Early Experiences and Lessons Learned from Femtocells

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ABSTRACT

There is a continuous pursuit by mobile operators (MOs) to improve indoor coverage in order not only to improve voice quality but also to enable higher data rates in home/office environments. Indoor coverage improvement, in conjunction with inexpensive (voice) offerings, will enable MOs to compete with and take away voice-call-related revenues from fixed network PTTs and/or VoIP operators. Femtocells constitute a promising solution to address all of the above. In this article we present our experience from our extensive study and trials of early (prestandard) femtocell solutions that were available in the 2007–2008 timeframe.

INTRODUCTION

As the revenues from voice tend to diminish, high competition forces mobile operators (MOs) to seek new revenue generating sources through innovation in services and technologies. The commercialization of femtocells was investigated in 2008 (through tenders, technical trials, and business models) by MOs worldwide. Femtocells or femto access points (FAPs) are miniature base stations connected to an MO's network via a broadband connection (e.g., asymmetric digital subscriber line [ADSL]), typically designed for use in residential or small office/home office (SOHO) environments [1–3].

For MOs, femtocells may constitute a solution to:

- Increase mobile usage indoors — and thus revenues — by combining coverage/capacity enhancements with inexpensive voice services
- Offer innovative data services (music/photo/video download/synchronization, mobile TV, etc.), thus making the mobile phone competitive with a fixed phone, PC, and/or TV
- Offer fixed-mobile convergence (FMC) in response to WiFi/voice over IP (VoIP), Homezone, and UMA offerings.

In addition, femtocells may contribute to:

- Churn reduction (e.g., by "capturing" all the members of a family)
- Operational expenditure (OPEX) savings on the (macro) backhaul network (due to traffic offload)
- Capital expenditure (CAPEX) savings since no new base stations or capacity expansions are needed.

End-user benefits from the introduction of femtocells, apart from better coverage and inexpensive voice tariffs within the "femto zone," may include "one-phone-one-number-one-bill" and the same services indoors and outdoors.

An MO, prior to commercial introduction of femtocells, has to address a considerable list of issues such as possible interference with the macro network [4], impact on the core network, security concerns, interoperability, regulatory/electromagnetic compatibility (EMC) concerns, use of service level agreements (SLAs) for quality of service (QoS) guarantees (especially for voice) over the broadband connection, and availability of platforms/features and packages to be offered.

The aim of this article is to investigate whether femtocells may add value to the user and operator. The analysis is based on certain decision making factors (both technical and commercial) that will be assessed according to the experience gained through a request for proposals (RFP), a technical trial, and a custom-made investment-revenues analysis tool.

The structure of the article is organized as follows. We present generic factors affecting the introduction of new services/technologies. We investigate the potential exploitation of femtocells based on the findings derived from certain projects run within COSMOTE in 2008. Finally, we draw some concluding remarks.

FACTORS AFFECTING NEW SERVICES'/APPLICATIONS' INTRODUCTION

The level of adoption and success of a new mobile technology and/or service or application depends on the value offered to both the user and the MO. On the user's side, value is offered by innovative services and applications

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(interactive gaming, instant messaging, m-payments, e-health, e-learning, video on demand, interactive mobile TV, etc.), high quality of experience anywhere and anytime, inexpensive tariffs, affordable terminals, and high-quality customer care/support. On the MO's side, value is accomplished by business profitability and promoting the company's brand name/vision/strategy (innovative applications, competitive advantage, etc.).

However, prior to the introduction of a new technology/service/application, an MO should consider a plethora of diverse (technical and commercial) factors, such as the impact on legacy network and service platforms, investment-revenue balance/payback period, regulatory/legal requirements, selection of the appropriate vendor/platform, timeframe for implementation, and marketability.

The weight assigned to the above factors, along with the assessment of the local market potential, may drive the operator's decisions on risks and opportunities based on its business strategy [8].

