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CHAPTER 1
Femtocell Design

What is a femtocell? In the broadest sense, we can use the following definition: a femtocell is: a *low-power* base station communicating in a *licensed spectrum*, offering improved *indoor coverage* with increased *performance*; functioning with the operator's *approval*; offering improved voice and broadband *services* in a *low-cost*, *technology-agnostic* form factor. Here we have purposely stressed specific key descriptions to convey our message. With the intention of operating indoors, the femtocell will transmit with low power in an authorized frequency band. One of the many benefits of operating in an authorized frequency band is that the operator has the sole rights to utilize it. Hence, the operator controls who communicates in that band and can guarantee a certain level of QoS to all who are involved in occupying the private band.

Providing indoor coverage can be a difficult task, especially due to the propagation path loss of the outer walls of the premises as well as the inter-floor loss. These losses can aggregate to a considerable amount, thus making high-speed 3G data access indoors extremely challenging. Relying on a base station physically located a few kilometers away in distance is not necessarily the best method to effectively deliver high-speed data services to an indoor user—especially since these high-speed data services typically have lower progressing gain and/or use higher-order modulation, such as 64-QAM, to arrive at the high-throughput performance.

The small coverage footprint coupled with the friendly indoor propagation environment will create an atmosphere of high SNR to provide improved performance to support multimedia services at a reasonable price target. Finally, the specific RAT used to provide this feature is operator dependent.

More specifically, the femtocell concept entails using a low-power base station; a cellular phone; and broadband Internet access such as XDSL, cable, or fiber-to-the-home (FTTH). In the residential case all traffic would be routed through the home's ISP connection. This concept is used not only to extend and provide cellular service but also to encourage other applications. The femtocell is sometimes called a personal base station (PBS) or Home NodeB (as referred to in the 3GPP standards body) [1].

This chapter will provide an introduction to the femtocell concept. We will discuss the impact on the complexity of the handset design, specifically with respect to cost, size, and power consumption. We will include a summary of the market evolution and the trends leading to the use of femtocells. Typical usage scenarios will be exercised such as home, friend's home, or party scene. We will also describe some expected applications.

Incorporating the femtocell into a home environment or small-office scenario will open a wide variety of opportunities. Traditionally, the home wireless applications have been less complex, with the exception of WLAN-related options. However, home cordless phones, wireless remotes, etc., have been not only less complex, but also easy to use and feasible for cost, risk, and other reasons. Placing the femtocell into the home will allow users to benefit from the many wide-ranging and highly complex multimedia applications available within the cellular handset sector. As time progresses, it is easy to point out the increased complexity and computing power within these cellular phones, which confer on them bragging rights as being one of the most complex consumer devices in the home. In fact, cellular phone manufacturers are moving their business plans to provide wireless applications to their respective handset platforms, such as Apple, Nokia, Google, and Microsoft.

1.1 The Femtocell Concept

Year upon year cellular service providers struggle to plan for subscriber growth. In order to be prepared for this inevitability, service providers analyze various cell site deployment options. In heavily congested areas the solution has followed a theme to reduce the inter-site distance and provide micro- and even pico-cellular service.

While providing superior system quality of service (QoS) performance, improving cellular coverage is absolutely pertinent, although it can be a daunting task when one tries to satisfy not only the outdoor and highly mobile user but also the indoor and leisurely mobile user. The wireless user will encounter a vastly different experience due to the physical nature of the propagation phenomenon.

It is well known that the lower frequency bands have better propagation characteristics than the higher frequencies and will allow signals to penetrate buildings to reach the indoor users. Moreover, the lower frequency bands improve the link budget, thus allowing the use of higher-order modulation, lower processing gains, etc., which results in higher data throughput to the user. This is part of the reason for the almost absolute about-face from the technology providers racing toward the higher frequency bands to their attempting to revive the lower-frequency bands such as 450 MHz and 700 MHz.

The femtocell or personal base station concept is realized when a cellular service provider places a base station in the home to not only provide better indoor coverage but also to alleviate traffic from the public macrocells. Hence as a user enters his or her home, the cellular phone will recognize the presence of the femtocell and then register to it. This will alert the public macrocell that any further communication to this user will be via the home ISP network. In this case, your cellular phone can behave as a traditional cordless phone; in other words, in addition to its typical cellular traffic, it will now see the traffic from the home usage.

The Femto user is still accessible by the cellular service provider but has freed up resources in the public macrocell that can now be used by additional users that are physically located outdoors. In doing so, the service provider must allow access into their private core network to provide the capability of sending user traffic to the home. This access is provided in the form of a gateway, specifically a femtocell gateway. This provides a dual benefit. First the network operator can now alleviate a fraction of their backhaul traffic to the ISP network. This freed-up capacity will be easily consumed by new users entering the network. The second benefit is to the end user—a higher data rate link can now be established to your phone. Now here is where it gets exciting: a higher data rate will ignite an influx of creative applications to be written for target cell phones.

In Figure 1-1 we show a sample network overview of the femtocell deployment. The homes are expected to have a broadband modem

