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A Base Station Switching Scheme for Green Cellular Networks

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Abstract: A cellular network is radio network distributed over land through cells where each cells include a fixed location transceiver known as a Base Station (BS). The major concern for cellular operators is achieving energy efficiency in cellular network. They have to maintain profitability and at the same time reduce the negative impact on environment. A lot of research has been carried out concerning energy efficient or green cellular networks. In a cellular network, the BSs consume the highest amount of energy compared to other components. The focus of this paper is on reducing the energy consumption in the BS. A cellular network can be made more energy efficient by using a design based on switching BSs. Significant energy savings can be obtained by considering the uplink and downlink traffic for the switching purpose.

Keywords: Green cellular network, energy saving, base station switching, green communication

I. INTRODUCTION

The ever increasing demand for global information access has led to rapid development of Information and Communication (ICT) industry. The amount of data transmission increases approximately by a factor of 10 per every five years with the corresponding associated energy consumption increasing by 20 percent per year [1].

Today more than 2 percent of energy consumption in the world is attributed to ICT industry and is expected to grow even more in the future. Studies have estimated the energy consumption in cellular networks to be 0.2 and 0.4 percent of global CO2 emission [2].The ever expanding cellular networks have tremendously increased the energy costs and greenhouse gas emissions.

Thus the idea of green cellular networks took birth. The central focus of these networks is to bring down the energy consumption of cellular networks but at the same time ensuring that the service remains good.

This paper focuses of reducing the energy consumption at the BS. The BSs consume major chunk of input energy about 60-80% of total consumption in cellular networks [3].

There are several techniques to achieve energy reduction at BSs from employing improvements in power amplifier, designing power saving protocols, implementing cooperative BS power management, using renewable energy resources and bringing some simple architectural changes.

In this paper we deal with switching off underutilized BSs to achieve energy savings. From Fig 1 which is consistent with data presented in [5], it can be seen that the traffic profiles between day and night times as well that between weekends and weekdays differ.

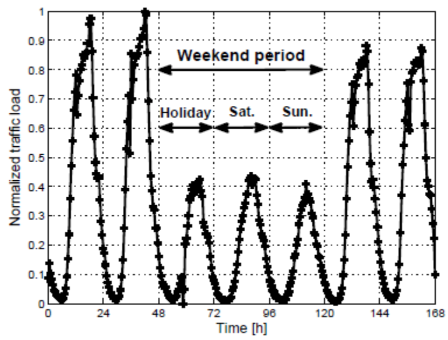

Fig 1: Normalized traffic load in a cellular access network

Hence many of the BSs remain underutilized especially at night and weekends. But even under these conditions the BSs consume most of their peak power. Dynamic switching on/off BSs can thus provide great energy savings. By switching off the BS during low traffic hours the energy consumption in cellular networks can be reduced.

A concept of Impact-evaluation factor is considered for each BS, which indicates how switching off the BS will affect the neighbouring BSs. Based on this factor we can determine which BSs should be turned off. The Impact-evaluation factor plays the crucial rule in determining which base station should be switched off by the base station using the switching on/off algorithm. This considers both uplink and downlink. The algorithm which provides the switching of BS is described in the proposed algorithm section.

II. PROPOSED ALGORITHM

A. System Model-

(1) Network Model: The number of BSs in a cellular network is denoted by B, located in an area A. The

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paper focuses on downlink communication as well as uplink communication.

(2) Traffic Model: The traffic arrival of a User Equipment (UE) located x at time t is modelled as Poisson distribution with the mean arrival rate λ(x, t). The traffic load [9] of the UE is,

$$\gamma(x,t) = \frac{\lambda(x,t)}{\mu(x,t)} \quad \text{[in bps]} \qquad (1)$$

(3) Channel Model: The number of channels is denoted by C and the channels are orthogonal. The channels are randomly allocated to each UE.

TABLE I: SUMMARY OF NOTATIONS

$A \in \Re^2$ $x \in A$ $b \in B$ $A_b \subset A$ N_b	Consideration region Location in continuous space BS index Coverage of BS *b* The set of neighbouring BSs of BS *b*
$\lambda(x,t)$ $\gamma(x,t)$ $s_b(x,t)$ $\rho_b(t)$ ρ^{th}	Traffic arrival rate of location *x* at time *t* Traffic load of location *x* at time *t* Service rate at location *x* from BS *b* at time *t* System load of BS *b* at time *t* System load threshold
E_{bs}	Operational expenditure of BS per unit time

(4) System Load: The system load of BS b at time t is defined as the fraction of resource to serve the total traffic load [9] in its coverage,

$$\rho b(t) = \int \frac{\gamma(x,t)}{sb(x,t)}\, dx \qquad (2)$$

The system load denotes the fraction of time required to serve the total traffic load in his coverage. All notations used is summarized in Table 1.