Assessment of Femtocells' Potential Exploitation

A typical femto solution (Fig. 1) is composed of:
- The FAPs
- A femto gateway (FGW) acting primarily as a FAP manager and authenticator (security gateway)
- An authentication, authorization, and accounting (AAA) server
- A Domain Name Service (DNS)/Dynamic Host Configuration Protocol (DHCP)/Network Time Protocol (NTP) server
- A couple of switches/routers interconnecting the femto nodes as well as the femto platform with the rest of the operator's circuit-/packet-switched (CS/PS) network
- A network management system (NMS)

In order to deploy a femto solution, apart from ensuring that specific platform-related requirements are met (cost efficiency, scalability, security, standardized interfaces, and multivendor interoperability), operators need to integrate the femto platform onto their legacy core/services networks, provision/manage/monitor FAPs, charge femto subscribers, ensure that FAPs can coexist with the macro network, and so on.

In the context of assessing the potential exploitation of femtocells, COSMOTE (within 2008):
- Conducted a second generation (2G)-femto technology trial with a major vendor
- Issued a third generation (3G)-femto RFP
- Developed an investment-revenues analysis tool to assess femtocells' business case and potential profitability

The major findings (concerns, pending issues, capabilities) stemming from the above projects (including real-life experience, information from various vendors, and the business case) will be exploited for the assessment of femtocell technology as far as the factors mentioned earlier are concerned.

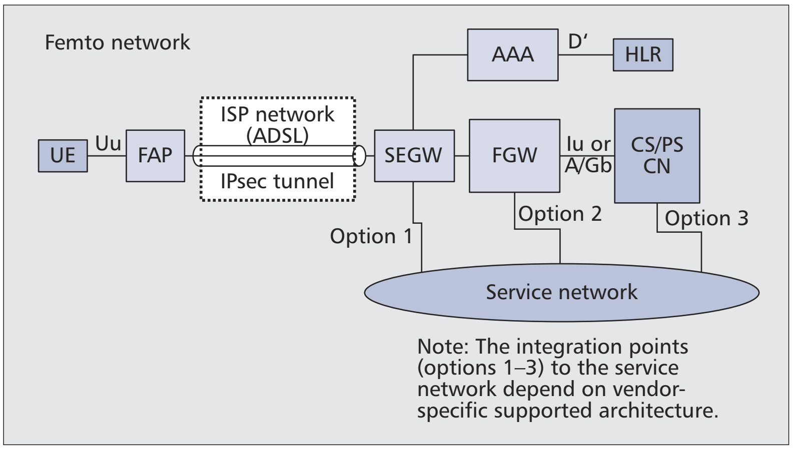

Figure 1. *A typical femto solution.*

Impact on the Existing Network and Service Platforms

From a technical viewpoint, the incorporation of a femto solution in an existing 2G/3G network implies:
- Preparations for installation of a femto solution, concerning site location, power, space, and cabling requirements
- Network design, including the identification of network elements to be interconnected with MSC/SGSN/HLR(s) and support systems, as well as the investigation of coexistence with and impact on existing core and macro networks
- Integration activities, including loading of configuration-related data onto network nodes, establishing and ensuring connectivity between the femto platform and the FAPs, CS/PS core network, service platforms, and the NMS/provisioning/billing systems
- Acceptance testing during which the functionality of the solution is verified

Installation Requirements — Femto solutions that can accommodate hundreds of thousands of FAPs and subscribers (a typical regional installation) can range from configurations of 2–12 cabinets, with proportional power needs. The diversity of installation needs stem from the fact that solutions implement different architecture configurations.

Design Phase — During the design phase, a long list of parameters should be defined in order to achieve femto platform integration, and interoperability with the macro, core network and service platforms, and users' provisioning. A non-exhaustive list of such parameters follows: MSC/SGSN SPC, femto LAI/RAI, IMSI series for femto subscribers' SIMs (and/or FAPs), fully qualified domain name (FQDN), global titles, IP addresses for routers/firewalls/AAA servers/DNSs/FAPs, and configuration data for firewalls/switches.

