Femtocells Networks

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***Abstract*—The surest way to increase the system capacity of a wireless link is by getting the transmitter and receiver closer to each other, which creates the dual benefits of higher-quality links and more spatial reuse. In a network with nomadic users, this inevitably involves deploying more infrastructure, typically in the form of microcells, hot spots, distributed antennas, or relays. A less expensive alternative is the recent concept of femtocells also called home base stations which are data access points installed by home users to get better indoor voice and data coverage. Femtocells expand the coverage of cellular networks, provide high data rate for users, decrease the transmission power of user equipments, and increase the spectrum efficiency. In this article, we will explore different characteristics of femtocell networks such as power control schemes, interference avoidance, capacity-coverage analysis, energy-efficiency and access control strategies.**

I. Introduction

The traditional cellular networks are already at the point of failure and cannot keep pace with this data explosion through the expensive and incremental methods of the past: namely increasing the amount of spectrum or by deploying more macro base stations. The demand for higher data rates is unrelenting, and has triggered the design and development of new data-minded cellular standards such as WiMAX (802.16e), the Third Generation Partnership Projects (3GPPs) High Speed Packet Access (HSPA) and LTE standards, and 3GPP2s EVDO and UMB standards. It is thus evident that, the architecture for cellular networks are undergoing a major paradigm shift from voice-centric, circuit switched and centrally optimized for coverage towards data-centric, packet switched and organically deployed for capacity.

The growth in wireless capacity is exemplified by this observation from Martin Cooper of Arraycomm: "The wireless capacity has doubled every 30 months over the last 104 years." This translates into an approximately millionfold capacity increase since 1957. Breaking down these gains shows a 25× improvement from wider spectrum, a 5× improvement by dividing the spectrum into smaller slices, a 5× improvement by designing better modulation schemes, and a whopping 1600× gain through reduced cell sizes and transmit distance. The enormous gains reaped from smaller cell sizes arise from efficient spatial reuse of spectrum or, alternatively, higher area spectral efficiency. [2]

One of most interesting trends to emerge from this cellular revolution are femtocells. Femtocells are small, inexpensive, short-range, low-cost, low-power base stations that are generally installed by the consumer for better indoor voice and data reception. The user-installed device communicates with the cellular network over a broadband connection such as digital subscriber line (DSL), cable modem, or a separate radio frequency (RF) backhaul channel. In these respects, they resemble WiFi access points, but instead they utilize one or more commercial cellular standards and licensed spectrum. Compared to other techniques for increasing system capacity, such as distributed antenna systems and microcells, the key advantage of femtocells is that there is very little upfront cost to the service provider.

Studies on wireless usage show that more than 50 percent of all voice calls and more than 70 percent of data traffic originate indoors. With femtocells, the subscriber is happy with the higher data rates and reliability; the operator reduces the amount of traffic on their expensive macrocell network, and can focus its resources on truly mobile users. Femtocells enable reduced transmit power while maintaining good indoor coverage. In an indoor setting, penetration losses naturally insulate the femtocell from surrounding femtocell transmissions. Fig 1 shows an overview of a macrocellular underlay network with femtocell home base station overlay deployment and Fig 2 shows a snapshot of the simulated scenario with 100 femtocells per macrocell sector, and house mode.

The capacity potential of femtocells can be verified rapidly from Shannons law, which relates the wireless link capacity (in bits per second) in a bandwidth to the SINR. The SINR is a

