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Power Optimization in Two-tier Networks

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Abstract— A future cellular network demands a new architecture that can facilitate the autonomous deployment of the infrastructure similar to Wi-Fi. A novel method of deploying a cellular network has been introduced with small cellular base stations, or femtocells, autonomously deployed by users in an underlay macro-cellular network. This autonomous cellular concept allows the network to grow in an organic manner, which reduces the traditional work on infrastructure installation, network configuration and maintenance. To this end, we propose hereafter an intelligent and automatic system for power control in the femtocell context.

The first simulation results seem to confirm the advantage of our solution in reducing energy consumption.

Keywords: *Macro, microcell, LTE, mobility management.*

1. INTRODUCTION

Femtocell networks are unique in that they are largely installed by customers or private enterprises often in an ad hoc manner without traditional RF planning, site selection, deployment and maintenance by the operator. Moreover, as the number of femtocells is expected to be orders of magnitude greater than macrocells, manual network deployment and maintenance is simply not scalable in a cost-effective manner for large femtocell deployments.

Femtocells must therefore support an essentially plug-and-play operation, with automatic configuration and network adaptation. In the LTE overall description specification [1], the self-configuration process is defined as the process where the newly deployed base stations are configured by automatic installation procedures to get basic parameters and download necessary software for operation. In this paper, we propose a new energy-aware handoff algorithm that tries to adjust femtocell power with the regards to unwanted mobility events.

There are several reasons for the growing awareness of energy-efficient wireless networks in the telecommunication community. Increasing energy prices imply that electricity bills have become a significant cost factor for mobile operators. In addition, mobile telephony and mobile broadband are entering new emerging

markets, with an increasing share of base stations that are not connected to the electricity grid. Such off-grid sites are typically diesel powered, where fuel is costly and distribution often unreliable for distant sites that are difficult to access. For operators with many off-grid sites, energy provision may contribute up to 50 percent of their total operational cost. There is also an increasing awareness in the society about manmade climate effects, and the need to slow down global warming. Moreover, political initiatives are beginning to put requirements on manufacturer and operators to lower CO₂ emissions of communication networks.

The rest of the paper is organized as follows: section 2 describes state of the art on energy management in wireless networks. Section 3 presents our algorithm for femtocell power adjustment. Section 4 and 5 try to evaluate our proposal through an analytical model and simulations.

2. STATE OF THE ART

The transmit power of femtocell consists of: (i) pilot power (responsible for cell selection and channel estimation) and, (ii) traffic power (includes signalling power and data power). Pilot power determines the coverage of the cell: large pilot power results in a large cell coverage and small pilot power may lead to insufficient coverage. Moreover the larger the pilot power the less the power left for traffic, which result in minimizing the throughput of the femtocell.

The related work in the literature on cellular power optimization mostly deals with centralized computation methods. Such mechanisms involve the calculation of parameters such as number and locations of base stations (BS), pilot channel transmit powers or antenna configurations using a central server running an optimization algorithm. The configuration statistics of the whole network are passed on to the central entity, which then computes the optimal/quasi-optimal configuration settings. The algorithms are Genetic Algorithms, Greedy Algorithms, Simulated Annealing or other classical optimization methods [2-6].

3. POWER SAVING ALGORITHM

We consider an overlay wireless network with two layers: macrocell and femtocell. During operation, information on the number of mobility events and their time are collected and used for further refinement of the coverage by self-optimization of the pilot power of the femtocell. We here propose an optimization method that takes decision based on unwanted mobility events from transient users into account that briefly hand over to the femtocell and handout immediately after passing.

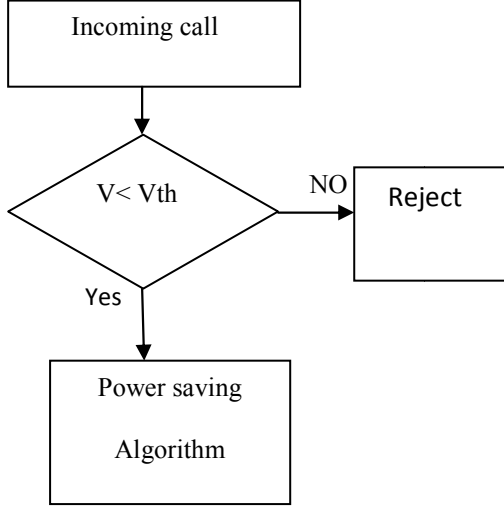


Figure 1: Mobility Management Scenario

We hereafter give a brief overview of the system model where a number of mobile users are deployed randomly under the coverage of the macro BS with varied velocity and undergoing calls of varied service type:

1. No handoff is performed from macro to femtocell within 'R' meter of radius of the macro base station because the SINR of mobile within this area is assumed to be quite high.
2. When the mobile user is moving at a very high velocity, no handoff from the macro to the femto is executed. The mobile remains attached to the Macrocell. As a user with very high velocity it undergoes huge number of macro/femto handoff within a very short period of time. The overhead of the macro BS thus increases unnecessarily. Hence, in this paper we have considered a velocity threshold V_{th} (see section 4).

