A Technical Comparison Between Data Rate Enhancement Options in Radio Communications Networks

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***Abstract*—This paper makes a comparative study between two newly emerged technologies in the radio communications domain: on the one hand, the small cells networks, designed to be implemented in the existing macrocellular networks, with the goal of enhancing the coverage area and the capacity of the whole network, and the 60 GHz wireless local area networks on the other hand. This latter technology is developed in order to offer high data rates taking advantage of the license free spectrum available around the 60 GHz frequency. The paper highlights the main common and disjoint aspects of both technologies and offers some implementation options.**

Keywords-60 GHz WLAN; applications; comparison; coverage;, femtocell; small cell.

I. INTRODUCTION

Due to the ever-increasing demands of today's end users, the service providers need to come up with solutions that match these requirements. The main necessities are in terms of the data transfer rates which need to be at higher levels in order for the operators to offer the desired services in radio communication networks.

Therefore, the two main fields of operation that attracted most users, i.e., cellular mobile communications and wireless local area networks, respectively, need to be enhanced in order to become viable solutions for the end users. Regarding the mobile cellular domain, new standards have been introduced, which can offer besides voice services, also data services at comfortable rates. Here, we speak of standards like HSPA/HSPA+ or LTE offered by 3GPP [1], or WiMAX offered by IEEE [2]. Even with this important enhancement regarding capacity and throughputs of the networks, services are not sufficient, especially in indoor environments, where very often the radio coverage is poor. Recent studies have shown that in cellular networks, about 60% of all voice calls and 90% of all data services, take place in indoor environments [3]. That is why it is extremely important to have a good coverage in these regions. Several recent papers present the difficulties encountered, by the traditional approach, in assuring a good indoor coverage [3],[4]. The issues relate especially to dense urban areas where it is very costly to obtain a good indoor coverage due to the geometry of the environment. Also, the capacity of the network is a sensitive problem, given the fact that using a strictly macrocellular approach, a large number of base stations would be needed, rising once again the costs. Additionally, the planning and optimization of the network would be hard to manage.

As a possible solution to these problems, the femtocell concept was developed and implemented. It is mainly designed to enhance both coverage and capacity of the traditional macrocellular network. Femtocells, also known as Home Base Stations, represent cellular network access points, which have the role of connecting the users to the operators network. The link to the macrocellular network is realized through a backhaul IP connection.

A Femtocell Access Point (FAP) is similar in concept to the wireless access point used in wireless local area networks, and it is designed to be implemented by the user. It has a low transmit power of maximum 250 mW [5], in case it is used for the residential environment. The number of active users is limited in this case, and can be up to 5 [6]. Given the fact that this equipment has a reduced transmit power, it can be implemented with a much larger density than macrocell base stations. Thus, due to the high deployment frequency, previous results show an enhanced spectral efficiency [4].

In the local area networks domain, the high density of equipment and users operating in the unlicensed ISM band has forced standardization bodies to search for alternatives to the current implementations. A possible solution is considered the implementation of the WLAN concept in the 60 GHZ frequency band. The 60 GHz millimeter wave technology is relatively new on the market and hopes to fulfill the needs of users for gigabit-scale traffic. The strong interest in the 57 – 66 GHz frequency band [7] is shown by the recent industrial and standard development efforts made by international standardization bodies like ECMA TC48, IEEE 802.15.3c and the proposed IEEE 802.11 VHT60 Task Group [8].

The high interest is due to the large bandwidth which is unmatched in any of the lower frequency bands [9]. Figure 1 shows the available spectrum for indoor wireless communications around the world. The fact that this band is unlicensed and largely harmonized across most regulatory regions in the world is a big advantage in comparison to the narrower spectrum available in other frequency bands, like 2.4 GHz and 5 GHz, available for 802.11 standards. Both ECMA and 15.3c employ a channel plan that consists in dividing the available spectrum into 2.16 GHz frequency bands for each channel.

