Evaluation of Femtocell Technology Challenges and Its Power Control Methodologies for Green Heterogeneous Networks

Mazen Al Haddad and Magdy Bayoumi
Center for Advanced Computer Studies, University of Louisiana at Lafayette, Lafayette, LA, U.S.A.

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Abstract: Femtocell technology brings extended low-power radio coverage directly in the indoor premises, where propagation loss is typically highest. It also enriches both macrocell wide-area and in-building solutions in terms of coverage & capacity. The integration of femtocells into heterogeneous cellular networks is foreseen as a low-power and low-cost solution to cope with the exponential growth of required data traffic volumes, offload the macro base stations and offer high performance mobile networks. However, the massive and unplanned deployment of femtocells and their uncoordinated operations may result in harmful co-channel interference and cause significant power waste in order to maintain an acceptable user performance. In this work, we survey the technical challenges of femtocells deployment and the available energy control techniques. Moreover, we look into adaptive mechanisms for femtocell technology to cover the way towards green-oriented mobile networks. Our intention is to examine how femtocell deployment can share the available radio resources efficiently in order to limit the average power consumption and mitigate co-channel interference. Besides the introduction of the basic ideas for optimizing the spectral and energy efficiency in femtocell networks, typical interference management techniques are discussed too, with a special emphasis on power control methodologies.

1 INTRODUCTION

Recent analysis has shown that wireless networks, not data centers, are the biggest energy drain in cloud services. This is because more and more people are accessing wireless networks with the prospect of being connected anywhere and anytime. Tablets, smartphones and laptops no longer need to connect to wireless networks via cable. Instead, WiFi or indoor/outdoor cellular solutions which are inherently energy inefficient and a heavy contributor to energy consumption are used (Bell Labs and University of Melbourne, 2013).

As shown in Figure 1, a femtocell is a cellular base station (BS) solution typically installed by the end-user and transmits with minimal transmission power to serve residential or small business environments. It connects to the service provider's network via broadband such as Digital Subscriber Lines (DSL) and typically supports only a few user equipments (UEs). Femtocells can be deployed in a variety of scenarios such as: Offices and residences (from single-family homes to high-rise buildings), public hotspots (shopping malls, airports, train/subway stations, stadiums) or outdoor public area sites.

Due to its advantages such as low cost and high energy efficiency, femtocell technology has been proposed and applied by the 3rd Generation Partnership Project (3GPP) in its Universal Mobile Telecommunications System (UMTS), Long-Term Evolution (LTE) networks and its Advancement (LTEA) (Knisely et al., 2009), (3GPP TR 36.814, 2010).

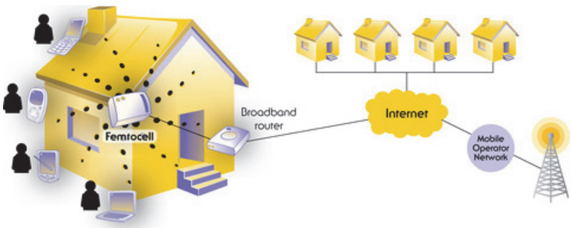

Figure 1: Basic Femtocell Network.

From the telecom provider's viewpoint, a significant amount of traffic can be moved from the macrocell networks to femtocell networks. Thus it reduces the number of macrocell BSs and equipments for backhaul transmission from macrocell BSs to their core network. This greatly

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diminishes cost and power consumption. From the customer's viewpoint, the femtocells can be conveniently deployed as desired, providing sufficient radio signals to the UEs whilst consuming less power in indoor environments. It may also not be powered at all times for further energy savings. The typical power consumption of a femtocell is likely to be in the range of a few Watts, which is obviously much less than that of macrocell BSs. One other benefit of femtocells is that they help the user's battery last longer indoors where data rate requirements are often highest. This is because less power is required to transmit a signal over the short distance to the femtocell rather than over the long distance to a macrocell BS.

