A Survey on Power Control Techniques in Femtocell Networks

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Abstract**—**Rapid increase in mobile data has raised the stakes on developing innovative new technologies and cellular topologies that can meet these demands in an energy efficient manner. One of the most interesting trends that will emerge from this cellular evolution is the femtocell networks. Femtocells are small, inexpensive, low power base stations that are generally consumer deployed, and are expected to significantly improve the coverage and capacity of the indoor users. Femtocell base stations (FBSs) have extensive auto configuration and self-optimization capability to enable simple plug-and-play deployment. The FBSs perform self-optimization function that continually adjusts the transmit power so the femtocell coverage does not leak into an outdoor area while sufficiently covering the indoor femtocell area. In this paper, different power control techniques in femtocell networks have been discussed and compared. The focus is on distributed power control techniques due to the decentralized nature of femtocell networks. The conclusion drawn from this review is that the distributed power control techniques using pilot power control schemes are simple and effective in optimizing the coverage of femtocells as well as reducing power consumption of the FBS. Furthermore a novel algorithm is still needed to perform power control optimization in femtocell networks.

Index Terms**—**heterogeneous networks, femtocell, power control

I. Introduction

Over the last decades, there is a dramatic increase in the traffic demands. This trend enforces the network service providers to rely on cell splitting or additional carriers to overcome capacity and link budget limitations while guaranteeing uniform user's quality of service experience. However, this deployment process is complex and iterative. Moreover, site acquisition for macro base stations with towers becomes more difficult in dense urban areas. A more flexible deployment model is needed for operators to improve broadband user experience in ubiquitous and cost effective way [1].

The 3rd Generation partnership Project (3GPP) Long Term Evolution-Advanced (LTE-A) standard has intensively discussed the support of heterogeneous networks (HetNet) [2]. Fig. 1, shows the concept of HetNet discussed in 3GPP. HetNet is a collection of low power nodes distributed across a macrocell network to improve the capacity and coverage of the network. There are various types of low power nodes including microcells, picocells, femtocells and relays, which are deployed in various environments including hotspots, homes, enterprise environment and low geometry locations [3]. Table I contains a comparison between some of these nodes.

Recent studies on wireless usage show that the major growth in data traffic originates indoors [4], where the majority of mobile users suffer from inadequate indoor signal penetration, which lead to poor coverage provided to consumers and they do not enjoy the full data capacity marketed by operators. In the light of the above facts femtocells are now seen as a good solution for providing higher capacity and coverage for in-building network environments [5].

To deploy femtocells in real network environments, there are many problems need to be considered, such as interference avoidance, handover, synchronization, cell selection, and self optimizing networks.

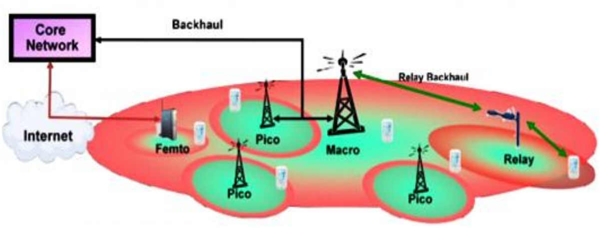

Fig. 1. The concept of heterogeneous networks [2].

TABLE I: A COMPARISON BETWEEN SOME LOW POWER NODES

Properties	Cell Type		
	Microcell	Picocell	Femtocell
Power	30dBm	30dBm	20dBm
Coverage range	Up to 500m	<100m	<30m
Backhaul	X2 interface	X2 interface	Home broadband
Access mode	Open to all users	Open to all users	Closed subscriber group
Deployment	Outdoors	Indoors or outdoors	Indoors
Installation	By the operator	By the operator	By the user
Cost	Expensive	Cheap	Very cheap

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There are three technical factors that can determine the successful implementation of the femtocell technology: (i) the guaranteed coverage area of the cell, (ii) the auto-configuration and the self-optimization capabilities of the cell, and (iii) the core network signalling caused by the user mobility.

The transmit power level of a femtocell base station affects its coverage range and the amount of interference it generates in the network. Although higher femtocells transmit power can provide wider coverage and better signal quality, it can, at the same time, cause tremendous interference to other surrounding users of the adjacent macrocell networks. Properly selecting the femtocell base station transmit power level can help manage the interference from the femtocells to the macro-users, while maintaining femtocells performance. One of the conventional practices is by applying transmitter power control technique. It is widely adopted as it can mitigate the femto-femto (co-tier) as well as femto-macro (cross-tier) interference and increase the network capacity.

