

# Femtocell and Beacon Transmit Power Self-Calibration

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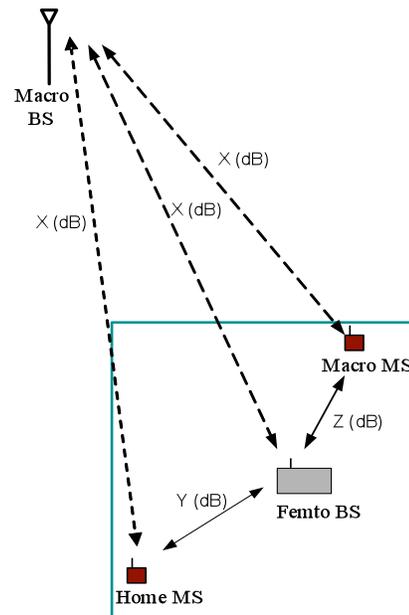
## ABSTRACT

*Femtocell power calibration is one of the key techniques for managing interference between femtocells and macrocells due to their unplanned deployment and restricted access. To ensure robust performance, rather than using a fixed transmit (Tx) power level for all femtocells in the network, power of each femtocell must be chosen based on its surrounding RF conditions. This requires calibration of Tx power for each femtocell. To achieve this goal, a suite of power calibration techniques has been designed to ensure satisfactory femtocell coverage with minimal interference to other cells. An overview of these power calibration techniques is provided in the paper. The methods presented here use RF (network listen) measurements made by femtocells, registration statistics from non-femto mobiles and RF measurement reports from femtocell mobiles to determine the optimal transmit power level. The techniques presented here can be adapted to various deployment scenarios such as open, restricted or hybrid access femtocells, co-channel femto-macro deployment or dedicated frequency femto deployment, and can be applied for femtocell forward link as well as beacon forward link power calibration.*

## 1. INTRODUCTION

Femtocells are a cost-effective solution to extend macro cellular network coverage to improve user experience and also offload traffic from the macro network without installing additional macro base stations. One key reason for this cost-effectiveness is that femtocells are deployed in an unplanned manner with minimal RF planning/engineering, thereby resulting in cost savings for an operator. However, such unplanned deployments require femtocells to self-configure and operate satisfactorily. Newly deployed femtocells should seamlessly integrate and operate with the existing femto-macro network and provide excellent performance irrespective of their location in the house or the macro network. For example, a femtocell should provide satisfactory coverage throughout the house even when it is installed in a basement or good coverage on the 2<sup>nd</sup> floor when installed on the first floor and vice versa. At the same time, if a femtocell is transmitting any channels (e.g., its forward link (FL) service channel or a beacon<sup>1</sup>) on the neighboring macro network frequencies,

then its interference to the macro network needs to be controlled to avoid service degradation for macrocell users. Similarly, interference to neighboring femtocells should also be minimized. This is especially important when femtocells are deployed with restricted access, where only certain users are allowed to access service from a femtocell. To balance this conflicting coverage vs. interference minimization requirement in unplanned deployment scenarios, femtocells need to calibrate their power based on the surrounding RF environment. To motivate this further, consider the simple scenario shown in Figure 1-1 to study femto-macro interference assuming femtocell is transmitting a channel on the macro frequency.



**Figure 1-1 Femtocell to Macrocell Interference Scenario**

The above model consists of a macro base station (BS) and a femto BS. It also consists of a home (femto) mobile station (MS) that is served by the femto BS and a macro MS that is served by the macro BS. The macro MS is in the vicinity of the femto BS and is restricted from using femto BS. Path losses (PL) between different elements are shown in Figure 1-1. Different parameter settings are summarized in Table 1-1 for two different femto locations with respect to the macro BS: cell edge – femto BS is at the edge of macro BS coverage (large PL between femto and macro BSs) and near cell site – femto BS is near the macro BS site (small PL between the two).

