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Femtocells – Natural Solution for Offload

a Femto Forum topic brief

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What is the Femto Forum?

The Femto Forum is the only organisation devoted to promoting femtocell technology worldwide. It is a not-for-profit membership organisation, with membership open to providers of femtocell technology and to operators with spectrum licences for providing mobile services. The Forum is international, representing more than 120 members from three continents and all parts of the femtocell industry, including:

- Major operators
- Major infrastructure vendors
- Specialist femtocell vendors
- Vendors of components, subsystems, silicon and software necessary to create femtocells

The Femto Forum has three main aims:

- To promote adoption of femtocells by making available information to the industry and the general public;
- To promote the rapid creation of appropriate open standards and interoperability for femtocells;
- To encourage the development of an active ecosystem of femtocell providers to deliver ongoing innovation of commercially and technically efficient solutions.

The Femto Forum is technology agnostic and independent. It is not a standards-setting body, but works with standards organisations and regulators worldwide to provide an aggregated view of the femtocell market.

A full current list of Femto Forum members and further information is available at **www.femtoforum.org**

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Content

Executive Summary

Mobile data is increasing at a compound annual rate of 108%[1] as a result of an increasing level of penetration of data-intensive devices (smart phones, broadband-enabled laptops, and other devices) and an increasing level of usage per device. Interestingly, a large portion of all macro-cellular traffic originates in one of two largely controllable environments: the home and the office.

While operators have historically been innovative and successful in expanding network capacity, the current rate of growth in demand is unprecedented. As described in this paper, femtocells offer a highly effective and cost-effective method of easing the traffic carried by the macro-cellular network. Offloading traffic frees capacity and therefore improves the data experience of users on the macro network. At the same time, users who connect to a femtocell tend to experience significantly improved performance - because of the nearly ideal radio environment created by the femtocell.

Femtocell technology to support this is standardised, is available from a wide ecosystem of vendors, and is increasingly commercially deployed by operators. As of Q2, 2010 at least ten (10) operators have *launched* commercial femtocell service while at least fifteen (15) have *committed* to deploy femtocells[2].

Data offload is effective for several reasons:

- Data usage occurs primarily indoors (i.e. home, office, and public places). According to Informa's 2008 report *Mobile Broadband Access at Home*[3], 55% of data usage occurs in the home and 26% occurs in the office. The percentage of traffic indoors has been increasing over time and is expected to increase further.

- Macro-cellular networks expend a disproportionate amount of radio resources attempting to reach the indoor subscriber. By providing the indoor subscriber with a dedicated radio infrastructure, all parties benefit. Neu Mobile[4] calculates that the marginal cost of adding 1 Mbps of capacity using a femtocell is approximately 1/200th of the cost of adding the same capacity using a macro-cellular infrastructure. Femtocells significantly improve the experience of the femtocell user. They also improve the experience of those *not* using the femtocell, by freeing capacity and enhancing the user experience for those users in the macro-cellular network.

- Femtocells represent an operator-deployed and managed service. They become part of a larger carefully engineered network, providing a seamless experience to users. Revenue-generating traffic is retained by the operator. The consumer gets additional capabilities (fast connectivity, consistent coverage, new services) with relatively little effort.

- According to the analysis originally conducted in the "Femto Forum Business Case Whitepaper", June 2009[5], and updated for this white paper, the use of femtocells can lower the marginal cost per GB of data delivered by 4 times with current technology in the capacity-constrained case and significantly more using a forward-looking scenario. In the forward-looking scenario the capacity-constrained marginal cost per GB for a macro-cellular network is $4.80 compared with $0.07 (7 cents) for the marginal cost of delivery through an existing femtocell. Femtocells reduce costs by offloading the radio access network (RAN), the backhaul network, and the radio network controller (RNC) which processes the growing level of smart phone smart phone signaling traffic.

- Femtocells can be added quickly, whereas macrocells take much longer to introduce, due to zoning, permitting, environmental, health, and other considerations.

- Small cells can support an exceptionally high traffic density. According to a study[6] by Dr. Hamid Falaki of NEC Europe, simulating the data rates of LTE macro, micro, and picocells, each in three different frequency bands, LTE picocells are able to deliver 200 times the traffic density of LTE macrocells. An enterprise or public access femtocell is the functional equivalent of a picocell.

- NSN and Ericsson both describe in white papers the uneven distribution of traffic. NSN[7] indicates that "50% of traffic is carried by 15% of the cells." Similarly, Ericsson[8] points to "20 percent of the sites carrying more than 50 percent of the total network traffic." Highly concentrated in-building traffic is relatively easy to offload with femtocells.

How could the widespread adoption of femtocells impact operator valuations? According to Arthur D. Little, significant levels of offload will translate into improved operating-free cash flow[9]:

> We expect operators to increasingly offload part of their mobile data traffic onto fixed broadband networks, through WiFi hotspots (already a very significant part of the iPhone traffic at Orange France, O2 UK and AT&T in the USA) or femtocells (just launched by Vodafone UK and SFR in France). If 30% of the traffic was captured this

way at a very low cost, it would boost long-term sector OpFCF by 4% thanks to large savings on 3G capacity capex.

The benefits of data offload, while compelling on a stand-alone basis, are just one component of the business case for femtocells. An operator may choose to offer femtocells to heavy users – for the reasons described in Section 8 – and, at the same time, make femtocells available to other segments based on a business case involving a much broader set of criteria. End user benefits include consistent high-quality coverage, simple and sophisticated "femtozone" services, and special home zone tariffs. Operator benefits include incremental revenue streams, reduced network costs, and reduced churn.

Introduction

As mobile data usage has increased dramatically in recent years, operators have become increasingly interested in the notion of *data offload* using femtocells.

The *concept* of data offload is very simple. In a traditional cellular network all of the traffic to and from mobile phones, mobile internet devices (MID), and mobile-broadband enabled laptops travel from the device to a cell site that is typically a fraction of a mile away (in the city) to several miles away (in suburban or rural areas). *Offload* means that some other device – either a femtocell or a Wi-Fi router – carries that traffic from the phone/MID/laptop over an alternative network (typically a DSL or cable broadband connection) to the operator and/or to another internet destination. While the industry frequently talks about “data offload”, the concept applies to voice traffic as well. Data captures most people’s attention because it is growing much faster than voice and, in heavy user circles (people with smart phones and laptops) data tends to dominate voice in its demand for radio network resources.

The effect of data offload is that the total traffic traveling over the operator’s wide area radio network is reduced. Reduced traffic means reduced network cost (reduced capital investment and reduced operating expenses) for the operator.

Data offload is one of *many* benefits that femtocells deliver. Data offload is extremely important and beneficial in some environments, and less important in others. In an urban environment with exploding data traffic, where the operator is running out of radio capacity, and is about to add additional radio carriers or split the cell, data offload may be critical. An operator may propose femtocells to extremely heavy users to reduce the load on the macro-cellular network. At the other end of the spectrum, someone in a lightly populated area with poor cellular signal might purchase a femtocell primarily for coverage. Their household might primarily consume voice services. The benefit of femtocells – enabling them to reliably make and receive calls – might be enormous (resulting in dramatically improved customer satisfaction, significantly increased voice revenue, and significantly reduced churn), while the contribution to mobile data traffic offload of such a femtocell will be small. The Femto Forum published an initial business case white paper in 2009[10] and a whitepaper on the business case for femtocells in the era of mobile broadband in 2010[11]. Each describes in nuanced terms the very different revenue and cost levers that contribute to the business case for femtocells.

Data offload cost savings benefit operators by allowing cost savings while it also benefits consumers as it may offer a higher quality of service (e.g. bandwidth) for the mobile data connection. Femtocells also improve coverage. Residential femtocells in the home and enterprise femtocells in the office each provide a growing range of services, making them appealing to consumers and enterprisers for reasons other than coverage and capacity.

