Dynamic Femtonode Switching by Means of a Low Power Radio Interface for Energy Savings and Interference Reduction

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Invited paper

Abstract

With the deployment of a large number of femto-cells, interference reduction and energy consumption considerations are becoming an important topic. This has been captured in TR 36.902, where it is stated that capacity could be improved through interference reduction by switching off those cells that are not conveying traffic at some point of time, in particular the H(e)NB's when the users are not at home.

So far several proposals have been made presenting different alternatives, for example detecting when the user is not in the coverage area of the nearest macrocell or proposing a specific solution based on S1 signalling. However, a simple and effective wake-up mechanism for a H(e)NB is one based on a specific short range radio interface for determining the proximity of the UE to the H(e)NB, provided that this short range radio interface does not add complexity to both the UE and the H(e)NB and the battery lifetime of the UE is not compromised.

Keywords. Femtonode, interference, energy consumption.

1. Introduction

The macro cellular architecture may be considered the first option for the deployment of any new radio access network technology and it has been the default solution when the main objective is to provide simultaneous outdoor and indoor coverage. This deployment is based on transmitters located on rooftops, but it cannot always ensure a good indoor coverage or a high throughput, because good SINR ratios are needed for properly receiving 16QAM or 64QAM modulations. The outer building walls and the internal rooms introduce additional losses that can only be overcome by means of an extra radiated power, which increases outdoor interference. This makes attractive any solution that provides coverage from base stations located indoors. As a result of the new traffic demand patterns, where most of the traffic comes from indoors, mobile telecom industry is working on the femtonode concept, also known as Home eNode B (HeNB for LTE, or H(e)NB for both UMTS and LTE) in 3GPP terminology, to provide indoor coverage from small base stations located at the customers' premises. The ultimate goal is to split the wireless mobile traffic between the biggest number of cells, optimizing the coverage and increasing spectrum usage efficiency.

However, the large scale deployment of femtonodes does not come without its own problems. The main concern is interference, both with the macro layer and between neighbour femtonodes. The former will be more severe if the femtonodes must share the radio spectrum with the macro layer, because a user equipment (UE) trying to connect to a macro base station can be strongly interfered from a nearby femtonode, and the latter will be always present in dense femtonode urban environments. Some solutions are being proposed in 3GPP to mitigate the interference problem [1] [2], for example the adoption of Hybrid CSG (Closed Subscriber Group) femtonodes [3], which accept connections from terminals that are not included in their restricted access lists in order to reduce the interference to users connected to the macro layer.

In the future millions of femtonodes will be installed at homes where there is nobody during an important part of the day.

3GPP TR 36.902 [4] states that network capacity could be improved through interference reduction by means of switching off those cells that are not transmitting traffic at some point of time, in particular femtonodes when the user is not at home, but this use case has not been completed in 3GPP release 9. If vendor predictions are fulfilled, in the future perhaps millions of femtonodes will be installed at homes where there is nobody during an important part of the day, generating unnecessary interference and wasting power for nothing. Therefore, a large fraction of the femtonodes could be disconnected, if some procedure to detect the user presence were implemented.

The current implementations that have been proposed for switching off the radio section of a femtonode are usually based on detecting when the user is not in the neighbourhood of the femtonode [5]. They detect when the UE is camped in the nearest macro cell to the femtonode in order to decide when switching on or off the femtonode. When the UE is not camped in a predefined macrocell it is assumed to be far away from home and the femtonode is switched off. This procedure can alleviate the problem, but there is no doubt that in many occasions the user will be in the whereabouts of the home served by the macrocell, but not really at home. A more powerful implementation is to really detect the customer presence at home, by means of a low-power radio interface activated in the UE [6], for example Bluetooth Low Energy or Wi-Fi, provided that some procedure is implemented for not degrading significantly the battery lifetime. When the user arrives home, the short range radio connection between the UE and the femtonode is established and the latter can switch-on its radio section accordingly (the opposite is done when the user leaves home and the short range connection is lost).

This paper is organized as follows: section 2 describes an analysis of the femtonode interference scenario, section 3 presents a femtonode deployment analysis from the energy efficiency point of view, section 4 describes some femtonode switching procedures, and finally section 5 is devoted to conclusions.

2. Analysis of the femtonode interference scenario

In this section we are going to analyze the impact of interference on the capacity that can be offered by a femtonode, with a special focus in the dense femtonode deployment scenario, where many femtonodes are installed in nearby houses. The goal of this analysis is to demonstrate the need for switching off those femtonodes that are not providing traffic in order to improve the overall capacity.