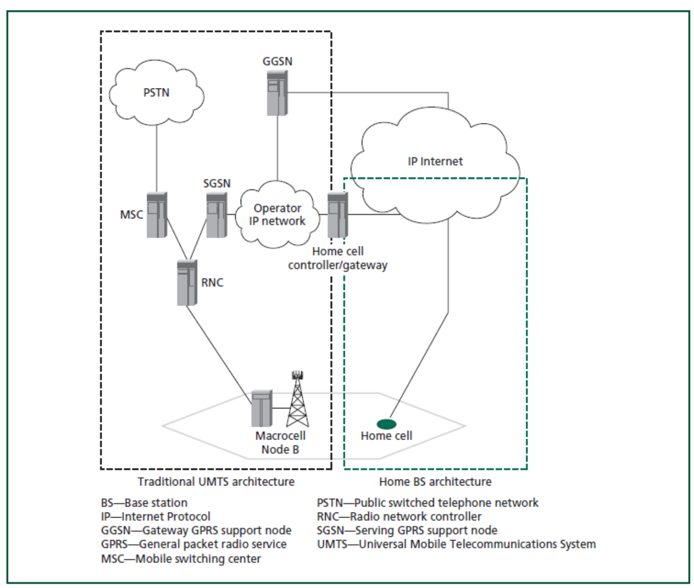


Fig. 1. Overview of a macrocellular underlay network with femtocell home base station overlay deployment [1]

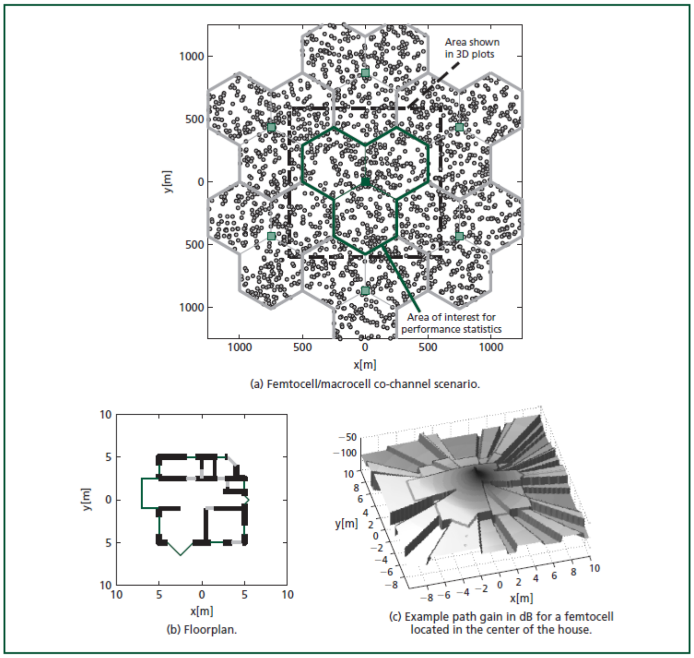


Fig. 2. Snapshot of the simulated scenario with 100 femtocells per macrocell sector, and house model [1]

function of the transmission powers of the desired and interfering transmitters, path losses, and shadowing during terrestrial propagation. Path losses cause the transmitted signal to decay as $Ad^{-\alpha}$, where A is a fixed loss, d is the distance between the transmitter and receiver, and α is the path loss exponent. The key to increasing capacity is to enhance reception between intended transmitter-receiver pairs by minimizing d and α. Simultaneously, additional benefits in network-wide spatial reuse can be obtained by, but not restricted to, exploiting diversity, and employing interference cancellation, interference suppresion, and interference avoidance techniques.

From a technology point of view, a femtocell is not only characterized by short communication range and high throughput, but also by its ability to seamlessly interact with the traditional cellular network at all layers of the network stack,performing tasks like handoffs (HOs), interference management, billing, and authentication. This necessitates substantial support by the appropriate standards bodies. Building upon the above discussion, the key facets and technical challenges facing femtocell networks are : interference co-ordination; allocattion of spectrum in the presence of intra and cross-tier interference; timing and synchronization; backhaul QoS; acess strategies; handover management; femtocell mobility; cell association and biasing.

In two-tier (macro and femto-cells) networks, interference is classified as follows:

- *Cross-tier* interference is caused by an element of the femtocell tier to the macrocell tier and vice versa.
- *Co-tier* interference occurs between elements of the same tier, for example, between neighboring femtocells.

The impact of interference depends on the techniques used for allocating the spectral resources to the macrocell and femtocell tiers, as well as on the method used to access the femtocells.

