Femtocells – Architecture & Network Aspects

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ABSTRACT

Femtocells are small, user-installed base stations that enhance coverage for in-building cellular services. The new paradigm introduced by femtocells also brings unique challenges, namely (i) unplanned deployment, (ii) user-installation, (iii) restricted access, and (iv) inter-operability with existing handsets and infrastructure. This paper describes the impact of these challenges on different deployment aspects such as interference management, mobility management, and self-configuration. Potential solutions to address the challenges are subsequently discussed. In addition, the standardized femtocell architectures for the UMTS and cdma2000 families of access technologies are introduced and compared.

1. INTRODUCTION

Femtocells are personal miniature base stations installed on the subscriber's premises for providing cellular service within the home or enterprise environment. Typically femtocells are connected to the Internet and the cellular operator's network via a DSL router or cable modem. Access to a femtocell can be open to any subscriber, restricted to a limited set of users, or a combination of both with priority for preferred users.

Femtocells offer benefits for both subscribers and operators. The subscriber experiences better voice service coverage and higher data throughput. Special service plans can provide additional incentives for home use (e.g., free calls from home). The operator is able to off-load traffic from the macro cellular network, thus reducing infrastructure cost. Moreover, indoor coverage problems can be resolved without deploying expensive macro base stations. Operators also have an interest in ensuring their mobile devices are used in the home despite the availability of competing technologies (e.g. Wi-Fi). Such "stickiness" with their features and services helps reducing churn. Finally, it supports a transition from wire line service to exclusive use of wireless devices at home.

Recognizing these benefits Verizon and Sprint have launched Femtocell products nationwide in the U.S. in recent months. Several operators in Europe have been conducting trials with femtocells. Operators, vendors, content providers and innovative start-ups founded the Femto Forum, a membership organization to promote femtocell deployments worldwide. A considerable list of OEMs offer solutions in this growing industry, including Alcatel-Lucent, Huawei, ZTE, ip.Access, Airvana, and Samsung, to name a few. Qualcomm announced the development of a Femtocell Station Modem™ (FSM™) in February. It will support HSPA+ and CDMA2000®, including 1X and EV-DO Rev. A and Rev. B. The chipsets will include baseband functions, network listen and integrated RF capabilities for all major wireless bands.

The next two sections introduce the terminology and the network architecture for UMTS/HSPA and cdma2000 systems with a brief outline of the differences. In the remainder of the paper we discuss the specific challenges and suggested solutions at a conceptual level. Section 5 identifies a few areas for further study and Section 6 summarizes our conclusions.

2. TERMINOLOGY

This paper covers aspects of UMTS/HSPA as well as CDMA2000® (1X and EV-DO also known as HRPD). To avoid confusing or cumbersome language, the terminology in Table 1 is used in this paper rather than explicit terms for each technology.

Table 1 Terminology

Term used here	3GPP Term	3GPP2 Term
DL	Downlink (DL)	Forward Link (FL)
UL	Uplink (UL)	Reverse Link (RL)
Pilot	Primary Scrambling Code (PSC)	Pseudo-noise sequence (PN)
Handset	User Equipment (UE)	1x: Mobile Station (MS) HRPD: Access Terminal (AT)
Macrocell	Node B	Base Station Transceiver System (BTS)[1]
Femtocell	Home Node B (HNB)	Femto Access Point (FAP)
Femto-GW	Home Node B Gateway (HNB-GW)	Femto Gateway (FGW)
FMS	HMS (HNB Management system)	FMS (femto Management System)
RNC	Radio Network Controller (RNC)	Base Station Controller (BSC)[2]
BSS	Base Station Subsystem (BSS = Node B + RNC)	1x: Base Station (BS = BTS + BSC) HRPD: Access Network (AN)
MSC	Mobile Switching Center (MSC)	Mobile Switching Center (MSC)
Serving Gateway	SGSN (Serving GPRS Support Node)	Packet Data Service Node (PDSN)
IP Gateway	GGSN (Gateway GPRS Support Node)	Home Agent
Air interface	Uu (UE-UTRAN Interface)	Um (MS – RAN Interface)

3. NETWORK ARCHITECTURE

Femtocells are envisaged to be deployed in large numbers by home and enterprise users at their premises. This new unplanned

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[1] Term not standardized in 3GPP2

[2] Term not standardized in 3GPP2

deployment model requires a network architecture which meets the following requirements:

(i) Scalable to a large number of femtocells with minimal or no impact to the existing infrastructure

(ii) Secure and reliable connectivity from femtocell to the operator's core network via the Internet

(iii) Remotely configurable

These properties form the basis of the standardized femtocell system architectures in both 3GPP and 3GPP2 which are described in the following subsections.