All the simulations have been made using a Telefónica's proprietary indoor simulation tool called SPIN, for the LTE standard in the 2.6 GHz band, and assuming a 10 MHz FDD bandwidth. This tool calculates the SINR level using statistical and semi-empirical procedures, considering the layout and characteristics of the materials that compose the reference flat. The interference scenario that has been simulated is pessimistic, that is, it is considered that all the femtonodes are radiating the same power, when it is possible that the interfering neighbour femtonode that is not supporting traffic (and thus could be switched off) will be transmitting a lower power in those conditions (just only radiating the common channels, like the broadcast channel or the reference signals).

2.1 Interference-free scenario analysis

The first scenario that has been analyzed, as a benchmark for comparisons, is an 8 m _ 10 m reference flat (Figure 1), with brick exterior walls and plasterboard partitions, with a femtonode correctly installed in a central location and not subject to any interference from any neighbour. In this scenario, no interference with the macro layer is taken into account (i.e. they use a different radio frequency).

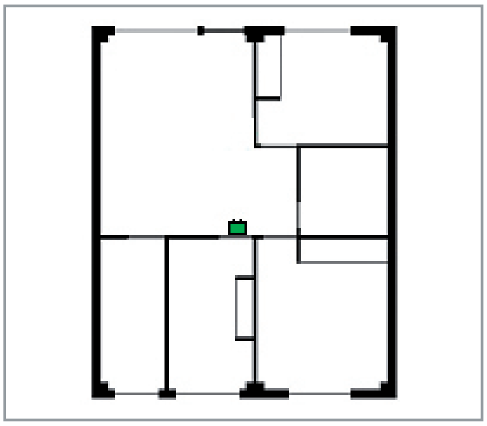


Figure 1. *Isolated femtonode in a reference flat*

The simulation results show that it is possible to provide a 27.5 Mbps throughput all over the flat, as it is depicted in figure 2. This is equivalent to a spectral efficiency of 2.75 bits/Hz.

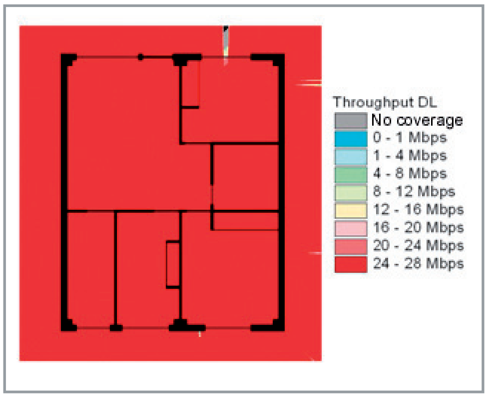
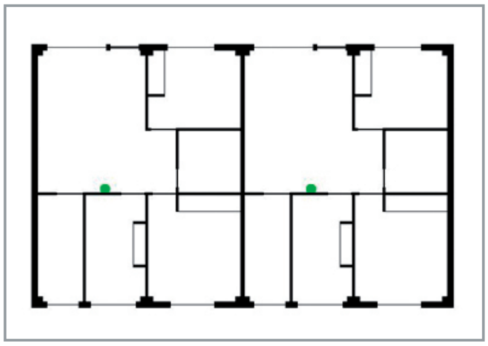


Figure 2. *Available throughput in an interference-free scenario.*

2.2 Simulation of inter-femto interference scenarios

Once the interference-free reference scenario has been considered, we proceed to simulate some deployments subject to interference. For example, figure 3 shows the case of two neighbour flats that install their own femtonode, both in a central location.



■ **Figure 3.** *Two femtonodes located in central locations in neighbour homes.*