As femtocells are customer-deployed without proper network planning, their interference mitigation is more complicated than the traditional macro-level networks. Thus, interference problems in femtocell networks cannot be solved by existing schemes typically used for macrocell deployments. In (Kan et al., 2011), it's shown that the interference can be categorized in two types, the interference between macrocell and femtocell (i.e., inter-tier interference) occurs when femtocells utilize the spectrum already allocated to the macrocell and the interference between femtocells themselves (i.e., intra-tier interference).

Without proper interference management, significant power is likely to be wasted in order to maintain an acceptable user performance and quality of service. For example, usually the high transmit power is radiated by a macrocell BS to provide the services for outdoor UEs. If no proper downlink power control is applied at the macrocell BS, interference is possibly generated to indoor UEs connected to the femtocell BS in case the whole or a part of the frequency band is shared between the femtocell and macrocell. Therefore, the femtocell BS has to increase its transmission power to maintain the communication with its indoor UEs. In this case, the overall energy consumption becomes even worse after deploying the femtocells. Interference management is therefore a key issue to being able to capitalize on the potential energy efficiency in femtocell networks.

In this paper, we analyze some power control techniques related to femtocell technology to mitigate the happening interference and keep energy saved where possible.

2 WHY SMALL CELLS AND FEMTO TECHNOLOGY?

Studies on wireless usage show that more than 50% of all voice calls and more than 70% of data traffic originates indoors (ABI Research, Picochip, Airvana, IP.access, Gartner, Telefonica Espana, 2007). For indoor devices, propagation and penetration losses will make high signal quality and hence high data rates very difficult to achieve.

In this sense, femtocells are the ideal complement to the macro network. A better, faster user experience is delivered from a lower power and a lower cost site. Customer-close sites can be deployed and re-deployed as data demand ebbs and flows in the network (The Small Cell Forum, 2013).

Types of small cells include femtocells, picocells, metrocells and microcells based on increasing size from femtocells (the smallest) to microcells (the largest). Any or all of these small cells can be based on 'femtocell technology'— i.e., the collection of standards, software, open interfaces, chips and know-how that have powered the growth of femtocells. Small cells are low-power wireless access points that operate in licensed spectrum and are feature edge-based intelligence. Femtocells or Home Node Bs have been a hot topic for quite some time since they offer benefits such as:

Improved Cellular Coverage and Capacity: femtocells facilitate a new variety of mobile services that exploit the technology's ability to detect presence, connect and interact with existing networks. The enormous gains reaped from smaller cell sizes arise from efficient spatial reuse of spectrum. In addition to the full coverage and high speed transmission at home, they increase the area spectral efficiency (total number of active users per Hertz per unit area) (Alouini and Goldsmith, 1999).

Better Link Quality, Significantly Lower Transmit Power and Prolong Handset Battery Life: because of their short transmit-receive distance, femtocells can greatly lower transmit power, prolong handset battery life, and achieve a higher signal-to-interference-plus-noise ratio (SINR). These translate into improved quality. The lowered transit power will mitigate interference from neighboring macrocell and femtocell users due to outdoor propagation and penetration losses.

Improved Macrocell BSs Reliability: when a pre-authorized MS enters the coverage of a home BS (femtocell), it automatically switches affiliation from the serving macrocell BS to the femtocell. Hence, initiating as well as receiving calls and data transmissions is performed as usual but through the femtocell network instead and over its IP backbone. This will enable the macrocell BS to redirect its resources towards providing better reception for mobile users and improve the service reliability and resource provisioning.

Offload Data Traffic from the Macrocell BSs: instead of deploying a lot of outdoor macrocell BSs, the heavy data traffic can be offloaded to femtocell networks. Offloading a fraction of the traffic to the femtocells will improve the macrocell BS capacity since it will have to handle less traffic.

Higher Performance and Customer Experience: weak in-building coverage causes customer dissatisfaction, encouraging customers to either switch operators or maintain a separate wired line whenever indoors. The enhanced home coverage provided by femtocells will improve customer satisfaction.

