Femtocells for Wireless in the Home and Office

RUNE HARALD RÆKKEN

Rune Harald Rækken is Senior Advisor, head of technical vendor management and LTE, Telenor Corporate Development

Femtocells have been a hot topic since 2007, but femtocells are still struggling to get market acceptance. So far we have seen 12 launches including trials, and there is still a large uncertainty of the future footprint of femtocells.

Toward the users the promises of femtocells are first and foremost better indoor coverage and capacity, as well as specific femtozone services like notifications when the children enter or leave the home. The femtocell is also a means for connecting the mobile phone smoothly to the connected home network.

For the operator femtocells can be a platform for maximising revenue and margin through significantly lower delivery costs, as well as the possibility of increasing network capacity without the need for further investments in macro network upgrades. Offloading of the macro network has became an extremely hot topic amongst operators experiencing capacity problems in the mobile broadband network due to extensive use of smart phones and large screen terminals (PCs) connected through the mobile broadband networks. It is imperative for the mobile broadband operators to handle the ever increasing capacity needs in a cost effective way to keep the business sustainable. Femtocells is a solution to meet the operator community's urgent need for handling the rapid increase in mobile broadband usage that challenges the operators' profitability.

We know quite well the technical performance and roadmaps of femtocells, whereas there is a larger uncertainty with respect to the market acceptance of femtocells. Even though several launches have been announced, the real proof of the concept is the market uptake and user approval of the femtocells technology.

Sprint in the US launched 2G femtocells supporting the CDMA 1xRTT standard in 2007 and is about to update the service to support the 3G CDMA EV-DO standard. The most recent launches are Vodafone UK's launch of the 3G UMTS/HSPA femtocell service named 'Sure Signal', as well as AT&T's femtocell launch in the US. Reports indicate a rapid growth in the uptake of femtocells in the UK, whereas the launch at AT&T is too recent to give any figures.

What are Femtocells? Why Should We Deploy Them?

Femtocells are small, low power base stations that utilise a fixed broadband connection as backhaul to provide 3G indoor coverage as shown in Figure 1. Femtocells use licensed spectrum owned by a mobile operator, and the aim is that there should be a smooth co-operation between the macro network layer and the femtocells layer to ensure a cost effective delivery of services as well as a good user experience. The main benefit of femtocells over competing solutions like UMA (Unlicensed Mobile Access) or Wi-Fi is that femtocells will support speech services over standard handsets in addition to mobile broadband services. Wi-Fi on the other hand benefits from the large penetration of Wi-Fi enabled devices like PCs,

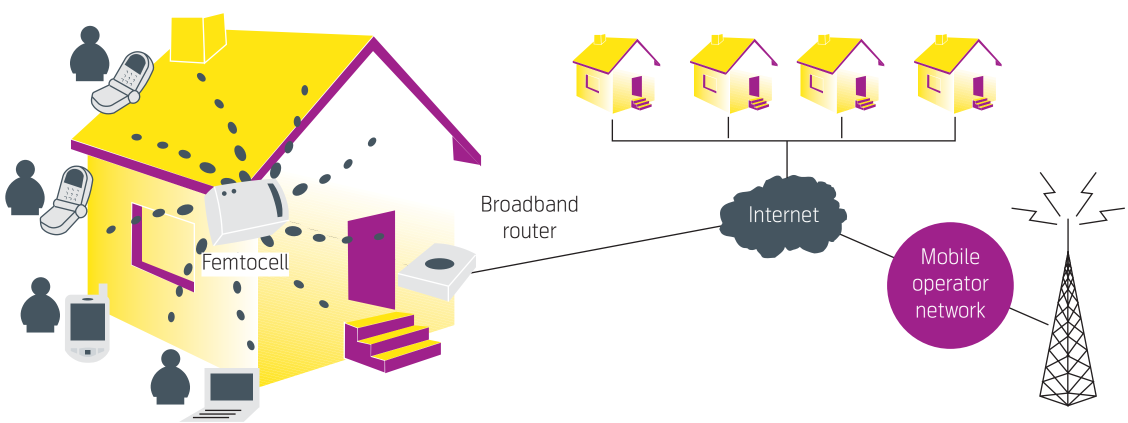

Figure 1 Femtocell network. Source: Femto Forum, www.femtoforum.org

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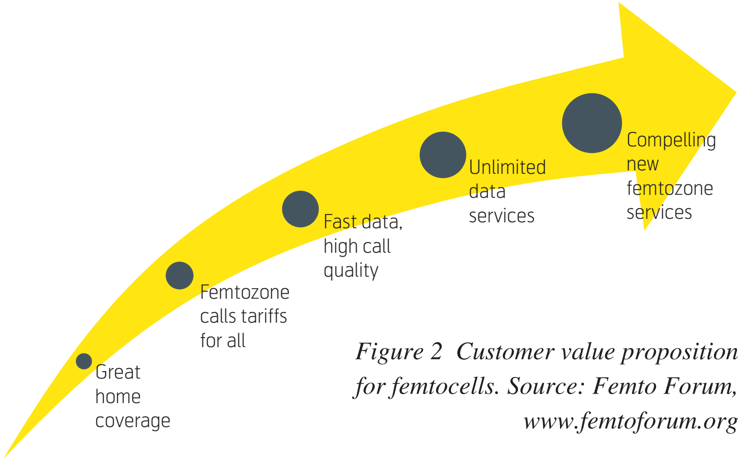

Figure 2 Customer value proposition for femtocells. Source: Femto Forum, www.femtoforum.org

but Wi-Fi lacks voice support and is hence not an adequate solution for subscribers suffering from poor indoor coverage.