Assuming the following macro and femto settings, the forward link performance of the home MS and the macro

<sup>1</sup> Beacons are used by femtocells to facilitate idle handoff from macrocell to femtocell. More discussion on beacons and their power calibration is provided in Section 4.

MS for different femto Tx power levels is shown in Table 1-2:

Macro Tx power = 43 dBm, 50% loading, femto loading = 100%, and Ecp/Ior (pilot to total power ratio) = -7 dB for both macro and femto BSs.

**Table 1-1 Parameters for simple femto-macro interference model**

Parameter	Location	
	Cell Edge	Near Cell Site
X = PL between macro BS and femto BS as well as home and macro MS	140 dB	105 dB
Y = PL between femto BS and home MS	80 dB	80 dB
Z = PL between femto BS and macro MS	80 dB	80 dB
Received signal strength (RSS) at macro MS and home MS (excluding femto contribution)	-95 dB	-62 dB

**Table 1-2 Performance with fixed femtocell Tx power**

	Cell edge location		Near cell site location	
	Ptx <sub>femto</sub> = -15 dBm	Ptx <sub>femto</sub> = +15 dBm	Ptx <sub>femto</sub> = -15 dBm	Ptx <sub>femto</sub> = +15 dBm
Macro MS Ecp/Io [dB]	-12	-38	-7	-9
Home MS Ecp/Io [dB]	-10	-7	-40	-12

The results show that in a cell edge location a low femto BS transmit (Tx) power is adequate to ensure good coverage and also minimize interference to the macro MS. On the other hand, for cell site location femto BS needs to transmit at high power to ensure good coverage for the

home MS. This shows that all femtocells in the network cannot be configured to transmit at a fixed power level. Each femtocell needs to adapt/calibrate its power based on the surrounding RF environment to balance the femto coverage vs. interference minimization trade-off.

This paper provides an overview of different Tx power calibration techniques and how they can be used jointly to provide robust performance in residential femtocell deployments. These techniques use network measurements made by the femtocell as well as measurements and statistics from mobiles in the femtocell vicinity to determine femtocell Tx power. These techniques are useful not only for long-term Tx power adaptation, but also for short-term Tx power adaptation to offer real-time protection to active macro users in the femtocell vicinity. The techniques presented here can be adapted to various deployment scenarios such as open, restricted or hybrid access femtocells; co-channel femto-macro deployment or dedicated frequency femto deployment. These techniques can be applied to both femtocell forward link (FL) as well as beacon FL power calibration with some modifications

The rest of the paper is organized as follows. Section 2 describes different power calibration techniques for femtocell power calibration. Section 3 describes overall power calibration algorithm that uses techniques described in Section 2. Section 4 briefly describes beacon power calibration. Finally, some concluding remarks are provided in Section 5.

## 2. Femtocell Tx Power Calibration

This section describes three key techniques that can be jointly used for femtocell Tx power calibration. Based on the femtocell's operating state (e.g., first time power-up, presence of an active macro user in the vicinity), the Tx power can be chosen using one of these techniques. Without loss of generality, we assume that femtocell FL and macrocell FL share the same carrier frequency for describing femtocell power calibration.

### 2.1 Network Listen Based Power Calibration

Based on the example discussed in Section 1, a simple power calibration approach is to measure neighboring macro BS's FL received signal (e.g., total received signal I<sub>o</sub> or pilot strength Ecp/I<sub>o</sub>) and set femtocell Tx power based upon the macro BS signal strength. For example, when macro Ecp/I<sub>o</sub> is weak due to femto BS location at macro cell edge, femto BS transmits at low power (~ -15 dBm in the example) and when macro Ecp/I<sub>o</sub> is good due to proximity to macro cell site, femto BS transmits at high power (~ 10-15 dBm in the example). This approach of measuring the FL signal quality of the surrounding network and accordingly choosing the power is referred to as Network Listen based Power Calibration (NLPC). To

facilitate NLPC, a femtocell is typically equipped with a Network Listen Module, which has mobile-like capabilities. NLM allows a femtocell not only to measure FL RF signals from neighboring BSs, but also to decode their overhead messages for various self-configuration purposes.

