Macro and Femto Network Aspects for Realistic LTE Usage Scenarios with Interference Management

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<th>Description</th>
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<tbody>
<tr>
<td>AMCS</td>
<td>Advance Modulation and Coding Scheme</td>
</tr>
<tr>
<td>BLER</td>
<td>Block Error Rate</td>
</tr>
<tr>
<td>CQI</td>
<td>Channel Quality Indicator</td>
</tr>
<tr>
<td>CP</td>
<td>Cyclic Prefix</td>
</tr>
<tr>
<td>CapEx</td>
<td>Capital Expenditure</td>
</tr>
<tr>
<td>E-UTRA</td>
<td>Evolved Universal Terrestrial Radio Access</td>
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<tr>
<td>eNodeB</td>
<td>Evolved NodeB</td>
</tr>
<tr>
<td>FAP</td>
<td>Femto Access Point</td>
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<tr>
<td>FDD</td>
<td>Frequency Division Duplex</td>
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<td>HRPD</td>
<td>High Rate Packet Data</td>
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<td>HSPA</td>
<td>High Speed Packet Access</td>
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<tr>
<td>ITU</td>
<td>International Telecommunication Union</td>
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<tr>
<td>LTE</td>
<td>Long Term Evolution</td>
</tr>
<tr>
<td>MRC</td>
<td>Maximum Ratio Combining</td>
</tr>
<tr>
<td>MIESM</td>
<td>Mutual Information Effective Signal to Interference and Noise Ratio Mapping</td>
</tr>
<tr>
<td>MIMO</td>
<td>Multiple Input Multiple Output</td>
</tr>
<tr>
<td>OFDMA</td>
<td>Orthogonal Frequency Division Multiple Access</td>
</tr>
<tr>
<td>OpEx</td>
<td>Operational Expenditure</td>
</tr>
<tr>
<td>PRBs</td>
<td>Physical Resource Blocks</td>
</tr>
<tr>
<td>SCFDMA</td>
<td>Single Carrier Frequency Division Multiple Access</td>
</tr>
<tr>
<td>SISO</td>
<td>Single Input Single Output</td>
</tr>
<tr>
<td>SINR</td>
<td>Signal to Interference and Noise Ratio</td>
</tr>
<tr>
<td>TDD</td>
<td>Time Division Duplex</td>
</tr>
<tr>
<td>TTIs</td>
<td>Transmission Time Intervals</td>
</tr>
<tr>
<td>UE</td>
<td>User Equipment</td>
</tr>
<tr>
<td>WCDMA</td>
<td>Wideband Code Division Multiple Access</td>
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1 Introduction

1.1 Motivation

The growth of mobile data traffic in the upcoming years is foreseen. The number of mobile broadband subscribers are expected to reach 1.8 billion worldwide by 2014, which makes up to 28% of total mobile subscribers, of which 153 million will be LTE subscribers [1]. The dominating part of the mobile broadband traffic is coming from laptops with in-built or USB modem and it is originating mostly from indoor [2]. Increased usage of video applications on mobile devices is also contributing towards gain in the data traffic. For example an average length YouTube video can generate the same amount of traffic to the network as 500,000 short messaging service (SMS) do [3].

Considering the high data rate requirement for indoor users, paradigm shift towards higher frequencies and vulnerability of the signals against the indoor penetration loss affects the Network’s capacity of the operator. Hence meeting the Quality of service (Qos) requirements and improving the user experience becomes a challenge for an operator in terms of costs and resources.

1.2 Goal

The aim of this thesis work is to analyze the impact of increasing indoor users on the macro network - network comprising of only outdoor base stations - in terms of capacity of the network. In order to combat the effect of reduced capacity, femtocells are to be deployed and used to serve the indoor users. Network performance in the aforementioned scenario is then to be evaluated. Later on, split spectrum technique is used in order to manage the interference between macro and femto network and to decrease the Block Error Rate (BLER).

From an operator’s point of view, the thesis work also highlights the effective offloading of the macro network by femto network which could be a point of interest for an operator’s business model.
1.3 Thesis Layout

The work is distributed as follows: Chapter 2 covers the overview of the Cellular Technology, Growth of Data Traffic and highlights some of the related work in this area; Chapter 3 discusses in detail about LTE and its Architecture; Chapter 4 presents the Simulation Environment and User Scenarios and Chapter 5 highlights the Performance Evaluation of the scenarios defined in Chapter 4 in terms of Macro Network Throughput. Lastly, Conclusion and Future work is covered in Chapter 6.
2 Cellular technologies

2.1 Evolution of Networks

Over the past few decades, the cellular communication industry has experienced a remarkable growth with the number of wireless subscribers reaching 4 billion. Major part of these subscribers comprises of Mobile users. Figure 2-1 depicts the rate of increase of Mobile broadband users as compared with Fixed Broadband [4] over the course of time.