Power control techniques in cellular networks have been studied in the literature. References [6,7,8] provide an extensive review on the subject. These papers present the big picture of this research area by classifying the works into its main research sub-areas. The classification in these papers is based on fundamental approaches for power control, particularly for conventional wireless networks with one tier. However, in femtocell networks, the femto base stations are installed in an ad-hoc manner without proper planning by the network operators or the femtocell owners. This increases the technical challenges for power control due to the decentralized architecture of the femtocell networks and there is uncertainty in terms of coordination between different number of femtocell base stations in a particular location. Therefore, power control technique approaches in the femtocell environment will be implemented in different ways, which is beyond conventional wireless network planning and optimization techniques. In case of dense deployment of femtocells, a sufficient power control technique is needed, can cope with the ad-hoc nature of femtocells and provide quality of service for both macro and femto users. It should also be kept in mind that the femto base station is a small low powered device and it should be able to handle the complexity of these techniques. Based on these reasons, different considerations should be taken when providing a classification of power control techniques in femtocell networks.

The major goal of this paper is to provide a comprehensive survey of power control techniques for femtocell networks. An analytical survey of the current contributions in the literature and comparisons between different power control techniques will be provided. Due to the ad-hoc nature of femtocell networks, the focus is more on distributed power control techniques. In addition, future directions related to the challenges in power control technique will be addressed at the end of this article.

This paper is organized as follows: section II provides an overview of femtocell technology and its benefits. The power control in femtocells and the proposed schemes in the literature are presented in sections III and IV respectively. A comparison between different power control techniques and our future work are presented in section V. Concluding remarks are given in section VI.

II. Femtocell Network Architecture and Properties

Femtocell also known as Home enhanced NodeB (HeNB) in 3GPP standardization, is a small size, low power (<10mW) base station with short service range (<30m) and can support under 10 users simultaneously. Fig. 2, shows the basic femtocell network in 3GPP LTE-A standard [9].

HeNB is considered as a plug-and-play consumer device, which is easily installed by the users. Unlike WiFi, femtocell operates in licensed spectrum owned by the wireless operators and can be deployed with macrocell networks in the same frequency (co-channel deployment) or different frequency (dedicated-channel deployment). Femtocell utilizes the user's existing broadband internet access (e.g. Digital Subscriber Line (DSL), cable modem, optical fibres, etc.) as a backhaul to communicate with the mobile operator core network [10].

A. *Access Modes*

One of the key features in any cellular model that includes femtocells is the type of access strategy. There are three types of access control modes for femtocells: (i) closed, (ii) open and (iii) hybrid mode.

For the closed access, only closed subscriber group (CSG) is allowed to connect to the femtocell. This mode is preferred by the femtocell owners but it can cause severe cross-tier interference to neighbours that are using macrocell services. On the other hand, the open access mode (OSG) allows all the users to have access to any femtocell network. This could mitigate the cross tier interference but in the cost of increasing the number of handoffs, in addition to increase in signalling on the core network mobility.

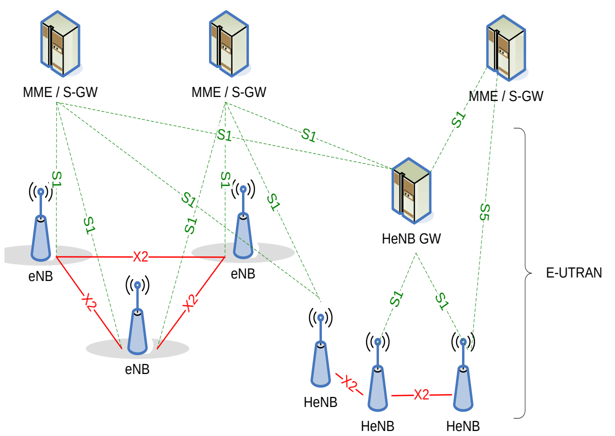


Fig. 2. Femtocell network in LTE-A Systems [9].

In hybrid access mode, only a particular outside users are allowed to access a femtocell. The conditions of access can be defined by each operator separately and entry to any guest or new user can be requested by the owner. The femtocell should have the capability to select the number of outside users to be allowed to access by keeping in view the performance of authorized users in a particular femtocell [11].

B. Femtocell Benefits

From the technical and business point of view, femtocells offer the following benefits:

- Coverage and capacity improvement: Because of their operation on a short transmit-receive distance, a higher signal-to-interference-plus-noise ratio (SINR) could be achieved. These translate into improved reception and higher capacity [12].
- High data rates and call quality: The improved coverage enables mobile phones to work at the peak of their capabilities.
- Improved macrocell reliability: Femtocell allows operators to offload a significant amount of traffic away from macrocell.
- Cost reduction for mobile operators: Femtocell minimizes the capital and operational expenditure by reducing the additional time for installation and operation cost.
- Compelling new femtozone services: Using the specific knowledge of the user's location femtocell can offer extra benefits such as control of devices around the home.
- Simple deployment: Femtocells are designed to be simple to install, configure and operate (zero touch installation) [13].