Cost-related Benefits: femtocell deployments reduce the operating and capital expenditure costs for network operators. The deployment of femtocells will reduce the need for adding macro BS towers. A recent study (Analysys Research Limited, 2007) shows that the operating expenses scale from $60K per year per macrocell to just $200 per year per femtocell. In addition, the end user will benefit too, for instance with special home-zone services— e.g., free calls, superior indoor coverage, and quality without changes in phones—and seamless services across all environments without dual or new hardware equipment.

3 FURTHER TECHNICAL FACTS ABOUT FEMTOCELL

The capacity potential of femtocells can be verified rapidly from Shannon's Channel Capacity law, which relates the wireless link capacity (bits/second) in a bandwidth to the Signal-to-Interference plus Noise ratio (SINR):

$$C = W \log 2 \left(1 + \frac{S}{N}\right) \quad (1)$$

[Where W is the bandwidth of the channel in Hz, S is the signal power in watts and N is the total noise power of the channel watts]. We could increase the capacity by increasing the amount of spectrum, if possible, or we could also increase the number of antennas at the transmitter and receiver, as done with MIMO (multiple input multiple output):

$$C = n * W \log 2 \left(1 + \frac{S}{N}\right) \quad (2)$$

[Where n here is # of antennas]. Another way to increase the capacity is to manipulate the SINR ratio. The SINR is a function of the transmission powers of the desired and interfering transmitters, path losses, fading and shadowing during terrestrial propagation. The transmitted signal is usually decomposed by Path losses. The simplest form of Path Loss is expressed in dB and can be calculated using the formula:

$$L = 10\, n \log 10\, (d) + C \quad (3)$$

[Where L is the path loss in decibels, n is the path loss exponent, d is the distance between the transmitter and the receiver, usually measured in meters, and C is a constant which accounts for system losses]. The key to increase capacity is to enhance reception between intended transmitter-receiver pairs by minimizing d and n.

Reducing distance to end-user and lowering femtocell transmit power will improve the capacity through increased strength and reduced interference. In addition, deploying femtocells will enable more efficient usage of precious power and frequency resources. Of course, the assumption here is that the wired broadband provides sufficient QoS over the backhaul. Otherwise backhaul capacity limitations could reduce the indoor capacity gains provided by femtocells.

New telecommunication radio technology like the Long-Term Evolution (LTE) network is reaching the limits of Shannon's law, the spectrum available for mobile data applications is limited, and the only solution for increasing overall mobile network capacity is to increase the carrier-to-interference ratio while decreasing cell size and deploying small cell technologies like femtocells.

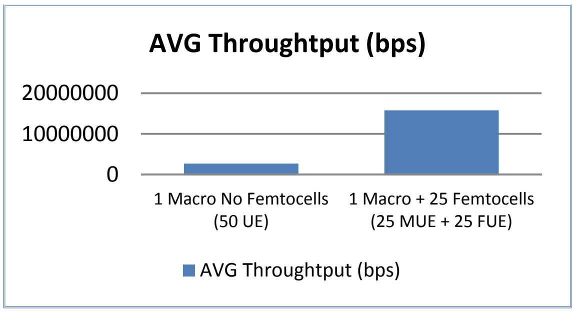

Figure 2: AVG. Throughput between UEs with/without femtocell deployment.

Example scenario - throughput as a function of macrocell / femtocell setup by using the simulator software in (Piro et al., 2011):

- Averaged Throughput, 1 macrocell deployment without femtocell support, and 50 UEs (all of them are served by the macrocell alone).

- Averaged Throughput, 1 macrocell deployment with femtocell support, and 50 UEs (25 served by the macrocell + 25 by femtocells).

As illustrated in Figure 2, we can see that the throughput has dramatically improved after introducing femtocell to support the macrocell deployment.

Table 1: Simulation system parameters.