![Figure 2-1: Increase in Data Traffic over time](image)

It is interesting to note that the increase in the overall network traffic is due to packet data and not the voice traffic. Figure 2-2 highlights the rate of increase in the packet data over the wireless network as compared with Voice traffic. Hence it makes it essential to analyze how the cellular networks are going to be affected by this boost in data traffic and what measures are needed to be taken to cope with such increasing demand [4].
2.2 Related Work

As we know that higher frequency signals are more prone to the path loss and it widely affects the coverage area of a network cell. Figure 2-3 represents the path loss distribution for different percentage of indoor users in a W-CDMA Network [5]. It is observed that as the number of indoor users increase, path loss shifts towards higher values. Since LTE use higher frequency than UMTS and 3G networks, it is of core importance to analyze the effect of indoors users on higher frequency networks.

Figure 2-3: Path loss distribution for cell radius R=577 m, σ=10 dB [5]
Capacity of a network, according to Shannon’s capacity theorem [6], is related to the amount of bandwidth available and is governed by the following equation.

\[ C = B \log_2(1 + SNR) \]  

Eq. 1

Figure 2-4 shows the fraction of indoor users that can be supported by a cell radius ‘R’ within the limit of 20% capacity reduction for different values of Indoor path loss Coefficient ‘K’.

*Figure 2-4: Maximum fraction of indoor users supported for a capacity reduction of 20% as a function of cell radius [5]*

As the cell radius increases, the percentage of number of indoor users, that can be supported by keeping the threshold of decrease in capacity (20%), also decreases [5].

For a cell radius of 500m, which is typically the cell radius in LTE, and for indoor penetration loss of 20dB, the number of indoor users that can be supported is around 30%, which also makes our analysis interesting as the number of indoor users expected to reach a value of around 80% in next few years [4].


3 Long Term Evolution (LTE)

3.1 Description

Long Term Evolution or LTE [7] [8] [9], as it is commonly known, is meant to bring the concept of singularity in communication, which all of the previously deployed networks lack.

For cellular networks, we use HSDPA/HSUPA (our latest 3.5 G) or 2G networks in some countries, and WIFI – IEEE 802.11a/b/g for our Internet access. For each of this technology to exist different equipments and frequency bands are used. What LTE does is unify all this into a single entity for communication [7] making the end-user save money and feel the comfort. WiMAX is a serious competitor to this technology but it loses to LTE on all grounds except for its deployment, which is complete in few countries.

![Figure 3-1: Evolution of cellular technologies](image)

LTE is regarded as a pre-4G Technology as it does not fulfill the International Telecommunication Union (ITU-R) requirements for data rate and heterogeneity of networks.

LTE can operate in the frequency range from 900 MHz to 2.6 GHz [7]. LTE is aimed to provide high data rate, low latency and packet optimized radio access technology supporting flexible bandwidth deployment. LTE supports a wide range of bandwidth from 1.25 MHz to 20 MHz. The 20 MHz bandwidth gives peak data rate of 326 Mbps using 4x4 Multiple Input Multiple Output (MIMO). For uplink, MIMO is not yet implemented so the uplink data rate is limited to 86 Mbps [7]. It supports Orthogonal Frequency Division Multiple Access (OFDMA) which gives high robustness and spectral efficiency against multipath fading [9].

While comparing to HSPA, LTE provides high spectral efficiency of two to four times. Moreover, LTE system in terms of its radio interface network is capable of providing low latency for packet transmission of 10 ms from network to User Equipment (UE). Similarly,
there is some improvement in cell edge performance, utilizing the same macro network. LTE supports both unicast and multicast traffic in microcells up to 100 of meters and in macro cells more than 10 km in radius. LTE system also supports FDD (Frequency Division Duplex) and TDD (Time Division Duplex), in its Half-FDD, UE is not require to transmit and receive at the same time which avoids the requirement of costly duplexer in UE. Generally, it is optimized for 15 km/h but can be used up to 350 km/h with some tolerance to performance degradation [9]. For its uplink it uses Single Carrier FDMA (SC-FDMA) access technique which gives greater coverage for uplink with the fact of low Peak to Average Power Ratio (PAPR).

