A Pricing Based Algorithm for Cell Switching Off in Green Cellular Networks

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***Abstract*—In this study, we propose a pricing based algorithm that assigns user terminals (UTs) to base stations (BSs) and optimizes the transmission powers in a way that minimizes the energy expenditure. The algorithm takes into account the fixed energy expenditure that occurs even if a BS does not transmit to any UT, therefore the proposed algorithm switches off the unnecessary BSs in order to minimize the total energy expenditure. We compare this algorithm with two benchmarks. One of them is a simple algorithm that connects each UT to the BS with best channel conditions. Transmission powers are then optimized iteratively. The second benchmark is the optimal solution that is found using a branch and bound technique. The numerical evaluations reveal that the pricing based algorithm performs very close to the optimal.**

I. INTRODUCTION

With the growing energy demand in cellular communication, energy saving techniques became more important. In [1] the authors show that base stations' (BSs) power consumption is approximately 57 percent of total cellular network energy consumption. Because of this, most of the efforts in energy-saving algorithms are focused on decreasing the energy consumption of BSs. In [2] authors mention about renewable energy resources, improvements in power amplifiers and energy-aware cooperative BS power management including BS switch-off scheme as prominent techniques for the reduction of BSs' energy consumption. Transmission power is not the only source of energy expenditure. Even if the BS is not transmitting, there is a fixed and significant amount of energy expenditure caused by the integrated circuits, signal processing and cooling equipment. An effective energy management requires entirely shutting down some of the BSs depending on the user terminal (UT) locations and system load [3].

BS switching (cell-switching) is one of the key features of the SON (Self-Optimizing Networks) in LTE (Long Term Evolution). In [4] BS switching algorithms under the section of energy savings are divided into three parts:

1) Fully centralized and switching done by central controller.
2) Partially centralized (or partially autonomous) depending on pre-specified circumstances.
3) Fully autonomous by gathering information from BSs via some interfaces.

There is a growing body of literature on energy efficient cell switch-off. For example in [5], [6], [7] the BSs are switched on and off at preset time periods based on the daily traffic pattern. They show that the number of switch-offs (single, double, triple etc.) in weekdays can change the level of energy consumption. However, the authors do not take into account interference. The study in [8] assumes that the interference is taken care of by some reuse techniques. The proposed algorithm allocates UTs to BSs according to rate and bandwidth requirements. The authors also define protection margin that saves some unallocated bandwidth for the UTs that may want to connect between the update periods. In addition, more BSs tend to sleep, which condenses traffic to BSs switching on, and hence their proposed algorithm makes providing the QoS difficult. The paper [9] assumes sinusoidal traffic profile throughout a weekday and analyzes the performance of a simple switch-off policy. The authors of [10] also study the energy efficient UT association problem, however they assume that a BS consumes transmission power proportional to the number of connected UTs, which is not realistic. In reality distant UTs require much more power, moreover transmission power varies exponentially with number of connected UTs, because of time and/or frequency sharing. Finally in [11] the authors combine cell switch-off with coordinated multipoint transmission (CoMP), which decreases the energy expenditure. However, instead of presenting an explicit switch-off algorithm, this paper applies CoMP on a BS set, after the switch-off procedure.

The problem that we address is basically a joint UT-association and power control problem. This problem was previously studied in the literature, like [12]. However in those works the objective of the problem is balancing the system load and maintaining QoS. Our objective, on the other hand, is minimizing the energy consumption possibly by switching off some of the BSs.

Pricing based algorithms have been studied extensively in the literature of power control, but as mentioned, like in [13], the aim of most of those algorithms is to decrease the transmit power. The main difference between power control and cell switch-off techniques is that power control algorithms focus on transmit power between BSs and UTs while cell switch-off techniques also take into account the fixed power expenditure. Besides pricing based algorithms, there are some other algorithms to provide energy savings in cellular networks. For example, the study in [14] shows that a genetic algorithm can be used for decreasing energy expenditure in dense cell deployment. In [15] each UT has SIR requirement and authors focus on maximizing the net utility function of UTs just based on SIR. On the other hand, in our system model each UT has a rate requirement and the net utility is the number of connected UTs minus the power expenditure.

