set as 5.38 from [12]. For micro BS with coverage radius smaller than 200 m, average value of p^i_β, p^i_γ and ψ_i are 33.7 W, 72.3 W and 6.35. P_S is 10% of maximal transmit power and ε is 0.01. M is 1 Mbit and B_W is 3MHz. HTTP service is supplied. Arrival rate is $\delta(x;t) = x \cdot \delta(t)$, x is 10^{-4} and $1/\mu(x;t)$ is 100 kbyte. We call the method in [12] as TESM, though it's not suitable for heterogeneous networks, we still set it as a baseline. Multiple parameter adjustment method in [11] is adopted.

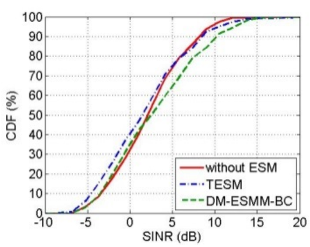
B. Result analysis

Based on Algorithm 1 and Algorithm 2, for Monday, number of switched-off BS variation is shown in TAB.I.

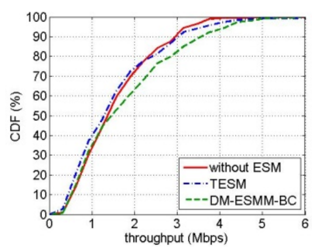
TABLE I. OUTCOMES FOR ALGORITHM 1 AND 2

Traffic	Time domain	Switched-off BS number	
		DM-ESMM-BC	TESM
Practical	24:00~5:00/ T_2	63	64
	6:00~9:00/ T_3	63,29,13,13	64,47,17,17
	10:00~21:00/ T_4	0	0
	22:00~24:00/ T_1	38, 63, 63	17,61,64
theoretical	1:00~4:00/ T_2	63	64
	5:00~11:00/ T_3	63,63,63,48,42,8,3	64,64,64,47,47,17,3
	12:00~15:00/ T_4	0	0
	16:00~23:00/ T_2	0,20,31,48,51,63,63,63,63	0,3,17,47,47,64,64,64,64

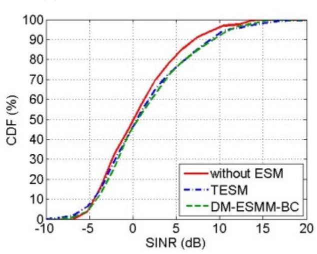
From TAB.I we can find more BS can be switch-off for practical traffic. And maximal number of BS for the two methods is almost the same. Results for other days are similar. Still, under practical traffic model, CDF of RSRP ⩾−120 dBm with our mechanism and TESM, and without ESM are 98.96%, 95.80% and 99.52% separately, our mechanism takes on just a little lower coverage than oridinary, but better performance than TESM.



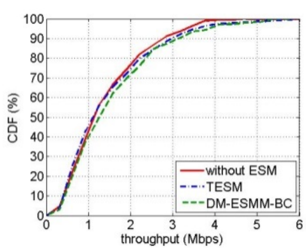
(a)Practical SINR distribution



(b)Practical throughput distribution



(c)Theoretical SINR distribution



(b)Theoretical throughput distribution

Fig. 4. Regional SINR and throughput distribution

From Fig.4 (a) we can find that interference is sacrificed for saving energy. But our mechanism is still better than TESM. From Fig.4 (b) we can find that 5% edge user throughput is degraded as tradeoff as well, but our mechanism is fairly lower than TESM. Similarly, for theoretical traffic model, as shown in Fig.4 (c) and Fig.4 (d), our mechanism takes on better service performance during most value intervals. As outcomes for other days during weekdays and weekends is similar with Monday. We just omit their analysis here.

At last, regional ES gain in this week for DM-ESMM-BC and TESM is shown in Fig.5. Maximal ES gain of our mechanism is 25.1% on Saturday. we can still conclude the following outcomes: 1) ES gain for theoretical traffic model is higher than practical model, as it is smoother as with longer T_1 and T_3. 2) As traffic in weekends is lower than weekdays, so ES gain of weekends is higher than weekdays. 3) For practical traffic model, ES gain for DM-ESMM-BC is lower than TSM, but deviation is lower than 2%. Still, for theoretical traffic model ES gain of DM-ESMM-BC is better than TESM, which means our mechanism is suitable for theoretical traffic model.

