A Power Management Algorithm For Green Femtocell Networks

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Abstract— **The femtocell concept is an emerging technology for deploying the next generation of the wireless networks, aiming at increasing capacity and offloading the overlay macrocell traffic. Energy costs account for as much as half of a mobile operator's operating expenses. Thus, finding radio networking solutions that can greatly improve energy-efficiency as well as resource-efficiency (Green Communications) is not only benefit for the global environment but also makes commercial sense for telecommunication operators supporting sustainable and profitable business.**

In this paper, we propose a green and distributed algorithm to dynamically optimize the coverage of a femtocell group by adjusting their transmitting power in an Administrative Domain. The resulting evolved algorithm shows the ability to optimize the coverage well, and consequently the resultant substantial energy consumption.

Keywords; femtocells, power management, self-optimization.

I. INTRODUCTION

Originally, femtocells were designed mainly for the home environment, but they could also be a cost effective solution for enterprises because of their self-organizing networks characteristics. Nevertheless, installing femtocells inside an Administrative Domain AD; such as Private Enterprise premises, Mall, office building, where more than one femtocell may be necessary, and where many guest users may enter the femtocell coverage, leads to major technical challenges.

This paper presents an automated and decentralized configuration and management algorithm for sets of autonomic Femtocell base stations in wireless enterprise networks. The system implements self-configuration and self-optimization for power management. Compared to existing centralized systems, where a central management device computes and disseminates management information, this approach improves reliability by eliminating the central point of failure and can increase performance due to parallel communication and processing. A second novel feature of this approach is the integration of external information into the distributed algorithm, further improving the quality of the configuration result.

A major portion of the related literature [1-4] focuses on determining the optimal Base station (BS) numbers or placements to achieve the operator's QoS or coverage targets. However, as pointed out in [2], such an approach is not always practical because network design is constrained by restrictions on BS placements. It is therefore more pragmatic to optimize the configuration of cellular networks where the locations of the base stations have been fixed. Moreover, related work in the literature on cellular coverage optimization use a central server running an optimization algorithm. With femtocell networks, the concept of precise pre-roll-out network planning becomes difficult to follow and economically unviable as the deployment could exhibit random plug-and-play patterns by the end-users.

The aim of coverage optimization in residential femtocell deployments is to ensure that leakage of coverage by a single femtocell into public spaces is minimized while at the same time maximizing indoor coverage [5][6]. For femtocell deployments in enterprise environments however, a group of femtocells are deployed where the individual cells need to work together to jointly provide continuous coverage in a large building or campus. The requirements for coverage optimization in this case differ significantly from residential femtocell deployments.

There are three access modes of femtocell operation:
Open access mode allows anyone to get access to femtocells. Since there is no restriction of access, when the signal received from femtocell is stronger than the signal received from macrocell, anyone can get accessed to femtocell as long as there is bandwidth left to serve the anonymous user. When users who are not registered access a femtocell then the owners of the femtocell will be allocated with less bandwidth, so a way to financially or technically compensate the owners is required (discount for Femto BS or provide faster data rate, for instance).
In enterprise scenarios, open access femtocells will lead to a decreased performance of the enterprise users when the number of guest users is too high, due to the sharing of resources and the heavy interference conditions.

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Furthermore, in CSG mode: Closed Subscriber Group mode, the macrocell coverage could not be sufficient to satisfy the quality of service (QoS) requirements of the guest users. Hence, it is important that femtocells can optimally balance their access control mechanisms.

In this paper we consider the case of hybrid mode where users are given priorities (the highest one L1 to the femtocell owner, L2 the medium priority to other enterprise employers and L3, the least one to any guest user).

II. FEMTOCELL ENTERPRISE ENVIRONMENT

A. *Femtocell coverage Network:*

This study considers a cellular network described in Figure 1. It is composed by one Macro BS and a group of N Femto BS in an enterprise environment. The enterprise is at distance D from the macrocell B0. Therefore, we assume that the N Femto BSs are at the same distance from the MacroBS. A Femto BS is located at the center of an office and covers initially R_{min} meters. Both Femto-BS and user are equipped with an omni-directional antenna. The Femto BS creates cell coverage with radiusR_f , which is adaptively adjusted by the proposed transmit power control algorithm in order to ensure an optimal overall coverage of the enterprise area and so that an optimal power consumption.