The goal of this paper is to minimize the total power expenditure on the network via pricing based algorithm we propose. The contributions of this algorithm are given as follows:

- Performance, which is optimal or very close to optimal.
- Being a very fast algorithm compared to Branch and Bound-based optimal method.
- Being amenable to distributed implementation.

II. SYSTEM MODEL

In this paper, we consider downlink transmission in a cellular wireless system. M BSs and N UTs are located in the service area. We assume that the channel between BSs and UTs only consists of distance-based path loss and shadowing. In other words, the BS assignment is made by taking into account the slow-varying channel conditions. Each UT has a rate requirement R_0 bps and the system bandwidth W Hz is reused by each BS. If multiple UTs are attached to the same BS, they access the BS using time-sharing. As the number of UTs connected to a BS (N_m) increases the required power also increases. For convenience, we show the notations to formulate the problems in Table I.

TABLE I: List of Notations

M	number of BSs
$\mathcal{M}$	set of BSs
N	number of UTs
$\mathcal{N}$	set of UTs
R_0	rate requirement for all UTs
W	bandwidth
N_m	number of UTs connecting to BS m
$\mathcal{N}_m$	set of UTs connecting to BS m
P_{mn}	power from BS m to UT n
P_m	average power of BS m
P_0	baseline power expenditure
h_{mn}	channel gain between BS m and UT n
N_0	noise level
$I_n(\overline{P})$	interference experienced by UT n
NU_m	net utility function for BS m
Γ_{mn}	$\frac{h_{mn}}{I_n+N_oW}$
$S_m^{N_m}$	set of best N_m idle UTs according to Γ_{mi}
α	price

Let the assignment of UTs to BSs result in N_m UTs connected to BS m. Once the BS assignments are made, the optimal powers can be calculated iteratively [16]. Interference $I_n(\overline{P})$ that each UT n experiences is calculated as

$$I_n(\overline{P}) = \sum_{m=1}^{M} P_m h_{mn}, \quad \forall n \in \mathcal{N}, \tag{1}$$

where $\overline{P} = \{P_1, P_2, ..., P_M\}$ Transmission powers from BS m to the connected UTs can be found using the following:

$$\frac{W}{N_m} \log_2 \left(1 + \frac{P_{mn} h_{mn}}{W N_0 + I_n(\overline{P})}\right) = R_0, \quad \forall n \in \mathcal{N}_m. \tag{2}$$

Transmission power from BS m to UT n can be found as

$$P_{mn} = (2^{N_m \frac{R_o}{W}} - 1) \frac{W N_0 + I_n(\overline{P})}{h_{mn}}, \quad \forall m \in \mathcal{M}, n \in \mathcal{N}_m. \tag{3}$$

As stated above UTs connected to a BS use time-sharing. Average transmission power of BS m can be found as

$$P_m = \left\{ \begin{array}{cc} 0 & N_m = 0 \\ \frac{1}{N_m} \sum_{n \in \mathcal{N}_m} P_{nm} & N_m > 0 \end{array} \right. , \quad \forall m \in \mathcal{M}. \tag{4}$$

Total power expenditure becomes

$$P_T = \sum_{m \in \mathcal{M}} P_m + I_{P_m > 0} P_0, \tag{5}$$

where P_0 is the baseline fixed power expenditure, which has to be used if at least one one UT is connected to the BS. $I_{P_m > 0}$ is the indicator function denoting that BS m is transmitting.