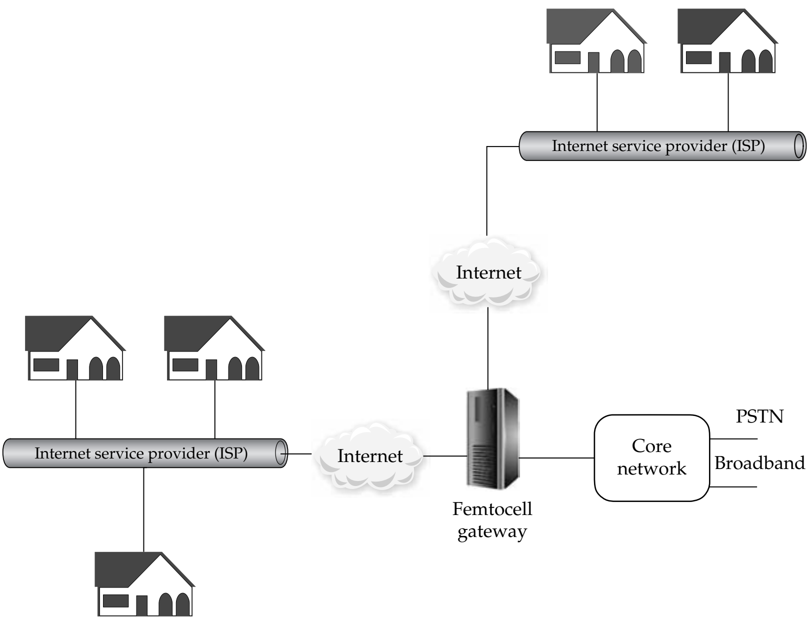

FIGURE 1-1 Architecture overview of a femtocell network

connection (i.e., XDSL, cable, or fiber) through their Internet service provider (ISP) to the Internet. The cellular specific data will be funneled through the femtocell and enter the femtocell (mobile) gateway for access back into the cellular network. For the Third-Generation Partnership Program (3GPP) network, the gateway would interface to the core network; this interface is called Iu-h.

We have also shown the cellular core network accessing the public service telephone network (PSTN) for voice services and a broadband interconnect for data services. As the core network evolves into a packet network, all traffic will be IP based, thus allowing for a convergence of services.

Cellular phones are sold for operation within specific frequency bands, since these phones are meant to operate in private frequency bands for particular cellular service operators. What this means is that the femtocell will not be allowed to transmit in regions where the service provider doesn't have service nor the rights to that particular frequency band. The owners of these licensed frequency bands are responsible for ensuring emissions satisfy the respective regulatory requirements. Hence, knowing the geographic location of this femtocell is extremely important. This is one particular reason that the femtocells have GPS capability: in order to report back to the cellular service provider the exact location the user is intending to power *on* the femtocell. This will supply the service provider with control needed to restrict the femtocell's operation. Moreover, knowledge of the geographic location is also used to support emergency services, as well as lawful interception and a host of other reasons. We wish to quickly follow up by noting that GPS is not the only method available to provide location information; service provider IP addresses and other means are also available. We believe a combination of all of these will lead to an accurate and satisfying experience.

We have thus far not described the use of the public ISM frequency band, meaning WLAN is not included in this definition. What we have discussed thus far is a system employing the cellular (or wide area network, WAN) RAT, and not one from the personal area network (PAN) such as Bluetooth or the local area network (WLAN or WiFi) such as IEEE 802.11, although VoIP traffic over WLAN service is increasing, especially with the introduction of the iPhone. We believe these WAN and PAN services will continue to coexist, since they solve specific issues and provide services that are sometimes orthogonal in nature to one another.

Cellular service providers have paid exorbitant prices for the regional licensed spectrum; hence, they have the legal rights to use the spectrum. Moreover, from one service provider to the next the spectrum properties (bands, regulations, etc.) differ not only nationally, but also from one country to another. For naming purposes, the network used in the femtocell will be called the *private* network, while the network used for typical cellular communications will be called the *public* network. This naming convention will be used to aid the descriptions that follow.

In Figure 1-2, we show the possible combinations of the private and public networks. Here the public macrocell is shown by a single, large oval coverage area. Within this area we have specifically drawn four Home NodeBs (HNB), using the 3GPP nomenclature. They are identified as follows:

- HNB-A is geographically located near the macro-NodeB.
- HNB-B is located near the cell fringe.
- HNB-C is located in an area where cell coverage is spotty.
- HNB-D is co-located with HNB-B.

Please notice we haven't differentiated between the private and public network user equipment (UEs), since they should be able to seamlessly travel within their respective networks. Next we will discuss each of these geographic locations.

The HNB-A position is located near the public, high-power NodeB. If the macrocell is using the same frequency band as the private cell, then the downlink of the private and public networks can see an increase in interference. As a result of this increase in the downlink interference, UEs located within the HNB-A coverage will see a degraded downlink from the public macrocell. When moving indoors, however, the public macro-signal becomes attenuated by the factors already discussed, whereas the indoor private femtocell signal is increased. Here the outermost wall is used in a positive manner and extremely welcome. This wall will not only attenuate the signal entering the home from the public cell but also attenuate the signal exiting the home from the private cell to help reduce downlink interference within the private and public networks, respectively.

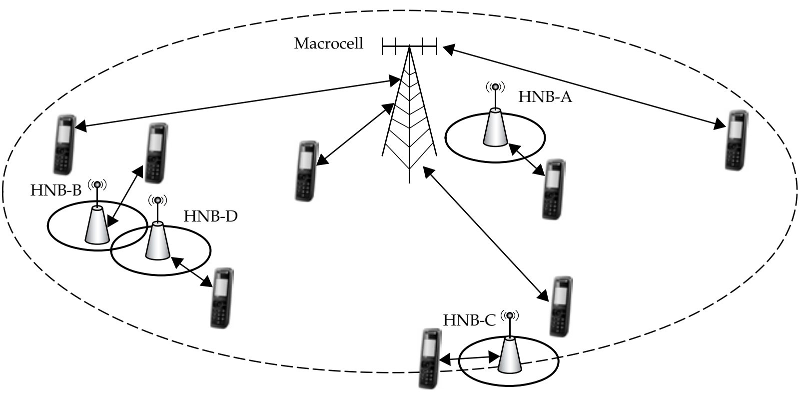

FIGURE 1-2 Femtocell (Home NodeB) interactions with macrocell

The HNB-B position is located near the cell edge. If the macrocell is using the same frequency band as the private cell, then we would generally expect to have smaller downlink interference due to the increased propagation loss on the downlink. In this scenario the use of the femtocell has increased the downlink throughput due to the better SNR of the femtocell compared to the public macrocell offering. However, the UE is located at the macrocell edge and will transmit with higher power than the UE associated with the HNB-B. Here the HNB-B uplink will experience a larger rise in interference, since the two UEs are not both associated with the HNB. Here interference mitigation techniques should be applied carefully so as not to allow an increase in the HNB transmit power to overcome this shortcoming, since closed loop power controlled systems have the potential to be unstable (or closely approach it, thus requiring QoS intervention).

