HETEROGENEOUS NETWORKS IN LTE

Summary

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1. Introduction

Today it's hard to imagine a world without connectivity, without access to various services from voice to 4K resolution broadcast movies, from web browsing to chat. The connectivity asset becomes more powerful in association with mobility, at that time when the location, moving speed and access technology are no longer a barrier to be an online entity. In current era, everything is developing fast, new technologies are born every day and new customer expectations appears.

Enabling technology for mobile phones was first developed in the 1940s but it was not until the mid-1980s that they became widely available. Since 1980s, the development processes went through many phases and generations driving the mobile networks to better performance, coverage, capacity, continues increasing the end user experience in parallel with a cost-effectiveness [1]. Mobile network providers make considerable efforts to adapt existing infrastructure to accommodate new requirements and combine new technologies with legacy technologies to shape future mobile communication networks. Taking into consideration all these aspects the evolution from a single layer / technology network to a Heterogeneous Network multi-layers/ multi-technology is imposed.

1.1 Problem statement

Based on "World Cellular Information Service (WCIS)" studies, in 2016 more than 75% of mobile calls were made in an indoor environment [2]. The trend of increased indoor power consumption induces a natural action from many countries' sides: enlarge health safety norms [3]. Lowering the maximum allowed power complicates the network planning and makes it more difficult to compliant with these requirements using only macro equipment. A low power and most cost-effective solution is offered by small cells.

Nowadays the data traffic in the mobile network is rising and the subscribers' performance expectations are growing, so supplementing the existing macro networks with small cells is an effective way to provide a better coverage and a higher capacity in the indoor environment and outdoor area; in the public space, enterprises and in homes.

Small cells are low-cost, low-power base stations designed to improve coverage and capacity of the wireless networks. By deploying small cells on top and in complement to the traditional macro cellular networks, operators are in a much better position to provide the end users with a more uniform and improved Quality of Experience (QoE) [4]. Taking into consideration all the challenges that come with "always online statement, the evolution from a single layer / technology network to a Heterogeneous Network multi-layers/ multi-technology is imposed. The multi-layer networks can take many forms, from the first used criteria, where inside the same radio access technology we play with the size of the cell, up to mixtures of cells size and technologies inside the same system.

Once combining indoor and outdoor cells need to take care of particularities such as: different rage of transmitted power, processing capacity and specific interferences.

1.2 Thesis objectives

The main goal of this thesis is to bring new and relevant contributions in the area of LTE Heterogeneous Networks. The contribution presented in this thesis correspond to several different research directions which will be described below.

The study of in-building performance and feasibility of LTE Small Cells with Beamforming capabilities was the first deliverable of my research. After the first encouraging results, I continue to explore the subject by discovering various ways to improve LTE indoor coverage using also MIMO capabilities of the small cells.

Next main topic addressed was HetNet performance analysis and performance improvement studies on several directions:

- Handover mechanism optimization by replacing signal strength indicator - RSRP with signal quality indicator - RSRQ as main trigger in handover mechanism.
- Improvement of overall uplink throughput by performing a network densification using small cells
- Reducing interference effects and cluster capacity increase through eICIC technology and parameter customization for a HetNet.

The third topic addressed was to analyze the end user experience in mobile networks and to determine the mobile networks influences against the human bodies (analyzed the impact of electromagnetic radiation, SAR - Specific Absorption Rate).

2. Background and motivation

We are living in the communication generation, massive networking and internet computing where everything is connected everywhere. Everything is developing fast: new technologies are born every day as more capable user equipment's are developed and users are constantly demanding a higher data traffic and getting a better performance. Since the introduction of the first mobile network up to now, the mobile networks evolved to better performances, better coverage, higher capacity, higher throughput per user and clean architecture, easily deployable and cost effective [5].

LTE employs Orthogonal Frequency Division Multiplexing (OFDM) as its radio access technology, together with advanced antenna techniques like Multiple-Input-Multiple-Output (MIMO), spatial multiplexing and beam-forming. The choice of OFDM technology not only helps LTE to fulfill the requirements for spectrum flexibility but also enables cost-efficient solutions for very wide carriers with high peak data rates.

