On the Uplink Coverage and Capacity of UMTS Femtocells in Enterprise Environment

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***Abstract*— This paper investigates the uplink capacity and coverage of femtocells for enterprise UMTS applications to better understand the trade-offs and the expected performance of such a deployment. A radio system model is used where a large number of randomly distributed users are in an open office layout, where Home NodeBs are deployed. The interference effect is studied and the performance with interference mitigation is determined. The results and methodology could be used to plan a system deployment. Furthermore, results show that advanced receiver technology implemented in the Home NodeB will significantly enhance the uplink capacity and coverage, and minimize the overall cost of a femtocell enterprise solution.**

I. Introduction

Femtocells are wireless access points (or Home NodeB), which were first proposed as a solution for residential use [1], [2], where users in households with poor coverage could get improved service by connecting a femtocell to their broadband router [3]. The introduction of femtocells gives rise to a number of technical challenges, including the IP interface to the backhaul network, closed or open access, synchronization and interference [4]. In the residential use-case co-channel interference of the femtocell underlay system has been studied by a number of authors [5]–[7].

What hasn't been very well addressed is the utilization of femtocells in the enterprise or office environment [8]. Here the utilization of femtocells has significant advantages in that user traffic is offloaded from the outdoor macro wireless system to save cost for the operators and enterprise.

In this paper, we consider the uplink interfering scenarios in a 3GPP UMTS network for the early deployment of femtocells in enterprise envrionment, where a closed-loop power control algorithm to accommodate a large number of femtocell connected User Equipments (UEs) is proposed. The approach can be extended to plan high speed access solutions. We focus on the femto-to-femto interaction in a shared carrier for multiple femtocells. Furthermore, we consider interference mitigation techniques to enable the network operation even in extreme cases. The overall capacity and coverage of the enterprise femtocells can be enhanced dramatically by employing such advance receiver technology.

II. System Model

In this study, a static network simulator is proposed to evaluate the performance of the enterprise femtocell system. Through modeling channel, femtocell connected UEs and NodeBs, the results over a large number of simulations are used to generate the average stastics for the system.

A. Channel Model

The network simulations are conducted at a carrier frequency of 2GHz. The signal transmission power is subject to a propagation characterized by the ITU-R.P 1238 model [9], which is suitable for the indoor office scenario. The propagation pathloss is given by:

$$PL = 20 \times \log_{10}(f_c) + 30 \times \log_{10}(d) - 17, \qquad (1)$$

where f_c is the carrier frequency, d is the distance between the transmitter and the receiver. The Additive White Gaussian Noise (AWGN) floor at the NodeB receiver is -95dBm over an 5MHz spectrum. There are no internal walls/windows assumed to attenuate the transmitted signals.

B. Femtocell Connected UE Modeling

The enterprise femtocell UEs (FUE) in the simulations can transmit at 12.2kbps (voice call), 64kbps, 144kbps and 384kbps, with the corresponding spreading factor being 64, 16, 8 and 4 respectively. The requirement on the received Signal-to-Interference Ratio (SIR) conforms to the minimum requirement on 3GPP UMTS base stations [10], [11]. The UE traffic portfolio can be adjusted to reflect a specific traffic model in the realistic scenario. The FUE transmit power is capped at 20dBm. The UEs are modeled to camp on the NodeB associated with the minimum pathloss.

C. Home NodeB Modeling

The Omni-directional antenna is employed at the enterprise Home NodeB. Round-Robin scheduling is employed at the base stations to provide equal service to all active UEs. The Rise over Thermal (RoT) threshold at the NodeB scheduler is set to be 12dB.

III. Closed-Loop Power Control Algorithm for Enterprise Femtocells

A. Link Budget and Interferences

Given the pathloss $PL(k, k_s)^1$ between the UE and its serving NodeB k_s, the NodeB AWGN floor $N_0(k_s)$, and the

[1] The antenna gain and loss are absorbed in the pathloss term, for the sake of simplicity.

UE's SIR requirement SIR_k, i.e. the target SIR, the initial transmit power $P_t(k)$ of the k^{th} UE can be computed as:

$$P_t(k) = PL(k, k_s) \times N_0(k_s) \times SIR_k, \quad (2)$$

where $k \in \Psi(k_s)$ and $\Psi(k_s)$ is the FUEs' set on the serving NodeB k_s. The initial transmit power $P_t(k)$ is the required transmit power for the k^{th} UE in the single-user channel, which is the lower bound of user power in multi-user systems.

