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Femtocell Systems Overview

for cdma2000 Wireless Communication Systems

Revision History

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v0.13	Initial Publication Version	July 28, 2011

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Foreword

This foreword is not part of this Technical Report.

"Femtocell System Overview for cdma2000 Wireless Communication Systems" is published by 3GPP2, and may be republished by its Market Representation Partners (MRPs) in efforts to assist in proliferation and deployment of femtocells.

1. SCOPE

This document is intended as a guide to wireless network operators, FAP (Femtocell Access Point) vendors and other Infrastructure vendors to assist in the deployment of 3GPP2 femtocell systems. Every effort was made to make the contents of this document consistent with other cdma2000[1] femtocell related specifications developed in 3GPP2. If any ambiguity exists, 3GPP2 technical specifications shall take precedence. As femtocell systems evolve and their standardization continues into subsequent system releases, this Overview will be updated accordingly, within those subsequent releases.

This document is informative. As such, any usage of normative-sounding language (e.g., “shall”, “should”, and “may”), if used on occasion, should be viewed contextually, e.g., as operational advice to operator, not as a system or feature requirement. It is of note that 3GPP2 feature/service requirements developed by TSG-S Stage 1 and SRD contain normative language, strictly speaking, only if that language appears within clearly enumerated requirement statements (see for example S.R0126 [7]).

2. INTRODUCTION

This document describes the key features of the 3GPP2 femtocells that have been specified in various 3GPP2 specifications. This document further serves as a femtocell deployment guide and recommends exemplary procedures and parameter settings and addresses the issues that are considered useful in a real world phased deployment scenario.

Deployment decisions and procedures which are different than those discussed in this document are feasible, and are in no way prohibited by the contents of this document.

2.1 Document Conventions

“Shall” and “shall not” identify requirements to be followed strictly to conform to this document and from which no deviation is permitted. “Should” and “should not” indicate that one of several possibilities is recommended as particularly suitable, without mentioning or excluding others, that a certain course of action is preferred but not necessarily required, or that (in the negative form) a certain possibility or course of action is discouraged but not prohibited. “May” and “need not” indicate a course of action permissible within the limits of the document. “Can” and “cannot” are used for statements of possibility and capability, whether material, physical or causal.

[1] cdma2000® is the trademark for the technical nomenclature for certain specifications and standards of the Organizational Partners (OPs) of 3GPP2. Geographically (and as of the date of publication), cdma2000® is a registered trademark of the Telecommunications Industry Association (TIA-USA) in the United States.

2.2 References

This section contains a list of specifications and other documents that are used as references in this document. All references are informative. The earliest applicable revision and, if listed, version, of a reference is listed. Unless otherwise stated, any subsequent revision and/or version update is equally applicable. If Revision is not listed, Rev. 0 (-0) is implied. User should consult the latest 3GPP2 publication for updated (publication version) information.

[1] 3GPP2 A.S0024 Interoperability Specification (IOS) for Femtocell Access Points

[2] 3GPP2 C.S0001 Introduction to cdma2000 Standards for Spread Spectrum Systems

[3] 3GPP2 C.S0002 Physical Layer Standard for cdma2000 Spread Spectrum Systems [C.S0003]

[4] 3GPP2 C.S0003 Medium Access Control (MAC) Standard for cdma2000 Spread Spectrum Systems

[5] 3GPP2 C.S0004 Signaling Link Access Control (LAC) Standard for cdma2000 Spread Spectrum Systems

[6] 3GPP2 C.S0005-0 Upper Layer (Layer 3) Signaling Standard for cdma2000 Spread Spectrum Systems

[7] 3GPP2 S.R0126-0 System Requirements for Femto Cell Systems, May 2008

[8] 3GPP2 S.S0132-0 Femtocell Security Framework, January 2010

[9] 3GPP2 S.S0135-0 Network Architecture Model for cdma2000 Femtocell Enabled Systems, April 2010

[10] 3GPP2 C.S0010-D Recommended Minimum Performance Standards for cdma2000 Spread Spectrum Base Stations

[11] 3GPP2 C.S0024-B cdma2000 High Rate Packet Data Air Interface Specification

[12] 3GPP2 C.S0032-C Recommended Minimum Performance Standards for cdma2000 High Rate Packet Data Access Network

[13] 3GPP2 X.S0059 cdma2000 Femtocell Network:
-000 Overview
-100 Packet Data Network Aspects
-200 1x and IMS Network Aspects
-400 1x Supplementary Service Aspects
Editor's Note: The above document is a work in progress and should not be referenced unless and until it is approved and

published. Until such time as this Editor's Note is removed, the inclusion of the above document is for informational purposes only.

[14] 3GPP2 X.R0063-0 Femtocell Configuration Parameters
Editor's Note: The above document is a work in progress and should not be referenced unless and until it is approved and published. Until such time as this Editor's Note is removed, the inclusion of the above document is for informational purposes only.

[16] Broadband Forum: TR-196/TR-262 Amendment 2, CPE WAN Management Protocol v1.1, December 2007

[17] Broadband Forum: TR-196 Femto Access Point Service Data Model, April 2009

[18] 3GPP2 C.S0016-A Over-the-Air Service Provisioning of Mobile Stations in Spread Spectrum Standards, December 2001

[19] 3GPP2 C.S0016-D Over-the-Air Service Provisioning of Mobile Stations in Spread Spectrum Standards, January 2010

[20] 3GPP2 C.S0035-A CDMA Card Application Toolkit (CCAT), August 2007

[21] 3GPP2 C.S0023 Removable User Identity Module (R-UIM) for cdma2000 Spread Spectrum Systems

[22] 3GPP2 C.S0065-B cdma2000 Application on UICC for Spread Spectrum Systems, January 2010

[23] 3GPP2 C.S0005-E Upper Layer (Layer 3) Signaling Standard for cdma2000 Spread Spectrum Systems, June 2010

[24] IETF RFC 4306 Internet Key Exchange (IKEv2) Protocol, December 2005

[25] 3GPP2 C.S0010-C Recommended Minimum Performance Standards for cdma2000 Spread Spectrum Base Stations, March 2006

[26] 3GPP2 C.S0032-B Recommended Minimum Performance Standards for cdma2000 High Rate Packet Data Access Network, May 2008

[27] 3GPP2 X.S0011-001-E v1.0, cdma2000 Wireless IP Network Standard: Introduction, November 2009

[28] 3GPP2 A.S0013 Interoperability Specification (IOS) for cdma2000 Access Network Interfaces - Part 3 Features

[29] 3GPP2 A.S0008 Interoperability Specification (IOS) for High Rate Packet Data (HRPD) Radio Access Network Interfaces with Session Control in the Access Network

[30] 3GPP2 A.S0009 Interoperability Specification (IOS) for High Rate Packet Data (HRPD) Radio Access Network Interfaces with Session Control in the Packet Control Function

3. DEFINITIONS AND ABBREVIATIONS

The terms and abbreviations which are used within this document are listed as follows:

3GPP2	Third Generation Partership Project #2
AAA	Authorization, Authentication, Accounting
ACL	Access Control List
A/D	Analog to Digital
AN	Access Network
APPIM	Access Point Pilot Information Message
AT	Access Terminal
AWGN	Additive White Gaussian Noise
BIP	Bearer-Independent Protocol
BS	Base Station
CA	Certificate Authority
CCLM	CDMA Channel List Message
CDMA	Code Division Multiple Access
CFSCNM	Candidate Frequency Search Control Message
CFSRPM	Candidate Frequency Search Report Message
CFSRQM	Candidate Frequency Search Request Message
CPE	Customer Premises Equipment
CS	Circuit-Switched
CSIM	CDMA Subscriber Identity Module
dB	Decibel
DSL	Digital Subscriber Line
GPS	Global Positioning System
GSRDM	Global Service Redirection Message
EUI	Extended Unique Identifier
FAC	Femtocell Access Control
FAM	Femto-Aware Mobile
FAP	Femtocell Access Point
FCS	Femtocell Convergence Server
FEID	Femtocell Equipment Identifier
FGW	Femtocell Gateway
FL	Forward Link
FMS	Femtocell Management Server
HRPD	High Rate Packet Data
IC	Interference Cancellation

ICGI	IS-41 Cell Global Identifier (see Ref. [27])
ID	Identity
IE	Information Element
IEEE	Institute of Electical and and Electronics Engineering
IETF	Internet Engineering Task Force
IKE	Internet Key Exchange
IMS	IP Multimedia Subsystem
IMSI	International Mobile Subscriber Identity
IOS	Interoperability Specification
IP	Internet Protocol
IPSec	Internet Protocol - Secure
km/h	Kilometers per hour
LAC	Link Access Control
LAN	Local Area Network
LAT	Latitude
LIPA	Local IP Access
LM	Legacy Mobile
LON	Longitude
LTE	Long Term Evolution
MCL	Minimum Coupling Loss
MHz	Megahertz
MPS	Minimum Performance Standard
MRP	Market Representation Partner
MS	Mobile Station
MSC	Mobile Switching Center
MSCe	Mobile Switching Center Emulation
NAT	Network Address Translator
NID	Network Identity
NL	Neighbor List
NLM	Neighbor List Message
OAM&P	Operation, Administration, Management & Provisioning
OTASP	Over-The-Air Service Provisioning
PCF	Packet Control Function
PDSN	Packet Data Serving Node
PMRM	Power Measurement Report Message
ppb	parts per billion
PSAP	Public Safety Answering Point
PSMM	Pilot Strength Measurement Message

PUZL	Preferred User Zone List
PN	Pseudo Noise (or Pseudo-random Noise)
QoS	Quality of Service
RAN	Radio Access Network
RL	Reverse Link
R-UIM	Removable User Identity Module
RF	Radio Frequency
RFC	Request For Comment
RIPA	Remote IP Access
RoT	Rise over Thermal
Rx	Receiver
SA	Security Association
SeGW	Security Gateway
SID	System Identity
SMSPP	Short Message Service Point-to-Point
SNR	Signal-to-Noise Ratio
SON	Self-Organizing Networks
SRD	System Requirements Document
TLS	Transport Layer Security
TSG	Technical Specification Group
Tx	Transmitter
VPN	Virtual Private Network
WAN	Wide Area Network
WiFi	Wireless Fidelity
WLAN	Wireless Local Area Network

4. FEMTOCELL SYSTEM FEATURES AND ARCHITECTURE OVERVIEW

4.1 Architecture and Interfaces

This section provides an overview of the architecture and interfaces to support Femtocell base station with cdma2000 network. Additional details are provided in X.S0059-000 [13], A.S0024 [1], and S. S0135 [9]. Each of the documents contains a view of the system architecture and interfaces from a slightly different perspective within the network. The intent of this document is to offer a supplemental general view without invalidating in any way the views offered in the three listed specifications.

4.1.1 Femtocell Architecture for cdma2000 1x Circuit-Switched Services

Figure 4.1-1 and Figure 4.1-2 show the RAN reference architecture for IOS-based 1x access from a FAP with the support of the A1p/A2p and the A1/A2 interfaces, respectively. Figure 4.1-3 depicts SIP-based simplified femtocell network reference architecture for cdma2000 1x circuit-switched service access.

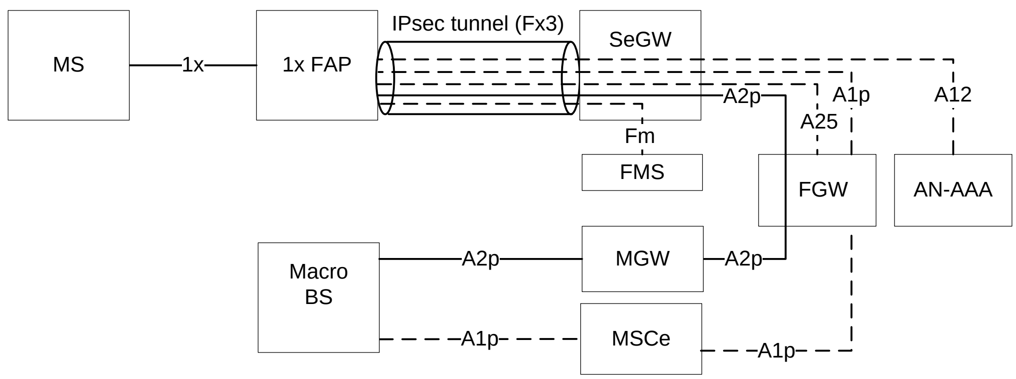

Figure 4.1-1 Femtocell IOS-based 1x Voice Architecture with A1p/A2p Interfaces

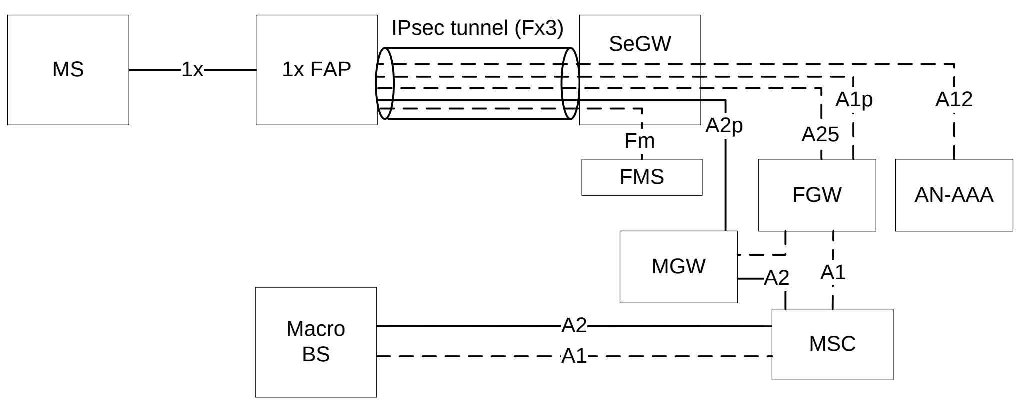

Figure 4.1-2 Femtocell IOS-based 1x Voice Architecture with A1/A2 Interfaces

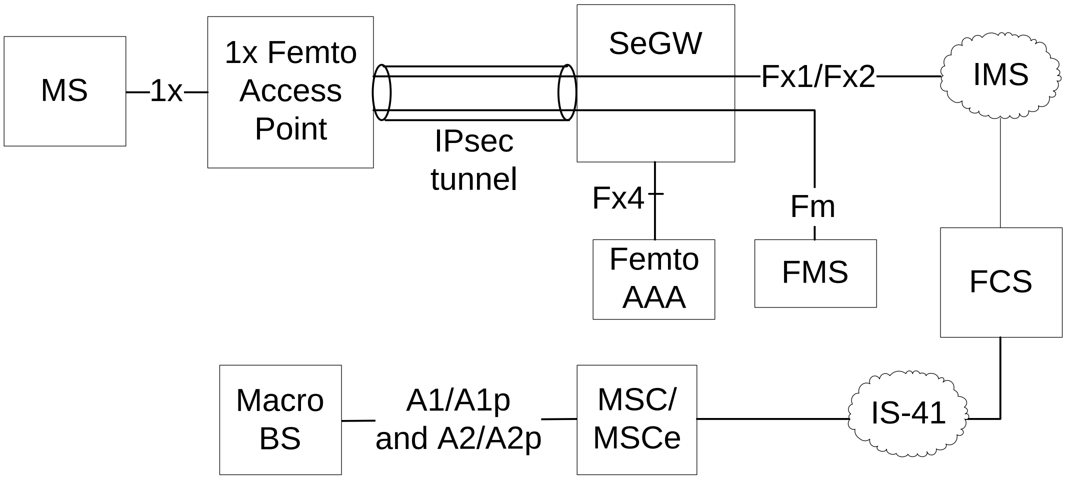

Figure 4.1-3: SIP-based simplified cdma2000 1x CS Service Femtocell Network Architecture with MSC

Femtocell Access Point (FAP): provides cdma2000 coverage in a small area, usually a private residence or a small office, and connects the MS to an operator's network via a broadband IP connection (e.g., DSL, cable). The FAP may operate in cdma2000 1x mode, HRPD mode, or both modes. The FAP may also provide the femtocell access control function.

Femtocell Convergence Server (FCS): provides equivalent functions to an MSC/VLR in the macro network, e.g., providing processing and control for calls and services. However, 1x CS FAP and FCS do not communicate using the legacy BS - MSC interface. Instead, Fx1 and Fx2 interfaces based on the IP Multimedia Subsystem (IMS) framework are used. From the perspective of a macro MSC, the FCS appears as another MSC and supports the X.S0011 [27] interface for inter-MSC communication.

The Femtocell Gateway /Femtocell Legacy Convergence Server (FGW/ FLCS) resides in an operator's network and provides gateway convergence functions between either an MSC (over the A1/A2 IOS interfaces), an MSCe (over the A1p/A2p IOS interfaces), or the MAP network (over the E interface) and the FAP (over the Fx6 interface). The FGW/FLCS provides aggregation, proxy, and signal routing functions for the FAPs to access services within the system operator's core network.

Femtocell Management System (FMS): is used for the auto-configuration of the FAP. FMS also supports configuration for Femtocell Access Control (FAC).