II. Access Control Mechanisms

The selection of an access control mechanism to femtocells has dramatic effects on the performance of the overall network, mainly due to its role on the definition of interference. When the access method blocks the use of the femtocell resources to a subset of the users within its coverage area, a new set of interfering signals is implicitly defined in such area. Contrarily, the deployment of open femtocell access points (FAPs) would solve this issue, but bringing security and sharing concerns to the customer. Furthermore, when users move across areas with large numbers of open FAPs, the number of handovers and thus the signaling in the network increases.

Access control mechanisms play an important role to mitigate cross-tier interference and handover attempts, that is why they have to be carefully chosen depending on the customer profile and the scenario under consideration. The different approaches that have been proposed are, namely, Closed Access, Open Access and Hybrid Access.

In order to describe the access control procedures to femtocells in a two-tier network, users need to be classified according to their femtocell connectivity rights. In this context:

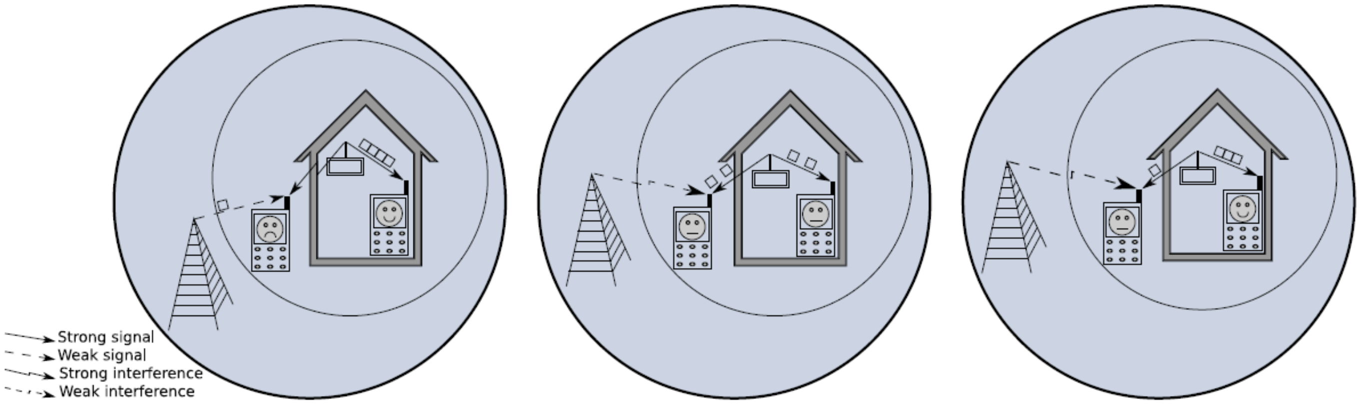
- A *subscriber* of a femtocell is a user registered in it. Subscribers are thus the rightful users of the femtocell, and they are usually mobile terminals that belong to the femtocell owner, their family or friends.
- A *non-subscriber* is a user not registered in the femtocell.

In the following, the access control procedures to femtocells are described in terms of this classification. Fig 3 shows the different access methods.

A. Closed Access

In closed access, only the femtocell subscribers are allowed (also called, closed subscriber group) to connect to the femtocells and non-subscribers are not allowed to connect to the network through a femtocell, even if its signal is stronger than the one of the closest macrocell. Therefore a strong component of cross-tier interference exists between both tiers, e.g., femtocells could jam the downlink communication of passing non-subscribers connected to a far macrocell, and non-subscribers located close to a femtocell could jam the femtocell uplink. Intra-tier interference also comes up between neighboring femtocells in dense deployments. In many cases, users will install their femtocells in random positions within their homes, e.g. close to a room of a neighbor or close to a window. This case, subscribers will be sometimes severely jammed by neighboring femtocells, thus being unable to connect.

In order to guarantee femtocell connectivity and mitigate interference, the power radiated by the FAP must be tuned to ensure a sufficient coverage to the femtocell subscribers and minimize the leakage of power outside of the premises. This can be done by self-optimizing the femtocell radiated power where each femtocell sets its power to a value that



(a) Closed Subscribers Group (CSG). (b) Open Access. (c) Hybrid Access.

