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Surveys

Evolution of multiple-access networks — cellular and non-cellular — in historical perspective. Part 3

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Introduction: *The goal of this issue is the analysis of evolution of the current and novel wireless networks, from second generation (2D) to fifth generation (5G), as well as changes in technologies and their corresponding theoretical background and protocols — from Bluetooth, WLAN, WiFi and WiMAX to LTE, OFDM/OFDMA, MIMO and LTE/MIMO advanced technologies with new hierarchy of cellular maps design — femto/pico/micro/macro.* ***Methods:*** *We use new theoretical frameworks for description of the advanced technologies, such as multicarrier diversity technique, OFDM and OFDM novel approach, MIMO aspects description based on multi-beam antennas approach, various cellular maps design based on a new algorithms of femto/pico/micro/macrocell deployment, and a new methodology of a new MIMO/LTE system integration based on multi-beam antennas.* ***Results:*** *We have created a new methodology of multi-carrier diversity description for novel multiple-access networks, of usage of OFDM/OFDMA modulation to obey inter-user and inter-symbol interference in multiple-access networks, of how to obey the multiplicative noises occurring in the multiple-access wireless networks, caused by multi-ray phenomena, and finally, of how to overcome propagation effects occurring in the terrestrial communication links by use combination of MIMO and LTE technologies based on multi-beam antennas. For these purposes we present new stochastic approach that accounts for the terrain features, such as buildings' overlay profile, buildings' density around the base station and each user antennas, and so forth. These parameters allow us to estimate for each situation occurs at the built-up terrain area the effects of fading, as a source of multiplicative noise.* ***Practical relevance:*** *New methodology of how to estimate effects of multiplicative noise, inter-user and inter-symbol interference, occurring in the terrestrial wireless networks, allows us to predict a-priory practical aspects of the current and new multiple-access wireless communication networks, such as: the users' capacity and user's links spectral efficiency for various configurations of cells deployment — femto, pico, micro, and macro, as well as the novel MIMO/LTE system configuration for future networks of 4*th *and 5*th *generation deployment.*

Keywords *— capacity, close subscriber group, CSG, dedicated spectral assignment, DSA, femtocell, femto access point, FAP, grade of service, GoS, quality of service, QoS, microcell, macrocell, open subscriber group, OSG, path loss, picocell, shared spectral assignment, SSA, signal-to-noise ratio, SNR, waveguide-street model, stochastic model of urban environment, wireless fidelity network, WiFi, wireless metropolitan area network, WiMAX.*

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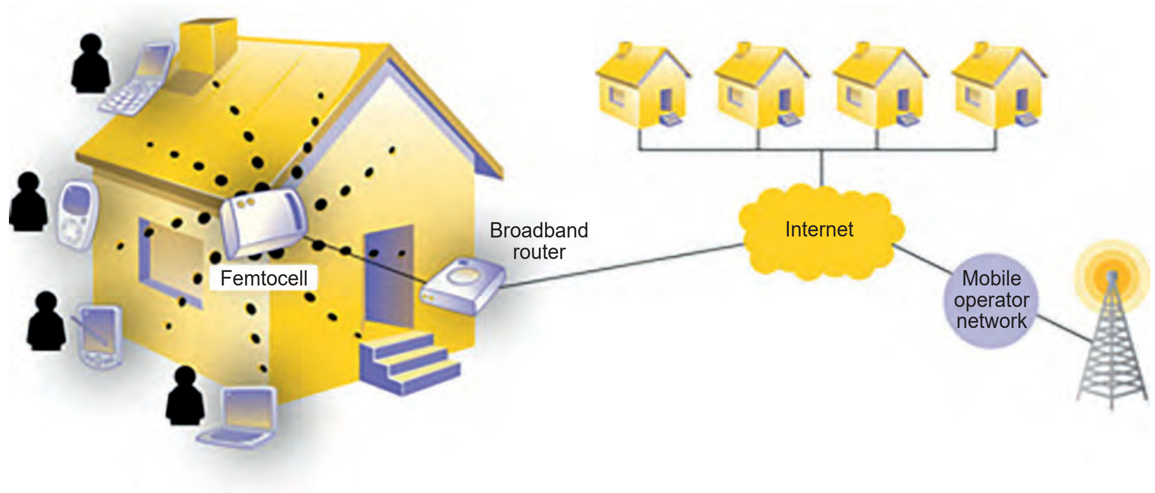
Novel femtocell concept for modern networks from 4G to 5G

The femtocell concept is one of the example of new technologies, that makes use as of the existing 3G homogeneous and non-homogeneous cellular networks to yield high speed mobile communications (up to 1 Gbps) [83–94]. A femtocellular concept was introduced, as an example of how to improve GoS and QoS for modern MIMO networks by introducing a non-standard planning of the cells' pattern instead of existing technologies of cells' pattern design [22, 95, 96]. We present now a recent configuration of femtocell concept combined with WiFi-WiMAX existing networks for the purpose to perform of a new 4th generation of wireless networks. Such a configuration is presented schematically in Fig. 17.