Femtocell Security Gateway (SeGW): provides secure communication between the FAP and the operator's core network. IP packets traversing between FAP and operator's core network are encapsulated in an IPSec tunnel. The SeGW is also responsible for authenticating and authorizing the FAP.

Femtocell AAA: provides an authorization function for FAP; may also provide FAC policy.

4.1.2 Femtocell Architecture for HRPD and cdma2000 1x Packet Data

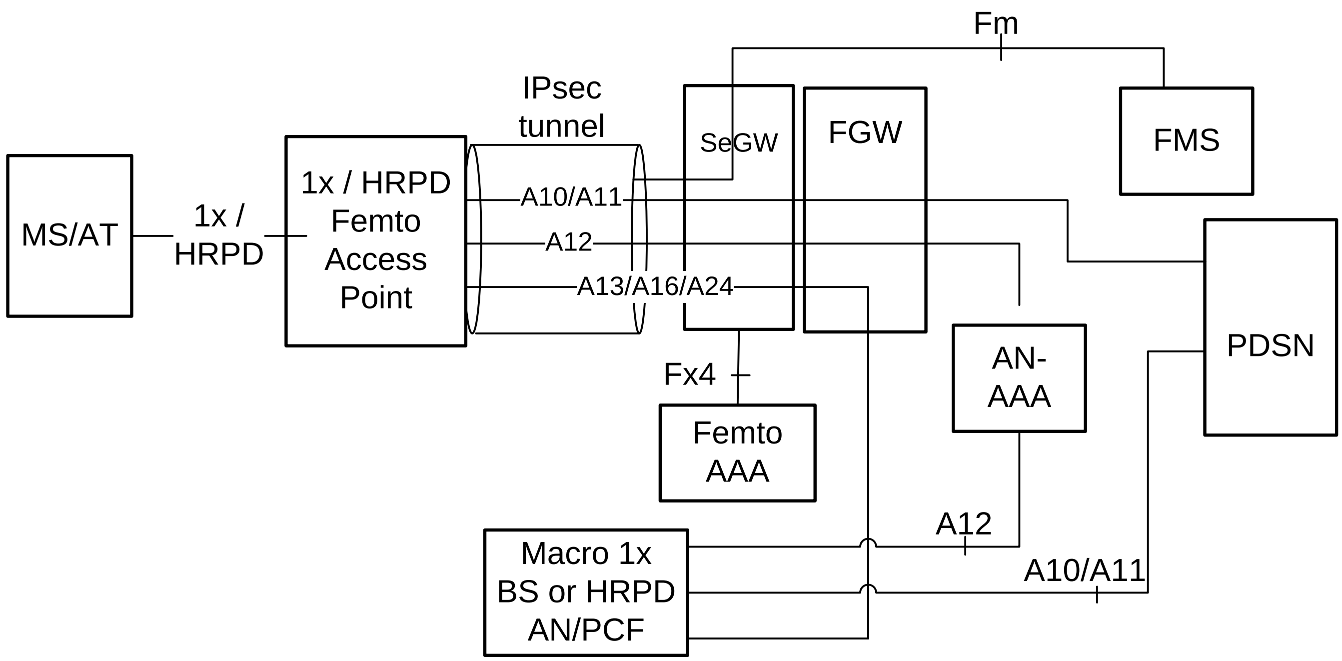

Figure 4.1-4: Simplified HRPD/cdma2000 1x Packet Femtocell Network Architecture

Figure 4.1-4 shows a simplified 3GPP2 architecture supporting packet data services through either cdma2000 1x or HRPD air-interfaces. In case the FAP supports both cdma2000 1x CS and cdma2000 1x/HRPD packet data, common entities (i.e., SeGW, Femtocell AAA and FMS) and interfaces (i.e., IPSec tunnel and Fm interface) are used.

Femtocell Gateway (FGW): is a network entity that provides aggregation for A10/A11/A12/A13/A16/A24 interfaces and proxy functions for the FAP to access services within the system operator's network.

Refer to section 4.1.1 for description of FAP, SeGW, Femtocell AAA and FMS.

4.2 Features and Specifications

4.2.1 Femtocell Subscriber Features and Services

Table 4.2-1. Femtocell System and Subscriber Features and Services

Feature/Service	TSG-S	TSG-C	TSG-A	TSG-X	Comment
Femtocell Activation	S.R0126	*C.S0001~5*	A.S0024	X.S0059-100 X.R0063	Feature is also referred to as "FAP Power-Up"; Historically the term "Power-Up" has been used in the 3GPP2 specifications to include such activities as activation, authorization and registration. See A.S0024-0 Section 4.1.1 or X.S0059-100 Section 3.
Idle hand-in (cdma2000 1x)	S.R0126	*C.S0001~5*			
Idle handoff from FAP to macrocellular system (cdma2000 1x)	S.R0126	*C.S0001~5*	*A.S0013*		
Active hand-in (cdma2000 1x)	S.R0126	*C.S0001~5*	A.S0024	X.S0059-200	
Active hand-out(cdma2000 1x)	S.R0126	*C.S0001~5*	A.S0024	X.S0059-200	
Idle hand-in (HRPD)	S.R0126	*C.S0024*	*A.S0008* *A.S0009*	X.S0059-000	
Idle hand-out (HRPD)	S.R0126	*C.S0024*	*A.S0008* *A.S0009*	X.S0059-000	

Connected State session transfer from FAP to macrocellular system (HRPD)	S.R0126	*C.S0024*	A.S0024-0 *A.S0008* *A.S0009*	X.S0059-000	
Connected State session transfer from macrocellular system to FAP (HRPD)	S.R0126	*C.S0024*	A.S0024-A *A.S0008* *A.S0009*	X.S0059-000	
Local IP Access (LIPA)		*C.S0024-A*	A.S0024-0	X.S0059-000 X.S0059-100	See A.S0024 Sections 2.5 and 4.3
Remote IP Access (RIPA)		*C.S0024-A*		X.S0059-000 X.S0059-100	
Location Services	S.R0126	*C.S0022* *C.S0001~5*	*A.S0024-0*	X.S0059-000 X.S0059-100 X.S0059-200 *X.S0002* *X.S0024*	
Emergency Services	S.R0126			X.S0059-000 X.S0059-100 X.S0059-200	
Short Message Service (SMS)	*S.R0126*	*C.S0001~5*	*A.S0024-0*	X.S0059-000 X.S0059-200	

Call Origination	*S.R0126*	*C.S0001~5*	*A.S0024-0*	X.S0059-000 X.S0059-200	
Call Termination	*S.R0126*	*C.S0001~5*	*A.S0024-0*	X.S0059-000 X.S0059-200	

Note: Some specifications required for Femtocell support have no explicit references to femtocells. Those specifications are said to be “transparent” to femtocells. Transparent specifications are listed in Table 1 in *blue italic font*.

4.2.2 Test Specifications

Table 4.2-2 Test Specifications

Feature/Service	TSG-S	TSG-C	TSG-A	TSG-X	Comment
Minimum Performance Standard (MPS) for FAP Transmitter (cdma2000 1x)	S.R0126	C.S0010-D			
Minimum Performance Standard (MPS) for FAP Receiver (cdma2000 1x)	S.R0126	C.S0010-D			
Minimum Performance Standard (MPS) for FAP Transmitter (HRPD)	S.R0126	C.S0032-C			
Minimum Performance Standard (MPS) for FAP Receiver (HRPD)	S.R0126	C.S0032-C			

5. FEMTOCELL SYSTEM GUIDELINES

This section contains general guidelines for the phased deployment of femtocell systems and details the recommended procedures and parameter settings corresponding to the individual feature or service aspect.

A number of technical possibilities and deployment options are discussed. However, this does not imply mandatory support of these features, either in products, or in terms of deployment.

5.1 Deployment Phases

Femtocell systems are an evolving technology, expected to offer an increasing array of features, as wireless communication systems evolve from the traditional macro-system model to the one which uses femtocells as prominent deployment feature. This evolutionary path is gradual, though marked with distinct events associated with introduction of Mobile Stations (MSs) with various capabilities, called Types herein:

- Type A: Legacy MSs;
- Type B: Femto-aware mobiles (FAMs) supporting unchanged radio interface;
- Type C: FAMs supporting updated revisions of radio interface.

With Type A, the wireless network assumes an MS which has no awareness of Femtocell Access Point (FAP) presence in the network. The MS contains no enhancements (be it built-in or provisioned later) designed to operate with a FAP.

Type B MS design is enhanced (e.g., to detect a presence of femtocell), while it can still operate with an unchanged radio interface. MS supports internal configurations, be it provisioned by the network, self-provisioned, or built-in, all designed with the specific purpose of femtocell operation with increased efficiency, flexibility, and versatility. This results in improved communication performance (e.g., faster FAP discovery for hand-in to a FAP) or better system performance (e.g., ability to operate a FAP without relying on pilot beacons). Thus the operator can offer improved performance associated with femtocells, while having more flexibility with any plans for radio interface evolution in its network.

Type C MS has further awareness of Femtocell System in terms of being able to receive system configuration messages introduced with the specific purpose to support femtocell systems.

Although marked with distinct events of initiation of deployment of different types of MSs, these types can overlap in a given network, i.e., the network can support a mix of legacy MSs and one or both types of FAMs simultaneously.

From the network configuration perspective, there are several distinct states of deployment:

State 0: Macro system state (pre-femtocell deployment)

State 1: Network configured to support femtocells with legacy MSs (Type A)

State 2: Network configured to support femtocells with legacy MSs and FAMs without radio interface change (i.e., Types A and B)

State 3: Network configured to support femtocells with legacy MSs and MSs with or without radio interface change (i.e., Types A, B, and C)

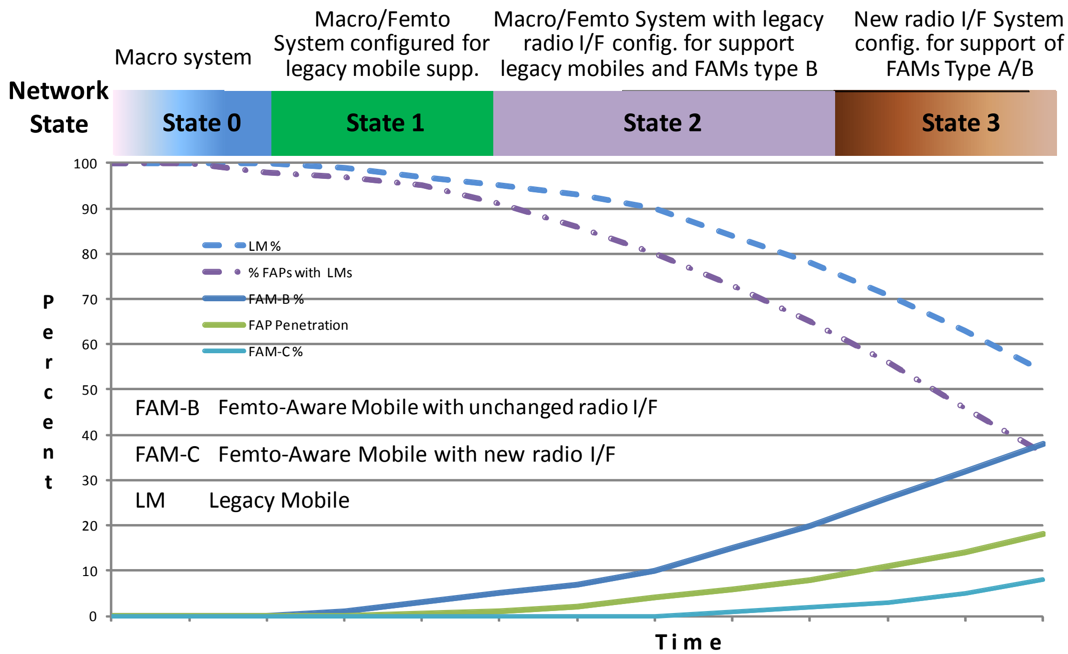

Figure 5.1-1: Network State Evolution and Femtocell Penetration

This is depicted in the diagram on Figure 5.1-1. Note that the diagram is strictly illustrative, not meant as a forecast.

The diagram shows migration through Network States from State 0 through State 3, with the mix of MSs of various kinds, as well as FAP penetration (percentage of MSs associated with at least one FAP, e.g., percent of those MSs owned by members of a household with a FAP installed).

An operator can start “seeding” (activating in advance) FAMs prior to an actual network configuration in support of femtocells. Alternatively, FAM deployment can coincide with, or be deferred until network configuration for femtocells (State 1) is conducted.

When deciding to start femtocell deployment, operator configures the network to State 1, which supports femtocells using legacy MSs (Type A). Operator can choose to leave the network in this state for a long time, meanwhile allowing the percentage of Type B and later Type C MSs, as well as FAP penetration to increase, as well as percentage of FAPs associated with legacy MSs to drop.

Operator may then decide to move to State 2 configuration, in which Type B MSs are fully supported, noting that by that time the percentage of Type B MSs may be considerable. Operator can choose to leave the network in this state for a long time, meanwhile allowing the percentage of Type B and C MSs, as well as FAP penetration to increase, and possibly percentage of FAPs associated with legacy MSs to drop.

Operator may then optionally, with full discretion in terms of decision and timing, upgrade the network to State 3, in which all MS types are fully supported.

As evident in the above outline, network operator can migrate the network through all these states. Alternatively, operator may choose to skip certain state or states, such as 1, 2, or 3. Each operator should carefully evaluate the strategy of migration of the network through these states, upon considering the performance and other objectives for the system. One of the purposes of this document is to assist cdma2000 operators in such evaluation in their decision making process.

5.2 Radio Frequency Planning

5.2.1 Dedicated Frequency and Co-Channel Deployment Scenarios

There are two basic radio frequency planning scenarios for femtocell deployment.

Scenario 1: Dedicated RF carrier. In this scenario, one of the 1.25 MHz RF carriers available to the operator is dedicated for femtocells, while others are exclusively used by the macro system. If and when the operator chooses to deploy HRPD femtocells, then the total of two 1.25 MHz RF carriers are dedicated to femtocell deployment, while remainder can be used for the macro system. In this scenario, the macrocell and the femtocell systems are segregated in terms of RF spectrum use. A carrier with no adjacent macro carriers may be preferred to avoid adjacent channel leakage from femtocells.

Scenario 2: Macro/femto co-channel deployment. In this scenario, the macro system can share with femtocells some or all RF carriers that are used by the macro system. When deploying femtocell systems, the operator typically selects an RF carrier and deploys femtocells on that carrier, while leaving macrocell frequency use unchanged. This effectively means that the selected RF carrier shares the spectrum between the macro- and the femtocell system. When HRPD femtocells are deployed, one of the HRPD RF carriers is likewise selected for sharing between the macrocell and the femtocell systems.

Figure 5.2-1 depicts schematically the two RF planning scenarios.

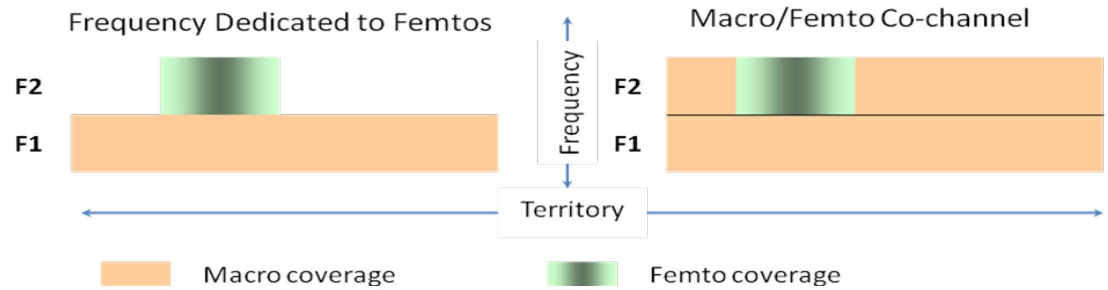

Figure 5.2-1: RF deployment scenarios for femtocell systems

In figure 5.2-1, femtocells are deployed on frequency F2. Frequency F1 is used exclusively for macro system. In the co-channel deployment scenario, frequency F2 is used by both the macrocell and the femtocell system.

Co-channel deployment scenario (2) has an advantage over the dedicated scenario 1 in many deployment scenarios in terms of total system capacity. This is because in scenario 2, frequency F2 can also carry macro system traffic, adding to the total capacity of the system. Whenever a MS is not in the vicinity of a femtocell, it can use frequency F2, in addition to frequency F1. Unless femtocells are deployed very densely, scenario 2 will yield higher system capacity. In the case of only 2 RF carriers, as shown in Figure 5.2-1, the macro system capacity for scenario 2 is approximately twice the capacity of scenario 1. However, if more than 2 RF carriers are available, the capacity gain of scenario 2 is not as pronounced. Thus, an operator concerned with the system capacity will often choose scenario 2, while an operator having much available spectrum may consider scenario 1 when balancing interference and system capacity issues. Proper interference management techniques, as described in section 5.4, are crucial to mitigate the impact of interference on the FL and RL macro performance, when choosing deployment scenario 2. One of the advantages of scenario 1 is that the interference between the macro system and the femtocell system may be easier to mitigate. Additionally, since the macro system may interfere less with the femtocell system, the coverage area of a femtocell is potentially larger than in the case of scenario 2. An operator may initially select scenario 1 if there is no capacity constraint, since interference control is one of the biggest risks in femtocell deployment. Then as capacity becomes constrained, particularly as data service uptake starts demanding more HRPD carriers, the operator may migrate to scenario 2, as the advantages of using femtocells begin to clearly outweigh the drawbacks.