Fig. 3. Access Methods [9]

on average is equal to the received signal strength from the closest macrocell at a target femtocell radius. Another solution to mitigate the interference problem is the use of sector antennas in the FAPs to minimize the overlapping of coverage areas. Furthermore, the use of several radiating elements to perform beamforming and adapting the coverage area of the femtocell to the shape of the household has also been suggested. Moreover, OFDMA (Orthogonal Frequency Division Multiple Access) femtocells have the advantage of allowing the allocation of orthogonal frequency/time resources to the users. Thus, interference avoidance can not only be handled through power or antenna management, but also through subchannel and time slot allocation.

B. Open Access

In open access, all users (subscribers and non-subscribers) are allowed to connect. There is thus no distinction between these two groups, and they are just referred here as users. The use of open FAPs at home would reduce the interference problems caused by CSG FAPs. Indeed, all passing users would be authorized to connect to any femtocell, reducing thus the negative impact of the femtocell tier on the macrocell network. In this case, the users are always connected to the strongest server (either macro or femto), avoiding cross-tier interference. As a result, the overall throughput of the network increases as can be seen in fig /blah.

Still, open access schemes have their share of drawbacks, it reduces the performance of the femtocell owner due to the sharing of the femtocell resources with non-subscribers. Moreover, open access increases substantially the amount of handovers between cells due to the movement of outdoor users. A user moving in a residential area will handover from one femtocell to another or to the umbrella macrocell. This will have a negative impact in the operator because the signaling in the network increases and also the probability of the call being dropped due to failure in the handover process. Furthermore, the chances for handover failure increase if the femtocell neighboring list is not properly configured and updated. The number of neighbouring relationships will be insufficient in large open access femtocell deployments, where the relationships between femtocells (more likely to be turned on and off) must be handled in a different way than between macrocells and femtocells. Moreover, the reuse of cell IDs within the coverage of a single macrocell would be necessary, and collision and/or confusion between some of them would be unavoidable.

Regardless of this, different solutions have been proposed in which a centric sensing of the radio channel is used as a mean to obtain parameters about the surrounding environment and to update the femtocell neighboring list. Before open FAPs are widely deployed, research is required in order to support new algorithms to handle more neighbors and their different nature in a fast manner. Figure 4 shows that open access reduces the negative impact of femtocells on the macrocells.

C. Hybrid Access

Hybrid access methods reach a compromise between the impact on the performance of subscribers and the level of access that is granted to non-subscribers. Therefore, the sharing of femtocell resources between subscribers and non-subscribers needs to be finely tuned. However, in hybrid access schmes, users subscribed to the femtocell may get preferential charging in comparison with users not subscribed to the cell that receive service from it.

In order to support this deployment scenario, the femtocell access point should have an awareness of the users CSG membership before preempting a non-subscribed user in connected mode (e.g., while in a call) to allow the subscribed user access to the femtocell. Unlike open and closed, where the access mode is clearly defined, hybrid access offers flexibility and a full range of algorithms that can be defined in order to control who accesses the femtocell and how the connection is configured. Such an approach brings thus together, the best of both worlds (closed and open access). Therefore, research is still needed to find hybrid access approaches well adapted to the different deployment scenarios.

III. Handover

In general, handover from a femtocell to the macrocell network is significantly easier (as there is only one macro BS) than handoffs from the macrocell to the femtocell. Current second-generation (2G) and 3G systems broadcast a neighbor list used by a mobile attached to the current cell to learn where to search for potential handover cells. Such a handover protocol does not scale to the large numbers of femtocells that neighbor (actually underlay) the macrocell, and the underlying network equipment is not designed to rapidly change the lists as femtocells come and go. This motivates 4G handover procedures to take the presence of femtocells into consideration.