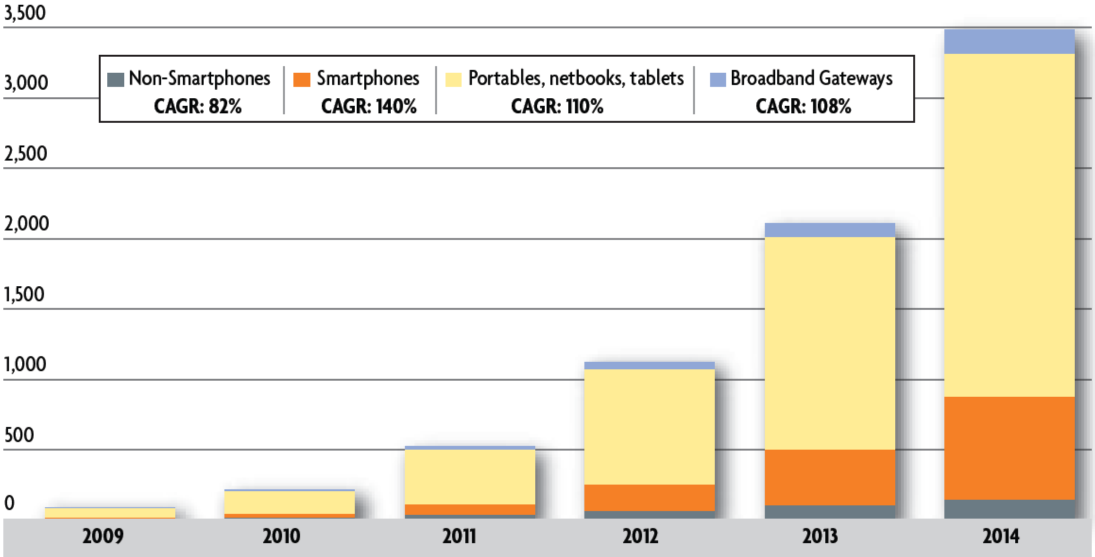
Finally, data offload benefits non-femtocell subscribers by freeing macro-cellular radio network resources. Traffic migrated to femtocells will add to the bandwidth available to users of the macro-cellular network, improving each person's experience.

The Challenge of Rapidly Increasing Mobile Data Traffic

Mobile data is growing worldwide at a compound annual rate per year of 108%.[12] Consumers in North America and Europe are embracing smart phones *en masse*. At the same time, smart phones are getting smarter (improved user interfaces, vastly increased numbers of applications, faster processors, improved radio access technologies) and are consuming increasing amounts of data. Finally, the early adopters and the early majority are discovering mobile broadband. Just as smart phones consume many times more data than feature phones, mobile broadband enabled laptops consume many times more data than do smart phones.

Growth in data usage therefore comes from increased penetration of data intensive devices (3G USB dongles, smart phones) and increased usage per device. The effect is that total data usage is increasing at a compound annual rate of 108% per year, as shown in Figure 1.

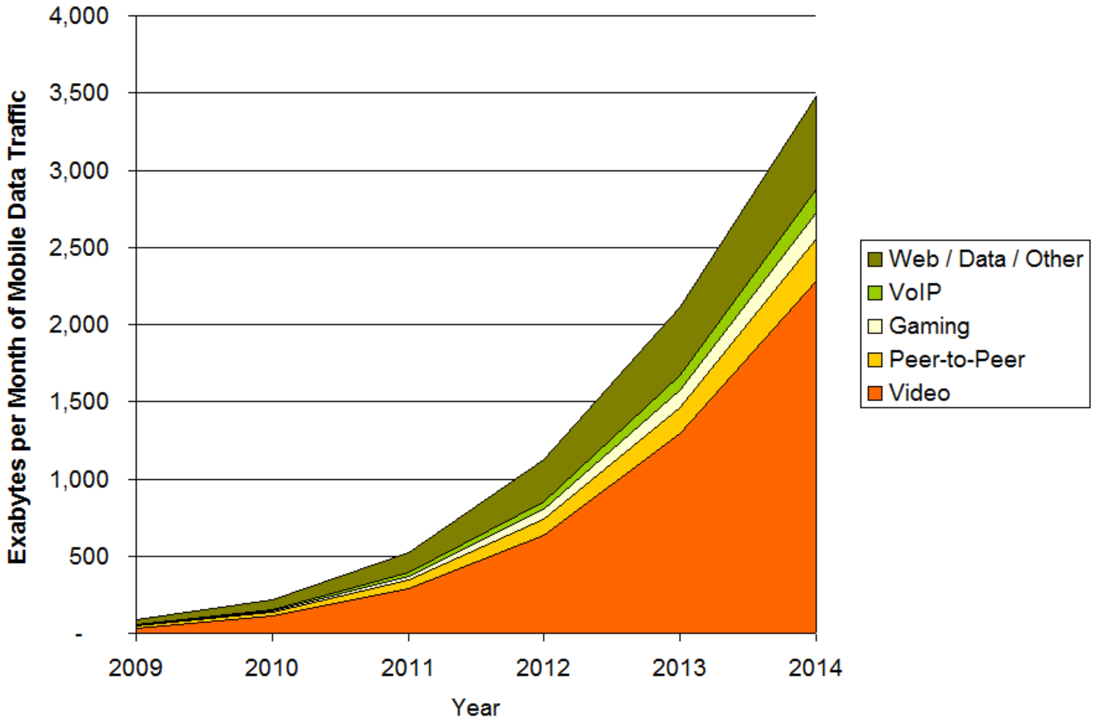
Figure 1: Global Wireless Data Usage (Exabytes per Month)[13]



Source: Cisco Visual Networking Index: Global Mobile Data Traffic Forecast Update, 2009 –2014

If we examine mobile data by *application* we discover that *video* is the greatest single contributor in both fixed and mobile networks. Since a lot of video consumption (flash videos on the internet, streamed television programming, etc) occurs in the home, femtocells offer the operator a powerful tool for diverting a significant portion of video traffic from the macro-cellular network, while enabling the end-user to enjoy rich video content. Figure 2 shows mobile data growth by application:

Figure 2: Distribution of Mobile Data Traffic by Application[14]



Data volumes are growing at a rate that exceeds operators' ability to grow capacity. Capacity growth typically comes from growth in the number of sites, from increased spectrum resources, and from enhancements in radio access technology. How quickly can operators increase their network capacity?

History provides some insight. In the United States – for example – the amount of spectrum available to mobile operators has increased over the past 25 years from 50 MHz (2x12.5 MHz for each of two mobile operators) to approximately 368 MHz (cellular + PCS + AWS + 700 MHz bands), a factor of 7.36 times. This seemingly large increase is actually not that impressive. Spectrum in the US has grown on a *compound annual basis* (7.36 ^ 1/25) only 8.31% per year. Moreover, there is a problem of *sustainability*. If the 368 MHz currently available increased 7.36 times over the *next* 25 years, in frequency bands below 3 GHz (preferred for mobile communications), then licensed mobile spectrum would occupy 90% of all spectrum below 3GHz.

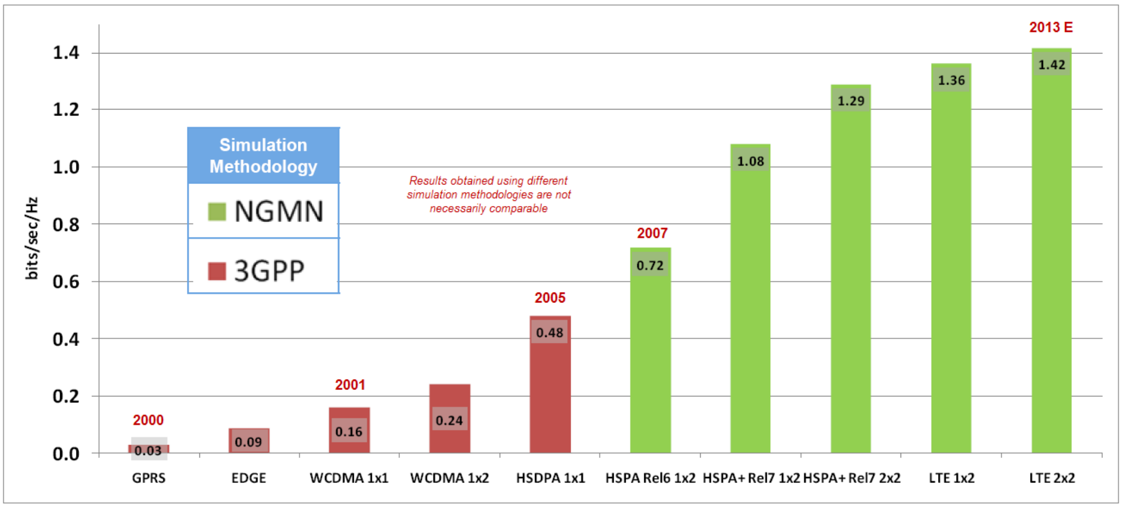
Unfortunately, there are other applications that exist in these bands. These include: police and fire communications, broadcast television, broadcast radio (AM and FM), mission-critical air-to-ground communication (valued by pilots and air travellers alike), navigation (GPS, Galileo, GLONASS), unlicensed applications (cordless phones, cordless mice, Bluetooth headsets, Wi-Fi access points, microwave ovens), etc. It is unlikely that these “other” applications will give up their spectrum to mobile operators. It is therefore unlikely that the next 25 years will see the rate of growth of mobile spectrum witnessed in the last 25 years. While the spectrum allocations in every country are different, the long term trend in most industrialised nations is similar to that of the United States.