The above scenarios discuss the case where only a single carrier is used for femtocell deployment. Although this might be sufficient for most deployments, very high femtocell deployment densities in the long-term may require multiple carriers to mitigate interference issues between femtocells. In very high density deployments, there is a tradeoff between inter-femto interference and impact to active macro users. An efficient way to balance this tradeoff is by using a scheme in which the operator allows femtocells to use multiple RF carriers, but assigns a preference order to these carriers. All or some of these carriers may be shared by the macro network depending on spectrum availability.

The frequency planning of cdma2000-1x and HRPD can be done independently, i.e., cdma2000-1x system can have dedicated femtocell spectrum, whereas HRPD may share macro frequency spectrum, since an operator may have different amount of spectrum available for femtocell deployment for the two technologies.

5.2.2 Narrow-band and Broad-band Signal Sampling

Frequently, an operator has many more RF carrier frequencies available than the two shown in Figure 5.2-1. In such cases, selecting which RF carrier to use for femtocell deployment should undergo a careful consideration. To illustrate this, we refer to figure 5.2-2, showing a case where a total of thirteen RF carriers (F1 to F13) are available to an operator. In principle, the operator may choose any one of the thirteen RF carriers for femtocell deployment. We show the case where the operator opted for a carrier somewhere in the middle of available band of carriers, F8.

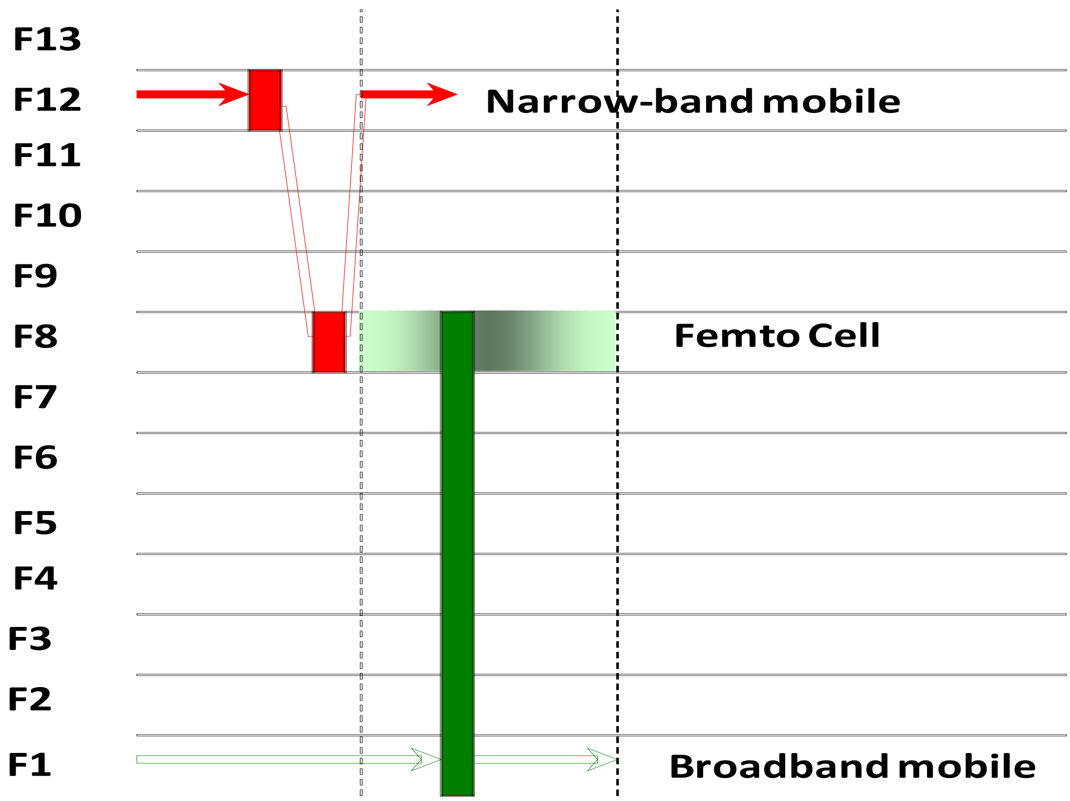

Figure 5.2-2: Narrow-band and broad-band sampling

To illustrate significance of this choice, we show cases of two MSs on the macro system. A MS using narrow-band sampling (“narrow-band mobile”) is shown in red, monitoring frequency F12. Another MS using broad-band sampling (“broadband mobile”) is shown in green. Each MS’s trajectory of travel is depicted schematically with arrows indicating that they each initially enter the coverage area of the subject femtocell operating on frequency F8. We assume that both MSs are in idle mode, each monitoring its assigned frequency. Hence they sample the RF signal during the paging cycle's wake time, so that they can search for pages and for idle handoff conditions (pilot E_C/I_0 of a new cell being at certain level to warrant idle handoff to a new cell and start monitoring paging channel of that new cell). In addition to that, if a FAM supports femtocells, and if it has an indication to be in the vicinity of a target femtocell (details of how this indication of being in the vicinity can be acquired by the MS are discussed in a later chapter), it also samples the signal on frequency F8, not necessarily in every paging cycle, but frequently enough to meet the target femtocell discovery delay time.

In order not to miss any pages, narrow-band MS tunes to frequency F8 and take a signal sample at a time that is different from its page wake cycle, then retune back to frequency F12, and continue to monitor the paging channel at the paging wake time.

In contrast to that, the broadband MS can take a signal sample across several RF carriers, i.e., it can conduct multi-carrier sampling. This allows it to be awake no more than it would be required to just monitor paging channel on the macro frequency. The advantage of broadband (multi-carrier) sampling is apparent. The broadband MS can save much power by virtue of multicarrier sampling. However, the frequency range over which this broadband sampling can occur is limited by the speed of the A/D converter in the front end of the baseband processing hardware of the broadband MS. This is the reason to select the femtocell frequency in the middle of the frequency band range, if that range is extensive. By doing so, the femtocell frequency can be reached by broadband sampling from either side of the femtocell frequency, in the best case covering the entire range of the spectrum controlled by the operator.

Broadband sampling MSs will be fielded at an increasing rate, and will quite soon become a commonplace, as network capabilities migrate toward broadband technologies such as HRPD Rev. B and LTE. Hence, operators should take these technical issues into consideration when planning the radio channel assignment for femtocells.

5.2.3 Femtocell Discovery

One of the critical problems with femtocells is enabling a MS to find the femtocell, when the MS moves within coverage area of the femtocell.

Referring back to figure 5.2-2, each MS is hashed to one of the frequencies listed in the CDMA Channel List Message broadcast on the paging channel (see C.S0005 [6], Section 2.6.2.2.4). In the case depicted in Figure 5.2-2, CDMA Channel List Message would contain the 13 RF carriers F1 ~ F13. The MS registers on the frequency where it is hashed, monitors paging channel on that frequency, and uses the access channel on that frequency when initiating a call. This ensures uniform distribution of MSs across the 13 RF carriers, hence uniformly distributed access and paging channel load across the available carriers.

However, unless a MS is hashed on frequency F8, it would not ordinarily detect the femtocell operating on that frequency. In the dedicated frequency deployment scenario, this would always be the case. To detect a femtocell on a different frequency, a MS needs to perform inter-frequency pilot searches, which may not be triggered unless macrocell signal quality is poor.

The following two solutions are offered to solve the problem of femtocell discovery:

1) Beacons, designed to support legacy MSs
2) Preferred User Zone List (PUZL), designed to support FAMs.

5.2.3.1 Beacon Based Femtocell RF Design

One way to remedy the situation for legacy MSs is to have the femtocell transmit a beacon on the frequencies other than the one where femtocell operates on. A cdma2000 1x beacon consists of pilot, paging and sync channels. An HRPD beacon consists of pilot, MAC and control channel.

When MS enters the femtocell coverage area and detects sufficient beacon pilot strength (generally 3 dB higher than the macrocell pilot it had been monitoring), it would perform idle hand-in (see Section 5.7.1.1.2). This entails reading the paging channel overhead messages. In cdma2000 1x paging channel carries messages such as CDMA Channel List Message (CCLM) or Global Service Redirection Message (GSRDM) that re-direct the MS from the beacon/macro frequency to the femtocell frequency. These messages are broadcast by the femtocell on the beacon on all 13 frequencies. GSRDM can re-direct the MS to any frequency band where the femtocell is located. Alternatively CCLM can be used, but may have limitations in terms of band support. HRPD beacon control channel carries Redirection message for this purpose. Hence the MS will tune to F8, read the overhead messages broadcast by the femtocell, and register on the femtocellular system. More details about recommended SID/NID configuration of the femtocellular system are provided in Section 5.3.3.

Table 5.2-1: Contents of CDMA Channel List Messages

Cell Type, Frequency	CDMA Chanel List Contents
Macro Base Station, All Frequencies	[F1 .. F13]
FAP, Femtocell Frequency	F8
FAP, Beacon Frequencies	F8

Sections 5.7 on mobility procedures contain additional discussion on how beacons are used for idle and active state handoffs in femtocell systems.

Continuous transmission of beacons on all macro system frequencies would require complex RF transmitter design in the femtocell, in addition to consuming considerable additional power, and causing added interference in the macro system. To avoid these drawbacks, beacon can be transmitted in a time shared fashion, referred to as hopping beacon. This is illustrated in Figure 5.2-3.

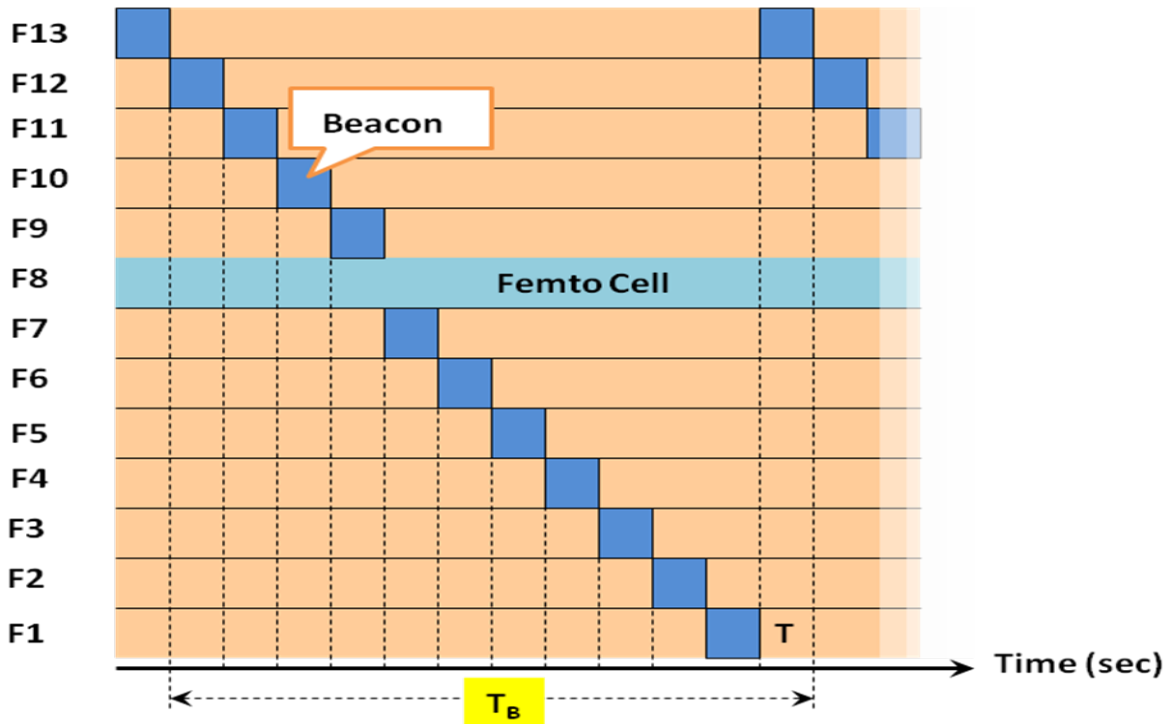

Figure 5.2-3: Hopping Beacon Transmission Timing

A pilot is searched during MS's wake-time of the slot cycle. Hence the beacon period T_B (time required to cover all slots on all beacon frequencies) shown in Figure 5.2-3 will be at least equal to the slot cycle time multiplied by the number of frequencies. For example, for a system set with slot cycle index of 1 (typical in many networks), the slot cycle time is 2.56 seconds, so T_B is at least 12 x 2.56 = 30.72 seconds, which represents the order of magnitude of the maximum delay of detection of a femtocell by a MS. Note that beacon transmission segments need not be identical to slot cycle segments; beacons can be designed to hop faster. The detection delay performance limitation is applicable to legacy MSs and for beacon-based femtocellular system design. As indicated earlier, femto-aware MSs can have a much reduced femtocell detection delay. These MSs need not rely upon beacons for femtocell detection. More details on FAMs are provided in later sections.

Two key design aspects of beacons are:

- Beacon transmit power calibration;
- Beacon scheduling

Though useful for femtocell discovery, beacon acts as interference to passing-by users who may not stay within femtocell coverage area for long.

This interference may degrade somewhat voice call quality of MSs in femtocell vicinity. Therefore, it is critical to manage beacon interference and simultaneously provide satisfactory beacon coverage inside the home. To achieve this, a femtocell can self-calibrate beacon transmit power using information about signal strength of the surrounding macro network. For a properly calibrated femtocell and beacon transmit power, and properly implemented interference management techniques, the impact on voice quality should not be significant.

A beacon transmission schedule dwell time on each frequency (T) should be long enough to allow a MS to read overhead messages from the beacon. For active state hand-in implementation, the dwell time is long enough to cause the MS to transmit PSMM upon detection of beacon (see more details on active state hand-in in Section 5.7.1.2.2). At the same time, it is desirable for the dwell time to be short to minimize the impact of beacon interference on active macro calls of users in the femtocell vicinity.

HRPD beacon scheduling can be independent of cdma2000 1x beacon. By time multiplexing cdma2000 1x and HRPD beacons, a single transmit chain can be used for both in a dual-mode system. HRPD beacon duty cycle can be lower, e.g., beacon can hop on HRPD frequencies once after several cycles of hopping on cdma2000 1x frequencies.

It is also possible to further reduce HRPD beacon hopping, if the dual mode FAP is capable of recognizing that a new cdma2000 1x MS has arrived and has sent a registration message to this FAP. The FAP can suppress HRPD beacon transmission until such a registration is recognized by the FAP. FAP can then transmit HRPD beacons for a short period of time, allowing a dual-mode MS/AT to discover HRPD FAP frequency.

5.2.4 Beacon-less Femtocell System Design

5.2.4.1 Preferred User Zone List (PUZL)

As part of enhancements to cdma2000 specifications to support femtocells, the Preferred User Zone List (PUZL) feature capability, first introduced in the Over-The-Air Service Provisioning C.S0016-A [18] was recently augmented to enable efficient femtocell discovery/system selection by FAMs. Originally, the concept of user zones was defined to support private and tiered services (e.g., in a university or enterprise campus deployment). This concept has been extended in C.S0016-D [19] to optimize MS performance in femtocell deployments.

The updated PUZL is a database that can be customized and stored in each MS, which defines a list of “user zones” within the macro network to aid the MS in searching for and finding specific femtocells. Each PUZL entry (user zone) is defined by geographical (GEO) information (e.g., latitude and longitude) and/or RF coverage characteristics of the macro network (e.g., macrocell PN Offset, BASE_ID, SID/NID, etc.) around the femtocell. In addition, the PUZL contains information about femtocell PN, frequency, unique ID (Access Point Identifier – AP_ID), etc. that identify a subject femtocell for each database entry. Thus, PUZL defines a "fingerprint" for each femtocell (or a group of femtocells) of interest to a given FAM, which allows this FAM to perform targeted search for a femtocell(s). For example, a PUZL entry corresponding to a user's home femtocell can be defined based on the location of the home. Using this information, a user's MS can perform targeted search for the home femtocell only when it detects the condition of being in or near the target locality (in this case its home), but not when far away from the home. This reduces femtocell searches by making system selection more efficient, thus extending stand-by battery life.

Another key feature of PUZL is that it allows a MS to distinguish between desired ("whitelisted") femtocells and non-desired ("blacklisted") femtocells. For example, if a MS cannot access service from a particular femtocell due to access restriction imposed by the femtocell, such a femtocell can be blacklisted in the PUZL database. Thus, upon encountering this femtocell, a FAM can remain on the macro system, and avoid registration on restricted femtocells. In addition, PUZL can eliminate the need to transmit beacons for femtocell discovery because a FAM can directly search for a femtocell on the frequency specified in PUZL. Thus, for example, a home-installed femtocell with all MSs in the household having FAMs can suppress beacon transmission.