As far as the macro network is concerned, if FAPs are capable of automatically adapting (self-configuration, self-optimization) certain radio-related parameters (e.g., BCCH, power, *Femto cells necessitate mutual authentication/certification between FAP-FGW. Depending on FAP vendor, this is done either using standard SIM/USIM authentication or using a hard protected built-in module (e.g. authentication chip).*

scrambling code), interference with the macro network [4] and other closely located FAPs could be mitigated. Otherwise:

- For a 2G-femto network, a different set of BCCH frequencies shall be allocated for the femto network than that utilized in the macro network to avoid co-channel interference between femto-macro layers. Trial results indicated that co-channel interference between neighboring FAPs can be particularly intense (no call establishment) in distances less than 4 m in an open space environment, whereas no adjacent channel interference was observed (either FAP-FAP or FAP-macro).
- For a 3G-femto network, if utilization of a separate carrier is not possible, the scrambling codes allocated to FAPs shall be distinct from those allocated to the macro network.

In terms of mobility and service continuity support, there are the following alternatives for the operator:

- Adjustment of macro and femto network cell reselection parameters so that user equipment is automatically camped on FAPs once detected[1]
- Exploitation of hierarchical cell structure (HCS) to achieve prioritization of the femtocell layer over the macro one
- Definition of a separate PLMN-ID (for exclusive use by the femto network)
- Introduction of equivalent PLMN feature, which, unlike the case of a separate PLMN-ID, does not require any UE SIM modification

In the 2G-femto trial, COSMOTE adopted the vendor's recommendation on the use of a second PLMN-ID. This approach provided inherent support of rove-in and rove-out of the femto network, by means of searching for the preferred HPLMN (femto network) or an allowed VPLMN (COSMOTE), respectively. The trial results indicated that the time required for the rove-in procedure (macro->FAP) may vary from a couple of seconds up to six minutes (i.e., the minimum timer value that can be set at SIM for periodic search of the HPLMN), while the rove-out procedure (FAP->macro) requires a few seconds up to a couple of minutes to be completed, during which the femto subscriber remains "out of coverage," experiencing service unavailability.

On the operator's side, the implementation of a dedicated second PLMN-ID for femtocells necessitates considerable effort, including:

- Request for a new PLMN code (femto PLMN-ID) from the local regulatory authority
- Massive replacement of SIM cards for all (existing) subscribers who become femto users[2]
- Establishment of new international roaming agreements (for the new IMSI series)[3]
- Activation of additional features on core network elements

In addition, it shall also be investigated whether the core network nodes to be connected to the FGW need to be upgraded (software and/or hardware) so as to support the FGW interfaces. A 3G-FGW, for example, may support standard Iu-CS/Iu-PS interfaces over IP toward the core network, while a 2G-FGW may support a Gb over IP interface to the SGSN. In addition to network element upgrades, bandwidth upgrades on specific interfaces (backhaul, backbone, "routes" to the Internet) might be required. The expected traffic on these interfaces can be assessed by means of a dimensioning study.

Integration — In the context of COSMOTE's 2G-femto trial, the integration tasks included IP interconnection tasks like FQDN to IP mapping within DNS[4] and configuration of a DHCP server to provide IP addresses to FAPs, connectivity tasks like time-division multiplexing (TDM) and Gb over IP links between FGW-MSC/SGSN (for 2G-femto), SS7 links between AAA-HLR hosting femto subscribers and/or FAPs (SIM-based authentication), in order for users to have access to all services provided to ordinary subscribers (SMS, MMS, WAP, Internet, voice mail, information services, etc).

The adoption of the second PLMN implementation necessitated:

- The activation of the "multiple PLMNs" feature at all MSCs/SGSNs
- New femtocell PLMN definition, along with PLMN-specific parameters, at all MSCs/SGSNs and HLR(s)
- The activation of the "National Roaming" feature at all MSC/SGSN nodes, along with the appropriate configuration, in order to restrict the usage of the femto HPLMN only to femto subscribers and force femto subscribers to use COSMOTE's macro network while roaming out of FAP coverage
- New IMSI analysis (for the IMSI/GPRS attachment of femto subscribers) at all MSCs/SGSNs
- Definition of the femto location/routing areas at all MSCs/SGSNs
- Number Portability Registrar update with entries for the new femto IMSI series and femto MSISDN ranges pointing to the respective HLR(s)

The HLR/AuC(s) were configured with the IMSI and authentication data for the FAP embedded SIM cards and the femto subscriber SIM cards. In addition, the Alias-IMSI feature was activated at the HLR to support mapping of two IMSIs to a single MSISDN.