According to [83–94], we define femtocell as the *home access point* (HAP) [called also *Femto-Aps* or *FAPs*] arranged inside the existing micro- or macro-cell networks for the increasing of the rate of information data stream for each home subscriber. The increasing demand observed during the recent decades for higher information data rate in standard wireless networks has triggered the performance of advanced cellular technologies and modern networks. Thus, the third-generation partnership projects (3PPP and 3PP2) [86, 87], HSPA [93], wideband code division multiple access



■ ***Fig. 17.*** Schematic presentation of Femtocell-WiFi-WiMAX configuration

(WCDMA-2000) and WCDMA/HSPA standards, the modern forth-generation (4G) technologies and the corresponding networks on the basis of WiMAX (based on the protocol 802.16e) and LTE standards [83, 85, 90], were continuously adopted to supply the real mobile broadband experience for the mobile customers. This occurs because of the growing demand for mobile wireless communications, which requires to determine and to fully understand the capacity limitations of each technology due to the fact that the capacity limit formulates the maximum data rates based on the channel capacity equation that was introduced firstly by Shannon [84].

One of the main approaches to overcome the fundamental capacity limitations and as a result to increase the maximum user throughput is to use the higher-order modulation techniques for broadband networks, such as OFDM [91]. However, such a technique requires smaller cell radius especially when the reuse of one frequency scheme is used.

Femtocell access point (FAP) networks have recently received considerable attention from communication society due to their enormous potential for capacity improvements by answering the small cell radius requirement [83]. The initial standardization of FAP by the 3GPP, 3GPP2, WiMAX Forum [85–87, 90, 94] was completed lately, signaling that femtocell technology has been recognized by the highest profile standardization structures worldwide.

Finally, the femtocell concept allow designers of such combined femtocell-microcell or femtocell-macrocell networks to achieve a higher capacity, that is, maximum possible rate of signal data passing via such indoor-outdoor channels with minimization in the multiplicative noise due to fading and the noise caused by interference between users [83, 92–94]. At the same time we notice that the co-existence between the FAP, neighboring FAPs and micro- or macro-cell BSs (denoted as MBS), remains a key problem that needs to be addressed [85–87].

A precise control of femto-macro cellular (FMC) interference should be performed. This control relates to sub-band scheduling and interference cancellation. Thus, to control FMC interference the macrocell bandwidth should be split into sub-bands and the short-rage femtocell links should allow their power across these sub-bands. The corresponding procedure of the macrocell partitioning into sub-bands is done as follows.

The sub-band Δf_i, $i \in [1, N]$, is used in all M cells and serves users located close to the each cell BS. The other sub-bands Δf_j, $j \neq i$, serve users close to the cells' edges. During sub-band partitioning, an adaptive power control technique is usually used. Such approach of powers allocation across the sub-bands can maximize loading and GoS.

Finally, using femtocell APs, we can satisfy the problem of macrocell interface, reduce inter-cell interference between adjacent macrocells, mitigate the femtocell-macrocell users interference, and improve cell edge users' performance. The main goal of femtocell-macrocell and femtocell-microcell deployments is to avoid co-channel interference and to increase the overall cell capacity, which in turn allows achieving high data rate for each indoor subscriber.

All these benefits depend strongly on the propagation phenomena (i. e., physical background) that occur in indoor-outdoor communication environments. A good prediction of these propagation effects allows solving the problem of full radio coverage for each femtocell (e.g. indoor) subscriber located in the area of each FAPs service.

Here, we focus our effort on the co-existence analysis that takes into consideration the different scenarios of FAPs deployment. The analysis is performed in terms of channel capacity estimation for different FAPs deployment strategies. Following the [88–96], we formulate the capacity analysis on the basis of four main terminologies:

— dedicated spectral assignment (DSA), that is, the FAP deployment by using a dedicated spectrum that is not used for the macro-cell network;

— shared spectral assignment (SSA), that is, the FAP deployment by using the same frequency carrier as a macro-cell network;

— closed subscriber group (CSG), that is, the FAP is accessible only for a local group of users according to the defined access list;

— open subscriber group (OSG), that is, all MBSs might access the FAP coverage service.

All the combinations DSA with CSG and OSG, as well as SSA with CSG and OSG, we will analyze below. We also notice that in the CSG case, the only users, which are inside the indoor environment, are assumed to be served by the FAP.

Some of the details on shared spectral channel assignment deployment can be found in [88–90]; the comparison between the closed and open access group list is analyzed in [91], and different power control techniques are discussed in [92]. The Femto forum white papers have also included studies for co-existence analysis in terms of mutual interference [94].

Channel capacity models

To analyze the potential of channel capacity of mobile users in networks with integrated femtocell deployments, Shannon's equations were introduced considering different FAP available configurations (CSG and OSG) and spectral channel assignment strategies (DSA and SSA) mentioned above. The following conditions in such femtocell deployments and channel capacity models were assumed:

a) the total spectral bandwidth of the system, B_t, is assigned to FAPs and MBSs according to the considered configuration: DSA, SSA, CSG, or OSG;

b) all users have the same available bandwidth, which is assigned to comply with the highest available demand of service in the network, that is, each MS receives the equivalent part of the B_t;

c) all FAPs and MBSs transmit simultaneously to all active subscribers, whether stationary or mobile.

We notice here that to calculate the average received signal strength accounting for slow and fast fading phenomena caused by multiple scattering, diffraction and reflection, the unified propagation models for outdoor, indoor and outdoor-indoor scenarios were used following References [22, 77–89].

Now, let us introduce the main formulas for considering different FAP available configurations (CSG and OSG) and spectral channel assignment strategies (DSA and SSA).