Femtocells also make it possible for the operator to provide quality of service (QoS). Another benefit of femtocells is the very accurate indoor location of the users. This enables significantly improved presence management, making it possible to generate notifications or tailored information to users entering the femtocell coverage area, one of several so-called femtozone services.

Femtocells are also available for GSM/EDGE, CDMA 1xRTT, CDMA-2000 and WiMAX, and LTE femtocells are under specification. A prototype of an LTE femtocell was shown at the Mobile World Congress in Barcelona this February. Throughout this article focus will be on 3G UMTS/HSPA and LTE femtocells.

For the operator the main drivers for femtocells are cost efficient deployment of coverage and capacity for data hungry mobile broadband users, through offloading of the macro network. This seems particularly attractive as a majority of the mobile broadband users are located indoors. High building penetration losses from outdoor base stations to indoor users significantly reduce coverage as well as cell throughput from outdoor base stations. Offering better coverage and capacity to the users, as well as offering 'sticky' services will also tie the customer closer to the cellular operator. Hence femtocells is a means for the operators to significantly reduce churn.

Figure 3 Product examples. Home femtocell to the left and enterprise femtocell to the right. The home femtocell shown in this figure is the femtocell that is available in the Vodafone UK 'Sure Signal' offering. Source: Alcatel Lucent

For 3G femtocells improved coverage for speech services will be the main initial driver. For LTE, promising extremely high data rates to each individual user, it will be imperative for the operator to provide dedicated indoor solutions like femtocells to meet customer requirements. Femtocells will play a more important role in LTE than in 2G and 3G. Even though the initial LTE deployment strategy would be to build coverage outside-in, as the usage increases a wiser coverage strategy could be to build capacity inside-out.

For the user the main drivers are better coverage and capacity, as well as better price plans and access to compelling new femtozone services and true Fixed and Mobile Convergence (FMC) as the femtocells can be the bridge between the connected home and the users' personal mobile phone. This is illustrated in Figure 2.

Home femtocells have to be cheap and match the end-user price level of Wi-Fi routers to become a success, meaning that the target price could be somewhere around $100. If products are not available at this price the operator should consider subsidising the femtocells, as we have seen in some of the current deployments.

Femtocells for home usage generally have to be deployed by the user to save installation and operation costs. This means that femtocells should be 'plug and forget' and utilising the customers' fixed broadband connection for backhaul. Just let the user connect power and backhaul to the femtocell, then the femtocell self-configures, and let the operator do the maintenance remotely without user interaction.

Whereas the femto community initially were focusing on femtocells for home usage, they have recently been focusing on so-called enterprise femtocells. These have larger capacity than femtocells being intended for home usage. As enterprises are not as price-sensitive as the consumer market, it should be possible for the operator to take a more active role with respect to deployment and maintenance in the enterprise femto market. Hence the OPEX is not considered the same hurdle for enterprise femtocells as is the case for femtocells for use in private homes.

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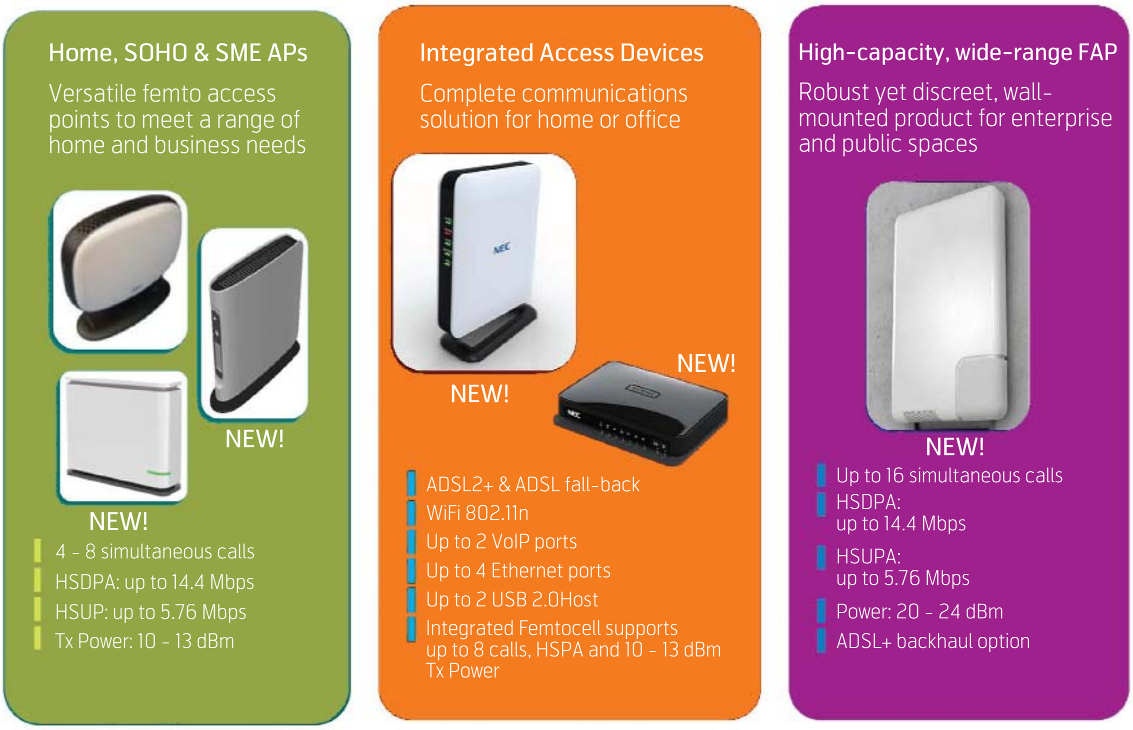

Figure 4 Different types of femtocells, with variable capabilities. Status per March 2010. Source: NEC

Product examples of home and enterprise femtocells are shown in Figure 3 and Figure 4.