Note that the remainder of Section 3 utilizes technology-specific terminology.

3.1 3GPP Femtocell Network Architecture

Figure 1 illustrates 3GPP femtocell architecture described in this section. More details about this architecture can be found in [1].
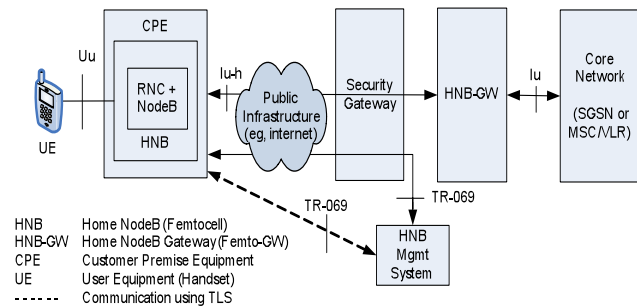

Figure 1 - 3GPP Femto Architecture

HNB supports NodeB and RNC-like functions. It connects to the handsets (UEs) via existing Uu interface and to the HNB-GW via new Iu-h interface. It is typically owned by the end user.

HNB-GW concentrates HNB connections (many-to-one relationship between HNBs and HNB-GW) and presents itself as a single RNC to the core network (CN) using the existing Iu interface. This allows for scaling to large numbers of HNBs, and avoids new interfaces and HNB-specific functions at the CN.

Home Management System (HMS) is used for provisioning HNB configuration data remotely using the TR-069 family of standards. TR-069 is traditionally used for DSL modem configuration.

Security Gateway (SeGW) uses IPSec [2] to provide a secure link between the HNB and the HNB-GW (over Iu-h) and between the HNB and the HMS. These links can either use the same or different SeGWs. The SeGW is also responsible for HNB authentication.

3.2 3GPP2 Femtocell Network Architecture

This section describes two architectures for femto systems as specified by 3GPP2. Detailed descriptions for both architectures can be found in [3].

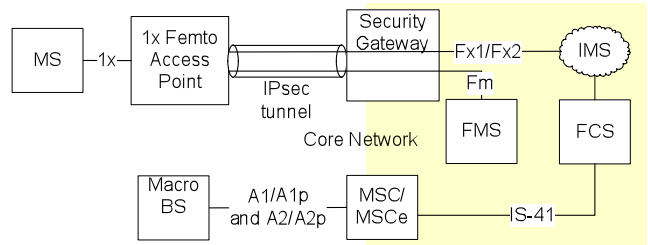### 3.2.1 1x Circuit-Switched Voice Femto System Architecture

Figure 2 - cdma2000 1x Circuit-Switched Voice Femto Architecture

Figure 2 shows the architecture for supporting circuit-switched (CS) voice service via a femtocell.[3]

Femto access point (FAP) has equivalent functions to a Base Station (BS) in the macro network, e.g., communicating with the handset (MS) and setting up a voice circuit with the CN.

Femto Convergence Server (FCS) provides equivalent functions to an MSC 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 which are 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 IS-41 interface for inter-MSC communication.

Femto Management System (FMS) is used for remotely configuring the FAP via the Fm interface. Like in the 3GPP architecture, this OA&M interface is based on TR-069.

Security Gateway (SeGW) provides secure communication between the FAP and the operator's core network. IP packets between FAP and CN are encapsulated in an IPSec tunnel. As a security gateway the FGW is also responsible for authenticating and authorizing the FAP.