NLPC is useful for initial power setting upon first time power-up. NL measurements can also be used to determine change in RF environment due to events such as femto location change and accordingly re-calibrate Tx power. Such re-calibration can be autonomous or directed by the network.

2.1.1 Algorithm Overview

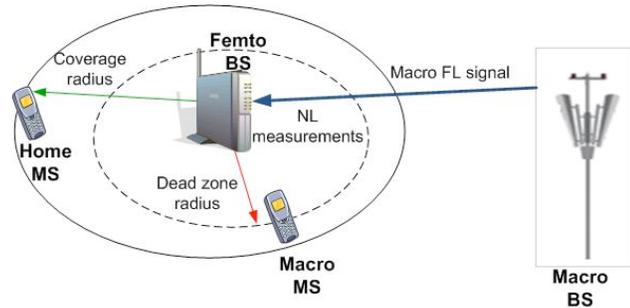


Figure 2-1 Network Listen based Power Calibration

Assume that femtocell needs to provide coverage up to a certain path loss (e.g., 80 to 90 dB coverage radius), which is adequate to cover a typical apartment or a house. Similarly, assume a certain path loss (dead zone radius) within which a mobile connected to a macro BS is likely to be affected due to femtocell interference. Then, femtocell Tx power is chosen by measuring FL macro channel quality using NLM to satisfy one or more of the following constraints:

- 1) Macro Mobile Protection Constraint:
  - a. Choose a Tx power level such that a macro mobile at the dead zone edge receives a certain minimum macro channel quality in the presence of femtocell interference.
  - b. If macro BSs are transmitting on adjacent carriers, then choose a Tx power level such that a macro mobile on adjacent carrier at the dead zone edge receives a certain minimum macro channel quality in the presence of femtocell interference. The dead zone radius for co-channel vs. adjacent channel macro mobile protection can be different and depends on the adjacent channel interference ratio (ACIR).
- 2) Home Mobile Coverage Constraint:
 

Choose a Tx power level such that the SNR experienced by a home mobile at the edge of coverage

zone does not exceed a certain threshold. This constraint ensures that femtocell does not transmit at an unnecessarily high power level and thus minimizes interference to macro and other femto BSs.

For power calibration in dedicated femtocell frequency deployment, the macro mobile protection constraint can be applied only for adjacent channel protection. Similarly, this constraint can be relaxed when a femtocell has open access policy, i.e., it allows any user to receive service.

2.1.2 Limitations of Network Listen based Power Calibration

Though NLPC is widely recognized (e.g. [1]) as a solution for femtocell power calibration, it has some inherent limitations. The fundamental assumption in a NL based algorithm is that the measurements made by the femtocell are representative of the RF environment experienced by mobiles in the femtocell vicinity. In practice, there can be a mismatch between the RF conditions measured by the femtocell and those experienced by home and macro mobiles in the vicinity, which can result in inaccurate estimation of femtocell coverage and interference. Figure 2-2 illustrates the difference between macro pilot energy (Ecp) observed at a mobile vs. the macro Ecp observed at the femtocell during field trials in a typical apartment unit. It is evident that there can be a mismatch of approximately +/- 20 dB in the NL measurements.

