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Introduction to Femtocells

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1.1 Introduction

In this chapter we establish the basic 'why, what and how' for femtocells. All of the issues discussed here are covered in greater depth in later chapters, but this chapter should serve as a rapid introduction to the whole subject.

1.2 Why Femtocells? The Market Context

Mobile phones have been one of the fastest-growing consumer technologies of all time. Digital mobile phones were introduced in the early 1990s, and have now grown to include around 4 billion mobile phone subscriptions worldwide – nearly 60% of the world's population. The number is continuing to grow quickly, and is expected to reach 5.63 billion by 2013 (1). Mobile phone data traffic is forecast to grow by between 10 and 30 times between 2008 and 2013, depending on the pricing and promotion of these services (2).

In the same period, the Internet has also become a mass-market technology, growing to 1.6 billion users worldwide, nearly 25% of the world's population (3). Internet protocol traffic is forecast to grow by over 10 times in the period from 2006 to 2012 (4).

Since the introduction of third-generation mobile services in the early part of the new millennium, the dream has been to combine mobile and Internet technologies, giving fast, reliable access to the Internet via personal mobile devices. While there have been false starts in achieving this dream, there are now clear signs that demand for Internet services is taking off. In 2007 particularly, the availability of 3G networks, usable mobile devices and flat-rate near-unlimited data plans came together to produce a tipping point in the take-up of mobile data services. This rapid growth has been exhibited in terms of both the quantity of mobile broadband data consumed and the revenues derived from this data, and this growth is widely forecast to continue and even accelerate (5).

Revenues generated by many mobile operators from mobile broadband data also increased substantially in 2007, as shown in Table 1.1. Yet the table also shows that voice revenues are

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Table 1.1 Growth of operator revenues for leading operators in Q3 2007, relative to the previous 12-month period (6)

Mobile operator	Data revenue growth	Voice revenue growth
AT&T	64%	6%
Verizon Wireless	63%	7%
Rogers	53%	15%
Telstra	50%	5%
Vodafone (W. Europe)	45%	1%
Sprint	28%	–9%
T-Mobile Germany	24%	–4%
KDDI	18%	1%

growing much more slowly and are declining in some cases, as prices fall under competitive and regulatory pressures.

Although the growth of data in 2007 was from a relatively small base, the combination of this with the relatively flat market for mobile voice services (at least in developed economies) has made mobile data a significant and growing component of overall operator revenues, reaching nearly 20% in 2007 (6). The overall market is already very large. For example, the financial analysts Merrill Lynch had this to say in 2007 (6) (our emphasis):

> Wireless data services are now a $115bn global market, growing at 28% annually, contributing ~2 pts to aggregate telecom services revenue growth – *outstripping fixed broadband revenues and growth*.

So operators have a compelling reason to pay close attention to the mobile broadband data market. Yet they also have challenges. While both data volumes and revenues have increased, the volumes have increased far faster than the revenues and this trend is expected to accelerate in the future (Figure 1.1). In order to maintain healthy margins, operators need to find ways to substantially decrease the cost per bit of delivering this data, while not placing limits on customers' appetites for consuming the data.

1.3 The Nature of Mobile Broadband Demand

To determine how to serve mobile broadband demand cost effectively, it is important to understand the nature of this demand – and most particularly, where it occurs.

Traditionally, mobile service was primarily about services to mobile *users* – those travelling between homes and offices via public or private transport, where communication services are not available in any other way.

Increasingly, however, the most important – and biggest - components of mobile demand are services delivered to mobile *devices*, yet stationary *users*. In other words, mobile devices are increasingly personal and are used by individuals when they are not on the move, typically within buildings, including both the home and the workplace.

As a reasonable rule of thumb, roughly one-third of all cellular traffic today is at home despite networks not typically being designed to provide a solid home service and tariffs often being unattractive compared with fixed-line networks. Another third is in the workplace, with the remaining third being the 'traditional' traffic generated on the move. It is expected that