Shared spectrum assignment with close subscriber group. In case when the total spectrum bandwidth B_i is shared between the FAP network and the macro-cell BSs (MBSs), the capacity of MS user i_F in FAP coverage, can be introduced as follows [95, 96]:

$$C_{SSA\_CSG\_indoor\_i} = = B_{tN} \log_2 \left(1 + \frac{S_{Fi}}{kTB_{tN} + \sum_{j=1, j \neq i}^{J} I_j + \sum_{l=1}^{L} I_l} \right). \quad (33)$$

Here, $B_{tN} = B_t/N$ is a bandwidth normalized to number of users N served by FAP; S_{Fi} is the signal strength of the FAP in the location of MS user i_F served by FAP with $i_F \in (1{:}N)$; I_l is the interference strength of MBS antenna with $l \in (1{:}L)$, where L is a total number of MBSs; I_j is the interference strength of the neighboring FAP j with $j \in (1{:}J)$, when J is a total number of FAPs; kTB_t is the thermal noise, where k_B is a Boltzmann coefficient and T is a temperature (in Kelvin). We notice that the MS users, which were allocated indoor are considered to be registered in the CSG, otherwise they are not allowed to be served by FAP. The capacity of the outdoor MS user i_M can be calculated as follows [95, 96]:

$$C_{SSA\_CSG\_outdoor\_i} = = B_{tP} \log_2 \left(1 + \frac{S_{Mi}}{kTB_{tP} + \sum_{j=1}^{J} I_j + \sum_{l=1, l \neq i}^{L} I_l} \right), \quad (34)$$

where $B_{tP} = B_t/P$ is a bandwidth normalized to number of users P served by MS; S_{Mi} is a signal strength of the MBS in the location of MS user i_M served by MBS with $i_M \in (1{:}P)$.

Shared spectrum assignment with open subscriber group. The main difference for this case is that the MS users that are located outdoor can be potentially served by FAP. Therefore, for MS users i_{Fo}, which are served by FAP and located outdoor, the channel capacity can be written as [95, 96]:

$$C_{SSA\_CSG\_outdoor\_iF} = = B_{tN} \log_2 \left(1 + \frac{S_{Fi}}{kTB_{tN} + \sum_{j=1}^{J} I_j + \sum_{l=1, l \neq i}^{L} I_l} \right). \quad (35)$$

The decision if the outdoor MS served by FAP or by MBS antenna is done by simple handover threshold, that is, the transmitter (FAP or MBS antenna) with highest signal strength gets to serve the MS.

Dedicated spectrum assignment with closed subscriber group. In case the dedicated spectrum is assigned to the femtocell network, there is no mutual interference between the MBS and the FAP, however the total bandwidth B_t is divided between the FAP and MBS network in some manner, that is, the allocation can be potentially not symmetrical. Therefore the channel capacity for the MS user i_F that is in FAP coverage can be introduced as follows [95, 96]:

$$C_{DSA\_CSG\_indoor\_i} = = B_{tNd} \log_2 \left(1 + \frac{S_{Fi}}{kTB_{tNd} + \sum_{j=1, j\neq i}^{J} I_j} \right), \quad (36)$$

where $B_{tNd} = B_t \cdot FNR/N$, and FNR is a FAP network ratio, which defines the part of total B_t spectrum allocated for FAP network. The capacity of the outdoor MS user i_M, which is served by MBS can be calculated as follows [95, 96]:

$$C_{DSA\_CSG\_outdoor\_i} = = B_{tPd} \log_2 \left(1 + \frac{S_{Mi}}{kTB_{tPd} + \sum_{l=1, l\neq i}^{L} I_l} \right), \quad (37)$$

where $B_{tPd} = B_t \cdot FNR/P$ is, as above, a bandwidth normalized to number of users P served by MBS.

Dedicated spectrum assignment with open subscriber group. In such a scenario, the channel capacity for the MS users, i_F, that is, located under the FAP radio coverage (having better signal strength), can be introduced as follows [95, 96]:

$$C_{DSA\_OSG\_outdoor\_iF} = = B_{tNd} \log_2 \left(1 + \frac{S_{Fi}}{kTB_{tNd} + \sum_{j=1}^{J} I_j} \right), \quad (38)$$

where $B_{tNd} = B_t \cdot FNR/N$ is, as above, a bandwidth normalized to number of users N served by MS antenna.

Addressing the problem of optimal resources allocation in the predefined built-up areas of interest and for the above four scenarios, let us introduce a well-known power allocation procedure called in the literature the "spatial water-filling" [108–110].

Analysis of femto/micro/macrocell network configurations

In our numerical analysis of the four scenarios described above, we assume that the users are randomly, but uniformly, distributed in the investigated area of service. For the analysis two representative areas were selected: one is for an urban, and one is for a suburban area (see definitions in [21, 22]).

We also assume that each FAP has 3 categories corresponded to the output antenna power of 10, 15, 21 dBm, respectively. In each category, the power dynamic range is 30 dB. Each FAP affects other users within a radius of 150 m.

For each distribution described above, we need to optimize the maximum transmitted power. The optimization criterion is to maximize the site's total ergodic capacity, that is, the sum of maximum available capacity for each user in the site under investigation [95, 96]:

$$C_{total} = \sum_i C_i (outdoor\_users) + + \sum_i C_i (outdoor\_users\_no\_femto) + + \sum_i C_i (outdoor\_users\_with\_femto). \quad (39)$$

Propagation aspects of femtocell networks. To analyze various scenarios in the outdoor-indoor communication environments for the femtocell-macrocell joint planning tool deployment, the multi-parametric stochastic approach for signal strength prediction in urban environment is used. This approach is fully described in [21, 22] and some details on the stochastic models for regular and non-regular distributions of buildings in the urban environment are presented in references [97–107]. This stochastic approach combines the multipath propagation along straight crossing streets, areas surrounding streets and other natural or man-made obstructions randomly distributed (according to Poisson's law as an ordinary flow of scatterers) on the rough terrain. General formulas were obtained in references [99–102] for prediction of the signal path loss in various scenarios with different elevations of the base station and the subscriber antennas. In this paragraph, the simplified approach based on reference [101] is proposed, where multiple diffraction and scattering, having the coherent and incoherent parts, have been rearranged in the simple forms.