The main challenge with supporting inbound handover to a femtocell is for the source eNB (LTE) or RNC (UMTS) to identify the target femtocell access point (HNB or HeNB). In normal macrocell operation, the operator is expected to plan the allocation of physical cell identities (PCIs) to neighboring macrocells in such a way that the PCI of a macrocell is locally unique. In the LTE case, for example, the network sends a measurement configuration to the user to measure and report cells on the carrier where the user is being served. The user is expected to detect neighbor cells and send measurement reports (unless certain PCIs are blacklisted). Since the PCIs are locally unique, the source eNB can readily identify the target eNB and prepare it for the handover. However, femtocells are expected to be deployed in an unplanned manner; hence, under a given macrocells coverage, there might be a large number of femtocells configured with the same PCI (considering that there are a limited number of PCI values available). When user detects a femtocell PCI and sends a measurement report to the network, the network cannot be sure about which target cell the user has reported on based solely on the reported PCI. This so-called PCI confusion issue has to be resolved in order to allow successful inbound handover to a femtocell. Fig /blah illustrates the PCI confusion issue.

The issue of PCI confusion can be addressed using a user-based or network-based solution. In the user-based solution, the UE is expected to read the system information of the cell (e.g., triggered by detection of a PCI in the list reserved for CSG cells) to acquire a globally unique identity of the femtocell. This can then be sent in the measurement report together with the PCI. The eNB can then use the cell global identity (CGI) information in the measurement report to resolve the PCI confusion. In addition to acquiring the CGI, the user may perform a preliminary access check of whether it is allowed to the CSG cell in order to help the network only to initiate the handover preparation toward an allowed CSG cell. In network-based solutions, the network (eNB for LTE) takes care of resolving the PCI confusion.

IV. Power Control in Two-Tier Femtocell Networks

Femtocells or home base stations are being used to improve indoor coverage and capacity. Femtocell users experience superior indoor reception and can lower their transmit power. Consequently, femtocells provide higher spatial reuse and cause less interference to other users. Due to cross-tier interference in a two-tier network with shared spectrum, the target per-tier SINRs among macrocell and femtocell users are coupled.

Contemporary wireless systems employ power control to assist users experiencing poor channels and to limit interference caused to neighboring cells. In a two-tier network however, cross-tier interference may significantly hinder the performance of conventional power control schemes because a user on the cell-edge transmits with higher power to meet its receive power target, and causes excessive cross-tier interference at nearby femtocells.

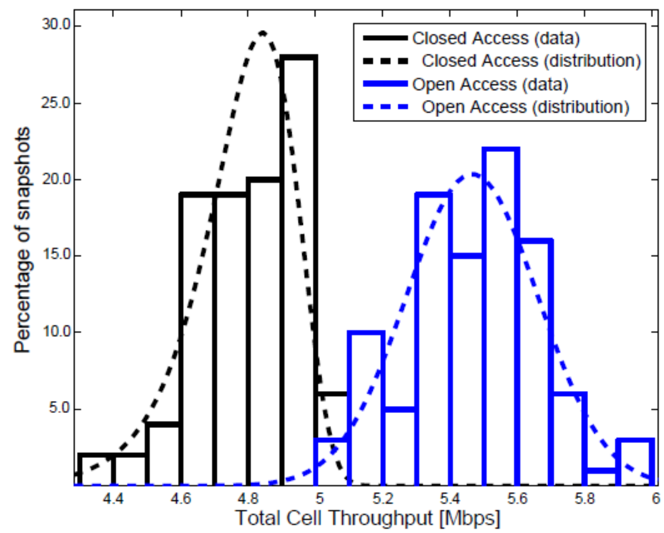


Fig. 4. Total downlink network throughput in a residential (200 x 100 m) area covered by 22 OFDMA femtocells and 1 macrocell (10MHz bandwidth). Each house hosting a femtocell contains 2 indoor users demanding 128 kbps each. Furthermore, 10 macro users were located outdoors demanding 64 kbps each. The system-level simulation is based on Montecarlo snapshots [9]

Interference management in two-tier networks faces practical challenges from the lack of coordination between the macrocell base-station (BS) and femtocell APs due to reasons of scalability, security and limited availability of backhaul bandwidth.

[4] assumes Closed Access (CA), which means only licensed home users within radio range can communicate with their own femtocell. With CA, cross-tier interference from interior femtocells may significantly deteriorate the SINR at the macrocell BS.