III. PRICING BASED CELL SWITCH-OFF

In this algorithm, we benefit from a *net utility* concept, where the net utility of a BS is defined as the number of supported UTs (i.e., utility) minus the power expenditure by the BS (i.e., cost). The utility and the cost (hence the net utility) become zero, if the BS does not support any UT (i.e., is switched off). The net utility function can be found as

$$\begin{aligned} & NU_m(N_m) \\ & = N_m - \alpha \times \left(\frac{1}{N_m} \sum_{n \in \mathcal{S}_m^{N_m}} \frac{2^{N_m \frac{R_0}{W}} - 1}{\Gamma_{mn}} + I_{N_m > 0} P_0 \right), \\ & \qquad \forall m \in \mathcal{M}. \end{aligned} \tag{6}$$

In this expression, the set $\mathcal{S}_m^{N_m}$ is the N_m UTs (among the unconnected ones) with the highest value of Γ_{mn}. Γ_{mn} is the channel gain between BS m and UT n divided by the interference plus noise of UT n. The parameter α is the power price. As α decreases, the BSs tend to connect to more users.

In the pricing algorithm in Algorithm 1, initially the price α is set to a high value. In the inner iteration (Lines 4-19) each BS looks at the UTs that are not connected to other BSs yet. The optimal set of UTs to connect (the ones with best channel gain to interference ratio) is found according to the net utility function (6). If net utility is positive, then the BS m^* with maximum net utility connects to those UTs (Line 9). At this point the BSs have to communicate their net utility values with each other. Transmission power and interference values are updated by all BSs (Line 10). The

Algorithm 1 : The proposed pricing based algorithm

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1:  Initialize price $\alpha = \alpha_0$, and $I_n = 0$, $P_m = 0$, $P_{n,m} = 0$, $\mathcal{N}_m = \emptyset$, $\forall n \in \mathcal{N}, m \in \mathcal{M}$.
2:  Set $\mathcal{S} = \mathcal{M}$, converge = false
3:  while $\bigcup_{m=1}^{M} \mathcal{N}_m \neq \mathcal{N}$ do
4:      while converge = false do
5:          Set $P'_m = P_m, \forall m \in \mathcal{M}$
6:          for $m \in \mathcal{S}$ do
7:              Among the UTs in $\mathcal{N} - \cup_{m' \neq m} \mathcal{N}_m$, find the optimal set of UTs $\mathcal{N}_m^* = \arg\max\{NU_m(\mathcal{N}_m)\}$ using (6). Note that $N_m \leq N - \sum_{m' \neq m} N_{m'}$
8:          end for
9:          Find $m^* = \arg\max_{m \in \mathcal{S}}\{NU_m^*(\mathcal{N}_m^*)\}$, and Set $\mathcal{N}_m = \mathcal{N}_{m^*}^*$
10:         Iteratively update $P_{mn}$, $P_m$ and $I_n(\overline{P})$, $\forall m \in \mathcal{M}$, $n \in \mathcal{N}$ using (1), (3), (4)
11:         if $\sum_{m \in \mathcal{M}} |1 - P_m/P'_m| < \epsilon$ then
12:             converge = true
13:         else
14:             $\mathcal{S} = \mathcal{S} - m^*$
15:             if $\mathcal{S} = \emptyset$ then
16:                 $\mathcal{S} = \mathcal{M}$
17:             end if
18:         end if
19:     end while
20:     $\alpha = \beta \times \alpha$, where $\beta < 1$
21: end while
```

UTs communicate their interference values and connection status with the BSs. BS m^* is excluded from the set $\mathcal{S}$ and the remaining BSs try to include UTs until the power values converge. The outer iteration checks, if there are still any unconnected UTs. If there are, then the price value is decreased by multiplying with $\beta < 1$ (Line 20). The algorithm terminates when all the UTs are connected to a BS. If the total cellular area is small, then one BS (with the best connection) usually connects all UTs in the first iteration (which will be observed in the numerical results). The proposed algorithm can be implemented distributively. The algorithm is also able to work when a new UT joins the network.

IV. BENCHMARK ALGORITHMS

A. Nearest Base Station Assignment

In nearest BS assignment each UT n is assigned to the BS m^* maximizing h_{mn}. Then the transmission powers are optimized iteratively using (2), (3), (4) and (1). The algorithm can be summarized in Pseudocode 2. This algorithm can be implemented in a distributed manner. Once the BSs send pilot signals, each UT can connect to the one with the highest received power. Each BS then computes the required transmit powers based on the channel conditions of the connected UTs. UTs then send their interferences values, and power computation goes on in a distributed manner until convergence.

Algorithm 2 : Nearest base station algorithm