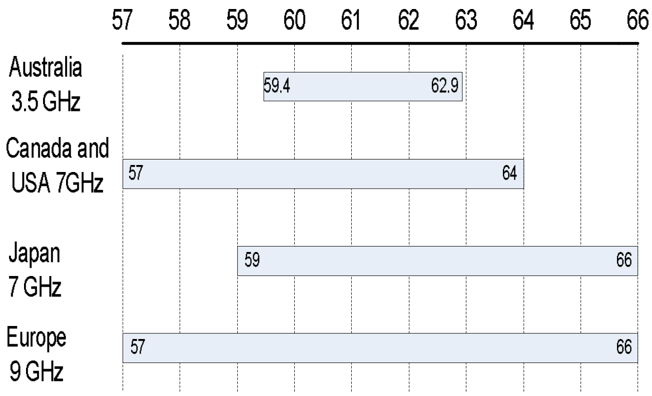

Figure 1. The available spectrum for indoor wireless communications in the 60 GHz band around the world

Both technologies present high perspectives for future implementations, offering important benefits to the users. They both try to enhance the user experience by offering higher data rates, one for wireless local area networks, the other for radio mobile communications.

Given the tendency of developers to integrate and unify the current technologies, the 60 GHz WLAN and femtocell networks, offer real perspectives, but it depends on the users choice, regarding which will have the best advantage.

The rest of the paper is organized as follows: in Section II, we present a comparative study between the two technologies, regarding some technical aspects encountered in the implementation process. In Section III, we consider a case study involving an indoor office environment in which the two networks will be implemented and studied. An analysis is done regarding aspects like the obtained coverage, the resulting interference or the attenuations introduced by the environment objects. Finally, Section IV concludes the paper and presents some future aspects.

II. Comparison of Technical Aspects

The fact that both technologies address the same market segment, i.e., that of the clients situated in the indoor environment which need enhanced data rates for communication, constitutes an important start point in developing a solid comparison. Being in the early stages of network implementations, offers the possibility to have a much wider view concerning the research in these domains. In this way, the development of common points can be realized, leading in the future to the integration of these two types of technologies, in order to enhance the quality of service experienced by the client.

In this section, we will emphasize the main characteristics of the two technologies regarding some key aspects like the integration with the existing implementations, the connectivity to the current networks, mobility and handover possibilities and also interference within the deployed network or with the existing one.

A. Integration with the existing implementations

Regarding the 60 GHz WLAN technology, possibilities of integration with existing 2.4 GHz and 5 GHz wireless LANs, represent a major research topic; this is primarily due to the high costs, which result in the implementation of a purely 60 GHz network, as we will see later in the paper. The authors of [9] present a method to integrate the three WLAN technologies, facilitating the commercialization of equipment operating in triple band. Using this, the client can choose the operating frequency depending on the needs and the environment: 2.4 GHz for applications with reduced needs, 5 GHz for applications regarding confidential traffic and 60 GHz for high transfer rate applications. Thus, a mandatory enhancement of the equipment and terminals used must be done, in order to facilitate the implementation of the new 60 GHz technology. This, however, would not be an easy task given the fact that most of the current access points operating in the 2.4 GHz and 5 GHz frequency bands, have omnidirectional antennas, which, in the case of the 60 GHz technology, is not a well suited option because of the high attenuation of the waves transmitted on this frequency. Thus, especially for Non-Line of Sight (NLOS) communications, antennas with higher gains are mandatory in order to reach the receiver. The use of the omnidirectional antennas for the 60 GHz operating frequency would be viable only for direct Line of Sight (LOS) communications, which is not always the case in real life scenarios. The addition of new antennas will rise up the costs, leading to a poorer interest in the technology. Therefore, different approaches need to be found.