The characteristics of the home femtocells could typically be 4-8 simultaneous users, 16 users in the access list (if closed subscriber groups are applied, meaning that only pre-registered users are allowed to access through the femtocell), HSPA/HSPA+, Wi-Fi and ADSL+ are available. For the enterprise femtocells there could for instance be 16-24 simultaneous users and femto-to-femto handover implemented as well. The enterprise femtocells could be completely integrated into the voice and data solution of the enterprise. According to the vendor roadmaps it is clear that the femtocells' capabilities and functionalities will continue to evolve in the years to come. This will in the longer run open up for operators deploying dense femto networks with inter-femto service continuity and open access. Hence these femto networks will serve the users like traditional picocell deployments. Self-optimising networks is an important part of such deployments.

So far, UK-based picoChip has been the leading vendor for baseband chipsets for femtocells. The picoChip picoXcell PC232 is a system-on-chip (SoC) femtocell solution incorporating a HSPA+ modem. This allows manufacturers to build a full-featured femtocell with downlink speeds up to 42 Mbits/s and uplink speeds up to 11.5 Mbit/s, supporting up to 24 simultaneous users. In addtion to serving feature-rich enterprise products, the SoC femtocell can also be used for 'greater femto' applications for metropolitan or rural environments, supporting cell radius of up to 2 km and terminal speeds of up to 30 km/h [1].

Recently it has been announced that chipset giant Qualcomm is preparing for femtocell chipsets, supporting both the CDMA and GSM families of standards. Qualcomm lists a number of technical features for the upcoming chipsets:

Figure 5 picoChip system module for embedding of femtocells into third party products like set-top boxes and home-gateways. Source: picoChip

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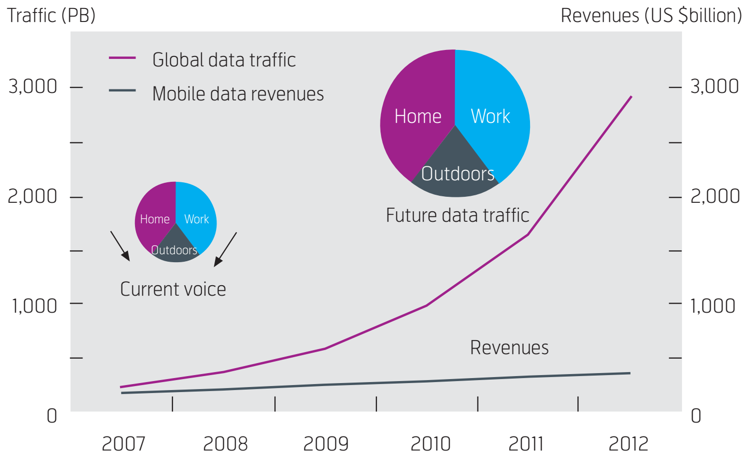

Figure 6 Mobile data revenues and traffic, 2007-2012 [2]. There is an urgent and compelling need to reduce the cost per bit to maintain a sustainable case for mobile broadband data

- A combined radio chip and 3G baseband controller;
- Support for 3G CDMA standards as well as 3GPP technologies, such as High-Speed Packet Access Plus (HSPA+);
- A 1 GHz Snapdragon processor and a GPS receiver.

Qualcomm claims that it will deliver samples in the second half of 2010 [3].

Business and Service Aspects

The combination of an explosive growth in demand for mobile broadband services and a low willingness to pay for the increased data consumption has created challenges for the mobile operator community. The operators are forced to look for significantly more cost-efficient ways of providing coverage and capacity to the users. The change from a voice centric to a data centric approach is challenging the operators' business cases and value proposition. One single

Figure 7 Advertising banner showing a commercial for Vodafone UK's "Sure Signal" service

YouTube video can consume the same amount of network capacity as 500,000 short messages (SMS), but can definitively not be charged in the same manner. The operators' answer to this challenge is to significantly lower the production costs per bit.

Femtocells is a promising technology for macro network offloading, as support of all standard terminals is inherent in the femtocell concept. Selective IP-traffic offload (SIPTO) will allow direct, standardised breakout of data traffic at the femtocell, offloading the mobile core network much more efficiently than other offloading options do.

Radio Coverage and Interference Aspects

Various studies from several sources have shown that a majority of mobile calls and mobile data sessions are made from indoor users. At frequencies above 2 GHz these users are not served optimally from outdoor base stations due to high building penetration losses dramatically reducing coverage and capacity. As can be seen from Figure 7 "guaranteed mobile signal in your home" is the initial market positioning of Vodafone's 'Sure Signal' femtocell concept [4].

