Measurements of Inter-femtocell Reverse Link Interference

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Abstract: This paper presents results from a series of experiments using commercial CDMA femtocells to characterize and better understand reverse link inter-femtocell interference. Under conditions of significant RF dragging which can occur with closely spaced femtocells, reverse link interference and potential instability were observed when doing high speed data uploads. The experiments reproduced some of the effects described theoretically in the literature, but only under a very limited set of scenarios.

Key words: Femtocells, interference, wireless.

1. Introduction

Residential smallcell technology (also known as femtocell) has rapidly evolved from research, development and operator trials [1-10] to deployments exceeding one million units [11]. Small cells now represent an important tool for mobile operators seeking to provide high quality indoor coverage required for data enabled smart phones in suburban and rural residences that are not close to a macrocell. Smallcells use the licensed spectrum of mobile operators, but unlike macro cells that are deployed in a planned way, residential femtocells are deployed totally ad-hoc. Early researchers modeled the deployment of femtocells as uniform within the macrocell coverage area, but research described in Ref. [11], illustrates that femtocell placement tends to be concentrated in the annular region at the fringe of macro cell coverage. The models used in the literature also asserted that the placement of one femtocell was totally independent of the next femtocell. This also has been shown to not be correct because there likely will be multiple customers of a mobile operator that have a femtocell to fill the same coverage holes. When a

coverage hole intersects a large apartment block or other dense residential area, it is likely that there will be multiple customers in the same building or complex having femtocells. Data presented in Ref. [11] show statistics of the distance between nearest neighbor femtocells taken from one of the major operators. It shows that there are now a relatively large number of femtocells within the mutual coverage and interference zone of each other (50 meters or less).

CDMA based 3G (third generation) wireless technologies such as CDMA-2000 and UMTS/WCDMA operate using a frequency reuse of 1 and depend for reverse link stability on fast, efficient, soft-handoff power-control to minimize the amount of reverse link transmitter power and therefore the amount of reverse link interference in a CDMA network. In 3G systems, an Access Terminal (AT or UE) in soft handoff can be simultaneously power controlled by up to 8 different sectors and the algorithms select the lowest reverse link power that satisfies the target bit-error rate. Current generation residential femtocells generally do not support soft-handoff either between femtocells or between femtocells and the macro network (most support voice hard handoff to the macro network but not to other femtocells, and generally no data handoff) and there is

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potential for reverse link interference between femtocells as the density of deployment grows.

“RF dragging” occurs when a handset device at the cell edge actively connected to one cell wants to handoff to another cell because it senses a stronger signal from the new cell, but because handoff is not supported, the handset remains attached to the weaker cell and therefore power controlled by it until the connection drops. The greatest potential for inter-femtocell reverse link interference exists under conditions of RF dragging between closely spaced femtocells when the mobiles are operating at high reverse data rates using either 1xEV-DO or HSUPA in which case the mobile transmitter power is significantly higher than that used for voice calls.

As the density of femtocells increases, the requirement to better understand interference between densely packed femtocells has grown from an academic problem to one of concern to operators of large femtocell networks. This paper presents results from a series of experiments using commercial femtocells and access terminal devices to characterize and better understand the problem of reverse link interference between femtocell mobiles.

A detailed discussion of interference scenarios encountered in femtocell deployments is presented [1]. What is missing from the body of literature described in theoretical studies is a set of measurements using commercial femtocells, and commercial handsets to understand the conditions and severity of these effects. This paper describes experiments using commercial 1xEV-DO Revision A (the high speed data for CDMA-2000) to measure and better understand the effects of femtocell to femtocell reverse link interference due to RF dragging. The experiments focus on uplink data services as opposed to voice because high speed data require significantly higher uplink transmitter power than low rate voice services.

2. Experiment Design

Fig. 1 illustrates how to create the conditions for

significant reverse link interference between femtocells. A semi-permanent calibrated test bed that can be used for experimenting when needed was created in the Ball Engineering Building at University of Massachusetts Lowell. Two commercial femtocells, we call F1 and F2 are located in adjacent classrooms separated by concrete brick walls. This use case represents the situation of co-channel femtocells located in adjacent apartments. Each of the femtocells is instrumented with purpose built software tools to periodically query and record the received signal level (RSSI) and the reverse link (uplink) data rate. From these measurements we determine the effective reverse link noise rise-over-thermal and the associated reverse link throughput. A series of calibrated waypoints was created in the halls and classrooms of the building. These are labeled “d” through “i” in Fig. 1. Generally a connection initiated on femtocell F1 will drop in the region between waypoints denoted “f1” and “f2” because the signal strength from femtocell F2 is much greater than that from femtocell F1 (handoff between femtocells is not supported). At the point denoted “f”, the pathloss between femtocells F1 and F2 are both approximately 72 to 77 dB.