III. Power Control in Femtocells

The transmit power of HeNB 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. Furthermore, large pilot power may introduce high outage probability to neighbouring non-CSG users due to interference [14].

HeNBs have extensive self-organization capabilities to enable simple plug-and-play deployment and are designed to automatically integrate themselves into an existing macrocell network. These self-capabilities are implemented using an algorithm that automatically changes certain network configuration parameters (radiated power, channels, neighbour list, and handover parameters) in response to any change in the environment it is operating in. In order to successfully execute the process of self-organization, there are three main functions need to be performed: (i) Self-configuration in pre-operational state, (ii) Self-optimization in an operational state, and (iii) Self-healing in case of failure of a network element. One example of self-organizing capabilities in femtocell deployments is power optimization. In this way a self-configuration function can transmit power based on the measurement of interference from neighbouring base stations in a manner that achieves roughly constant cell coverage. The HeNB then performs a self-optimization function that continually adjusts the transmit power, so that the femtocell coverage does not leak into an outdoor area while sufficiently provides indoor coverage [15].

In general power control is adopted for at least one of the following reasons: (i) to mitigate the interference in order to increase capacity of the network, (ii) to conserve energy in order to prolong battery live, and (iii) to adapt to channel variations in order to support Quality of Service (QoS) [8].

Power control algorithms are advantageous in that the macro-eNB (MeNB) and HeNB can use the entire bandwidth with interference coordination. The dynamic power setting can be performed either in a proactive or interactive manner each of which again can be performed either in open loop power setting (OLPS) mode, where the HeNB adjust its transmission power based on its measurement results or a predefined system parameters, or closed loop power setting (CLPS) mode in which the power adjustment is done by the HeNB based on the coordination with MeNB [16].

IV. Classification of Power Control Techniques

Different power control techniques in femtocell networks have been proposed in the literature. These techniques could be classified according to different criteria such as non- assistance-based vs. assistance-based, centralized vs. distributed techniques. We hereafter present a brief overview of the state of the art on power control techniques. Fig. 3, illustrates the classification of power control techniques in femtocell networks that we are going to analyze in the following sections.

A. Non-Assistance-Based Methods

In this category HeNB sets its transmission power according to itself measurement reports or predetermined system parameters.

1) Fixed HeNB power setting

In this scheme HeNB transmission power is fixed. This means that the HeNB would not consider any surrounding information. In this case, when a macro user (MUE) is close to a HeNB which is deployed at the edge of MeNB cell, the interference from the HeNB to the MUE would be high since the desired signal level from MeNB to MUE would be smaller than the interference signal from HeNB to MUE. This would lead to a need for adjustable HeNB power setting scheme based on surrounding information [17].

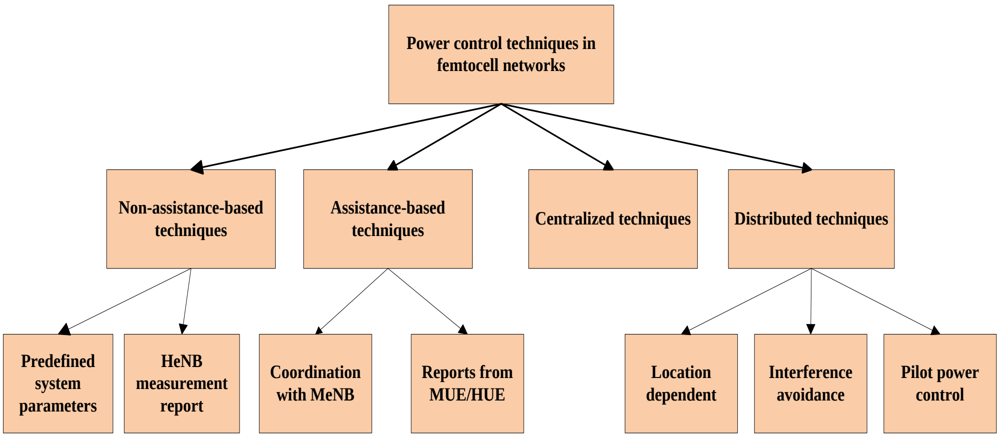


Fig. 3. Classification of power control techniques in femtocell network.