In the case of the femtocell networks, the transmitters must integrate into the existing cellular architecture with no modifications to the first. Thus, the existing terminals must be able to connect to the femtocell with no enhancements needed. The fact that the femtocells use the same operational frequency as the macro network is an important advantage. However, architectural modifications need to be done in order to cope with the femtocell concept. Given the opportunistic nature of the femtocell deployment, meaning that the femtocell base stations are implemented by the user, and not by the operator, one may not be able to predict their location; thus, radio planning simulations, prior to the actual deployment, can not be done in order to enhance the operation. Therefore, a new entity must be defined in order to manage and enhance the functionality of femtocells among them, and within the core network. This entity is called the Femto GW and it is the preferred option by the standardization bodies [10]. Its main role is to manage and control the operation of the active femtocells. Among its functionalities are: assuring a secure connection between the femtocell base station and the core network (CN), providing support for paging and handover procedures, transparent transfer of Layer 3 messages between the User Equipment (UE) and core network. A more detailed description of the structure and roles of the Femto GW or Home NodeB GW, in the 3GPP terminology, is given in [11] and [12]. The Femto GW interfaces towards the other entities of the network are defined in [13], [14] and [15].

The dual mode operation Wi-Fi/ 3G is not needed in the case of using femtocells, but this could be a further research topic regarding the integration of femtocells and 60 GHz equipment within the same device.

B. Connectivity to the current networks

Maybe the most important issue regarding the 60 GHz WLAN concept is represented by the short coverage area of a transmitter. It is well known that the waves emitted within the 60 GHz frequency band are very much attenuated by the surrounding environment and also by the oxygen, because of the fact that this frequency is the resonance frequency for oxygen. A detailed study of the attenuations involved is presented in [8]. Therefore, a concrete wall, for example, acts as an isolator for the radio waves, introducing an attenuation of up to 40 dB [16], depending on the width of the obstacle. Practically, in order to implement a 60 GHz WLAN network, a transmitter needs to be implemented in each room of the indoor environment. Thus, we can clearly say, without creating an abuse of terms, that the 60 GHz WLAN acts as a cellular WLAN. In [16], Genc et al. present an architecture for this kind of network, in which the transmitters are connected through fiber optics. Considering this, we can establish a common point between the femtocell concept and the 60 GHz WLAN, taking into consideration that the femtocell network is connected to the core network of the operator through a similar backhaul connection. Figure 2 presents a practical generic architecture that can be implemented for both technologies.

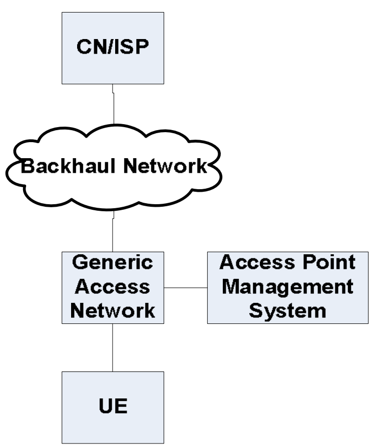

Figure 2. Generic architecture for 60 GHz and femtocell networks

In each case, an AP-MS (Access Point Management System) must be developed in order to coordinate the functioning of the transmitters. Both types of technologies use a backhaul connection in order to connect to the existing infrastructure, i.e., the core network (CN) in the case of the cellular communication network, and respectively the network of the Internet Service Provider (ISP) for the case of the wireless local area network. The existing mechanisms to integrate an AP into a WLAN must be modified in order to cope with the characteristics of the 60 GHz technology. The access mechanisms used until now in WLANs, CSMA/CA can no longer be used given the fact that due to the isolation created by the environment, the 60 GHz cells will have very little superimposing of the coverage areas, thus the receivers can detect only one transmitter in any point in the environment. In the case of the femtocells, a Femto GW device has been developed which enables the access points to communicate with the core network and between them. Practically, a femtocell is seen by the terminal as another macrocell, and therefore the handover process may remain the same, except for the fact that it is realized through the Femto GW.

C. Mobility and handover possibilities

When a wireless local area network is implemented in a specific location, the user must have the desired mobility rights. Given the fact that the superimposing of the coverage areas is very small in the 60 GHz technology, especially near windows or doors, the handover process from one transmitter to another needs to be done in this area. Thus, a very fast handover procedure needs to be done in order to maintain the connection of a user passing from one room to another. One such solution is given in [16], which proposes that WLAN cells should be grouped in such a way that all the cells in a specific group transmit the same information on the same channel. Using this, we obtain larger cells that may be planned easier, in such a way that the superimposing of the coverage areas is enlarged, making it easier for the handover procedure to be realized.