If spectrum is limited, what about increasing the number of cell sites? In the United States the total number of cell sites reported by the Cellular Telephone Industry Association (CTIA) has grown from 81,698 in 1999 to 175,725 in 2004 to 247,081 in 2009[15]. This represents an 11.70% compound annual growth rate over ten years or a 7.05% compound annual increase over five years. Here is a concern: the rate of growth in cell sites is slowing, not increasing. Moreover, there is a definitional issue. A “cell site” in the CTIA’s survey is not a unique *physical* location but the sum of the number of “sites” reported by each operator. If multiple operators share the same physical site – as many do – then the reported number of cell sites will increase, even though the total number of unique physical locations may not be increasing or may be increasing at a much slower rate.

If a farmer takes a 1,000-acre farm and subdivides it into quarter-acre residential lots, the number of parcels increases from 1 to 4,000. Does he have more land? No. He has the same amount of land, now divided into many little pieces. If theoretical capacity is proportionate to unique locations times the amount of spectrum, buying and selling spectral and real estate assets will not increase that theoretical maximum capacity. In fact, a large portion of site locations are now owned by tower companies that make space available to all operators. The total number of physical cell site locations in the United States is increasing, but at a modest rate. Permitting processes, environmental impact concerns, and public concerns about EMF have contributed to a cautious decision-making environment, which has slowed the growth of cell sites to less than 7% per year.

If the available amount of spectrum and the available number of sites are growing slowly, what about technology? In the 13-year period from the introduction of GPRS to the introduction of LTE with 2x2 MIMO spectral efficiency will have increased at a 35% CAGR. Unfortunately, the years of rapid increases are largely behind us. In the five-year period from the first commercial launch of HSPA release 6 to the expected commercial launch of LTE with 2x2 MIMO the gain in spectral efficiency is merely 12% per year. These historical increases in wireless spectral efficiency are shown visually in Figure 3:

Figure 3: Historical Increases in Spectral Efficiency[16]



If available spectrum is increasing at 8% per year and the number of cell sites is increasing at 7% per year and technology performance is improving at 12% per year then operators can expect their network capacities to increase – on average – at 29% per year (1.08 x 1.07 x 1.12). If network capacity is growing at 29% per year and demand is growing currently at 108% per year, then there is a significant gap, which begs for further innovation.

What other options exist? One possibility is *architectural* innovation. What if the definition of a "cell site" were radically changed, in such a way that the number of "sites" dramatically increased and the cost per unit of capacity (after adjusting for the inevitable lower utilisation of smaller sites) significantly decreased? Similar innovation has occurred before in the cellular industry. Decades ago omni-directional sites were sectorised. Operators began adding "down tilt" to their urban site designs. Operators began introducing underlay and overlay sites.

The architects of GSM put in place a hierarchical cell structure, allowing macro, micro, and picocells to hand up or down a hierarchical chain of command to one another, so as to best serve the customer and most effectively carry traffic. Technologists and infrastructure manufacturers developed smart antenna solutions that extend coverage and increase capacity. Marty Cooper, developer of the Motorola Dyna-Tac, the first handheld cellular phone, observed that the number of radio conversations that are theoretically possible per square mile in all spectrum has doubled every two and half years for the past 104 years[17]. Femtocells represent the next step in a long history of architectural innovation.

Femtocells won't solve every problem. Their limited capacity, limited transmit power, limited antenna gain, and limited antenna height make them inappropriate for covering large expanses of land. Even so, if they are able to capture a significant amount of indoor traffic (home, office, or public venue) they have the potential to partially address the operator's rapidly growing need for capacity.

Most of our discussion so far has focused on capacity needs in the radio access network. While these needs are immensely important and arguably the most pressing of the operator, there are other bottlenecks. The core network is also experiencing an explosion of demand, but for very different reasons. Operators have increasingly discovered that smart phones are extremely "chatty". Not only do they consume data – which should come as no surprise – they consume it in a vast number of small bites. Unlike a laptop, which might connect to the network, download 30 e-mail messages with large attachments, browse a few websites, stream a video or two, then disconnect (translation: lots of data over a short period of time), a smart phone is likely to nibble: to handoff from site to site, update its stock quotes, update its Facebook alerts, check for e-mail every few minutes (whether it has any or not), and geolocate itself a few dozen times. In other words, the smart phone engages in a large number of tiny transactions. Each of these transactions demands Radio Network Controller (RNC) and Serving GPRS Support Node (SGSN) resources in far greater proportions per MB of data transmitted than a laptop.

Operators have discovered that they are purchasing RNCs in increasing numbers to handle the core network processing power demands of a growing population of smart phones. The result is an additional monthly network cost per smart phone above and beyond the cost of the actual data transmitted. Unlike traffic in the radio access network, which is a true bottleneck, the increasing demand on RNC and SGSN resources can be solved with money: by throwing additional hardware resources at the problem. Smart phones are "chatty", consuming processing power in the RNC and SGSN as a result of their many small data requests. When flat IP core networks eventually become the norm, the impact of the smart phone on the cost of the core network will be extremely small. In the current environment, with traditional core networks, the impact is greater. One advantage of femtocells is that they absorb the RNC function, eliminating much of the cost impact of smart phones.

A Large Portion of Data Traffic is Generated Indoors, in the Home and Office

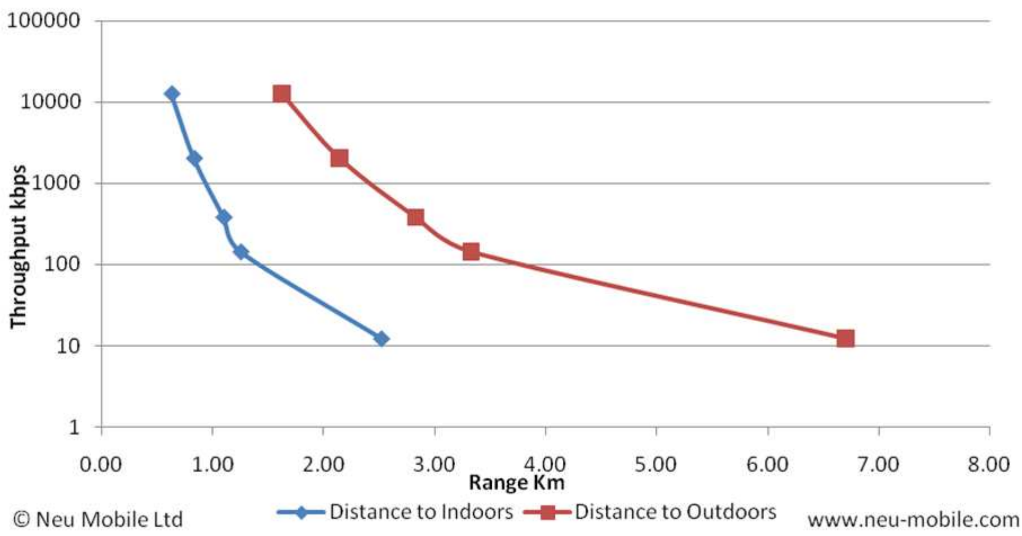
A number of companies track mobile usage, using a variety of measurement and forecasting tools. Informa recently released a report on mobile access at home.[18] They forecast that by the year 2012 55% of all mobile data usage will occur at home and 26% will occur in the office. The proportion occurring in other venues (out of the home/office or on the move) will be the remaining 19%. If a consumer has a femtocell at his home and office then a large portion (81%) of his total usage will disappear from the macro-cellular network.

If every subscriber had a femtocell in his home and office then macro-cellular traffic could be reduced by up to 81%. Since femtocells will be adopted by consumers and businesses over time, the actual reduction will be this theoretical number times the rate of adoption. If heavy users adopt femtocells at a disproportionate rate (which operators should encourage), then significant levels of offload could be achieved relatively quickly.

The story actually gets better. Indoor traffic demands greater radio resources from the macro-cellular network than outdoor traffic because signals from the macro-cellular site must penetrate one or more walls to reach the indoor subscriber. Therefore, the benefit to the macro network is actually greater than the percentage of traffic offloaded, because those subscribers whose data is offloaded are not average users; they are the most *demanding* users, because they are all sitting behind radio-wave absorbing walls, which make them harder to reach than the subscriber sitting outdoors on a park bench.

The impact of environment (an indoor user versus an outdoor user) on achievable data rate is shown in Figure 4:

Figure 4: Cell Range versus Data Rate, Indoors and Outdoors[19]



Neu Mobile[20] calculates that the marginal cost of adding 1 Mbps of capacity using a femtocell is approximately 1/200th of the cost of adding the same capacity using a macro-cellular infrastructure.