2.1 Heterogeneous networks (HetNet)

The use of mobile devices has been increasing in an exponential fashion in the past few years. The exponential increase in the use of interconnected mobile devices will result in the growth of data traffic [6]. Because there are too many users demanding too much data, the problem currently being faced by the networks operators is not the coverage anymore, which is now quite good, but the network capacity [7].

Heterogeneous Network (HetNet) is being considered as a most promising approach to enhance network capacity and increased data throughput, overall performance and to increase coverage in a cost-effective way [8]. A HetNet consists of regular macro cells transmitting typically at high power level, overlaid with low-power small cells such as pico cell, femto cell, metro cell, Remote Radio Head (RRH), etc. The incorporation of such small cells allows offloading traffic from macro cell and providing better network experience by connecting UEs in small cells with low transmission power.

But, this overlaying of macro cell and small cells results severe inter-cell interference in networks, in particular for cell-edge users of small cell [8].

Different types of deployment scenarios for HetNet are currently used. In multicarrier deployment, small cells utilize different carrier frequency than the macro cell. This process effectively reduces ICI but does not ensure proper spectral utilization. On the other hand, co- channel deployment is utilized by using the same carrier for both of macro cell and small cell in which the spectral efficiency is increased via spatial reuse and popular deployment approach in HetNet. Though co-channel approach ensures effective spectrum utilization but bring high ICI among the macro cell & small cells [9].

A generic HetNet architecture can be seen in Figure 1, where all relevant cell types are presented [10].

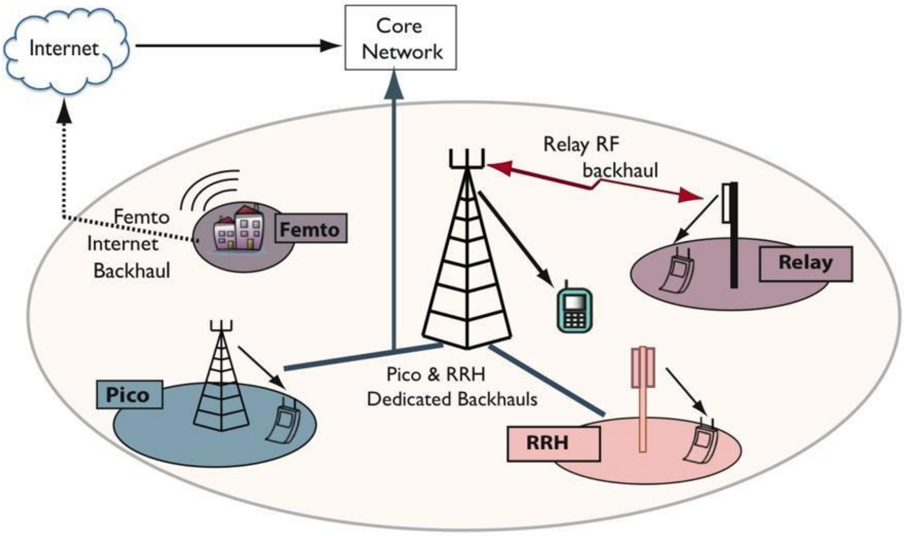

Figure 1: Typical HetNet Architecture

3. In-Building Performance and Feasibility of Small Cells

Small cells deployment is subject to service delivery requirements, as well as to the actual constraints specific to the targeted areas. For a good uniformity of service, in populated areas where presence of buildings is the main reason for significant radio signal attenuation, small cells may need to be closely spaced, e.g. within a couple of hundred meters from each other. Naturally, the performance of small cells is highly dependent on the environment specific characteristics, such as materials used for building construction, their specific propagation properties and surroundings. It is particularly important to have a proper characterization of an environment where small cells are deployed.

The work was focus on in-building performance and feasibility of LTE small cells through measurements, taking as reference both outdoor small cell and indoor pico cell deployments. In order to evaluate the outdoor and indoor cells feasibilities, we created scenarios where wireless connectivity within a target building is offered either by small cells located on the exterior of other buildings (small cells with outdoor characteristics) or simply by small cells located within the target building (pico cells with indoor characteristics). Those scenarios are analyzed and evaluate from different perspectives, from the coverage perspective, to UL and DL throughput and handover performance [4].