Parameter	Scenario Macro only	Scenario Macro and Femto
Apartment size	10m2	
Nr of apartment on a building	25	
Nr of buildings	1	
Building Type	5x5 grid	
Nr of Macrocell	1	
Nr of HeNB (Femtocell)	0	1 per apartment (25 per Building)
eNB power transmission	43 dBm, equally distributed among sub-channels	
HeNB power transmission	20 dBm, equally distributed among sub-channels	
Radius of Macrocell	1km	
Nr. of users/UEs	50	
Speed of UE	3 km/h	
Total bandwidth	20 MHz	
Flow Duration	10 Second	
Frequency reuse schema	N.A.	Reuse-1/4
Activity Factor	1	
Scheduler	Proportional Fair	
Traffic	(Best Effort Flows) Infinite Buffer	
Access Policy	Open Access	
Frame Structure	FDD	

4 GREEN FEMTOCELL TECHNOLOGY

It's discussed in (Bell Labs and University of Melbourne, 2013) that Mobile networks, and especially their radio access parts (frontend to user), are by far the dominant and most concerning drain on energy in the entire clouding system. The energy calculations show that by 2015 wireless cloud will consume up to 43 TWh in comparison to only 9.2 TWh in 2012. That is an increase of 460% which is in carbon footprint from 6 megatons of CO2 in 2012 up to 30 megatons of CO2 in 2015. Figure 3 shows up to 90% of this consumption is attributable to mobile and access networks (data centers account for only 9%).

Therefore, the focus should be on making cloud systems more energy-efficient by developing more energy-efficient radio access network technologies and specifically the upfront ones like small and femtocells.

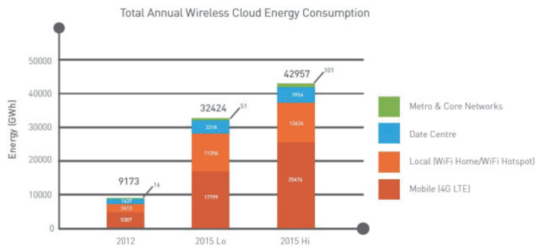

Figure 3: Estimate for annual energy consumption broken down into the various components of the wireless cloud ecosystem, 2012 and 2015 (Lo and Hi scenarios).

In (Al Haddad et al., 2012), a new indicator is introduced which enables us to calculate the consumed CO2 emission per kWh and enlighten the green effect of any technology based saved energy amount. The kWh is converted to kg of carbon saved. For instance, the conversion factor for the United States is 0.62747 kg CO2 saved for each kWh produced from a carbon free source.

The factor is based on the carbon emissions generated by the current United States' power stations per kWh generated. This factor includes other greenhouse gasses such as methane and nitrous oxide which are converted to their carbon dioxide equivalents so the value is really kg CO2 eq. per kWh. The CO2 consumption can be calculated as shown in the following equation:

$$\text{CO2 Power (Watt)} * \text{Conversion factor} \qquad (4)$$

5 ANALYSIS OF FEMTOCELL DEPLOYMENT IN CELLULAR NETWORKS

In heterogeneous networks, where high data rates are desired, more dense deployment of femtocells is seen as an enabling solution. They are deployed with the macrocells in an overlay, overlapping or disjointed area in cellular networks. With such hyper-dense networks, the problem of interference comes between the macro cells and small cells as well as among the small cells themselves. The interference between macrocell and femtocell, i.e., inter-tier interference, arises from the fact that femtocells may utilize the spectrum already allocated to the macrocell. Without proper interference management, significant power is likely to be wasted in order to maintain an acceptable user performance.

Main challenges with femtocell Technology are the Coordination between macrocells and ad-hoc femtocells, Interference mitigation with macrocells and femtocell deployment in a power-aware and green way. Further challenges to be considered with femto technology:

Tx Power Management: the RF environment is constantly changing and each femtocell needs to adapt its transmit power as other cells are being added, relocated or removed to maintain a continuous coverage and avoid interference.

Location Uncertainty: the location of femtocell is randomness and unpredictable, and as the owner likes.