B. Problem Formulation-

The total energy expenditure in cellular networks during time T is minimized by using the switching algorithm [10].The minimization function is given as,

$$\min \sum_{b \in B} \int_0^T E_{bs} \cdot a(t)\, dt \qquad (3)$$

$$\text{s.t } 0 \le \rho_b(t) \le \rho^{th} \; \forall b,t \qquad (4)$$

where Ebs is the base station power consumption and a(t) is the activity function, a(t) ∈ {0,1} of a base station b at time t. The system load threshold is used to balance the trade-offs between system stability and energy efficiency.

C. BS Switching Algorithm

Each base station knows the number of neighbouring base stations $|Nb|$.The traffic profile is modelled as sinusoidal with period time D. Thus the switching procedure takes place once during D period time. Base stations consume most of the peak power even when unutilized. Switching off the BSs during this time can provide good energy savings.

The Impact-evaluation factor can be considered for switching off the base station. But switching off a BS will definitely increase the load on other BSs. The UEs associated with the switched-off BS should be transferred to the neighbouring BS and also lower service rates sb (x, t) will be expected due to greater distance between the UE and the BS. But turning off a BS may also produce a positive impact on the system load due to decreased inter-cell interference.

The number of neighbouring BSs of a base station b is denoted by Nb and n ∈ Nb is the neighbouring BS that provides the best signal strength to the UE at the location x ∈ Ab [9],

$$n = \arg\max_{i \in Nb} g(i,x).Pb \; for\, x \in Ab \qquad (5)$$

Base station n is the BS to which traffic loads will be transferred after switching off BS b.The base station will be switched off only if the below criterion [9] is satisfied,

$$\underbrace{\int_{An} \frac{\gamma(x)}{sn(x)}}_{\rho_{u+d}} + \underbrace{\int_{Ab \to n} \frac{\gamma(x)}{sn(x)}}_{\rho b \to n} \le \rho^{th} \qquad (6)$$

$A_{b\to n}$ is the coverage of UEs who will be handed over from BS b to neighbouring BS n when the BS b is switched off. The system load ρ_n is defined as the internal system load of BS n, and the system load increment by the neighbouring BS's switched off $\rho_{b\to n}$ is the external system load from BS b to BS n.

The load transfer to the neighbouring base stations is taken into account for calculating the Impact-evaluation factor which can be expressed as,

$$N_i = \max_{n_i \in Nb} (\rho_{u+d} + \rho_{b \to n}) \qquad (7)$$

After this value is computed, the BS with the lowest value of Impact-evaluation factor is switched off as shown below,

$$b = \arg\min_{b \in B^{on}} Ni \qquad (8)$$

This process goes on till there are no active base stations that satisfy the condition in (6). The system load is the metric used for the Impact-evaluation factor. There do exist some switching on/off algorithms [9], [10], [14] but here both uplink and downlink system load is considered for the Impact-evaluation factor calculation.

D. The BS Switching-Off Scheme

The signal strength and system load are periodically shared among BSs and UEs, and each BS determines whether it should be turned off or not [10].The switching-off algorithm has three parts:

1) Pre-action state: The UEs provide periodic feedback about the signal strengths and base station ID. When a BS b turns off the UEs are handed over to the second best BS. This information is used to calculate the additional load increments due to the turning off the base station.
2) Action state: every base station first calculates the Impact-evaluation factor from the information received from the UEs and neighbouring BSs. If the Impact-evaluation factor Ni < ρ_{th} then the BS sends request to switching-off (RTSO) to the neighbouring BSs. The Impact-evaluation factor considers both uplink as well as downlink. The BS switches off only after it receives the clear to switching-off (CTSO) signal from the neighbouring base stations.
3) Post- action state: The BS switches off only after receiving the CTSO signal from all the neighbouring BSs. The load of the BS is transferred to the neighbouring BS with the second best signal strength.

E. The BS Switching-On Scheme

The key concept of switching-on algorithm is that the BS should be turned on when the system load reaches the value when the BS was turned off. It can be viewed as the reverse of switching-off algorithm. Since the BS that is turned off has no knowledge about the current system load (both uplink and downlink), the neighbouring BS to which the load was transferred records the value. When the load values become equal the BS is requested to switch on. The algorithm has three steps:

1) Pre-action state: if a base station receives the confirmation to switching off (CLSO) from another BS then it records the system load from the base station b.
2) Action state: the neighbouring BS b' sends a request to switch on (RTSON) signal to the BS b when the current system load reaches the recorded value.
3) Post-action state: when the base station b receives the RTSON signal it turns on and depending upon the signal strength the UEs are given service by the BS.
The flow of the algorithm is shown below. It shows the working principle of both switching on and switching off algorithm taking into consideration both the uplink and downlink.