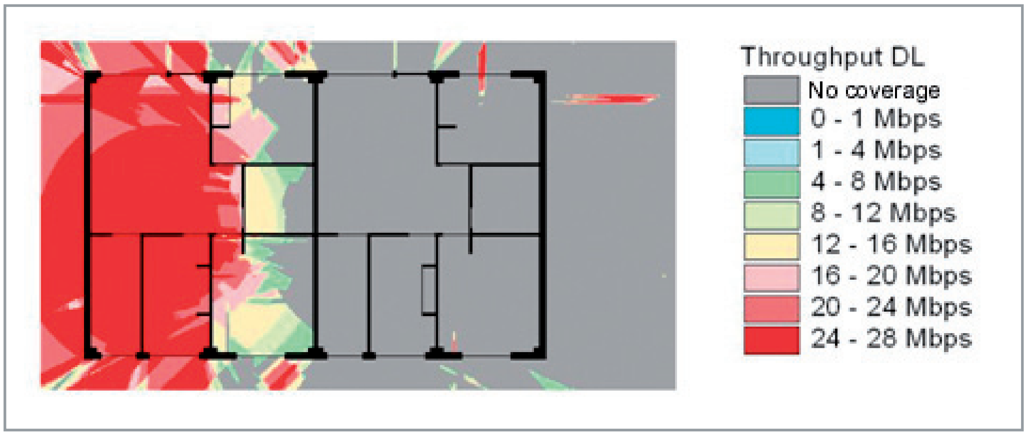
The simulations show a severe degradation of the available throughput in the border region between the femtonodes. Figure 4 depicts the available throughput in the left apartment only, considering the signal from the right apartment as interference. This figure shows that at a distance of 1 or 1.5 meters from the dividing wall the femtonode service can be even totally disrupted.

The situation can be even worse if the femtonodes are not optimally located. For example, if both devices are installed close to the dividing wall, the effect on the available throughput can be quite dramatic, as it is depicted in figure 5.

The obvious conclusion from these simulations is that in dense femtonode deployments, the available throughput in a given femtonode will be seriously affected by the presence of neighbour femtonodes, making it very convenient to switch off as many femtonodes as possible.

3. Femtonode analysis from the energy efficiency point of view

In this section, we are going to analyze a deployment scenario that could be typical in the future: a heterogeneous network for LTE coverage, supported on a macro layer for outdoor and partial indoor coverage, and a set of femtonodes that are installed in a significant fraction of the apartments in the coverage area. In this case, both throughput and energy consumption will be taken into account, in order to compute energy efficiency figures of merit. This analysis will further motivate the implementation of some femtonode switching off procedures, in order



■ **Figure 4.** *Left flat throughput, two femtonodes located in central locations in neighbour homes*

■ **Figure 5.** *Left flat throughput, two femtonodes located near the dividing wall.*

A large fraction of femtonodes could be disconnected if some procedure to detect the user presence were implemented.

to alleviate the energy consumption problem in the case of massive femtonode deployments.

The reference scenario is a dense urban area in Madrid's city centre, with an area of 2.86 km2, served by 18 LTE macro eNodeBs (54 cells), at an average inter-site distance of 250 meters. The eNodeBs transmit a power of 38 dBm per sector, the operation frequency is 2 GHz (different to the femtonode layer in order to avoid macronode – femtonode layers interference problems) and the bandwidth is 10 MHz. The overall capacity of this scenario is calculated considering 10 active users per cell, i.e. 540 active users are randomly distributed over the whole scenario, outdoors and indoors.

For the energy requirements analysis, outdoor base stations that do not need any shelter nor air conditioning have been selected, thus the maximum consumed power per site, with three cells, is 790 W.

The macrocell reference scenario has been evaluated by means of a radio planning tool [7] that calculates the signal level by means of ray tracing and real cartography of Madrid's city centre. The signal level is calculated in a grid of points in the reference scenario, and in a subsequent step the throughput at each point is calculated using a LTE look up table (SINR – throughput), obtained from a Telefónica's proprietary link level simulator. Finally the scenario's average capacity is computed.

In the same geographical area a fraction of the houses will install a femtonode. We are again using the Section 2 reference flat. In the reference scenario, the in-building area has a ground floor extension of 975,188 m2, and taking into account that the average number of stories per building in the district is five, the total indoor area is 4,875,942 m2, and therefore there are 60,949 reference flats in this area. The indoor section of the reference scenario has been evaluated by means of the same tool described in Section 2. In this exercise, it is proposed a situation of a high femtonode acceptation ratio, where an arbitrary 18% of the apartments, 10,971, have installed a node. The femtonodes are divided into three categories:

- Type I –Serving Femtocell surrounded by one interferer femtocell. The simulation scenario sets that a 10% of the femtocells fall into this class (1,097).

- Type II – Serving Femtocell surrounded by two interferer femtonodes. 40% of the scenario femtocells are classified Type II (4,388).

- Type III – Serving Femtocell surrounded by five interferer femtonodes. 50% of the femtocells are considered to be Type III (5,486).

Every femtocell is located at a height of 1 meter and radiates 15 dBm from a 6 dB gain omni-directional antenna. The consumed power per femtocell is 8 watts (a typical value of commercial 3G femtonodes). The operation frequency is 2.6 GHz and the bandwidth is 10 MHz.