Also the capacity enhancing techniques applied to 3G, adaptive modulation and coding and efficient packet schedulers favour the users located close to the base stations. Users having less favourable radio propagation conditions will get a poorer service. In addition these users will reduce the overall cell throughput and hence also contribute to a poorer service for the rest of the users attached to the same cell. This leads to a situation where the practical data rate in a macro cell environment will become only a fraction of the theoretical values. This will be even worse if the operator intends to provide some kind of DSL-like services over mobile broadband, 'guaranteeing' a bit rate to some users. If the guaranteed bit rate user is in poor radio conditions, he will occupy most of the radio resources lowering the overall system throughput significantly.

Hence – what is required to maintain high cell throughput is good indoor signal quality and a low number of simultaneous terminals attached to a cell. These demands are met by the femtocells, which offer improved indoor coverage and capacity at a low deployment cost, while supporting standard mobile phones and terminals. As femtocells offload the macro network, the users still relying on the macro network would hence get better services and higher throughput, as the users with the poorest radio conditions are removed from the macro network layer and given services through the femtocell instead. Hence –

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in terms of coverage and capacity – deployment of femtocells will be a win-win situation both for the femtocell user and for the users relying on coverage and capacity from the macro network.

There are however some challenges with the femtocells concept as well. From the radio technology side interference management between femtocells will be an issue, as the home femtocells are deployed by the users in an un-coordinated manner. In such a scenario a centralised radio-planning is completely out of scope. From similar user deployments of Wi-Fi access points, we know that the system performance is vulnerable to interference, and system capacity decreases dramatically when the interference level increases. Mutual interference between the macro base stations and the femtocells might also be an issue, especially if the femtocells are deployed on the same carrier as the macro network. The possibility of doing intra-frequency handover in the macro network when co-channel interference becomes a problem will help this situation.

It is worth noting that Vodafone UK's Sure Signal is deployed on a separate carrier not being used in the macro network. Vodafone is recommending home broadband with line speeds at least 1 Mbit/s as backhaul. According to unofficial reports about 100,000 femtocells have been deployed so far.

Anyhow, the radio configuration of the femtocells needs to be adaptive and 'automated' to the extent possible, for instance with respect to current and maximum output power and scrambling codes used, to ensure the best possible system performance. The Femto Forum has put significant effort into how to handle interference in a 3G or LTE femtocell scenario, and has provided white papers on interference management as shown in the reference list, see [5] and [6].

Backhaul and Security Aspects

Using fixed broadband as backhaul is also a challenge, as this broadband backhaul can be used for several purposes simultaneously. The provider of the backhaul is not necessarily the same as the provider of the femtocells, meaning that there can even be a need for some service level agreements between the different providers to ensure end-to-end service quality.

However, to ensure a reasonable service, the GSM Association femtocell group have put forward a series of demands as listed in [7], for instance that it should be possible to provide four simultaneous speech connections over a femtocell backhauled by a DSL offering minimum speed of 200 kbit/s.

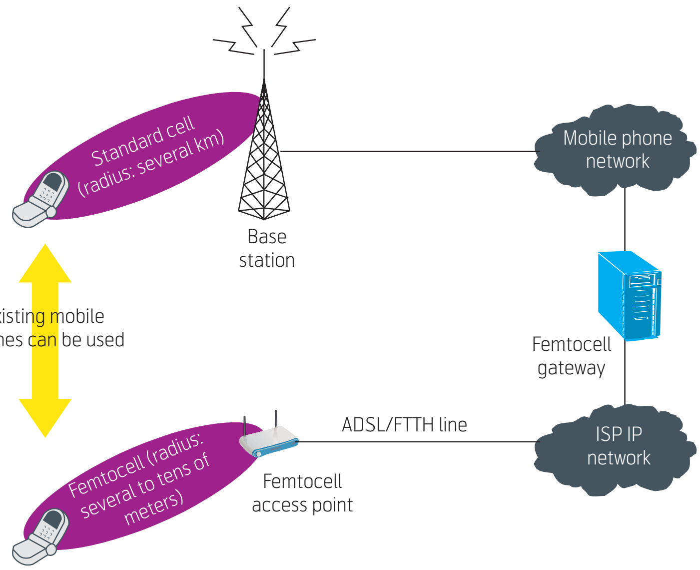

Figure 8 Overall femtocell architecture [7]

Another important issue is security aspects. The femtocells security consists of two major parts: the femtocells device authentication and the ciphering/encryption of the bearer and control information across the untrusted Internet connection between the femtocell and the femtocell gateway. The femtocell gateway is the gateway between the femtocells and the mobile core network, controlling the femtocells attached via the IP backhaul, and acting as a concentrator to aggregate the traffic from a large number of femtocells.

The authentication is taken care of using standard 3GPP methods, and the transmission security can be taken care of through secure tunnel establishment between the femtocell (femto access point) and the femto gateway.

Standardisation and Interoperability

To make femtocells become a success, the femtocell ecosystem needs to be established in a proper way. To make the ecosystem sustainable, there is a need for large volumes of femtocells, which can only be obtained by standardised solutions. This will also allow for femtocell devices to be embedded in other devices like cable-TV modems, xDSL modems and fibre-to-the-home residential gateways as well as in all types of consumer electronics. Wi-Fi will be embedded in the same devices as well. Standardisation will also imply that femtocells equipment from different vendors can connect to the femto gateway as well as to the mobile operators' core networks.