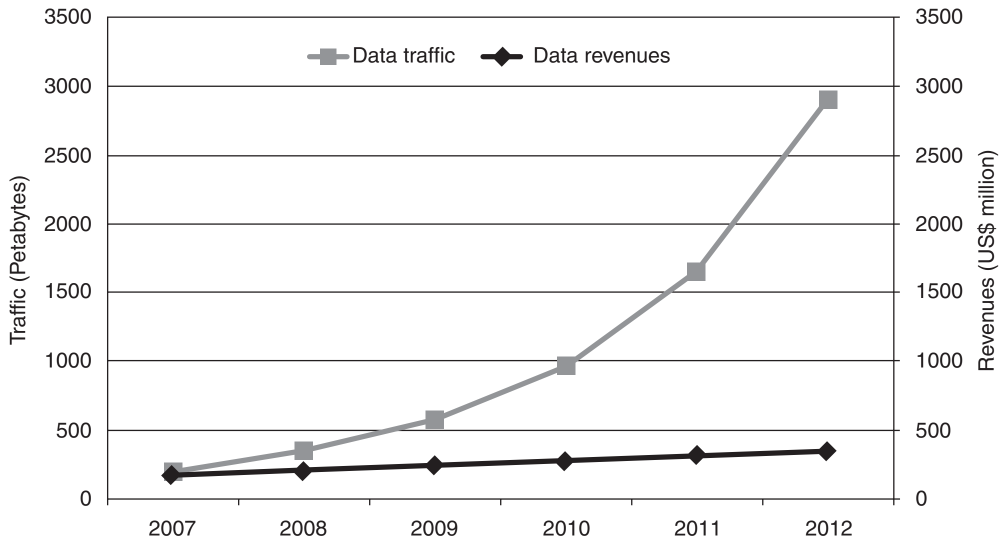

Figure 1.1 Forecast global mobile data revenues and traffic. *Reproduced by permission of Informa Telecoms and Media Ltd*

these proportions will grow in the future even as the overall data volumes grow, due to the need for users to be looking at a screen when consuming most high-bandwidth data services (e.g. web browsing or mobile video) – see Figure 1.2.

Studies of these traffic patterns show that in Western Europe 57% of mobile minutes at home or work (8). In-building traffic on 3G networks is expected to grow to 75% of the total by 2011 (9). Home coverage remains patchy: for example, the UK is generally considered a well-developed market with over 90% population coverage for 3G and far higher for 2G (10). Nevertheless, a detailed study of users in the UK showed that 19% of mobile phone owners regularly encounter coverage problems in the home (11). Of these, 53% report that coverage is poor throughout the house, while the remainder report coverage problems in selected rooms.

Why is this growth happening? We can imagine numerous influencing factors, including the following:

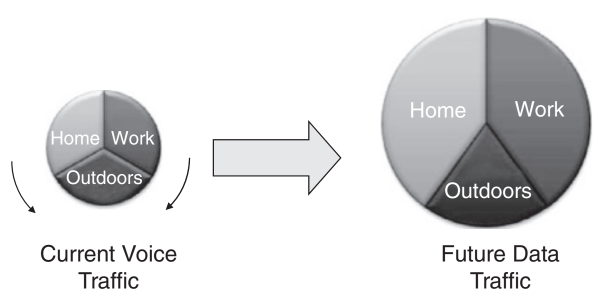

Figure 1.2 Increasing proportions of traffic generated indoors

- Service take-up often starts at home and then spreads to the enterprise: witness the way in which Wi-Fi, although originally intended as an enterprise technology, only reached a mass market via usage in homes before being adopted in corporate environments.
- Voice minutes are increasingly moving from fixed line to mobile, as an increasing proportion of users come to rely upon their mobile as their main – or even only – telephone.
- Operators (not only mobile ones) are increasingly offering 'quadplay' and other bundled flat-rate tariffs, which include large quantities of mobile service along with fixed line, Internet and television services.

There are increasingly real, compelling data services which users wish to use on mobiles:

- mobile multimedia – including television;
- media synchronisation (wireless sideloading);
- presence applications;
- consumer push email.

For more information on the potential evolution of future mobile applications, see this author's predictions in (12).

Any and all of these services point towards the need for operators to deliver a high-quality service to users at home and at work, including reliable coverage and high data rates, while reducing the cost per bit for delivery. Femtocells have emerged at just the right time to address these issues.

1.4 What is a Femtocell?

A femtocell is a low-power access point, based on mobile technology, providing wireless voice and broadband services to customers in the home or office environment. As shown in Figure 1.3, the femtocell connects to the mobile operator's network via a standard consumer broadband connection, including ADSL, cable or fibre. Data to and from the femtocell is carried over the Internet – or at least, over an Internet-technology network provided by an Internet service provider.

Typically, a single femtocell will deliver voice services simultaneously to at least four users within the home, while allowing many more to be connected or 'attached' to the cell, accessing services such as text. Additionally, femtocells will deliver data services to multiple users, typically at the full peak rate supported by the relevant air interface technology, currently several megabits per second and rising to tens and hundreds of megabits per second in the future.

Data from multiple femtocells are concentrated together in a gateway, managed by the mobile operator, and ultimately find their way back to the operator core network along with the data from the conventional operator macrocell network. The operator core network also contains a management system which provides services to the femtocell, ensuring that the services experienced by the user are secure, of high quality and can coexist with the signals from other femtocells and the outdoor network.