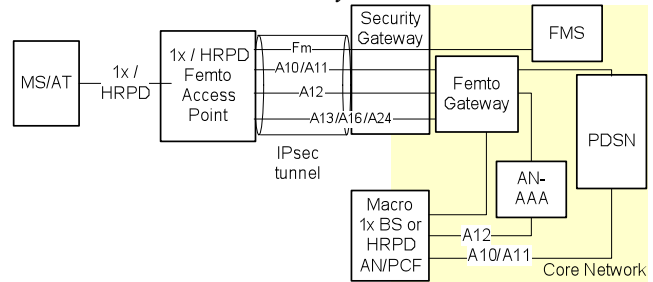### 3.2.2 Packet Data Femto System Architecture

Figure 3 - cdma2000 1x and HRPD Packet Data Femto Architecture

Figure 3 shows the 3GPP2 architecture supporting packet data services through either 1x or HRPD (also known as EV-DO) air-interfaces. In case the FAP supports both 1x CS and 1x/HRPD

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[3] Note that it is also possible for FAPs to use A1p/A2p interfaces to connect with an MSC. This architecture is allowed in the standard and is in use for current femto system deployments by Verizon Wireless and Sprint.

packet data, common entities (i.e., FGW and FMS) and interfaces (i.e., IPSec tunnel and Fm interface) will be used.

FAP provides functions equivalent to an HRPD access network (AN) or a 1x BS.

Femto Gateway (FGW) provides proxy function support for HRPD AN interfaces such as A11, A12, A13, A16, and A24 interfaces. This allows the FAP to transfer an air-interface session to and from the macro AN in both idle and active states for seamless handoff. It also supports paging of an AT from the macro AN to the FAP. The use of FGW is optional in the standard.

PDSN routes MS/AT originated or MS/AT terminated packet data traffic and establishes, maintains, and terminates link layer sessions to ATs. For seamless IP mobility, the FAP should connect to the same PDSN as the macro AN or BS in the area. Since the FAP reuses A10/A11 interfaces which are identical to interfaces used by a macro AN/BS, the FAP appears as just another AN/BS from the perspective of the PDSN.

AN-AAA (AN Authentication, Authorization and Accounting) server is responsible for authenticating and authorizing ATs via A12 interface for both macro AN and FAP.

3.3 Differences between 3GPP & 3GPP2 Femtocell Network Architectures

Although there are many similarities between the 3GPP and 3GPP2 architectures, there are some notable differences:

(i)   To address scalability issues, the 3GPP architecture concentrates all HNB connections at the HNB-GW and thus makes all HNB RNCs appear as a single RNC to the CN. This is not the case in 3GPP2 where the FCS is a dedicated CN element supporting 1x femtocells. For HRPD, the required states in the PDSN scale with the number of ATs and not with the number of FAPs.

(ii)   The femto architecture for CS and PS is the same in 3GPP, whereas in 3GPP2 they are different.

(iii)   The femto-GW in 3GPP2 only provides the proxy function for HRPD AN interfaces.

4. CHALLENGES & SOLUTION CONCEPTS

Femtocells introduce a set of basic challenges due to the following four factors:

- *User-installed*: the femtocell may be installed by subscribers without special training or knowledge regarding antenna placement and system configuration.

- *Unplanned deployment*: unlike a macro network, femtocells are deployed without network planning; no special consideration is given to traffic demand or interference with other cells.

- *Restricted access*: to protect the use of limited resources (femtocell capacity, DSL/modem connection), femtocells may be configured to limit access to only a few authorized subscribers (e.g. family members or hotel guests)

- *Legacy system support*: currently available handsets are femto-unaware; femtocells need to support femto-unaware

handsets as well as femto-aware handsets; moreover, they need to interface with existing access and core networks.

This section describes the impact of these challenges and outlines potential solutions.

4.1 Interference Management

Since RF coverage of femtocells are not manually optimized by the cellular operator and deployment is generally ad hoc, RF interference issues may arise unless appropriate methods are utilized. Furthermore due to limited spectrum available to operators macrocells and femtocells can share at least one frequency in order to increase efficiency of spectrum use. In the following we outline potential RF interference issues related to femtocell deployments.