The HNB-C position is located at the cell fringe, where we have included the possibility that cell coverage can be nonexistent. If the macrocell is using the same frequency band as the private cell, then the downlink interference is expected to be small, but the uplink can be significant, depending on the location of the public UEs. In this case the femtocell has increased the cell coverage and also improved the available data rates to the end user.

The HNB-D position is located near HNB-B, where we have purposely needed to include interference generated by neighboring femtocells operating in either the same frequency or adjacent frequency. Here both femtocells experience uplink and downlink interference from the macrocell. We must note for multiple cases, however, that the interference from HNB can now deteriorate performance of users in the macrocell. Hence users operating near a few hundred HNBs, for example, may experience some sort of performance degradation within close proximity. The 3GPP standard's group is working diligently to minimize this occurrence.

Although this single-cell example was used to convey the potential interference the femtocell would need to overcome, similar issues arise when multicell deployment scenarios are considered. Finally, when the adjacent frequency bands are considered, interference issues still exist and should be carefully planned. Let’s consider the apartment complex scenario where many users are operating within the building and potentially the adjacent complex. Users associated with the macrocell can easily have degraded performance not only outside but also indoors due to the rise in co-channel interference (CCI).

To fully support the femtocell concept, a few components need to be defined: personal base station, handset, ISP, gateway, and cellular network. Figure 1-3 provides an example of a single femtocell architecture. Here we have a single UE communicating to the HNB, which has a coverage area that can extend slightly beyond

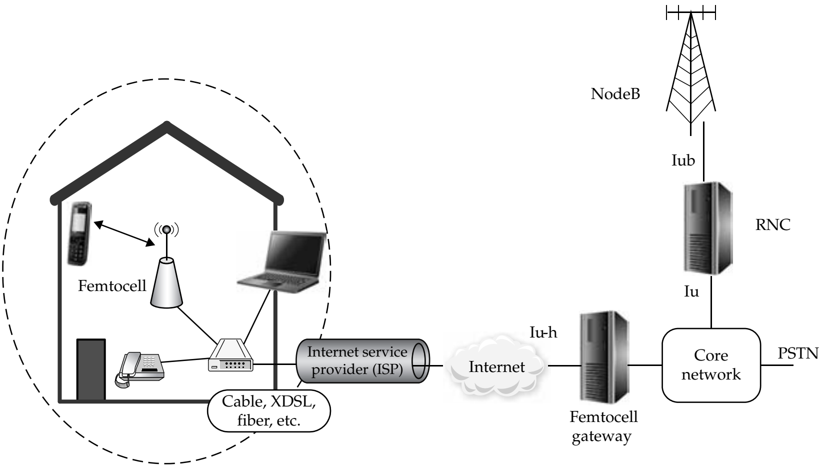

FIGURE 1-3 Femtocell architectural components

the home premises. This HNB plugs into a broadband modem to access the Internet. Access back into the cellular network is available through the femtocell gateway. We have also drawn upon the fact that many users currently get their dial tones via the IP packet network. Also, home desktop computers are connected via a broadband modem to high-speed Internet access.

1.1.1 Market Overview and Direction

At the time of writing of this book, there are many companies providing a partial or complete lineup of femtocells solutions. Here is a small sampling: chipset providers such as Picochip; service providers such as AT&T, Verizon, Orange, Telecom Italia, Telefonica, and T-Mobile; and manufacturers such as Samsung, Motorola, and Nokia.

A high-level block diagram of the implementation components of the Home NodeB is shown in Figure 1-4. A HNB can be a separate "box" that would essentially connect to the broadband modem, or the modem functionality can be integrated.

Homes will also need telephone lines for already available corded and cordless telephones; hence, the RJ11 connection is available. Home security systems can use this method as well. The broadband modem can connect to a WiFi access point or router to allow other devices such as a desktop computer to access the Internet. Also, many homes have WiFi service; hence, this can also be a separate box or have this functionality integrated as well. Many options exist, and we believe the variable worth optimizing is cost when considering initial deployments.

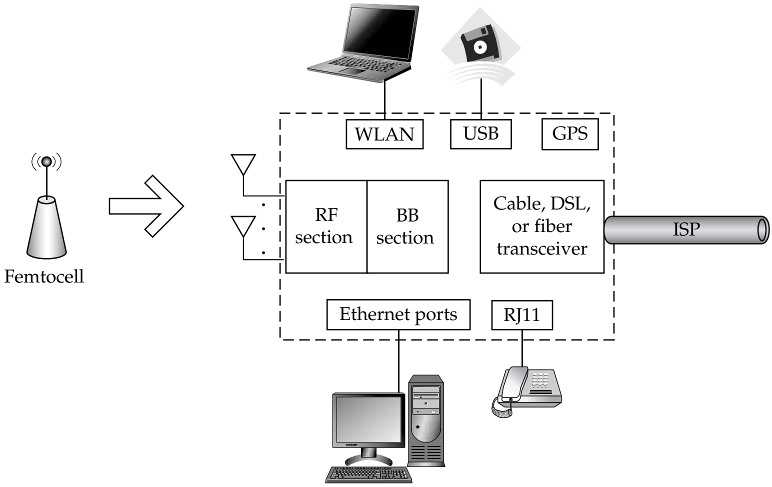

FIGURE 1-4 Home NodeB components

A long-term strategy should also be considered. One obvious solution would be the integration of WLAN protocols such as 802.11a, b, g, and n. We expect and hope the integration would provide an overall cost advantage. One point worth mentioning is the rate of evolution of the various technologies integrated. For example, the WLAN standards have been evolving at a faster pace than cellular. If not carefully studied unnecessary limitations can be imposed on consumer product roadmaps.