In practice, the femtocell may be either a stand-alone device, which connects into the customer's existing broadband router, or may form a key component of a home gateway device which incorporates the router and other technologies, such as a broadband modem, Internet router and Wi-Fi access point into a single integrated device. Examples of both types are illustrated in Figure 1.4. Note that femtocells are consumer devices, intended to be suitable

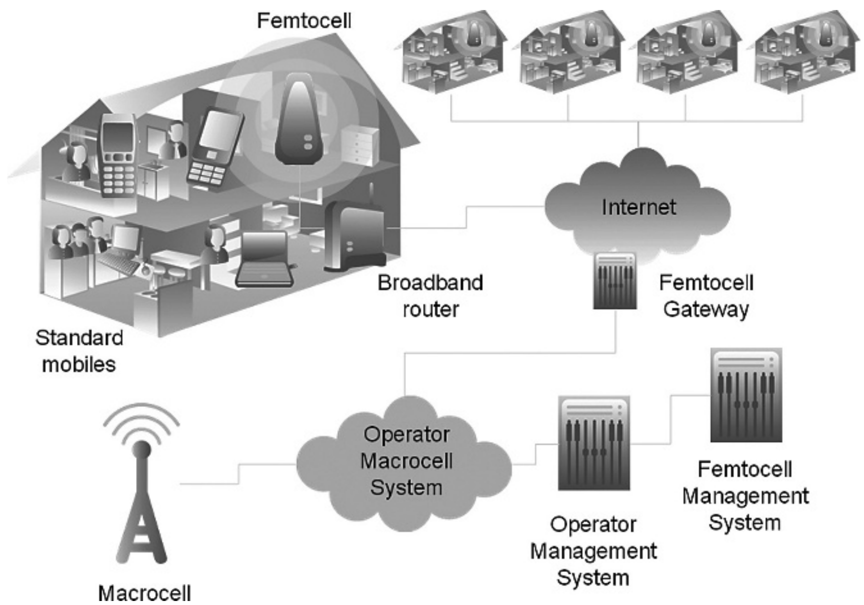

Figure 1.3 Basic femtocell network. *Reproduced by permission of Femto Forum Ltd*

Figure 1.4 Some stand-alone and integrated femtocells. *Reproduced by permission of Ubiquisys Ltd., ip.access Ltd., Radio Frame Networks Inc. and Airvana Inc*

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for installation in a home environment and to be manufactured in large volumes in line with other consumer products.

In some respects, femtocells resemble other home wireless devices such as cordless phones and Wi-Fi access points. However, there are important differences, which are highlighted in Section 1.6. A clear definition of a femtocell is therefore required.

1.4.1 Femtocell Attributes

The Femto Forum has created the following set of attributes, *all* of which are necessary for a device to qualify as a femtocell.

A femtocell is a low-power wireless access point, incorporating all of the following:

- **Uses mobile technology**. Femtocells use fully standard wireless protocols over the air to communicate with standard mobile devices, including mobile phones and a wide range of other mobile-enabled devices. Qualifying standard protocols include GSM, WCDMA, LTE, Mobile WiMAX, CDMA and other current and future protocols standardised by 3GPP, 3GPP2 and the IEEE/WiMAX Forum, which collectively comprise the technologies included in the ITU-R definition of IMT.[1] The use of such protocols allows femtocells to provide services to several billion existing mobile devices worldwide and to provide services that users can access from almost any location as part of a wide-area network.
- **Operates in licensed spectrum**. By operating in spectrum licensed to the service provider, femtocells allow operators to provide assured quality of service to customers over the air, free from harmful interference but making efficient use of their spectrum.
- **Generates coverage and capacity.** As well as improving coverage within the home, femtocells also create extra network capacity, serving a greater number of users with high data-rate services. They differ in this from simple repeaters or 'boosters' which may only enhance the coverage.
- **Over Internet-grade backhaul**. Femtocells backhaul their data over Internet-grade broadband connections, including DSL and cable, using standard Internet protocols. This may be over a specific Internet service provider's network, over the Internet itself or over a dedicated link.
- **Permits low prices.** The large volumes envisaged for femtocells will allow substantial economies of scale, driving efficiencies in manufacturing and distribution in a manner similar to the consumer electronics industry and with pricing projected to be comparable with access points for other wireless technologies.
- **Fully managed by licensed operators.** Femtocells only operate within parameters set by the licensed operator. While they have a high degree of intelligence to automatically ensure that they operate at power levels and frequencies that are unlikely to create interference, the limits on these parameters are always set by operators, not by the end user. The operator is always able to create or deny service to individual femtocells or users. This control is maintained whether the femtocell itself is owned by the operator or the end user.
- **Self-organising and self-managing.** Femtocells can be installed by the end customer. They set themselves up to operate with high performance according to the local and network-wide

[1] International Mobile Telecommunications, comprising IMT-2000 (usually known as 3G) and IMT-Advanced (which may become known as 4G).

conditions regarding radio, regulatory and operator policies, with no need for intervention by the customer or operator. They continue to adjust themselves over time as the customer, operator and regulator needs evolve to maximise performance and reliability.