In the case of the femtocell concept, things are different. It mainly depends on what access mechanism the femtocells use: in open access mode, all the users of the macrocellular network are able to connect to the femtocell, thus a handover procedure can be done; in closed access mode, the outside users are not allowed to connect to the femtocell device, and in this case the FAP acts as an important interference source. The scientific literature proposes also a hybrid mode, in which full access is given to the registered users (subscribers), while the non-subscribers are allowed only limited access to the resources, for minimal applications [17]. However, even when considering the open access mode, the large number of handovers which a mobile user may experience while passing through the coverage areas of several femtocells, may lead to increased signaling on the network, which degrades the performance. The authors of [6] present an algorithm which may be used in order minimize the core network signaling.

D. Interference Issues

One important issue in designing any cellular network is represented by the interference which occurs between the transmitters, at the receivers site.

In the case of the purely 60 GHz WLAN, interference is not a problem given the fact that a cell created by a transmitter is isolated by the environment obstacles. This is due to the high attenuations created by the objects in the surrounding environment on the waves operating on this frequency. In the case of a combined 2.4 GHz and 60 GHz network, the principle is the same for the 60 GHz transmitters, while for the ones operating at 2.4 GHz, the access mechanism used, CSMA/CA avoids the negative impact of the interference between the transmitters.

However, this issue is of critical importance while implementing a femto-macro network. Here, interference between the femtocell and macrocell layers occurs, due to the closed access mechanism implemented in the femtocell. Using this, only subscribers are allowed to connect to the femtocell. For the other macrocell users that enter the coverage area of a femtocell, this acts as a powerful interference source which can degrade de QoS experienced by the user in such a way that it could lead to outage. Other types of interference are represented by the interference caused by a MacroBS to user that is connected to a FAP and results in a downgrade of the SINR level; interference caused by a macro user on the uplink communication, to a FAP, or even femto-to-femto interference which can occur in dense urban areas where femtocells can be deployed close to each other. In the femtocell domain, ways of reducing the cross- and co-tier interference represents the major research topic. Several possibilities have been presented in papers like [18]-[21]. However, a stable and final solution has not yet been found, but research is currently making important progress.

III. CASE STUDY DEPLOYMENT

In this section, we will concentrate on the behaviour of the two technologies described above, from the radio propagation point of view. Therefore, we will analyze the impact of deploying both the 60 GHz WLAN access points and the cellular communications femtocell access point. In order to have a better understanding of the impact resulted from the deployment of each technology, we will consider the same environment conditions for both cases.

The scenario involved in this experiment consists of an indoor office environment, in which the two technologies will be deployed. The environment and the simulations are realized using the RPS (Radiowave Propagation Simulator) program [22], a tool which is no longer available under this brand, but the same functionalities are encountered in the tool provided by Actix [23].