Our framework utilizes the ray tracing tool WiSE [11] for 3D modeling of environments where measurements have been taken. In particular, this framework can determine detailed performance levels or channel characteristics at any point of interest within a building and allows for fast and easy what-if scenarios testing. It can be used to create rules of thumb for deploying small cells and can be applied to large scale small cell deployments.

3.1 LTE Small Cell Field Trials

The goal of the field trials was to investigate the indoor performance and feasibility with LTE small cells placed in outdoor and in indoor. The measurements are performed at 2.6 GHz over 10 MHz bandwidth, in dedicated small cell carrier (no presence of macro-cell signal at 2.6 GHz) [12].

For our experiment, the outdoor small cell, with integrated 8x8 antenna, was attached on the exterior of the building on the same level as the middle floor. The arrow in the Figure 2 shows the main direction of the beam formed by the small cell. We refer to this beam orientation as the 0° beam. During measurements, this beam has been also electronically steered by +/-30° in the azimuth plane. For each instance of the beam we have taken independent measurements within the building (only one beam instance was active during measurements). Considering the tree analyzed scenarios for building coverage: using one outdoor BeamCell, using one indoor pico cell and using two indoor pico cell we can conclude that the beam forming demonstrator enable us to obtain better indoor coverage using low power base stations, mounted outdoor, with possibility to adjust the beam electrically, remote, without OPEX costs.

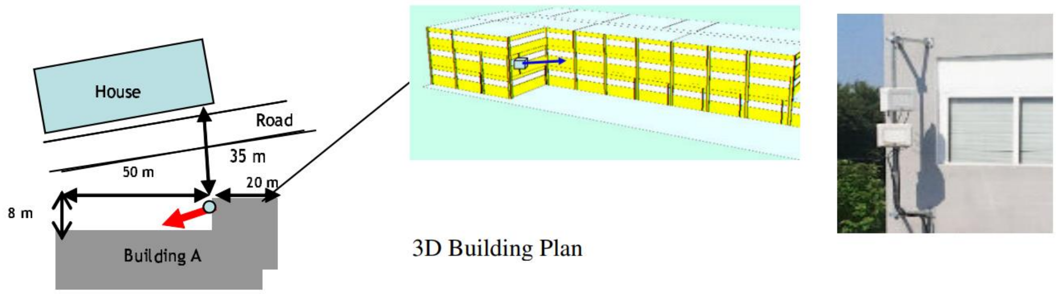

Figure 2: Layout and 3D building plan of the measurement building and its surroundings.

Analyzing the SNR values we observed an interference area in proximity of windows, at that point where the reflection of electromagnetic waves is maximum. This area with high interference can be determinate in both ways: empiric and theoretical.

Experimental results run in related work showed the feasibility of beamforming for LTE small cell deployments in outdoor for covering indoor environments through measurements. With a single small cell employing directive antennas and using low power we were able to establish good indoor coverage (Only 5% of measured locations have a SNR below 7 dB) delivering high data rates for large parts of an office building (for a theoretical max throughput of 30 Mbps, we obtained 15 Mbps for more than 85% of the measurements points). These results are in line with our other LTE measurement campaigns associated with other buildings.

For each azimuth value we showed that the antenna footprint is well preserved within the building. This result encourages the simultaneous use of multiple narrow beams with high gains to cover indoor environments. The scattering within the building contributes to coverage of locations which are not in line-of-sight of the transmit antenna, yielding service continuity throughout a building. Our measurement results indicate low angular spread at the transmitter side and high angular spread at the receiver side.

Furthermore, we showed an analytical 3D performance prediction framework, which we calibrated and validated against available field measurements. The framework provides detailed performance levels at any point of interest within a building; it allows to determine the minimum number of small cells required to deliver desirable coverage and capacity levels, their most desirable location subject to deployment constraints, transmission power levels, antenna characteristics (beam shapes) and antenna orientation (azimuth, tilt) to serve a targeted geographical area. The good match between measurements and predictions encourages the use of the 3D performance prediction framework, in complement to field measurements, to support small cell deployments [4].

