INDUSTRY PERSPECTIVES

FEMTOCELLS

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Femtocells, also known as home NodeBs (HNBs) or femto access points (FAPs), are low-transmit-power (100 mW or less) small-form-factor cellular base stations typically deployed indoors in residential, enterprise, and hotspot settings. Femtocells operate on licensed spectrum and provide voice/data service to mobile phone users by connecting them to the Internet and an operator's core network using a broadband Internet connection (e.g. ADSL, cable) as a backhaul. Femtocell users experience excellent voice call quality and near peak data rates due to improved radio frequency (RF) coverage. Cellular operators benefit from reduced infrastructure deployment costs that are otherwise needed for network evolution, including capacity upgrades and coverage improvements. In addition to coverage extension, femtocells offload traffic from a macro network and provide significant capacity gain by using the same spectrum multiple times over smaller footprints. This helps macro users to achieve higher throughputs since fewer users share precious macro network resources. Recognizing these benefits, different operators, vendors, and content providers founded the Femto Forum, which is a membership organization to develop femtocell technology and promote its deployment worldwide [1].

To minimize deployment costs, femtocells are typically deployed with minimal or no RF planning. This requires femtocells to be capable of self-configuring (self-organizing) in terms of choosing the available radio resources such as frequency (or time slots) of operation and scrambling codes (pseudonoise [PN] offsets) as well as their RF output power such that they create minimal interference to non-femto users (macro users and users belonging to other femtocells). Interference management on both the downlink (DL) and uplink (UL) is a key element to ensure successful femtocell deployments [2, 3].

CURRENT STATUS

The last two years have witnessed significant success in terms of femtocell deployments, consumer acceptance, and technological maturity. More than 10 major operators worldwide (e.g., Sprint, Verizon, and AT&T in the United States, Vodafone in Europe, Softbank in Japan) have commercially launched residential femtocell deployments, and more than 50 other operators are currently performing field trials [4]. In parallel, the Third Generation Partnership Project (3GPP) and 3GPP2 standards bodies have standardized wideband code-division multiple access (WCDMA)/Long Term Evolution (LTE) and CDMA femtocells, respectively. Some key technology aspects that have been standardized (or are currently under consideration) include:

- Overall network architecture to allow integration of a femto network with a macro network
- Access/authentication modes: allow femtocell operation in "open" (access for all users), "closed" (access to a limited set of users), or "hybrid" (mix of open and closed) modes to meet different deployment requirements
- Interference management and other self-organization techniques to ensure coexistence of femtocells and macrocells
- Operations, administration, and management (OAM) protocol to allow efficient management of large-scale deployments
- Femto awareness in handsets to support different femto access modes and efficient femtocell discovery when a user moves from macro to femto coverage, and enable new femto-zone services
- Local IP access (LIPA) and remote IP access (RIPA) to allow a user to locally or remotely access a home network (printers, multimedia servers, etc.) through a femtocell

These features enable true "zero-touch" femtocell deployment by the end-user.

Figure 1. *Caption*

EMERGING TRENDS

While the first phase of commercial deployments have firmly established 3G femtocells (WCDMA and CDMA) as the next performance leap in wireless communications, new trends have begun to emerge that point to the future evolution of this technology. LTE-based 4G femtocells will drive this evolution over the longer horizon. In addition to residential deployments, the next big wave of deployments is envisioned in the commercial/enterprise space. We briefly discuss some emerging trends next, with the main emphasis on commercial multi-femto deployments.

COMMERCIAL MULTI-FEMTO DEPLOYMENTS

Commercial multi-femto deployments are targeted at large enterprises, big-box stores, dormitories, malls, airports, and other public places. In addition to voice and data, commercial femtocells, which are also known as enterprise femtocells, are intended to support features like IP-PBX, LIPA, and quality of service (QoS). Like residential femtocells, commercial femtocells also have low power and small form factor. However, enterprise femtocells differ significantly from residential femtocells in terms of coverage planning and installation, interference management, and self-configuration as well as mobility management requirements due to the multiple femtocells typically required to cover an enterprise.