2) Strongest MeNB received power at HeNB

In [17] the power setting is based on the strongest MeNB received power at HeNB. In this technique, HeNB adjusts its transmission power according to the following formula:

$$P_{tx} = \max\left(\min\left(\alpha.P_m + \beta, P_{\max}\right), P_{\min}\right)[\text{dBm}] \qquad (1)$$

where, P_{max} and P_{min} are the maximum and minimum transmit power of the HeNB, respectively, P_m denote the received power from the strongest co-channel MeNB on HeNB. α is a linear scalar that allows altering the slope of power control mapping curve, and β is a parameter expressed in dB that can be used for altering the exact range of P_m covered by dynamic range of power control.

However the measurement of MeNB received power might be insufficient in some operation scenarios, especially when HeNB and HUEs are located in different rooms or floors as shown in Fig. 4. Therefore without the measurement reports from MeNB/MUE/HUE, this technique may determine an inaccurate value for the HeNB power setting. When HeNB measures a relatively higher RSRP from MeNB as shown in Fig. 4 (a), it may set a relatively higher transmit power. This may increase the interference level to the MUEs. On the other hand, when HeNB measures a relatively lower RSRP from MeNB as depicted in Fig. 4 (b), it may set a relatively lower transmit power. Although the interference to MUEs is decreased, the HeNB coverage is significantly reduced. Therefore, this mechanism could be adopted when HeNB is turned on or when HeNB cannot receive measurement reports from HUE/MUE.

B. Assistance-Based Methods

In this category HeNB sets its transmission power based on measurement reports from MUE/HUE or the coordination with MeNB.

1) Pathloss between HeNB and MUE

The transmission power of the HeNB is set as:

$$P_{tx} = median\left(P_m + P_{offset}, P_{\max}, P_{\min}\right)[\text{dBm}] \qquad (2)$$

where power offset is defined by:

$$P_{offset} = median\left(P_{inter-pathloss}, P_{offset-\max}, P_{offset-\min}\right) \qquad (3)$$

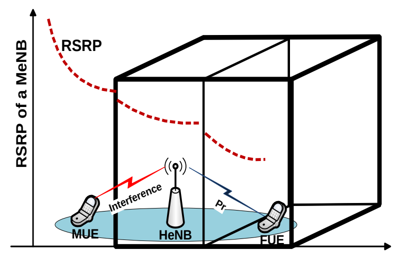
with $P_{inter\_pathloss}$ denoting a power offset value that captures the indoor pathloss and penetration loss between HeNB and the nearest MUE, and P_{offset_max}, P_{offset_min} are the maximum and minimum values of power offset, respectively [18].

This method can provide better interference mitigation for MUE and maintain good HeNB coverage for HUE. However the signalling between the HeNB and MUE or between MeNB and HeNB is required. If HeNB cannot successfully receive the MUE measurement reports, this method cannot work properly.

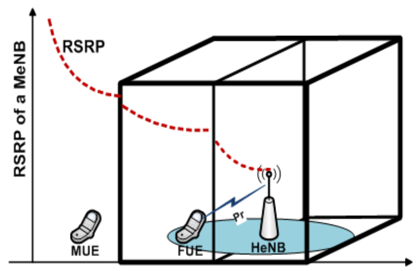
2) Objective SINR of HUE

HeNB sets its transmission power based on HUE measurement and the objective SINR of HUE, using the following equation.

$$P_{HeNB} = \max\left(P_{\min}, \min\left(PL_{estimation} + P_{HUE\_received}, P_{\max}\right)\right)[\text{dBm}] \quad (4)$$



(a) Small penetration loss



(b) Large penetration loss

Fig. 4. Scenarios where HeNB transmit power is not appropriately set.

where the $PL_{estimation}$ is the pathloss estimated between HeNB and the HUE, with

$$P_{HUE\_received} = 10\log_{10}\left(10^{I/10} + 10^{N_0/10}\right) + x[\text{dBm}] \qquad (5)$$

where, I is the interference detected by the served UE, N_0 is the background noise value, x is the target SINR for the HUE [19].

The purpose of this technique is to reduce the interference to MUE by restricting received power of HUE to a desired level. Since HUE is connected to HeNB, HUE can report the measurement information to its serving HeNB, which can enhance the accuracy of power setting.