1.1.2 Insights into the Cellular Roadmap

The intention of this section is to give the reader insight into the evolution of the cellular radio access technologies (RATs) such as GSM, WCDMA, and LTE. These standards are evolving in order to reduce end-to-end latency, provide packet services capability, increase the data throughput, increase user capacity, etc.

In Figure 1-5 we plot the data rate (in Bps) versus the spectral efficiency (in Bps/Hz) for the various RATs. There is a clear trend toward increasing the spectral efficiency as the standards evolve. We have chosen to display the reference deployment information when comparing the overall cellular roadmap.

Spectral efficiency can be used to further calculate user data rate, throughput, or even system capacity, which then justifies our reasoning for choosing the performance metric. This figure shows us WCDMA offered some performance improvement over GSM and further improvement when HSPA was deployed. Here Higher-Order Modulation (HOM), as well as other techniques, was used to produce this improvement. Even further improvements can be seen with the introduction of Long-Term Evolution (LTE).

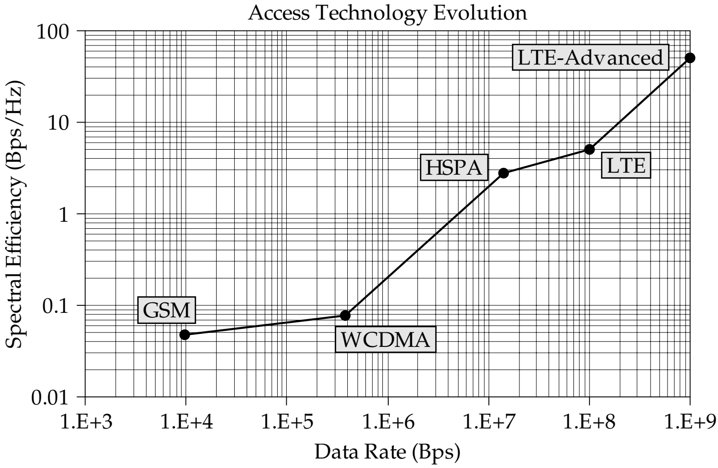

FIGURE 1-5 Cellular radio access technology evolution

In Figure 1-6 we compare the respective evolutionary paths of GSM, WCDMA, and LTE. For example, GSM is evolving to GPRS, EDGE, and EDGE Evolution. This migration is shown along the leftmost straight line in the figure. Next WCDMA is evolving to HSDPA and HSDPA-Plus using higher-order modulation schemes, MIMO, and dual-carrier techniques. Finally, LTE has evolved to LTE-Plus using increased MIMO techniques and then to LTE-Advanced.

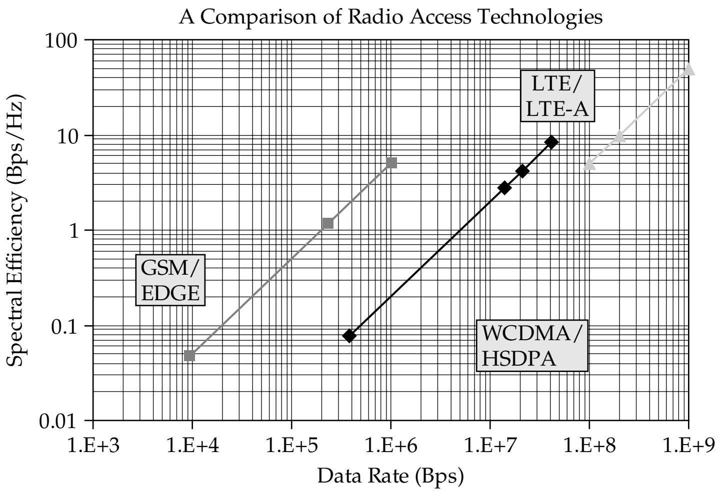

FIGURE 1-6 Comparison of cellular radio access technologies

1.2 Femtocell System Benefits

The femtocell concept will bring forth many questions on performance, use cases as well as benefits. Next, a list of expected benefits to not only the user, but also the network provider will be reviewed [2].

1.2.1 Typical Deployment

In this subsection we will outline the items to consider for a typical deployment.

The femtocells are allowed to transmit in certain frequency bands. Service providers have purchased large chunks of frequency bands for large sums of money. These frequency bands are referred to as *licensed* bands. This operational scenario is very different from the well-known WLAN case, which happens to use the unlicensed bands (ISM bands of 2.4 GHz and 5 GHz, etc.).

It is commonly accepted that a significant portion of cellular phone calls are started from within buildings. Hence we should consider cases when phone calls (or traffic sessions) initiate indoors and then eventually may need to be carried over to the outdoor public macro-network. In this case a hard handoff is made from one cell to another. Similar reasoning can be applied in the opposite direction, where phone calls were originated outdoors and then enter the femtocell coverage area. It is expected that the phone call (or traffic session) would hand off into the private network in order to gain the expected performance improvements.

Increasing the number of macrocells in a network is expensive. Pushing part of the network build-out to the end customer can alleviate some of the operator costs; however, for a deployment to be considered successful, millions of customers should be using the service. Hence the operators should have a good plan to support many HNBs and their associated UEs.

How Will the User Configure the Femtocell?

After turning *on* the femtocell, do we rely solely on the GPS signal to obtain the femtocell geographic coordinates to be transmitted back to the cellular network to identify if this femtocell is indeed in a valid area? This may very well be the case, but it is worth mentioning that the access IP address and/or cellular neighbor cell list can also be used to help with HNB authentication and registration. We believe a combination of the above or others will lead to an accurate indication of location.

How Will We Address Open vs. Closed Networks?

Next, we briefly describe the concept of open and closed networks. Open networks essentially allow anyone near the femtocell access to it, while closed networks do not allow any UE to connect to the femtocell unless the UE has permission from either the home user or network provider. This enables the home owner and the service provider to control what users can access their network. Initial deployments are expected to be closed networks. They allow for a more controlled version of the initial deployment. Moreover, one should also consider the situation of when the indoor users have been addressed, the next logical step would be to allow the HNB coverage zone to extend to the outer sections of the home premises to accommodate pedestrian traffic. This will surely require open network deployments. Moreover campus and/or small business style scenarios would benefit from an open network.