We will present the total path loss, presented in [21, 22], accounting additionally for penetration of the radio signal inside buildings and the additional loss caused by walls, that is,

$$L_{total}(r) = -32{,}4 - 30\log f_{[\mathrm{MHz}]} - 30\log r_{[\mathrm{km}]} - - L_{fading} - L_{walls} + (G_{BS} + G_{MS}), \quad (40)$$

where, as in [22],

$$L_{fading} = 10\log\frac{\gamma_0 l_v F^2(z_1, z_2)}{|\Gamma|\left[\frac{\lambda r}{4\pi^3} + \left(z_2 - \bar{h}\right)^2\right]^{1/2}}, \quad (41)$$

$F^2(z_1, z_2) = \left(\bar{h} - z_1\right)^2$; all other parameters are described above in Part 2. Here we introduced also a new term called loss by walls, $L_{walls} = 10\log|T|$, $|T| = \sqrt{1 - \left(X|\Gamma|\right)^2}$, $0.5 < X < 1$ according to Reference [85], where $|T|$ is the absolute value of refraction coefficient that equals: $|T| = 0.9–0.95$ for glass, $|T| = 0.75–0.85$ for wood, $|T| = 0.55–0.65$ for stones, and $|T| = 0.15–0.2$ for concrete (for $X = 0.5–0.9$) [106, 107]. The wavelength of the radio wave has a wide range that varies from $\lambda = 0.05$ m to $\lambda = 0.53$ m and covers most of the modern wireless networks [22, 105–107].

As for indoor channels, here we use the same combination of the statistical waveguide model describing propagation phenomena along the corridors and inside rooms lining each corridor (see [22]), where instead of the time t, we account for relations between time $t = \left(r + \tilde{r}\right)/d$ and distances r and $\tilde{r} = \left[d^2 + r^2 - 2rd\cos\varphi\right]^{1/2}$. After straightforward derivations, we get:

$$\begin{aligned} L_{total} &= -32.4 - 20\log f_{[\text{MHz}]} - \\ &-10\log\left[\frac{\gamma_0(r+\tilde{r})}{d}\sin^2\frac{\alpha}{2}\right] - 2.4\{\gamma_0(r+\tilde{r})\} - \\ &-10\log\left(|T_{wall}\|T_{floor}|\right) - 10\log\frac{d\left((r+\tilde{r}) - d\cos\varphi\right)}{(r+\tilde{r})^2 - d^2} - \\ &-8.6\frac{|\ln X|}{a'(\varphi)}\frac{\left[(r+\tilde{r})^2 - d^2\right]}{(r+\tilde{r}) - d\cos\varphi} + (G_{BS} + G_{MS})|_{\text{dB}}. \end{aligned} \quad (42)$$

In this formula we account for attenuation loss caused by walls and by floors, as was done in [105, 107] by introducing the absolute values of the coefficients of attenuation caused by walls, T_{wall}, and by floors, T_{floor}: $|T_{wall}| = \prod_m |T_{wall,m}|$ and $|T_{floor}| = \prod_n |T_{floor,n}|$ according to [105, 107]. Formulas (40) and (41) will be used below for analysis of situation with path loss in outdoor macro- and micro-cell environments and formula (42) will be used for analysis of propagation inside femto-cell indoor links.

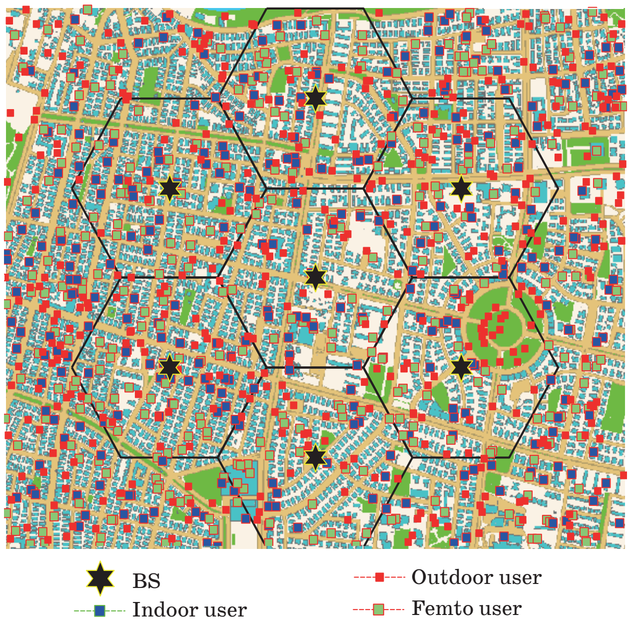
Numerical analysis of different femtocell network deployments. We analyzed numerically two types of deployments for different types of femtocell configurations:

a) there are three types of standard FAPs with maximum output power of 10, 15, and 21 dBm, mentioned above;

b) the same analysis was performed after the implementation of the power optimization algorithm using the spatial water-filling approach proposed previously.

Since both types of techniques gave the same results [95, 96], we present one of them on the basis of the water-filling approach. Numerical computations were performed for the urban scene that corresponds to the one of the built-up area of 1.5 × 1.5 km (Fig. 18), after the power allocation optimization algorithm using the water-filling mechanism. As it follows from Fig. 18, there are 7 cells uniformly distributed in this area. The MS users were randomly, but uniformly, distributed across the selected area where the part of them was randomly allocated in the indoor environment according to the real clutter definition (that is, a different percentage of indoor calls of 20, 40, and 60 % were simulated according to conditions considered in [95, 96]).