The initial femtocells concept was developed in various variants by the various vendors advocating their own solutions. This is of course not a sustainable

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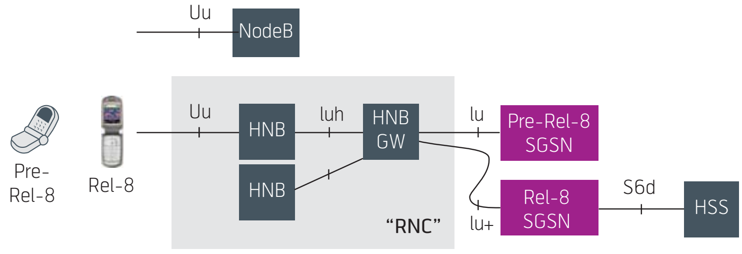

Figure 9 3GPP HomenodeB (femtocells) architecture and interfaces. Iuh is the standardised reference point between the HomenodeB (HNB) and the gateway. The HNB Gateway acts as a concentrator to aggregate a large number of HNBs. The HNB GW also has security gateway functionality. The interfaces towards the core network are standardised 3GPP interfaces connecting to the Serving GPRS Support Node (SGSN) and Home Subscriber Server (HSS). For LTE femtocells the femto gateway is an optional part of the system, as LTE is based on a flat IP architecture

model, and the GSM Association formed its femtocells group to agree upon the operator community's demands for femtocells as well as putting demands on vendors for standardised solutions. Further information is available from the GSM Association Info centre [8].

The Femto Forum was was also started in 2007 and now consists of more than 80 vendors and operators. Femto Forum's main goal is to promote femtocells in the market and ensure that the femtocells standardisation process runs as smoothly as possible. Femto Forum is also focusing on removing barriers for introduction of femtocells and femtozone services. Femto Forum has proven to be an effective forum for discussing and building consensus on key issues that are later forwarded to the standardisation organisations. For further information, see the Femto Forum website [9].

3GPP Femtocell Standardisation

3GPP has standardised WCDMA/3G femtocells (in 3GPP denoted HomenodeB (HNB) as a logical network node and HomeBS for its RF specifications) in its Release 8 specification. The same set of 3GPP specifications has also included initial support for LTE femtocells as well (known as Home eNodeB). 3GPP Release 8 was functionally frozen in December 2008 and some remaining elements of the specification were finalised in March 2009 and June 2009.

3GPP has continued to develop these standards into its Release 9, functionally frozen in December 2009, including end-to-end support for LTE femtocells. 3GPP is additionally studying the potential for standardising TD-SCDMA femtocells, following the standard deployed in the Chinese market.

With respect to standardisation of security and overall architecture of HNB, this was completed in 3GPP Release 9. This means that an end-to-end femtocell system is now completely specified by 3GPP. The major implication of this is that the femtocell concept now can be considered to be technologically mature.

Broadband Forum Standardisation

Broadband Forum TR-196 'Femto Access Point Service Data Model' was published in April 2009. TR-196 updates and enhancements are anticipated to catch up with the progress of the relevant work in 3GPP and 3GPP2.

Broadband Forum's TR-069 is the basis for auto-configuration of the femtocells, software and firmware management, status and performance monitoring and diagnostics [10][11].

3GPP2 Femtocell Standardisation

3GPP2 published requirements for CDMA-based femtocells in May 2008.

Support for residential use for legacy mobiles and femto-macro mobility, assuming the same radio interface for the femto and macro layers is expected to be completed in early 2010.

Phase 2: Enhancements (including new femto-aware mobiles) to permit femto-femto mobility, mobility between dissimilar radio interfaces and possibly enhancements to permit denser femtocells deployments. Details and progress are under consideration.

WiMAX Forum Femtocell Standardisation

The WiMAX Forum has created a set of detailed requirements for WiMAX femtocells. Two phases are envisaged:

Phase 1: Basic femtocell with limited network features and no change in the underlying air interface and system profile. No change will be required to the underlying IEEE standards. Support for WiMAX Release 1 (IEEE 802.16e-2005) and Release 2 (IEEE 802.16 Rev2). Phase 1 was completed Q1 2010.

Phase 2: Full femtocell function with advanced network features and air interface optimisation, which will include PHY and MAC layer enhancements in the IEEE 802.16m standard. The system requirements definition document for IEEE 802.16m already includes explicit support for femtocells. Phase 2 features are under consideration.

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Interoperability and Economies of Scale

By the end of March 2010 the Femto Forum announced completion of the world's first femtocell 'plugfest' (interoperebaility testing event). The event, which took place in cooperation with ETSI (the European Telecommunications Standards Institute), had widespread vendor support with over twenty companies participating, including vendors of network equipment and femtocells as well as software and hardware components.

The companies involved were Ablaze Wireless, Acme Packet, Airvana, Alcatel-Lucent Telecom, Alpha Networks, Askey Computer Corporation, C&S Microwave, Cisco Systems Inc, Contela, Continuous Computing, Genband, Huawei, IntelliNet Technologies, ip.access, Kineto Wireless, NEC, Node-H, Nokia Siemens Networks, picoChip, Technicolor, TRaC Global and Ubiquisys.

The primary objective of the interoperability testing event was to demonstrate the effectiveness of the 3GPP femtocell standards in supporting interoperability between femtocell access points and network equipment from different vendors to ensure that there is consistent interpretation of the standard.

Standardized femtocells provide operators and consumers with a richer ecosystem of femtocell products, as well as facilitating economies of scale. The fact that the plugfest was carried out so quickly after the completion of the 3GPP standard is testament to the industry's support for standardized femtocell access points and network equipment. This process will ultimately allow operators to multisource the technology as they do with mobile handsets today.