The general principle of the proposed scheme is depicted in Figure 1.

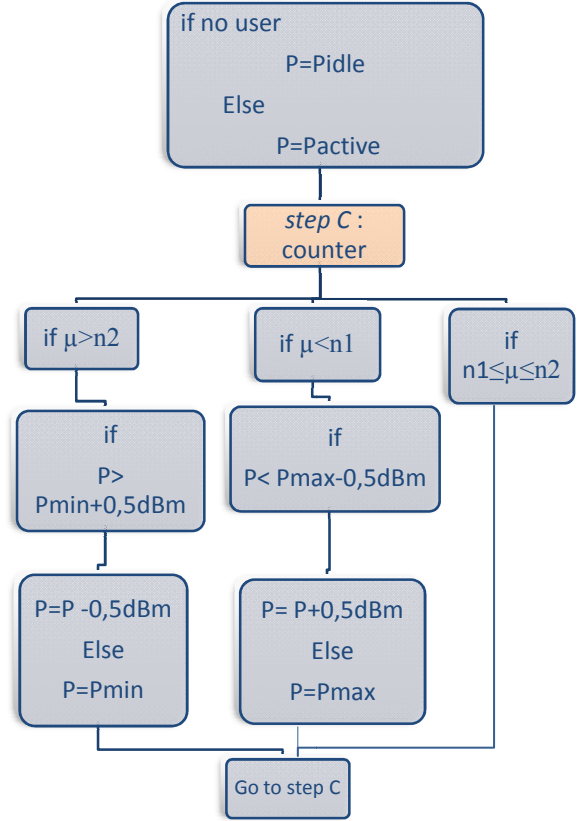


Figure 2: Power Saving Algorithm Flow Chart

A. Algorithm

1) Initialization phase

Initially, the femtocells are considered to be in the idle mode with all the pilot transmissions and associated radio processing at lower power sniffer (*Eidle*). The femtocell becomes active (*Eactive*) only when any user is active under its coverage. This idle/active status aims to enhancing the energy consumption.

2) Optimization phase

We define two priority levels: the highest one U1 for the FAP owner and U2 for any other guest user.

The algorithm follows Claussen and al. [7] method. It eliminates unwanted mobility events from transient users that briefly hand-in to the femtocell and hand-out immediately after passing the femto:

- i. If the number of unwanted mobility events of passing users exceeds a pre-defined value of $n1$ events per time $t1$ the femto must reduce its pilot power by -

0,5dBm. However, the minimum FAP power should cover U1 user if he is attached to his femtocell.

- ii. The femtocell then starts a new mobility event count for the updated configuration. If the number of unwanted events is smaller or equal to $n2$ events for a time period $t2$, this is a stability phase, no power modification.
- iii. Finally, if the number of unwanted events is bigger to $n2$ for a time $t2$, the femtocell increases its pilot power by +0,5dBm, to provide improved indoor coverage. The maximum Power is limited by an upper value Pmax to avoid inter-femtocell interference.

This means that at the initial stage:

$$(1) \quad E_{min} = E_{idle}, \text{ and } E_{max} = E_{active}$$

However, at the optimization stage:

$$(2) \quad \text{If } U1 \text{ exists} \quad E_{min} = E(\text{just to cover } U1)$$

$$\text{Else} \quad E_{min} = E_{idle},$$

In case of power increasing scenario, the Femtocell j must measure the level of other-cell interference I that is received from its vicinity (V) as it's illustrated in the figure below.