For this purpose new network architecture is designed with the aim to support packet switched traffic with seamless mobility, low latency and high quality of service (QoS). Some basic LTE parameters related to air interface is summarized in Table 1.

![LTE RADIO ATTRIBUTES](image)

**Table 1: Radio Attribute of LTE system**
3.2 OFDM & MIMO Systems

3.2.1 OFDM
LTE uses Orthogonal Frequency Division Multiplexing — OFDM [8] [9]. For modulation it employs 64 QAM (Quadrature Amplitude Modulation Technique) which combines both ASK-Amplitude Shift Keying and PSK-Phase Shift Keying thereby enabling several bits to be transmitted per symbol. Every symbol used will now be a result of a particular amplitude and phase. Also, the adjacent symbols are now wider hence bringing down the Bit Error Ratio [9]. In LTE a 64 array QAM is used [Figure 3-2]. The data is multiplexed in several slow rate channels which sums up to more data. These sinusoidal signals as spaced close together orthogonally without interfering with each other. Hence the available spectrum is efficiently used i.e. more bits per seconds per Hz (Spectral Efficiency). Every sub-carrier is modulated by using QAM technique. OFDM signal is hence a composite of several low rate data streams which are flat-fading channels [10].

![Different modulation techniques; QPSK, 16QAM and 64QAM](image)

**Figure 3-2: Different modulation techniques; QPSK, 16QAM and 64QAM**

Time Domain – Orthogonality is ensured by limiting the integral number of cycles occurs for each within a specific time window [9] [10].

Frequency Domain – Ensured by placing the peak of any one of the carrier wave with the nulls of rest [Figure 3-3].

The benefit from such spacing is that the demodulator can now easily and distinctly distinguish between the frequencies and hence the receiver extracts the correct frequencies. This is highly essential in terrestrial environment with several distortions [9] [10].
Since the distributive channel effects are eliminated in OFDM, MIMO – Multiple Input Multiple Output radio antennas can be used effectively also. OFDM divides the channel into several sub-frequencies making this is an effective scheme to implement. This boosts the throughput as several independent data streams are transmitted in parallel via different antennas.

Since these sub-frequencies are orthogonal which means that they do not correlate with each other. The subcarrier frequency is shown in the equation given below:

\[ f_k = k \Delta f \]  

where \( \Delta f \) is the subcarrier spacing.

Subcarrier is first modulated with a data symbol of either 1 or 0, the resulting OFDMA symbol is then formed by simply adding the modulated carrier signal. This OFDM symbol has larger magnitude than individual subcarrier and thus having high peak value which is the characteristics of OFDMA technique [10].
3.2.2 MIMO

MIMO is an acronym for ‘Multiple input Multiple Output’ [11][12]. If the length of the guard interval is equal or less than the MIMO channel order then OFDM generates a set of parallel frequency flat MIMO channels. If the MIMO channel order is more than the guard interval length per tone-equalization is used. While designing, the interference is taken to our advantage by beam-forming, this improves the throughput at the cell edge and NLOS- NON-LINE-OF-SIGHT is effectively achieved [12].

![Figure 3-4: Multiple Input Multiple Output-MIMO antennas [10]](image)

Also the channel has a total of (number of transmission antennas)*(number of receiver antennas). This significantly improves the data rates [Figure 3-4]. Say 6 base station antennas are set up with respect to 6 terminal side receive antennas hence one will be receiving 6 parallel data streams providing a theoretical multiplying factor of 6 to the throughput. This is called Spatial multiplexing wherein the transmission rate boost is proportional to the number of transmission side antennas. MIMO only increases the spatial paths between the receiver and the transmitter. Hence the bandwidth is not increased to increase the throughput rather the spatial domain is exploited to increase the throughput making it unique and highly efficient [10][12].

Interference to advantage:

As a result of multi-path propagation which may also result as a result of obstructions or various interferences there would be loss in packets. The data rate is always favored to be constant for voice. Whereas in packet-data services it is not required at differential intervals i.e. falling short interval peaks of data rate will not be noticeable. LTE uses this phenomenon instead of suppressing the negative surges of data rate to efficiently use the mobile resources.
3.3 Network Architecture

System Architecture Evolution (SAE) [13] is referred to as the Core-Network (CN) Architecture in the modern cellular networks. The important factor of this network architecture is that it is heterogeneous. It enables other wireless networks (2.5G, 3G) to co-exist and LTE is merely an extension. SAE has been evolved from the GPRS Core Network. This makes the implementation on the LTE networks cheap and use the existing network infrastructure and making LTE a much better choice in comparison with the other wireless technologies.