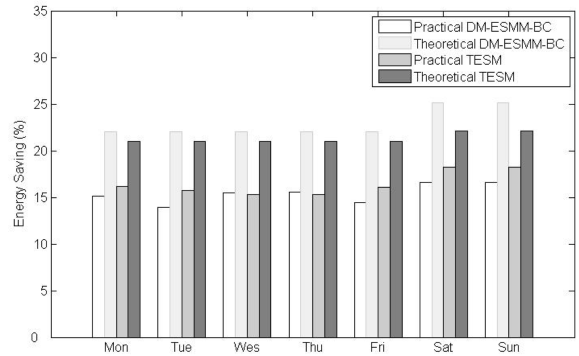


Fig. 5. Regional ES gain in one week

As more BS can be switched-off in our mechanism than methods which execute ES trigger and recovery once, such as methods in [7-11], so our ES gain will higher than them. Comparing to TESM, our mechanism takes on better performance for RSRP, SINR and throughput, and even more energy efficient for theoretical traffic model. Moreover, complexity of our algorithms is just O(N), but TESM is O(N^2), so we can conclude that our mechanism is a reasonable, feasible and efficient ESM method.

V. CONCLUSIONS AND FUTURE WORK

Next new technologies such as CoMP (Coordinated Multi-Point), ICIC (Inter-Cell Interference Coordination) will be considered in ESM. Moreover, other efficient evaluation metrics for ESM mechanism such as ECG (Energy Consumption Gain), and energy consumed per bit and per km will be assessed as well.

ACKNOWLEDGMENT

This research is supported by the Funds for Creative Research Groups of China (61121061), NSFC (61271187) and Chinese Universities Scientific Fund (BUPT2012RC0608).

REFERENCES

[1] T. Chen, Y. Yang, H. Zhang, H. Kim and K. Horneman, "Network energy saving technologies for green wireless access networks," *IEEE Wireless Communications*, vol. 18, no. 5, pp. 30-38, 2011.

[2] C. Lubritto, A. Petraglia, C. Vetromile, S. Curcuruto, M. Logorelli, G. Marsico and A. D'Onofrio, "Energy and environmental aspects of mobile communication systems," *Energy*, vol. 36, no. 2, pp. 1109-1114, 2011.

[3] Z. Niu, Y. Wu, J. Gong and Z. Yang, "Cell zooming for cost-efficient green cellular networks," IEEE Communications Magazine, vol. 48, no. 11, pp. 74-79, 2010.

[4] 3GPP TS 32.551, V11.3.0, "Energy Saving Management (ESM); Concepts and requirements," 2012.

[5] INFSO-ICT-216284 SOCRATES, D 2.2, "Requirements for self-organising networks," 2008.

[6] H. Tao and N. Ansari, "On greening cellular networks via multicell cooperation," IEEE Wireless Communications, vol. 20, no. 1, pp. 82-89, 2013.

[7] L. Chiaraviglio, D. Ciullo, M. Meo and M. A. Marsan, "Energy-efficient management of UMTS access networks," in ITC 2009, 2009, pp. 1-8.

[8] K. Samdanis and M. Brunner, "Self Organized Network Management Functions for Energy Efficient Cellular Urban Infrastructures," Mobile networks & Applications, pp. 119-131, 2011.

[9] O. Eunsung and B. Krishnamachari, "Energy Savings through Dynamic Base Station Switching in Cellular Wireless Access Networks," in GLOBECOM 2010, 2010, pp. 1-5.

[10] M. F. Hossain, K. S. Munasinghe and A. Jamalipour, "An eco-inspired energy efficient access network architecture for next generation cellular systems," in WCNC 2011, 2011, pp. 992-997.

[11] P. Yu, W. Li and X. Qiu, "A novel Energy-Saving Management mechanism in cellular networks," in CNSM 2012 , 2012, pp. 1-9.

[12] C. Peng, S. Lee, S. Lu, H. Luo and H. Li, "Traffic-driven power saving in operational 3G cellular networks," in MobiCom'11 , 2011, pp. 121-132.

[13] K. Son, H. Kim, Y. Yi and B. Krishnamachari, "Base station operation and user association mechanisms for energy-delay tradeoffs in green cellular networks," IEEE Journal on Selected Areas in Communications, vol. 29, no. 8, pp. 1525-1536, 2011.

[14] S. Bhaumik, G. Narlikar, S. Chattopadhyay and S. Kanugovi, "Breathe to stay cool: Adjusting cell sizes to reduce energy consumption," in SIGCOMM Green Networking '10, 2010, pp. 41-46.

[15] D. Chee, M. S. Kang, H. Lee and B. C. Jung, "A study on the green cellular network with femtocells," in CUFN 2011, 2011, pp. 235-240.