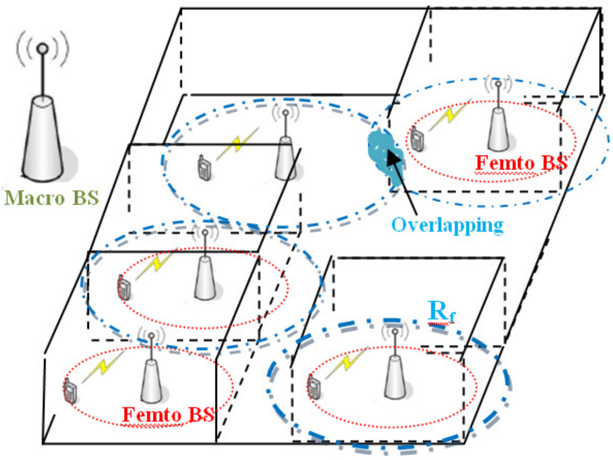

Figure 1. Femtocells Deployment in Enterprise Environment.

The transmit power control algorithm is divided in two steps:

- Initial Startup Configuration
- Power optimization

First, every Femto BS initializes its transmit power. Then, it tries to self-optimize its cell coverage based on the measurements on the radio environment and the distribution of users.

B. *User's Behaviour*

Let F-BSi be the state that employer E stays in the office i, M-B$S0$ be the state that employer E moves through the macrocell, $T1_i$ be the time period for the ith residence in his office (L1-Priority), $T2_i$ be the ith time period for residence in another office (L2-Priority) and $T3_i$ be the time period for the ith residence in Macrocell.

E initially resides in his office (at state F-BS0). Then E may either stay at his office with probability P1, or visit other office (at state F-BSi) of the enterprise with P2 probability or move over the Macrocell area with P3-probability (at state M-BS0).

Assume $T1_i$ are i.i.d. random variables with mean $1/\lambda$, $T2_i$ are i.i.d. random variables with mean $1/\mu$, and $T3_i$ are i.i.d. random variables with mean $1/\theta$.

The input parameters $T1_i$, $T2_i$ and $T3_i$ are normalized by η.

For example, if the expected macrocell residence time is $1/\theta$=*6minutes,* where: θ= (1/P3) x η, P3=0.1 and $1/\eta$= 1hour, then λ = (1/P1) x η *and* μ= (1/P2) x η, that means that the expected residence period (in self-office) is 45minutes per hour and the expected residence period in neighbor office is 15 minutes per hour approximately (where P1=0.8 and P2=0.2).

Thus, the number of users (L1-Employer, L2-Employer and L3-Guest User) per femtocell F-BS$_i$ is determined by their average according to their levels over a defined period $1/\theta$.

- N_1: number of L1-Employers which increases with the arrival of new one over $1/\theta$.
- N_2: average of L2-Employers per $1/\theta$.
- N_3: average of L3-Users per $1/\theta$.

III. POWER CONTROL ALGORITHM

A. *Initial Sartup configuration*

Initially, every day early in the morning, each Femto BS F-BS$_j$ re-activates its pilot power transmission. Its measures the average received power of pilot (over multiple frames to average out fast fading effect) from the neighboring Macro BS I_{macro}. The Femto BS configures its transmit pilot power such that the received pilot power from F-BS and M-BS are identical on average at an initial cell radius of R_{min}, i.e., $R_f = R_{min} = R_{indoor}$. Thus, the initial femtocell pilot power $P_{f_j,min}$ (dBm) is determined such that F-BS power received at R_{min}, is equal to I_{macro}, as follows:

$$P_{f_j,min} = \min\left(I_{macro} + L(R_{min}), P_{f,max}\right)$$

Here, Pmax and L are maximum femtocell power and path loss, respectively. The initial self-configuration only provides the initial cell coverage of a femtocell R_f, which is refined by the following self-optimized power control based on the measurements of radio environments and the distribution of users.