- *Desensitized Femtocell or Handset:* In cellular networks handsets and base stations are designed to operate in a certain dynamic range. However, femtocells and handsets can be arbitrarily close and create very high signal levels beyond the sensitivity range of the receiver. On the DL this situation can saturate the handset receiver and create degraded demodulation performance. On the UL this situation can create a very high noise rise (RoT) at the femtocell and render the system unstable.

- *Interference between macro and femto cells:* Femtocells can cause interference both on the UL and DL. For example, a femtocell installed near a window of a residence can cause significant DL interference to the handsets outside the house (i.e., macrocell handset) that are not served by the femtocell. On the UL the home handsets that are served by a certain femtocell can cause significant interference to the macro cell handsets.

- *Inter-femto Interference:* Femtocells can also create significant interference to each other due to unplanned deployment. For example, in a multi-apartment structure femtocells installed near a wall separating two apartments can cause significant interference to neighboring apartments. In such a case, the strongest femtocell for a home handset (in terms of RF signal strength) may not necessarily be the serving femtocell due to the restricted access described in the introduction to Section 4.

To achieve the desired performance, the following interference and mobility management methods need to be employed as part of the femtocell design. These methods constitute the baseline recipe for femtocell interference and mobility management. They reduce the outage probability, improve voice and data performance, and enable robust system operation by adapting to the particular RF conditions of each femtocell.

4.1.1 Femtocell DL Tx Power Self Calibration

As femtocells create desired coverage in the home area, coverage holes may be created around the home for other (non-associated) mobiles. Thus each femtocell's transmit power needs to be adjusted carefully depending on the particular femto location in a macrocell (e.g., cell edge vs. cell site) and deployment scenario (suburban vs. urban). This can be achieved via autonomous self calibration where femtocells make DL measurements from macrocells and other femtocells, and then calculate the required transmit power levels.

4.1.2 Carrier Allocation to Femtocells and Inter-frequency Handover for Macrocell Users

For efficient use of available frequency spectrum it is desirable that femtocells share some of the carriers with the macrocell. Thus, although femtocell power calibration limits the coverage holes, macrocell users on the same carrier passing by the femtocell residence may still experience an outage (e.g., if the femtocell is located near a window). In such cases, macrocell handsets need to perform inter-frequency handover to another macro carrier to avoid the femtocell coverage hole. Only few carriers should be allocated to femtocells so that high mobility macrocell users do not perform very frequent inter-frequency handovers. On the other side, if there is strong inter-femto interference, it is desirable to assign neighboring femtocells on different carriers. As a compromise, an autonomous femtocell carrier allocation algorithm is recommended for femtocells where femtocells have a preferred carrier and they choose another carrier (within the allowed carrier set) only when strong interference is detected on the preferred carrier. Significant performance gains can be achieved with multiple carrier deployments with proper inter-frequency handover mechanisms. Mobility simulations show some potential impact on handset battery life with legacy handover methods. Also for 3GPP2 femtocells, a reduction in adjacent channel interference is desirable.

4.1.3 Mobility Support and Management for Femtocell Users (Beacon Tx)

When a femtocell handset arrives at home, it is usually desirable for the handset to camp on the femtocell (e.g., to offload traffic from macrocells or to offer "free in-home minutes"). This applies even if the femtocell does not offer better signal quality than the macrocell or even if the handset is operating on a different carrier on the macrocell compared to the femtocell carrier. Typically, the handset searches for other frequencies only when the current macro carrier is weak. In 3GPP systems, cell reselection parameters should be adjusted to enable a mobile user to detect its own femtocell operating on a different carrier. In 3GPP2 systems, beacons can be radiated by femtocells to re-direct the handset to the femto carrier frequency. The power and periodicity of the beacon needs to be adjusted properly not only to reduce interference to non-associated mobiles (e.g., in vicinity of a home) but also to minimize delay in femtocell discovery for handsets entering the femtocell coverage [4].