How Do We Add More Users to the Femtocell in the Home?

Will users have a special user interface to identify that a home network is nearby and to ask for permission? This will be a truly personal experience.

When you come home and hand off to the femtocell, then your cellular calls and home calls should be sent through your home femtocell. Is there an audible signal or user interface (UI) icon that indicates the call is from the cell or POTS?

The typical femtocells have emerged with the capability to support up to four simultaneous users within the home or small office. This will support both voice and data traffic. It is envisioned that as time progresses the capacity of the femtocell will increase with the continued introduction of advanced receivers for both the handset and the NodeB. Last but not least, having a better understanding of the interference problems and in turn the interference mitigation techniques will also help toward increasing capacity.

Control should ultimately go to the service provider, since it is their spectrum being used. Having a femtocell that will automatically configure itself (scrambling codes, frequency, etc.) is desirable and an integral component to the interference mitigation. The optimal approach, from the service provider's perspective, is to not perform additional radio planning and network dimensioning every time a new femtocell is sold. In fact, a network that is self organizing (SON) is highly desirable.

Migrating from legacy RATs, such as GSM, to newer systems using LTE is interesting. Various options can be considered here. First, the application of LTE to femtocells can be an excellent introduction to the RAT. However, this means that the UE must be available and not only support LTE, but also WCDMA and the expected GSM services as well. As with any new technology introduction, initially the power consumption will be more than is desirable, and size may be an issue. Once system measurements are collected, we would be able to observe improvements in the network that should result in better overall customer satisfaction.

1.2.2 Advantages to the Femtocell User

In this section we outline the envisioned femtocell benefits to their users. Placing the femtocell indoors in either a home or small office environment will unleash a great potential to the user. The following is a list of expected benefits to the femtocell users.

- **Simple deployment** It is advantageous to simplify the user's involvement in setting up the femtocell deployment in the home or small office environment. This reduction in complexity should assuredly lead to an increase in the probability of a successful deployment.
- **Increased user throughput** With the user physically close to the femtocell, a reduction in block error rate (BLER) is certainly possible, as well as expected. This would increase the average data throughput to the user, opening up possibilities. As is well known, users closer to the NodeB will enjoy higher throughputs than those closer to the edge of the cell.
- **Improved indoor coverage** Placing the femtocell indoors would alleviate the concern to include an additional 10–15 dB of loss into the system link budget. Hence, depending on the location of the home or small office with respect to the public macrocell, in-building coverage can be an issue. Moving a low-power NodeB indoors will extend the cellular footprint of the service provider, and the user would benefit from this. From the public macro-perspective, propagating through walls is undesirable, but required. However, from the point of view of the femtocell, using the walls to keep the interference inside and attenuate it outside is an extremely good property.
- **New applications** Having a convergence of mobile and home-based devices will lead to a wide variety of new applications for the user. These applications are applicable to both home and small office environments. As phones continue to allow for open applications development, unlimited personal and professional uses arise. For example, to provide the ability to use the femtocells to support electronic medical devices (such as electronic bandaids and EKG meters) and allow such information to be routed to the medical community should accelerate this nascent field.
- **Reduced power consumption** The user will no longer need to transmit with high power, since the femtocell is located near the user. This will translate into smaller current drain from the battery, resulting in longer standby times and increased talk times.
- **Enhanced multimedia/IP services** Allow the user to have an enhanced experience with videos, home services, phones, computers, etc.
- **Improved voice quality** Having the user so close in proximity to the femtocell will provide a better communication link. This will allow the use of better-sounding, higher–data rate speech vocoders to be used.

- **Security** Since the femtocell's connection is via the public ISP and traffic will be routed to the private cellular network, the user must authenticate himself to the network; the service provider can use IPsec. The users can rest at ease knowing that personal or professional information will be secure.
- **Improved customer satisfaction** With benefits of improved indoor coverage and high throughputs, service providers expect the user to have a satisfying experience.
- **Business** With the current direction of cellular phone applications, it is conceivable that owners of these private femtocells can have specific applications that would allow such users special privileges and could possibly bypass the public macrocell for certain scenarios. As a related comment, the near-term femtocells accommodate up to four simultaneous users.

Among other areas of concern to femtocell users, let us outline the following:

- **Billing** This has the potential to be devastating to the femtocell user. Here the user will receive a separate broadband connection bill, possibly from the cable or telephone company rather than the cellular service bill. Moreover, the cellular service bill will now have additional costs of using the femto service. Service providers will be faced with difficult decisions on whether to charge users on a call origination basis or use another more creative approach such as a flat monthly rate. We believe the basic operating premises should be low cost and clarity. Piling on additional costs, charges, and fees to femtocell users has the strong potential to slow adoption of this service. Similarly, delivering a confusing payment plan can be disastrous.
- **Measurements** For the scenario when many femtocells are deployed, the UE connected to the macrocell will not only be able to make measurements on the macrocells, but also the many femtocells it encounters. There is a potential negative side effect that the UEs in this particular femtocell area will report back many measurements to the public network that may or may not be useful for certain configurations. The UE can potentially make many more neighboring cell measurements, which can in turn overwhelm the core network with the reporting of such measurements.
- **Home resources** Depending on the level of integration, a few boxes may be needed to complete one home. In doing so, more of your home's real estate area has been taken up, not to mention the additional electric power bills to supply energy to those boxes.

1.2.3 Advantages to the Network Provider

In this section we outline the envisioned femtocell benefits to the service providers. Placing the femtocell indoors in either a home or small office environment will open up great opportunities to the service providers. The following is a list of expected benefits to these operators.