PUZL provides flexibility to support cdma2000 1x, HRPD or hybrid 1x/HRPD femtocells. The entire PUZL database or specific entries in PUZL can be provisioned by the operator by means of Over-The-Air Service Provisioning (OTASP) defined in C.S0016-D [19], SMS Point to Point (SMS-PP) defined in C.S0035-A [20] (CDMA Card Application Toolkit) and Bearer-Independent Protocol (BIP) [20]. In addition, the PUZL database can be augmented by autonomous provisioning, either conducted by the FAM itself (exploratory searches and database acquisition by learning the frequently acquired femtocells), or assisted by user actions. For example, a user can trigger a femtocell scan and select a new PUZL entry by adding a nearby femtocell that transmits human readable text ID.

The network-provisioned information can be stored in the UIM, Removable User Identity Module (R-UIM), CDMA Subscriber Identity Module (CSIM), Smart Card or any other non-volatile database through traditional interfaces defined in C.S0023 [21] and C.S0065 [22]. Future enhancements are aimed at supporting the storage of learned PUZL entries in the Smart Cards.

5.2.4.2 MS Autonomous Construction of PUZL

PUZL database is customized in every MS, in accordance with that MS's patterns of movement and availability of femtocells in localities where this MS expends considerable amounts of time in relatively stationary state (e.g., one's home or office, a favorite café, friend's home, certain shops, etc.). A FAM may be able to autonomously construct its own PUZL, or supplement one which may be initially configured. This process of autonomous PUZL construction is also referred to as learning.

Exactly how a PUZL may be autonomously constructed by the MS learning is subject to that MS design. Some possible approaches are briefly outlined here. Note however, that this is not meant to either mandate or limit possible repertoire of approaches.

The operator may configure a FAM with a kernel of PUZL at the time of femtocell activation for a user. This can be done in a number of ways, for example FAM may download an application (at the time of femtocell activation in the user's household), which when invoked, based on the SID/NID observed by the FAM, places a PUZL kernel in the FAM's UIM (be it removable or not). This downloadable application may be administered by the operator, which may have in its database all the necessary information for the PUZL entry associated with the femtocell located in that user's home (upon its activation). Otherwise, the kernel may just contain minimum information needed for the FAM to facilitate the PUZL learning process: SID/NID for the home system, and carrier frequency or frequencies where femtocells are being deployed.

The fundamental process by which a FAM autonomously configures and maintains its PUZL is exploratory searching for femtocells. Having acquired a kernel, the FAM is effectively enabled to conduct exploratory searches. When on the macro system indicated by the kernel's SID/NID, the FAM can periodically or otherwise conduct exploratory searches on the frequency or frequencies indicated by the kernel, in an effort to expand its PUZL. When a new femtocell is found, the FAM determines whether or not it is open for access to this MS, and if so, can place it in its PUZL. FAM can also maintain the record of the last time each of its PUZL entries was actually accessed. Hence, if it so happens that the number of PUZL entries eventually exceeds the memory capacity dedicated to PUZL, the FAM can replace the least used one, or least recently used one by the newly acquired one.

When in the coverage of SID/NID other than that indicated by the kernel, the FAM may expand the search to a broader set of RF carriers, or it may use the aforementioned application to access the operator's database and learn which frequencies, if any, are used in the current SID/NID for femtocell deployment. Thus the FAM's exploratory search strategy may be refined accordingly.

The frequency of exploratory searches is a subject to FAM design. Since searching may involve tuning to a different frequency than the one currently monitored by the FAM, it adds to battery consumption. An obvious approach is to use periodic search, whenever the FAM is on the macro system. A FAM may have means to be more selective when committing to an exploratory search. For example, FAM may be able to make reasonable determination on whether it has been in a stationary or near-stationary state, and may commit to the exploratory search only when in such state for an extended period of time (e.g., more than 30 minutes). The determination on whether or not it is in such a state need not have absolute accuracy. Reasonable likelihood would suffice. The evaluation of mobile vs. stationary or semi-stationary state can be based on the constancy of set of macro base stations that the FAM observes, and degree of variability of pilot phase deviations over a set period of time.

5.3 Provisioning and Configuration

5.3.1 Macrocell Configuration in Support of Femtocells

One of the key objectives of the femtocell system deployment is to minimize the impact on the macrocellular system. This is particularly important for configuration of the macro system Radio Access Network (RAN). Ideally, operator would not need to perform a major reconfiguration of radio access parameters in the macro system, when deploying femtocells. This section illustrates how operators can manage macro system configuration evolution with such minimum impact in mind, as femtocell systems are deployed, and as femtocell density increases, while the system capabilities improve from legacy MS support to sophisticated FAMs, resulting in a well performing fully integrated macro/femto system over time.

5.3.1.1 Neighbor List Configuration for Support of Legacy MSs

Initial configuration of the macro system should address the support of legacy (femto-unaware) MSs. For a legacy MS to be able to search and find a femtocell, the Pilot PN Offset used by the femtocell is explicitly included in the neighbor list broadcast by the macro system. Our objective is not to change the Pilot PN Offset configuration for the macrocells. This will allow a relatively simple re-configuration of the neighbor lists, which can be summarized as follows:

- Leave the list of macrocell neighbors unchanged in the Neighbor List Message (NLM)
- Add a few new neighbors to each list, dedicated specifically for femtocells

Table 5.3-1 at the end of discussion of Pilot PN Planning option (see Section 5.3.1.2 provides an example of neighbor lists for some planning options.

In other words, for each macrocell, take the existing list of macro neighbors, and add to it a fixed list of femtocell neighbors. This fixed list of femtocell neighbors is added throughout the system, e.g., throughout a given metropolitan area, though the list may vary from one metropolitan area to another.

The optimum approach would be to choose the fixed femtocell neighbor list such that macrocells do not use any of the PN offsets from that list, i.e., the macro neighbor PN offset pool and the femtocell neighbor PN offset pool are distinct from each other.

This strategy allows the operator to continue planning the macro system independently, and in an unchanged fashion, regardless of the femtocell initial deployment and their evolution. For example, when operator places a new macrocell in operation by cell splitting, it can do so without having to worry about the impact of the choice of a PN offset for the new cell on any femtocell PN offsets that may be already deployed or will be deployed in the area. Likewise, the PN offset planning for the femtocells will be independent, confined to the pool of PN offsets reserved for femtocells.

Next, this is explained in a little more detail, using a specific example.

Parameter PILOT_INC is used when configuring neighbor list to outline spacing of PN Offsets in a network. The value of this parameter determines how many PN Offsets are available for assignment in a neighbor list. In the example used here, PILOT_INC value of 4 is assumed for the macro system, resulting in the total of 512/4 = 128 total available Pilot PN Offsets in the pool which the macro network can use.

The spacing of PN Offsets is determined from the pilot signal period, which is $T_P = 2^{15} = 32{,}768$ chips (26.667 ms). This means that for the example of PILOT_INC = 4, the PN Offset spacing will be 26.667/128 ms = 208 μs. This is an important value with repercussions on macrocell radius and maximum search window size, which will be discussed later in more depth. Just as a reference, observe that the value of 208 μs corresponds to propagation delay distance of 63 km.

Pilot signals are all identical pseudo-random sequences shifted in time (phase) from each other. Owing to the periodic nature of these signals, it's convenient to illustrate Pilot PN Offsets in a radial coordinate system, as shown in Figure 5.3-1.

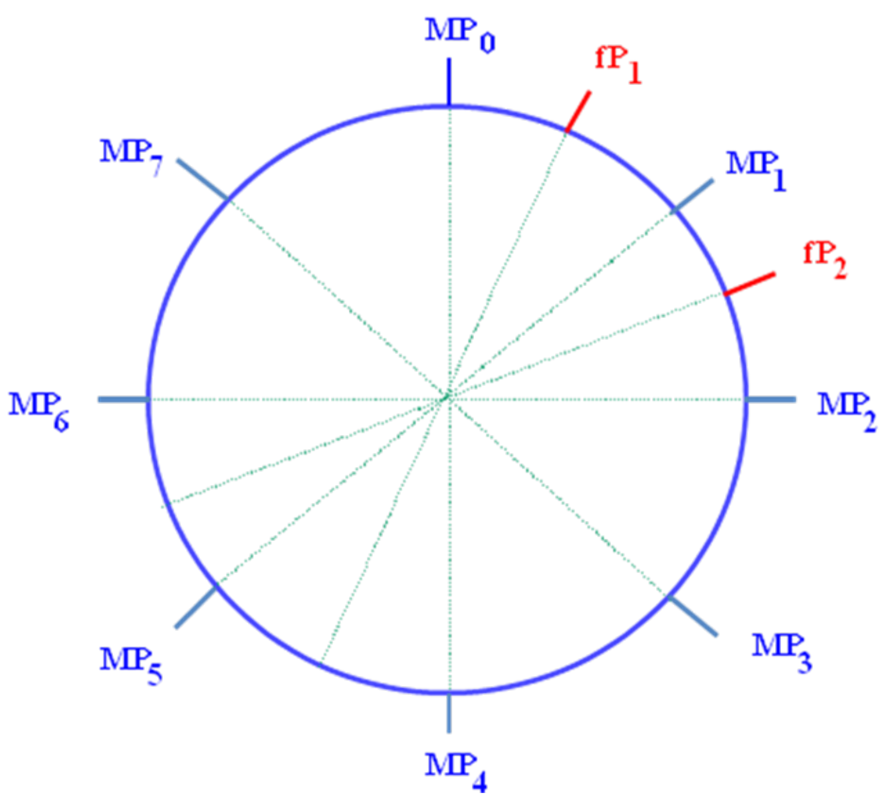

Figure 5.3-1: Macro- and Femto-cell Pilot Phases – PILOT_INC Approach

The example shown in figure 5.3-1 is for a higher value of PILOT_INC = 64, resulting in the total of 8 distinct macro pilot PN offsets, MP_0 through PM_7 shown in blue. This is for the purpose of illustrating the concept without making the figure too busy and illegible.

One convenient way to separate the Macrocell PN Offsets from Femtocell PN Offsets, while retaining the macrocell PN Offset pool as it was prior to femtocell deployments, is to place femtocell offsets exactly half way between macrocell offsets. This is illustrated in Figure 5.4-1 as fP_1 and fP_2 shown in red. Effectively, this means halving the value of PILOT-INC, but using the macrocell PN Offsets as if no change in PILOT_INC took place (i.e., retaining the pilot phase plan that existed prior to femtocell deployments). Thus one of the objectives outlined earlier is fulfilled.

Viewed differently, upon decrementing PILOT_INC to half of the value it had prior to femtocell deployment, the macrocells would use the even numbered PN offsets, while femtocells would be assigned a small subset of odd numbered PN offsets.

For the example of PILOT_INC = 4 prior to femtocell deployment, the pools of macrocell and femtocell pilot phases are mathematically described as:

- 128 macrocell PNs @ $2\pi/256 * 2i$; i= 0 ..127
- 128 femtocell PNs @ $2\pi/256 * (2i+1)$; i= 0 ..127

The new value of PILOT_INC would be 2.

For the support of legacy MSs, the newly created phase space for femtocell pilots would only partially be used. This is because of the NLM size limitation. Operator can decide how many femtocell PN offsets to use for this purpose. In further text it is assumed that a total of 5 femtocell pilot offsets are reserved. However, that number can be higher or lower, as operator determines, and it may be adjusted as femtocell system grows over time. These reserved femtocell pilots are then reused in the system. This may seem like a severe limitation in the number of available PN offsets for femtocell. However, it should be kept in mind that in the initial phases of femtocell deployment, their density will be relatively low for possibly several years, and in many cases, the femtocells will actually be isolated, or in small clusters. So, one can manage femtocell PN assignment reasonably well and cope with interference between them. Over time, the fielding of femto-aware MSs will allow expansion to a much bigger pool of Pilot PN Offsets for femtocells, so that very high density of femtocells can be supported.

To summarize, for the purpose of legacy MS support with femtocells, the operator can make the following system configuration adjustments to obtain more PN Offsets:

- Decrement PILOT_INC to the half of its previous value
- Add to the NLM in each macrocell a fixed list of additional neighbors to be used for femtocells from the pool $2\pi/256 * (2i+1)$, where i can range from 0 to 4 in our example of 5 PN Offsets

Note that the operator need not choose the first 5 values from the odd Pilot PN Offset range, in principle that can be any set of 5 distinct values within the pool of 128 phases. However, there is no advantage in randomly spreading the 5 PN offset across the available phase space.

Note that the method of Pilot phase planning described above is a particularly convenient one, with least possible disruption to the operator's RAN configuration management. Others methods can be used, per operator's judgment (see Section 5.3.1.2).

If an operator had used in the macro system plan a PILOT_INC of an odd value, then the methodology described cannot exactly be used. In those cases, operator would probably have to use one of the other methods of Pilot PN Offset planning described in Section 5.3.1.2.

5.3.1.2 Femtocell Pilot PN Offset Planning Options

The example in Section 5.3.1.1 shows how Pilot PN Offsets can be planned with minimum impact on the macro system, and relatively easy reconfiguration of Neighbor Lists. However, reducing the value of PILOT_INC may not be feasible in each deployment case. For example, if cells are broadly spaced and require large search window, while the initial PILOT_INC results in dense phase spacing, an operator may judge that any further reduction of PILOT_INC value is too risky, potentially creating searcher ambiguity. This ambiguity arises, for example, when pilot signals from two cells are detected within the same window, and are combined by the receiver when they should not be – i.e., the searcher incorrectly assumes that they are two multi-path components of the same signal. In addition to that, a decrease in PILOT_INC results in an enlarged Remaining Pilot List. Though MS searcher is not required to search over the Remaining List (or if it does, may do so with reduced search frequency), the potential exists in certain MS designs to expend too much effort on Remaining List searching, which may reduce battery stand-by time. As a result, if the methodology for Pilot PN Offset planning shown in Section 5.3.1.1 is decided to be deployed, the operator should set SRCH_WIN_R to zero.

If an operator judges that a given deployment cannot use the PILOT_INC approach, the first alternative is to clear a section of pilot phase space and dedicate it to femtocells. This is illustrated in Figure 5.3-2. With PILOT_INC unchanged, the MPn Pilot Phase space is re-programmed so that a section of phase space is set aside for femtocells.

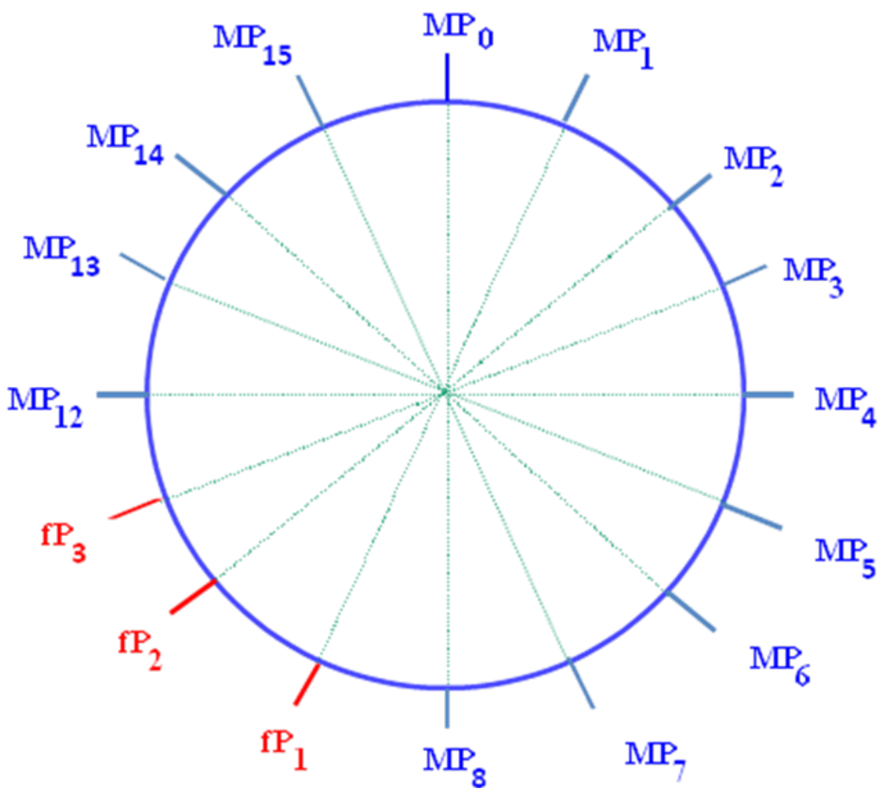

Figure 5.3-2: Macro- and Femto-cell Pilot Phases – Partition Approach

This approach is similar to the one described in Section 5.3.1.1, in the sense that a dedicated set of pilots across the network is used for femtocell phases. Some macrocell PN Offsets may need re-programming, with Neighbor List repercussions, but the PN Offset spacing need not be re-evaluated, since PILOT_INC is same as before re-planning. However, a disadvantage is that, in addition to macro re-programming, expansion of PN Offset space for more dense femtocells in later years may be limited. On balance, both of these approaches lend themselves equally well to Self-Organizing Networks (SON) implementation of PN Offset planning.