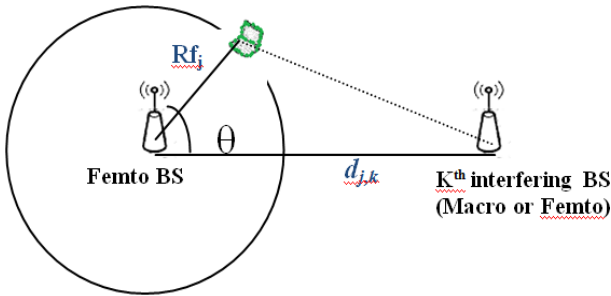


Figure 3: Interference Evaluation Scheme

The interfering signal received at the edge border of the cell at the i th iteration is expressed by:

$$(3) \quad I^i(Rj) = I_{macro} + \sum_k \frac{P^i_k}{A_s L_w (Rj^2 + d_{j,k}^2 - 2 Rj d_{j,k} \cos \theta_k)}^{-\alpha/2}$$

Where:

Rj is the current femtocell radius, $d_{j,k}$ is the distance between the Femto j and the Femto k , I_{macro} is the interfering signal from the macrocell, P^i_k is the surrounding femtocells k transmit power and, α, A_s, L_w are the path loss exponents and the wall penetration loss.

The femtocell j evaluates the received interference plus-noise power and Pmax is calculated so that:

$$(4) \quad 10 \log I^i(Rj) + W < \gamma_{thj}$$

Where,

γ_{thj} is predefined threshold for tolerate interference level at femtocell j and W is the noise.

4. ANALYTICAL MODEL

In this section, a simple analytic model is developed to mainly analyze the performance parameters of the proposed scheme.

Let's first begin by defining the speed upper bound for our proposal. Given a mobile user UE with an average speed v and traversing a two-tier network (for a distance Δ), a valid handover occurs if: the time that the mobile will spend in the femtocell is long enough to compensate for the data loss due to the switching overhead. This means that:

$$(5) \quad v < v_{th} = \frac{\Delta(R_{femto} - R_{macro} - \rho)}{(R_{femto} - \rho)T_h}$$

Where:

T_h is the handover delay,

R_{femto} is the throughput of the femtocell and R_{macro} is the throughput of the macro.

ρ is a hysteresis factor introduced to avoid handover when the two competing cells have negligible bandwidth difference.

In our proposal, the active state is divided into 3 cases:

1. The number of unwanted handoff k is under $n1$ in which case the femtocell Power P has to be increased by +0,5dBm. With the respect of an upper power limit Pmax.
2. The number of unwanted handoff is $n1 \leq k \leq n2$ in which case no change in femtocell Power (so E is set to $E_{current}$)
3. The number of unwanted handoff is $k > n2$ in which case P has to be decreased by -0,5 dBm (with respect

to an under power limit that correspond to the idle state P_{idle})

Let's now try to calculate the probability of an unwanted handoff.

In this work, the $P(k, T)$ denotes the probability of k handover events occurring within the period time T . In general, the Poisson distribution is represented as

$$(6) \quad P(k, T) = \frac{(\lambda T)^k}{k!} e^{-\lambda T}$$

Where λ is the average proportion of the event happened. The probability of a handover which has not occurred within time T_j is $P(0, T_j) = e^{-\lambda_j T_j}$, Where, $\lambda_j = \frac{1}{t_j}$ and t_j is the time period of the received SNR of Femtocellj (FBSj) from the UE is larger than the threshold value. The $\lambda_j T_j$ is the average handover number within the time duration T_j .

The probability of handover is then:

$$(7) \quad 1 - e^{-\lambda_j T_j}$$

The average energy consumption for the data transmission of a UEj (user equipment) performing a handover in the Ashraf protocol [7] is:

$$(8) \quad E_A(t) = e^{-\lambda_j t} * E_{idle} + (1 - e^{-\lambda_j t}) * E_{active}$$

Where E_0 is the average energy consumption of the data transmission of an UE before entering the coverage of FBSj.

We introduce two values of $tdwell$ and $texpected$, where $tdwell$ is the dwell time of a UE of keeping the communication with FBSj, where the UE is in the coverage of FBSj and $texpected$ is the expected transmission time of data of the UE. If a UE cannot completely transmit all of the data within the $tdwell$, then an unwanted handoff occurs.

The probability of a wanted handover is when the remainder data of UEj can be completely uploaded within time $texpected_j$ through the FBS i.e. no handover within $texpected_j$:

$$(9) \quad P(0, t_{expected_k}) = e^{-\hat{\lambda}_k t_{expected_k}}$$

where the $\hat{\lambda}_k = \frac{1}{t_{dwell_k}}$ is the average number of complete uploading within time $tdwell_k$, where $texpected_k$ is the average expected transmission time using FBS_k and $tdwell_k$ is the time starting from the UE communicating with FBS_k and stopping to communicate with FBS_k.

The expected transmission time can be calculated as:

$$(10) \quad t_{expected_k} = \frac{D_{remainder_k}}{R_k}$$

Where, $D_{remainder_k}$ is the remainder data and R_k the average transmission rate of FBS_k.