Currently there are 24 different HSPA capable femtocells available in the market [12].

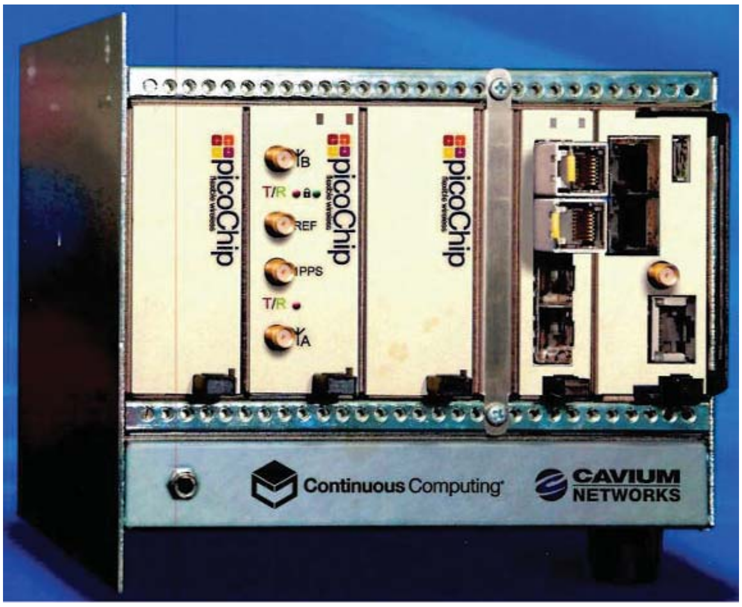

Figure 10 Prototype of LTE femtocell, shown at the Mobile World Congress, February 2010. Source: picoChip, Cavium Networks and Continuous Computing. This is a prototype of a 'greater femto', aimed for metrozone deployments

LTE Femtocells

As LTE becomes mature, it is expected that there will be an increased need for dedicated indoor solutions to achieve the expected coverage and capacity. Even more than for HSPA, LTE users will be large screen users having their data sessions from indoor locations. This means that indoor coverage will be very important for LTE.

In the introductory phase, the number of LTE subscribers will be relatively low, and it is not reasonable to expect them to be 'concentrated' in a few specific buildings. The low user density means that each macro (outdoor) base station can cover a relatively large area without the risk of being overloaded. For a given budget, a larger portion of users can be served if using LTE macro base stations as compared to using indoor distributed LTE networks.

When there is a need for LTE capacity expansions, dedicated indoor solutions will be feasible for serving indoor areas that have turned into high-traffic areas. Indoor distributed solutions will then increase throughput and reduce traffic load in the macro base stations, hence providing a better user experience both for the targeted indoor users and for those left at the macro base station. It is in general when the traffic volumes get high that the dedicated indoor solutions can provide the best savings through offloading of the macro network.

Hence it is only a matter of time until LTE coverage and capacity will be built inside-out. LTE femtocells will be a good tool for providing indoor coverage and capacity at dedicated hot spots in deployment phase two when initial coverage is already ensured by macro network deployment.

For LTE femtocells the specification is much better aligned with the LTE overall standardisation process, which gives an even better outlook for LTE femtocells as early availability makes it much easier to integrate LTE femtocell in the overall LTE deployment.

Also the self organising networks (SON) capabilities will make the LTE femtocells operation smoother than the operation for 3G femtocells. Even more

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Operator Service	Launch Date	Femto Supplier	Type of Femto Service*	Number of Femtos Deployed	Femto Price/Service Subscription
AT&T 3G Microcell	September 2009	Cisco (ip.access)	3G UMTS	N/A	Prices vary: $150 for femto and rebates available with subscriptions to AT&T services, for example
China Unicom 3G Inn	November 2009	Huawei	3G UMTS	N/A	N/A
NTT DoCoMo My Area	November 2009	Mitsubishi	3G UMTS	N/A	Free femto with ¥980 ($11) monthly subscription and ¥2,100 ($24) installation charge
Optimus Sinal On	December 2009	Huawei UMTS**	3G	Up to 500 in first half of 2010	€99.90 ($136) for femto plus €7.70 ($10.50) monthly fee (which includes 50 minutes for calls)
SFR Home 3G	November 2009	NEC (Ubiquisys)	3G UMTS	N/A	€199 ($272) for femto
Softbank	February 2009	NEC (Ubiquisys)	3G UMTS (IMS)	Less than 100****	Free femto
Sprint Airave	August 2008	Samsung	2G CDMA	N/A	$99.99 for femto plus $4.99 monthly subscription; also, $10 monthly subscription is available for unlimited calling
StarHub Home Zone	November 2008	Huawei	3G UMTS	N/A	Free femto for contract customers plus S$15 ($10) monthly Home Zone subscription
Verizon Wireless Network Extender	January 2009	Samsung	2G CDMA	N/A	$249.99 for femto, no monthly charge
Vodafone Sure Signal	July 2009	Alcatel-Lucent/ Sagem	3G UMTS***	N/A	£50 ($75) for femto – or £5 ($7) per month for 12 months – with monthly price plans of £25 ($38) or more. Alternatively, £120 ($182) for femto – £5 ($7) per month for 24 months – with monthly price plans of less than £25 ($38)

Sources: operators, vendors, Light Reading Mobile
* All services are for consumers unless otherwise indicated
** For business customers
*** For consumers as well as small and medium enterprise (SME) customers
**** Softbank says it has deployed 'a few tens' of femtocells

Table 1 Commercial Femtocell Services [13]

important is however the timing of LTE femtocells that fits well with the cellular operators' need to find suitable means for offloading their macro network. Femtocells is one obvious answer to the offloading needs.