Provisioning of a Femto User and/or FAP SIM Card — Femtocells necessitate mutual authentication/certification between the FAP and FGW. Depending on the FAP vendor, this is done using either standard SIM/USIM authentication or a hard protected built-in module (e.g., authentication chip). In case of SIM/USIM authentication, FAP SIMs shall include — among other data — the following information: IMSI, Ki, certification authority (CA) root certificate, and the FQDN of the FGW. SIM-specific information shall also be configured in the HLR.[5]

To bypass the international roaming agreements requirement (due to the second PLMN implementation) COSMOTE investigated and

[1] In this case special attention shall be paid to the avoidance of any "ping-pong" phenomenon.

[2] SIM cards include the new IMSI (femto PLMN IMSI) along with other configuration data such as a VPLMN in priority order, a timer controlling the periodicity of searching for the HPLMN, and so on.

[3] To overcome the time-consuming roaming agreements, COSMOTE investigated the "dual-IMSI SIM" implementation.

[4] The DNS has to be configured with data mapping the provisioning and default FQDNs to FGW IP address(es) according to the FQDN format.

[5] Operators need to (also) apply an enforcement policy that will prevent SIM cards from being used in subscriber handsets.

implemented "dual-IMSI subscribers SIMs"; provided by an undisclosed SIM vendor. The dual-IMSI SIMs, by utilizing a purpose-built applet at power-on, enabled the use of femto-IMSI whenever a subscriber roams within the allowed PLMNs in "home country" (femto HPLMN or roaming in COSMOTE's network), whereas the "COSMOTE" PLMN IMSI is used only when the subscriber is roaming abroad, thus eliminating the need for new roaming agreements for the new IMSI series.

The dual-IMSI SIM shall be provisioned with a single authentication key (Ki) for both IMSIs along with SIM-specific algorithms to enforce the desired functionality. For the realization of the dual-IMSI SIM concept, the HLR shall support mapping of two IMSIs to a single MSISDN, made possible through the alias-IMSI feature.

Proper operation of the dual-IMSI SIM card (location update within FAP, macro, and foreign network) was verified through numerous tests.

Integration Charging/Provisioning/OSS Systems — The majority of 2G/3G-femto solutions rely on the core network elements to generate call detail records (CDRs), which are subsequently sent to the existing billing system. The implementation of a special charging plan for femto services may force operators to perform a number of tariff-related modifications within their existing billing system. Modifications should allow for tariff differentiation of transactions performed by femto subscribers between the femto and macro networks or between FAPs. The femto solution itself, however, should support the generation of location-specific information (unique identifiers) within CDRs according to which tariffs shall be applied. In the 2G-femto trial, tariff differentiation between the femto and the macro was enforced by means of a unique location area assignment to FAPs.

A femto solution may incorporate its own provisioning system or be integrated into an existing one. A separate provisioning system will need to be integrated into third party (existing) business support systems like customer relationship management (CRM, northbound) and to third party network elements (HLR or AAA, southbound). Prior to any integration, an operator should verify interface compatibility and proceed with the necessary adaptations (if required). The integration of an interactive voice recognition (IVR) system or SMS to the femto provisioning system would require additional (integration) effort.

Integrating a femto solution in an existing provisioning system is considered less complicated. The procedures used for the provisioning of services to ordinary subscribers shall apply to femto subscribers as well. As a result, only a few amendments to existing procedures may be anticipated.

Finally, FGW support (fault management, network statistics, traffic monitoring) in the existing operating system support (OSS) shall be investigated.