The SAE Architecture is an all IP based network. Every service in Network is in PS (Packet Service) Domain and not CS (Circuit Switched) Domain. The Architecture also inadvertently supports mobility to other systems like the WiMAX, 2G and 3G.

In addition to the GPRS core of the network, the Evolved Packet Core (EPC) is embedded to facilitate LTE [13]. This will provide IP-Based voice and data service simultaneously. Also the scalability of the services application and users will increase. There will also be minimal upgrades once it is embedded into the network as the services become IP based. The Control Plane functions are made simpler and easier to implement [10] [14].

LTE/SAE network includes many new network elements like MME and SAE GW. Only remaining element in radio access network is (evolved) eNodeB [10]. eNodeB is the base station in the LTE/SAE network.

Its main functions are [13]

- Radio resource management
- IP header compression and encrypting of user data stream
- Selection of an MME at UE attachment
- Routing of user plane data towards SAE gateway
- Measurement and measurement reporting configuration for mobility and scheduling

SAE gateway consists two different gateways; Serving SAE gateway and Public Data Network (PDM) SAE gateway. Serving SAE gateway is the contact point to the actual network when Public Data Network (PDM) SAE is the counterpart for external networks. Along with processing the user-plane data, these gateways handle the tasks related to the mobility management inside LTE and between other 3GPP radio technologies. SAE gateway is a SW upgrade to existing GGSN network element [13].

Mobility management Entity’s (MME) main task is to take care of signaling of control plane, and especially for mobility management and idle-mode handling [13] [10].

In LTE the voice calls are delivered over the Internet or other IP networks in a totally packet-based session. This solution is better known as Voice over IP (VoIP).

![Flat architecture of LTE and SAE](image)

**Figure 3-6: Flat architecture of LTE and SAE [13]**

### 3.4 Frame Structure

The 3GPP has set the standards for the Evolved UMTS (Universal Mobile Telecommunication System) Terrestrial Radio Access Network – E-UTRAN. The Mobile devices connect to these radio networks. The communication is IP packet based making the Entire system unified in the IP network. The packet data based network enables the switch
between the speeds for voice-data packets and rich multimedia packets offering high data rates [10] [8].

![Figure 3-7: Standard OFDM Frame structure](image)

### 3.4.1 Frame/Sub-Frame
Each Frame consists of 10 sub-frames containing 14 OFDM Symbols [15]. The Frame is of 10 ms duration and each sub frame is 1 ms in duration. Each Sub Frame is further sub divided into time slots containing 6-7 OFDM symbols, depending up to the length of the cyclic prefix. The LTE downlink physical channels consist of, Physical Downlink Shared Channel (PDSCH) – consumes 3 ODFM symbols per sub-frame. This is 21% of the Symbols in the sub-frame, hence 14% over- head for control.

Physical Downlink Control Channel (PDCCH) [15]– consumes 3 ODFM symbols. It states the mobile device specific information to optimize the communication.

Common Control Physical Channel (CCPCH) - It states the cell-wide control information. It is transmitted near to the centre frequency [9] [15].

The Cyclic prefixes used can be seen in the diagram. They can also be used as pilot signals as a reference for the MIMO. Every Resource Block can be divided into 12 (sub carrier frequency range) x 14 Symbols and the mapping is based on scheduling – localized or Distributed (Distributed preferred) [10].

### 3.5 Sub-Carrier Allocation and User Scheduling
The OFDMA orthogonal frequency division multiple access characterizes every user with a sub carrier. In a single channel spectrum several sub carriers are allocated to every used based on his requirement. This scheme is particularly useful in downlink when the number of users are high. If the data rate required is low then scheme is adapted as it consumes less
resource and the delay is reduced effectively. The mobile users can be synchronized in time domain and frequency domain. This makes the uplink to be orthogonal and in sync [16].

In LTE the data is sent in resource blocks with each of them encompassing 12 sub-carries in a single time slot. This resource block size is maintained constant [15].