Configuration Variation: some femtocells configuration parameters might be adjusted by the owners for operation and performance. The degree of uncertainty in the deployment increases if the femtocells configuration could be set differently for each femtocell.

Access and Security Control: OSG (Open Subscriber Group) or CSG (Closed Subscriber Group). Different access control mechanisms for femtocells may result in different interference environments much more complicated to control than that of the conventional wireless cellular networks.

Resource and Interference Management: femtocells can operate in their own dedicated channel or share a channel (co-channel) with the existing network cells. Femtocells deployed in co-channel manner as macro cells need to coordinate with macro cells to determine the optimal resource partitioning and maximize traffic offloading to femtocells.

Mobility Management: femtocells need to discover neighbors autonomously to facilitate UE handover.

Backhaul Management: bandwidth of customer backhaul cannot be guaranteed. When femtocells experience limitation in backhaul bandwidth, they should prioritize user classes or transferred packets.

All in all, Introducing femtocells should not significantly degrade the performance of other/prior deployed networks, therefore all the above listed challenges should be considered and solved.

6 INTERFERENCE MANAGEMENT TECHNIQUES FROM POWER CONTROL PROSPECTIVE

It is crucial to mitigate the interference which arises when femtocells are deployed in macrocell networks and ensure that the spectral efficiency is better than that of the macrocell only networks. Several interference management schemes for cellular networks with femtocells are presented.

- Optimization of Resource Allocation in case of coexisting femtocell and macrocell network (cognitive radio) like analyzed in (Femto Forum Working Group, 2009); (Boudec, 2012); (Luo and Yu, 2006) or by utilizing new features like “range expansion” that allows a User Equipment (UE) to be served by a cell with weaker received power (3GPP R4-092042, 2009) (RP – 111369, 2011).
- Radio resource coordination by allocating different resources between neighboring eNBs in the time or frequency domains as shown in (3GPP R4-093349, 2009).
- System/Design improvement by adding more resources like MIMO design as shown in (Cui et al., 2004).
- Dynamic Resource Management where new techniques like “opportunistic small cells” are introduced (Qualcomm, 2013), which dynamically turns the femtocell “ON” or “OFF” based on the need for capacity for instance proximity of users or traffic status e.g. idle status, to not only reduce interference but also lower energy consumption.
- Power Control (PC) which is necessary to mitigate the interference by manipulating the transmission power settings.

In this chapter we will go through the existing PC-related solutions only. There are Downlink and Uplink Power Control techniques for Interference Mitigation and Power Setting Tuning. In this section we try to summarize the most recent and important ones.

6.1 Uplink Power Control

In the uplink (UL), the interference from the outdoor Home UE to the macro eNB becomes a serious problem when the Home UE is located close to the macro eNB. In this case, the transmit power from Home UE has to be reduced in order to mitigate such interference. On the other hand, the indoor Home UE, which is close to its serving Home eNB and far from the macro eNB, can increase transmit power with a bit or even no interference to macro eNBs. Therefore, it is necessary to apply the uplink power control in femtocell networks.

The uplink power control for LTE as currently defined in 3GPP standards (3GPP TS 36.213, 2013) is composed of open and closed loop components. The open loop power control (OLPC) is responsible for a rough setting of UE transmit power. It compensates slow changes of pathloss (including shadowing) in order to achieve a certain mean received signal power for all users. The closed loop power control (CLPC) is used for user specific adjustments of the power settings considering such factors as Modulation and Coding Scheme (MCS), measurement errors and rapid changes in radio conditions. It can be also used for further optimization of general network performance, as e.g. described in (Boussif, 2008); (Boussif, 2010). The equation defined in 3GPP for setting transmit power of Physical Uplink Shared Channel (PUSCH) is as follows (dB scale):

$$\mathrm{P} = \min\left\{ \begin{matrix} \mathrm{PMax}, 10\log_{10}(\mathrm{M}) + \mathrm{P0} + \alpha \cdot \mathrm{PL} + \\ \mathrm{deltaMCS} + \mathrm{f(deltai)} \end{matrix} \right\} \quad (5)$$