The FAPs were also randomly uniformly distributed between the indoor users. Different percentages of indoor MS users (from all number of users located in area of service) of 50, 70, and 100 %, which have FAPs, were also simulated. Different distributions of FAPs between the MS users were simulated for the following configurations: uniform, where 80 % MS users are concentrated at the cell edge and 20% are concentrated in the cell centre, and vice versa.



■ *Fig. 18.* The tested urban area. The big stars correspond to the MBS; different collared quadrates correspond to femto users, indoor users and MS outdoor users, respectively

All types of FAPs configuration (CSG, OSG) with SSA and DSA, were simulated and are presented in Fig. 19–22 for the above mentioned scenarios of MS users' distribution. The analysis was performed within the centrally positioned 7-cell pattern in the cluster assuming the frequency reuse of one. In numerical computations, the users' density was taken to be 480 users per square kilometre [95, 96].

Thus, in Fig. 19, *a*, *b* the CDF of signal data capacity for four network configurations (CSG, OSG, SCA, DCA) and for different FAP's distributions.

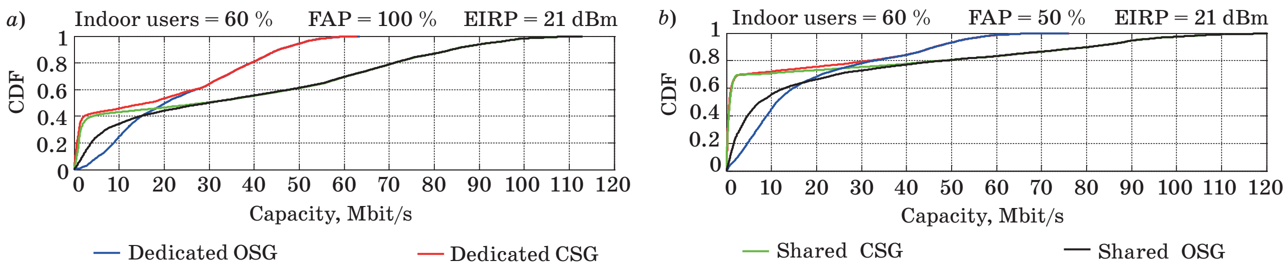
The effective irradiated power is 21 dBm and the number of indoor users is 60 % from all subscribers in the tested area. Once can see that the preferable network configurations are the shared and dedicated CSG and OSG femto-network configurations. Figures 20 show the total probability of the signal capacity (or maximum data rate) for shared CSG (*a*) and dedicated OSG (*b*) for different FAPs densities, of 50, 70, and 100 %, for indoor users using FAP of 60 % from the total number of indoor users in area of service.

The dedicated OSG allows for achieving higher data rate for the same usage of FAPs — 50, 70 or 100 %.

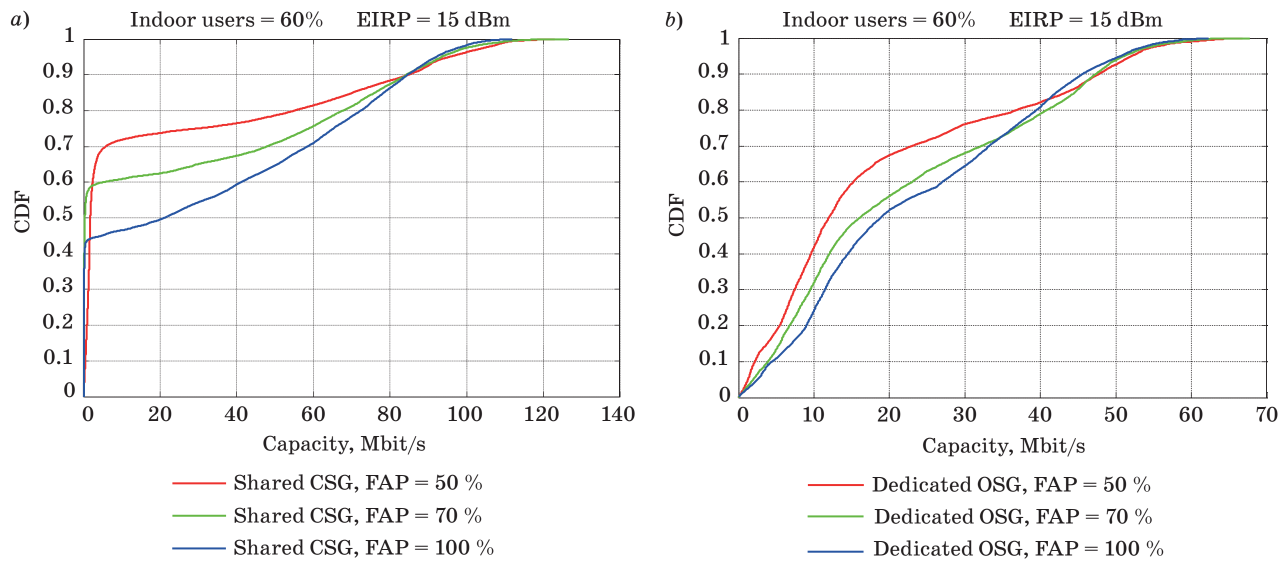
Figures 21 and 22 show the CDF of the signal capacity for the dedicated CSG and shared network configuration, respectively, for different percentage of indoor users, 20, 40, and 60 %, and for number of FAPs used by these indoor users: 70 % (*a*) and 100 % (*b*).