3) Objective SINR of MUE

This method is based on SINR sensing by MUE, and the HeNB transmit power is given by:

$$P_{tx} = \max\left(\min\left(\alpha.P_{SINR} + \beta, P_{\max}\right), P_{\min}\right)[\text{dBm}] \qquad (6)$$

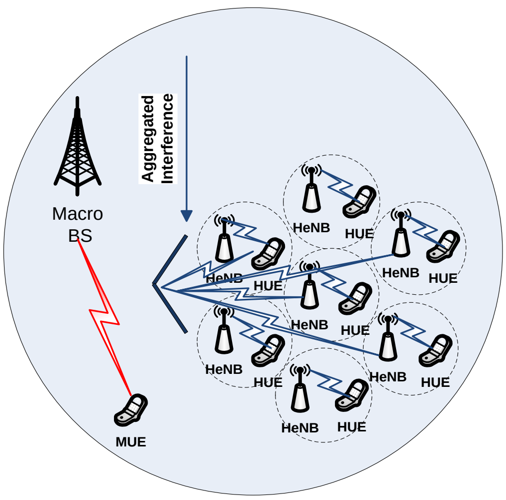
where, the P_{SINR} is defined as the SINR between the MUE and the nearest HeNB [20].

The aim of this method is to guarantee a minimum SINR at the MUEs to protect the reception of control channel of MUEs.

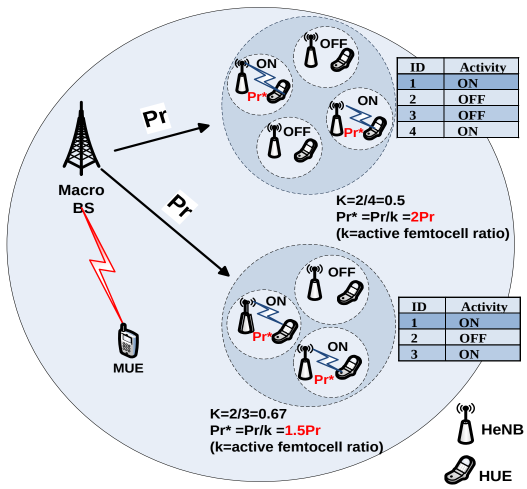
Table II represents a comparative summary of assistance-based vs. non-assistance-based power control techniques for femtocell networks.

TABLE II: SUMMARY OF ASSISTANCE-BASED VS. NON-ASSISTANCE-BASED POWER CONTROL TECHNIQUES NODES

Scheme	Scheme Classification	Scheme principle	Cooperation among femto and macro	Access mode	Advantage	Disadvantage
Fixed HeNB power setting [17]	Assistance-based	Predetermined system parameters.	Not required	Closed, open, and hybrid	(i) Only 1.0% of FUEs could be in outage. (ii) High FUE throughput (56.6Mbps). (iii)Simple and easy to implement.	18% of MUEs could be in outage.
Strongest MeNB received power at HeNB [17].	Assistance-based	HeNB Measurement reports	Not required	Closed, open, and hybrid	(i) MUEs outage is reduced to 8.7%. (ii) Suitable for scenarios where the reports from MeNB/MUE/HUE are not available.	(i) FUE throughput decreased to 46.7Mbps. (ii) Measurements might be insufficient in some operation scenarios.
Pathloss between HeNB and MUE [18].	Non-assistance-based	HeNB and MUE measurement reports	Required	Open and hybrid	(i) Outage reduction up to 7.4% for MUEs. (ii) Maintaining good HeNB coverage.	HeNB should communicate with MeNB or MUE to get reports from MUE and that would have a great impact on RAN specification.
Objective SINR of HUE [19].	Non-assistance-based	HUE measurements and objective SINR of HUE	Not required	Closed, open, and hybrid.	Improve the cell- edge HUEs spectral efficiency by 11.9% compared to no PC scenario.	This method cannot work before HeNB receives the signalling from HUE.
Objective SINR of MUE [20].	Non-assistance-based	SINR sensing of MUE	Required	Open and hybrid	The outage of MUEs is minimized to 6.0%.	(i) FUE throughput is reduced to 37.2Mbps compared to FPS. (ii) MUE need to report SINR to HeNB however there is no direct connection between HeNB and MUE .



(a) Centralized sensing



(b) Distributed sensing

Fig. 5. Sensing-based opportunistic power control [21].

C. Centralized Techniques

The centralized power control technique needs a central controller and global information of all the link gains. Moreover it requires extensive control signalling in the network and it is subject to delays and congestion of wireline internet access. Therefore distributed techniques that only use local information to make a control decision are easier to implement, due to the decentralized nature of the femtocells and the uncertainty about the number and location of the femto base stations.

The concept of power control for HeNB on a cluster basis in which the initial power setting for HeNB is done opportunistically based on the number of active femtocell in cluster (Fig. 5) is proposed in [21]. The algorithm reflects the number of active femtocell per cluster to effectively control the aggregate interference. Two sensing algorithms are proposed, the centralized sensing in which a MeNB can estimate the number of active femtocells per cluster and broadcast the interference allowance information to femtocells for their initial power setting. Alternatively, distributed sensing is used where each cell senses if the others are active in the same cluster and adjusts its initial power setting accordingly.