1.4.2 Femtocell Standards

Most air interfaces included in the global ITU-R IMT family have active programmes to develop standards for femtocells. These include:

- 3GPP standards for Home Node-B, which is a WCDMA femtocell. Both FDD and TDD options are likely and a TD-SCDMA variant is also planned.
- 3GPP standards for Home eNode-B, which is an LTE femtocell. Both FDD and TDD options are envisaged.
- 3GPP2's programme for femtocells for cdma2000, cdma2000 1x, HRPD, 1x EV-DO and UMB.
- WiMAX Forum's programme for WiMAX femtocells based on IEEE standards.

In all cases femtocell standards will support deployments in all of the existing licensed spectrum bands in which macrocells operate.

1.4.3 Types of Femtocell

Individual femtocells are likely to come in various hardware types. Although individual standards differ in their definitions, the following broad classes can be identified, though these are not exclusive or prescriptive:

- **Class 1.** This is the class of femtocells that has emerged first and is currently best known. Femtocells in this class deliver a similar transmit power and deployment view to Wi-Fi access points (e.g. typically 20 dBm of radiated power[2] or less) for residential or enterprise application. They will each deliver typically 4–8 simultaneous voice channels plus data services, supporting closed or open access. Installed by the end-user.
- **Class 2.** Somewhat higher power (typically up to 24 dBm of radiated power), perhaps to support longer range or more users (say 8–16). Supports closed or open access. May be installed by the end-user or the operator. May be viewed as an evolution of picocell technology.
- **Class 3.** Still higher power for longer range or more users (e.g. 16 or greater). Typically carrier deployed and may well be open access. Could be deployed indoors (e.g. in public buildings) for localised capacity, outdoors in built-up areas to deliver distributed capacity or in rural areas for specific coverage needs.

1.5 Applications for Femtocells

Femtocells started as a means of delivering services to residential environments. This remains a core application for femtocells and it enables femtocell technology to be produced in large

[2] Effective Isotropic Radiated Power - EIRP

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volumes and low costs. However, femtocells are not limited to this application and early deployments for other purposes are anticipated. Current applications include:

- **Residential** – Femtocells are installed indoors within the home by the end user and may be stand-alone devices or integrated with other technology such as residential gateways. Access to the residential femtocell will often be closed – restricted to a specified group of users – but may also be open to all registered users in some cases. Typically these application needs will be met using class 1 femtocells.
- **Enterprise –** Enterprise femtocell deployments may be in small-office, home-office situations, in branch offices or in large enterprise buildings. Femtocells for this purpose are usually of class 1 or class 2 and will typically support additional functionality compared with residential devices such as handover between femtocells, integration with PBX and local call routing. Will primarily be used indoors, but could also be used to serve a corporate campus. Installation will probably be managed by the carrier, but may be achieved by the enterprise itself or its IT subcontractors. Access may be closed or open.
- **Operator –** This class encompasses a wide variety of applications where operators use femtocells to solve specific coverage, capacity or service issues in both indoor and outdoor environments. These could be composed of class 1, 2 or 3 devices and will usually be open access. They will be installed by the operator or by third parties under the operator's direction.
- **Others –** These application classes are not exclusive and it is expected that other innovative ideas for the application of femtocells will emerge, for example on aircraft, trains or passenger ferries. In all cases the essential attributes of femtocells described earlier will be observed, enabling full compliance with relevant local customer, operator and regulatory requirements.

1.6 What a Femtocell is not

A femtocell could be confused with other devices. It is helpful to contrast its behaviour with several of these, specifically Wi-Fi access points, repeaters (or boosters), cordless telephones and conventional cellular base stations.

Wi-Fi Access Points While these also provide wireless broadband access to portable devices, there are important differences. Wi-Fi almost always operates in unlicensed (or licence-exempt) spectrum. This means that an operator is unable to guarantee any service quality over the air, since interfering devices can legally appear close to any given user. Most Wi-Fi devices operate in the 2.4 GHz frequency band, where only three non-overlapping channels are available, so the potential to avoid interference is limited. In contrast, femtocells, operating in licensed spectrum, ensure that an operator is in control of every transmitting device and can manage interference to deliver an appropriate quality of service to every user. Wi-Fi access points and client devices all transmit at a power of around 100 mW, which does not change even when far less power is required, increasing the incidence of interference and draining batteries. By contrast, in cellular technology both the mobile devices and the femtocells continually adjust their transmit power to the minimum necessary to deliver adequate service, increasing the number of users which can access a given channel, reducing interference and increasing battery life.