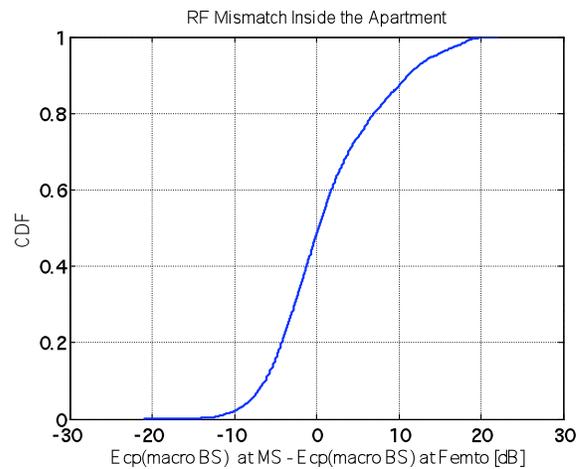
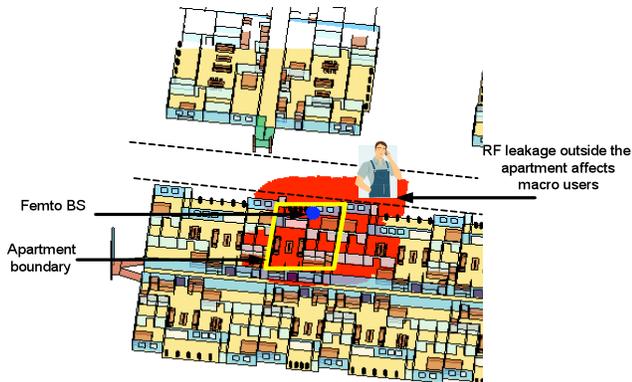


Figure 2-2 Distribution of mismatch between macro Ecp measurement at the femtocell and at the mobile

For example, when femtocell is placed near a window as illustrated in Figure 2-3, it is likely to receive strong macro signal compared to indoor locations and therefore it will transmit at high Tx power, which is unnecessary from

coverage standpoint. Figure 2-3<sup>2</sup> shows that femtocell not only covers the entire apartment (coverage criteria:  $E_{cp}/I_o$  from femto >  $E_{cp}/I_o$  from macro by 3 dB), its transmission leaks outside the apartment on to the street quite a bit. This interference can degrade voice call quality of passing-by macro mobiles. In addition, RF leakage outside the apartment can cause passing-by idle macro mobiles to register with the femtocell, even though such mobiles are not likely to stay in femtocell coverage for long.



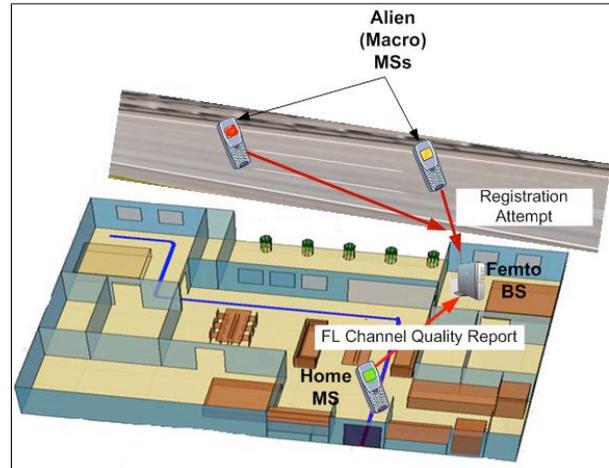
**Figure 2-3 Example of coverage and interference with NL power calibration**

Further, the NLPC assumes a certain desired coverage radius. The desired coverage radius depends on the apartment or house size, which is unknown to the femtocell. Thus, NLPC by itself cannot provide a robust power calibration solution in all scenarios. The performance can be improved by fine tuning Tx power using mobile measurement reports and registration statistics as discussed in the next section.

## 2.2 Mobile Assisted Range Tuning

For better adaptation to the deployment scenario (e.g., small apartment vs. large house, femto BS near a window vs. basement), femtocell Tx power and therefore the coverage range should be fine tuned using mobile assistance. Mobile assisted range tuning (MART) achieves a balance between coverage and interference minimization requirements by using:

- 1) Statistics of registrations performed by alien (non-home or macro) users over a certain period with the femtocell
- 2) FL channel quality reports obtained from home mobiles.