Given this heterogeneous reference scenario, we proceed to analyze the aggregated throughput and power consumption. It is assumed that the femtocells and the macrocells are using different frequencies; therefore there is not significant interference between the macrocell and femtocell layers.

The simulations that have been done to evaluate the aggregated capacity of the hybrid reference scenario, taking into account the type of femtocells, provide a total aggregated capacity of 195,534 Mbps for the femtonodes, and 350 Mbps for the macrocells. Regarding energy consumption, the femtonodes are responsible of 87,768 W, and the macrocells of 7,038 W.

It can be observed that in the hybrid macro and femto approach, most of the capacity, but also most of the power consumption, are related with the femtonodes. Even though the power efficiency, measured as capacity per watt, is much better in the femtonode case (2.2 Mbps/W) that in the macro case (0.05 Mbps/W), it cannot be denied that the total power consumption is huge and should be reduced, implementing some switching-off procedures when they are not providing service.

4. Femtonodes switching procedures

4.1 Switching off procedures based on UE location

Some possible triggers for waking up a femtonode when a user is getting close to it have been proposed [8] based in well known location procedures, like for example:

Tracking Area – The Tracking Area known to be in the vicinity of the femtonode could be configured as the trigger event for switching a femtonode. Due to the commonly big TA size, this option has a poor efficiency in terms of the number of femtonodes that are likely to be in stand-by mode.

Closest serving macro cell – When the mobile enters a macrocell known to be in the vicinity of the H(e)NB. This macrocell could be learnt by the UE when being connected to the H(e)NB. The location accuracy is the cell, which is likely to be small in dense areas where the femto-base stations density will be high, thus limiting the probability to have femtonodes activated.

Satellite or triangulation – The mobile or the network is able to get mobile position thanks to a triangulation from measurements on signals from several neighbouring cells, or by means of a satellite navigation functionality embedded in the UE. The triggering zone may then be defined by geographical coordinates. This option has the advantage of flexibility, since the triggering zone has not to be aligned with cell edges. However, satellite navigation is not available indoors and cell-based triangulation does not provide accurate location estimations.

4.2 Femtonode switching off procedure based in a short-range radio interface

In order to detect when a user is or is not really at home, some very precise location method must be implemented. As the satellite navigation systems are not indoor-operative, and as cell based location methods do not provide the required accuracy, the most simple and precise procedure is to make use of a low power radio interface, which establishes a short range link between the femtonode and the terminal only when both are in close proximity, as it has been proposed by the authors in 3GPP [9]. This radio interface will be always active in the mobile, and therefore some procedure must be implemented for not significantly degrading its battery lifetime. Some technological candidates are Bluetooth Low Energy or Wi-Fi, being both very common in many mobile phones.

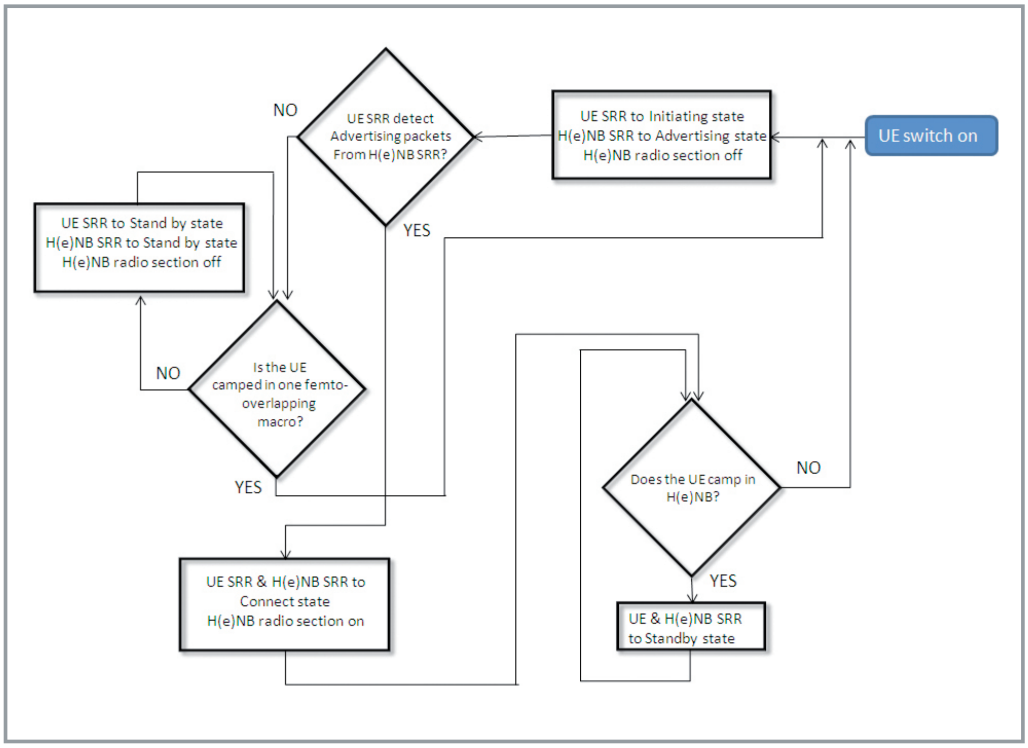
When the user arrives home, the femtonode detects the low power radio interface (with a typical indoor range in the order of 10 to 15 meters) and switches-on the radio section of the femtonode. The opposite is done when the user leaves home and the low power radio interface connectivity is lost. It could be possible to totally switch-off the femtonode, not only its radio section, but this option is not recommended, because the wake-up time of a switched off femtonode is in the order of minutes, making impossible any inbound handover.