Wi-Fi is mainly associated with delivering Internet or private LAN connectivity to laptop devices. In this role it has been extremely successful, with the majority of new laptops including embedded Wi-Fi capability. In contrast, while femtocells can serve the increasing numbers of laptops with cellular connectivity (either embedded or via 'dongles'), they are designed primarily to serve the much larger numbers of personal devices including mobile phones and newer ultra-mobile PCs.

Relatively recently, Wi-Fi has been extended to serve 'dual-mode' devices such as phones. However, the number of such devices is tiny compared with cellular phones, so while there may be a market for such devices it is not expected to address the huge potential user base addressable by femtocells.

Early Wi-Fi failed to provide adequate data security. While these issues have been addressed in later standards, the issue remains in many legacy devices and causes considerable concern and confusion for users. By contrast, the security standards used in cellular systems have been proven to be robust, are well trusted by users, and are used directly in femtocells, together with additional safeguards to ensure the authentication and encryption of devices and traffic connected across the Internet.

For the avoidance of doubt, then, there is no such thing as a 'Wi-Fi femtocell'.

Repeaters (or 'Boosters'). Repeaters are bi-directional amplifiers, used to increase coverage in systems, including cellular mobile. They operate by receiving service from an outdoor base station cell via an external antenna, amplifying it, and retransmitting it via cables and an antenna placed within the area for coverage improvement. They are a useful tool in many networks, and can certainly improve coverage, but there are many differences from femtocells. Repeaters require careful professional installation for good results, with the external and internal antennas requiring proper location to deliver appropriate coverage while being isolated from each other to avoid feedback. The gain of the amplifier must be adjusted within tightly defined limits: too little will fail to deliver adequate coverage improvement, while too much will cause feedback between the antennas, degrading or even denying service for all the users in the coverage of the external 'donor' cell. By contrast, femtocells are zero-touch devices, requiring no professional skills for set-up. As well as amplifying the signals from the mobile devices, repeaters necessarily inject some noise into the outdoor base station receiver. This limits the number of repeaters which may be used in a given cell, typically to a handful per cell, since more will unacceptably degrade the base station performance for all other users in a cell. Femtocells, with appropriate interference mitigation techniques, may be used in very large numbers in a given area. Repeaters require that a given location already has acceptable outdoor coverage and only requires improvement indoors, while femtocells can operate in a completely isolated area provided broadband connectivity is available. Although repeaters can deliver the improved coverage, which is one important motivation for femtocells, they do not deliver additional capacity into the network or any capability to provide differentiated services. Lastly, repeaters tend to be far more expensive than the target prices for femtocells, even before the cost of professional services is counted.

Cordless Telephone Systems Cordless phones and their associated base units, originally based on analogue FM and now typically based on DECT, were one of the first wireless devices to be deployed in volume in the home. Their success lies in delivering convenience to users, of being able to access fixed lines while being able to move freely around the home. In that respect they are similar to femtocells. However, they are single-function devices, with few delivering anything other than voice. They are not personal devices, in that handsets are shared amongst all users. They do not deliver data services in the main. Most importantly, they deliver no wide-area mobility (although DECT-GSM dual-mode devices were once available). It is entirely possible that cordless phones will diminish in popularity once femtocells are widely available.

Cellular Base Stations Femtocells do share much in common with conventional mobile base stations, producing almost indistinguishable signals over the air in order that standard handsets can be used unmodified. However, there are many differences. Femtocells have limited capacity, suitable for a single domestic installation, while conventional base stations must serve tens or hundreds of users. Base stations are therefore professional products, with costs to match, while femtocells are consumer products, produced in volumes to meet consumer pricing expectations. Femtocells are designed to work over Internet-grade backhaul, typically DSL or cable, while base stations operate over dedicated backhaul, such as leased lines or microwave links. As a result, femtocells do not have the same interfaces as standard base stations: the interface is optimised to reduce the bandwidth requirements, while also increasing the level of security to protect traffic which may be routed over the Internet rather than a dedicated network. In order to provide local management of system and radio resources, they include much more intelligence than a conventional base station, being comparable to the combination of a base station and a ‘collapsed’ radio network controller, which would usually manage the resources of several base stations together. Base stations would usually be planned and optimised by professional radio planners, while such intelligence is automatic within femtocells. Lastly, femtocells of course radiate at substantially lower powers than base stations, being typically around 10 000 times lower. So while a femtocell does have some similarities with a base station, it is both much more and much less than one, and the two should not be confused.

These differences are summarised in Table 1.2. Overall, while femtocells have much in common with some other devices, drawing on proven technologies and customer demand where appropriate, they represent a unique new class of device.