[Where PMax is the maximum allowed UE transmit power, M is the number of Physical Resource Blocks (PRB) scheduled for the given user in a time slot, P0 is parameter related to target mean received power (user or cell specific), α is pathloss compensation factor (cell specific), PL is the downlink pathloss measured by the UE (3GPP TS 25.814, 2006), deltaMCS is a parameter depending on the used MCS (user specific), and f(deltai) is a user specific CLPC correction]. In this case the cell specific parameters of the OLPC are considered (P0, α) as they have the main impact on the inter-cell interference.

If this simple power control method is applied in the uplink, a too strong signal transmitted from the outdoor Home UE possibly can cause interference to nearby macro eNB(s). In order to deal with this problem, the PL between Home UE and its nearest neighbor macro eNB has to be estimated for additional actions. Some well-known methods developed for uplink power control are:

- **Power Cap Based PC*:*** the maximum transmission power density (i.e., power cap) of the HUE is restricted in order to avoid heavy interference to macro eNB(s). The power cap of the HUE is calculated as a function of the estimated PL between HUE and its nearest neighbor macro eNB. Then, the HUE is power-controlled based on the PL from the HUE to its serving Home eNB, up to the level of the power cap (3GPP TS 36.104, 2007).
- **PL Difference based PC*:*** with the knowledge of the difference between the PL from the Home UE to its serving Home eNB and its nearest neighbor macro eNB, the Home eNB calculates the power offset as a non-decreasing function of the PL difference. Then, this offset value is sent to the Home UE via a radio resource control message to further adjust the uplink transmission power. Based on these facts, the Home UE transmit power can be adjusted accordingly (3GPP TS 36.104, 2007).
- **Adaptive Target Mean received po>Wer (Adaptive P0)*:*** the proposed solution in (Jacek, Pedersen, Szufarska and Strzyz, 2010) is to define the OLPC parameter P0 in equation (5) in a way that would reflect the distribution of interference levels within macrocell, e.g. as a function of pathloss towards closest macro-eNB:

$$\mathrm{P0} = \mathrm{round}\{\mathrm{APo} + \mathrm{BPo} \cdot \mathrm{PLLA_{WA}}\} \quad (6)$$

[Where P0 is the calculated OLPC parameter for a local area node, PLLA_WA is the downlink pathloss to the closest wide area node. APo and BPo are parameters of the function that can be e.g. operator or vendor specific]. The algorithm introduces two additional parameters (APo, BPo are the same for all Home eNBs) but it allows full individual configuration too. To achieve similar effect with the basic OLPC procedure, each local cell would have to be configured with an individual set of parameters.

- **Link Budget Analysis:** a link budget analysis is provided which enables simple and accurate performance insights in heterogeneous networks. In (Chandrasekhar, Andrews, Muharemovic, Shen, and Gatherer, 2009), a distributed utility-based SINR adaptation at femtocells is proposed in order to alleviate cross-tier interference at the macrocell from co-channel femtocells. The Foschini-Miljanic (FM) algorithm is a special case of the adaptation. Each femtocell maximizes their individual utility consisting of a SINR based reward less an incurred cost (interference to the macrocell). The radio link quality for a cellular user is determined, given a set of N transmitting femtocells with different SINR targets. Achieving higher SINR targets in one tier fundamentally constricts the highest SINRs obtainable in the other tier.

6.2 Downlink Power Control

Several interference mitigation schemes using femtocell BS power level setting in DL have been investigated:

- **Basic fixed Power Approach:** it is based on a preconfigured value which is common for all femtocell BSs regardless of the surrounding RF conditions. Advantages of this scheme are its simplicity and ease of implementation. Disadvantages are its difficulty to adapt to the surrounding RF conditions and likeliness to cause large interference. If the fixed power level is too low, the femtocell BSs located close to the macrocell BS have poor coverage because the interference from the macrocell BS is high. On the other hand, if the fixed power level is too high, the femtocell BSs located at edge of the macrocell provide a large interference to the near macrocell MSs because the interference from the femtocell BSs to the macro MSs becomes high.