Small cells can support an exceptionally high traffic density. According to a study[21] by Dr. Hamid Falaki of NEC Europe, by simulating the data rates of LTE macro, micro, and picocells, each in three different frequency bands, LTE picocells are able to deliver 200 times the traffic density of LTE macrocells. An enterprise or public access femtocell is the functional equivalent of a picocell.

NSN and Ericsson both describe in white papers the uneven distribution of traffic. NSN[22] indicates that "50% of traffic is carried by 15% of the cells." Similarly, Ericsson[23] indicates "20 percent of the sites carrying more than 50 percent of the total network traffic." Highly concentrated in-building traffic is relatively easy to offload with femtocells.

Finally, it is important to ask "What do we mean by usage?" If usage is measured in MBs and GBs then the above argument is complete. If usage is measured in time, as in "How many hours per day do you use your smart phone at home, at the office, and elsewhere?" then we need to add another dimension to the calculations: usage intensity. If someone is seated in their office it is easy to imagine them consuming large amounts of data. If that same person is sitting at home sipping a cup of coffee, watching a video that is being streamed to a laptop, it is also easy to envision that person using a lot of data.

If that same person is driving a car or walking down the street there are some applications they may use, but they are generally less data intensive. While driving, the subscriber might be using a navigation application. Their phone might also be downloading e-mail in the background, for viewing at a later point in time. They're not likely to be watching a streaming video or browsing the web. In the same way, someone walking down the street might receive a text message or might receive a set of alerts from their social networking application. While each of these is engaging and beneficial, neither consumes a significant amount of data.

Thus, if "usage" is determined via an end-user survey (as opposed to a quantitative measurement tool, such as a piece of software running on the subscriber's phone counting packets) the end-user is more likely to describe their behaviour: time spent interacting with a mobile device or the benefit derived from the device, as opposed to the number MBs of data consumed. To the extent these home/office/elsewhere ratios reflect behavior, as opposed to actual data usage, then the ratios of actual usage may be even more skewed than we first imagined. The discussion above highlights the tremendous opportunity to reduce macro-cellular traffic using femtocells.

Finally, it is important, to note that as traffic is offloaded, end-user experience typically improves, because the femtocell produces a nearly ideal radio environment. The latest versions of HSPA support advanced modulation techniques (e.g. 64 QAM). In a femtocell environment users are likely to benefit from these features. In a macro-cellular environment only a small portion of users will, at any point in time, be in a sufficiently ideal radio environment to use 64 QAM (as an example). Thus, some of the capabilities of modern radio access technologies are most likely to be experienced first in a femtocell environment.

If you are in a public venue and need to make phone calls or download data and you discover that one room has excellent macro-cellular coverage and another room does not, in which room are you most likely to stand or sit as you talk and/or download information? Most people would say "the one with the better coverage". Thus, creating environments (home, office, public venue) where radio performance is excellent is likely to attract data-hungry users and data usage in greater numbers than in poorly covered or poor-performing (from a capacity perspective) areas.

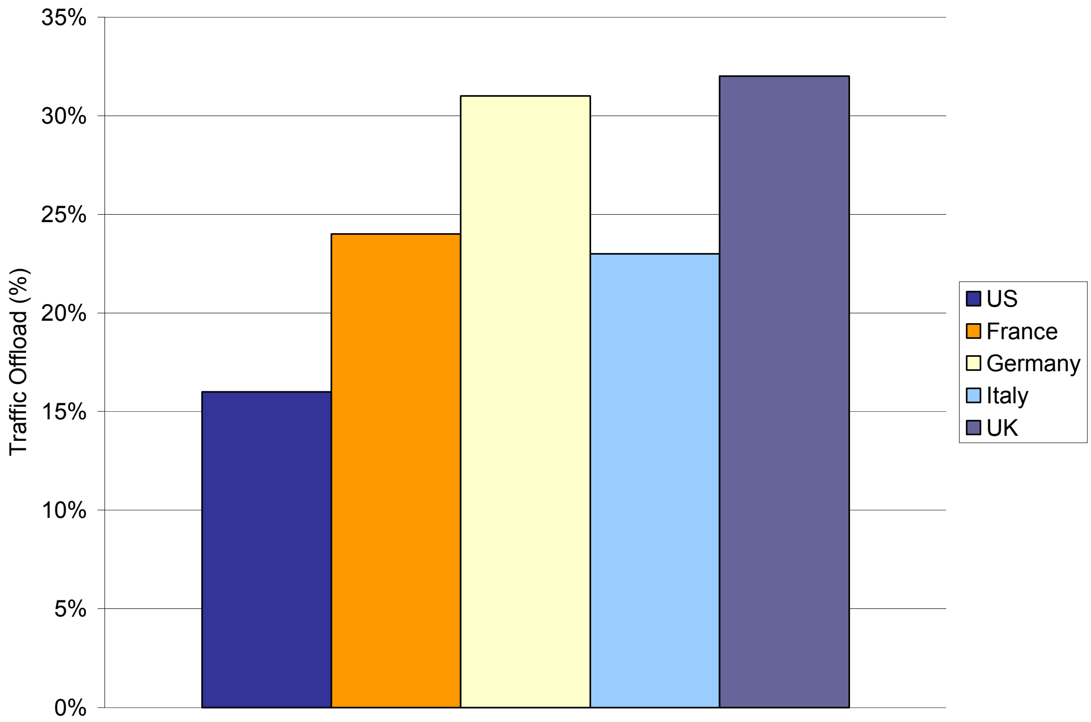
An analogy in the physical world is the M25 motorway[24] that encircles London. Envisioned in the 1930s, constructed in pieces beginning in 1973, and completed in 1986, its traffic quickly exceeded its maximum designed capacity. By 1993 the motorway, which was designed to carry 88,000 vehicles per day carried 200,000 vehicles per day. This unexpected increase in traffic led to multiple phases of widening (increasing the number of lanes) and to the introduction of a number of sophisticated traffic management technologies.

London motorists, like motorists in many other cities, know a good thing when they see it. If they can move quickly from point A to point B using a new infrastructure they will choose to do so. Similarly, when mobile subscribers "discover" new network capabilities (greatly improved coverage, significant increases in data speeds) they will often adapt their behaviour to reap the benefits. Mobile operators often plan for years for a new site, then discover, as soon as it goes on the air, that traffic appears from nowhere to fill a large portion of its capacity.

Technologies for the Home: Femtocells, Wi-Fi, Ethernet

How much data is currently offloaded in the home, and via which technologies? Cisco's VNI Global Mobile Data Forecast, which examines the factors influencing offload, estimates the portion of traffic that is likely to be offloaded to Wi-Fi and/or femtocells by country. Representative numbers for North America and Western Europe appear in Figure 5:

Figure 5: Expected Macro-Cellular Data Offload by Country in 2010 25



If 30% of the traffic is being offloaded today in "high offload" countries, then 70% of the traffic is *not* being offloaded. As femtocells become more common one would expect an increasing percentage of traffic to be offloaded onto femtocells.

Wi-Fi is an inexpensive and widely available solution today. As femtocells begin to ship in greater volumes, their wholesale and retail prices will decline. In many cases today the retail price reflects not only the hardware cost of the femtocell, but a significant operator subsidy, reflecting the motivation of the operator to place femtocells in the hands of consumers who will use them.

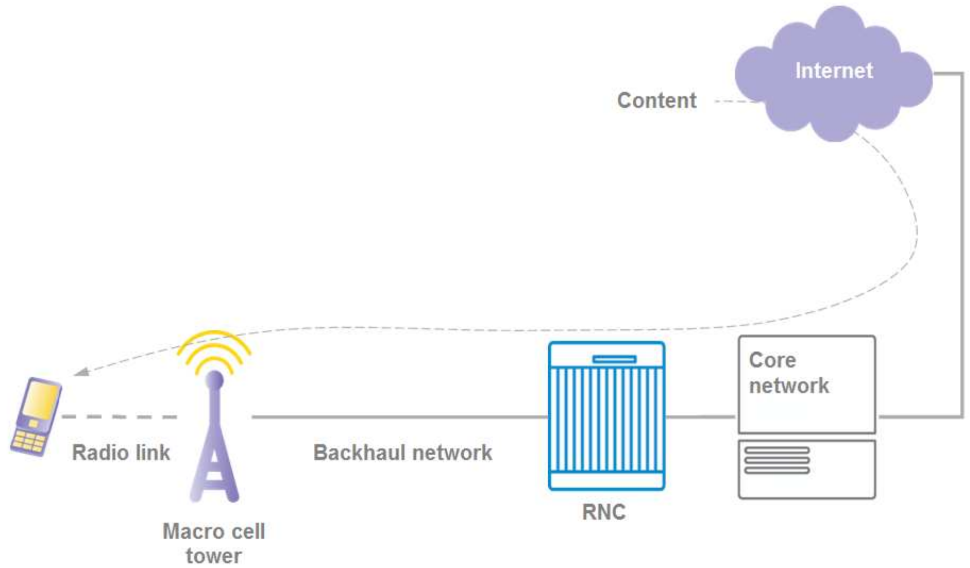
The strength of femtocells, from an offload perspective, is that they capture 100% of the traffic, whether it is voice or data, and whether it originates from a feature phone, a smart phone, or a mobile broadband-enabled laptop. An end user can choose to send traffic over other networks (e.g. Wi-Fi) by unplugging a laptop's USB dongle or otherwise disabling the wide area radio. In the absence of a conscious decision, however, data will flow over the femtocell. Since a femtocell is an extension of the operator's network, mobile devices find the femtocell automatically and authenticate themselves using the same protocols they use on the macro-cellular network. There are no passwords to memorise and no need to choose among available networks. Femtocells are effective, in large part, because they require no effort on the part of the subscriber. Some operator-managed networks of Wi-Fi hotspots have also automated registration, bringing cellular and Wi-Fi radio access technologies closer together.