4.1.4 Adaptive Attenuation on UL and Limiting Handset Tx Power

Handsets in the proximity of femtocells can create very high signal levels (compared to thermal noise floor) at the femtocells and result in significant UL performance degradation and instability. One particularly bad scenario occurs when a restricted handset close to a femtocell is transmitting bursty UL data to a neighbor femtocell or a macrocell. To provide robust operation under such conditions an adaptive UL attenuation algorithm needs to be used. Additional UL attenuation is applied at the femtocell whenever strong UL interference is present.

4.1.5 Enhancements for Very Dense Femtocell Deployments

For very dense femtocell deployments and for operators with limited frequency spectrum further improvements are possible with performance enhancement methods such as:

- *Switched Beams*: Directional antennas can be used in femtocells in order to null out the interference to and from neighboring femtocells on the UL and DL. Significant performance improvement is shown with multiple tx/rx antennas. However, this method adds additional cost to femtocell equipment.

- *Handset DL Interference Cancelation:* Handset interference cancelation methods can improve performance significantly under scenarios such as strong neighbor femtocell DL interference.

- *Femtocell UL Interference Cancelation of Out-of-cell Handsets:* Uplink interference management can be utilized to cancel interference from neighbor handsets if they create strong interference on the femtocell UL. This method can achieve significant performance gains. However, it requires the handset-specific UL codes to be shared between femtocells and macrocells.

More details of interference management techniques can be found in [5], [6].

4.2 Restricted Access and Femtocell Selection

Since femtocells are typically owned by the end users or by a private enterprise, it is often desirable to allow only authorized subscribers to access their own femtocells. Restricted access on a per cell basis is a new operating model that poses certain challenges to femto-unaware handsets in femtocell selection. These handsets cannot differentiate between a macrocell and a femtocell and cannot discern if the handset is allowed to access the femtocell. Access authorization to a femtocell, therefore, has to be performed at the network via the registration procedure. A handset that performs indiscriminate and frequent access and registration attempts on non-allowed femtocells will reduce its battery life and impose a high registration load on the network. Furthermore, a registration rejection, under certain circumstances, may cause the handset to bar and avoid that frequency for some period of time and force it to search for another suitable frequency to camp on. During that time, the handset may miss pages or experience disrupted service.

The issues described above affect those handsets that encounter non-allowed femtocells. A handset that camps on its allowed femtocell, on the other hand, can experience battery savings where the macro coverage is poor, because it does not need to periodically search for a better cell or frequency.

In early deployment phases with low or medium femtocell density, the problems stated above with femto-unaware handsets are less pronounced and should not deter femtocell rollout with restricted access. For femto-unaware handsets, the following two access modes still provide better performance than restricted access:

- *open association*: a handset is allowed to access any femtocell

- *signaling association*: an unauthorized handset is allowed to camp on the femtocell in idle mode but would be directed to a macrocell when it makes a call.

For future handsets and networks, improvements can be made to better support femtocell selection in restricted access. A femto-aware handset can "select right" vs. "select any" as described above for femto-unaware handsets. In the "select right" paradigm,

the handset only selects to a femtocell if the femto subscription identity broadcast by the femtocell matches with the one in the handsets "white list". The handset's white list contains a set of allowed femtocells. It can be provisioned by the network or learned by the handset, such as through manual femto selection procedure initiated by the subscriber. By selecting right, the femto-aware handset can avoid unnecessary access and registration attempts on non-allowed femtocells.

To further assist femto-aware handsets with femtocell selection, the network (macrocells and/or femtocells) can broadcast a set of pilots reserved for femtocells to differentiate them from macrocells. Alternatively or in addition, an indication can be broadcast identifying dedicated carrier frequencies for femto deployment. A femto-aware handset with femto subscription can use such information to search for femtocells, whereas one without subscription can use it to avoid searching for femtocells.

Selecting right in a restricted access femto deployment reduces the standby time impact on the femto-aware handset, minimizes unnecessary registration load on the network, and provides better service to the subscriber.

4.3 Mobility

Subscribers and operators alike expect femtocells to provide the same service experience as macrocells. Thus, it is critical that all handsets transition seamlessly into and out of femtocell coverage. Due to the limited coverage and density of femtocells, it is possible for the handsets to quickly and frequently transition in and out of the coverage of a femtocell. This poses challenges for both idle and active call handover.