3.2 Improved LTE Macro Layer Indoor Coverage Using Small Cell Technologies

The most important asset of a mobile network provider is the ability to cover in an efficient way the territorial area. From quantitative perspective, the Regulators impose for a commercial network two requirements: percentage of territorial coverage and percentage of population. The qualitative perspective analyzes aspects from Quality of Experience area as: call success rate, call block rate, drop call rate and speech quality (MOS- Mean Opinion Score). [13].

In the qualitative approach, the in-building segment become an important component. A cost effective and low power solution to meet the indoor requirements is offered by small cells solution.

Two LTE metro cells deployed in indoor as well as LTE macro cells deployed in outdoor are considered. The later rely on small transmission power levels combined with easiest deployment of small cells. We considered an indoor area covered by one useful metro eNodeB and one external macro eNodeB. The second metro cell eNodeB emit on the same frequency as macro cell to degrade the quality on macro layer to reach typical macro layer radio conditions in the field. Analyzing radio parameters for different configuration we highlight the benefits of using small cells to increase the indoor coverage and the end-user experience. We showed the feasibility of small cell deployments to develop LTE network, covering indoor environments, through measurements. With a single small cell employing directive antennas and using low power we were able to establish good indoor coverage delivering high data rates for large parts of an office building. In the same environment we performed a set of handover test where we highlight the capacity of metro cells to accept the mobiles coming from macro cells offering to users a continuality of services inside the buildings.

4. Heterogeneous networks improvements and optimizations

Wireless communications traffic continues to grow rapidly due to wide spread adoption of smart phones devices and the subsequent fast extension of mobile applications. To carry on the traffic, grow and in the same time to improve user experience and network coverage constant technology innovations are required. The development efforts in LTE are oriented to increase spectrum efficiency and reduce the “price per bit”. All these are reached by using edge hardware technologies and avant-garde features.

HetNet architecture with the overlay of macro cells and small cells of the same air interface is a promising direction for evolution. It authorizes integration of diverse technologies and network architectures in achieving high spectrum efficiency and quality of service (QoS) [4]; [14].

Small cells or small cellular base stations contain a number of different technologies but could describe them as anything other than a typical macro site. These are implemented to address network capacity issues in a relatively small area, as a hot spot or an important area that is a subset of the macro cell coverage. Small cells typically have a range from 10 meters (femto) to several hundred meters (metro) [15].

4.1 Uplink performance improvements in LTE HetNet

In this section we explore uplink connection performances in a LTE HetNet. Based on experiments we analyze the system performance in different LTE HetNet configurations and emphasize the advantage of small cells utilization. We perform a set of experiments in two different LTE HetNet configurations and focus on uplink coverage and capacity within an office building. The current results are obtained in single user equipment (UE) environment but the network optimization recommendations are valid also for multi-UE scenario, with or without mobility [16]. The analysis is based on two of the most important indicators for end user experience:

- UE data throughput
- UE power consumption

In LTE HetNet arrangement there are eNodeBs (eNodeBs) with different transmission power. The high power eNodeB provides the macro cell and the low power eNodeB serve the small cells located within the coverage area of the high power eNodeB. Macro cell and most small cells are connected via S1/X2 interface and are implemented by the operator, in a planned manner.

The experimental results suggest that a network densification using small cells technology is highly recommended for indoor coverage. Additionally, the small cell eNodeB is suitable for network densification in small areas with high user density. The reported measurements were done without activating DL enhanced Inter Cell Interference Coordination (eICIC) feature in the experimental network due to low number of small cells in the cluster, but activating maximal ratio combining (MRC) algorithm in UL. An extensive analysis regarding the eICIC opportunity is given in [17], where is proved that the cluster capacity gain increases proportionally with the number of small cells in the cluster. Each experiment presented in this paper was iterated at least 50 times and the results were averaged.

4.2 HetNet Handover optimization using RSRQ as trigger

In LTE networks handover performance are of high importance. In this chapter are presented the results obtained during several handover experiments in LTE HetNet considering for handover trigger the A3 event and different parameters: RSSP and RSRQ. We also provide some recommendation for parameter tuning for different scenarios. All the measurements are performed in a cabled environment under the conditions characteristic for dense urban settings. Our results show the improvement of two important indicators for end user experience: data throughput and User Equipment (UE) power consumption. [18].