Initially the number of users (L1-Employer, L2-Employer and L3-Guest) per office $Ni_{(i=1..3)}$ =0. It increases significantly according to the arrival of users and their access probabilities to the enterprise.

Thus, the enterprise network is still at its IDLE mode with the cell range set to its minimum $R_f = R_{min}$, disabling femtocell overlapping area. While significant zone in the enterprise still covered by Macro-BS. The following figure Figure.2 illustrates this concept:

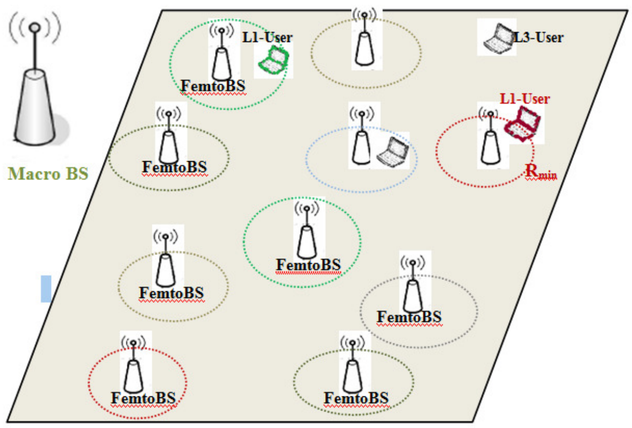

Figure 2. Femtocells deployment in IDLE Mode

B. Power Optimization

B.1 Power Optimization Approach

This paper deals with coverage planning in femtocell enterprise environment. Given the locations of F-BSs, the problem amounts to determine cell coverage with minimum cost in term of power usage. Minimum-transmit power concept tends to make cell size as small as possible; such a solution may have negative impact on handover performance. To tackle this issue, the objective is to perform power minimization with the requirement of allowing sufficient overlap between cells.

In the literature, traditional related work define power minimization problem as:

Power-Minimization System: With given a set of users and a set of base stations, find a set of turned-on base stations to provide network coverage for all users.

With this concept, we do not consider the capacity of the femtocell base station in the terms of available bandwidth, or the traffic requirement of the user. With such model, the problem is a variant of Set Cover problem, which is a famous NP-complete problem.

In this paper, as users don't have the same priorities in their access to each Femto BS, we added another parameter here referred as E that reflects the user's arrival rate according to his access Level in the system.

E is considered also as the association of E_1, E_2 and E_3 : where: E_1 is the L1-user's arrival rate in the enterprise, E_2 is the L2-user's arrival rate and E_3 is the L3-user's arrival rate.

Our optimization power problem can be extended as follows:

$$S \begin{cases} S1 = \begin{cases} \max Coverage\ \ C \\ \quad \min(\theta) \qquad when\ E\ (E1, E2) increase\ significantly \\ \quad \min\,(Energy) \end{cases} \\ S2 = \begin{cases} Adapted\ \ Coverage\ C\ with\ Employer - Movements \\ \qquad\qquad when\ E\ \ in\ Low \\ \qquad \min(Energy) \end{cases} \end{cases}$$

We hereafter propose a simple heuristic for this NP optimization problem:

Where:

- *Input System*: a set of users with priority L1, L2 and L3, a set of Femto BS.
- *Output System*: a minimum power level for turned-on base station and network overlapping ratio θ

B.2 Power Optimization Algorithm

Our algorithm is based on three concepts:

- Measure of Interference and SINR.
- Update of Transmit power level
- Coverage radius fit.

➢ *Measure of interference and SINR*: F-BS_j measures the level of other-cell interference $I^i(R_{f_j})$ that is received from its vicinity (*V*) of Femto BSs and the Macro BS. as it's illustrated below.