**Figure 2-4 Mobile Assisted Range Tuning**

Idle-mode registration attempts by alien users (i.e., non-femto users) serve as an indication of femtocell leakage outside the home. Therefore, if large number of alien user registrations are seen over a certain duration (e.g., past 24 hrs), then femtocell power is reduced to minimize leakage.

Adequate coverage for home users can be ensured by using channel quality reports from home mobiles. A femtocell can request a home mobile to periodically measure and report back FL channel quality metrics such as pilot strength ( $E_{cp}/I_o$ ) from different pilots and total received energy ( $I_o$ ) on femtocell frequency using existing signaling mechanisms like Periodic Pilot Strength Measurement Messages (PPSMM) for cdma2000 1xRTT mobiles and Measurement Report Messages (MRMs) for UMTS mobiles. Depending on the technology, these measurements can be requested by the femtocell from idle and/or active mobiles. If supported, measurements from other frequencies such as the beacon frequencies or adjacent frequencies can also be requested by the femtocell using existing signaling mechanisms (e.g., Candidate Frequency Search Reports for cdma2000 mobiles). By using these reports, femtocell can estimate the path loss between itself and a home mobile at different locations in the home and also learn the macro signal quality at these locations by requesting the mobile to measure macro pilots also. Unlike NL measurements, reports from home mobiles allow the femtocell to sample RF environment at different locations in the home. Thus, a femtocell can learn the desired coverage range and also handle the RF measurement mismatch issue that plagues NLPC. As a result, by combining information from alien user registration statistics and home mobile reports, a femtocell can determine the optimal power setting to achieve the right coverage vs. interference tradeoff.

<sup>2</sup> Based on simulation results using a detailed propagation model that simulates femtocell deployment in a dense urban environment with many apartment buildings.

### 2.2.1 Algorithm Overview

This section provides a high level overview of mobile assisted range tuning algorithm. We assume that a femtocell is able to distinguish between home mobiles and alien mobiles based on their unique identifiers such as International Mobile Subscriber Identity (IMSI) or Electronic Serial Number (ESN). MART is performed periodically, with periodicity of the order of few hours to days. The following key steps are performed to update power during each MART cycle:

1) *Mobile data collection:*

Mobile data collection involves collecting alien mobile registration statistics and channel quality reports from home mobiles.

- Alien mobile registration statistics:  
Registrations performed by alien mobiles since the time of last MART cycle are tracked to compute total number of registrations by alien mobiles.
- Home mobile reports:
  - Femtocell requests a home mobile to send FL channel quality reports corresponding to femtocell and neighboring macro as well as other femto BSs. Reports can be requested every few seconds or minutes.
  - A database of home mobile reports collected across several days is created to use long-term statistics for power calibration.

2) *Transmit power estimation:*

The required Tx power is estimated using home mobile reports collected over past several days using the following procedure:

- The path loss observed between femtocell and home mobile is estimated using information contained in home mobile reports. Depending on the technology, FL pathloss between femtocell and the home mobile may be directly reported by the home mobile or it can be estimated by the femtocell. For example, if home mobile reports back femtocell  $E_{cp}/I_o$  and  $I_o$ , then femtocell pilot energy received at the mobile can be obtained. Using this received  $E_{cp}$  and the transmitted  $E_{cp}$ , which is naturally known to the femtocell, FL pathloss between femtocell and the home mobile can be derived.
- The desired femtocell coverage radius and dead zone radius is estimated using path loss statistics.
- The home mobile coverage and macro mobile protection constraints described in Section 2.1.1 are then applied using the estimated coverage and dead zone radii and macro channel quality learnt from home mobiles to compute the required Tx power level.

3) *Power update:*

Power is updated based on alien mobile registration statistics. If the number of registrations performed by alien mobiles does not exceed a threshold, then femtocell Tx power is increased to improve coverage. Otherwise femtocell power is decreased to reduce interference while ensuring that coverage is not significantly. This is ensured by taking into account the estimated Tx power level. The radiated Tx power is controlled within some permissible minimum and maximum levels.