Femtocells have a further advantage in that they do not increase battery drain. A laptop can easily operate a mobile broadband dongle and Wi-Fi. Wi-Fi-enabled smart phones can also do so, but frequently they experience increased battery drain because of the power required to operate two radios. While Wi-Fi power management is rapidly improving, the prospect of increased battery drain remains a concern for some users.

Traffic Offload: How it Works

In the operator's macro-cellular network the operator leases a site, incurs significant civil (site improvements, shelters) and ancillary (antennas, coaxial cable, battery backup, air conditioning) costs, purchases radio infrastructure, and purchases (microwave) or leases (T1/E1) backhaul infrastructure before delivering the first phone call, text message, or e-mail update. As usage increases, these costs also increase. Operators may add capacity to existing sites or may build entirely new sites. The architecture of a traditional macro-cellular network is shown in Figure 6:

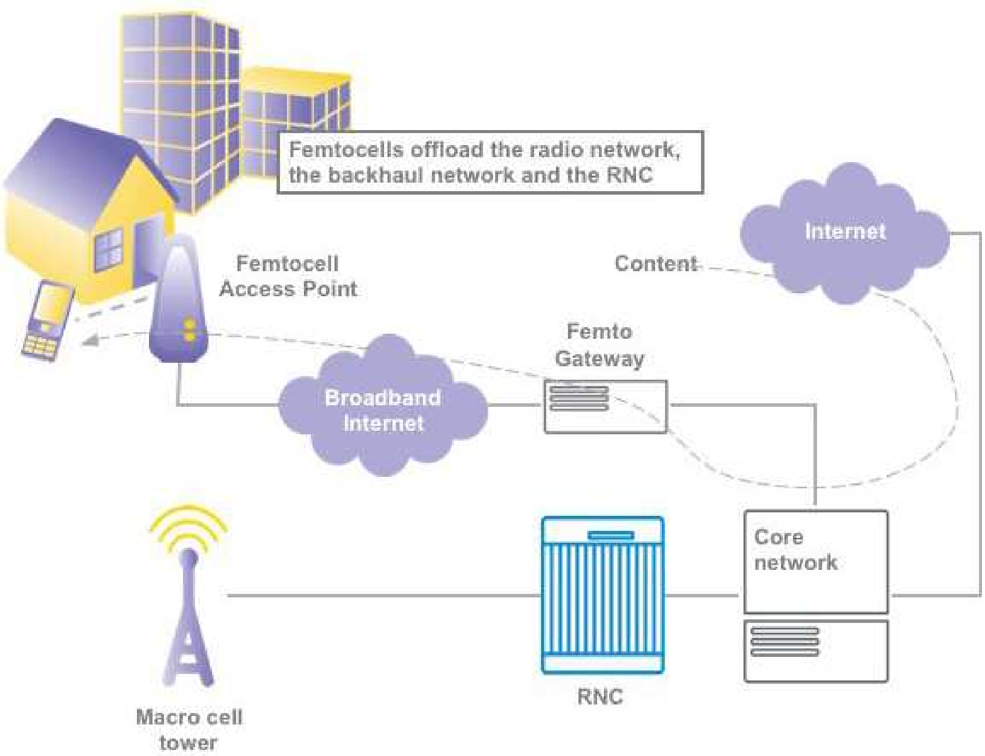
Figure 6: Internet Access via a Macro-Cellular Network



In a femtocell environment the operator supplies a femtocell. The consumer attaches it to his or her broadband connection. Traffic then flows over the air to the femtocell then over the internet to the operator's core network, and/or to other internet destinations. In a residential environment a femtocell is likely to supply as much data bandwidth as the subscriber is able to consume. If there is a limitation it is most likely in the speed of the residential or enterprise broadband connection, but this same limitation also applies to wired and Wi-Fi connected devices in the home or office.

When a subscriber enters his home or office the devices automatically associate with the femtocell. Traffic that would have flowed between the macro-cellular site and the subscriber's phone/PDA/MID/laptop flows instead through the femtocell and the subscriber's broadband connection.

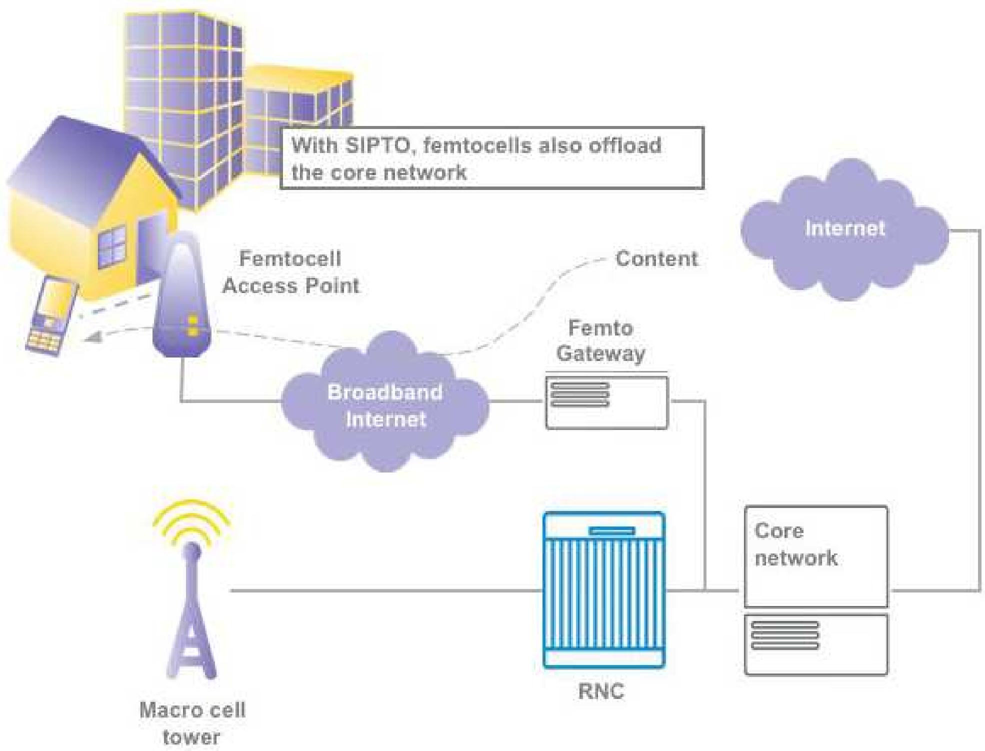
Figure 7: Internet Access via a Femtocell



Studies of measured traffic indicate that mobile broadband usage peaks in the late afternoon, evening, and late evening – the very hours most consumers are at home. Thus, residential femtocells are likely to be highly effective in reducing demand during those periods that matter most to operators.

Architecturally, the femtocell also absorbs the RNC, which further lessens the load on the macro-cellular network. Finally, the industry is developing a new standard called *Selected IP Traffic Offload (SIPTO).* SIPTO allows internet traffic to flow from the femtocell directly to the internet, bypassing the operator's core network, as shown in Figure 8.