With the capacities we foresee for LTE it may very well happen that the backhaul is the limiting factor rather than the radio interface. To utilize LTE radio access to its fullest, ADSL has too low data rates to be sufficient as backhaul. VDSL or fibre should be the preferred backhaul solution to utilise the potential of the LTE radio. The consequence of the ever increasing demand for bandwidth is that there is a need for upgrading the backhaul to higher data rates as well.

Femtocell Market Situation and Outlook

So far there have been 12 femtocell launches, including three trials. The latest announced are SFR in France and Vodafone in the UK, as well as AT&T in the US. Network Norway in Norway has announced that they are testing femtocells aimed at the business market with NEC. For an operator in the market setting of Network Norway, who to a great extent buys coverage and capacity from the competitors in the market, femtocells would be a perfect and cost-efficient tool to direct a larger portion of the total traffic into their own network.

Maybe the biggest hurdle for femtocell deployment so far has been the lack of a clear business model. This will be subject to change as more operators are now focusing on data offloading from their macro networks.

Femto Forum has also put large efforts into developing realistic business cases for femtocell operation, showing good profitability over the years to come of a femtocell introduction. The study, conducted by Signals Research, claims that:

- Increasing the wholesale cost of the femtocell by 50 per cent (from US$200 to US$300) only reduced the basic value proposition for femtocells by a modest 16.3 per cent;

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- The cost savings associated with offloading as little as 1.4 GB of HSPA data per month via the femtocell from a coverage-constrained macro cellular network would justify an operator offering a subscriber a free femtocell;

- A European operator wanting to provide a reliable 2.5 Mbps in-building service for the most coverage-challenged households, could do so for €320 per household if it used a femtocell strategy, whereas providing a similar in-home service with the means of the macro cellular network alone would cost €900 [14].

The business case, while compelling in 2009, improves further as data use continues to increase and as operators move from purely coverage-driven femtocell deployments to deployments based on macrocell-offload, performance enhancement, and personalized home-zone and office-zone services. Home-zone and office-zone services, which are included only in a few of the analyses in this report – principally in connection with the enterprise – will provide significant additional upside [15].

- Femtocells to reach addressable market of $2.4bn, over 18 million units shipped, market for systems integration over £360m by 2013 *(America's Growth Capital, July 2008)*
- WCDMA femtocells market $2.2bn by 2012. 30% of 3G networks will deploy femtocells by 2010, rising to 80% by 2012 *(Rethink Research, April 2008)*
- Global equipment revenues growth CAGR of 126% from 2008 to $4.9bn, integrated home gateway shipments exceed 23 million units in 2012 *(Rethink Research, April 2008)*
- Femtocells deployed by end of 2013 to exceed 40 million, 22 million units added in 2013, offloading up to 8% of total mobile traffic *(Informa, September 2008)*
- 39.97 million femtocells deployed by end 2014, serving 132 million subscribers *(ABI research, October 2009)*
- Sales of FMC network element equipment and femtocell equipment grow at healthy rate through downturn, to $8 billion world-wide by 2013 and world-wide growth 160% CAGR from 2008 to 2013 *(Infonetics, March 2009)*
- Femtocell based 3G service revenue $9bn per annum by 2014 *(Juniper Research, June 2009)*

Figure 11 Femtocell market forecasts [16]

Femtocell Pros and Cons

There are several pros of femtocells that can make them an interesting and promising offering both for customers and operators:

- Improved indoor coverage;
- Offloading of macro network; will be more important as the number of data-hungry smart phones and large screen terminals increases significantly;
- Extremely cost efficient way of building network capacity;
- Enabler for fixed mobile convergence (FMC);
- Inherent support for voice and data services;
- Supports standard handsets and terminals;
- Secure 3GPP authentication;
- Support of specific femtozone services;
- Superior for presence management and presence based services (eg. enabler for personalised public information services);
- Link between mobile terminal and connected home network;
- Reduced churn due to superior indoor coverage as well as sticky services offered via the femtocells;
- Standardised end-to-end solutions are now available in volumes;
- Large momentum in industry and effort on ensuring interoperability and economies of scale.

On the con and challenge side we can mention:

- The femto concept will struggle if the customer wants to get rid of fixed broadband access and rely only on mobile broadband (MBB);
- How much support will the customers need for femtocell set-up and operation?
- Need to establish a regime for keeping control of the backhaul quality levels when several operators are involved;
- Interference with other femtocells and the macro cells need to be managed;
- Challenging to position femtocell for emergency calls (same problem as for fixed IP-telephony);
- Maintenance and upgrades might be a challenge, despite of standardised methods;
- Need to reach price point of consumer electronics;
- Still unclear business model for femtocells.

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Alternative Solutions for Indoor Coverage

There are lots of alternative solutions for indoor coverage, like indoor micro base stations with active or passive antenna distribution systems, home repeaters, fibre optic distribution systems, leaky coaxial cables and distributed base station systems. Several of these technologies have quite a widespread use today. In this article these technologies will not be studied in detail. Attention will be paid to the one indoor solution that at the moment has the most widespread deployment – namely wireless local area networks or Wi-Fi.