For the experiments reported in this section we use a HetNet LTE cabled test bench. The RF configuration is complex and involves several components creating a controllable environment. In the test scenario two eNodeB are considered: one macro and one small cell eNodeB both transmitting in 1900 MHz (B2 band) each using adjacent 10 MHz bandwidth of the total 20 MHz bandwidth.

We develop this test bench according to Figure 3 trying to emulate a real dense urban environment, with a macro cell placed outdoor as an umbrella cell affected by AWGN noise and fading added by a channel emulator, and a small cell placed inside the building [15]. To add impairments for the macro, cell the uplink and downlink signals are separated using circulators/duplexers and splitters/combiners how can be seen in Figure 3.

When the UE goes into the building, significant macro cell signal degradation occurs and a HO procedure is triggered.

Analyzing the results, we can assert that the widespread use of RSRP as a handover trigger, even in the indoor environment, results in a much diminished transfer rate for moving mobiles that pass from a macro cell to a cell metro. Additional to the throughput improvement the reduction of power consumption is another important factor which improves the overall user experience.

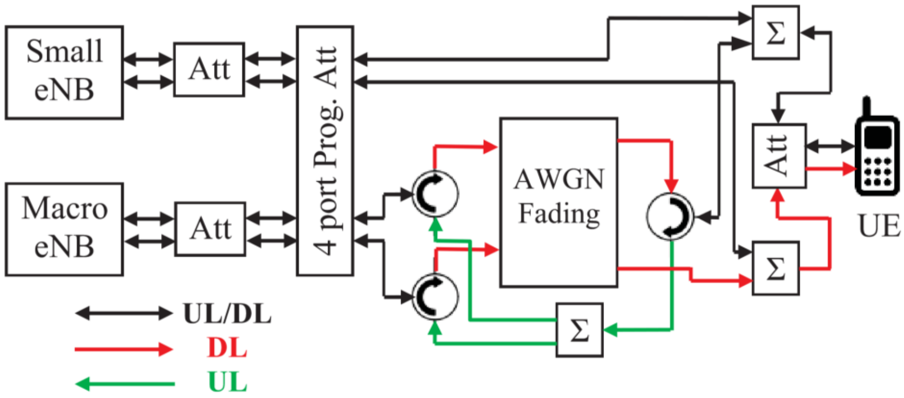

Figure 3: Experimental cabled test bench

4.3 Interference effect mitigation in Heterogeneous Networks

The heterogeneous architecture also introduces several concerns regarding the complicate cell access and mobility procedures. Besides, incorporation and co-existence of macro and small cells introduce several new interference scenarios which can degrade the overall system performance.

In one approach, interferences avoidance is addressed by means of Inter Cell Interference Coordination (ICIC) in frequency domain and relies on carrier-aggregation (CA) technique. In the other approach, interferences avoidance and inefficient resources utilization inside SC are addressed by means of ICIC in time domain. The eICIC new technique overcomes these two problems by extending the SC radius by adding the so called Cell Range Extension (CRE) and by reserving for this area a part of MC resources through Almost Blank Subframes (ABS) approach [19]; [20].

The aim of the experiments is to analyze the eICIC functionality in specific network architecture. In all the experimental scenarios we consider the same 30% ratio for ABS resources reservation and different range expansion offset values. In the experiments initially the UE is attached to the small cell and has ongoing DL transfer, reaching the maximum cell capacity of about 100 Mbps. From this point UE starts moving with constant speed towards the Macro cell. The UE performs HO and changes the serving cell to macro cell, continuing to move inside Macro area until reaching the best signal quality. After that the UE returns back to the small cell through HO moving with the same speed until he reaches again the best signal quality also on small cell [17].

In order to find out the best offset value for eICIC we repeat the experiment for different offset values between 1 and 10 dB. For a more relevant analysis of the spectral efficiency of CRE, we compute the mean CQI for each offset values. The optimum offset value is 6dB and corresponds to the maximum CQI and therefore to the maximum of spectral efficiency. For large offset values the eICIC efficiency decreases, due to the poor radio conditions for the UE at small cell edge, as the small cell radius increases. In the second experiment we analyze the cluster capacity by measuring the total UE throughput. We consider first the simplest case of a cluster with a single small cell. Based on this result we analyze the cluster behavior when the number of small cells increases. For this analysis all small cells are considered to be located approximately at the same distance from the Macro eNodeB, without coverage overlapping between neighbor's small cells.