Thus, unlike in NLPC, where coverage and dead zone radii are assumed to be known and macro channel quality is assumed to be the same throughout the house, these quantities are learnt from home mobile reports and used to determine Tx power level. This allows femtocell to adapt better to deployments such as small apartment or a large house. Interference to alien users is effectively controlled based on the number of registrations performed by them. The performance improvement with mobile assisted range tuning is illustrated in Figure 2-5<sup>3</sup>. The green plot represents coverage with MART while the red plot represents coverage with NLPC (coverage criteria:  $E_{cp}/I_o$  from femto >  $E_{cp}/I_o$  from macro by 3 dB). It is evident that MART reduces leakage and therefore interference outside the apartment to other alien users and at the same time ensures good coverage inside the home.



Figure 2-5 Example of coverage with MART

The above algorithm can be applied with some modifications to femtocells with different access policies. For femtocells with open access, the registration limits for alien users can be higher than for femtocells with restricted or signaling-only (hybrid) access mode. The registration limits can be chosen based on field trials and considering deployment scenarios such as dense urban areas or suburban areas.

<sup>3</sup> Based on simulation results using a detailed propagation and user mobility model. Apart from RF propagation in dense urban neighborhood, mobility of different users (e.g. pedestrians, vehicles, etc.) is also modeled.

In the MART algorithm, we assumed femtocell and macrocell are on the same frequency. Similar concept can be applied for femtocell power calibration even when femtocell is on a dedicated frequency. Home mobile reports can be used to estimate the desired coverage range and sample RF conditions in the home to set Tx power appropriately. It must be noted that power calibration is less critical with dedicated frequency deployment, but still needed to limit inter-femto interference and protect adjacent carriers.

To apply the MART algorithm, we assumed that femtocell is able to distinguish between home mobiles and alien mobiles based on their identifiers such as IMSI or ESN. This information can be provisioned by the network to the femtocells as part of operations, administration and maintenance (OAM) procedures. However, if this information is not available then the above algorithm can be applied using total number of registrations by all users as the metric. Large number of registrations is still an indication of large femtocell coverage and therefore can be used to control femtocell Tx power.

Also note that as part of the MART power update, NL measurements can be done to determine if surrounding environment has changed significantly or not due to events such as femtocell location change. If new NL measurements are significantly different from old NL measurements, then the power is updated using NL measurements and registration statistics until new home mobile reports are collected. Once adequate home mobile reports are collected power is fine tuned using MART. This NL based re-calibration procedure allows femtocell to react to changes in RF environment due to change in location of femtocell or surrounding objects quickly and eventually reach the optimal power setting based on MART.

### 2.3 Active Macro Mobile Protection

Mobile assisted range tuning helps to reduce femtocell interference to macro users, but it cannot completely eliminate this interference. For example, guest users visiting a femtocell home and receiving service from a macrocell can still face significant interference. This interference can degrade voice call quality of such active macro users and even lead to call drops. It must be noted that femtocell interference is an issue even with open access femtocells because active handoff from a macrocell to a femtocell is not supported in the present day femtocell deployments. Thus, it is critical to protect active macro mobiles that are in femtocell proximity from femtocell interference. Rather than sacrificing femtocell coverage by always transmitting at a very low power, a solution that allows dynamic, real-time power adaptation only when active macro mobiles are near a femtocell is more desirable to solve this problem. Such an algorithm to protect active macro mobiles is described below.