- **Self-configuration based on Macrocell BS Signal:** self-configuration of transmit power level based on the measured received signal level from the macrocell BS was developed by Claussen et al., (2008).
- **Self-optimization Approach based on SINR:** a self-optimization of coverage in accordance with the information on mobility events of passing and indoor users is used. Li et al., (2009) used downlink power control to achieve SINR for both macrocell and femtocell users.

Guidelines on how to control UMTS Home NodeB (HNB) and LTE Home eNodeB (Home eNB) interference by transmit power level setting are given in (3GPP TR 25.967, 2012) (3GPP TR 36.921, 2012). However, the previous techniques have not adequately accounted for the interference with neighboring macrocell users and surrounding conditions.

- **RSRP Approach:** the largest Reference Signal Received Power (RSRP) corresponding to the nearest macro eNB is used as one of the parameters for tuning downlink power control (3GPP R4-093557, 2009). As the RSRP decreases, which means that the Home eNB is located close to the edge of the macro cell, the transmit power should be small in order to mitigate the downlink interference to the macro UE. If a Home eNB is close to a macro UE, lower transmit power should be set to mitigate its interference to the macro UE. With the knowledge of the largest RSRP and power offset, the Home eNB selects the transmit power of the reference signal as the median values of the sum of the largest RSRP and power offset, the lower and the upper limit values of transmit power.
- **Adaptive power level setting approach:** two adaptive power level setting schemes are possible here as shown in (3GPP TR 36.814, 2010):
  a) Adaptation based on DL Reception Power from MBS:

This technique is based on downlink co-channel reception power of the reference signal of the strongest macrocell BS. The femtocell BS measures the reception power at the initial configuration phase or in operational phase and adaptively set the transmit power level accordingly. This scheme corresponds to the measurement based self-configuration scheme given in (Morita, Matsunaga, and Hamabe, 2010). The femtocell BS sets the transmit power of the reference signal as:

$$P_{\_tx} = \mathrm{MEDIAN}(P_m + P_{offset}, P_{\_tx\_upp}, P_{\_tx\_low}) \quad (7)$$

[Where the function MEDIAN() means the returned value is the median of all arguments. P_m[dBm] is the reception power of the reference signal from the nearest macrocell BS measured at the femtocell BS and is dependent on the path loss between the nearest macrocell BS and the femtocell BS which includes the penetration loss at the building wall. P_{offset}[dB] is the predetermined fixed power offset compensating for the indoor loss. $P_{\_tx\_upp}$ and $P_{\_tx\_low}$[dB] are the upper and the lower limit value of the transmit power. $P_{\_tx\_upp}$ is needed to limit the interference from the femtocell BS to the macrocell MS. $P_{_tx_low}$is also needed to guarantee a certain minimum performance for femtocell even if the surrounding macrocell cannot be detected].

A disadvantage of the schema is that it is not enough for only fixed power offset to compensate for the indoor path loss. Each building has different properties, such as the penetration loss at external walls and P_{offset} should be tuned accordingly.

b) Adaptation based on DL Reception Power from macrocell BS and UL Reception Power from macrocell MS:

This technique is based on downlink (DL) co-channel reception power of the reference signal of the strongest macrocell BS and uplink (UL) reception power from neighboring macrocell MSs. The femtocell BS adaptively measures the DL and UL reception power at self-configuration phase and then optimizes the transmit power during the self-optimization phase. The femtocell BS sets the transmit power of the reference signal as follows:

$$P_{\_tx} = \mathrm{MEDIAN}(P_m + P_{\_offset\_o} + K * L_E, P_{\_tx\_upp}, P_{\_tx\_low}) \quad (8)$$