Coverage Planning & Installation — Enterprises can range from small offices to large offices with different floor layouts (e.g. walled offices, cubicles, large open spaces). As a result, some form of coverage planning and technician assistance (e.g., IT technician or operator) is recommended for enterprise installations akin to enterprise WiFi deployments. Based on the floor area of an enterprise and the coverage provided by a femtocell, which typically is ~5000–10000 ft^2 depending on the enterprise building structure and floor layout, a technician can choose the required number of femtocells. The technician can install them by distributing femtocells more or less uniformly in the enterprise to provide complete coverage. It must be noted that to minimize RF planning and installation effort with no special training for a technician, femtocells need to incorporate adequate self-configuration capabilities.

Interference Management and Self-configuration — Interference management and self-configuration is challenging in multi-femto enterprise deployments primarily due to:
- Significantly higher variation in RF conditions in an enterprise. For example, macro signal strength can vary in an enterprise by 20–30 dB.
- A larger contiguous coverage area may be required compared to residential femtocells.
- In "closed access" deployments (e.g., femtocell use is limited to enterprise users only), restricted users are more likely to come in the femtocell vicinity in enterprise scenarios and may experience DL interference from femtocells when femtocells and macrocells share same RF frequency channel.

In the UL, femto users at the edge of femtocell coverage can create interference on the macro UL. Both DL and UL interference issues can be mitigated by limiting the coverage of each femtocell to ~5000–7000 ft^2 and increasing the number of femtocells to cover a floor. Smaller coverage per femtocell significantly reduces RF leakage and therefore interference outside the building. Furthermore, interference management also requires a level of coordination to limit Tx power imbalance between neighbor femtocells. Large Tx power differentials should be limited to prevent DL-UL imbalance issues that arise when neighbor femtocells have very different coverage footprints. A technician walk in the enterprise is required to establish the femtocell coverage boundary and calibrate Tx power accordingly. UL interference to the macro network can be managed by limiting the coverage range of a femtocell so that edge users do not transmit at very high Tx power, controlling noise rise properly at the femtocell, and, if needed, by limiting the Tx power (and data rate) of edge users.

Mobility Management — Supporting user mobility across femtocells in an enterprise is critical to provide a seamless voice and data experience to users. This requires supporting inter-femto handoffs either using soft handoff (SHO) or hard handoff (HHO) between femtocells. As one would expect, SHOs can provide better voice call quality than HHOs primarily due to added diversity provided by SHO and network delay involved in HHO. Performance with HHOs can be improved by utilizing DL transmit diversity techniques (e.g., closed loop Tx diversity [CLTD] in Universal Mobile Telecommunications System [UMTS]) and optimizing network architecture such that handoff delays are minimized.

FEMTOZONE SERVICES AND APPLICATIONS

Future femtocells will support "femtozone" services and applications that enrich a user's digital life and also open new revenue streams for operators. Femtozone applications can provide location and contextual services such as alerting family members when someone enters a femtozone, changing handset profiles to prominently display productivity applications when in an office femtozone and display entertainment applications when in a home femtozone, and synchronize content between mobile and home media servers in a home femtozone. Apart from developing new applications, innovations in terms of data security, mining, and management of location and contextual information, and enhancements to LIPA and RIPA are needed to make femtozone services a reality.

INTEGRATION WITH HOME DEVICES

In the future, rather than standalone devices, femtocells are likely to be integrated with other digital devices such as ADSL routers, set-top boxes, and media servers. This will make femtocells the focal point of connecting a user's mobile device to other devices in the home from anywhere in the world.

SUMMARY

In summary, femtocells have ushered in a new revolution in wireless communications by providing significant coverage and capacity gains by efficient spectrum reuse. With baseline standards in place and further technology enhancements underway, femtocells deployments are envisioned to become widespread in both residential and enterprise spaces in the next few years.

REFERENCES

[1] Femto Forum, http://www.femtoforum.org/femto/.
[2] Femto Forum, "Interference Management in UMTS Femtocells," http://www.femtoforum.org/femto/Files/File/FF_UMTS-Interference_Management.pdf.
[3] M. Yavuz *et. al.*, "Interference Management and Performance Analysis of UMTS/HSPA+ Femtocells," *IEEE Commun. Mag.*, vol. 47, Sept. 2009, pp. 102–09.
[4] Femto Forum, "Informa Femtocell Market Status Q2 — June 2010," http://www.femtoforum.org/femto/index.php?id=69.