4.3 Short-range radio interface procedure refinement for UE battery lifetime optimization

Even though the main goal of the short-range radio interface procedure is to keep switched off the femtonodes when they are not strictly necessary, a secondary goal is to keep the short range radio interface of both the UE and the H(e)NB in stand by state for as long as possible, in order to reduce the UE battery power consumption, and to reduce the radio interference produced by the short range radio interface of both the UE and the H(e)NB. Therefore, we are proposing that this low power radio interface is only active in the UE when it detects the macrocell that is closest to the H(e)NB, and inactive when the UE does not detect this macrocell, and to keep it also inactive when the UE is already camped in the H(e)NB.

The procedure description in the following paragraphs is based on Bluetooth Low Power as the implementation of the short range radio (SRR) interface, but this is only for indicative purposes and used only to provide a detailed description of the process, and does not preclude any other implementation.

This procedure keeps the H(e)NB and the UE short range radio interfaces in stand by state all the time, with the exception of the occasions when the UE is camped in some of the macrocells listed in a UE-stored list (Femto-Overlapping Macrocells list), but not camped in the H(e)NB itself. When the UE is not camped in one of the macrocells included in the Femto-Overlapping Macrocells list the UE SRR will be in an “Initiating” state, and the femtonode SRR will be in an “Advertising” state. This “Initiating” and “Advertising” states are respectively defined in



■ **Figure 6.** *Femtonode and short range radio switching procedure*

In the hybrid macro and femto approach, capacity and power consumption are related with the femtonodes. Total power consumption should be reduced implementing switching-off procedures.

Bluetooth Low Power for the Master and the Slave roles in a point-to-point connection.

The state diagram of the femtonode switching procedure is depicted in the next figure.

As it is shown in the figure, the switching procedure is as follows. When the UE is turned on, its SRR will be set to the Initiating default state. The H(e)NB will be in its default Advertising state, and its 3GPP radio section will be in its default switch off state. In the Initiating state, the EU is searching for advertising radio packet emitted from the femtonode SRR.

If the UE SRR does not detect the advertising packets from the femtonode SRR, the UE checks if it is camped in some of the macrocells included in the Femto-Overlapping Macrocells list. If it is not camping in any of these macrocells, and no advertising packets from the femtonode are detected, the UE determines that it is not either in the neighbourhood of its femtonode or camped in it, so it switches its SRR to stand by status, in order to save battery power. Then, the UE could require to the H(e)NB, following a procedure that should involve the mobile core network and the S1 interface, to switch its SRR to stand by state. The latter would be done in order to reduce the level of radio interference generated by the femtonode SRR.

If the UE SRR does not detect the advertising packets from the H(e)NB, but it is camping in some of the macrocells included in the Femto-Overlapping Macrocells list, then the UE determines that it is in the neighbourhood of its H(e)NB but not camped in it, so it switches its SRR to Initiating state (in the case it were in stand by state), and the UE could request to the H(e)NB to switch its SRR to Advertising. This is done in order to allow the establishment of the short range communications link supported by the SRR between the H(e)NB and the UE, once the femtonode and the UE are close enough to each other.