We can see that, again, the shared CSG concept allows us to obtain higher data rate (or capacity) for the same number of FAPs deployed by indoor users.

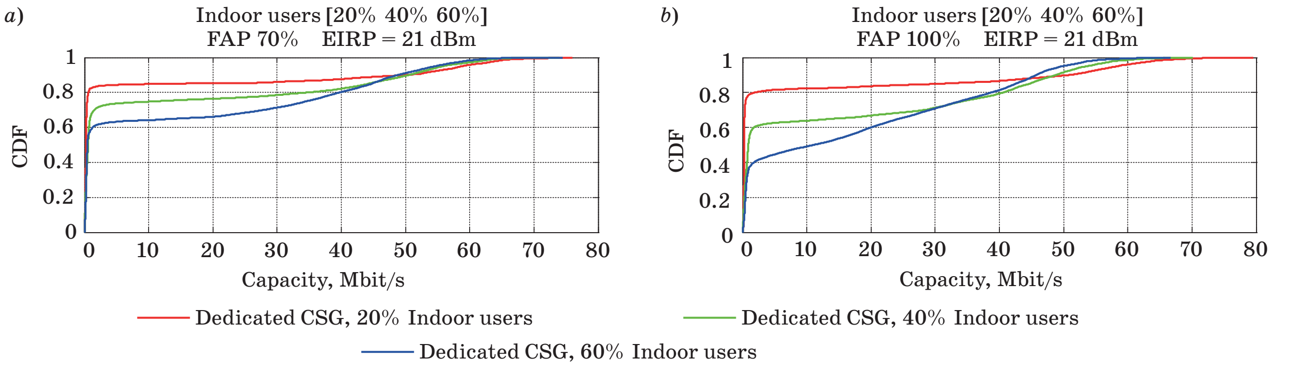
The obtained results allow us to conclude that the water-filling techniques for the optimal power allocation of FAPs can be fully implemented for predicting the different femtocell-macrocell network configurations with different tradeoffs for indoor, outdoor and femto-users densities. The similarly obtained results



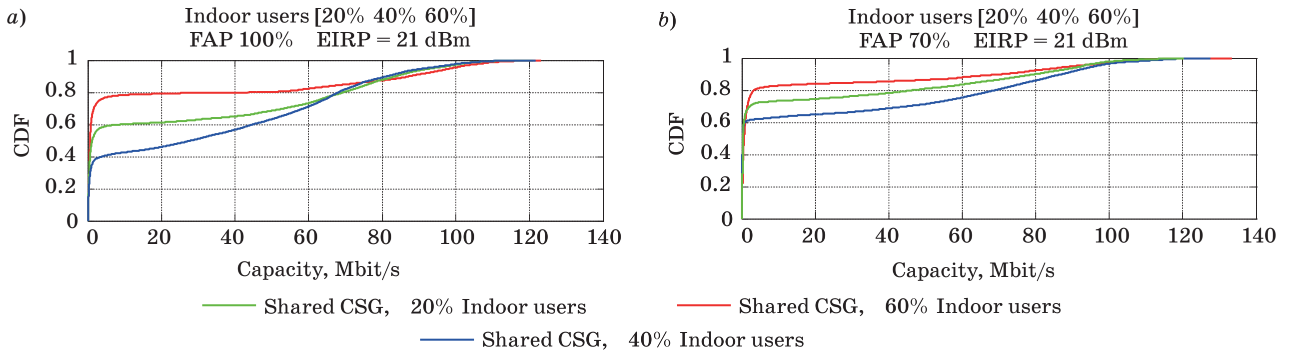
■ ***Fig. 19.*** Distribution of signal data capacity for four network configurations for different FAP's distribution: 100 % (*a*) and 50 % (*b*). The effective irradiated power is 21 dBm; the number of indoor users is 60 % from all subscribers in the tested area



■ ***Fig. 20.*** CDF of signal capacity for shared CSG (*a*) and dedicated OSG (*b*) for different FAPs densities, of 50, 70, and 100 %, for indoor users using FAP of 60 % from the total number of users in area of service



■ ***Fig. 21.*** CDF of the capacity for the same dedicated CSG network configuration for different percentage of indoor users, 20, 40, and 60 %, and for number of FAPs used by these indoor users: 70 % (*a*) and 100 % (*b*)



■ ***Fig. 22.*** Network configurations vs. different percentage of indoor users, 20, 40, and 60 %, for shared CSG scenario

for two frameworks, with and without the water-filling mechanism, have shown an improvement in the capacity distribution results between the users of joint femtocell-macrocell co-existing systems.

Experimental verification of the total path loss in femtocell — microcell areas

Now we will compare results of numerical computations of propagation outdoor-indoor model for femtocell employments in picocell and microcell environments with experiments curried out in special built-up environment [22].