#### 2.3.1 Algorithm Overview

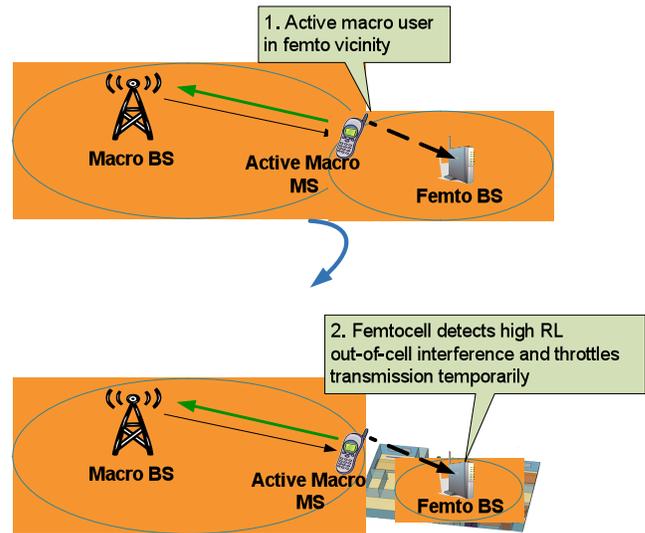


Figure 2-6 Active Macro Mobile Protection Illustration

As illustrated in Figure 2-6, assume an active macro mobile is in femtocell vicinity and therefore is being interfered on the FL by the femtocell (macro and femtocell are co-channel). This active macro mobile can be protected from femtocell interference as follows:

- 1) Femtocell detects the presence of a macro user in its vicinity by continuously measuring out-of-cell interference on the reverse link (RL) frequency. Typically, the received signal from a home mobile is below the thermal noise level. However, the received signal from an alien mobile can be significantly high. For example, if an alien mobile is at macrocell edge, it transmits ~20 dBm Tx power on the RL. Even at 80 dB path loss from the femtocell, the received signal from this mobile at the femtocell will be -60 dBm, which is significantly above the typical thermal noise floor at the femtocell. Thus, out-of-cell interference level above a certain threshold serves as an indication of the presence of an active macro user in femtocell vicinity.
- 2) When out-of-cell interference greater than a certain threshold is observed, femtocell “throttles” its FL transmission, i.e., it reduces Tx power on its FL or completely shutdowns FL temporarily to protect the active macro mobile. The new Tx power level can be determined as a function of the out-of-cell interference level. For example, a very high out-of-cell interference is likely due to macro user being in very close proximity. In such a case, femtocell Tx power should be reduced significantly compared to the case when out-of-cell interference is relatively low. Normal FL transmission is resumed by discontinuing throttling

after a time-out (typically, few minutes) or once the out-of-cell interference level falls below a certain threshold.

In this manner, active macro mobiles can be protected in real-time from femtocell interference. Since the throttling is temporary, it is not likely to affect home users significantly. If there is an active home mobile being served and throttling needs to be applied, then reducing Tx power is more preferable compared to shutting down the FL transmission in order to minimize impact on the active home mobile.

Similar throttling mechanism can be applied to protect alien users during active hand-out/re-direction with signaling-only access femtocells. With signaling-only access, alien users are allowed to be connected with the femtocell in idle mode and are re-directed to a macrocell for active mode service during incoming or outgoing call. To protect this alien user, femtocell transmission is throttled temporarily.

### 3. Summary of Power Calibration Procedure

Each of the power calibration technique discussed in previous sections serves a specific purpose and improves performance. Therefore, for optimal performance it is recommended to use these techniques jointly for femtocell power calibration. The overall power calibration procedure using these techniques is illustrated in Figure 3-1.

At a high level, the overall power calibration procedure can be summarized as:

- 1) Upon power up, femtocell Tx power is initialized using NLPC.
- 2) After initialization, MART is performed periodically to fine tune power by collecting channel quality reports from home mobiles and registration statistics of alien mobiles.

- 3) Femtocell continuously monitors for the presence of an active macro mobile in the femtocell vicinity by measuring out-of-cell interference on RL frequency (or frequencies) and throttles FL transmission temporarily to protect this active macro user. Once active macro mobile protection ends, femtocell continues to fine tune its power using MART.
- 4) A NL based re-calibration is performed when directed by the network. NL re-calibration may also be performed periodically and combined with mobile assisted range tuning to determine the optimal Tx power level.