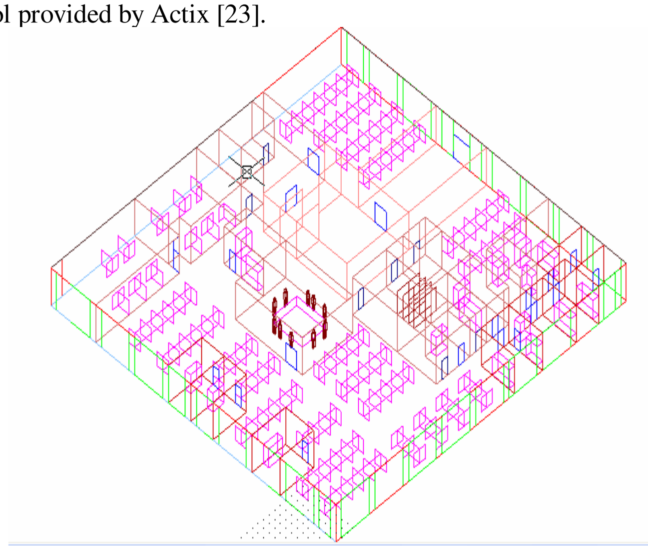

Figure 3. The deployment scenario

The medium is built in the Environment Editor, a program similar to AutoCAD [24], which enables the construction to be realized on layers, each of them being characterized by a series of parameters: thickness, electrical permittivity, the possibility to allow or not penetrations, diffractions or reflections. The environment consists of an office scenario in which the effects of the presence of the outer and inner walls, of the windows and doors, are taken into consideration in the evaluation of the coverage. The environment is very complex from the point of view of the types of materials used: concrete, brick, reinforced wood, wood, glass, and we have even simulated the presence of the human body, which has an important effect especially on the 60 GHz wireless local area network. The created scenario is illustrated in Figure 3.

In order assure a sufficient coverage of the environment using only transmitters that must operate at the 60 GHz frequency, the resulting network would be extremely costly, resulting in a number of up to 27 transmitters. The technical parameters of each one are presented in Table 1, taken from [4].

TABLE I. TECHNICAL PARAMETERS OF THE 60 GHZ TRAMSMITTERS

Tx name	Antenna type	Orientation of the antenna		Antenna height [m]	Tx power [dBm]
		Phi	*Theta*		
Tx1	Omni	0	0	3	12
Tx2	Omni	0	0	3	12
Tx3	Patch	45	0	3	12
Tx4	Patch	330	0	3	12
Tx5	Patch	280	0	3	12
Tx6	Omni	0	0	3	12
Tx7	Patch	135	0	3	12
Tx8	Omni	0	0	3	12
Tx9	Omni	0	0	3	12
Tx10	Patch	220	0	3	12
Tx11	Omni	0	0	3	12
Tx12	Patch	45	0	3	12
Tx13	Omni	0	0	3	12
Tx14	Omni	0	0	3	12
Tx15	Patch	270	0	3	12
Tx16	Patch	270	0	3	12
Tx17	Patch	110	0	3	12
Tx18	Omni	0	0	3	12
Tx19	Omni	0	0	3	12
Tx20	Omni	0	0	3	12
Tx21	Omni	0	0	3	12
Tx22	Omni	0	0	3	12
Tx23	Patch	270	0	3	12
Tx24	Omni	0	0	3	12
Tx25	Horn	260	0	3	12
Tx26	Patch	180	0	2	12
Tx27	Horn	90	0	2	12

A sample snapshot of the level of the received signal strength for the deployment of the 60 GHz WLAN access points is presented in Figure 4. One may notice the strong attenuations introduced by the environment upon the signal waves transmitted with the 60 GHz frequency. Practically, in order to assure the coverage in all the indoor environment, at least one transmitter is necessary in each closed area.

Moreover the presence of the human body significantly attenuates the level of the received signal strength.

That is why such a solution is not feasible, and the proposed solution presented also in [4], would be to combine the 60 GHz technology with the existing 2.4 GHz network. The placement of the 60 GHz transmitters in only a few points of the environment would ease the implementation and help reduce costs.

However, such a solution needs to be supported by the ability to integrate these two types of wireless LANs. Practically, we have implemented a 2.4 GHz network in all the environment, able to offer services for users that need support for common applications, while the 60 GHz network is implemented in only a few key points of the environment, like conference rooms, executives offices, etc., able to support the need for high data rates applications like video conferences or the transfer of large files.