The intracell as well as the intercell interference for the k^{th} user's transmission link can be computed using the initial transmitting power as follows:

$$I_{intra}(k) = \sum_{j \in \Psi(k_s), j \neq k} \frac{P_t(j)}{PL(j, k_s)}, \quad (3)$$

$$I_{inter}(k) = \sum_{l \neq \Psi(k_s)} \frac{P_t(l)}{PL(l, k_s)}. \quad (4)$$

B. Femtocell UE Link Adjustment Procedure

In the closed-loop power control algorithm proposed in this papser, the instantiate SIR at n^{th} iteration for the k^{th} UE can be computed as:

$$SIR_k^n = \frac{P_t^n(k)}{(N_0(k_s) + I_{intra}(k) + I_{inter}(k)) \times PL(k, k_s)}. \quad (5)$$

Compare to the target SIR, denoted as SIR_k, we can measure the SIR difference as:

$$\Delta_{SIR_k}^n = \frac{SIR_k^n}{SIR_k}. \quad (6)$$

If this SIR difference at n^{th} iteration is greater than the power control step, i.e. $|\Delta_{SIR_k}^n| > \Delta$, we need to increase or decrease the UE transmitting power and update the intracell and intercell interference to m^{th} UE $(m \neq k)$ as follows:

$$P_t^{n+1}(k) = \frac{P_t^n(k)}{\Delta_{SIR_k}^n}, \quad (7)$$

$$I_{intra}^{n+1}(m) = I_{intra}^n(m) + (1/\Delta_{SIR_k}^n - 1)\frac{P_t^n(k)}{PL(k, k_s)} \quad (8)$$

$$I_{inter}^{n+1}(m) = I_{inter}^n(m) + (1/\Delta_{SIR_k}^n - 1)\frac{P_t^n(k)}{PL(k, k_s)}. \quad (9)$$

It is worth mentioning that the we skip the incremental power control steps in above link adjustment for faster power control convergence.

On the other hand, if the SIR difference at n^{th} iteration is smaller than the power control step, i.e. $|\Delta_{SIR_k}^n| \leq \Delta$, we will claim that the power control is converged for the k^{th} at $(n+1)^{th}$ iteration.

We start the above closed-loop power control from the first femtocell UE, i.e. $k = 1$, until the power of all UEs are converged to satisfy the target SIR. In order to manage the convergence of the power control algorithm, we limit the maximum number of power control iterations to be 30. In the case of non-convergence happens, we will claim the UEs are in outage if they cannot meet the target SIR.

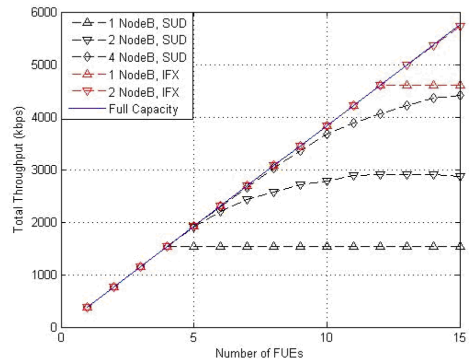

Fig. 1. Uplink capacity for enterprise femtocells

Furthermore, in the above mentioned algorithm, single-user detector (SUD) receiver is used as an illustrative example in determining the co-channel interference as well as received SIR. For more advanced receiver techniques, the procedures to compute the effective co-channel interference and SIR updates need to be adjusted accordingly. For example, if an iterative Parallel Interference Cancelation (PIC) based multiuser detector (MUD) is employed, the interference term should be the effective interference remaining after a number of iterations.

IV. Simulation Results

A. Simulation Setup

In this section, we present the system simulation results for an enterprise femtocell serving high speed UEs with a data rate of 384 kbps. Two types of enterprise Home NodeBs are considered in the simulation. "NodeB SUD" employs conventional SUD receiver, and "NodeB IFX" represents the advanced NodeB with intra-cell interference cancelation capability. The office environment under consideration is confined to a rectangular region ($9600m^2$, $80m \times 120m$). There are up to four NodeBs in the office, and the NodeBs are deployed in the middle of the service area so that the whole office area can be covered evenly. The FUEs are deployed randomly with uniform distribution in the office area. The cell capacity is evaluated at an outage probability of 5%.