If advertising packets are detected at the UE, the UE checks if the H(e)NB identification (e.g. CSG ID) is included in its list of authorized femtonodes (i.e. H(e)NB Whitelist). If it is in the list, both the UE and the H(e)NB SRR will change to the Connect status. Once the connection of the short range radio link between the UE SRR and the H(e)NB SRR has been established, the femtonode will switch on its radio section.

Femtonode switching on, even when only the radio section must be turned on and the remaining femtonode functionalities have been active, is not a trivial task. For example, in the case of 3G femtonodes (HNB's), during the period of time when the radio section was switched off any other HNB could be switched on and radiate with the same pair of Absolute Radio Frequency Channel Number (UARFCN) and Primary Scrambling Code (PSC). Before switching on the radio section of the HNB, it will have to check the validity of the previously used radio physical channel. One possibility is that the HNB checks the previously used UARFCN and PSC, and in the case they are not in use it radiates the signal with the same values that were used before switching off. In the case these values are in use, the HNB will have to select the UARFCN and the PSC with lower detected power from a set of possible values.

Once the radio section of the femtonode has been switched on, the UE will try to camp in it. Both the H(e)NB and the UE will wait for a predetermined time period (a Camping Check Time) to check if the UE has camped in the femtonode. If the UE has camped in the femtonode after the Camping Check Time has elapsed, both the H(e)NB SRR and the UE SRR will be switched to the Stand by state. The rationale for switching to the stand by state is twofold: saving battery energy resources in the UE and reducing the radio spectrum occupation and the level of interference produced by the SRR.

In the case the UE has not camped in the H(e)NB after the Camping Check Time has elapsed, the UE SRR should be switched again to the Initiating state, and the femtonode SRR to the Advertising state, and the could switch off its radio section again. This could happen if the UE is trying to camp in a femtocell which has banned its connection, for example due to an update of the CSG list.
When the UE leaves the coverage area of the femtonode, it will not be camped in it any longer, so the same procedure described in the last paragraphs will be applied: the UE SRR will be switched to the Initiating state, the femtonode will switch to the Advertising state and the H(e)NB will switch off its radio section.

One additional advantage of this procedure is that it could be applied also to other non-3GPP radio interfaces included in the H(e)NB. For example, it is expected in the next future that many H(e)NB's will include an IEEE 802.11 (Wi-Fi) Access Point functionality, and its always-on radio section will unnecessarily pollute the ISM radio spectrum when the user is not at home and consume power. The procedures described so far could be applied to switch-off not only the H(e)NB radio section but also the Wi-Fi radio section.

5. Conclusions

The femtonodes are a good solution to improve indoor mobile broadband coverage and capacity, but interference and energy consumption problems must be solved before any massive deployment. We have demonstrated that in an urban reference scenario, the capacity supported by the femtonodes can be several orders of magnitude higher than that of the macrocell layer, but the same can be said of the total consumed energy. In order to alleviate these problems, the femtonodes radio sections must be switched off when they are not providing service to any user and an efficient way to perform this is detecting the real user presence by means of a short range radio link between the user terminal and the femtonode.

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Biographies

Luis Cucala García, Telecommunication Engineer MSc from the Polytechnic University of Madrid, Spain, in 1990, joined Telefónica I+D in 1991. He has been involved in the development of high-speed optical interfaces, Optical Networking, Radio on Fiber systems, and wireless mobile access communications. Since 1998 his activities have focused on solutions for indoor and outdoor coverage, developing network systems for Telefónica. Since 2000 he led the Radio Transmission Systems division in Telefónica I+D, and currently leads the Indoor Coverage and Connectivity group, running laboratory and field tests on femtonodes. He holds patents in the optical and wireless communications fields, and currently participates in EU FP7 BeFEMTO and TREND projects, developing novel femtonode concepts for LTE and home networking.

Emilio Mino Díaz received his Telecommunication Engineer degree from the Polytechnic University of Madrid, Spain in 1981. In 1982 he was working in the semiconductors and logic components, test and failure analysis in Telettra Spain. In 1988 he moved to Telefónica I+D, initially in the semiconductor area, but after an initial period he changed to mobile networks activities; interferences and coexistence between mobile systems, mobile coverage in tunnels used by high speed trains, and currently studies of LTE performance and femtonodes networks. He has participated in the European research projects: STRIKE, WINNER I, WINNER II and BeFemto. He is author of several conference and journal papers and co-author of two books related with LTE-A and cooperative wireless communications. Currently he is project leader in the Indoor Coverage and Connectivity group.