```
Initialize $I_n = 0, \forall n$, $P_{n,m} = 0, \forall n, m$
for each UT n do
    Find the BS $m^* = \arg\max_{\mathcal{M}}\{h_{mn}\}$ and $\mathcal{N}_{m^*} = \mathcal{N}_{m^*} \cup \{n\}$
end for
while not converge do
    Calculate $P_{mn}$ for all $m \in \mathcal{M}$, $n \in \mathcal{N}_m$ using (3)
    For all $m \in \mathcal{M}$, calculate $P_m$ using (4)
    Calculate the new interference values $I_n(\overline{P})$, $\forall n \in \mathcal{N}$ using (1)
end while
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B. Optimal Solution Based on Branch and Bound

Branch and bound technique [17] is used to find the optimal UT association and transmission power. This is an exhaustive search technique, where each possible UT association is formed as branches of a tree and some sub-trees can be totally eliminated from search, if they are guaranteed to be suboptimal. The root of the tree is the case that UTs are not associated with any BS, and its branched into M branches, which correspond to UT 1 associated with BS $1, 2, ..., M$, respectively. Each of these branches are further branched into M branches which correspond to BS association of UT 2. A node on this tree, with depth D defines the BS association of the first D UTs, and the rest of the associations are defined in its subtrees. The upper and lower bound for the energy expenditure of each node on the tree are defined as follows:

1) Upper Bound: The nodes $D+1, D+2, ..., N$ are associated to their respective nearest BSs. Then the iterative power optimization is performed by applying (1) to (4). Total power expenditure is calculated by (5).
2) Lower Bound: First the iterative power optimization is performed over the nodes 1 to D, and the total power expenditure is calculated by (5). Then, each of the nodes $D+1, D+2, ..., N$ are connected the nearest BSs, but their corresponding transmission powers are calculated as if they to do not experience any interference, and as if they use all the available bandwidth W.

At each step the branch with the lowest lower bound is found and further branched (forming new nodes). If the lower bound of any branch is greater than the upper bound of any other branch, then the former branch is pruned. This eliminates the sub-branches of that branch improving the efficiency of the exhaustive search.

V. NUMERICAL RESULTS

In Table II simulation parameters are given. For simulation parameters, we benefit from ITU-R M.2135 report [18]. The BSs are uniformly spaced and the UTs are placed randomly according to uniform distribution inside the square cellular layout. Figure 1, Figure 2, Figure 3 represent BSs and UTs deployment scenario 10 and UTs associations for nearest base station algorithm, pricing based algorithm, and optimal solution, respectively.

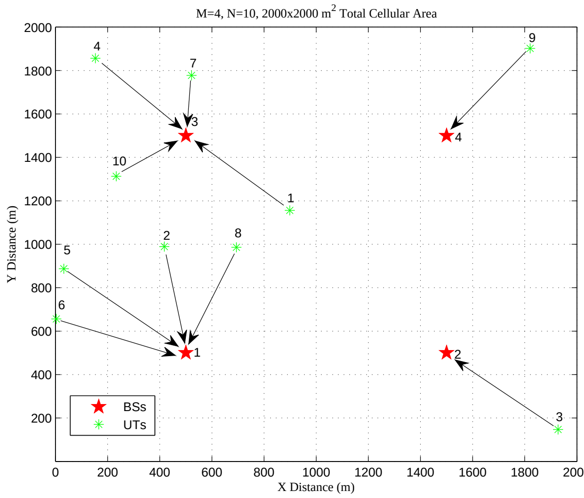

Fig. 1: BSs and UTs deployment scenario 10 and UTs associations for nearest base station algorithm: M=4 BSs, N=10 UTs, 2000×2000 m^2 area.