Figure 8: Internet Access via a SIPTO-Enabled Femtocell Architecture



The Economics of Traffic Offload

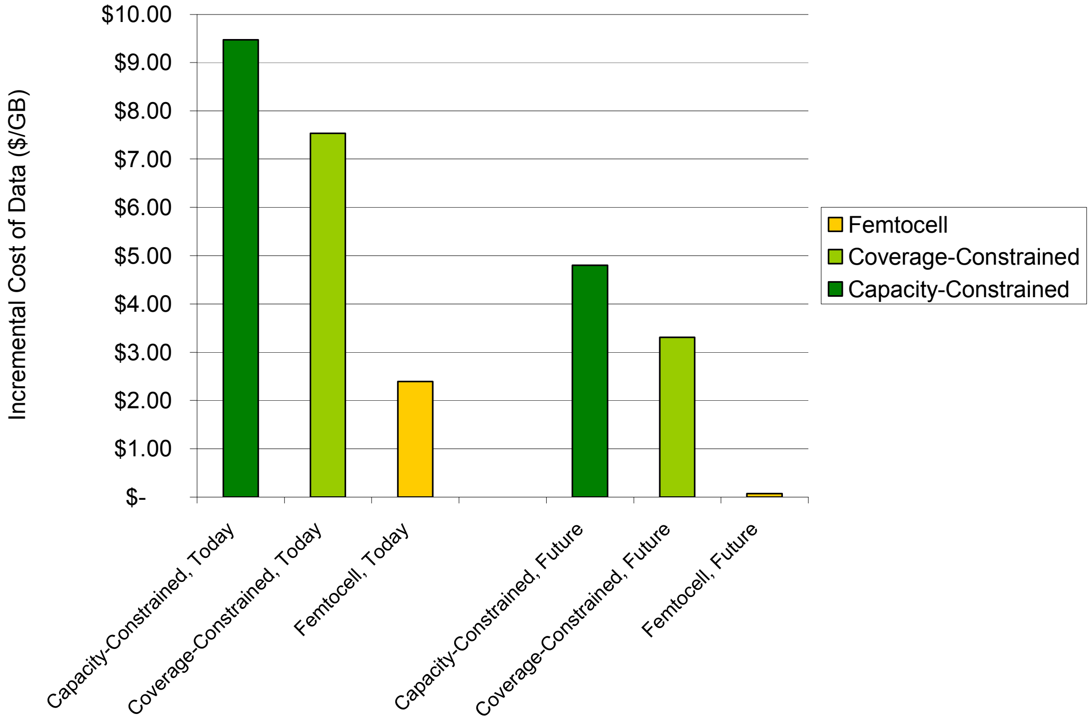
Macro-cellular costs vary by radio access technology, amount of spectrum, market demographics, and overall demand. Macro-cellular costs can be calculated on a unit cost basis ($/minute, $/MB).

According to the analysis originally conducted in the “Femto Forum Business Case Whitepaper”, June 2009 , and updated for this white paper, the use of femtocells can lower the marginal cost per GB of data delivered by 4 times with current technology in the capacity-constrained case and significantly more using a forward-looking scenario. In the forward-looking scenario the capacity-constrained marginal cost per GB for a macro-cellular network is $4.80 compared with $0.07 (7 cents) for the marginal cost of delivery through an existing femtocell. Femtocells reduce costs by offloading the radio access network (RAN), the backhaul network, and the radio network controller (RNC) which processes the growing level of smart phone smart phone signaling traffic.

Figure 9 shows the marginal cost per GB of capacity-constrained and coverage-constrained macro-cellular networks today and in the future. It also shows the cost per GB of data traffic flowing through existing femtocells.

The important conceptual frameworks and the many numerical assumptions behind these calculations are described in a section at the end of the paper, entitled “Note on Cost per GB Calculations.” The interested reader is strongly encouraged to read that section.

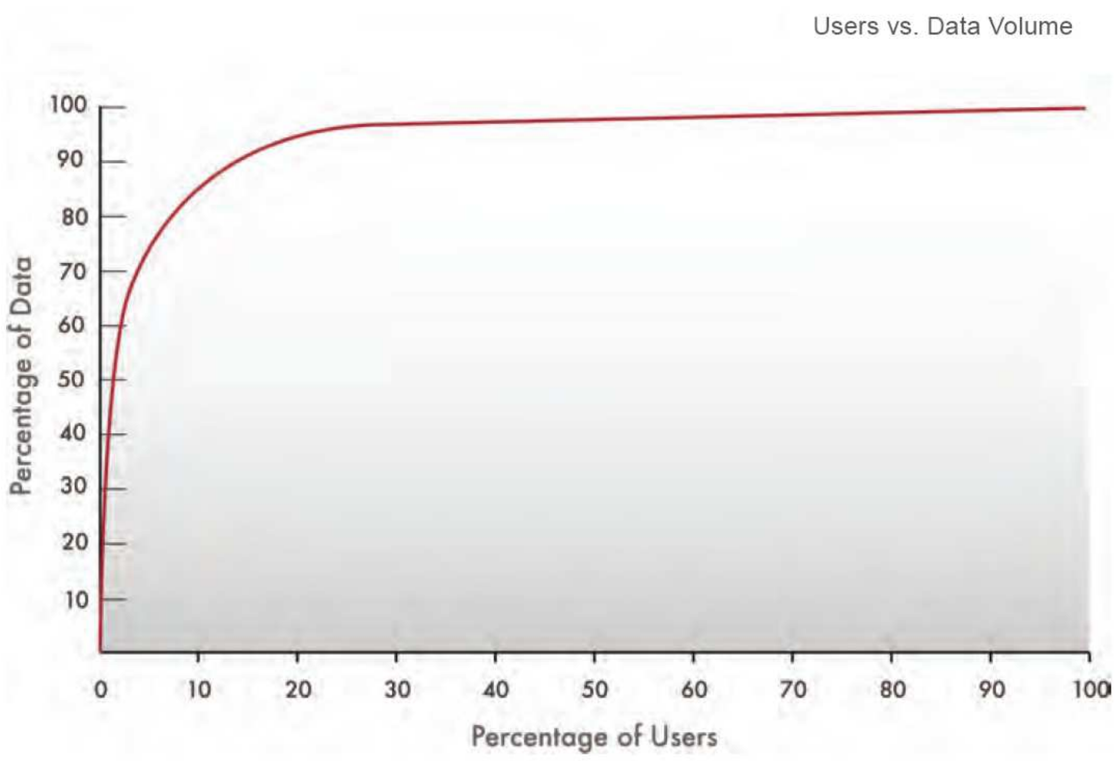
Figure 9: Marginal Cost per GB



Important Observations

Many industry observers point out that a small percentage of users consume most of the data. In almost every type of data network (mobile infrastructures, ISPs, corporate data networks) a distribution, showing the number of users versus the number of GBs consumed per user, is heavily skewed to the right. This means that the average (mean) usage is much greater than the median usage. In other words, a small percentage of the users generate the vast majority of traffic. Figure 10 shows a mobile environment where 85% of the usage comes from 10% of the data users.

Figure 10: Percentage of Users versus Percentage of Data (Cumulative Distribution)[26]



An operator seeking to reduce macro-cellular traffic might encourage heavy data users to become early adopters of femtocells. The operator benefit is proportional to usage. Monthly data offload cost savings is the monthly usage in GBs (macro-cellular cost less femtocell cost) times the percentage of that usage that occurs in the home, times the marginal cost per GB of usage on the macro-cellular network. The benefit to the operator of offload is therefore the present value of the monthly cost savings over the expected life of the subscriber.

Here is an illustrative calculation. Imagine that an "average" mobile broadband data subscriber consumes 1 GB per month. Someone in the "top 10%" of users might therefore consume 8.5 times 1 GB, or 8.5 GBs per month. Further assume that 55% of mobile data usage occurs in the home and that the average data user has a lifetime of 48 months. If the macro-cellular network is coverage-constrained at a marginal cost of $3.30 per GB, if the marginal cost of data transmitted through a femtocell is $.07 per GB, and if the weighted average cost of capital is 10%, then the present value of the data offload cost savings is PV(10%/12, 48, 1x55% x (85%/10%)x($3.30 - $.07)) = $595.38. If the fully-allocated cost of a femtocell (the access point + a large number of allocated costs) is $200.00, then the operator saves a significant amount of money by providing the heavy user with a free femtocell.

In looking for offload opportunities an operator might ask the following questions:

- Is data usage distributed evenly across the subscriber base or do some individuals or, more importantly, some families or enterprises consume a disproportionate amount of data?

- In considering a typical heavy user, is their usage distributed evenly across many cells or does it occur largely in one or two locations? If usage is concentrated in one or two locations this might indicate an opportunity for data offload via a femtocell.

How could the widespread adoption of femtocells impact operator valuations? According to Arthur D. Little, significant levels of offload will translate into improved operating free cash flow[27]:

> We expect operators to increasingly offload part of their mobile data traffic onto fixed broadband networks, through WiFi hotspots (already a very significant part of the iPhone traffic at Orange France, O2 UK and AT&T in the USA) or femtocells (just launched by Vodafone UK and SFR in France). If 30% of the traffic was captured this way at a very low cost, it would boost long-term sector OpFCF by 4% thanks to large savings on 3G capacity capex.