Wi-Fi Based Indoor Solutions

Wi-Fi is a brand referring to wireless communication based on the IEEE 802.11 standard, the latest version being IEEE 802.11n. Wireless local area networks based on IEEE 802.11 have been in the market for about a decade. The first implementations can be thought of as pure cable replacements. Later on higher data rates and new functionality like better security and roaming capabilities, as well as Wi-Fi mesh networks has been added throughout the various amendments to the standard. The 802.11n standard has recently been approved, even though pre-802.11n products have been in the market for several years already.

IEEE 802.11n provides peak throughputs at the physical layer of around 300 Mbps and reasonable peak rates at the application layer of approximately 75 Mbps. Experienced throughput varies with the user's distance from the Wi-Fi access point, the number of simultaneous users, and interference from other Wi-Fi access points and other equipment like garage door openers and microwave ovens operating in the same unlicensed spectrum. Outdoor Wi-Fi range is typically 80 metres and an indoor Wi-Fi access point can in most cases cover an apartment.

Wi-Fi for indoor access to the Internet is in most cases limited by the Internet connection, eg. a DSL line, and as such Wi-Fi will in most cases not be the capacity bottleneck. In case of fibre backhaul this will change.

Wi-Fi is now embedded in a majority of new laptop PCs sold, as well as being present in high end and data-centric smart phones. The strong market presence is one of the strongest assets of Wi-Fi.

The major drawback for offloading the macro network utilising Wi-Fi is the lack of reliable solutions for seamless mobility and roaming between indoor Wi-Fi access points and outdoor public Wi-Fi as well as HSPA/LTE base stations. Such solutions need to be implemented. Telenor Norway has implemented such a solution based on Mobile IP (MIP), called 'Mobilt kontor 5', which is implemented through a PC client software.

For increased security, an AAA platform supporting Wi-Fi SIM authentication will be needed. This is something to consider when deploying multi-access services, as a hostile attacker would enforce your communication device to access the services via the weakest protected access.

The cost of a consumer Wi-Fi access point is typically \$50-100 when large quantities are bought. High-end business access points typically cost \$1000.

There are also some drawbacks of Wi-Fi, such as:

- Lack of voice support;
- Wi-Fi on most laptops is not 'plug and play', but would generally require some setup to be able to connect to the network; you would need passwords to access encrypted Wi-Fi networks. Users tend to avoid 'hassle' when possible, this is one of the reasons for the extreme popularity of mobile broadband solutions even when sitting next to the Wi-Fi access point.
- If small screen devices are to be handed off to Wi-Fi whenever possible, these devices will experience shorter battery life time. Access points and terminals compliant with the Wi-Fi Alliance's WMM Power save standard may overcome this in the future.
- Offering a mix of real-time and best-effort services will be challenging as QoS class definitions between mobile broadband (HSPA and LTE) and Wi-Fi are not identical.
- It is uncertain whether protocols to offer seamless handovers between HSPA/LTE and Wi-Fi will be embraced by the market.
- Interference can be a problem in the 2.4 GHz frequency band, limiting range and throughput and usefulness of the Wi-Fi solution. This has especially proved to be a real hurdle for Wi-Fi in markets with less stringent regulation of the emitted power than what is the case in European markets.

To sum up, the large availability of Wi-Fi enabled devices is a clear pro for Wi-Fi based solutions for offloading of the mobile networks. The con is the current lack of support for voice services as well as the still limited mobility solutions towards mobile

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broadband – mobility solutions that are inherent in femtocells from day one.

The trend is clearly that femtocells will have Wi-Fi built in as well.

Femto Forum have also conducted a study on femtocells versus Wi-Fi and concluded that these two technologies have complementary strengths, and that taking fibre closer to the home, together with a combination of Wi-Fi and femtocells is going to help us manage bandwidth and provide a great experience to our customers no matter where they connect [17].

Conclusion

Femtocells is a promising concept for improving indoor coverage and offloading the macro mobile broadband network that are moving rapidly towards congestion. Now standardised end-to-end femtocell solutions are available, and there is consensus in the industry to ensure interoperability and create large volumes and economies of scale. There is a strong industry support behind femtocells.

With the increasing number of mobile broadband users, as well as each individual user on average increasing mobile data usage, dedicated indoor solutions for coverage and capacity will be the next tool the mobile broadband operators need to deploy to cope with coverage and capacity demand in a cost efficient manner.

Femtocells have been a hot topic for some years already, and the concept has been heavily hyped before it finally matured. As standardised end-to-end solutions are now available, the time for more and larger femtocell deployments is due. First movers on femtocells will be operators having problems with poor indoor coverage, or mobile virtual network operators who want to keep more of the traffic inside their own network. Later, operators wanting to offload their macro network and build excess capacity in a cost-effective manner will join the femtocell community.

Femtocells – strategically placed – offer the operator a powerful tool to handle escalating network costs and to significantly enhance the end user experience. Femtocells have finally reached the tipping point.

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Rune Harald Rækken holds an MSc from the University in Trondheim, Norway, and he is a business graduate from the Norwegian School of Management. Since 1987 he has been employed by Telenor Research department, starting with GSM standardisation. He has also been involved in research towards UMTS and LTE, as well as being a research manager. The latest years he has been focusing on mobile broadband, including femtocells. He has been responsible for Telenor's LTE trials in Oslo. Currently he is Senior Advisor and head of the technical vendor management and head of LTE, Telenor Corporate Development.

email: rune-harald.rakken@telenor.com