- **Increased revenue** An increase in the average revenue per user (ARPU) would occur when both the number of users in the network increases and the monthly revenue increases. Having the femtocell capability with the service provider would hopefully attract additional users. Moreover, the femtocell application can be viewed as an additional feature/service, not currently covered under your contract, in which case the service providers would be able to charge the user for use of the service.
- **Reduced cost** As the service providers strive for increased coverage and capacity, the network complexity grows, and unfortunately with this so does cost. Shrinking the public cell size from macro to micro and then to pico has its capacity benefits, but it adds to network costs (deployment, maintenance, backhaul, recurring expenses, site rental, etc.). Using an already-available network such as the Internet, cost reduction is certainly feasible, given the communications move to the all-IP-based structure. Having said this, it is expected that this cost savings will eventually make its way to the end user.
- **Increased capacity** Having users currently connected to the public macro-network move to the private femtocell would open up physical resources (frequency, time slots, scrambling codes, etc.) so that others can connect with the public cell, while still maintaining the present customer base. This will increase the numbers of users in the system overall.
- **Improved indoor coverage** Service providers have for the longest time struggled with coverage, especially indoor coverage using a public macrocell NodeB. Placing the femtocell indoors will extend the coverage region of the provider, since the additional 10–15 dB required to penetrate the building walls and floors would no longer be needed. In fact, under ideal conditions, the service provider should take these no-longer-needed dBs and use them to provide a higher cell throughput.
- **Enhanced services** Using the user's access to the Internet, the service provider can reveal enhanced services tailored around the user's phone, cellular network, and home, hopefully to improve the user's efficiency and quality of life.
- **Compete with other convergence technologies** Currently, the most effective and commonly used RAT to access the Internet from the home environment is via the WLAN.

As cellular technology data rates improve, this would hopefully allow users to also use the cellular network to transfer data, in addition to the voice and multimedia traffic expected.

- **Product differentiation** When considering the stiff competition among cellular service providers, the option or capability for this femtocell service along with the cell phones is a great product differentiation.
- **Improved customer satisfaction** With benefits of improved indoor coverage and high throughputs, service providers expect the user's expectations to be satisfied.

It is interesting to consider how ISPs will react to cellular service being carried over their networks if they don't reap the financial benefits. A few service providers that provide cellular and broadband service to homes will find that this easily supports the quadruple-play service model. For the rest of the world, a different picture emerges. Broadband providers have collaborated to bring forth WiMax services, while almost simultaneously outdoor WiFi hot spots have appeared offering low price points to attract and potentially keep wireline customers.

Among other areas of concern to the cellular service providers, let us outline the following:

- **Business** With the current direction of cellular phone applications, it is conceivable that owners of these private femtocells can have specific applications that would allow such users special privileges and could possibly bypass the public macrocell for certain scenarios. As a related comment, the near-term femtocells accommodate up to four simultaneous users (with long-term targets in the neighborhood of 20 users). The concept of a public femtocell will be interesting.
- **Measurements** For the scenario in which many femtocells are deployed, the UEs will report measurements not only from the macrocells, but also from the many private femtocells. This may present a need to increase the measurement processing capability of the network.

1.3 Handset Impact

In this subsection we will address various hurdles, issues, and questions related to the impact of the femtocell scenario to the complexity of the already-complicated handset. The handset has been riding the waves of improved battery life, reduced size, and enhanced features (such as multiple cameras and displays), and it would be a shame if this femtocell capability would be disruptive to this progression rather than an enabler. Whenever possible, the associated issues surrounding the femtocell will be discussed in order to provide a more complete picture of the system issues. Our intention is to also provide a non-polarized viewpoint to the reader.

The first question we would like to address is: Does the phone need to be modified?

We believe the best match would be to have a cellular phone that is femto-capable. By this we mean it is aware of the special femto environment and can therefore perform as well as support specific features that are amenable to the home or small office application. Having a small icon letting the user know it is now in its home network is a powerful awareness tool. After all, this has been done for 3G and is expected to be used for LTE and so on.

Some femtocell adoption strategies have been to load a web-based application on a home computer that would allow additional users to join your home private network as guests. This would mean for every new visitor, you would need to walk over to the computer to allocate the necessary permissions. It is conceivably a better situation if the home user's cellular phone would have this application embedded into the handset as well, to give more flexible control over not only adding new users, but also removing them as necessary. Moreover, it would allow the home user to exercise some preference over which users are allowed and which are not. Recall the early femtocell models allow up to four users, which is extremely limited when the home is hosting a family gathering or having a celebration.

When we view this femtocell scenario, the following additional features should be located on the phone:

- **Display icon** Having an indicator that tells the user whether she is on the private cell or the public cell is important. If any features associated with the private network have a financial impact, the end user would like to verify its operation.
- **Audible beeps** If cellular phones will be used in the home as some evolved cordless phone, a habit must be overcome of looking for the second phone. When a cellular phone is in the private cell and receives phone calls from the private network for the home, a special ring tone, audible beep, or other signal should be used to alert the user of the type of phone call she is about to answer.
- **User interface for femto-control** Having the private UEs with control capability is an excellent feature. Because of the above-mentioned interference concerns, it would behoove the home or small office private network to allow certain users to connect to its network. Similarly, there may be times when certain UEs should be forced off the private network when others of higher priority return to the network.
- **Preference setting for hand-offs** Just as cellular phone users can now select 2G versus 3G preferences, it would be beneficial to offer the same capability to the femto users as well.

- **Femtocell quality indicator** For the scenarios when many femtocells are deployed, the femto user may want to have an interference or quality picture (snapshot in time) of the present situation. This parallels the advanced uses of WLAN scenarios we currently see in the market.
- **Applications** The femtocell is an excellent opportunity to mix certain home applications that would otherwise potentially use WLAN technology. Applications that utilize multimedia in the home are extremely valuable and meant to increase the user's experience.

Other features will doubtless find their place.