The last alternative for PN Offset planning is to allocate PN Offsets in an ad-hoc fashion. Within the coverage area of each macrocell a different set of PN Offsets for femtocells is used. None of the PN Offsets in a given macrocell's Neighbor List can be used for femtocells, since this can create ambiguity in the searcher. A complication with this approach is, since macrocell coverage overlaps with coverage of its neighbor cells, the neighbor list adjustment would have to be carefully managed. This is laborious and prone to errors. When choosing this approach, operator is advised to be very careful in the network planning, especially if the need arises to deploy new macro- or micro-/pico-cells. One particular area of concern expressed by some operators is the physical limitation in the Neighbor List Message. Some existing macrocell deployments have very few spaces in the NLM for expansion required for femtocells. Since in this planning approach, macrocells on cell boundary should include in their NL both femtocells within macrocell X and its neighbor Y, Z, this can result in NL exhaust. Finally, femtocell deployment PN Offset planning decisions may be more complex to implement in a SON environment.

An example of PN Offset planning and neighbor list configurations is shown in Table 5.34-1 for the two recommended approaches: PILOT_INC and Partition.

Table 5.3-1: Pilot PN Offset Planning Examples

Parameter	**Start Cell Config.**	**End Config. for PILOT_INC Approach**	**End Config. for Partition Approach**
PILOT_INC	4	**2**	4
Own PN Offset	504	504	**132**
Ngbr 1 Offset	8	8	8
Ngbr 2 Offset	68	68	68
Ngbr 3 Offset	84	84	84
Ngbr 4 Offset	184	184	184
Ngbr 5 Offset	336	336	336
Ngbr 6 Offset	356	356	356
Ngbr 7 Offset	372	372	372
Ngbr 8 Offset	448	448	448
Ngbr 9 Offset	476	476	476
Femto Ngbrs	None	**2,6,10,14,18**	**492, 496, 500, 504, 508**
Ngbrs of BS	504 is in NL	**Add Femto Ngbrs to NL**	**(1) Change 504 to 132 in each of the 9 NLM;** **(2) Add Femto Ngbrs to NL**

Note that Pilot PN Sequence Offset Index is expressed in units of 64 PN chips, per C.S0005 [6], so that for example, for PILOT_INC of 4 it takes on values from 0 to 508 in increments of 4.

5.3.1.3 Neighbor List Configuration for FAMs

Long term, density of femtocells can be very high. For example, in a corporate campus environment, the femtocells can form a dense grid of coverage, requiring careful PN offset reuse, similar to the patterns seen on macro systems. Furthermore, femtocells can be not only horizontally spaced, but also vertically in floors of multi-storey buildings. The conclusion is that long term, there should be as many femtocell PN Offsets available as macro PN offsets.

The PN offset planning in support of legacy MSs outlined in the preceding section points a way to PN offset planning in denser femtocell deployments, which will be supported with the introduction of FAMs. The operator has to simply extend the pilot phases from the 5 in our example in support of legacy MSs, to the entire set of 128 shown in the first example discussed in the above section. This entire set cannot fit into the NLM, so other means of conveying the neighbor list are outlined in the standards, by introducing the Access Point Pilot Information Message (APPIM). This new message is introduced in C.S0005-E [23].

5.3.1.4 Transition Issues from Legacy to FAM Support

Reference to figure 5.1-1 may be helpful for the discussion in this section.

Pre-seeding the network with FAMs can help pave the way to smoother transition to a more comprehensive PN Offset planning stage (Network State 2 and less limited femtocell PN Offsets) by the operator. New MSs placed into service, whether they are activated for femtocell support or not, can be FAMs. In addition to supporting APPIM, FAMs support other features, for example autonomous femtocell discovery (see Section 5.2.4).

Pre-seeding with FAMs can occur even before initial femtocell deployment for legacy MSs only. When the operator decides to transition to support the femtocell system with MS femto-awareness, it can expand and use the additional PN phase space (e.g., from 5 to 128), with immediate benefit of these seeded MSs being able to use the femtocells with the additional 123 PN offsets. Assignment of the PN Offsets to a femtocell upon this expansion should be in accordance with the following rules:

- If new femtocell activation is in a household with at least one MS that is not femto-aware, the PN offsets chosen for the femtocell should be from the initial pool of 5 (explicitly listed in the NLM).
- If all MSs in a household are femto-aware, the PN offset for new femtocell activation can be from the expanded portion of newly available 123 PN offsets.
- If an already activated femtocell is in a household with all MSs being femto-aware, this femtocell may be re-configured to use a newly expanded pool of 123 PN offsets.

This strategy, and in particular the last two points, warrant some discussion.

The expansion from the assignment of 5 initial PN offsets to the additional PN offset pool of 123 phases, or re-configuration to take advantage of these additional PN offsets can start immediately upon introduction of APPIM. However, the expansion to additional PN Offsets should be deferred to the maximum extent possible. The expansion should occur when femtocell density in the vicinity of the subject femtocell warrants additional PN offsets. To understand this, let us take a case of a PN offset being assigned from the expanded pool of 123, i.e., not appearing in the NLM on the macro system. FAMs, most importantly those owned by the household members where the femtocell is located, will have no problem using it. However, if a visitor using legacy MS should enter the coverage area of the femtocell, there may be some impact to such a MS, along the following lines.

Consider first the impact in idle state. In each slotted cycle wake time, the MS takes a sample of the CDMA signal during its assigned paging slot, and evaluates E_C/I_0 of the pilots from its neighbor list, in addition to the pilot of the macrocell whose paging channel is currently monitored by the MS. Normally, a MS would perform idle handoff when another pilot's E_C/I_0 exceeds the currently monitored paging channel pilot by 3 dB (typically). However, since the femtocell pilot is not listed in the NLM, no idle handoff will take place when a MS is at a location which otherwise would trigger idle handoff. Instead, the monitored paging channel pilot E_C/I_0 will deteriorate, while still being the strongest. This will remain so until the interference from the femtocell is so high that the monitored pilot E_C/I_0 drops below a threshold causing the MS to enter system determination sub-state. The MS will conduct a systematic search of pilots, without regards to the neighbor list. The MS will find the femtocell pilot, and will be able to use it, subject to access control rules. More discussion on access control is in Section 5.6.

In summary, there may be a small disruption in service for the MS, resulting in a very small probability of a missed page. However, the scenario of visiting MS has a relatively low incidence rate, so the overall impact is small.

Let us now consider the impact of the PN offset expansion on legacy MSs in the active state. Referring to Fig. 5.2-3, if the MS on the macro system is on frequency F8 approaching a femtocell with PN offset that is not in the NLM (this is the same case of e.g., a visitor we discussed in idle state case), as MS gets closer to the femtocell, it will experience ever increasing level of interference. Since the femtocell pilot is not in the neighbor list, there will not be a trigger for handoff; it will merely affect interference level. Forward link power will increase to cope with this increased interference, and depending on the macro/femto geometry (interference ratios), the system may not be able to overcome it (e.g., forward link power level may max out). The call may drop as a result.

The above discussion illustrates the benefit of delaying the expansion to additional 123 PN offsets for femtocells. With time, the ratio of femto-aware to legacy MSs in the system improves (see Figure 5.1-1), thus lessening the impact on the system. The timing of re-configuration should consider two major factors:

(1) Femtocell density in the locality

(2) Nature of femtocell, i.e., public one (such as in a café) vs. home installed one – the former should be kept within the initial pool of 5 PN offsets for an extended period of time, since likelihood of legacy visiting MSs is higher.

It is worth noting that reprogramming of PN offsets can be automatic without one-by-one intervention by the operator.

If MS is in active state on one of the frequencies other than F8, the situation will be similar, except that increased interference will occur only when the hopping pilot lands on the frequency the MS is using. There may be a temporary signal loss, or some speech frames may be lost, however, it is unlikely that call will drop, since in all but the most extreme cases power control will quickly restore frame loss rate to acceptable level. Still, user impact may be noticeable. In this case, the fewer the number of carriers, the more pronounced the user impact. There will be some negative system performance impact as well. The beacons transmitted on macro frequencies do add to the interference in the system as a whole. This is discussed in more detail in Section 5.2.3.

Once again, this scenario illustrates the point regarding advantages of deferring expansion of PN offsets beyond the NLM. The same selective migration strategy outlined above applies here as well.

5.3.2 Femtocell Configuration and Provisioning

5.3.2.1 General

In general, deployment of a FAP is different from a macro base station deployment in the following aspects:

- *User-installed*: A FAP may be installed by a customer who may not have special training or technical knowledge, including antenna placement and system configuration.
- *Unplanned deployment*: Unlike macro base stations, FAPs are typically deployed without a priori network planning; no special consideration is given to traffic demand or interference with other cells.

While network planning for coverage, capacity, and RF interference management is a key aspect of pre-deployment optimization for macrocells, it is not economical to extend the traditional methods of network planning to femtocells.

Given the expected scale of femtocell deployments, automatic configuration of femtocells is a critical function for improving coverage and capacity of the network while mitigating interference with the macrocell network, as well as between neighboring femtocells. Automated fault and performance management of femtocells is also required for efficient network management.

To overcome the challenges of configuration, performance, and fault management, Broadband Forum's TR-196/TR-262 [16] device management framework has been adopted for cdma2000 femtocell networks, originally conceived in Broadband Forum for management of broadband devices. This has resulted in Broadband Forum extending the scope of the device data model to support femtocells. The data model is contained in an amendment to Broadband Forum TR-196/TR-262 [16] specification. The FAP configuration data model is maintained in the femtocell and the FMS, and data elements are exchanged using TR-196/TR-262 [16] protocol. They allow for automatically configuring a FAP, as well as for fault notification, periodic performance reporting, and FAP firmware management.

Interference management issues and solutions highlighted in Section 5.4 are a critical aspect of FAP configuration, requiring proper choice of radio parameters for the FAP. The femtocell data model allows the FAP to communicate the downlink radio environment of the neighboring macrocells as well as femtocells to the FMS to aid in the selection of femtocell configuration parameters such as neighbor list configuration. This helps ensure good network performance despite deployment without manual network planning. The data model also allows the FAP to perform local optimization on some parameters (e.g., maximum transmit power) based on the range suggested by the FMS.

As part of the initial configuration, location of the FAP is determined by the femtocell system for compliance with legal requirements (spectrum license boundary), emergency call support and location-based services. This can be done based on system operator policy via one or a combination of the following methods:

(i) (A-)GPS;
(ii) Radio environment measurement;
(iii) IP address lookup (broadband access termination point address);
(iv) Database lookup of street address where the FAP is installed

The subject of FAP configuration and provisioning is very broad and complex. All FAP configuration parameters are listed in X.R0063 [14], which feeds into the aforementioned TR-196/TR-262 [16] data model. These documents should be consulted for more comprehensive study of the subject. The remainder of this section covers some of the critical items of FAP configuration and provisioning, outlining methodologies used by the FAP itself, or in conjunction with the FMS, to configure them in an optimized fashion, resulting in smooth operation of the femtocell and macrocell networks.

5.3.2.2 Timing and Synchronization

This secion discusses options for synchronization of femtocell with the macrocellular system.

As do the macrocells, the femtocells maintain synchronization with the macrocellular system. C.S0010 [10] stipulates the recommended synchronization error limit of 3 μs, and in the worst case (hard limit) of 10 μs. This level of synchronization is important for the proper functioning of the system. The principal approach in achieving it in the macro system is by way of GPS. That approach is certainly available for the femtocells as well. However, macrocell location is typically prominent (i.e., open to satellite reception). In rare situations when that is not the case, an extended GPS antenna and cable are comparatively simple to equip without adding too much complexity to the process of installing the base station. In contrast, the femtocell are expected to work when installed indoors by a consumer with minimal technical expertise, possibly inside a cellar or at low floors of a high-rise building, where satellite reception may be insufficient.

Methods of FAP synchronization other than GPS-based ones may be desirable to be supported for maximum flexibility in configuration and operation. One possibility is to synchronize the femtocell off the macrocell covering the territory. This is conceptually simple: Femtocell is equipped with elements of the forward link receiver, that acquires the transmit signal from the macrocellular base station, which then is used for synchronization.

A comparative evaluation of this method relative to GPS is provided in Table 5.3-2.

Table 5.3-2: Evaluation of Synchronization Techniques

Function	GPS Receiver	(Macro) FWD Link Receiver
Installation	Restrictive physical placement, may need GPS antenna, cable extension	Potentially less restrictive placement, (basement, low floors)
Geo-Location	Accurate, self-contained	Less accurate; Has dependency on core network support
Femtocell Configuration Assistance	Little or none, beyond geo location.	Can help configure femtocell neighbor list (macrocell and femtocell), assist in PN offset setting, geo location, femtocell transmit power, etc.

It should be pointed out that the objective of the evaluation in the table is not to steer product development; rather the main objective is to say that there are several alternatives, each of which has advantages in certain deployment situations. Configuration assistance is an important additional function of the forward link receiver in the FAP, which is further discussed in Sections 5.3.2.5 and 5.3.2.6. In other words, synchronization is not the only reason for including the forward link receiver in the FAP. Furthermore, full MS modem functionality is not needed for this forward link receiver. What is required is reduced functionality of a forward link demodulator, amounting to the ability to decode the pilot and sync channel, no traffic channel, or message exchange (layer 3) support with the macro is necessary. Also, there is no reverse link transmission baseband processing that is necessary. Hence, the synchronization function should not be thought of as a feature of significant impact on the femtocell hardware and software complexity.

Synchronization off the macro system can be helpful when GPS visibility is low, assuming macro system reception is better. But even if the femtocell is placed in a location with low macro system signal penetration, this type of synchronization is feasible. This is because FAP antenna has higher gain relative to a MS station antenna, which additionally can be configured, with relatively small added complexity, as steerable directional antenna, as a FAP design option.

Synchronization off the macrocellular system is conceptually a simple solution: The forward link receiver in the FAP tunes to a nearby macrocell, and derives the clock from it. Since the FAP also transmits on the forward link in the same band, the signal transmitted by the FAP can cause adjacent-band interference to the signal received from the macro BS. Maximum possible separation of the macro frequency used for synchronization is advised. Also, interference cancellation (IC) techniques can be very effective in this situation, since the FAP transmit signal is known to the FAP and can be subtracted from the received signal.

When using synchronization off the macrocellular system, excessive signal propagation delay error from the macro BS to the FAP needs to be compensated.

Femtocell timing can be adjusted based on the knowledge of FAP location (see Section 5.3.2.3 on methods for determining FAP location). Note that it of no importance how the FAP location is obtained, it could be by way of address database lookup, triangulation, or other means. The identity and location(s) of one or more of the neighbor base stations is also known by the system (also immaterial how it is acquired).

There are other ways for the femtocell to obtain synchronization, but the methods described are likely to be most common, allowing a great deal of flexibility in FAP installation options and situations.

5.3.2.3 Location

5.3.2.3.1 General

This section discusses methods for determining FAP location for some of the following purposes:

- Allowing activation (radio transmisison) in the licensed territory;
- Network radio planning and control
- Emergency calling

FAP can use a variety of techniques for determining its location. It can use GPS. If GPS signal is too low in the FAP installation locality, the femtocell system can determine FAP's location from the macrocellular system using triangulation techniques.

In principle, if a FAP is equipped with a GPS receiver or CDMA forward link receiver, any of the techniques used by the MS are possible. The performance (e.g., accuracy, speed of location determination) should exceed MS's location determination performance. This is due to a variety of factors:

- GPS receiver in the FAP is likely to have better antenna configuration;
- FAP is in a fixed location;
- If location using forward link triangulation is used, FAP can spend much time searching for pilots of neighboring macrocells, and integrating CDMA signals from very weak pilots;
- Battery limitation is not an issue in a FAP;
- FAP antenna configuration typically has higher gain compared with MS, and is more likely to have receiver diversity, and/or be steerable.

Note that location determination is not the only reason to equip a FAP with an advanced antenna configuration; other benefit are discussed in detail elsewhere, and include improved interference reduction.

5.3.2.3.2 Forward Link Traingulation Techniques

The technique can be briefly described as follows:

- FAP tunes on a macro frequency known to contain only macrocells.
- FAP detects the CDMA system and synchronizes itself with the strongest pilot.
- FAP comprehensively searches for pilots it can detect, down to a very low E_C/I_0. Thus, the FAP can typically detect a large number of pilots, even though with very low E_C/I_0.
- FAP collaborates with the OAM&P system using triangulation technique to determine its location.

FAP reports to the OAM&P system pilot PN Offsets it detected and their relative timing (offset from the nearest and typically strongest pilot). FAP also reports E_C/I_0 of each of the pilots detected. The contents of this report are very similar to the contents of the Pilot Strength Measurement Message on the radio interface reverse link (see C.S0005 [6] Section 2.7.2.3.2.5), but the information can be of higher accuracy, and with increased timing resolution (FAP can use baseband over-sampling to achieve that).

OAM&P system knows geographic location (LAT/LON) of the macrocells in the report from the FAP, and performs triangulation to determine the location of the FAP, which it can send to the FAP.

GPS signal strength is likely to be low in dense urban environments (e.g., urban canyons or indoors in low stories of high-rise apartment buildings), where on the other hand CDMA coverage is likely to be present, and macrocell density high. Hence, this technique of location determination is useful when it’s most needed.