The simulation results show that in distributed sensing algorithm, the outage probability is kept to lower level than the centralized sensing algorithm. This is because each femtocell is initially allocated a lower transmit power than the centralized sensing, which result in lower aggregate interference in macro base station. On the other hand the total cell throughput of distributed sensing algorithm incurs about 1.9% of loss when compared to the centralized sensing.

D. Distributed Techniques

The distributed power control techniques can avoid the bottleneck effect of a centralized entity. Some examples of such approach are given hereafter:

1) Location dependent power control schemes

The basic requirement for a femtocell is to provide strong signal strength to the UEs within its coverage. On the other hand, the femtocell transmitted power should not be too large to create strong interference to neighbouring femtocells or macrocell UEs.

A method that discriminates between indoor and outdoor users in a simplified way is in [22]. The discrimination procedure is divided into two stages. The first one is solely performed by the HeNB and is based on the reference signal received power (RSRP). The second stage is performed using the information gained from the MeNB in the vicinity. Since served femto UEs (HUEs) only reports the RSRP from the nearest MeNB, these reports do not provide sufficient information for power control. Thus the location information gained from the discrimination procedure together with the required SINR for the HUE is used to perform power control for the HeNB. The simulation results show that the proposed scheme outperforms the random power scheme by providing higher SINR for the HUEs.

However the performance gap between the proposed scheme and the random method has decreased in environments with higher shadowing effect. This is due to the decreased accuracy of positional state discrimination.

In [23] a location dependent power setting (LDPS) method has been proposed. In the LDPS the femtocell base station (FBS) measures the received signal strength (RSS) from the macrocell base station (MBS). If the FBS is closed to the MBS high power level is used to provide connection to its indoor users. When the FBS is located near the edge of the MBS the receiver sensitivity (-80dBm) should be taken into account so that the power will not be set to a value bellow it. This scheme has been used to open access femtocells and compared to the fixed power scheme (FPS) where all the FBSs within a certain region transmit at the same power level. The LDPS saves the FBS energy with an exception when the FBS is close to the MBS because in this case the FBS should use a high power level to provide connections to its indoor users.

2) Power control based interference avoidance schemes

The co-channel deployment of femtocells with macrocells is investigated in [24]. A novel macro user (MUEs) assisted HeNB power control scheme is proposed to keep the increased interference caused by femtocell low. The scheme adjusts the transmit power of the HeNB when receiving interference message from an MUE. Two timers T1 and T2 are used to control the decrease and increase of the transmit power of the HeNB, timer T1 is used to frequently reducing the transmit power. On the other hand, timer T2 is used to control the time when the HeNB should begin to increase the power transmission. The system level simulation results show that the proposed scheme can not only lower the interference to the victim MUE but also avoid unnecessary performance loss of a femtocell. However, the interference between the femtocell base stations is not considered in the study. Moreover the MUE needs to send interference messages to HeNB, yet there is no direct connection between HeNB and MUE, which implies possible delay and low reliability in transmitting the control information.

Reference [25] has focused on solving the down link interference problem. The power control based interference mitigation algorithms have been designed and evaluated. First the fixed power level operation is considered. Then two additional adaptive power control algorithms are designed: (i) Femto-QoS power control which performs FBS power back-off under the constraint of minimum QoS at Femto-users being maintained. And (ii) Macro-QoS power control which limits FBS interference to the macro network certain requirements of macro user performance. Results show that the FBS power control can reduce the number of macro users driven into outage by the FBS, but in the cost of reducing the femto user data rates.

The power control problem is formulated in [26] considering the worst case scenario, assuming no dominating interferer. A heuristic distributed algorithm is executed to determine the optimum power level, if no feasible solution for a sub-channel the algorithm determines the admissible subset of users on the given sub-channel by eliminating the interferers causing excessive interference level.

In order to reduce the interference, [27] suggests a new time-division-duplex (TDD) frame structure called listening-TDD frame (LTDDF) for femtocells. In LTDDF femtocell has both downlink and uplink periods during downlink period of macrocell. The uplink period in macrocell is used as a listening period in femtocell that is used to overhear signals from surrounding macrocell users (MUEs) to obtain their channel quality information (CQI). Based on the CQI of MUEs, the FBS adaptively adjusts its transmission power. Results show that using LTDDF helps to effectively mitigate the interference so MUE has better capacity than using a conventional TDD frame. However the capacity of femtocell decreases due to shorter downlink period than macrocell.