From the experimental results analysis, we can conclude that even for the worst case scenario, when the cluster contains only one small cell located in the area covered by Macro, the eICIC mechanism activation increases the spectral efficiently of the cluster.

5. User Experience in mobile networks

From the network perspective, the system performance can be measured by collecting and investigating technical indicators known as Quality of Service (QoS) parameters. These relevant indicators collected at network layer are: throughput, delay, jitter and packet loss rate. At UE level the parameters are: signal level, noise and interference level, connection establishment time and connection drop rate.

Quality of Experience is the overall performance of a system from the end-user point of view and is affected by various technical, business and contextual factors. QoE can be appreciated as a measure of the end-to-end performance level from the user perspective and as an indicator of how well this system meets the user needs.

Actually, QoE provides an assessment of human perceptions, feelings, emotions, and intentions with respect to a particular product, service and application [21]; [22]. In this context it is critical to identify requirements for mobile multimedia applications that are associated to the wireless network QoS as well as to the UE context and UE feedback.

Field drive testing is an essential part of the network deployment starting on the early stage of network operation and provides true real world measurements of the RF environment. On the other hand, drive testing is a time-consuming technique and requires very expensive equipment's. For these reasons LTE release 10 and 11 propose the minimization of drive tests by introducing new UE measurements capabilities.

The alternative method collects measures made by the user equipment: these can be regular measurements (for power control, handover, timing advance) sent by the user to eNodeB (eNodeB) or measurements provided by special applications installed on UE. These applications are developed based on new capabilities offered by smart-phones.

In our study we use a technique based on DATUM application provided by SPIRENT Technologies [23]. Datum is an application that can be downloaded and installed on smart UE. This application connects to cloud-based servers including: the call server, used to initiate tests, the media server containing media files and the data base server where the UE measurement results are stored. Representative tests include: web browsing, file transfer, streaming data, multiservice (voice call and data) and latency. Centralized test scenarios are developed and tasks can be combined in any desired order of preference for tests purposes.

5.1 UE used as measurements equipment

We conduct a set of measurements in real. We transform the real UE in to a measurement equipment by using the client functionalities of the DATUM platform. In the complex equation of end user experience are involved several factors as: voice quality, call performance, data performance, web browsing, video performance, location accuracy and application performance and battery life. Analyzing all these parameters we estimate an important but also subjective parameter related to end user experience: user perception. We propose a solution for increasing Quality of Experience (QoE) that consists in network densification with Small Cells equipment's customized for targeted building.

The aspects that we set out for our research are:

- Analysis the feasibility of commercial UE usage as a measurement tool.
- Evaluation of service quality ensured by two different service providers (in the analysis we considered 3G and 4G networks) inside a typical office building.

- Proposal of the network densification in the target area, based on the experimental measurements.

The measurements were performed on the middle floor of this building at an average pedestrian speed of 5 km/h and at an average UE height of 1.5 m.

For all the tests our focus is the analysis of the LTE layer, but we also perform a limited set of 3G measurements to provide a baseline reference. We use UE provided by different vendors (Samsung, LG, and Sony) in order to mitigate the impact generated by the UE category, hardware platform and signal processor type to our final results.

The experimental results suggest that a network densification using small cell technology is highly recommended. We already analyze in different scenarios the benefits for network densification using small cell technologies for the same building in [15]; [18]; [24]. In these papers we analyze the UL, DL and handover (HO) performance in the context of Heterogeneous Networks configuration.

In order to have an accurate view of the end user experience for various services we develop and run the following test types:

- FTP transfer simultaneous on 2 LTE capable UE
- FTP downlink test comparison between 3G capable UE and LTE capable UE
- HTTP downlink test comparison between one 3G capable UE and one LTE capable UE
- Downlink + Uplink FTP test simultaneous on 2 LTE capable UEs

Therefore, in order to meet the customer expectation, the network operators are required to increase the density of the network. In the considered environment the macro layer densification is hard to be performed due to interference and public safety norms. The recommended feasible solution remains the small cells implementation in a Heterogeneous Networks [25].