5.3.2.3.3 Other Techniques

An alternative approach is LAT/LON lookup from the address (point of termination of fixed broadband connection), from a database which may be accessible to the wireless network operator, whether it’s the same as the broadband network operator or not. Note that databases of this kind may not yet be available in some countries.

Multiple methods of location determination can be used as check of consistency, hence more robust, and adding to the system security, e.g., it can be used to detect any attempts of misrepresenting the actual location of the FAP.

5.3.2.4 Femtocell PN Offset Planning

Section 5.3.1.2 elaborates on PN Offset planning options for the cdma2000 system as a whole. This section contains a brief discussion of how PN Offset is chosen to be assigned to a newly installed FAP. The underlying assumption is that one of two PN Offset planning approaches is used: PILOT_INC approach illustrated in Figure 5.3-1, or Partition Approach illustrated in Figure 5.3-2. The Ad-Hoc FAP PN Offset allocation is not elaborated.

For the legacy MS support, there is no material difference between the PILOT_INC and the Partition approaches, when it comes to FAP PN Offset assignment methodology. For the longer term, if denser femtocell placement is required, the approaches diverge. One of the key requirements in PN Offset planning is to ensure that the plan is stable, i.e., once assigned, FAP PN Offset should not be changed. Re-planning, especially if it also involves macrocell re-planning, can result in significant complexity and is prone to errors. Hence long term planning is critical. Therefore, operator should very carefully study the choices available, as outlined in Sections 5.3.1.1 and 5.3.1.2.

In the initial phases of femtocell deployment (see section 5.1), a newly deployed FAP will likely have to support legacy MSs (e.g., at least one of the MSs in a household is not a FAM). The system will have a limited number of PN Offsets, explicitly listed in the macro neighbor lists, one of which will be assigned to a new FAP. Assuming the FAP has forward link measurement capability, the FAP PN assignment process can be outlined as follows:

- FAP performs system acquisition (detects a neighboring macrocell or femtocell) and takes comprehensive forward link measurements of all visible pilots E_C/I_0. Note that FAP can take detailed searches and measurements of low value of E_C/I_0, since it is not time- or power-constrained, as is the case for a MS.
- FAP typically has a much better antenna than an MS. Hence FAP can have rather good visibility of its surroundings of both the macro system, as well as any femtocells nearby.
- FAP reports its findings to the FMS, i.e., provides a detailed list of the PN Offsets and pilot strength measurements, possibly also BS IDs that it can detect.
- Based on the FAP findings, and the pool of PN Offsets reserved for femtocell usage, the FMS selects a specific PN Offset and commands the FAP to use it. Alternatively, FMS can provide a set of choices, from which the FAP selects one and report back to the FMS on its selection.

Though the FAP can make good measurements and detect weak femtocells at some distance away, it is important to give the FMS the final say as to which PN Offset is selected. This is because a neighboring femtocell may be temporarily turned off at the time measurements are taken, possibly leading to a bad autonomous selection by the FAP. FMS on the other hand has information about the FAP configurations in the vicinity. FMS can apply a selection algorithm that identifies which PN Offset from the available pool is reused in the FAP that is furthest away from the location of the FAP being activated. Such selection is then confirmed or modified, as appropriate, by the FAP’s measurements discussed above.

If the FAP that is being activated has no forward link measurement capability, then there is little choice but to have FMS assign the PN Offset value based on its knowledge of the surrounding femtocells.

This relatively simple algorithm will ensure correct PN Offset selection until such time that the pool becomes too small for the given density of femtocells. At that point, the pool can be expanded. Due to practical neighbor list size limitations in the macro system, this expansion often hinges upon considerable population of FAMs in the system. FAMs don't have to rely on the legacy neighbor list message for conveying cell searching information.

Although it does not provide algorithmic details outlined above, BBF specification TR-196 [16] contains all the necessary parameters required for the PN assignment in accordance to the outlined procedure.

5.3.2.5 FAP Transmit Power

The discussion in this section is primarily pertinent for the macro/femto co-channel deployment scenario, and to a degree, for dedicated RF carrier scenario if the femtocell carrier is adjacent to a macro carrier. In the case of dedicated RF carrier scenario where there is sufficient separation from the macro RF carrier, so that adjacent channel energy leakage is negligible, setting FAP transmit power is decided by the operator based on the femtocell coverage (cell size) objective, and is usually a constant value, or a value dependent only on the target environment (e.g., it may differ for dense urban high-rise buildings from suburban or rural environment).

FAP transmit power level controls femtocell coverage footprint by balancing the macrocell power level with femtocell power at the intended femtocell coverage boundary. Proper setting of power level goes a long way to controlling radio interference (see Section 5.4).

As in the case of FAP PN Offset (see Section 5.3.2.4), FAP and FMS can collaborate to set FAP transmit power. Forward link measurement capability by the FAP makes this process considerably more precise and leads to better performance, while streamlining the procedure by allowing the FAP to autonomously configure itself. The process is briefly outlined in the following steps:

- FAP indicates to the FMS if it supports self-configuration of its transmit power (in effect, this is an indication if FAP has forward link measurement capability);
- If capable of such measurements, FAP may additionally provide measurement(s) of received signal strength;
- If FAP is capable of self-configuration, FMS may provide a range of transmit power values to be used by the FAP. FAP selects from the range and reports its selection to the FMS.
- If FAP is not capable of self-configuration, the FMS determines the transmit power selection for the FAP. To achieve proper coverage balance, it is necessary to have map database, so that FMS can,

based on the location of the FAP, make the appropriate determination of power setting.

FAP may adjust transmit power based on cell performance, once activated. For example, frequent handoffs in and out of femtocell may indicate that perhaps power is not balanced in the often-occupied area in and around the household. In such a case, FAP may adjust transmit power upwards in an attempt to reduce frequency of handoffs, while not violating the range limits imposed by the FMS.

5.3.2.6 Configuration of Other Radio Parameters in a Femtocell

For a number of other radio parameters, FMS can generally set their values, since many are system level parameters (e.g., contents of CDMA Channel List message). For some of the parameters, FAP can provide assistance, or set them autonomously, and merely report the setting to the FMS. In many of such cases forward link measurement capability is helpful, as was illustrated with PN Offset and FAP transmit power settings in the preceding sections.

An example of such a parameter is neighbor list. If the FAP has forward link measurement capability, it can determine the neighboring macro- and femto- cells, and autonomously configure the neighbor list.

If on the other hand a FAP does not have such autonomous configuration capability, the FMS sets the FAP's neighbor list. As in the case of transmit power setting, the FMS relies on macro and femto coverage database for such function, and includes in the list macro neighbors that have a rather small chance of actually being neighbors to this FAP. Neighbor list configuration may later be streamlined after FAP has been in operation for some time, based on actual handoff statistics data.

5.3.2.7 SeGW and FMS Discovery by FAP

As amply illustrated in the preceding text, FMS works in conjunction with the FAP to configure and activate it, even if the FAP is capable of self-configuring many of the radio and other parameters required. Moreover, before any user traffic is allowed on the network, and before the FAP is allowed to access the FMS and other network resources, the FAP is authenticated. In order to do so, the FAP discovers (learns the IP address of) the Security Gateway (SeGW). X.S0059-100 [13] and S.S0132 [8] contain detailed security procedures associated with FAP activation.

5.3.3 Network Level Configuration and Provisioning

In addition to radio parameters (Pilot PN Offset, Search Windows, etc.) discussed in other sections of this document, System Parameters Message (see C.S0005 [6]) contains network level parameters that need to be configured for a FAP. This section discusses some of the critical parameters.

The SID/NID pair configuration can be used to cause MS to register when moving between the macrocellular and femtocellular networks. Though there are other ways to induce registration, this is the recommended system configuration. For the parameter change registration to occur during idle handoffs, at least one of the parameters in the SID/NID pair can be configured differently for the FAPs than for the macrocells. Two approaches for assigning SID/NID pairs to FAPs are outlined, both using the same SID configuration for FAPs as the surrounding macrocelluar system:

- Uniform NID Configuration: In this approach a single NID is uniformly applied for all FAPs, but distinct from the macrocellular NID. To account for the possibility of femtocell-to-femtocell handoff (e.g., in enterprise environment), page escalation can be used to surrounding FAPs, or blanket paging in zones of closely spaced femtocells.
- NID Set Configuration: In this approach, a limited size set of NIDs can be assigned to FAPs in a way that there is never a possibility of femtocell-to-femtocell handoff between FAPs that use the same NID. One particularly convenient approach is to select a set that mirrors one-to-one the Pilot PN Offsets reserved for FAPs (see Section 5.3.1.2

Setting of most other non-radio parameters should be consistent with such settings for the macrocellular system.

Settings of RF parameters such as handoff thresholds should be carefully analyzed by the operator, and may be different than such settings on the macrocells.

5.4 Interference Management

Key benefits of femtocells can be outlined as:

- Excellent user experience (through better coverage for voice and higher data throughput);
- Offloading traffic from macrocellular network;
- Reduction of infrastructure deployment efforts.

To achieve these benefits, femtocell deployment is accompanied by a set of solutions to mitigate RF interference issues, including:

- Dealing with restricted access (see Section 5.5.1) (i.e., femtocells restrict usage to a set of MSs);
- RF deployment planning involving uncoordinated placement of FAPs, with each user independently deciding in which exact location to install a FAP;
- Low isolation between different coverage areas (e.g., femto/macro isolation, in case of a FAP installed near a window).

Potential RF interference issues related to femtocell deployments are outlined in the following.

5.4.1 Interference between Macro- and Femto-cell

Femtocells can cause interference both on the reverse link (RL) and forward link (FL) of the macrocells. For example, as illustrated in Figure 5-1, a FAP installed near a window of a residence can cause FL interference to a user served by a macrocell outside the house (a user not served by the FAP). On the RL, a user served by a FAP can cause interference to a user served by a macrocell if it is allowed to transmit at a very high power level. Similarly, a user served by a macrocell that is being power-controlled by a distant macrocell can create significant rise-over-thermal (RoT) at the FAP receiver, when in its vicinity.

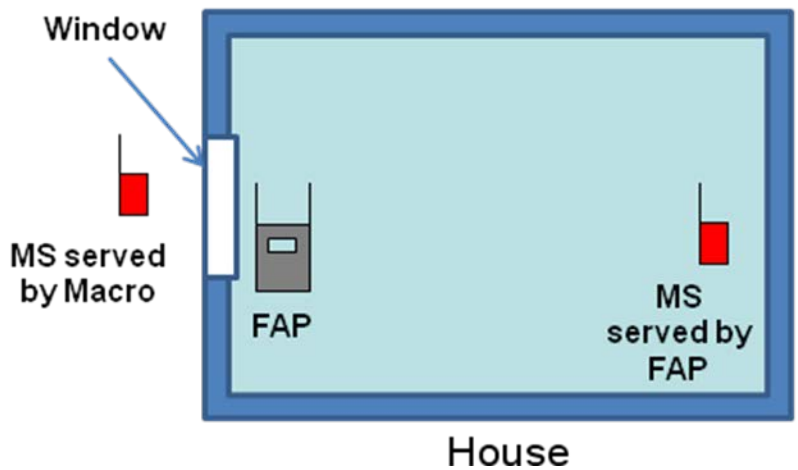

Figure 5.5-1: Femtocell and a closely located macro MS

5.4.2 Inter-Femto Interference

Femtocells can also create interference to each other due to uncoordinated deployment (each femtocell placement in a residence or business premise is individually decided by the installer). For example, in a multi resident apartment, a FAP installed near a wall separating two residences can cause significant interference to a neighboring residence. In such a case, the strongest femtocell for a home MS (in terms of RF signal strength) may not necessarily be the serving femtocell if access is restricted (see section 5.5). Such a scenario is shown in Figure 5.4-2 where FAP 1 is causing significant FL interference to MS2 served by FAP 2 due to low Signal-to-Noise Ratio (SNR). On the RL, MS2 served by FAP 2 is resulting in significant interference (high RoT) at FAP 1.

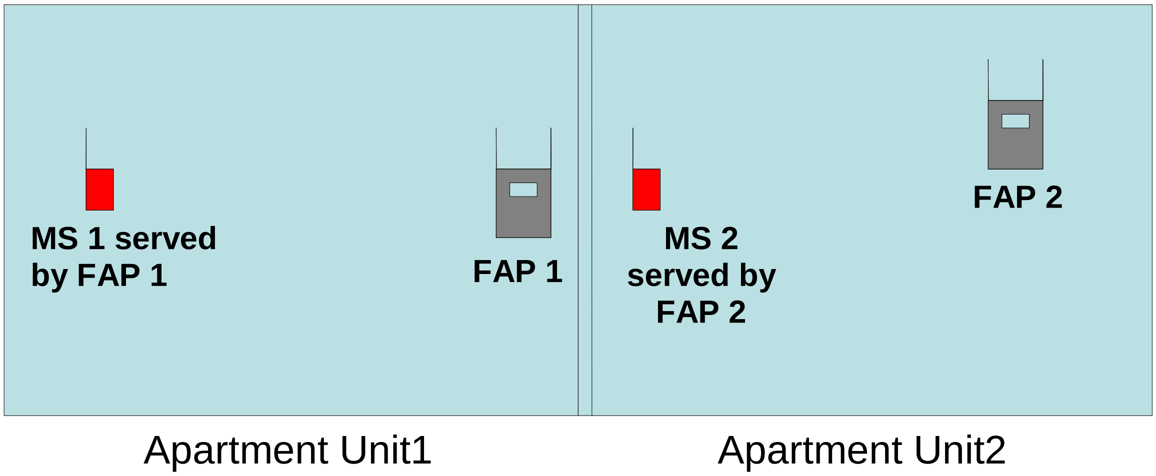

Figure 5.4-2: Inter-femto Interference Scenarios

As evident from the above examples, serious RF interference issues may arise unless appropriate methods are utilized to mitigate them. However, with proper interference management techniques, high quality user experience can be achieved with femtocells with minimal impact on the macro network performance.

As femtocells create desired coverage in the home/enterprise area, coverage holes may be created around the region for MSs that are not served by that femtocell. Thus transmit power of each femtocell needs to be adjusted carefully depending on the particular femtocell location within a macrocell (e.g., cell edge vs. close to macrocell site) and deployment scenario (suburban vs. urban).

If the macrocell signal is strong in the vicinity of the femtocell, the femtocell would need to transmit at relatively higher transmit power level in order to be able to provide coverage for a desired area without impacting the macro users nearby. On the other hand, if the macrocell signal strength is already low, nearby macro users cannot tolerate large interference, therefore the femtocell power needs to be chosen more conservatively.

Support of active state hand-in (see Section 5.7) reduces interference to an MS that is on a call approaching a femtocell, by allowing the call to be handed in to the femtocell, in case of open access or for authorized MS for that FAP.

If active hand-in is not supported, this reduction of interference cannot be achieved even for the case of open access. If active hand-in is not supported, an active user has to continue to be served by the macrocell. Any transmission from the femtocell on the same macro carrier would result in interference to that user. Additionally, the active user transmission would impact the noise floor of the femtocell, affecting the FAP reverse link performance. If beacon transmissions are utilized to enable discovery of femtocells, proper power calibration of the beacon becomes crucial, since beacon is transmitted on the macro carrier. Any possible leakage from the femtocell to adjacent macro carriers also needs to be factored in while setting the transmit power levels.

The transmit power settings can be determined via a centralized power calibration algorithm, or by an autonomous self calibration scheme where FAP takes into account FL measurements of the macrocell and nearby femtocell signal strength to calculate the required transmit power level in order to achieve the desired coverage region with minimal impact on the macro network. Even in the presence of RL interference due to nearby users on a macrocell or another femtocell, the femtocell users should still get satisfactory RL performance, overcoming this interference. Measures should be taken in an effort to limit the interference impact of femtocell users on the macro network.

5.4.3 Out-of-Band Interference

As is the case with macrocells, femtocells' out-of-band emissions (OOBE) may cause interference to adjacent band systems. Interference mitigation is achieved through increasing the isolation between transmitter and victim receiver. Factors contributing to isolation are: digital modulation roll off, passive filtering, antenna gain discrimination, cable losses, environment losses, and spatial separation. Operators have good success mitigating macrocell adjacent band interference through use of RF filters, antenna placement, and site collocation.

Femtocell deployment represents a different challenge in adjacent band interference management compared to macrocells. Macrocell interference mitigation techniques such as additional RF filtering and antenna placement coordination do not apply to femtocells. Interference potential between femtocell and macrocell in adjacent band is greatly reduced if adjacent band macrocells are collocated. If interference does occur, flexibility in femtocells channel assignment is the key to mitigating adjacent band interference. For ease in troubleshooting, the operator can utilize data from the Fm interface (FMS to femtocell), which provides the operator with the femtocell location, and allows operator to control the femtocell channel assignment and/or power level settings.

5.5 Access Control

5.5.1 Types of Access

The primary intent of use of a femtocell is for occupants of a household in a home installation, or a business for enterprise installation. Some femtocells may be installed in public places, such as coffee shops, with the purpose similar to current use of Wi-Fi hot-spots in those situations, namely allowing internet access as a convenience to coffee shop patrons. For the case of femtocell, this is further enhanced by allowing these users both data and voice services using their mobile phones.