Laboratory calibrated handset devices instrumented with purpose built logging software established connections to their respective femtocells F1 and F2. There is no active connection handoff, either hard or soft, between femtocells other than the call dropping and the handset reselecting the new femtocell.

To serve as reference measurement, a handset device is connected to femtocell F2 (call it AT_{F2}) and is positioned in a static location in the vicinity of the handoff zone between F1 and F2 as shown in Fig. 1. Because AT_{F2} is relatively far from F2, it must transmit more power to maintain a constant upload rate. Repeated ftp uploads of large files serve to create a near constant offered load. The AT_{F2} mobile is power-controlled only by femtocell F2, even though it may be able to receive both femtocells F1 and F2 on the forward link. The change in the received signal level at

Fig. 1 Basic setup of inter-femtocell reverse link interference test.

F2 relative to times when there is no activity on femtocells F1 and F2 are recorded and analyzed. The handset device is instrumented to log the forward link requested data rate (DRC), the forward link Received Signal Level, the reverse link transmitter power (both pilot and total power), and all signaling information.

Next, a second handset data device, we call it AT_{F1} establishes a connection to femtocell F1 and starts an ftp upload. Device AT_{F1} is moved away from femtocell F1 starting at point “d” towards point “f2” to a point beyond “f1”, just before the call drops, creating a condition known as “RF dragging” where device AT_{F1} is closer in terms of pathloss to femtocell F2 than it is to femtocell F1. Since there is no soft or hard handoff between F1 and F2, AT_{F1} is power controlled only by F1 and a situation of “RF dragging” is created in which F2 should be power-controlling AT_{F1} but cannot. Again the reverse link transmitter power, forward link received signal power and link quality are measured at the mobile terminals and at the femtocells.

The third step is to turn on reverse link interference mitigation and repeat the second step. The data are analyzed by timestamp synchronizing the

measurements from the 4 devices (2 femtocells F1 and F2, and two mobile devices AT_{F1} and AT_{F2}).

3. Measurement Results

The first set of experiments was conducted using two laboratory calibrated CDMA-2000 femtocells operating with 1xEV-DO Revision A. A second identical set of measurements was conducted for CDMA-2000 1xRTT voice, but no significant interference was observed due to the relatively low reverse link transmitter power.

The first step in the experiment was to create the reference or baseline as shown in Fig. 2 in which a simple upload from AT_{F2} with AT_{F1} idle is performed. Assuming that the femtocell receiver noise figure is on the order of 10 dB, the base noise level at the femtocells should be on the order of approximately -104 dBm plus or minus one or two dB (the blue trace in Fig. 2). Looking at the femtocell F2 RSSI we see that the level varies from about -104 dBm when all transmitters are turned off to a maximum high of about -92 dBm (12 dB above the baseline) when there is a single mobile device uploading at about 900 kbps and

Fig. 2 Baseline ftp upload of femtocell F2 with no other activity.

Fig. 3 Simultaneous uploads on AT_{F1} and AT_{F2} .

Mobile moves from point d to point f1 in Fig. 1. Brown trace: Total uplink Tx Power for UE2. Dark Blue: Total Tx Power for UE1. Yellow: Femto F1 Reverse link throughput, Magenta: Femto 2 Reverse Link Throughput, Light Blue: Femto 2 Total Reverse Link RSSI, Light purple Femto 1 Reverse link RSSI.

power controlled by the femtocell. We observe that the AT_{F2} transmitter power (the yellow trace in Fig. 2) stays in the -20 to -30 dBm range for 900 kbps uplink throughput (the purple trace in Fig. 2).

Fig. 3 (see figure for explanation of the colors that represent different simultaneously logged parameters) shows the case of two mobile devices simultaneously

uploading to their respective femtocells. In the figure AT_{F1} is moving from waypoint “d” towards waypoint “f1” as shown Fig. 1 and then stays for a few moments at point “f1” then moves back towards point “d”. As the mobile moves away from its home femtocell it powers up to maintain the required E_b/N_0 set point. AT_{F1} causes interference to femtocell F2 which instructs

AT_{F2} to power up to overcome the interference from the other mobile, which in turn causes interference to femtocell F1, etc. until both mobiles have reached their maximum power of 23 dBm.

