Reduction of Transmit Energy using Intelligent ON/OFF Algorithms in a Femto Cell based Green Network

Green Networks Final Project Report

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Abstract - The project deals with reducing the amount of energy consumed by a delay tolerant femto cell based mobile network. With the increase in number of smartphones, mobile carriers are moving towards deploying micro and femto cells so as to address the growing need of data bandwidth. In the present scenario, these femto cells are being deployed in a random manner. In our project we have designed a network which takes into account the density of users in a cell in order to deploy femto cell base stations. Three algorithms: a random based, a traffic based and a base station distance based algorithm have been proposed so as to turn OFF base stations intelligently. From our findings we were able to obtain a reduction in transmit energy up to a value of 40% using the traffic based algorithm and 35% using distance based algorithm as compared to the random based algorithm. We show in the simulation that transmit power is decreased if mobile users can tolerate delay before transmission occurs. These concepts when used together help in realizing a ‘green’ network.

Keywords: Femto cells, Base Stations, Mobile Users, OFF algorithms, green network

I. INTRODUCTION

The rise in the number of smartphones being used has accrued a meteoric increase in the data bandwidth demands in a mobile network [1]. The transition from 3G to 4G LTE and a rising trend among users to use data hungry applications will bring about a further rise in the data need. The current cellular model does not provide an efficient way to handle this rising demand. For this reason mobile service providers are moving towards the deployment of micro and femto cells. According to ABI research, by the end of 2012, around 36 million femto cells are expected to be sold [2]. In foresight, a major hindrance which could occur is the random fashion in which these cells are deployed. Also, the data usage and user density varies spatially and temporally, which needs to be taken into account while deploying base stations.

The amount of energy used by a network has also been a major concern over the past few years. There have been numerous works aimed at reducing the network energy usage [3]. While some suggested a total revamp in the design of communication equipment deployed at the BS, others focus on more energy efficient communication schemes. A rising trend in this regard is the concept of Base Station turn ON and OFF [4-6]. It has been seen that turning Base Station On and OFF based on some deterministic schemes can save energy up to the order of 73% [7] in some cases. Such delay tolerant networks benefit from the fact that data transmission does not need to occur instantaneously and thus can tolerate some delay. We have proposed and explored that as the amount of time a user is willing to wait increases, the amount of transmission energy used by user reduces. This occurs because with BS turning ON and OFF, the longer a mobile user waits the more likely it is to find a Base Station at a closer distance. As transmission energy is a function of distance, this reduces the amount of energy used in transmission.

In our paper, we first define key system parameters in section II. In section III, we propose two different network models where bases stations are either placed randomly or placed based on user density. Then, in section IV we explain how we generate ON/OFF events. In section V, three deterministic algorithms in order to turn Base Station OFF are proposed. The first does this randomly and provides us a baseline to compare our improvements with. The second takes into account the user call rate to determine which Base Station to switch OFF. While the third takes into account the distance between the Base Stations in order to decide which one is to turn OFF. The findings from these experiments are then quantified in terms of the average transmit distance and energy for each transmit threshold and the distribution of energy and transmit...
distances among all users in the network is discussed in section VI.

II. KEY SYSTEM PARAMETERS and ASSUMPTIONS

We assume that base station (BS) station is switched off when it is not in operation and state is called OFF state. BS is switched on when it is in operation and it is called ON state. We assume that only data communication is occurring between mobile user (MU) and BS. Voice traffic is not being handled in the simulation. Meanwhile, MUs have the same traffic distribution so that at a given time it’s equally likely for each mobile to transmit. When a MU transmits, it has only a single packet instead of a stream of packets. Thus, as soon as MU finds an active BS according to its connecting scheme, data transmission occurs. We have defined several parameters which are going to be used throughout the simulation.

Maximum Time Delay ($T_{\text{max}}$): The maximum time delay MU is willing to wait and can tolerate before transmission occurs. Otherwise a mobile user transmits to any closest base station.

Threshold distance ($R_{\text{TH}}$): The maximum transmit distance MU is willing to transmit without any time delay. Therefore, if mobile finds an ON base station within threshold distance, it will transmit immediately.

Average Time Delay ($T_{\text{avg}}$): The average time delay MUs experienced. This will be used as a performance metric to compare different algorithms.

Average Transmit Distance ($R_{\text{avg}}$): The average transmit distance mobile users transmits in simulation time. Mobile users search within the threshold distance for a closer base station that is ON during the maximum time delay ($T_{\text{max}}$).