In idle state, the handset needs to register when it hands into and out of a femtocell to enable efficient paging. Since the femtocell may be deployed on a different frequency than the macrocells, a mechanism is needed for the handset on the macrocell frequency to detect the presence of the femtocell. As outlined in the previous section, frequent registrations affect the handset battery life. They can occur, e.g., if the handset is traversing an area with dense femtocells using open association or signaling association.

In active state, a challenge arises on how to identify the target femtocell. For handover from a source macrocell to a target macrocell, the target macrocell is *uniquely* identified by the combination of the pilot it is transmitting and the identity of the source macrocell. However, due to the limited number of possible pilot sequences compared to the number of femtocells, the pilot transmitted by a femtocell is no longer unique.

While these challenges have been addressed for the femto-aware handsets and infrastructure [1], the situation is more difficult for the handsets which are not femto-aware. Moreover, the complexity and cost of modifying deployed infrastructure limits the solution space for these handsets..

The active handover problem for the femto-unaware handsets can be addressed by either (i) letting the target femtocell sense the uplink pilot during handover to confirm the presence of the handset in the vicinity or (ii) creating a unique signature for each femtocell by transmitting multiple pilots simultaneously on a femtocell.

The idle handover problem for femto-unaware handsets can be alleviated by a properly designed pilot beacon [4]. To fundamentally resolve the problem, however, the handsets need to be able to distinguish whether the received pilots belong to femtocells or not. This requires enhancements in the air-interface signaling. With these enhancements, various optimizations can be applied. E.g., the handsets could limit handover to femtocells to only an area of interest (i.e., in a preferred user zone). Furthermore, the handset can delay idle handover to a femtocell to avoid registering unnecessarily with a femtocell in case it is just passing through.

4.4 Backhaul

Femtocells use public infrastructure, such as the Internet, as a backhaul to connect to the femto-GW and the operator's core network. This backhaul presents the following issues: (i) Lack of security (ii) Lack of QoS (iii) Limited bandwidth.

Security: Since femtocells and femto-GWs communicate over public infrastructure instead of operator-controlled links, any communication between them must be secured for data confidentiality and integrity. Security protocols such as IPSec can be used for this purpose. Additionally, the femtocell is deployed as customer premise equipment (CPE) operated by the end user. To protect the CN against a spoofed or modified femtocell, it is necessary to perform mutual authentication between the femtocell and the Security Gateway (which maybe inside or outside the femto-GW) using device credentials that are securely stored within the Femtocell.

QoS: In the absence of a dedicated backhaul with QoS, the communication between the femtocell and the femto-GW is impaired by packet loss, delay, and jitter which can vary greatly with the network, location, and time. These factors can affect real time applications such as voice communication where speech can become muted or unintelligible. To address these issues, both the femtocell and the femto-GW may classify delay-sensitive packets using Differentiated Services Code Point (DSCP) bits in IP headers. Herewith, intermediate routers between the femtocell and the femto-GW can prioritize these packets properly to minimize jitter. However, packet prioritization also results in out-of-order packet deliveries. Since IPSec only allows a limited degree of out-of-order packets per security association to prevent replay attacks [7], delay-sensitive packets should be encapsulated in a different security association than other packets. Otherwise, packets might be discarded unnecessarily. For additional protection, the link quality could be monitored and the handset redirected to a macrocell if the backhaul quality drops below a threshold.

Limited Bandwidth: Typically, Internet Service Providers (ISPs) provide asymmetric bandwidth to broadband users, with more bandwidth available on the downlink than on the uplink. Hence, the number of simultaneous user plane paths of a femtocell might be limited by the uplink bandwidth over the secure tunnel. In case of CS data, where payloads are small, the restriction on the number of user plane paths results mainly from the high overhead of the secure tunnel (IPSec). To reduce the relative overhead and alleviate the uplink bandwidth limitation, multiplexing of multiple CS user plane paths (corresponding to multiple handsets on a femtocell) over the same secure tunnel can be employed. Header compression is another technique that can be used either independently or in conjunction with multiplexing to address the issue.