The macrocell is modeled as primary infrastructure, meaning that the operators foremost obligation is to ensure that an outdoor cellular user achieves its minimum SINR target at its BS, despite cross-tier femtocell interference. Indoor users act in their self interest to maximize their SINRs, but incur a SINR penalty because they cause cross-tier interference.

A. System Model

The system consists of a single central macrocell B_0 serving a region $\mathcal{C}$, providing a cellular coverage radius $R_{\mathcal{C}}$. The macrocell is underlaid with N cochannel femtocells APs B_i, $i \geq 1$. Femtocell users are located on the circumference of a disc of radius R_f centered at their femtocell AP. Orthogonal uplink signaling is assumed in each slot (1 scheduled active user per cell during each signaling slot), where a slot may refer to a time or frequency resource.

Ignoring the cochannel interference from neighbouring cellular transmissions for analytical tractibility. During a given slot, let $i \in \{0, 1, ..., N\}$ denote the scheduled user connected to its BS B_i. Designate user i's transmit power to be p_i Watts. Let σ^2 be the variance of Additive White Gaussian Noise (AWGN) at B_i. The received SINR γ_i of user i at B_i is given as

$$\Gamma_i \leq \gamma_i = \frac{p_i g_{i,i}}{\sum_{j \neq i} p_j g_{i,j} + \sigma^2} \quad (1)$$

Here Γ_i represents the minimum target SINR for user i at B_i. The term $g_{i,j}$ denotes the channel gain between user j and BS B_i. In matrix-vector notation, (1) can be written as

$$\mathbf{p} \geq \mathbf{\Gamma G p} + \boldsymbol{\eta} \; and \; \mathbf{p} \geq 0 \quad (2)$$

Here $\mathbf{\Gamma} \triangleq \text{diag}(\Gamma_0, ...\Gamma_N)$ while the vector $\mathbf{p} = (p_0, ..., p_N)$ denotes the transmission powers of individual users, and the normalized noise vector equals $\boldsymbol{\eta} = (\eta_0, ...\eta_N)$, $\eta_i = \sigma^2 \Gamma_i / g_{i,i}$. The $(N+1)(N+1)$ matrix $\mathbf{G} \geq 0$ is assumed to be irreducible meaning its directed graph is strongly connected - with elements given as

$$G_{ij} = \frac{g_{i,j}}{g_{i,i}}, i \neq j \; and \; 0 \; else \quad (3)$$

For all $\boldsymbol{\eta} \geq \mathbf{0}$,

$$(\mathbf{I} - \mathbf{\Gamma G})^{-1} \boldsymbol{\eta} \geq \mathbf{0} \Leftrightarrow \rho(\mathbf{\Gamma G}) < 1 \quad (4)$$

where the spectral radius $\rho(\mathbf{\Gamma G})$ is defined as the maximum modulus eigenvalue $\max\{|\lambda| : \mathbf{\Gamma G} - \lambda \mathbf{I}_{N+1} \text{ is singular}\}$. The solution of (2) $\mathbf{p}^* = (\mathbf{I} - \mathbf{\Gamma G})^1 \boldsymbol{\eta}$ guarantees that the target SINR requirements are satisfied at all BSs. Further, $\mathbf{p}^*$ is Pareto efficient in the sense that any other solution $\mathbf{p}$ satisfying (2) needs at least as much power componentwise. When $\mathbf{\Gamma} = \gamma \mathbf{I}_{N+1}$, then the max-min SIR solution γ^* to (4) is given as

$$\mathbf{\Gamma} = \Gamma \mathbf{I}_{N+1} \Rightarrow \Gamma^* = \frac{1}{\rho(\mathbf{G})} \quad (5)$$