1.3.1 Complexity Discussion

The impact of the deployed frequency band to handset complexity is specifically visible when receive as well as transmit diversity is used. The physical location of the antennas becomes more important as we lower the frequency band of operation. This arises from the spatial separation requirement to obtain close to uncorrelated waves at each of the receiver antennas. For certain multipath environments, this minimum separation is on the order of half of a carrier wavelength.

The initial deployment of the LTE RAT is expected to be around the 700 MHz frequency band range. However, worldwide service demands do vary.

The frequency synchronization or frequency stability is standardized by 3GPP and chosen to be 0.25 ppm [3]. The HNB manufacturer has a few options in order to achieve this stringent goal. One is to use the GPS signal itself to derive a stable clock. Since the GPS is envisioned to be used in the femtocell configuration and authentication phase, this seems like a reasonable approach. Please be aware that any satellite-based location service works best when line of site is available. In other words, placing the GPS receiver close to a window or open space would be favorable. A second technique is for the femtocell to have a UE receive option that it can use to demodulate the macrocell DL in order to lock onto the 0.05ppm clock stability of the macrocell. In this case the manufacturer would then schedule periodic measurement intervals where the HNB would monitor the public cell for frequency stability reasons [4]. In fact, this can be carried further to also demodulate the broadcast channel to extract useful network information from the surrounding public cells such as scrambling codes, etc. This information can be used in an interference mitigation algorithm to control and/or reduce neighboring femtocell interference.

Various other options exist such as combinations of Internet clock synchronization and purchasing of tighter crystals such as Temperature Compensated Crystal Oscillator (TCXO) as well as other more expensive components. But please be aware that crystals have an aging specification that should not be ignored if the user is expected to have the femtocell for more than a few years. In any case, all techniques have a certain cost associated with them and can be used in the product differentiation aspect of the femtocell. More details surrounding the 3GPP performance requirements will be supplied in later chapters.

1.3.2 Dual-Mode Designs (WLAN + Cellular)

With the tremendous success of the WLAN technology, it is only natural to suggest a network or a service that would make use of this not only technically but also from a financial perspective. Many homes, coffee shops, airports, parks, and other public places already offer such free and/or pay WLAN access. In order to address this comment, we will briefly look at the potential of a handset with not only the cellular (i.e., femtocell) capability, but also the WLAN as well.

Figure 1-7 shows a simple block diagram of the so-called dual-mode handset operating in the expected usage scenarios.

Our discussion will center on the following items:

- **Complexity** The additional handset complexity will be seen from both the hardware and software perspectives. First, the cellular platform will need to support the WLAN (i.e., IEEE 802.11a/b/g/n) features. The exact protocol a dual handset must follow to scan for available WLAN or public cellular networks is not fully defined by either standards group. In fact, this would deserve special attention, since this would affect performance. Moreover, the additional measurements required for supporting handoffs from one RAT to another, etc., should be considered. This complexity can lead to longer design, development, and manufacturing time lines, all leading to longer time to market.
- **Cost** Additional chipsets are required to support this WLAN functionality besides the cellular chipsets. These chipsets should make use of the combination of other RATs such as

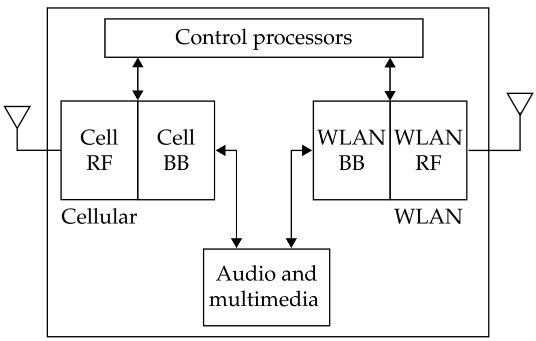

Figure 1-7 Dual handset usage scenario

GPS, BT, FM, and DVB-H. The addition of such features can preclude entry into the low-tier market sector. To some extent this is already being seen with the adoption of the iPhone on the Asian markets.

- **Battery life** Based on the upper-layer protocols chosen, having the handset periodically scan for either cellular (both public and private) or WLAN service will create a drain on the battery current. This has the potential to significantly reduce talk time and stand-by time in the dual-mode cellular handset, especially when both of these operations are occurring frequently. This would negatively impact the marketing of such cellular phones and hurt overall competition and product differentiation. There are many potential solutions to this conundrum. For example, if GPS is used the coordinate can be collected to trigger the WLAN searching capability. Similarly the indication that a femtocell is near can also be used to assume a WiFi access point is not far away.
- **Availability** When compared to the entire handset population, the dual-mode capability has a limited selection of handsets. As time progresses, this limitation will surely be lifted and users will have more options. From the handset perspective, as the adoption of Open OS continues to proliferate, the dual-mode landscape will surely change.
- **Mobility** Having the dual-mode handset will allow users to operate in environments that support either WLAN or cellular. We use the phrase "or" because an original motivator in dual-mode handsets was reducing the cost to the end user; however, with the continually dropping costs of service providers, this motivation may need to be revisited, albeit on a case-by-case basis. Moreover, with the improved coverage of cellular service in airports, libraries, etc., the landscape is continually changing.
- **Performance** Special attention should be paid to the overall use cases, especially to concurrent scenarios. Having a phone simultaneously perform the following functions is challenging: receive an MM message via the cellular system, use GPS to update/track position on a map, have WLAN download a web page, and have BT send audio to the earpiece. The processor speeds on a cell phone are lower than laptops and desktop computers (albeit the gap is becoming more and more narrow every few years). Hence the users should not expect the same throughput performance as observed on a computer.

A service that currently exists and can be viewed by some as a complimentary service to femtocells involves WLAN technology. Service provider A can have WCDMA femtocells, while Service

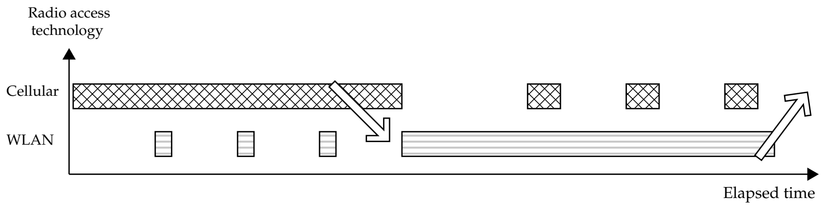

Figure 1-8 Dual handset monitoring example

provider B also has WLAN. Service provider B would be able to support handoffs to and from the cellular network.