Average Transmission energy ($R^2$): The average transmit energy consumed by the user to transmit distance $R$ is proportional to $R^\alpha$, where $\alpha$ is path loss component. Average transmission energy is key metric to compare the efficiency of the algorithms.

Active and sleep rate ($\lambda_\text{a}, \lambda_\text{s}$): These are the exponential rates at which BS stays ON, and OFF state on the random case, meaning ON/OFF scheme does not depend on any deterministic rule.

III. NETWORK MODEL

A typical cellular network model consists of base stations and mobile users. This section presents two different network models used for evaluating the potential of the proposed approach. To make the network more realistic we assume that there is a minimal distance between any two BS. To realize this, we use a grid structure, and in each element of a grid we place a BS or not. Placing a BS in a grid can be done in random and intelligent fashion.

Random Network Model:
In the random network model, MUs and BSs are randomly placed on the grid. Figure 1 shows some grid elements that have high number of users do not have any base stations nearby. On the other hand, other grid elements which have less number of users are closer to base stations than high density grid element. Base stations are placed randomly on the grid.

![Random Network Model: Base stations are placed randomly](image)

Intelligent Network Model:
In the intelligent network model, initially MUs users are randomly placed on the grid. Then, BSs are placed on the grids which have the highest number of MUs i.e. This network structure is more realistic since cellular companies prefer to deploy BS to densely populated regions. Base stations are placed based on user density as shown in Figure 2.
IV. ON/OFF EVENT GENERATION

The goal of the simulation is to compare random ON/OFF schemes with the intelligent ON/OFF scheme. In order to realize such simulation environment, where both random and intelligent schemes can be implemented, we generated a chain of random ON and OFF events is generated. Simulation start with a fixed number of base stations that are in ON state \( N_{\text{ON}} \) and OFF state \( N_{\text{OFF}} \) based on sleep and active rates \( \lambda_{a}, \lambda_{s} \). Then, according the number of base stations in the ON and OFF state, two random variables, \( X_{\text{on}} \) and \( X_{\text{off}} \), are generated based on exponential distribution with \( \lambda_{a} \) and \( \lambda_{s} \) as given by the equation.

\[
\lambda_{\text{OFF}} = \lambda_{a} N_{\text{ON}} \quad (1) \\
\lambda_{\text{ON}} = \lambda_{s} N_{\text{OFF}} \quad (2) \\
X_{\text{off}} = -\frac{1}{\lambda_{\text{OFF}}} \log(1 - U) \quad (3)
\]

In (3) we calculate random number exponential with \( \lambda_{\text{OFF}} \), where \( U \) is a random variable uniform with \((0,1)\). We use similar way to calculate other exponential random variables namely \( X_{\text{on}} \). Decision of ON or OFF event is made based on which event

On comparing the values of \( X_{\text{on}} \) and \( X_{\text{off}} \) the next state is decided.

\[
\text{Event} = \begin{cases} 
\text{ON} & X_{\text{on}} < X_{\text{off}} \\
\text{OFF} & o / w
\end{cases}
\]

The time between two consecutive event is a function of the number of base stations in ON and OFF state, as well as their active and sleep rate and it’s exponential with \( \lambda_{a} N_{\text{ON}} + \lambda_{s} N_{\text{OFF}} \).

Upon OFF event, we select a base station to turn OFF based upon the algorithm that is used. Upon ON event, the base station to turn ON is selected randomly from the base stations that are in the OFF state.

V. ALGORITHMS

Baseline Algorithm:

We propose a very simple random algorithm to turn off base stations and call it the baseline algorithm. As per this algorithm, base stations have fixed exponential sleep and active rates, \( \lambda_{a} \) and \( \lambda_{s} \) respectively. The ON/OFF events occur at the time intervals as explained in the ON/OFF section. At any event (either ON/OFF), a base station is picked randomly and turned ON/OFF. After turning a base station ON/OFF, all mobile users are re-associated with the closest possible base station.

We apply the baseline algorithm to both the topologies. The results show that the topology where base stations are placed in an intelligent manner has smaller average transmit distance and smaller average wait times of the mobile users (Figure 5, 6). Hence, we select topology with base stations placed in an intelligent manner and apply 2 more intelligent algorithms on it. We then compare the 2 other intelligent algorithms we propose with the baseline algorithm.