[Where P_m, $P_{\_tx\_upp}$, and $P_{\_tx\_low}$ have the same meaning as (7). $P_{\_offset\_o}$[dB] is a predetermined power offset value compensating for the indoor path loss excluding the penetration loss. K is an adjustable positive factor and can be determined by the priority of the femtocell BS operation. L_E[dB] is the penetration loss which assumed to be ideally estimated]. A macrocell MS is assumed to be located in close proximity to a femtocell BS. This means the distance from the macrocell BS to the macrocell MS is nearly the same as that from the macrocell BS to the femtocell BS. The penetration loss L_E can be calculated as follows:

$$L_E = \frac{1}{2} * \left(P_{tx\_f} - P_{rx\_f} - L_a\right) \quad (9)$$

[Where P_{tx_f}[dBm] is the UL transmit power virtually calculated by the femtocell BS. P_{rx_f}[dBm] is the UL reception power from the macrocell MS measured at the femtocell BS. L_E [dB] is open - air propagation loss between the macrocell MS and the femtocell BS excluding the penetration loss]. L_E is a predetermined value and is assumed in advance so that the distance between the macrocell MS and the femtocell BS can be minimized under the conditions in which the interference from the macrocell MS to the femtocell BS is tolerable. When the path loss between the macrocell MS and the femtocell BS excluding the penetration loss is within La, the penetration loss in equation (9) is estimated to be smaller than its real value and the transmit power is suppressed. When the path loss is outside L_E, the penetration loss is estimated to larger than the real value and the transmit power is released. This power setting technique can resolve the problem of the last power setting schema.

- **Auto-tuning of DL Power of Femtocells Adaptive to Various Interference Conditions:** the power offset in previous introduced technique has not been adequately optimized for various interference conditions. In (Kan et al., 2011), the proposed scheme automatically tunes the power offset so that the femtocell throughput can increase while maintaining the macrocell throughput based on macrocell mobile stations' interference detection reports. In comparison to the last technique where the $\mathbf{P_{\_offset\_o}}$ is fixed, various interference conditions such as size of buildings where femtocell mobile stations exist and distance to a street where macro MSs exist are not sufficiently considered. The macrocell or femtocell throughput may degrade if the initial value is too large and too small compared with the conditions.

Therefore, (Kan et al., 2011) introduces different auto-tuning schemes using individual offset where the $P_{\_offset\_o}$ is tuned individually per femto BS or using common offset where the $P_{\_offset\_o}$ is tuned commonly among femto BSs in a macrocell with per-femtocell or per-macrocell measurement, respectively. This approach uses a stepwise tuning of $P_{_offset_o}$based on Interference Detection Ratio (IDR1) indicator, which is the ratio of the number of interference detection reports to the number of macro MSs that receive the measurement control message from the serving macro BS.

7 CONCLUSIONS

With the steadily increasing demand for mobile traffic, it is important that the telecom networks are modernized with all the capacity, quality and coverage extension technologies available and especially the energy efficient ones such as femtocell technology. In 3G networks, small cells are viewed as an offload technique whereas from 4G networks onwards, the principal of heterogeneous networks is introduced where the network is based on layers of small and large cells together. Whether it's a low indoor coverage, bad network performance in rural areas, required capacity increase and high data rates or qualified coverage guarantee in hard-to-cover areas, a cost-efficient way to address these issues is femtocell solutions.

There are no distinct standards to define the physical power transmission of a femtocell but only recommendations. This survey work provides an overview of the power control and saving methodologies with regard to femtocell technology. It also discusses its challenges and different potential ideas for improvements. The femtocell technology is still young and fertile research is still required here.

In our future research work, we will be further identifying the ability for femtocell technology to help with the green initiatives. For instance, future network releases need to support the coordination among femtocells and not only between macro and femto cells and take into account conditions of both surrounding environment and networks. In addition, other topics will be further investigated like enhancing existing power control methodologies, powering down small cells based on traffic situation, improvements on cell phone battery life and throttling small cell power down based on cell type and usage.

Future innovations and further research are strongly required to overcome the challenges coming with this immature technology.

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