As readily apparent, there is a variety of use cases for femtocells. As is the case with home Wi-Fi installations, access can be restricted, or analogous to Wi-Fi access when installed in public places, it may be open. (Note that this addresses only the concept of access and not others such as authentication, and usage accounting). These use cases may overlap, e.g., a home installation may be open, so that guests in a household may use it. Hybrid cases are also possible, e.g., a FAP may be open only to a select set of subscribers, or may be specifically excluded to a set of cellular users.

A FAP can be configured to have one of the following types of access (refer also to A.S0024 [1]).

- Open Access: A femtocell is open for any cellular subscriber to access and use without restrictions.
- Restricted Access: A femtocell access is restricted to a user or a group of users defined in the Access Control List (ACL).
- Signaling Association: This is a variant of Restricted Access, where use of a femtocell is restricted to users in the ACL. Other users are allowed to register on the femtocell, monitor the paging channel, and use the access channel of the femtocell, but when traffic channel resources are needed, the network assigns them on the overlaid macrocell system.

Note: Access Control is sometimes referred to as “Access Association”.

Note: Local IP Access (LIPA) refers to routing option for certain services that bypasses Wireless Operator’s packet data core network, and is unrelated to radio access. LIPA is discussed in Section 5.9.1.

Note that this division is somewhat loose and variants of each may be exercised by the network, depending on the situation (e.g., an open access FAP may be effectively temporarily turned into the signaling association FAP, when traffic channel or broadband transmission resources are exhausted).

5.5.2 Open Access

As noted, open acess works well when the intent is to provide easy access to all network subscribers for both data and voice services. Since legacy MSs were designed for open access macro networks, this form of femtocell access is simplest to implement and deploy. If the intent is to limit services to a select group (e.g., a specific customer set in an enterprise installation or friends and family in a home installation), a signaling association or restricted access should be considered. Also, the difference between these two forms of limiting access should be weighed.

5.5.3 Non-Open Forms of Access

Where access is not completely open, femtocell access control (FAC) is required. FAC support includes:

- Identification of access control enforcement point;
- ACL - the list of MS/ATs that are authorized to access services through the FAP;

- Signaling between the ACL storage point and the enforcement point.

In cdma2000-1x or HRPD systems, when the Femtocell Management System (FMS) is the ACL storage point, then the FAP acts as the enforcement point. In HRPD systems, ACL may optionally be stored at the AN-AAA. The FAP acts as the enforcement point through its interaction with the ACL storage point, which binds the ACL with the FAP through Femtocell Equipment Identifier (FEID).

5.5.3.1 Restricted Access

When an MS/AT registers with the FAP, the FAP verifies the MS/AT identity (e.g., the IMSI) with the ACL. If the MS/AT is not in the ACL, for a restricted access, the FAP does not accept the registration and may redirect the MS/AT to a macro BS/AN. While this conserves resources in the FAP for use by authorized MS/ATs for this femtocell, a rejected legacy MS/AT close to the FAP on an active call may become a significant source of RF interference to authorized users in that FAP. There may be other problems directly affecting a restricted legacy MS/AT, such as re-attempting to access the restricted FAP upon detection of a pilot beacon transmitted on the macro RF carrier (system selection loop). For these reasons, signaling association is preferred form of access relative to restricted access. More on this subject can be found in the Interference Conrol Section 5.4.

5.5.3.2 Signaling Association

With Signaling Association, any MS/AT can access and register with the FAP, i.e., the MS/AT is reachable/pageable via the FAP. However, a MS/AT that is not in the ACL may be redirected to macro network when it attempts to establish a traffic connection.

This way, a non-authorized user can camp on the FAP, receive pages and control signaling, without consuming significant backhaul resources of the FAP. When active, this user does not pose significant interference problems to the authorized users, since it is assigned traffic channel resource on a different frequency on the macro network. Upon exiting from the active state on the macro network, the MS/AT may return to camp on the femtocell.

Signaling Association solves a lot of problems associated with the Restricted Access that are pointed out in section 5.5.3.1, particularly with legacy MSs.

5.6 Femtocell System Security Aspects

The Security Framework for Femtocell Systems is defined in S.S0132 [8]. The MS/AT uses the cdma2000 air interface to access services through a FAP using existing security mechanisms as defined in the published cdma2000-1x and HRPD specifications. The FAP uses a Security Gateway (SeGW) to securely connect to a cdma2000 operator's core network. The SeGW discovery procedures are defined in X.S0059-100 [13]. Since the IP network, including broadband connection between the FAP and the SeGW, is assumed to be untrusted, mutual authentication (FAP Device Authentication) is performed and secure tunnel(s) are established between the FAP and the SeGW before any traffic from the FAP is allowed into the cdma2000 core network.

5.6.1 FAP Device Authentication

The mutual authentication between the FAP and the SeGW is performed using IKEv2 (see RFC 4306 [24]) with certificates. The FAP certificate is pre-assigned to the FAP during manufacture using an operator trusted Certificate Authority (CA). This means that an operator allowing FAPs from a particular vendor, needs to add the vendor's FAP CA certificate to the list of CA certificates that SeGW uses to authenticate the FAP. Similarly, the SeGW is assigned a SeGW certificate by the operator using a FAP trusted CA (such as the operator's CA or a trusted 3rd party CA). This means that the FAP manufacturer needs to add the SeGW CA certificate to the list of trusted CA certificates that the FAP will trust to authenticate the SeGW.

Once the FAP device authentication is successful, one or more pairs of IPsec SAs are established to protect all traffic between the FAP and the cdma2000 core network.

In order to aid interoperability between the FAPs and the SeGW, the required profiles for FAP certificates, SeGW certificates, IKEv2, IPsec are also specified in S.S0132 [8]. The FAP device certificates are identified using the FAP Device Identity, called FAP Equipment Identifier (FEID).

5.6.2 FAP Device Identity

The FAP Equipment Identifier (FEID) is a globally unique identifier that uniquely identifies a FAP device. The FEID is either the 64-bit or 48-bit IEEE hardware address of the FAP and is represented in the EUI-64 (Extended Unique Identifier – 64) format. Administration of FEID assignment is performed autonomously by FAP manufacturers.

5.6.3 FAP Secure Environment

The highly security sensitive FAP credentials (e.g., private key of the FAP certificate, trusted CA certificate store) and cryptographic operations that make use of these credentials need to be isolated from unauthorized access and/or modification from other software modules inside the FAP. This is achieved by requiring a well-defined Secure Environment within the FAP, a logically separate entity within the FAP that provides secure storage and secure execution functionalities. The Secure Environment also supports the secure start-up and other device integrity validation procedures in order to ensure that the various components (e.g., software modules) needed for the secure operation of the FAP have not been tampered with or otherwise compromised.

5.6.4 FMS Security

The Femtocell Management System (FMS) is the management entity used to manage the FAPs. If the FMS is inside the operator's core network, the FAP communicates to the FMS via the SeGW. In this case, the traffic between the FAP and the SeGW is protected using the IPsec tunnel. In addition, the management traffic between the FAP and the FMS may be further protected using TLS (Transport Layer Security).

In certain scenarios (e.g., the FAP is unable to connect to SeGW), the operator may place an FMS on the public IP network (e.g., the Internet) for diagnosis and initial configuration of the FAP. When the FMS is in the public network domain (as opposed to the FMS in the protected network domain and only reachable through the SeGW), it is critical to ensure that the security measures are deployed in order to secure the FMS as well as the traffic between the FAP and the FMS.

Managing a FAP using an FMS may often require transfer of files between the FAP and a management server, such as those used for initial configuration, or for updating the FAP software. When the FAP needs to download a file, the FMS may either provide the file directly, or it may provide a link to the actual file for download. In such circumstances, the file transfer between the FAP and the FMS (or another server) and the related commands on the file are protected using the Signed File Transfer mechanism called the Signed Package Format.

The required profiles for FMS security and the Signed Package Format are specified in S.S0132 [8].

5.7 Mobility in Femtocell Systems

Since both the user and the operator expect femtocell to provide the same service experience as macrocell, it is critical for a connection to transition seamlessly as the MS/AT moves in and out of femtocell coverage.

Due to limited coverage and, over time, high density of femtocells, an MS/AT may quickly and frequently transition in and out of femtocell coverage. This poses challenges for both idle and active state femtocell handoff.

There are many aspects of mobility, which are addressed in detail in the relevant technical specifications. The intent here is to minimize repetition of information in those specifications, but rather to provide a comprehensive picture of the types of mobility supported in the current release of the specifications, how mobility is supported with legacy MSs, and what improvements can be anticipated with FAMs.

The section is organized as follows.

- Air Interface Style: cdma2000-1x procedures are described first, followed by HRPD procedures;
- Connection State: Within each air interface style, idle (dormant) connection state procedures are described first, followed by active (connected) state procedures;
- Direction: Within each interface style and connection state, first the direction of movement away from the FAP (i.e., hand-out) is discussed, followed by movement toward the FAP (i.e., hand-in);
- Service Category: Within cdma2000-1x, voice services related discussion is conducted first, followed by data services discussion, if applicable (i.e., if there is any unique differentiation among the two);
- Handset Class: In each of the above cases, the initial discussion focuses on procedures with legacy MSs. If any opportunities for improvement using FAMs exist, this is pointed out at the end of the discussion on a given subject.

5.7.1 cdma2000-1x Procedures

5.7.1.1 Idle Handoff Procedures

5.7.1.1.1 Hand-Out

Hand-out is a handoff from a femtocell to macro-cellular network. The idle hand-out processing is identical to the legacy procedures for idle handoffs, as described in details in C.S0001~0005 [2 ~ 6] set of air interface specifications, briefly summarized herein.

The initial condition is:

- MS is in idle state
- MS is monitoring a FAP Paging Channel
- MS is registered on the femtocell system

For femto/macro co-channel deployment scenario, the FAP neighbor list consists of one or more macrocell BS PN Offsets which are of significant strength in the location at or around the FAP. In the idle state, in each paging slot cycle, the MS evaluates pilots received from the BS for the currently monitored Paging Channel, plus pilots in the Neighbor List of the currently monitored BS (in this case the FAP). As the MS moves away from the FAP, the received pilot E_C/I_0 of the FAP pilot weakens, hence the macro BS pilot(s) relative strength increase(s). When the dominant macro BS pilot

E_C/I_0 becomes stronger (typically 3 dB) than the FAP pilot, the MS performs idle hand-out as follows:

- MS begins demodulating Paging Channel of the target macro BS
- MS receives System Parameters Message from the macro BS, which includes SID/NID pair for the macro system.
- Upon determining that the SID/NID pair is different from the stored SID/NID pair (for the femtocell system), MS registers on the macro system (see Section 5.3.4).

Note that a FAP may intentionally be configured without any pilots in its neighbor list. The operator can choose that configuration in order to effectively extend femtocell coverage. As the MS moves away from the FAP, if no neighbors are listed, it will remaining camping on the FAP until it can no longer decode the paging channel. This can be useful in the following cases:

1) To extend femtocell coverage for legacy MSs, whose hand-out hysteresis thresholds cannot be controlled by the FAP;

2) In dedicated carrier femtocell deployment scenario, which would otherwise require inter-frequency macro neighbor search; depending on MS design, this can result in battery standby time penalty, if the MS separately tunes to femtocell frequency for paging channel monitoring, and to macro frequency for neighbor searching;

With no macro pilots in the neighbor list, the MS camps on the FAP as long as link quality is good. When it can no longer decode the paging channel reliably, the MS will discover a macrocell via system (re)acquisition.

Hand-out for FAMs can be controlled by the FAP by means of handoff hysteresis values for both intra- and inter-frequency handoff in the Access Point Identification message (see C.S0005-E [23]).

5.7.1.1.2 Hand-In

Hand-in is a handoff from macrocellular network to a femtocell. Hand-in processing contains some unique issues compared to idle handoff between two BSs in macrocellular systems. The most significant issue is MS detection of having entered the FAP coverage area.

5.7.1.1.2.1 Legacy MS Hand-In

A MS in idle state on macrocellular system is hashed to one of multiple CDMA RF carriers comprising the deployed macrocellular system. If macro-femto co-channel RF plan is employed (see section 5.2.1), and the frequency the MS was hashed to happens to be the same frequency used by the FAP, then the idle hand-in procedures are identical to macrocellular BS-BS idle handoff (however, see the discussion on MS registration on the target FAP at the completion of idle hand-in). In all other cases (dedicated femtocell RF deployment, or MS hashed to a frequency other than the one used by the FAP), the legacy MS searcher in the idle state needs some sort of assistance from the network in order to detect the presence of the femtocell, once within its coverage. This can be accomplished, for example, with pilot beacons (see Section 5.2.3.1).

The NLM broadcast by the currently monitored macro BS includes the Pilot PN Offset of the FAP (see section 5.3.1). Hence, during the active part of the slotted cycle, the MS will search, among others, the PN Offset of the pilot used by the FAP. Even while camped on an RF carrier other then the one used by the FAP, once in the target femtocell coverage area, when the hopping pilot beacon transmits in that MS's paging slot, the MS will detect the FAP's pilot. This detection may occur with some delay, a function of the hopping beacon period and the exact timing of MS movement to the femtocell coverage area. Once the MS is at a location where the beacon pilot becomes dominant, the MS will initiate idle hand-in procedure to the FAP, briefly outlined as follows:

- MS adjusts its system time to the hand-in target FAP beacon timing;
- MS demodulates Paging Channel of the FAP beacon;
- MS receives (Global) Service Redirection Message, and tunes to the FAP frequency; starts monitoring main Paging Channel of the FAP;
- MS detects System Parameters Message from the FAP, which contains the SID/NID pair for the femtocell system;
- Upon determining that the SID/NID pair is different from the stored SID/NID pair (for the macro system), MS registers on the femtocell system (see X.S0059-200 Section 5.1.1.2 on MS Registration)).

5.7.1.1.2.2 FAM Hand-In

A FAM equipped with a PUZL database (see section 5.2.4) can accelerate the timing (reduce delay) of idle hand-in, i.e., not depend on the femtocell beacon to trigger the hand-in procedure. When a FAM detects that it is in the zone described in one of its PUZL entries, in addition to monitoring the macro cellular RF carrier to which it is hashed, it can tune in and sample the frequency on which the FAP is deployed. This frequency is one of the Informational Elements (IEs) included in the PUZL database entry.

The FAP frequency sampling can occur, for example, in every paging cycle (when within the PUZL target zone), making idle hand-in delay performance exactly the same as that of macro idle state handoff. Subject to MS design, if MS cannot perform multi-carrier sampling, and if idle state stand-by time is a concern, the FAP frequency sampling can occur less frequently (e.g., at several multiples of the paging cycle time).

FAM can use this improved-performance hand-in trigger, and can also skip the steps associated with pilot beacon from the hand-in procedure outlined in Section 5.7.1.1.2.1, whenever handing in to a FAP that it is in its PUZL database. Since frequently visited FAPs will be in the PUZL, this can for all practical purposes occur in a very large percentage of hand-in cases, while for the remainder the beacon based approach outlined in 5.7.1.1.2.1 can continue to be used.

For the PUZL-based idle state hand-in, the procedure is simplified to these steps:

- FAM tunes to the FAP frequency, takes samples, and evaluates pilots;
- Upon detection of a dominant pilot from a FAP that is in its PUZL, FAM adjusts its system time to the FAP timing;
- FAM demodulates System Parameters Message from the FAP, which contains the SID/NID pair for the femtocell system; This should match the SID/NID pair recorded in the FAM's PUZL for this FAP;
- Since the SID/NID pair is different from the stored SID/NID pair (for the macro system), FAM registers on the femtocell system.

After the MS registers with the FAP, it is preferable for the MS to stay on the FAP and not hand off back and forth to and from the macro base station until the MS definitely moves away from the FAP. This reduction of ping-pong effects is accomplished for FAMs by means of handoff hysteresis values for both intra- and inter-frequency handoff in the Access Point Identification message (see C.S0005-E [23]).

5.7.1.2 Active State Handoff Procedures

5.7.1.2.1 Hand-Out

From the air interface perspective, Active State Hand-Out from a FAP to a macrocell is identical to the handoff procedures on the macrocellular system. From the network perspective, a good analogy for active state hand-out would be inter-MSC hard handoff. This is because in the femto-to-macro hand-out, call control is moved from the FCS (which can be thought of as roughly equivalent to MSC for the femtocellular system) and a macro MSC. The details of the RAN/network procedures are provided in X.S0059-200 [13]. A brief summary follows.

The beginning state is a voice call between the MS, via the FAP and FCS to the PSTN or a macro network to the party on the far end.

The hand-out procedure depends on the deployment scenario, i.e., femto/macro co-channel, or the dedicated femto carrier deployment. Initially, while the connection is on the FAP, the MS has a single pilot in the active state belonging to the FAP. For the case of femto-macro co-channel deployment, in the course of forward link demodulation, the MS measures E_C/I_0 of the active pilot plus neighbor pilots on the same carrier. When the MS detects that the pilot E_C/I_0 of one or more of the macrocells listed in the NLM exceeds the handoff threshold, the MS sends PSMM message to the femtocellular system, which may trigger a hand-out. The FAP can control the handoff thresholds (e.g., T_ADD, T_COMP parameters) by means of overhead messages.