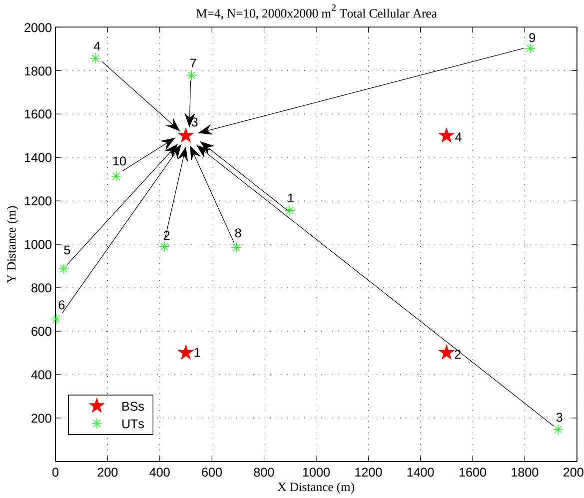

Fig. 2: BSs and UTs deployment scenario 10 and UTs associations for pricing based algorithm: M=4 BSs, N=10 UTs, 2000×2000 m^2 area.

All UTs have 500 kbps rate requirement and each BS has 5 MHz bandwidth. In the pricing based algorithm, the initial price is N/P_0, and $\beta = 0.95$. Among the deployment scenarios, we chose the Urban-Macro (UMa) cell scenario and the path-loss depends on several parameters , which are listed in Table II. When the values in Table II are used, the path loss model boils down to,

$$PL\ [\text{dB}] = 8.19 + 39.08\log_{10}(d). \tag{7}$$

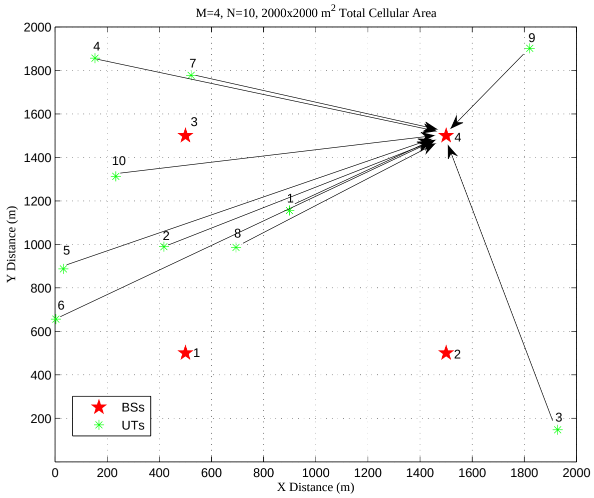

Fig. 3: BSs and UTs deployment scenario 10 and UTs associations for optimal solution: M=4 BSs, N=10 UTs, 2000×2000 m^2 area.

TABLE II: Simulation Parameters

Parameter	Value
Cellular Layout	Square
Number of UTs	10, 20
Number of BSs	4, 9
Thermal Noise Level	-174 dBm/Hz
Log-normal Shadowing	6 dB
Street Width (S)	20 m
Average Building Height (h)	15 m
BS Height (h_{BS})	25 m
Carrier Frequency (f_c)	2.5 GHz
UT Height (h_{UT})	1.5 m
Fixed Power Expenditure (P_0)	50 W
Rate Requirement (R_0)	500 kbps

We compare the performances of three solutions, which are the pricing based algorithm (Algorithm 1), nearest BS allocation (Algorithm 2), and the optimal solution (Algorithm 3). Figure 4 shows the power expenditure performance for M=4 BSs, N=10 UTs, 2000×2000 m^2 total cellular area, and for 20 randomly generated scenarios. These randomly generated scenarios are created by generating the user locations and channel gains. The BSs are fixed and equally spaced in the cellular area. As seen from the results, pricing based algorithm results in almost three times less power expenditure than the nearest BS algorithm.The nearest BS algorithm spends very low transmit power, but of them uses all the four BSs, resulting in a high fixed power expenditure (200 W). We see in almost all scenarios that the pricing based algorithm results in optimal power expenditure, and uses only one BS.