At initial time $t=0$: The femtocell energy can be $E_{current} = E_{idle}$ if no attached user to the femto else $E_{current} = E_{active}$.

$$(11) \quad E_S = E_0 + \frac{1}{n} \sum_j e^{-\lambda_j T_j} * E_{idle} + \frac{1}{n} \sum_j (1 - e^{-\lambda_j T_j}) \left((1 - e^{-\hat{\lambda}_j t_{dwell_j}}) * E_{current} + e^{-\hat{\lambda}_j t_{dwell_j}} * E_{opt} \right)$$

Where:

$$\text{If } j < n1 \quad E_{opt} = \begin{cases} E(X = P_{current} + j * o, 5) & \text{if } X \leq P_{max} \\ Else & \\ E_{max} = E_{active} & \end{cases}$$

If $n1 \leq j < n2$

$$E_{opt} = E_{current}$$

If $j > n2$

$$E_{opt} = \begin{cases} E(X = P_{current} - j * o, 5) & \text{if } X \geq P_{min} \\ Else & \\ E_{min} & \end{cases}$$

It is easily seen that $E - E_S \geq 0$; since $E_{current} \leq E_{active}$ and $E_{opt} \leq E_{active}$.

Our proposal outperforms a classical approach in terms of energy consumption.

5. SIMULATION RESULTS

In this section, simulation results are presented to evaluate the performances of the proposed scheme in LTE networks with femtocells. For comparison purpose, the performances of the network with Ashraf solution [7] are also presented.

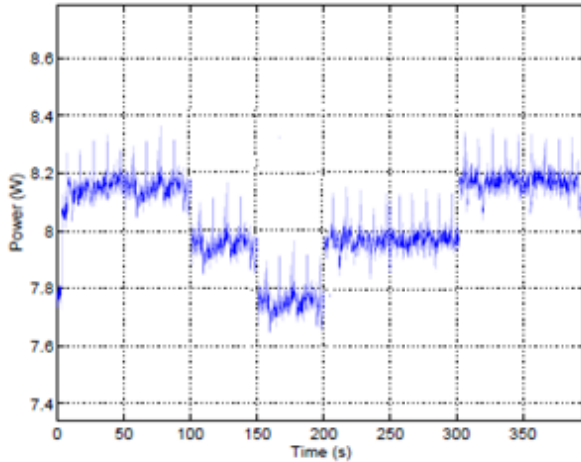


Figure 4: Handover blocking probability

Ashraf et al. [7] recently proposed an energy-saving procedure that allows the femtocell to completely switch off its radio transmissions and associated processing when not involved in an active call. From our point of view, this method is not realistic because wake up will be done each time a new user come, which will be energy consuming and will increase the ping pong effects in the network. Figure 4 shows that our algorithm reduces handover blocking probability because the network coverage is optimized in order to eliminate unwanted mobility events.

Figure 5 confirms that our proposal reduces considerably the amount of energy consumption (the gain is more than 25% in a heavy network). These simulations show the power of a femtocell implementing our dynamic power allocation algorithm. The power is auto-configured, then auto-optimized according to users' mobility. We can see that femtocells have different coverage due to different optimized transmitting power. Our proposal is more context-aware than previous works. Moreover, it decreases holes in the network compared to [7].

6. CONCLUSION

In this paper, we have proposed an energy efficient mobility based algorithm for reducing unnecessary handoff in hierarchical macro/femto networks while balancing the load of macro and the femto BSs at minimal energy consumption. The performance of the proposed

algorithm is also analyzed using an analytical model. Simulations show good performances.

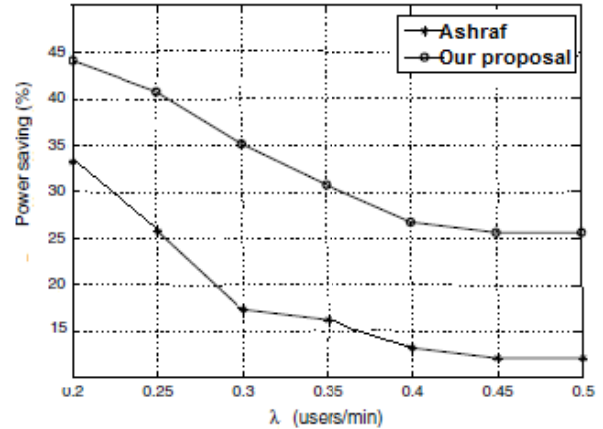


Figure 5: Network energy consumption

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