For the dedicated carrier femtocell deployment scenario, the MS searches for macrocell pilots on another carrier (i.e., perform candidate frequency searches) while still maintaining the call on the femtocell carrier. To minimize tuning away to the other carrier, these searches can be requested by the FAP only when the MS reports certain events such as active cell (FAP) pilot E_C/I_0 below a threshold, or frame erasures exceeding a threshold. The MS can report such events through regular signaling messages such as

PSMM and Power Measurement Report Message (PMRM). The MS can be directed to perform a single or periodic search of macrocell pilot(s) on one or more macrocell carrier frequencies through Candidate Frequency Search Request Message (CFSRQM) and Candidate Frequency Search Control Message (CFSCNM). In response, the MS searches for macrocell pilot(s) and reports their E_C/I_0 via Candidate Frequency Search Report Message (CFSRPM). Based on the CFSRPM, the FAP may initiate hand-out to the qualified macrocell(s) reported in the CFSRPM.

The remainder of the RAN and core network procedures is addressed in detail in X.S0059-200 [13]. The FAP looks up the hand-out target macrocell(s) from the <PN offset, ICGI (IS-41 Cell Global Identifier)> mapping provisioned by the FMS. The FCS works with the target MSC to complete the hand-out. From the macrocellular network perspective the procedure is analogous to an inter-MSC handoff. The target frequency for the hand-out may be any macro RF carrier deployed in the macro system, not necessarily the macro/femto co-channel carrier, if that deployment scenario is used.

The end state is MS in a voice call via the target BS and the target MSC.

5.7.1.2.2 Hand-In

In addition to the issue of MS detection of having entered the FAP coverage area elaborated in the idle hand-in case, the active state hand-in has one more critical issue – resolution of ambiguity of the hand-in target FAP.

5.7.1.2.2.1 Legacy MS Hand-In

A MS in active state can be using any of the multiple CDMA RF carriers comprising the deployed macrocellular system. If the macro-femto co-channel RF plan is employed (see section 5.2.1), and the connection is on the same frequency used by the FAP, then the detection of the FAP pilot and trigger for hand-in is identical to the case of macrocellular BS-BS active state handoff. In all other cases (dedicated femtocell RF deployment, or the call is on a frequency other than the one used by the FAP), the legacy MS searcher in the active state needs some sort of assistance from the network in order to detect the presence of the femtocell, and report to the macrocellular system to trigger hand-in.

As is the case with idle state procedures, this network assistance can be accomplished, for example, with pilot beacons (see Section 5.7.1.1.2.1). The NLM broadcast by the macro BS includes the Pilot PN Offset of the FAP, and the MS will search it while in the active set. Once MS is in the femtocell coverage area, when the hopping pilot beacon transmits in the RF carrier frequency occupied by the MS in the active state, the MS will detect the FAP's pilot. As explained for the case of idle procedures, this detection may occur with some delay. Once the beacon pilot exceeds handoff threshold, the MS will transmit PSMM, thus triggering hand-in.

Two cases are considered:

(1) Open Access FAP (see Section 5.5.2), or Restricted Access FAP, where this MS is allowed to access the FAP
(2) Restricted Access for this MS/FAP pair, including Signaling Association (see Section 5.5.3)

For the case (1), the network performs hand-in.

For the case (2), the network may perform hard handoff to a macrocell on a different frequency, if the original frequency is the same one used by the FAP. This would reduce interference of the call with the FAP on which the MS is not allowed (see Section 5.4 on RF Interference Control). This can be accomplished either by direct inter-frequency macrocellular handoff (this option requires some changes in the macrocellular system to differentiate open and restricted femtocell access), or by performing hand-in immediately followed by hand-out to a different macro-frequency (hand-in/hand-out sequence). If hopping beacon is used by the FAP, hand-in trigger may occur again, if the call is still in progress during the next beacon cycle, and MS remains the FAP coverage area. To prevent a handoff loop, the macro network may ignore this repeated hand-in trigger, however this would likely require a macrocellular system upgrade. The case (2) is not further elaborated here.

The hand-in procedures for case (1), when hand-in is allowed, are described in detail in X.S0059-200 [13] and A.S0024 [1], and are briefly outlined herein.

The hand-in procedure is triggered when the MS sends a PSMM per C.S0005 [6] to the macrocellular network. Based on the identity of the strongest pilot in the PSMM (PN Offset given to a FAP), the MSC directs handoff request to the FCS, hence to a FAP. The FCS cannot determine with certainty which of the FAPs among multiple candidates using that PN Offset is the hand-in target (because there are only up to 512 discrete PN Offset values, which is insufficient to uniquely identify one of possibly tens or hundreds of thousands of FAPs that may be under the control of a single FCS). The FCS sends a measurement request message to all candidate FAPs located in the vicinity of the source macrocell, which are assigned that PN Offset. Each candidate FAP attempts to detect the MS by reverse link measurements. Based on the results of the measurements or by supplemental means not elaborated here, the target FCS can positively identify the target FAP. The remainder of the procedure is similar to what was already discussed for the case of hand-out (i.e., inter-system handoff).

As seen from the above description, fanning out measurement requests to multiple FAP (sensing the MS on the reverse link) as potential hand-in targets and dealing with their responses is all done within the femtocellular system. From the perspective of the macro BS and the MSC, the procedure is identical to hard handoff to a BS in another MSC. The source macro BS only needs to be configured with a value of ICGI (Target MSC ID and Target Cell ID) for each pilot PN assigned to FAPs in the area.

5.7.1.2.2.2 FAM Hand-In

A FAM equipped with a PUZL database (see Section 5.2.4), and either capable of multi-carrier sampling (see Section 5.2.2) or containing multiple receive RF chains, can offer several benefits associated with active state hand-in, including:

- Reduce delay of active state hand-in;
- Be independent from the FAP beacon to trigger the hand-in procedure, thus allowing the possibility of FAP operation that does not rely on pilot beacons;
- Reduce incidence of adjacent channel interference to the FAP caused by FAMs in active state on the macrocellular system near a FAP;

When a FAM in the active state detects that it is in the zone described in one of its PUZL entries, it can start multi-carrier sampling encompassing the frequency on which the FAP is deployed. Alternatively, if a FAM has multiple receive chains (e.g., for the purpose of simultaneous HRPD operation while monitoring cdma2000 1x paging channel, or for receive diversity), it can engage an additional receive RF chain to measure the femtocell frequency of deployment to detect FAP pilot. In this regime, the FAM uses sampled material from the current macro-only RF carrier for normal receiver function in the active state processing, but it uses sampled material from the FAP frequency for the purpose of monitoring relative strength of pilots and triggering PSMM. Hence, the FAM will transmit the PSMM as soon as it detects FAP’s pilot relative strength in excess of handoff threshold, i.e., it will not depend on the hopping beacon cycle for such detection. This reduces hand-in delay, thus maximizing the usage of femtocell resources by reducing the dwell time of the FAM in the vicinity of the FAP. This reduction of dwell time can translate into an important performance enhancement associated with adjacent channel interference (see Section 5.4 on RF Interference Management). If it happens that the macrocellular frequency used by this call is adjacent to the FAP frequency, and if the macro coverage in the FAP locality is weak, it would translate to MS using high transmit power. While in this hand-in dwell situation, this can result in significant adjacent channel reverse link interference with the FAP.

In cdma2000 1x Revision E, FAP paging channel can transmit the Access Point Identification message (refer to the Section 5.2.3 on FAP Discovery) which contains the values of its Target MSC ID and Target Cell ID. If there is a hand-in trigger to this FAP, the source (macro) BS can use this information to initiate handoff. The MS reports the values of MSC ID and Cell ID during handoff. Thereafter the source (macro) BS continues hard handoff procedure as described in Section 5.7.1.2.2.1.

5.7.2 HRPD Procedures

HRPD procedures largely parallel those for cdma2000 1x. The only small exception is for the case of idle (dormant) state handoffs, as discussed below.

5.7.2.1 Idle Handoff Procedures

In HRPD, additional complexity in idle handoff procedures arises from the need to transfer HRPD session between the macro AN and the HRPD FAP. Without HRPD session transfer, the AT needs to close and re-negotiate the HRPD session upon every handoff between macro AN and the HRPD FAP. HRPD session transfer can be accomplished via A13 interface (see A.S0024 [1]).

While it is simple to configure a FAP with the IP address of the source macro AN from which to request an HRPD session, it is more complex for the existing macro AN to be configured with all of the IP addresses of FAPs that the macro AN may need to request a session. Therefore, for hand-in the Femtocell Gateway (FGW) is used as A13 Interface Proxy for FAPs. The macro AN requests the HRPD session for an AT through the FGW. The FGW thereafter relays the request to the appropriate FAP (see A.S0024-0 [1]).

5.8 Sevices Aspects of Femtocell Systems

5.8.1 Local IP Access (LIPA)

This service is applicable to HRPD air interface, and has two distinct aspects:

- Servers locally connected to the FAP can be accessible by the AT connecting through the femtocell. For example, a media server, nanny cam, or home automation controller can be accessed directly from the AT, i.e., femtocell provides similar functions to a Wireless LAN access point.
- Direct access to the Internet can be achieved by the AT through the landline broadband access while bypassing the cellular core network. This offloads Internet traffic from the cellular core network via femtocells, reducing required resources for data services whenever a subscriber is connected to a femtocell.

Figure 5.8-1 is a simplified diagram illustrating LIPA and RIPA (see Section 5.8.2) architecture.

For access to a local server (IP Host in the figure), an AT uses home router to which the FAP and the server are connected. For access to a host in the Internet, the IP packets are sent outside of the secure IP tunnel and thus are forwarded by the home routers through the Internet Service Provider to the IP Host.

LIPA uses the existing AN-PPP connection over HRPD access stream between the AT and the FAP. The AN-PPP connection, previously used only for HRPD access authentication, has been modified to support LIPA, as elaborated in detail in A.S0024 [1]. 3GPP2 specification does not include LIPA support for legacy ATs.

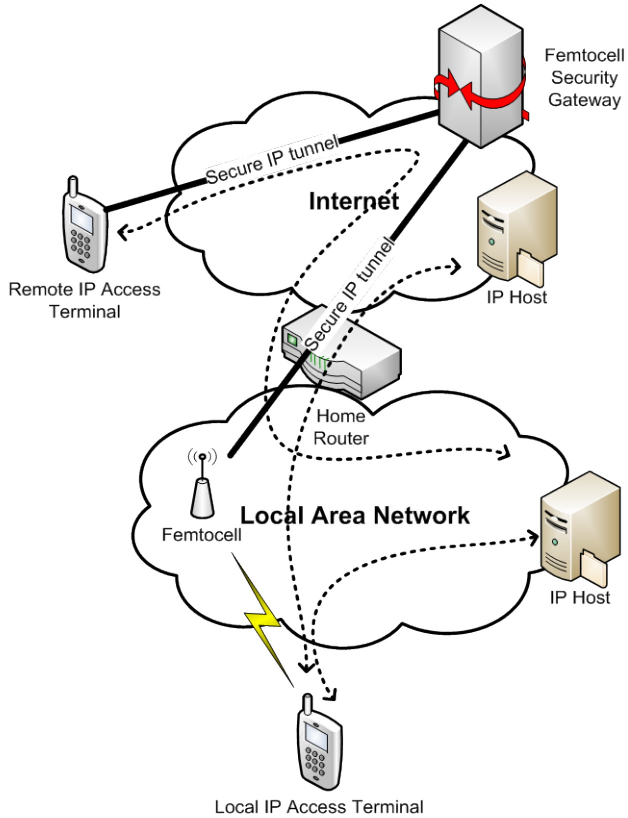

Figure 5.8-1: Simplified LIPA/RIPA Architecture

5.8.2 Remote IP Access (RIPA)

Typically, home networks or enterprise networks are protected by firewalls which can prevent any access initiated by IP hosts from outside of the firewall. Furthermore, an IP host located in a LAN may not have a public IP address and therefore can only be accessed by other IP hosts that also have local IP addresses within that LAN. RIPA is a service that allows an authorized cellular subscriber to remotely access a local network, similar to Virtual Private Network (VPN) service, via the femtocells. For details, refer to X.S0059-100 [13].

RIPA makes use of the AT's security credentials to automate the authentication and authorization of the AT's access to the local network. Furthermore, it also reuses many existing functions that the femtocell has, for example, the IPsec connection between the femtocell and the core network.

An AT using RIPA service is assigned an IP address from the network in which the femtocell resides. RIPA IP packets are routed between the AT and the local network through the secure IP connection traversing Network Address Translator (NAT) and firewall.

5.8.3 Emergency Call Services

Emergency call service is supported with femtocells.

When determining location of the user who placed the emergency call, the location of the strongest adjacent macrocell will be used instead for the purpose of routning the call to the correct PSAP. Precise location information for the purpose of dispatching assistance to the caller is supported by the femtocell specifications.

5.8.4 Supplementary Service Support

All the CS supplementary services subscribed to by the user can be supported when the user is under the coverage of a femtocell. For details, refer to X.S0059-400 [13].

5.9 Minimum Performance Standards

5.9.1 Introduction

The existing cdma2000 BSs/ANs are governed by the minimum performance specifications (MPS) defined in C.S0010-C v2.0 [25] and C.S0032-B v1.0 [26]. Originally, these specifications were developed for macrocells for wide area network applications. However, femtocells have significantly different operation and design criteria as well as business case compared to macrocells. For example, femtocells have low transmit power since they are typically intended for indoor coverage with a small footprint whereas macrocells are intended for large, ubiquitous indoor as well as outdoor coverage. Given these differences, requiring femtocells to meet the same specifications as macrocells, such as supporting high speed (e.g., 100 km/h) users, burdens these consumer devices with unnecessary design complexity. Thus, there is a need to define different MPS requirements for femtocell base stations. With this in mind, MPS for cdma2000 femtocell base stations were defined to guide femtocell developers, vendors, operators and the technical community at large.

The main thrust of the work is to standardize separate MPS requirements for femtocells by studying and modifying (relaxing or making more stringent, as the case may be) the existing MPS requirements, and also defining any new requirements that are needed for femtocells. The distinction between femtocells vs. macrocells can be made by defining a limit on the maximum transmit power of femtocells and specifying requirements that apply only to such low power femtocell base stations. The main test specifications approved for femtocell base station MPS are described in Sections 5.9.2 and 5.9.3 below.

5.9.2 Femtocell Base Station Transmitter MPS Requirements

- ***Maximum RF Output Power***: Limit maximum RF output power at the antenna port to 20 dBm to ensure that femtocell base station has a small coverage footprint.
- ***Frequency Tolerance***: For low complexity design, increase (relax) frequency tolerance to 100 ppb (parts per billion) compared to macrocell requirement of 50 ppb such that a femtocell base station

can support low mobility users that will be encountered in typical indoor applications.

- ***Limitations on Spurious Emissions***: Make the emission limits stricter for femtocells in order to protect users on channels near-by the femtocell channel from femtocell interference. This is necessary because the minimum coupling loss (MCL) between a user and a femtocell is lower than that between a user and a macrocell. Therefore, a user on a near-by channel may be adversely impacted from femtocell interference without good control over spurious emissions. The femtocell specification is -36 dBm/MHz for frequency offsets greater than 4 MHz.

5.9.3 Femtocell Base Station Receiver MPS Requirements

- ***Receiver Sensitivity:*** Femtocell base station receiver (Rx) sensitivity is relaxed to -110 dBm in order to reduce design complexity. With small coverage footprint, femtocell reverse link budget can still be met by MSs even with relaxed Rx sensitivity, thus ensuring satisfactory performance.
- ***Receiver Dynamic Range:*** The upper limit of the dynamic range of femtocell base station is increased to the maximum received power of -39 dBm per RF input port from the -65 dBm requirement for macrocell base station. This increase enables the femtocell base station to handle strong reverse link (RL) signal from a MS in the vicinity of a femtocell whose power is controlled by a macrocell.
- ***Single Tone Desensitization, Inter-modulation Response, and Receiver Blocking***: These requirements are relaxed to reduce design complexity and enable practical receiver designs. Modifying these requirements does not affect femtocell RL performance because RL link budget can still be met by the MS in the presence of a jammer due to smaller femtocell coverage footprint. For the single tone de-sense test, the power of the tones that are at 900 kHz and 1.25 MHz offset from the center frequency is reduced to 65 dB relative to MS power. The power of the CDMA waveform, relative to the MS power, is reduced to 63 dB for the inter-modulation response test. The out-of-band receiver blocking test is also relaxed such that the blocker level is 91 dB instead of 100 dB.
- ***Demodulation Performance:*** Test for femtocell receiver demodulation performance is defined only for additive white Gaussian noise (AWGN) and low speed, single path channel conditions that are typically encountered in femtocell deployments. The 8 km/h 2-path and 100 km/h 3-path channel tests in the macro base station specification do not apply to femtocell base stations.