In [28], both functions of frequency channel allocation and transmission power adjustment are proposed. Each interfered HeNB reduces its transmit power, thus the handover procedure will be triggered for the victim HUEs to re-associate with another HeNB for better QoS. This algorithm is applicable only for open access femtocells. Moreover a dedicated channel scenario is assumed to reduce the cross-tier interference however the efficiency and flexibility of using the valuable spectrum will be scarified.

3) Pilot power control schemes

The issue of pilot power management is considered in [29], a simple switched multi-element antenna system is proposed, which allows to generate a set of different gain patterns by simply switching between one or multiple of the available antennas. Self-optimization methods are proposed, that jointly optimizes the pilot power and selects the appropriate antenna pattern. This allows better match the femtocell coverage to the shape of each individual house which in turn improves the indoor coverage and reduces the core network signalling resulting from mobility events.

In [30] users can access the femtocell according to three priority levels. The adaptive coverage coordination scheme dynamically optimizes the Femto-enterprise coverage according to the number of users per femtocell and their access level, while satisfying the decision criteria imposed by the threshold SINR condition.

Enterprise femtocell requires different deployment solutions as multiple units are necessary to jointly provide the capacity and coverage. Furthermore in public places the wireless environment is more complex and the interference is relatively serious whereas the distances between the femtocells are short. An approach for enhancing the pilot power and the antenna pattern of enterprise femtocell base stations is proposed in [31]. To reduce the complexity of the algorithm, the optimization procedure is divided into two steps: first the pilot power optimization approach based on Newton’s method is used to maximize the coverage while reducing overlapping area. For further reduction of overlapping and interference between femtocells and hence achieve better coverage, a joint selecting of all the FBSs antenna patterns is done using simulating annealing (SA) algorithm. Results show that the proposed algorithm improves the performance of the network, such as coverage, throughput and call drop ratio. The bottleneck of balancing coverage and interference is broken and more users can be served with increased throughput.

A focus on the problem of distributed FBS coverage optimization by means of updating the FBSs pilot channel transmit power is done in [32]. The algorithm consists of two update cycles: A more frequent P_{tx} update to achieve load balancing and infrequent BS minimum pilot power threshold update for reducing coverage holes and overlap. The algorithm makes use of the local status information of the FBS to take local decisions to achieve global objectives such as load balancing. The effectiveness of the algorithm is collaborating by means of simulating a realistic enterprise environment that encapsulates comprehensive channel and user mobility modeling.

Table III represents a comparative summary of distributed power control techniques for femtocell networks.

IV. Comparison of the Techniques

Several power control techniques have been discussed in this paper. The benefit of the non-assisted based techniques is that no signalling transaction is required between HeNB and MeNB/HUE/MUE. Hence they could be easily implemented. However these techniques are not adapted to the MUEs interference level from femtocell. Moreover there may be a significant difference between the RF conditions measured by HeNB and those experienced by MUEs or HUEs. On the other hand, the assisted-based techniques can only be adopted if the HeNB could successfully receive measurement reports from HUE/MUE or the coordination request from MeNB. Therefore the assisted-based and non-assisted-based techniques can be applied in different operational scenarios, hence HeNB should have a hybrid power setting scheme and it switches between power setting modes according to the operation scenario.

From the overall performance point of view, the network with centralized control can achieve better performance than with distributed control. The centralized algorithm can efficiently find the optimal solutions at low communication and computational cost when the system scale is small. Owing to the increased size of femtocell networks and the decentralized nature of femtocells and the uncertainty about the location and number of femto base stations, it becomes impractical to use the centralized algorithms. Developing distributed algorithm is a highly challenging task as these algorithms has to work without global information and coordinated central control of network nodes. However the distributed control avoids the bottleneck effect of centralized control entity and could improve reliability by eliminating the central entity failure effect; which is quite advantageous from the implementation point of view.