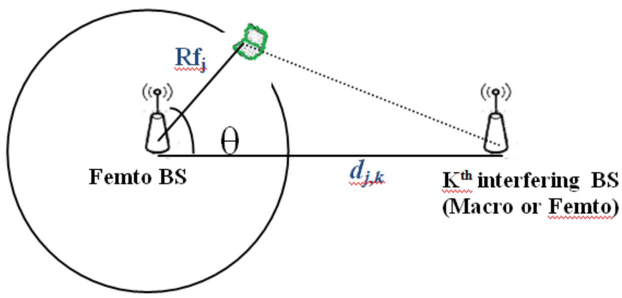

Figure. 3. Measure of the other-cell interference.

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

$$I^i\left(R_{f_j}\right) = \sum_{k=1}^{V} \frac{P_{f_k}{}^{(i)}}{A_s L_w \left(R_{f_j}^{(i)^2} + d_{k,j}^2 - 2R_{f_j}^{(i)} d_{k,j} \cos\theta_k\right)^{-\propto/2}} + I_{macro}$$

Where $d_{k,j}$ is the distance between the F-BS$_j$ and the F-BS$_k$.

We assume that the border of femtocell coverage is a circle with R_f radius, which is evaluated by the expression below:

$$R_{f_j} = \frac{k^{1/\propto}D}{|k^{2/\propto}-1|} \quad \text{(m)}$$

Here we approximate $k = \frac{P_{B0}}{P_{f_j}{}^{(i)}\ Lw}$, where P_{B0} and $P_{f_j}{}^{(i)}$ are the macrocell and femtocell F-BS$_j$ transmit power at the ith iteration and, $\propto, A_s$ and L_w are the path loss exponents and the wall penetration loss.

Then iteratively, the femtocell F-BS$_j$ evaluates the received interference plus-noise power $Zu^i\left(R_{f_j}\right) = 10log10(I^i\left(R_{f_j}\right) + W)$ (*Interference FUNCTION*) measured by each femtocell user during the ith iteration and is fed back to the currently linked femtocell F-BS.

➢ *Transmit Power Update:* Based on the decision variable the time-averaged SINR: Γas it's expressed by:

$\Gamma^i\left(R_{f_j}\right) = Q^i\left(R_{f_j}\right) - Zu^i\left(R_{f_j}\right)$ in (dBm) where:

- $Q^i\left(R_{f_j}\right) = P_{f_j}{}^{(i)} - L\left(R_{f_j}\right)$ in (dBm) represents the time-averaged received power of a femtocell user at $R_f(m)$,
- The outdoor and indoor path loss in (dB) are modeled as: $L\left(R_{f_j}\right) = A_s + 10 \propto \log\left(R_{f_j}/d_s\right) + L_w$, the reference distance ds = 1m

the transmit pilot power of the femtocell F-BS$_j$ at the (i+1)th iteration $P_{f_j}{}^{(i+1)}$ is updated by:

$$P_{f_j}^{(i+1)} = \begin{cases} \min\left(P_{f_j}^{ini} + \Delta P_1{}^{(i+1)}, P_{f_j,max}\right) for\ \Gamma_{th1} \le \Gamma^{(i)}(R_{f_j}), \\ P_{f_j}^{(i)} \quad for\ \Gamma_{th2} \le \Gamma^{(i)} \le \Gamma_{th1} \\ \min\left(P_{f_j}^{ini} + \Delta P_2{}^{(i+1)}, P_{f_j,max}\right) for\ \Gamma^{(i)}\left(R_{f_j}\right) \le \Gamma_{th2} \end{cases}$$

Where:

- P_{ini}: it takes the value of the initial femtocell transmit power;$P_{f_j,min}$.
- $\Delta P_1 = (C_1 N_1 \Delta P + C_2 N_2 \Delta P + C_3 N_3 \Delta P)$,

$\Delta P_2 = (C_1 N_1 \Delta P + C_2 N_2 \Delta P + C_3 N_3 \Delta P - k * \varepsilon)$: are the power control step in (dBm), it depends on :

- (N_1, N_2, N_3). The number of :
  - ❖ $L_1 - Employers$: This is increased according to the arrival of a new one.
  - ❖ $L_2 - Employers$: This is updated and averaged over the previous iterations.
  - ❖ $L_3 - users$: This is updated and averaged over the i previous iterations.
- (C_1, C_2, C_3): Weights-powered coefficients showing how to share the resource and power according to the access levels of users. F-BS provides more coverage for L1-Employers than L2-employers than L3-users. It considerably extends its coverage to ensure the continuity of L1-Employer service.
- ΔP , ε : are constant parameters.