Traffic Based Algorithm:

We apply traffic based algorithm to the topology with base stations placed in an intelligent manner. This is a deterministic algorithm. In this algorithm, upon an OFF event, we choose to switch off the base station with the least traffic to turn off. Hence, the base station which has minimum number of users is turned off. In figure 3, we turn off base station D since it has least number of users. When an ON event occurs, one of the base stations from ones in the OFF state is randomly selected and turned ON. After turning a base station ON/OFF, all mobile users are re-associated with the closest possible base station.

Fig. 3 How a BS is turned off in traffic based algorithm
**Distance Based Algorithm:**
We apply traffic based algorithm to the topology with base stations placed in an intelligent manner. This is also a deterministic algorithm like traffic based algorithm. In this algorithm, on an OFF event, the base station that has to be switched off is chosen based upon the distance between the base stations. First, out of all the base stations that are ON, a pair of base stations is found that has the minimum distance between them. Then, one of the base station among the two in the pair is switched off. To decide which base station to be switched off among the two, the distance from each base station to its respective second closest base station is measured. Then, the base station that is having a nearer second ON base station is switched off. In figure 4, A and B are base stations with least distance. Since, x < y, switch off BS A. When an ON event occurs, one of the base station from the ones in the OFF state is randomly selected and turned ON. After turning a base station ON/OFF, all mobile users are re-associated with the closest possible base station.

![Fig. 4 How a BS is turned off in distance based algorithm](image)

**VI. SIMULATION RESULTS**

In the simulation we used grid is 100x100 grid. Each grid element is 5x5 square i.e., thus, 400 grid elements in total. Total number of mobile users 2500 and the total number of base stations is 50. Simulation is run for 800 units of time. $\lambda_0, \lambda_i$ are chosen 0.3. Maximum tolerable delay changes between 1, and 3. Path loss component $\alpha$ is chosen 3.2.

We applied the baseline algorithm for both of our network topology models, random and intelligent. We calculated the average transmit distance and average wait time of users as a function of threshold distance.

![Fig. 5 Comparison of average transmit distance in intelligent network topology model and in random network topology model when baseline algorithm is applied](image)

Figure 5, the horizontal line is the threshold distance of MUs, and vertical line is corresponding average transmit distance. As expected, average transmit distance in random network topology is higher than that of intelligent network topology. Meanwhile, in both topologies, there exists an optimal threshold distance for which average transmit distance is minimized.

![Fig. 6. Comparison of average wait time in intelligent network topology model and in random network topology model when baseline algorithm is applied](image)

In Figure 6 we see the average delays experienced before transmission occurs in random and intelligent topologies. It’s clear that there is not a significant delay difference between random and intelligent topologies.

We applied the three algorithms discussed in section V to the intelligent network topology model. We calculated the average transmit distance and average wait time of users as a function of threshold distance.
Figure 7 compares average transmit distances of the three algorithms. It shows that traffic based algorithm performs better than the baseline and distance based algorithms. The reason is although distance based algorithm unifies the average transmit distances between base stations, thus, reducing average transmit distance to some extent, it doesn’t necessarily take into account of number of mobiles. For all algorithms there exists an optimal threshold distance at which transmit distance is minimum.

Figure 8 shows how transmit energy varies with respect to threshold distance. Similar to the results for average transmit distance, average transmit energy is minimum for traffic based algorithm. Also, there exists optimal transmit distance for all algorithms.

Figure 9 shows the CDF (cumulative distribution function) of transmit distances of users for different maximum tolerable delays. As expected average transmit distance decreases as tolerable delay increases.

Figure 10 shows the CDF (cumulative distribution function) transmit distance of users for different threshold values. We see that traffic based algorithm outperforms distance based algorithm in the sense that fraction of mobiles transmitting with less distances. Meanwhile, we observe that fraction of transmit distances less than 5 units in distance based algorithm is less than that of traffic based algorithm.
VII. CONCLUSION

Two network topology models and three sleep scheduling algorithms, one random and two deterministic, were developed and explored. The amount of energy saved by using deterministic turn on/off base stations saves more energy when compared to the random (baseline) on/off. Algorithm based on traffic minimizes transmission energy consumed by mobile users (MU) than algorithm based on distance. All algorithms show that there exist an optimal threshold distance for mobiles that minimize transmission energy for given sleep/awake schedule of base stations.

REFERENCES