B. Per-tier SINR Contours in a Femtocell-Underlaid Macrocell

In a two-tier network, let $\Gamma_{\mathcal{C}} = \Gamma_0$ and $\Gamma_i (i \geq 1)$ denote the per-tier SINR targets at the macrocell and femtocell BSs respectively. Define $\mathbf{\Gamma_f} \triangleq \text{diag}(\Gamma_1, ..., \Gamma_N)$ and $\mathbf{\Gamma} = \text{diag}(\mathbf{\Gamma_{\mathcal{C}}}, \mathbf{\Gamma_f})$. Any feasible SINR tuple ensures that the spectral radius $\rho(\mathbf{\Gamma G}) < 1$ with a feasible power assignment given by (4). Then

$$\mathbf{\Gamma G} = \begin{pmatrix} 0 & \Gamma_{\mathcal{C}} \mathbf{q}_{\mathcal{C}}^T \\ \mathbf{\Gamma}_f \mathbf{q}_f & \mathbf{\Gamma}_f \mathbf{F} \end{pmatrix} \quad (6)$$

Here the principal submatrix $\mathbf{F}$ consists of the normalized channel gains between each femtocell and its surrounding $N1$ cochannel femtocells. The vector $\mathbf{q}_{\mathcal{C}}^T = [G_{01}, ..., G_{0N}]$ consists of the normalized cross-tier channel gains between the transmitting femtocell users to the macrocell BS. Similarly, $\mathbf{q}_F = [G_{10}, ...G_{N0}]^T$ consists of the normalized cross-tier channel gains between the cellular user to surrounding femtocell BSs.

Theorem: Assume a set of feasible femtocell SINRs targets Γ_i $(i \geq 1)$ such that $\rho(\mathbf{\Gamma}_f \mathbf{F}) < 1$, and a target spectral radius $\rho(\mathbf{\Gamma G}) = \kappa, \rho(\mathbf{\Gamma}_f \mathbf{F}) < \kappa < 1$. The highest cellular SINR target maintaining a spectral radius of κ is then given as

$$\Gamma_{\mathcal{C}} = \frac{\kappa^2}{\mathbf{q}_{\mathcal{C}}^T [\mathbf{I} - (\mathbf{\Gamma}_f / \kappa) \mathbf{F}]^{-1} \mathbf{\Gamma}_f \mathbf{q}_f} \quad (7)$$

Given a set of N feasible femtocell SINR targets, Theorem 1 provides a fundamental relationship describing the maximum SINR target at the macrocell over all power control strategies. Given a κ (e.g. $\kappa = 1 - \epsilon$, where $0 < \epsilon < 1\rho(\mathbf{\Gamma}_f \mathbf{F})$), one obtains the highest $\mathbf{\Gamma}_{\mathcal{C}}$ for a given $\mathbf{\Gamma}_f$.

With $\mathbf{\Gamma}_{\mathcal{C}}$ obtained from (7) and SINR targets $\mathbf{\Gamma}^* = [\Gamma_{\mathcal{C}}, \Gamma_1, ..., \Gamma_N]^T$, a centralized power allocation is given as

$$\mathbf{p}^* = (\mathbf{I} - \mathbf{\Gamma}^* \mathbf{G})^{-1} \boldsymbol{\eta}^*$$
$$\text{where } \boldsymbol{\eta}^* \triangleq \text{diag}\left(\frac{\sigma^2}{g_{1,1}}, \frac{\sigma^2}{g_{2,2}}, ..., \frac{\sigma^2}{g_{N+1,N+1}}\right) \mathbf{\Gamma}^* \quad (8)$$

Next, assume that the N femtocells $B_1 ... B_N$ choose a common SINR target $\Gamma_i = \Gamma_f$ $(i \geq 1)$.

Corollary: Assume a common positive target femtocell SINR target $\Gamma_f < 1/\rho(\mathbf{F})$, and a target spectral radius $\rho(\mathbf{\Gamma G}) = \kappa$, where $\Gamma_f \rho(\mathbf{F}) < \kappa < 1$. The Pareto contours maintaining a spectral radius of κ are given as

$$\left\{ (\Gamma_{\mathcal{C}}, \Gamma_f) : \Gamma_f < \frac{1}{\rho \mathbf{F}}, \Gamma_{\mathcal{C}} = \frac{\kappa^2}{\Gamma_f \mathbf{q}_{\mathcal{C}}^T [\mathbf{I} - (\Gamma_f / \kappa) \mathbf{F}]^{-1} \mathbf{q}_f} \right\} \quad (9)$$

But due to the absence of coordination between tiers, implementing centralized power control will likely be prohibitively difficult. Authors of [4] have proposed a utility-based SINR adaptation scheme using miroeconomic concepts.