5.1 Monitoring end-user electromagnetic radiation in a HetNet

In order to be able to reduce the level of radiations, first of all, we need to understand the nature of these, to learn how to evaluate them qualitative and qualitative, and to have a proper tool able to measure them [26].

In the past years the usage of wireless communication devices in close proximity to the human body has been increasing dramatically. The risk of electromagnetic radiation was often considered and the Specific Absorption Rate is one of important characteristics used to evaluate the EM energy absorbed by human body. The Specific Absorption Rate represents a limiting factor in the high-field Magnetic Resonance. This paper presents a theoretical approach in analyzing the electromagnetic field penetration and monitoring of network radiation through a dedicated application.

SAR Watch application (Tracking Radiation Exposure) aims to measure radiation according to the sources of exposure. The classification criterion is defined by the level of control (amelioration) that the user can impose over the sources. Also, account must be taken of the physical capabilities of the phone, which are sometimes limited by manufacturer's constructive decisions.

Depending on the nature of the radiation, two categories are proposed: the effective radiation produced by the mobile phone and the ambient radiation produced by the wireless communication equipment's. Radiation specific to the mobile phone includes the radiation whose source is strictly limited to the UE. This particular type of radiation is the most harmful to the human body and represents the most dominant part of total cumulative exposure to which an individual is exposed.

The presentation logic of data gathered from the exclusive use of the phone also follows the source refinement approach. The two areas of interest captures by application's UI are:

- exposure due to initiating a voice call
- exposure due to the mobile data traffic

The highlighting or tinting of an area within which a measurement was executed is done by overlaying a circle that is colored according to the level of exposure. The origin point of the circle is given by the GPS coordinates of that measurement. The zoom level of a map view is given by the distance between the last measurements and the current user position.

Under the Android operating system, the implementation of the hardware abstraction layer (HAL) that directly make use of of hardware resources (GSM modem, sensors etc.) remains a duty for the smartphone manufacturers and not the provider of underlying operating system. Effective testing of the app on Android phones has revealed implementation differences (mostly in HAL) between critical modules and later used by application business rules. Therefore, we are trying to find some complementary solutions to minimize the impact of manufacturer's decisions.

6. Conclusions

Small cells are low-cost, low-power base stations designed to improve wireless network coverage and capability. By deploying small cells on top and in complement to the traditional macro cellular networks, operators are in a much better position to provide the end users with a more uniform and improved Quality of Experience (QoE) [4]. Small cells deployment is subject to service delivery requirements, as well as to the actual constraints specific to the targeted areas. For a good uniformity of service, in dense populated areas where presence of buildings is the main reason for significant radio signal attenuation, small cells may need to be closely spaced, e.g. within a couple of hundred meters from each other. Naturally, the performance of small cells is highly dependent on the environment specific characteristics, such as materials used for building construction, their specific propagation properties and surroundings. It is particularly important to have a proper characterization of an environment where small cells are deployed.

The results presented here were published in a series of papers co-authored by the author of this thesis. The author's contributions are summarized in what follows:

- Show trough experimental results the feasibility of using smart antenna array with beamforming capabilities.
- We calibrated and validated an analytical 3D signal coverage prediction framework (WiSE) against available field measurements.
- Proving the benefits of using small cells to increase the indoor coverage and the end-user experience.
- Improve handover performance in HetNET by using RSRQ parameter instead of RSRP parameter .
- eICIC parameters optimization and HetNet cluster capacity increase.
- Specific Absorption Rate analyses in Heterogeneous Networks.

Measurements validate that the combination of Small Cells and Beamforming improve the radio coverage in indoor environment. Performances depend on bandwidth allocation, adjacent or overlapping, but in both situations a significant improvement on HetNet performance can be ensured.

A decision of what network architecture will be used for each mobile network will be taken by each network operator base on they particularities. The results presented in this thesis create the premises for native Heterogeneous Networks especially through the prism of IoT and 5G specificities.

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