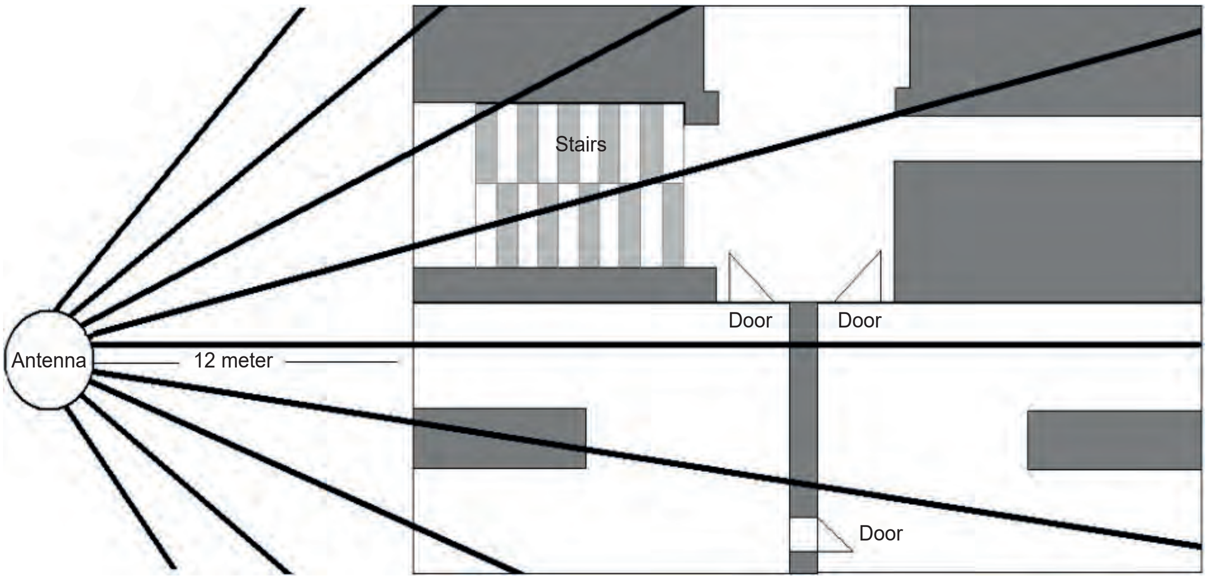
In the first cycle of experiments we show only the part of the specific area topographic map that corresponds to a femtocell-picocell environment surrounding one of the two-story building, as shown in Fig. 23, where the position of the transmitting antenna is denoted by the circle.

The vertically polarized transmitting sectoral antenna was installed 12 meters apart from the building, at 2-meter height. The receiving antenna was positioned inside the building at a height of 5 meters (i. e., at the 2nd floor). It was arranged at the notebook as a wireless card with its dipole micro antenna. This experiment corresponds to "femtocell-picocell-microcell" conditions.

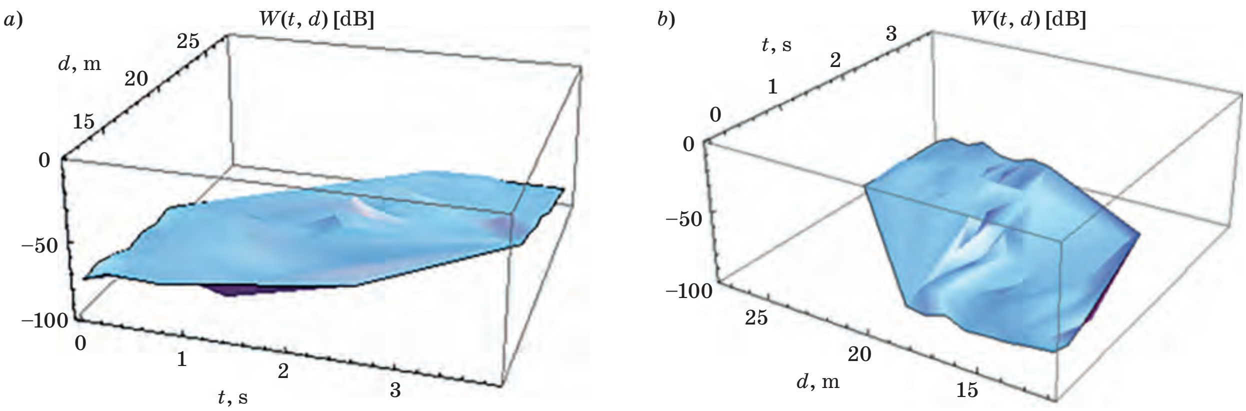
Measurements were carried out for each meter along the radiopath outside and inside the building, and the corresponding signal strength was measured. The power of the transmitting signal was 12 dBm and the frequency was 2.450 GHz. Due to scanning of the transmitting antenna (see straight lines in Fig. 23) in the azimuth domain, different angles of beam direction were taken, starting from 30 degrees up to 150 degrees, as it is seen in Fig. 23. We will present two characteristic graphs obtained experimentally according to 3D numerical code. The measured results are shown in Fig. 24, *a* and *b*.

The corresponding numerical simulations of the same conditions of the experiment are shown in Fig. 25, *a* and *b*.