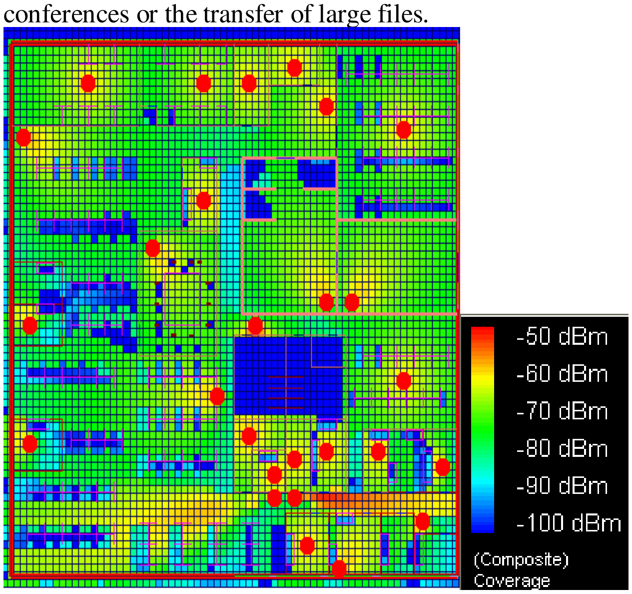

Figure 4. Level of received signal strength for the 60 GHZ WLAN.

The same scenario considering a femtocell-macrocell network would imply a different approach. Considering a macrocell network already deployed in the exterior of the building, the complicated structure of the scenario and simulations done, which reveal a poor indoor coverage of the macrocellular approach, demonstrate the need to implement a femtocell transmitter. By doing this, with only one femtocell transmitter, the coverage inside the office building is assured with good results. The technical parameters of the deployed transmitters are presented in Table 2.

Considering the cellular network implementation standard as being UMTS, the operating frequency chosen is considered to be 2 GHz. The considered macrocellular base station is placed at a distance of 550 meters from the indoor environment, while the femtocells are placed in the environment, at various positions such that they will assure a sufficiently high level of the received signal strength . The considered transmit power is 43 dBm for the MacroBS and 20 dBm for the FAPs. In case of the FAPs, an adaptive power control algorithm would be necessary to reduce the cross-tier interference that occurs between the femtocells and macrocell respectively.

TABLE II. TECHNICAL PARAMETERS OF THE CELLULAR NETWORK TRANSMITTERS

Parameter	MacroBS	FAP
Antenna type	UMTS 30.03 Sector antenna	Omnidirectional
Antenna Gain	1 dB	0 dB
Polarization	Linear vertical	Linear vertical
Orientation of the antenna	Phi = 90 deg.	Phi = 0 deg.
	Theta = 0 deg	Theta = 0 deg
Antenna height	7 meters	3 meters
Transmit power	43 dBm	20 dBm
Carrier frequency	2 GHz	2 GHz
Distance to the indoor location boundary (window)	550 meters	Variable, depending on position

A sample snapshot of the level of the received signal strength coming from the femtocell base stations is presented in Figure 5.

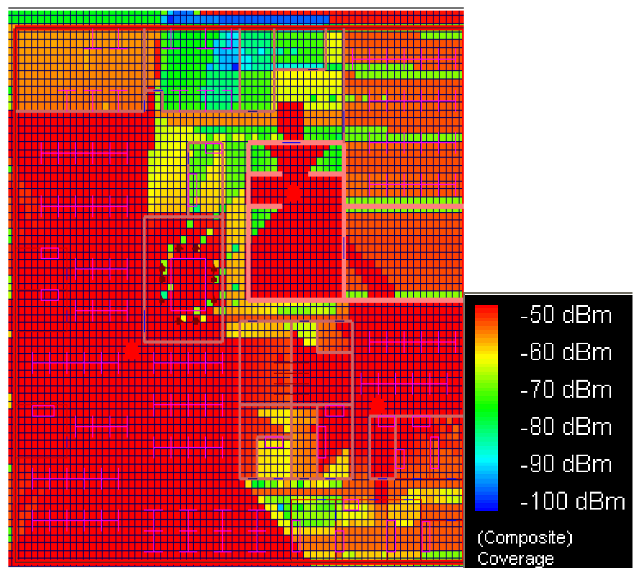

Figure 5. Level of received signal strength for the femto-macro network.

One may notice that in order to assure coverage inside the indoor environment only three femtocell base stations are necessary, considering also that we benefit from the outdoor signal of the macrocell base station. Therefore, from the point of view of the user, the cost are significantly lower in the case of using the femtocell solution, rather than the 60 GHz WLAN, mainly because of the much lower number of transmitters needed to cover that certain area.