1.7 The Importance of ‘Zero-Touch’

It is vital for femtocells to be simple to install, configure and operate. No special expertise must be necessary, since the cost of sending trained personnel to consumers’ homes would destroy the business case for the operator. Further, for users to adopt femtocells, femtocells must deliver service with an absolute minimum of intervention by the user. There should be no need to provide special security settings or to access any device (e.g. a computer) other than the femtocell and the user’s mobile device. This ‘zero-touch’ aspect of femtocells is critical for any femtocell deployment and is illustrated by Figure 1.5, which shows a typical extract from a femtocell user manual. Note the 10-minute configuration period. During this time the femtocell is engaged in some very sophisticated activities, including:

- Contacting the mobile network and establishing a secure, fully encrypted communications tunnel.

Table 1.2 Comparison of femtocells and other wireless devices

	Wi-Fi access points	Cordless telephones	Repeaters ('boosters')	Cellular base stations	Femtocells
Operates in licensed spectrum	✗	✗	√	√	√
Supports power control	✗	✗	√	√	√
Robust security	✗	√	Not applicable	√	√
Serves existing personal devices	✗	✗	√	√	√
Provides voice and data services	√ (but requires device-specific extensions)	✗	√	√	√
Provides wide-area mobility	✗ (unless combined with mobile systems and special enhancements)	✗	Not applicable	√	√
Supports existing personal devices	✗	✗	√	√	√
Consumer device and price	√	√	✗	✗	√
Consumer installation	√	√	✗	✗	√

- Mutually authenticating with the network and establishing the user's credentials, service options and location.
- Surveying the surrounding radio environment and configuring itself to operate within parameters set by the operator to deliver good service with minimal interference.

Users are entirely unaware of this activity other than a delay of a few minutes. They should simply be able to start accessing their femtocell services at the end of the period. They can subsequently leave the femtocell switched on permanently, or power it down when not required for an extended period. The femtocell will provide service much more quickly on subsequent start-up.

1.8 User Benefits

So why would a mobile user wish to use a femtocell? It is essential that the answer to this question is well articulated and developed if femtocells are to be successful. There are many parts to the answer, and the most appropriate will differ according to the market and market segment into which femtocells are sold. Operators will choose the most appropriate for the users to whom they are selling femtocells. A range of potential user benefits is summarised in Figure 1.6 and described individually here.

- *Coverage.* The most fundamental user benefit is the provision of reliable coverage throughout the home. This allows users to rely on their mobiles as a prime means of making and receiving

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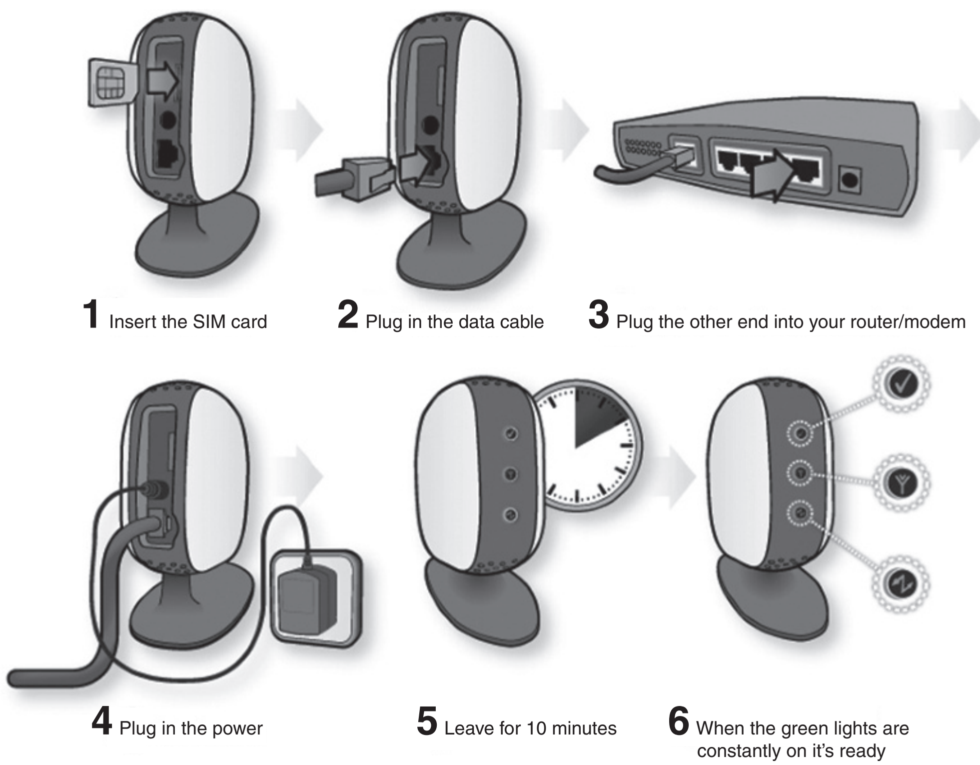