Iteratively, the femtocell transmit power increases by considering the control power step ΔP_1. It depends specially and respectively on N_1 number (as we define high level of the C_1 coefficient), then N_2 number (by considering moderate level of C_2 coefficient) and finally on N_3 (by considering low level of C_3 coefficient).

➢ *Coverage Radius Fit :* As the transmit power increases iteratively, the femtocell coverage progresses gradually until the stabilization state. Indeed $P_{f_j}^{(i+1)}$ is determined by comparing the decision variable $\Gamma^{(i)}(R_{f_j})$ with the threshold values Γ_{th1} and Γ_{th2} . The first one indicates the detection of considerable energy from another femtocell in the vicinity. The second delimits the allowed femtocell overlapping area θ.

If the Γ_{th2} is greater than the SINR at the cell edge, the F-BS decreases iteratively its transmit power P_{f_j} by considering the power control step ΔP_2 to reach the stabilization state. Its coverage is reduced gradually meter by meter to avoid the overlapping inter femtocells, and by consequence to reduce the interference.

IV. FEMTOCELL OPTIMIZATION CASES

Some input parameters used by our algorithm depend on the enterprise environment which change dynamically all over the day. Thus, we define hereafter 3 classical scenarios that can be executed to accommodate with different users behaviors at different moments.

The first scenario is executed at the beginning of the day at 7:00 and lasts for a maximum of 1 hour. Certainly it's the most significant time when the arrival rate of employers and users is the more important. For example, if the expected macrocell residence time is $1/\theta$ =6 minutes, then the maximum iteration level for stabilization scheme doesn't exceed 10.

In this case the parameters $(P_{ini}, \Delta P_{i,(i=1,2)}, (C_1, C_2, C_3), (N_1, N_2, N_3)$ and $\Delta P)$ are initialized as described below:

- $P_{ini} = P_{f_j,min}$.
- Initially $(N_1 = 1, N_2 = 0, N_3 = 0)$, they increase gradually according to the arrival of employers and users and updated every iteration step

The enterprise coverage area progresses iteratively until the stabilization state.

Usually during the day, employers move from one office to another to exchange works. Therefore, every $1/\mu$ period (where $1/\eta$= *3* hour) the Femto BSs update their coverage by executing the second scenario of our algorithm.

In the second approach, the parameters $(P_{ini}, ((N_1, N_2, N_3)$) are initialized as described below:

- P_{ini}:takes the resulting value of the femtocell transmit power as evaluated in the first approach when considering only the N_1value :

$$P_{ini}(Second.Approach) = P_{ini}(First.Approach) + C_1 N_1 \Delta P.$$

- N_1: It's incremented and updated according to the arrival of a new employer.
- $N_2 = 0,\ N_3 = 0$ These are updated and averaged over the iterations.

The femtocell coverage progresses iteratively until the stabilization state.

The last scenario takes place in the evening from 19:00h. Femto BSs will switch off to the Idle mode gradually. The femtocells-coverage will be reduced to $R_f = R_{min} = R_{indoor}$ which is more suitable for low traffic.

V. CONCLUSION

In this work, we have shed light on the energy consumption profile of femtocell deployments in enterprise environment. A novel self-optimized transmit power algorithm for Femtocells Network has been introduced that enables adaptive coverage according to the number of users per femtocell and their access Level while satisfying the decision criteria imposed by the threshold SINR condition. It's an efficient power scheme that ensures the power control and the coverage adjustment.

Future work will address the share of femtocell bandwidth resource between these three types of users.

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