An operator with an intimate knowledge of their customers can easily imagine incentives that would meet the operator's objective of offloading traffic via femtocells, and at the same time delight the data-oriented customer with exceptional indoor performance.

Additional Resources

The following publications might be helpful in developing a refined understanding of the issues discussed in this paper:

- Informa Femtocell Market Status - June 2010
  http://femtoforum.org/femto/index.php?id=69%29

- Wireless in the home: the need for both 3G femtocells & Wi-Fi access points - January 2010
  http://femtoforum.org/femto/index.php?id=69%29

- Femto Forum/Park Associates Consumer Market Research Report for the Femtocells World Summit – June 2010
  http://femtoforum.org/femto/index.php?id=69%29

- The Business Case for Femtocells in the Mobile Broadband Era - Signals Research - May 2010
  http://femtoforum.org/femto/index.php?id=69%29

Note on Cost per GB Methodology

Macro-cellular costs vary by radio access technology, amount of spectrum, market demographics, and overall demand. Macro-cellular costs can be calculated on a unit cost basis ($/minute, $/MB).

In calculating offload cost savings what we care about is the marginal cost – not the average cost – of the macro-cellular network. As a result, offload effects are greatest in a capacity-constrained environment, even though average operator costs are highest on a per MB basis in a coverage-constrained environment.

A business planning white paper published by the Femto Forum in 2009[28] shows macro-cellular HSPA costs in the range of $ 9.47 (capacity-constrained) to $ 7.53 (coverage-constrained), and femtocell costs of $ 2.39 per GB. These figures assume a traditional core network at 2008 costs, a 10% voice-oriented busy hour, and a backhaul network, which, although it uses a mixture of microwave and metro-Ethernet, has a cost similar to that of an E1/T1 backhaul, because the traffic levels are modest. The numbers also assume that 100% of the voice and data traffic of the femtocell flows through the operator's network (before SIPTO) – which is how it works today. These are relatively conservative assumptions and lead to a 4 times reduction in the cost of data delivery in the capacity-contrained case and and a 3 times reduction in the coverage-contriained case. Many forces are at work today (technological and regulatory) that will cause these numbers to decline.

If we fast forward a couple of years a different picture emerges. The rapid growth in data traffic will force operators to ask the question "What backhaul architecture is optimal?". This is a question operators have repeatedly asked since the inception of the wireless industry, but the answer keeps changing as the volume of voice and data traffic continues to increase, and as new backhaul technology choices emerge.

Greatly increased traffic per site will provide economic incentives to third parties to begin offering *aggressively priced* carrier-grade Ethernet solutions. Many of the issues that cause operators today to hesitate in migrating to Ethernet solutions (concerns about latency, jitter, service level agreements, and OA&M tools) will be solved. Pseudowire will become more common. We will also see a significant increase in the number of fiber-connect cell sites, but the cost of ubiquitous fiber connections – estimated by Neu Mobile[29] at € 350,000 per site, for countries which already have a significant amount of dark fiber – will limit the number of fiber connections.

Our forward-looking or "future" view (notionally 2012) assumes that 53% of sites enjoy "deep-discount" Ethernet backhaul connections. The others have T1 connections, or unstructured Ethernet connections with T1-equivalent prices. We assume that the "legacy" sites pay $300 per 1.54 Mbps of bi-directional bandwidth (>> $195 per 1 Mbps) and sites with "deep discount" backhaul pay ($75+$40)/2, or $57.50 per 1 Mbps of bi-directional bandwidth (e.g. 1 Mbps in each direction). These figures come from an analysis by Yankee Group[30] that estimates the cost of different types of connections, most of which are significantly lower than the average global cost of backhaul which they estimate at $228 per 1 Mbps per month ($6.7 billion/245,000 sites/10 Mbps per site/12 months) today.

We also recognise that with increasingly data-dominated networks, busy hours are flattening. Nokia Siemens Networks assumes a 7% data-only busy hour[31]. We have incorporated that assumption into our future-looking calculations.

It is important to recognise that a number of things are happening in the core network, that also significantly reduce cost. Operators – as they plan for LTE – are migrating to a flat IP core network. At the same time, Moore's law is reducing the cost of core network infrastructure. SRG's recent white paper on The Business Case for Femtocells in the Broadband Era[32] estimates the cost of the core network at $0.00050 per MB for data in 2012.

We have used this figure – with two adjustments – to calculate core network costs in the "future" figures. The first adjustment is that we have flattened the busy hour – consistent with NSN's assumptions – from 10% (reflecting a more traditional voice-oriented network) to 7% (reflecting a very flat data-oriented network). This "flattening" has a proportionate downward impact on costs. Secondly, we have assumed, in the case of the femtocell, that the SIPTO standard is invoked and that 80% of the data traffic does not flow through the operator network. In some countries there may be regulatory barriers to using SIPTO, in which case this additional 80% saving may not be realised. Finally, there are some benefits that a femtocell provides – such as replacing the RNC functionality of the network – which represent further cost savings. These cost savings have not been included in the marginal cost calculations.

The cost calculations shown in Figure 9 were calculated using the Femto Forum Business Planning Model v 2.01 (advanced tab)[33] with traffic levels adjusted to force the result to be either coverage-constrained or capacity-constrained. In the case of the macro-cellular network they include both site-related and core network costs, including a weighted average cost of capital of 10%. They assume a five-year straight-line depreciation on electronics and a ten-year straight-line depreciation on site-acquisition and civil costs. The femtocell business planning model – by default – removes certain large categories of cost (site acquisition/civil and monthly site lease) in calculating the coverage-constrained marginal costs, since in a coverage-constrained scenario – by definition – the number of sites will not change.

It includes most other costs (radio infrastructure, ancillary electronics, transmission expense, and maintenance/network optimisation costs), since each of these will vary with the number of radio carriers. Some of these costs, in fact, might "spike" when an operator adds an additional radio carrier. For instance, if the system needs to be re-optimised, then a lot of site technician time is involved. A large portion of the "average" maintenance cost (most of which is labour) is associated with physical changes to the network. If nothing is added or removed from a site then the amount of technician time needed to maintain that site may be close to zero. If the operator adds carriers in a new frequency band or changes the antenna configuration in any way, this involves a lot of labour and could also result in an increase in the site lease (more and/or larger antennas or more coaxial cables often means a higher monthly lease). The optimisation costs associated with adding a new carrier may actually be greater than those assumed in the model.

Some would argue that the marginal cost of an additional radio carrier is very small. Suppose, for instance, that an operator has spent the money to invest in dark fiber in the site and has purchased the electronics at either end to carry an almost unlimited amount of traffic. If the system needs no retuning then – one might argue – the cost of capacity is simply the cost of that additional radio carrier, divided by its usage. This argument is valid as long as its underlying assumptions are true. Unfortunately, that "space" where the assumptions are true is extremely narrow. At some point the operator will deploy the last radio carrier for which spectrum is available. The operator will be forced to bid in a public auction for additional spectrum (another large cost we have not included) or will purchase additional spectrum from a third party (if possible in that country), or will be forced to cell-split. If the operator cell-splits all the fixed costs associated with a site will be incrurred, plus – in this scenario – the extremely high cost of running dark fiber to the site (€350,000), which is necessary to achieve the low incremental cost of backhaul assumed in the scenario.

Rather than viewing costs in such extremes (near-zero incremental costs followed by large up-front expenditures when the capacity of the existing site is exhausted) we have assumed that operators would purchase connectivity from third parties who would smooth out the cost curve. A carrier-grade Ethernet provider, for instance, might make the enormous investment in fiber that enables them to offer high bandwidths at highly competitive prices per Mbps. That carrier-grade Ethernet provider – like anyone in a largely fixed cost business – might sell service initially at a price below their fully loaded cost, in the hope that as mobile operators purchase more and more bandwidth and as multiple operators sharing a site purchase bandwidth carried over the same fiber infrastructure, the profits of the Ethernet provider might, over time, become strongly positive, compensating for the provider's risk-taking and early years of losses.