PROFITABILITY/PAYBACK

Femto-related investment (CAPEX/OPEX) depends on the cost of the femto platform, FAPs, existing network upgrades, O&M/support services, rental and installation (for "public" use of FAPs), labor, advertising/marketing, user acquisition/retention, interconnection/termination fees, FAPs distribution, and so on, while revenues greatly depend on the number of femto subscribers (or FAPs), average revenue per user (ARPU) (based on monthly fee, extra call minutes), and so on.

As far as femtocell deployment is concerned, an MO should take into account certain tariffing restrictions arising from similar packages (e.g., home zone) of either the same operator or the competition and exploit possible opportunities, for example:

- Offer FAPs as a fixed-telephony-like alternative, to address the greatest possible market share —individuals or families/SOHO, small to medium enterprises (SMEs), users in public areas (malls, restaurants, cafes, etc.)
- Offer simple packages that may allow all members/employees to share a certain amount of free voice call minutes per month or customized packages offering differentiated sub-packages for each family member/employee
- Provide competitive services bundles (voice/non-voice applications: SMS, WAP/MMS, Mobile TV, VoD, etc.) with attractive/affordable pricing

Results from our own Investment-Revenues Analysis Tool, incorporating all the above mentioned parameters, indicate that the FAP price strongly affects the subsidization costs, thus becoming a crucial parameter for the profitability of extensive deployments [7]. It is envisaged that initially, femtocells will be utilized for operator coordinated coverage extension purposes (e.g., public hotspots, malls) rather than mass market offerings.

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TIMEFRAME FOR IMPLEMENTATION

From the technical viewpoint, a typical implementation project for the commercial launch of a 2G/3G-femto solution, including delivery of equipment, design, and installation/integration/acceptance testing would last for three to four months, depending on hardware availability (platform/FAPs), lead times, power/space availability, and SIMs availability.

At the time of the RFP, all 3G vendors offered proprietary solutions (in terms of the FAP-FGW interface), while most of them stated that commercial availability was expected at the end of 2008 or early 2009. Due to the absence of standards, wide market adoption and economies of scale could not be achieved at that time (limited variety and volume availability of FAPs, lack of homogeneity in terms of supported capabilities). 2G-femto solutions are commercially available today by a limited number of suppliers offering their own brands of FAPs.

Technology immaturity and unavailability of a fully standardized implementation (based on the Iuh interface), including FAPs from various manufacturers, may strongly affect MOs' strategic decisions regarding solution adoption and time to market.

Finally, the operator should not underesti-

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mate the time required for the preparation and provisioning of commercial offerings, since the provision of femto services is quite different than that of traditional mobile ones.

Regulatory Issues

Since femtocells are in essence base stations, public concern regarding the levels of RF radiation may appear. According to 3GPP TS25.104, the maximum output power of FAPs should range between 17–20 dBm (without/with transmit diversity or multiple-input multiple-output [MIMO]). In addition, FAPs must comply with the guidelines for human exposure to electromagnetic emissions issued by the International Commission on Non-Ionizing Radiation Protection (ICNIRP) and other relevant regulatory authorities.

Given the low output power of FAPs, they could be considered to have the same level of radio frequency (RF) exposure risk as WiFi access points, commonly used in home/office environments, thus facilitating wide market adoption. In this context, MOs could be relieved of reporting (to a regulator) femto base station locations and functional characteristics (e.g., operating frequency, output power, antenna polarization).

Vendor/Platform Selection

Simultaneous support of 2G and 3G by the same femto platform is neither currently supported nor foreseen. As such, an operators' first choice should be between 2G- and 3G-femto alternatives. It is worth noting that 2G-femto solutions address the whole subscriber base, thus saving the operator from replacement/subsidization costs; however, a 2G/3G handset owner with sufficient 3G coverage at the home/office, upon installing a 2G-femto, will no longer enjoy 3G/HSPA services, unless a 3G-only network is manually selected.