The complex nature of the environment influences the coverage differently in the cases of the two technologies. Therefore, one important factor because of which we need such a high number of transmitters in case of the WLAN, necessary to cover the scenario, is represented by the attenuation created by the environment to the traveling waves. Table 3, presents a comparative study between the attenuations that occur for the 60 GHz and 2 GHz, respectively. One interesting fact here, consists in the attenuation introduced by the human body to the waves operating at 60 GHz. As mentioned before, the 60 GHz frequency is the resonance frequency for oxygen, and given the fact that the human body is constituted in a high proportion out of water, such an obstacle practically creates isolation to a receiver situated behind it.

TABLE III. ATTENUATIONS INTRODUCED BY THE ENVIRONMENT

Obstacle	Attenuation introduced [dBm]	
	2 GHz	*60 GHz*
Outer wall (Concrete 40 cm)	27 ~ 30	No detectable signal
Inner wall (Glass 3cm)	3 ~ 4	10 ~ 12
Inner wall (Brick 10 cm)	16 ~ 19	No detectable signal
Door (Glass 2 cm)	2.5 ~ 4	3 ~ 5
Cubicles (Wood 5 cm)	3.5~ 5	18 ~ 23
Door (Reinforced wood 3 cm)	23 ~ 25	No detectable signal
Human body	13	No detectable signal

Considering these results, one important factor when choosing between one technology or the other is represented by the costs of the deployment at the user. Therefore, when implementing a combined 60 GHz – 2.4 GHz WLAN, the user would need to support the entire cost of the equipment. Even though the 60 GHz transmitters are positioned only in a few points in the environment, and with the research done in using the CMOS technology to develop these transmitters, the overall cost of the WLAN network would exceed that of choosing the femtocell technology. In this latter case, the user would need to acquire only the FAP, which is by definition of low cost; thus, the investment is minimal.

With the development of the new cellular standards like LTE and WiMAX combined with the femtocell implementation which assures the necessary radio coverage in the indoor environment, the user would be able to obtain comparable or even higher data rates, than by using the 2.4 GHz WLAN system. Another advantage in favor of the femtocell is that the handsets need no additional improvements in order to work using the femtocell technology considering the same operating frequency, while for the 60 GHz technology the terminals would need additional improvements in order to facilitate this operation.

But, the femtocell technology will never be able to achieve the high data rates offered by the 60 GHz WLAN. Therefore, when choosing one technology or the other the user must decide if it is worth to invest in a costly network, but which offers great transfer rates, or if its requirements can be supported by a less costly network, capable of assuring sufficient transfer rates.

IV. CONCLUSIONS

The goal of the paper was to realize a comparison between two upcoming new technologies that will be available on the market in the next few years: the 60 GHz technology with direct applications in the wireless local area networks domain, and the femtocell technology which will be implemented in order to enhance the coverage and capacity of the existing macrocellular networks.

Both technologies offer good advantages for the users: the 60 GHz WLAN offers great transfer rates, unmatched by any of the existing technologies; while the femtocell concept enhances the coverage of cellular networks leading to a higher QoS level at the receiver site, offering the possibility to obtain good transfer rates, enhances the capacity of the network by managing a part of the users that were normally handled by the macrocell, all of these with the advantage of mobility. Therefore, the femtocell is advantageous for both the operator and the user.

But, besides these benefits, the mentioned technologies have some drawbacks as well: in the case of the 60 GHz network, the major issue refers to the fact that the coverage of a transmitter is limited by the closed environment it is placed in. Also, another relevant problem is represented by the handover of a user between two transmitters, mainly because of the little superimposing of the coverage areas of two adjacent cells..

For the femtocell concept, the major problem relates to the interferences that occur between the femtocellular and macrocellular layers. This issue will probably be resolved in the near future due to the extensive research done in this domain in the last few years.

Therefore, in the mass market implementation the femtocell concept will outrank the 60 GHz WLAN, due to its low cost and mobility advantage that it provides. This does not mean that the 60 GHz WLAN will disappear from the market, on the contrary, its implementation will address more high demanding applications most likely for the technological and research domains.

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