Figure 5 shows the power expenditure performance for M=4 BSs, N=20 UTs, 2000×2000 m^2 total cellular area, and for 20 randomly generated scenarios. This is a denser network, and

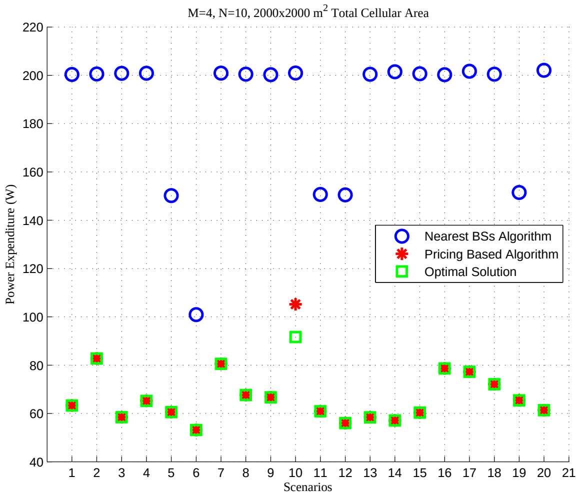

Fig. 4: Power expenditure for 20 random scenarios: M=4 BSs, N=10 UTs, 2000×2000 m^2 area.

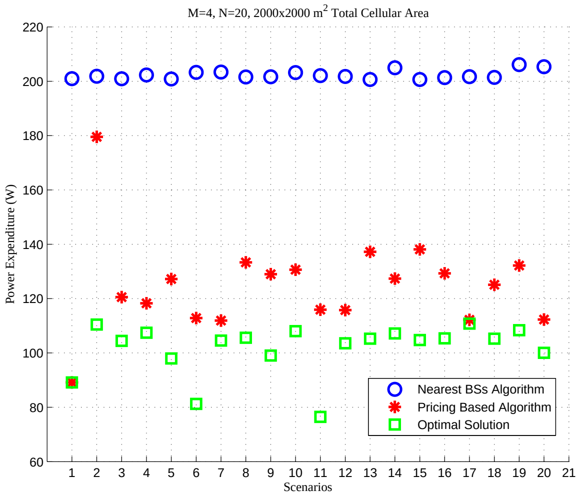

Fig. 5: Power expenditure for 20 random scenarios: M=4 BSs, N=20 UTs, 2000×2000 m^2 area.

the nearest BS algorithm uses all of the BSs in all scenarios. As seen from the results, pricing based algorithm usually uses two BSs and spends almost as half power as the nearest BS algorithm. In some scenarios the pricing based algorithm is very close to the optimal. On the average, the pricing based algorithm results in 15% more power expenditure than the optimal solution.

Figure 6 shows the power expenditure performance for M=4 BSs, N=20 UTs, 8000×8000 m^2 total cellular area, and for 20 randomly generated scenarios. In these scenarios, the transmit power dominates the total power expenditure, and more of the BSs are used. The pricing based algorithm finds the optimal solution in five scenarios. In addition, in many scenarios (6, 7, 8, 9, 10, 12, 14, 20) the proposed algorithm provides significant improvement with respect to the nearest BS algorithm. On average, the pricing based algorithm is within 5-6% of the optimal solution.

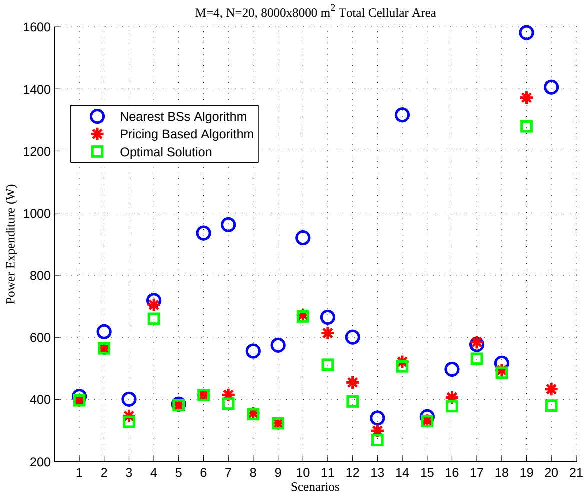

Fig. 6: Power expenditure for 20 random scenarios: M=4 BSs, N=20 UTs, 8000×8000 m^2 area.