Femtocell vendor selection takes into account a plethora of requirements regarding solution architecture, functionality of femto platform and FAPs, range and roadmap/evolution of femto products, NMS/charging/provisioning requirements, cost efficiency, and vendor experience and knowledge. An operator's typical wish list regarding femto platform features may include:

- Support of simultaneous voice and data sessions
- Network access policy (open, closed, group mode)
- Deployment options (same or other PLMN/carrier)
- Mobility support (FAP<->2G/3G reselection/handover, FAP<->FAP handover)
- Service (voice over data) prioritization
- Emergency calls (femto user, all users, pre-emption of a normal call)
- Active system presentation (location indication via PLMN-ID, SMS, MM_info, CBS)
- FAP auto-configuration (frequency, scrambling code, CPICH) and self-optimization
- FAP lock capability (SIM, FQDN, ADSL, CGI/LAI)
- Air interface synchronization (macro network, NTP/clock server)
- Security and authentication (IPsec IKEv2, EAP-SIM, EAP-AKA, FAP serial number ciphering)
- FAP management (remote software upgrade, TR-069, fault/performance management)
- Auto-fallback to macro in case of failure
- Access overload control

However, both the RFP and trials indicated that as of mid-2008 the femtocell solutions were still not ready for full-scale commercial deployment. This was justified by the following facts:

- The pre-commercial 2G solution trialed did not support ciphering, closed and group access modes, automatic femtocell planning, a backup mechanism for air interface synchronization where no macro coverage exists, macro<->FAP handover, emergency calls originated from non-femto users, ADSL and macro network (CGI or LAI) lock.[6]
- The majority of 3G vendors did not support: high-capacity FAPs (suitable for enterprise use), HSUPA, WB-AMR, open and group access modes, 2G/3G macro->FAP handover, FAP<->FAP cell reselection and handover, user prioritization, active call re-direction to macro, emergency calls for unregistered user, FAP locks (ADSL, FQDN based), self-optimization (incl. SC, frequency and output power), as well as auto-fallback to macro in case of failure, domain specific access control, access/barring, access overload control.
- All 3G-femto vendors offered proprietary solutions with respect to the FAP-FGW interface (GAN Iu (UMA), proprietary and/or standard Iu/IP implementation), putting certain restrictions on the variety and volume availability of FAPs.

In addition, we observed differences among the vendors' implementations regarding the following features/capabilities:

- HSDPA implementation (e.g., dynamic power allocation or semi-static code allocation, proportional-fair and/or Round-Robin scheduling)
- Support of multi-RAB combinations (e.g., 1CS+1PS, 2PS, 1CS+2PS, 3PS, etc. where PS can be DCH or HS-DSCH)
- Authentication (SIM/USIM-based or hard-coded information within a chip)
- FAP<->2G/3G macrocell reselection (via parameterization or HCS)
- UL/DL Interference estimation (path loss information, CPICH auto-configuration)

while major shortcomings may be identified in the support of macro->FAP handover; arduous manual definition of every single FAP (FAP Cell-ID, RNC-ID, scrambling codes, etc.) in 2G/3G macro neighbor lists.

Femtocell solutions necessitate the establishment of IPsec tunnels between the FAP and FGW over which traffic/signaling/OAM traffic is encrypted, while the IKEv2 and IPsec EAP protocols offer confidentiality. All vendors support normal core network authentication procedures between UE and the MSC/HLR. Air interface ciphering and integrity protection is not supported by all FAP manufacturers, but the imperative to utilize ordinary handsets and UE SIMs for

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[6] *Ciphering and air interface synchronization will not be supported in the next software release of the platform.*

accessing the FAPs forces them to use ordinary UMTS (Kasumi-based) encryption and integrity protection algorithms UEA1 and UIA1, respectively.

Access to FAPs can be restricted utilizing closed mode, where selected users/MSISDNs per FAP can be serviced, and/or group mode, where only selected users/MSISDNs may access a certain FAP group. Closed/group modes are not supported by all vendors.

Mutual authentication/certification between FAPs and FGWs can be based on dedicated FAP SIM/USIM (EAP-SIM/EAP-AKA),[7] hard-coded authentication chips built in the FAP, digital certificates stored in FAPs' SIM, software coded authentication certificates pre-stored in FAPs' Operating System or MAC addresses. Depending on FAPs capability (embedded SIM, built-in chip, etc.) the operator may be forced to support more than one authentication/certification options.