V. Improving Energy Efficiency of Femtocell Networks

There has been strong research interest in realizing green networks in recent years. However, only a little attention was paid to the energy efficiency in femtocell networks or macro-femto heterogeneous networks. Power control is one of the methods of improving the energy efficiency of these networks. In this section we will look at sleeping schemes for improving the energy efficiency.

A. Dynamic Idle/Sleeping Schemes

A femtocell commonly serves a few users, especially when it is deployed indoors. At most times, a femtocell is idle as there are no users requiring services from the femtocell, which is different from the macrocell. Thus, the most energy-efficient method is to switch off the femtocell being idle when there are no active users. In [6], the authors proposed two dynamic idle mode schemes, idle mode based on noise rise and reducing pilot power when Idle, which allow the femtocells transmitter and associated processing to be switched off completely when the femtocell does not need to support an active call. In [7], a sleep mode scheme is proposed for a single femtocell. In this scheme, a femtocell saves energy by aligning the listening windows of multiple mobile users. By doing this, the femtocell sends data to mobile users at the same transmit intervals. Minimum and maximum sleep intervals are defined, and adaptively changed based on traffic. Using Markov decision processes (MDPs), [8] proposes optimal sleep/wake up schemes for macro-femto heterogeneous networks, in which femtocells work in open access mode and can offload traffic from the macrocell. The basic idea of the proposed schemes is: when the macro-femto heterogeneous network is not highly loaded and the macro base station can alone handle the traffic, the femtocells are switched off; as the load increases, one or more femtocells are selected to be switched on.

The main focus of power control schemes is to manage interference, improve throughput, and conserve energy consumption while the RF and hardware of FBSs are always on; accordingly, the energy efficiency of power control schemes is limited. In contrast, idle/sleeping schemes focus on designing various approaches to turn on/off the RF and some hardware parts of FBSs, which could potentially save more energy but cause longer latency than power control schemes. On the other hand, power control schemes and idle/sleeping schemes are complementary with each other. Idle/sleeping schemes manage on/off switching of FBSs, while power control schemes adjust transmission power when FBSs are turned on. In reality, both types of energy conservation schemes can be deployed as in Long Term Evolution (LTE) systems, but may be applicable for different applications. For instance, idle/sleeping schemes are generally not suitable for real-time applications such as video streaming, but are more appropriate for applications with sporadic traffic such as smart metering. However, power control schemes could be a better choice for scenarios with densely distributed femtocells or supporting time-sensitive applications.

1) Fixed Time Sleeping Scheme: In FTS, an FBS works as follows. When there is no active user, it periodically alternates between sleeping and active states in an alternating fashion. The durations of active and sleeping periods are T_a and T_s, respectively. Both T_a and T_s are deterministic. In the active state, if access requests from users are received, the femtocell will serve these users until all the services terminate; then the femtocell will again alternate between sleeping and active states. When a femtocell is in the off state, access requests from users will not receive responses. If a users call or service request is not met by a femtocell, a call loss (CL) event occurs. To decrease the call loss ratio, which is the number of CLs divided by total call requests, we let the user wait for some time when they want to access the sleeping femtocell. We define T_w be the maximum waiting time a user can wait for a femtocell to be operational.

In the given FTS scheme, an FBS works in active or sleeping states, and all user equipment (UE) devices delay their accesses in a distributed manner. We do not schedule the active/sleeping time of an FBS or the maximum waiting time of UE by centralized methods. The FBS(s) (UE) can set its (their) active/sleeping time (T_w) according to its (their) local time clocks. When an FBS is back in the active state from the sleeping state, it will transmit a synchronization signal, and UE devices will synchronize to the FBS after detecting the synchronization signal. [5] simulates this and provides a performance evaluation for this scheme.

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