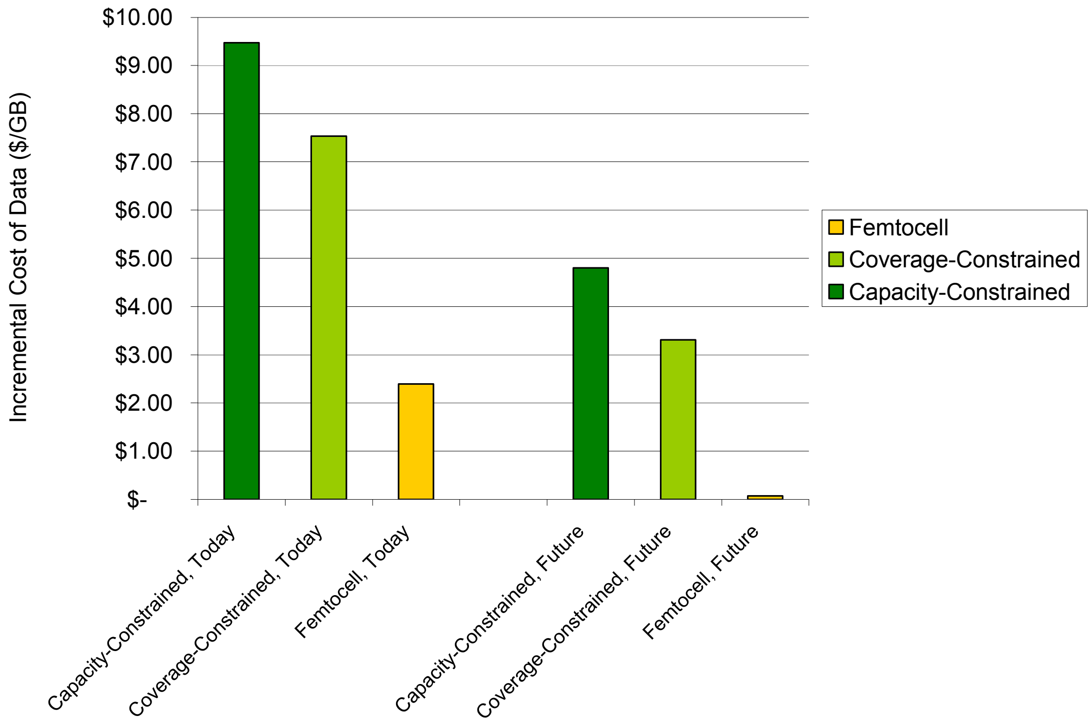
These are the same kinds of bets that any fixed operator will make. An incumbent fixed operator will invest in fiber in the hope of selling expensive advanced services. Those revenues might or might not be realised and the fixed operator might operate at a loss – on an incremental basis – during the transition period between the point in time when the new technology is introduced and when it is becomes sufficiently utilised to be clearly profitable on an incremental basis.

That operator, in turn, might sell services to their customers where the price of service is proportional to the maximum data rate or the volume of data. A DSL operator, for instance, is likely to sell 6Mbps service for significantly more than 1Mbps service, even though each uses the same copper loop and the same VDSL-capable DSLAM card. We have assumed, therefore, that third party carrier-grade Ethernet providers are likely to price their service in a way that is largely proportionate to the bandwidth consumed, even though their own cost structure might be slightly different.

In studying incremental costs there is also the issue of "lumpiness". A classical incremental cost discussion includes an airline with empty seats just before takeoff. One could argue that the increment cost of flying an additional passenger is simply the cost of the peanuts and the cup of coffee the flight attendants will feed that passenger. If the airline can sell the seat for $5.00 – the argument goes – it makes sense to do so, since $5.00 exceeds the cost of the peanuts and coffee.

If we step back, however, and look at incremental costs from a slightly broader perspective, there might be other options. If the airline has the operational flexibility it might downsize the flight to a smaller aircraft. Alternatively, it might leave the seats empty and load the belly of the plane with air freight that it had planned to put on a later flight, or the airline might choose to carry less fuel because the plane is far below its maximum gross weight and so might consume slightly less fuel. Finally, if the airline discovers the "trend" in passenger traffic with sufficient advanced notice, it might reduce its schedule of flights or consolidate two half-filled flights with closely separated departure times. The point is that, depending upon how we evaluate marginal costs, and what we do with the "lumps", we can arrive at different answers, each perfectly valid within its own set of assumptions.

Figure 9 (Repeated in Note): Marginal Cost per GB



Some will ask "How do you calculate the incremental cost of a femtocell?". The numbers in Figure 9 assume that the household already owns a femtocell. The marginal cost of the femtocell is, therefore, the difference in cost between leaving the femtocell on your bookshelf unused and turning it on so that it can carry traffic. If you asked the owner of a Wi-Fi access point, "What is the marginal cost of carrying traffic over your access point?" you would probably see a puzzled look then hear the answer "zero". The logic is simple. That consumer invested in the access point for convenience (so that they could use his devices anywhere within the home) or to avoid more costly alternatives (e.g. ripping out walls to string CAT5e cables). In the consumer's mind, the cost of the Wi-Fi access point is a sunk cost. The incremental cost of usage is, therefore, zero.

A femtocell is similar – with a twist. The consumer might have purchased it for coverage and/or for the features it enables. The question then is, "What does it cost to operate the femtocell?" Today, all traffic is routed through the operator network, so there is a small cost. As the SIPTO standard becomes available and as operators introduce it, much of that cost will disappear, because traffic will be offloaded from the core network. Imagine that the Wi-Fi owner purchased a Wi-Fi access point that was UMA enabled and used it for voice calls in conjunction with a mobile operator that supported that technology. In such a scenario those voice packets would be routed through the operator's core network, including a UMA gateway that is virtually identical to a femtocell gateway (in fact, some gateways support both technologies). Suddenly, in such an application, the Wi-Fi gateway is no longer free on a marginal-cost basis. Its marginal cost per minute would be similar – perhaps identical – to that of a femtocell.

Is there another way to look at the cost of the femtocell, which does not assume the household owns it? Yes. The approach one uses depends upon the purpose of the calculation. Consider two automobile owners. Owner A purchases an automobile then keeps it in her garage for a year without driving it. Owner B purchases an identical automobile on the same day, but drives it 100 miles a day (he is a traveling salesman). The two decide to meet for coffee one mile from their respective homes. Owner B hops in his car and drives to the café. Owner A thinks "I can't drive – its too expensive!". She looks at the depreciation of her brand new automobile over the past year and divides it by 1 (for one mile). She concludes that it is much cheaper to take a taxi. Is she correct? No. Her reasoning is flawed because she fails to realise that the decision to purchase the car – now a sunk cost – is independent of her decision to drive or to take a taxi to the café.

If the scenario were slightly different her logic might make sense. For instance, if she knew that she had a 10-mile daily commute she might use that information as part of her decision to buy the car. In such a context she could reasonably compare the fully allocated cost of the car (depreciation, cost of capital, maintenance, insurance, etc) to the cost of getting to work some other way (e.g. by mass transit). On that basis she could decide whether or not to buy the car.

We have calculated the marginal cost of a femtocell for a *specific purpose*. In Section 8 of this whitepaper we showed that an operator can compare the marginal cost of carrying traffic via a femtocell to the marginal cost of carrying traffic via the macro-cellular network. At a certain point, when the difference in the marginal cost per GB between the two networks times the usage per month of the customer is large enough, a rational operator will become highly motivated to get that customer to use a femtocell, and may be willing to heavily subsidise it, because the savings in network costs will quickly amortise the purchase price of the femtocell.

Finally it is important to highlight two additional dimensions: (1) the cost of the internet connection; and (2) the economics of enterprise and public venue femtocells. In a residence, we ignore the cost of the internet connection, since most residential broadband connections are flat-rate or, if they are tiered, have a relatively gentle slope. We therefore assume that costs do not change as a result of the femtocell. There are some instances where this may not be the case (highly usage sensitive broadband rate plans and competitive/regulatory scenarios where the mobile operator and broadband provider are at odds and the broadband provider seeks to extract revenue from the mobile operator for the use of bandwidth). There may also be instances where a single operator sells a bundle that includes both the broadband connection and the femtocell. In each case, the calculations would be different and one would consider the incremental cost of the additional fixed broadband traffic.

The enterprise and public access spaces are also different. The enterprise femtocell market is in its infancy, so dominant business models have yet to emerge. In some cases operators will sell the femtocell to the business and say "Plug it into your broadband connection. Make sure to provision the specified bandwidth." In other cases, the operator might actually pay for the broadband connection. In such a scenario the enterprise femtocell is similar to existing in-building picocellular systems, which operators instal under a wide variety of business arrangements.

In the public access space, a femtocell becomes very similar to a macrocell in how the operator calculates cost. Each requires a capital investment. Each has operating expenses (site acquisition, monthly site leases, etc) and each carries a certain amount of traffic. While the numbers (capital investment, operating expenses, and traffic) may be very different, the conceptual framework is the same. In such a scenario, the operator must become convinced that the public-space femtocell will carry enough traffic that, despite its greatly reduced cost, it is less expensive on a unit cost basis than a macrocell. A public-access femtocell in the middle of a shopping mall will probably meet this test with flying colours. A public-access femtocell on a farm – or in some other remote location – might not.

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