Marketability

For MOs, femtocells constitute an attractive solution for indoor coverage improvement, and may offload macro network traffic and/or offer inexpensive voice and data services. However, investment in core network infrastructure (and possible FAPs subsidization) is required; macro network planning can be affected, while SLAs may be required to guarantee QoS. End-user benefits may include quality of experience improvements (voice, data), inexpensive voice tariffs within the femto zone, "one-phone-one-number-one-bill," and the same services indoors and outdoors. The end user, however, is required to pay for a broadband connection to the Internet (which s/he may already own) and possibly for the FAP equipment; it depends on the operator's strategy.

The same architectural approach with femtocells is implemented by UMA/GAN. Although UMA/GAN is considered a mature and commercially available standards-based technology, for quite long time, wide market adoption has not been achieved yet since it necessitates the use of purpose-built UMA/GAN handsets.

Besides femtocells and UMA, other technologies could be exploited (repeater-like solutions, fixed wireless terminals) presenting similar capabilities and functionalities [5, 6]. Although not directly comparable, each solution addresses different technical and commercial issues. More specifically:

- Repeater-like solutions may boost indoor coverage, for both voice and data, without requiring core network infrastructure.
- FWT could be considered as a means to extend indoor coverage for data services only (via WiFi and Ethernet interfaces), while voice/fax services are provided via plain old telephony service (POTS) interfaces.

However, since both solutions reuse macro network resources, network expansions could be envisaged for extensive use. Home-zone tariffing may by applied to both of the above solutions, while — in contrast to femtocells — neither of them is functional in areas with no macro network coverage (at least –110 dBm required).

Conclusions

Our as well as other operators' involvement and experience with pre-standard femtocell solutions has revealed some of their early drawbacks that restrained them from massive-scale commercial launches. However, the accumulated experience from all these trials as well as the recent standardization activities in 3GPP/3GPP2 will lead to a new generation of standardized femtocell solutions and raise the expectation for commercial market success for operators and vendors alike. It is envisaged that initially, femtocells will be utilized for coordinated coverage extension purposes (e.g., public areas) and niche markets (high-value customers, enterprise packages), rather than mass market commercial offerings. Upon the advent of standardized 3G-femto solutions, the increase of competition at FAP level (models, volume availability, cost reduction) will contribute to the extensive commercialization of femtocells, which will be further boosted by the introduction of LTE home Node-Bs.

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Biographies

George Korinthios graduated from the Physics Department of the University of Athens (UoA) in 1994. In 1996 he received his M.Sc. in telecommunications from the Physics Department and the Department of Informatics and Telecommunications of UoA. In 2002 he received his Ph.D. in VLSI architectures for broadband communications systems from UoA. From 1996 to 2002 he worked as a senior research associate in the Electronics Laboratory of the Physics Department of UoA and the Telecom Laboratory of the Electrical Engineering Department of the National Technical University of Athens, actively involved in numerous research projects. Since 2002 he has been working with COSMOTE. He is the author of several scientific papers in the fields of design and implementation of high-speed parallel VLSI architectures for traffic scheduling/policing components for Broadband systems.

Elina Theodoropoulou is a graduate of the Physics Department of UoA. In 1994 she received her M.Sc. in radioelectrology and electronics from the same university. She has worked with two Greek mobile operators (1994–1997 Telestet Hellas, 1998–present COSMOTE, the leading mobile operator in Greece). From 1994 to 2000 she was involved mainly in radio network planning, while as a section manager for New Technologies and Special Projects (2000–2005), she was responsible for, among other areas, the radio planning of the COSMOTE network for the Athens Olympics in 2004. Since 2005 she has been section manager for New Access Network Technologies in COS-

[7] *In most implementations, the SIM's credentials are passed towards a AAA server which interrogates a standard HLR/AuC regarding the validity of the SIM. An enforcement policy should be applied so that the use of such SIMs is restricted (barring of all teleservices and packet access).*

MOTE with a range of responsibility covering the areas of wireless broadband access and broadcasting technologies.

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