4.5 Self-Configuration

Network planning for coverage, capacity and RF interference management is a key aspect of pre-deployment optimization for macrocells. However, given the expected scale of femtocell deployments, it is not economical to extend the traditional methods of network planning to femtocells. Femtocells are expected to be installed by the subscriber without any notion of cell site planning. Self-configuration of femtocells is thus a critical function aiming at improving the coverage and capacity of the network while mitigating interference to the existing macrocell network as well as neighboring femtocells. Fault and performance management of femtocells is also required for efficient network management.

To overcome the challenges of configuration, performance, and fault management, extending the scope of the existing TR-069 standard to femtocells has been the preferred approach in the industry. International standards bodies are defining 3GPP- and 3GPP2-specific data models. These data models are maintained in the femtocells and the FMS and are exchanged using TR-069. They allow for automatically configuring femtocells as well as for fault notification, periodic performance reporting, and femtocell firmware management. The interference management issues and solutions highlighted in Section 4.1 require proper choice of radio parameter selection during power up. During initialization, the femtocells listen to the downlink radio environment of the neighboring macrocells as well as femtocells and share this information with the FMS to aid in the selection of femtocell configuration parameters. This ensures good network performance despite deployment without network planning.

5. WHAT'S NEXT?

The issues and solutions discussed in Section 4 focus on immediate topics related to femtos. This section introduces a few areas which provide additional benefits, especially as femtocells become more prevalent.

Roaming Support: Offering wireless access through femtocells to subscribers of a different network provider extends the usefulness of femtos. This feature is useful for all femtocell access modes (open, closed, and hybrid). The challenge lies in accessing the correct HLR in the context of legacy systems and correctly maintaining its subscription list.

Temporary Membership: Certain scenarios (e.g. wireless service at a hotel) call for a temporary membership in a closed subscriber group. A desirable solution for this feature avoids frequent messaging to maintain subscription lists and ensures reliable removal of the subscriber while in or out of service.

Local IP Access: With this new type of service, servers local to the femtocell can be accessed without routing the traffic through the operator's network. Thus, e.g., a media server, nanny cam, or home automation controller can be accessed directly from the handset. Similarly, it enables direct access to the Internet through an ISP while bypassing the CN. Solutions for this feature have been designed, though the mobility aspect and some regulatory hurdles remain for further study.

Remote Access: Analogous to the Local IP Access described above, remote access allows servers in the home network to be accessed by a handset in the macro network or in another femto. The security concepts need to be extended to provide adequate protection.

Enterprise Features: Femtocells provide attractive solutions for enterprise and hotspot environments. Closed subscriber groups on a corporate campus or a vacation resort might replace the wire line PBX and allow for a more cost-effective mobility solution. Satisfactory service depends on the introduction of features such as seamless handover from femtocell to femtocell, subscriptions limited to the enterprise area, and tailored OA&M functionality.

6. CONCLUSIONS

We introduced the concept of femtocells and reviewed how 3GPP and 3GPP2 solved the architectural challenges. While the solutions are similar between the two technologies, there are a few distinct differences due to the existing architecture in the 3GPP and 3GPP2 network.

While femtocells introduce a number of difficult challenges, there appear to be good solutions available to address these. Interference management techniques provide sufficient protection even in the unplanned deployment scenario used for femtocells. For existing handsets, most solutions for femtocell restricted access control have some drawbacks but provide adequate performance. Though, only new femto-aware handsets enable the full gain provided by femtocells.

One of the more difficult problems lies in identifying the correct femtocell in a handover scenario. Changes to the existing macro network are likely required to arrive at an efficient, reliable solution. The use of unprotected, public resources on the backhaul, namely a DSL or cable modem connection, introduces challenges related to Security, QoS, and bandwidth efficiency. Solutions in all these areas are available, even though some of them might still need to be standardized. Femtocell self-configuration is the solution to the subscriber-based deployment model. For effective self-configuration, a network listen function is required.

Femtocells are being deployed in various markets while the standardization is still progressing. There are several technical areas which require further study as outlined in Section 5. Nevertheless, when fully deployed, femtocells will result in orders of magnitude increase in area spectral efficiency, thus maximizing the return on expensive 3G licensed spectrum.

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