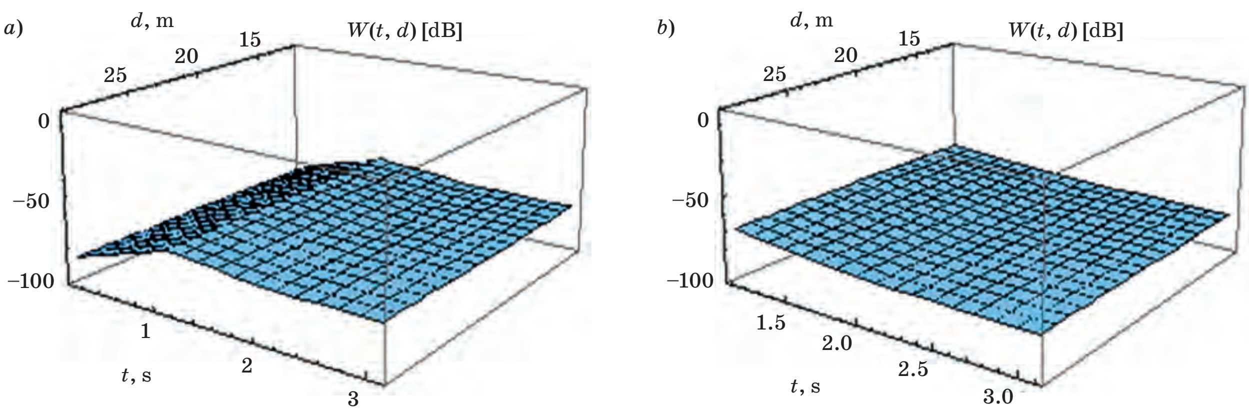
It was found, both, theoretically and experimentally that after passing a wall of bricks the signal intensity falls to −14÷17 dB, and then attenuates smoothly according to Equation (42) along the corridor. Despite the fact that the measured and the numerically predicted results of the signal 3D pattern have not the same shape and form, they both



■ ***Fig. 23.*** The scheme of the experimental site. The transmitter antenna is denoted by circle and located outside the building at the range of 12 m from the front wall of the building. Each line presents the radio path in azimuth domain where the angle is changed from 30 to 150 degrees



■ ***Fig. 24.*** Experimentally obtained 3D pattern of the signal power in the joint time-distance domain for the azimuth of 60 degrees (*a*) and 135 degrees (*b*)



■ ***Fig. 25.*** Numerical simulation outdoor-indoor link where all simulation data corresponds to the experiment: *a* — presented in Fig. 24, *a*; *b* — presented in Fig. 24, *b* predict the sharp attenuation during as the signal passes through the wall, and they predict the same attenuation with accuracy of ±(3÷5) dB.

We should notice that inside the building, due to multi-diffraction and multi-reflection effects from each inner architectural construction, the measured data showed strong oscillations of the recording signal strength (see Fig. 24, *a*, *b*), whereas the simulated data show much weaker oscillations (see Fig. 25, *a*, *b*).

Behind the building, theoretical model is a poor predictor of the experimental data. The difference between theory and experiment is of the order of 10–15 dB. This occurs because in formula (42) the effects of attenuation due to several walls is not taken into account, as well as the effects of furniture and other architectural structures that can work as the "secondary sources of diffraction", increasing overall intensity of the signal. Therefore, the multi-parametric stochastic approach, presented above, is limited, as a good predictor of propagation phenomena in indoor/outdoor femtocell-microcell communication environment, where all features and constructions, existing inside each room under testing, should be taken into account.

Ending follows.

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Эволюция многопроцессорных систем связи — сотовых и несотовых — в исторической перспективе. Часть 3

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Постановка проблемы: целью данного обзора является анализ эволюции систем беспроводной связи от второй генерации (2D) до пятой генерации (5G), а также изменения технологий и их существующих теоретических основ и протоколов — от Bluetooth, WLAN, WiFi и WiMAX до LTE, OFDM/OFDMA, MIMO и LTE/MIMO — продвинутых технологий с новой иерархической структурой дизайна сотовых карт фемто/пико/микро/макро. **Методы:** использованы новые теоретические подходы для описания продвинутых технологий, таких как многопользовательская техника разделения пользователей, OFDM и OFDM новейший подход, новые аспекты описания MIMO-систем на базе использования многолучевых антенн, дизайн различных сотовых карт на основе новых алгоритмов построения фемто/пико/микро/макро сот, а также новой методологии интегрирования новой MIMO/LTE-системы с помощью многолучевых антенн. **Результаты:** создана новая методология описания многопользовательского разделения, использования комбинированной OFDM/OFDMA-модуляции для обхождения интерференции между пользователями и между символами в новых многопроцессорных системах, мультипликативных шумов, имеющих место в беспроводных многопроцессорных системах связи, вызванных явлениями многолучевости. В итоге предложено, как обойти эффекты распространения, имеющие место в наземных каналах связи, используя комбинацию MIMO- и LTE-технологий, основанных на применении многолучевых антенн. Для этих целей разработан новый стохастический подход к проблеме, учитывающий особенности застройки земной поверхности, такие как профиль застройки домов, плотность застройки домов вокруг антенн базовой станции и пользователей и т. д. Эти характеристики позволяют в итоге оценить эффекты фединга как источника мультипликативного шума. **Практическая значимость:** новая методология оценки эффектов, созданных мультипликативным шумом, интерференцией между пользователями и между символами, имеющими место в наземных системах беспроводной связи, позволяет прогнозировать практические аспекты существующих и новых многопроцессорных беспроводных систем связи, такие как емкость (количество) пользователей и спектральная эффективность каналов пользователей для различных конфигураций построения сот — фемто/пико/микро/макро, а также новейших конфигураций систем MIMO/LTE для построения будущих систем 4-го и 5-го поколений.

Ключевые слова — емкость, закрытая пользовательская группа, CSG, установленное спектральное обозначение, DSA, фемтосота, пункт фемтопроцесса, FAP, уровень сервиса, GoS, качество сервиса, QoS, микросота, макросота, открытая пользовательская группа, OSG, потери на пути распространения, пикосота, выборочное спектральное обозначение, SSA, отношение сигнала к шуму, SNR, волноводная модель улицы, стохастическая модель городской застройки, беспроводная пользовательская сеть, WiFi, беспроводная сеть метрополии, WiMAX.

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ПАМЯТКА ДЛЯ АВТОРОВ

Поступающие в редакцию статьи проходят обязательное рецензирование.

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