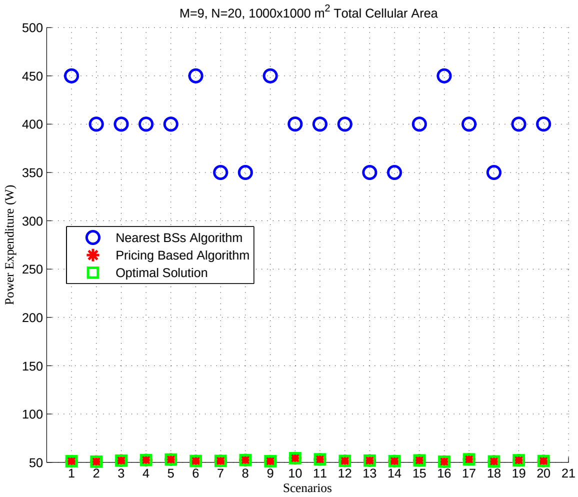

Fig. 7: Power expenditure for 20 random scenarios: M=9 BSs, N=20 UTs, 1000×1000 m^2 area.

Figure 7 reflects a very dense scenario with M=9 BSs, N=20 UTs and 1000×1000 m^2 total cellular area. The results clearly show that the proposed algorithm uses one BS and finds the exact optimal allocation in all of the scenarios. Since there are many close BSs, the nearest BS algorithm uses most of them and results in poor performance.

Figure 8 is generated for the scenarios of 9 BSs, 20 UTs and 4000×4000 m^2 total cellular area. The results are similar with the ones in Figure 5, where the pricing based algorithm

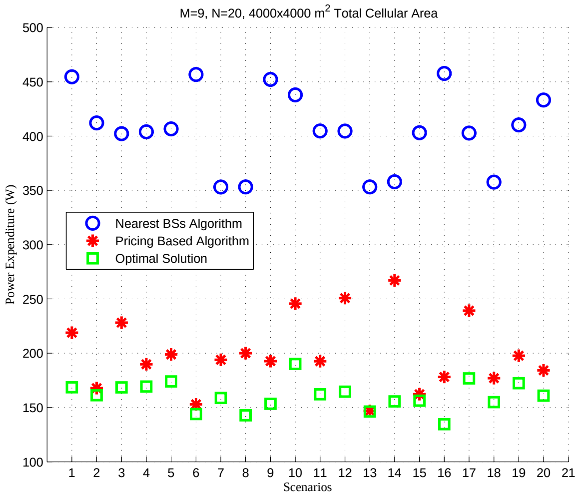

Fig. 8: Power expenditure for 20 random scenarios: M=9 BSs, N=20 UTs, 4000$\times$4000 m^2 area.

is within 23% of the optimal solution on average.

VI. CONCLUSIONS AND FUTURE WORK

In this work we studied an energy efficient BS assignment scheme for cellular networks. We considered schemes that switch off some of the BSs in order to avoid the fixed energy expenditure and decrease the overall energy expenditure. We proposed a pricing based iterative algorithm, where a power price is decreased until all of the UTs connect to a BS. The algorithm is amenable to distributed implementation. The simulation results reveal that especially for dense networks the proposed algorithm finds the optimal allocation. For the opposite case (larger networks) our algorithm is within 5% of the optimal. For the scenarios in between, our algorithm is within 20-25% of the optimal. In all of the scenarios, the proposed algorithm provides significant energy savings when compared with a nearest-BS algorithm.

A possible direction for future work is considering a dynamic scenario, where users randomly join and leave the network. In this case, the optimal cell switch off and power control can be modeled as a complex Markov Decision Process. In order to simplify this process, a simpler cellular model and interference model can be used. In fact our proposed algorithm can still be used, whenever a user joins or leaves the network. However our algorithm is *myopic*, as it only considers the current network condition rather than the future. In reality, reserving some resource for future user arrivals improve the energy performance. Another issue that has to be considered is investigating the effects of our algorithm on the *user* energy expenditures, in addition to *BS* energy expenditures.

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