We also notice in Fig. 3 that both handset 1 and handset 2 transmitter powers tend to synchronously oscillate. At the time we observed that the femtocell received power level has in some instances increased by close to 40-50 dB over the background thermal noise level of the receiver. This can be seen from a basic link budget calculation in which a mobile with 73 dB of pathloss to the closer femtocell and transmitting at maximum 23 dBm produces a received signal level of approximately -50 dBm. Clearly, in this corner case, the reverse link of both femtocells has become unstable and the effective reverse data rate drops to close to zero. This situation represents the limiting case in which handsets connected to closely spaced femtocells and in conditions of RF dragging and high power simultaneous data uploads cause significant mutual reverse link interference to both femtocells.

Correlation analysis between the total uplink transmitted power of AT_{F2} and AT_{F1} showed that under the conditions of RF dragging the transmitter powers of the two handsets became on the average 92% correlated. This explains the mutual oscillatory behavior as the power control of the two femtocells try to compensate for the interference rise.

3.1 Reverse Link Interference Mitigation

The ideal technique to control this type of reverse link instability would be to form ad-hoc clusters of femtocells that can support either hard or soft handoff. In the absence of inter-femtocell handoff, other forms of reverse link interference mitigation must be considered. The first technique can be implemented in the Automatic Network Planning Function [5] when the femtocells are initially provisioned so as to pull in the coverage of both of the femtocells so calls drop much earlier and there is minimal overlap of the forward link coverage.

A second technique for controlling this type of mutual interference is to significantly reduce the reverse link transmitter power (and therefore the data rate) of handsets when then the conditions of mutual RF dragging are sensed. There are two elements to successful reverse link interference mitigation algorithms using this technique: detection and reaction. In most cases detection attempts to sense high levels of interference on the forward link at the handset combined with high reverse link transmitter power that imply that there is mutual interference on the reverse link and the algorithm reacts to reduce the data rate of the mobile terminal (even reducing to 0) to reduce the total transmitter power and therefore the interference.

The forward link measurements can be done either based on primary measures of interference such as E_c/I_o reported by the handset or from secondary measures of signal quality such as DRC (1XEV-DO data rate control) or CQI (HSDPA channel quality index). When a femtocell detects that the handset is seeing significant forward link interference, it reduces the uplink data rate and therefore the transmitter power from the handset, potentially reducing throughput to 0 depending on the level of interference.

In the limiting case the femtocell terminates the data call in which the AT either attempts to reselect and then register on the other femtocell (open access) or goes to the macro network, but in either case the RF dragging induced interference will be stopped.

4. Conclusions

Measurements described in this paper were designed to better understand the scenarios described in Ref. [1] in real deployments. The use case of greatest concern in real world deployments occurs when "RF dragging" between handsets connected to closely spaced femtocells can lead to significant reverse link interference when users are doing simultaneous high speed uploads.

For voice calls where the total reverse link transmitter power is low and given the path losses

involved between handsets and femtocells, we were unable to reproduce the conditions of reverse link instability. In addition almost all femtocells support voice handoff which moves handsets off the femtocell near its cell edge and eliminates the problem of RF dragging.

For the case of high speed reverse link data upload with two handsets in condition of RF dragging, reverse link data rates and transmitter power were observed to oscillate under conditions of sustained upload. In other words the reverse link became unstable. Constraining the handset transmitter power by reducing uplink data rates, including the pilot, mitigated some but not all reverse link interference. In the limit the best approach other than forming ad-hoc clusters that support handoff is to require the algorithms that manage forward link coverage (the centralized network planning function) pull in the coverage of both of the femtocells so that RF dragging is minimized. Sensing and then disconnecting (dropping) calls that are in conditions of RF dragging is a final approach to interference management.

The good news from the study is that the conditions leading to inter-femtocell reverse link interference scenarios described in Ref. [1] are relatively rare and can be mitigated through a combination of RF planning (having the two femtocells pull in their coverage to minimize the RF dragging potential) and reverse link interference mitigation. As the femtocell density increases, the importance of algorithms in the femtocell to manage reverse link femtocell to femtocell reverse link interference increases.

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