### 4. Beacon Power Calibration

Beacons are used by femtocells to attract idle mobiles camping on a macrocell to the femtocell when femtocell FL frequency and neighboring macrocell frequencies are different [2]. Beacons typically consist of pilot and some control channels that are radiated on the macro frequency (i.e., beacons are co-channel with macrocells). This allows an idle mobile coming home from outside to detect a beacon, which then re-directs the mobile to femtocell service frequency. Thus, even when a dedicated frequency is allocated to femtocells, beacons are a potential source of interference to the macrocells and therefore their power must be calibrated carefully.

Power calibration algorithms and procedures described in Section 2 and 3 can also be applied for beacon power calibration with some minor modifications. For example, alien registrations to the femtocell are now due to beacons and therefore alien user registrations statistics can be used to fine tune beacon Tx power. Similarly, home mobiles can be requested to measure RF conditions on beacon frequency (or frequencies) and the MART algorithm can be applied. Active macrocell users can be protected from beacon interference by detecting the presence of a nearby active macro user and throttling beacon transmission.

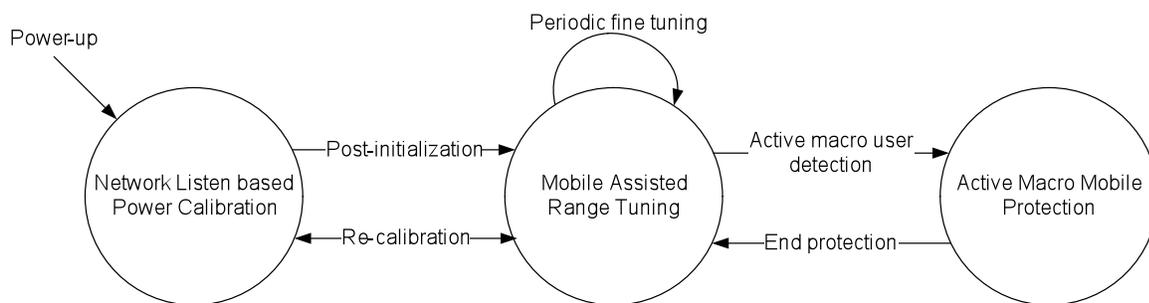


Figure 3-1 Power Calibration Procedure

Note that in such a scenario the femtocell needs to measure received signal strength (RSS) on a RL frequency different from its serving RL frequency to detect the presence of an active macro user. This can be achieved by using a special receive chain tuned to macrocell RL frequency for RL RSS measurements. Thus, the algorithms presented in this paper can be adapted for beacon power calibration also.

## 5. Conclusion

The paper presented different techniques for femtocell power calibration and described how these techniques can be used to complement each other for ensuring robust performance. Network Listen based power calibration provides a good initial set-point when femtocell is powered up. Femtocell coverage can be periodically fine tuned to a specific deployment scenario such as large house or a small apartment by using channel quality reports from home mobiles and registration statistics of non-home mobiles. This mobile assisted range tuning minimizes interference to

non-home users while ensuring excellent coverage for home users. We also presented a technique to protect active macrocell users from femtocell interference when they are in femtocell proximity by throttling femtocell FL transmission temporarily. This suite of power calibration techniques can be applied to different femtocell deployments scenarios such as co-channel femto-macro deployment or dedicated femto frequency deployment and open as well as restricted femtocell deployments. Thus, the techniques presented here provide a complete solution for power calibration on femtocell well as beacon forward link frequencies.

## 6. REFERENCES

- [1] 3GPP TR 25.967 Home Node B Radio Frequency (RF) Requirements (FDD).
- [2] P. Humblet, et.al. "System Design of cdma2000 Femtocells," IEEE Communications Magazine, pp. 92-101, Sept. 2009.