Algorithm 1:

1) Calculate traffic load, service rate and service load at each location.
2) Calculate the Impact-evaluation factor at
3) the BSs.
4) **If** Impact-evaluation factor <threshold value **then**
5) Send RTSO message to the neighbouring BSs
6) **If** receives CLSO **then** Send CTSO and hand over UE to neighbouring BS and shut down
7) **Else** continue operation
8) **Else** continue operation
9) **If** traffic load = switched off value **then**
10) Send RTSON and BS turns on and takes over the closest UEs
11) **Else** continue operation

III. RESULTS AND DISCUSSION

The simulation parameters are summarized in table II. When the traffic arrival rate increases, if the system load for any BS reaches ρ_{th}, then at this point the relative system load = 1. Considering the system reliability, the threshold value ρ_{th} for the proposed algorithm is set at 0.6.The BS switching strategy is evaluated using real traffic profile in Fig 1. The estimated sinusoidal traffic profile is shown in Fig 3 consistent with data in [10].

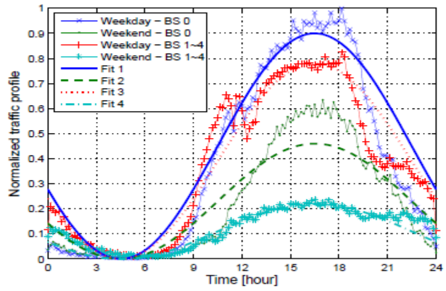

Fig 3: Normalized traffic profile of four different cases

The average peak blocking probability of the BS during weekday is illustrated in Fig 4 [10]. The average peak blocking probability is divided flat and increasing regions by the switching threshold.

TABLE II: SIMULATION PARAMETERS

Parameter	Value
BS transmission power	43*dBm*
Noise power	-176*dBm*/Hz
UE required data rate	256K*bps*
Transmission mode	M-QAM with BER=10^{-9}
Channel model	Path loss with exponent 4 log normal shadowing with 8*dB* std.

During the flat region, this value is obtained at the peak traffic time, and hence the region becomes the traffic dominant region. Fig 5 shows the simulation results of the energy savings that can be obtained by using the algorithm. By increasing the BS density the energy saving ratio can be improved. In the Fig 6 the number of times a BS is switched off is shown. The base stations are switched off according to the changes in the system load. When the system load becomes too much for the network to handle, the base station turns back on.

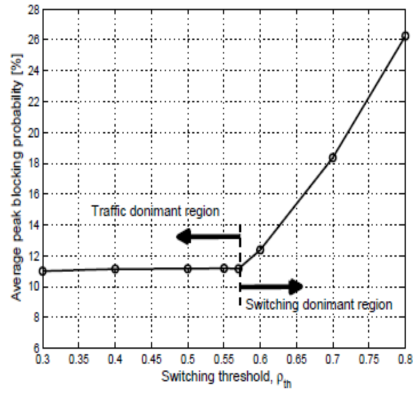

Fig. 4 Average peak blocking probability

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The turning off and turning on decision is based on both the uplink as well as the downlink. This provides good energy savings and also ensures the quality of service provided is not below par.

The UES which are serviced by the base station will be handed over to the neighbouring BS. This hand over will take place only if the load is less than the threshold value. This will ensure that the handover do not increase the traffic load of the network beyond a serviceable value.

Fig 5: Energy savings of the algorithm

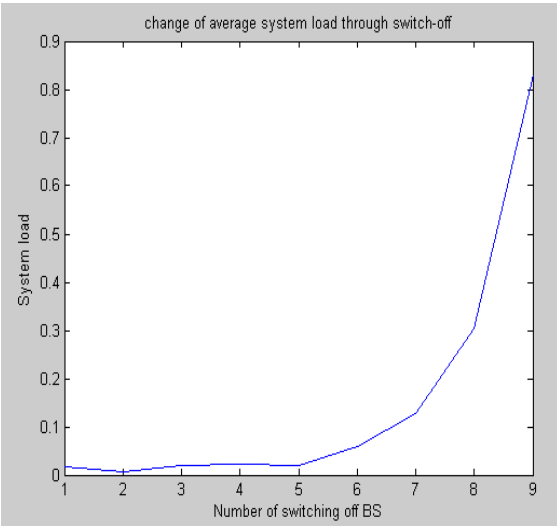

Fig 6: Number of switching off BS

IV. CONCLUSION

The focus of this paper is on the problem of BS switching for energy saving in green cellular networks. Taking into account the Impact-evaluation factor the BSs which are underutilized can be switched off. The Impact-evaluation factor takes into account both uplink and downlink. The algorithm is online distributed algorithm without the use of any centralized controller. Since BSs accounts for major part of the total energy consumption significant energy savings can be attained using the algorithm. The UEs serviced by the BS are handed over to the neighbouring BS only if the threshold condition is satisfied. When the BS turns back on then the UEs in its range will be taken over by it. Since feedback between the BSs in the form of RTSO, CTSO and CLSO are considered the switching off of the BS does not unduly increase the load of the network. This algorithm can bring good energy savings in a cellular network.

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