TABLE III: A SUMMARY OF DISTRIBUTED POWER CONTROL TECHNIQUES

Contribution	Scheme classification	Scheme principle	Access mode	Advantages	Disadvantages
Cho *et al*. [22]	Location dependent	Location of the femtocell user (i.e. indoor or outdoor)	Not provided	(i) Provides 7.5 dB gain for SINR of cell-edge HUEs. (ii) A 31.9% reduction in the outage of cell-edge HUEs is achieved compared to the random pick case.	The performance of the scheme decreases in environments with high shadowing effect (σ_{MeNB}=8dB, σ_{HeNB}=4dB).
Tsao *et al*. [23]	Location dependent	Distance between the FBS and MBS	OSG	LDPS scheme saves the FBS energy by not using excessive power.	(i) Low average UE SINR (13.3dB) compared to FPS. (ii) The scheme fails to save the FBS energy when it is located close to the MBS.
Wang *et al*. [24]	Interference avoidance	Interference messages from MUEs	CSG	(i) Improvement of cell-edge MUEs outage. (ii) Effectively avoid unnecessary adjustment of transmitting power.	A connection between MUE and HeNB is needed, yet no direct connection is available.
Yeh *et al*. [25]	Interference avoidance	Interference from the femtocell and the QoS to the users	CSG	The MUEs outage probability is reduced by 15% compared to FPS	Up to 14% degradation in FUEs data rates occurs compared to FPS since the FBS power level is lower.
Akbudak *et al*. [26]	Interference avoidance	SINR for each user.	CSG	(i) Delivers suboptimal results which are shown to be close to the optimal. (ii) Reduces the average total transmission power.	(i) A stationary network is assumed where the effect of user mobility is neglected. (ii) Cannot satisfy SINR of some users because it fails to defer some interference due to the usage of local information only.
Choi *et al*. [27]	Interference avoidance	New time division duplex (TDD) frame called listening-TDD	Not provided	Provides up to 30% higher MUE throughput than using traditional TDD by effectively mitigate cross-tier interference.	About 70% decrease in femtocell capacity could occur compared to conventional TDD due to shorter down link period.
Claussen *et al*. [29]	Pilot power control	Mobility-events of the pass by users and switched multi-elements antennas.	CSG	(i) An 18% improvement for indoor coverage is obtained compared to the single antenna solution. (ii) A simple one-to-four switch is used to keep the cost and complexity of the switching circuitry as low as possible.	Outdoor users may already experience bad link quality during the time that FBS reduces its transmit power after recognizing handover events for outdoor users.
Mhiri *et al*. [30]	Pilot power control	User access level and SINR.	Hybrid	(i) Overlapping ratio does not exceed 4.7% while it exceeds 33.8% using the traditional power scheme. (ii) The coverage is well optimized in response to femtocell load. (iii) Reduces energy consumption up to 50% when considering enterprise with stability level.	The value of the SINR threshold is fixed while it should be adjusted to ensure the optimization refinement of the overlapping area and the user QoS.
Li *et al*. [31]	Pilot power control	Optimize the pilot power based on Newton method and select antenna pattern based on simulating annealing (SA) method	Not provided	(i) A performance improvement of 18% in terms of supported traffic (Erlang) relative to FPS. (ii) A reduction of 80% in average pilot transmit power is achieved compared FPS.	The computational process is complex due to containing two parts for optimization.
Ashraf *et al*. [32]	Pilot power control	Local status information of the BS (neighbouring BS load, UE received power).	OSG	(i) About 8% improvement in average throughput is achieved compared FPS. (ii) Indoor user outage probability could be reduced up to 0.2%.	(i) FBSs are chosen randomly in each update slot to run the algorithm. (ii) Interference to macrocell users is not considered.

For distributed power control-based location techniques, when the power setting depends on location of HeNB to the MeNB the transmit power will be fixed and not adapted to the mobility of HUEs and MUEs and the QoS requirements for them. On the other hand, the techniques that require the location of the HUE would add more complexity due to the need of localization technique.

A substantial performance improvement (i.e. outage probability) could be achieved for the MUEs by using power control techniques based interference mitigation.

However this would be at the expense of the throughput degradation for the HUEs, therefore a trade off must exist.

The pilot power techniques are simple and effective in optimizing the coverage of femtocells, which can both significantly reduce the total number of mobility events caused by femtocells and improve indoor coverage of femtocells.

Motivated by what is mentioned above our future work is to propose an autonomous power control technique to manage the downlink interference in co-channel multi-tier macro-femto networks, while maintaining sufficient indoor coverage. In this scheme, the concept of coverage follows HUEs will be implemented by adjusting the transmit power of the HeNB based on the location of the HUE in the femtocell. However, the location will be estimated based on the path loss measurements of the HUE to eliminate the complexity of using positioning techniques. Moreover, the minimum level of power transmission will be constrained to the target SINR that could be set according to the QoS requirements, which usually stabilizes the actual HUE performance.

V. Conclusion

Femtocells are viewed as a promising option for the next generation wireless communication networks. In this paper, we have provided a critical review on different power control techniques in femtocell networks. Properly selecting the femtocell base station transmit power level would result in mitigating the interference from femtocells to macro-users while maintaining femtocell performance. In case of dense deployment of femtocells, a sufficient power control technique is needed that can cope with the ad-hoc nature of femtocells and provide quality of service for both macro and femto users. In designing power control techniques for femtocells, it should be kept in mind that femtocell base station is a small low powered device, but it should be able to handle the complexity of different power control techniques as highlighted in literature.

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