Figure 1.5 Zero-touch femtocell installation. *Reproduced by permission of Ubiquisys Ltd*

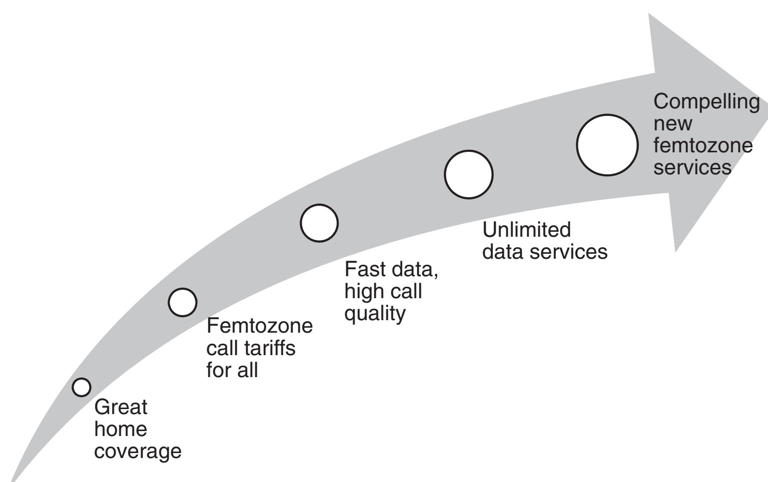

Figure 1.6 The range of user benefits associated with femtocells

calls. Even where coverage is already nominally available in a home, currently users will often turn to a fixed line to avoid the risk of dropping a call and will typically suggest the use of fixed-line numbers to friends and business associates when an important call is expected. In many cases, home coverage is patchy, perhaps available only on upper floors or close to windows. In many markets, residential densities below a certain level will lead to no coverage at all due to the difficulty of operators providing coverage with an adequate business case using conventional solutions. In all of these cases, femtocells should result in mobile phones being able to be used in a better way, allowing users to rely on their mobiles at home as their prime – or only – personal communication device.

- *Femtozone call tariffs.* Some femtocell operators include special tariffs for calls made or received on the femtocell, including a lower rate, a large bundle of minutes per month or matching the fixed-line rates. A wide range of tailored pricing options is possible, differentiating by user type, time of day, call destination and other dimensions. Some of these benefits may also be available to users when granted access to femtocells from the same operator in their friends' or colleagues' homes.
- *Fast data and high call quality.* The improved coverage and protection from interference available from femtocells enables mobile phones to work at the peak of their capability, including the highest possible data rates available over the air and the highest possible call quality. This is likely to lead to users making new uses of their phones and other mobile-enabled devices, including relying on them for the most important business calls and using them as their primary personal Internet and entertainment devices.
- *Unlimited data services.* Operators are likely to offer data services on femtocells which have far higher usage limits or are even uncapped, enabling users to use these services without fear of the associated charges. This will also encourage users to use such services for the first time, overcoming initial barriers to access and ultimately to adopt these services beyond the home as well.
- *Compelling new femtozone services.* As well as delivering existing mobile network services better and at more attractive prices, femtocells can also deliver brand new services, which use the specific knowledge of the user's location to offer extra benefits such as control of devices around the home, synchronisation of content to and from the mobile device and fast, high-quality access to data stored on other devices on the home network such as media servers.

1.9 Operator Motivations and Economic Impact

The delivery of services via femtocells impacts on the economics of those services for operators in all major dimensions, including increasing revenue, decreasing costs and speeding up deployment.

Revenue impact:

- Femtocells deliver new revenue streams from value-added services and by increasing mobile usage, both within the home and on the wider network, as users demand services they have first experienced on the femtocell.
- Location-specific tariffs such as 'homezone' tariffs defined by the coverage area of a few macrocells may extend over a large area potentially comprising the whole of a small town and therefore lead to revenue leakage. This decreases operator revenues without decreasing

the associated costs. Location-specific tariffs delivered via femtocells are precisely targeted and reduce the costs of delivery, thereby increasing the overall value to the operator.
- Family and group contracts, which increase the loyalty of the femtocell users to the operator, extending both the value and lifetime of the contract. The attractiveness of such contracts is also increased by the ability to offer service bundles including entertainment services, which are typically bought by the whole family rather than by a single individual.
- Differentiated services, encouraging users to adopt services from operators offering femtocells over those available from other operators.