B. Numerical Results

1) Capacity for Uplink Enterprise Femtocells: Fig. 1 shows the capacity of the enterprise femtocell by varying the number of NodeBs and comparing the performance of conventional NodeBs to that of the advanced NodeBs. It can be observed that the femtocell with conventional NodeBs can only support up to 1.5Mbps, 3Mbps and 4.5Mbps high speed UEs with one NodeB, two NodeBs, and four NodeBs respectively. On the other hand, the femtocell with one advanced NodeB can support up to 4.6Mbps before substantial outage shows up. This indicates a 200% increase in capacity can be obtained by deploying a single advanced NodeB, which is roughly the same as the improvement by deploying four conventional NodeBs.

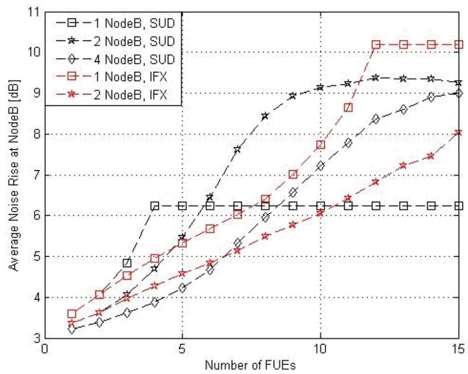

Fig. 2. Noise rise at uplink enterprise femtocells

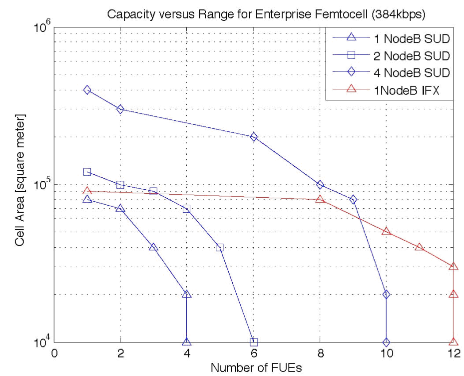

Fig. 3. Uplink capacity vs. coverage for enterprise femtocells

2) Noise Rise at Uplink Enterprise Femtocells: Fig. 2 shows the noise rise at NodeBs in the enterprise femtocells. As the femtocell with advanced NodeB can support three times of the high speed UEs as the NodeB SUD, the noise rise saturates around 10dB, which is close to the RoT. However, the noise rise at conventional NodeB only saturates at 6dB for one NodeB, and 9dB for two and four NodeBs. This observation shows that the advanced NodeB can work in heavily loaded scenarios to maximize the system capacity, while for the conventional NodeBs the noise rise may experience a drastic increase by admitting one more user into the system with moderate loading. Therefore, cells with NodeB SUD are unable to handle high-speed traffic.

3) Uplink Capacity vs. Coverage in Enterprise Femtocells: Fig. 3 shows the capacity versus coverage if the area of the office is varying between $10^4 m^2$ to $10^6 m^2$. It can be seen that generally one or two conventional NodeBs can provide a coverage up to $10^5 m^2$, while four conventional NodeBs can provide a coverage up to $3 \times 10^5 m^2$. For an office with area of $10^4 m^2$, an advanced NodeB can triple the servicing 384kbps UEs if one conventional NodeB is deployed and double the servicing UEs if two conventional NodeBs are deployed. It can even support two more UEs compared to deploying four conventional NodeBs. Furthermore, deploying one advanced NodeB has better coverage up to $7 \times 10^4 m^2$ compared to the deployment plan of four conventional NodeBs if four UEs are supported in the femtocell. Therefore, deploying femtocell with advanced NodeB will improve the system coverage significantly.

V. Conclusion

In this paper, we studied the uplink capacity and coverage of a UMTS femtocell networks for the enterprise scenario. We analyzed the femto-to-femto interaction with the interference among high speed (384kbps) FUEs. We simulated the system capacity and coverage by adopting the conventional single user detection and advanced interference mitigation techniques in the Home NodeBs. The results show that there are great benefits by deploying femtocell with advanced NodeB Receivers. The system capacity can be tripled while the noise rise at the NodeB is close to the designed RoT. The UEs served by the advanced NodeB generally transmit less power than served by the conventional NodeBs so that longer connecting time can be experienced by the UEs. Meanwhile, the coverage can also be enhanced, which means the cost of the enterprise femtocell solution is minimized for the offices with extensive area.

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