Figure 1-8 shows an example where the UE is operating on the cellular service and has the WiFi periodically awakened to scan for WiFi. Once WiFi has been found and/or other criteria have been met, then UE can connect to the WiFi service and have cellular periodically awakened to scan for public and private cells. As discussed previously, the periodicity as well as the exact triggering mechanism is considered to be part of the product differentiation picture. It suffices for now to note that the scanning frequency has a significant impact on the overall battery life.

1.4 Femtocell Applications

In this section we will review some of the common expected usage cases for the femtocell users.

1.4.1 Home Usage Models (Femtocell Architecture Overview)

We next provide an introduction to the Iu-h interface between the HNB and the HNB-GW in the 3GPP standard. Figure 1-9 provides a femtocell network architecture diagram along with the functionality partitioning suggested. Where HNB is used to denote Home NodeB, HNB-GW reflects the Home NodeB gateway operator, CN is the core network, and H-UE is the UE connected to the Home NodeB.

Near each entity we have listed several functions performed in each block. Pushing the radio resource management (RRM) functions to the edge of the network is a strategy to not only reduce system cost but also support increasing user capacity. Here we also see the gateway services to authenticate and register not only the UE, but also the HNB.

1.4.2 Femtocell Protocol Overview

The interface defined between the Home NodeB and Home NodeB gateway is named Iu-h [5], [6], and [7]. An overview of the protocol is provided in Figure 1-10, where the user and control planes are highlighted. In this configuration both circuit-switched (CS) and packet-switched (PS) data streams are supported.

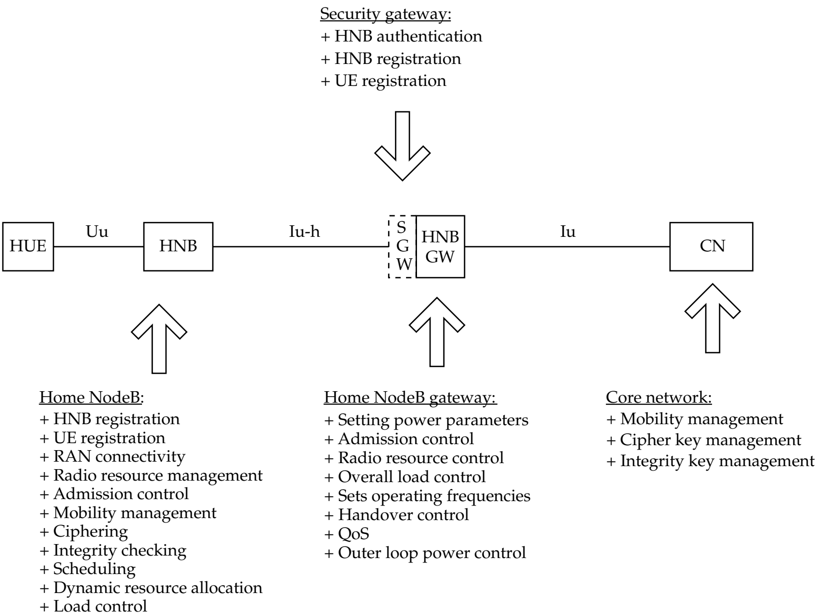

Figure 1-9 Femtocell network architecture

The protocol elements shown in Figure 1-10 will now be defined.

The UTRAN functions consists of radio access bearer (RAB) management, radio resource management (RRM), Iu link management, mobility management, and security, as well as other functions.

The HNB functions consist of HNB registration management, UE registration to the HNB, Iu-h management, etc.

The Radio Access Network Application Protocol (RANAP) is used in the control plane of the stack between the UTRAN (RNC) and the CN, specifically the Iu interface. This can be viewed as the control plane signaling protocol.

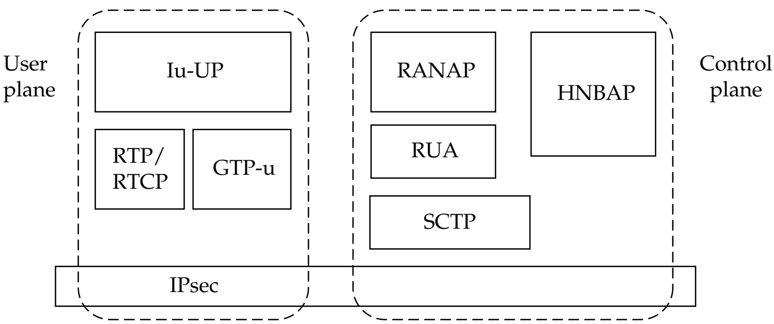

Figure 1-10 Home NodeB Iu-h protocol overview

RANAP user adaptation (RUA) supports HNB and HNB-GW, error handling, etc.

The Home NodeB Application Protocol (HNBAP) supports HNB registration, UE registration, HNB and HNB-GW communication, etc.

The Stream Control Transmission Protocol (SCTP) is a transport protocol (used by SIP) to provide secure and reliable transport for next-generation networks. It delivers datagrams where multiple streams are allowed.

The Iu-User plane is the Iu-UP user traffic plane.

The GPRS Tunneling Protocol (GTP) is defined as the protocol between GPRS support nodes (GSNs), for both signaling and data transfers.

The Real-Time Protocol (RTP) provides end-to-end delivery of data for real-time services.

The Real Time Control Protocol (RTCP) provides an indication of the transmission and reception of data carried by RTP.

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[7] 3GPP Technical Specification 25.467: "UTRAN architecture for 3G Home Node B (HNB); Stage 2," 2010.