Cost savings:

- Femtocells enable operators to defer and reduce the cost of macrocell roll-out to deliver enhanced indoor coverage and network capacity.
- Femtocells produce operational savings – especially on the major items associated with sites in power, backhaul and site rental.
- By reducing the likelihood of customer churn between operators, femtocells reduce the cost of customer retention.

Time-to-market:

- Femtocells allow rapid, low-risk, focused deployment of next-generation technologies such as LTE and WiMAX, avoiding the extended timescales and cost needed to secure site rights and construction resources to permit macrocell upgrades.
- New services can be rapidly provisioned to relevant users and locations, enabling them to be trialled and optimised for wider roll-out more quickly and with lower risk, enabling Internet-style speeds of new service introduction.

Overall, there is potential for substantial economic value to be created by the deployment of femtocells, challenging the traditional preconceptions of cellular economics.

1.10 Operator Responses

Operators in many regions of the world have responded to the potential for femtocells with an enthusiastic and rapid response. The first commercial femtocell deployments took place in the Sprint network in the United States in 2007 based on CDMA technology and further commercial launches based on WCDMA started in late 2008 and early 2009, including Starhub in Singapore, Softbank Mobile in Japan and Verizon in the United States.[3] Many other operators around the world are working towards service launches and wider rollout within 2009 and 2010. Publicly announced femtocell trials include Vodafone, T-Mobile, AT&T, Telefonica O2, mobilkom austria, Verizon and TeliaSonera. Examples of comments from operators include the following:

- 'Our Apple iPhone and flat rate data tariffs place huge capacity demands on our networks. Because so much of that usage is at home, femtocells could play a crucial role in underpinning the explosive growth of mobile broadband usage' (Vivek Dev, COO, Telefonica O2 Europe).

[3] This list will certainly be incomplete by the time this book is published. See www.femtocellbook.com for a more current list.

- '3G femtocells answer the needs of our mobile-centric strategy 100%' (Frank Esser, CEO, SFR).
- 'We intend to use [femtocells] to reduce macro capex spend by up to 20 percent in some areas' (Andy MacLeod, Director of Group Networks, Vodafone).
- 'Femtocells are fundamental to the future of mobile. They pave the way for new mobile services that put the mobile phone at the centre of the connected home' (Axel Kolb, Fund Manager, T-Mobile Venture Fund).

1.11 Challenges

As we have seen, there are many reasons why customers and operators are demanding femtocells and the services and economies that can be provided by using them. Yet there are many challenges in achieving this potential. These are briefly highlighted here and examined in greater depth in later chapters.

Market challenges:

- public awareness;
- public concerns regarding service, tariffs and alleged health issues;
- support for a wide range of use cases;
- business case.

Radio and physical challenges

- interference management between femto- and macrocells;
- radio resource and mobility management;
- implementation issues (e.g. synchronisation, signal processing and cost).

Network challenges

- architectures and interfaces;
- management and provisioning;
- scalability;
- security.

Regulatory challenges

- regulatory benefits;
- spectrum issues;
- service issues.

These issues and others besides have required significant and swift attention to permit femtocells to realise their full potential.

1.12 Chapter Overview

The remainder of this book is organised as follows.

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Chapter 2 examines the background for small cells, placing femtocells in the context of the history of other solutions for in-building service and explains the market and technological factors which have made femtocells a compelling proposition.

Chapter 3 addresses market issues, covering the benefits and motivations of femtocells for operators, the key market challenges, business case analysis and forecasts for the take-up of femtocells.

Chapter 4 looks at radio issues for femtocells, including the requirements and methods for interference management between femtocells, femtocell RF specifications and health issues.

Chapter 5 addresses the options for the network architecture of femtocells, particularly the interfaces and protocols for integrating femtocells with the operator network across the Internet and the way in which the various options differ between standards families.

Chapter 6 describes the requirements and approaches for provisioning and managing millions of femtocells in an efficient and scalable fashion.

Chapter 7 explains the security aspects of femtocells from a customer and operator perspective, including analysis of the potential threats and solutions.

Chapter 8 covers the standards for femtocells across the main mobile standards families, namely 3GPP, 3GPP2 and WiMAX Forum. It also introduces the industry bodies who are playing important roles in the introduction and proliferation of femtocells.

Chapter 9 shows the benefits of femtocells as seen from a regulatory perspective and highlights areas where regulations may need to be evolved to maximise these benefits and avoid delay to femtocell take-up.

Chapter 10 explains some of the considerations which are important for efficient implementation of femtocells in hardware and software.

Chapter 11 characterises the services that operators can offer to femtocell users, particularly the opportunity to extend services beyond those available from the macrocell network.

Finally Chapter 12 summarises the outcomes of this book and gives some predictions of the potential future for femtocells.