![LTE downlink physical resource based on OFDM](image)

**Figure 3-8: LTE downlink physical resource based on OFDM**

### 3.5.1 Time and Freq Domain – user scheduling [17]

The Channel’s quality can also be taken in this scenario wherein the user’s domain pertains to a particular time and frequency period with respect to the channel quality. Here the information on channel quality will have to be in transmission so that the base station can effectively slot the user in that that particular time and frequency domain. LTE reports the channel quality every 1ms [17]. At low mobility speeds, frequency selective scheduling performs equally or even better than stationary as the channel quality varies rapidly; hence there is more chance to transmit at good channel quality. The mobile device’s performance varies on different portions on the spectrum since the high frequency (20 MHz) causes frequency-selective fading. These best sub-frequencies can be determined by feedback information (Channel quality information) from the mobile device. There are two ways to select the better sub-carrier – Sequential scheduler and matrix based scheduler. The matrix based scheduler performs slightly better [14] [10].

Two types of Signals are primarily used to assign the resource elements to the UE.

**Reference Signals** [10] [17]: It is a product of an Orthogonal sequence and PRN sequence (pseudo-
random numerical). 3GPP estimates 510 unique reference signals. Each can be assigned to a cell to identify it in the network.

_Synchronization Signals_ [10] [17]: There are two Synchronization signals: Primary and Secondary. They are used in the cell search by mobile device. They are transmitted in the 0 and 10th slot in the frame.

### 3.6 LTE Benefits [10] [9]

- LTE can provide practical data rates of 100Mbps for downlink and 50 Mbps uplink (20 MHz Spectrum) with very low latency period of as low as <10ms.
- It has high spectral efficiency and Scalable bandwidth ranging from 1.25 MHz to 20MHz.

### 3.7 Indoor Solutions

As mentioned in Chapter 1, Increase in the overall cellular traffic is mainly due to indoor users. In order to cope with this ever increasing demand of bandwidth, there is a dire need to come up with a solution. WiFi and Femto Cells, both present an attractive alternative. We look through the pros and cons of each of them separately.

#### 3.7.1 WiFi

WiFi refers to wireless communication standard IEEE 802.11 [18]. The most recent standard is IEEE 802.11n [19] which can provide peak data rate up to 75 Mbps. As there is high penetration of WiFi access points and WiFi enabled devices, WiFi can be an attractive solution for indoor traffic-offload for mobile operators. WiFi works in an unlicensed spectrum but has no independent voice service and could result in higher latencies for the voice packets. Also, the WiFi protocol does not ensure the secure communication due to the vulnerability of its protocols such as WPA [20].

#### 3.7.2 Femto Cells

Femtocell can be defined as "a personal mobile network in a box" [21]. Femtocell uses a low power Femto Access Point (FAP) that utilizes fixed broadband connections to route Femtocell traffic to cellular networks. Moreover, it is a part of self organizing network (SON) with zero touch installation. It supports limited number of active connections 3 or 4 but can be extended from 8 to 32. It is used to improve indoor signal strength as it avoids walls penetration loss.
Femtocells can support indoor users with high signal strength and thus can offload these users from outdoor base stations. The main driver for user is improved coverage and capacity thus offers better quality of service, not only to indoor users but also to outdoor users by offloading.

Femtocell uses the licensed spectrum owned by a mobile operator. Smaller cells are typically used in homes and there is an option for enterprise femtocells. As femtocell can connect user's mobile phone with home network, it can be seen as true initiative for fixed mobile convergence [21] [3].

### 3.7.3 Choice of solution

For the scope of this research work, we chose Femto Cells as part of the indoor solution to offload the indoor traffic due to several of the above reasons. It is also critical to highlight the commercial aspect of deployment of femtocells and how, for operators, it would affect the management of the network.

Femtos provide quick solution to meet high capacity requirements wherever needed. Capital (CapEx) and Operational (OpEx) Expenses are much lower as compared to deployment of a macro site. They are also compatible with high frequency Next Generation Technologies (e.g. LTE).

### 3.8 Interference Management

With the deployment of femto cells within the macro cells, the role of interference management becomes extremely important. The idea is to optimize the macro network behavior with respect to interference and capacity relationship. Macro-Macro, Macro-Femto, Femto-Macro Interferences are considered. For the sake of simplicity, interfering impact of a femto cell on the neighboring femto cell (Femto-Femto) is not considered, mainly, because femto cells are low powered devices and added penetration loss due to indoor environment would make the impact insignificant.

As a starting point, Shared Spectrum technique, in which both macro and femto cells are using the same frequency band, is applied which was then compared against Split-Spectrum technique, in which both femto and macro cells have dedicated non-overlapping bandwidth available, to evaluate the impact of the two techniques in enhancing the macro network performance.
4 Simulation Environment

4.1 Simulation tool

For the scope of this thesis LTE system level simulator provided by Vienna University of Technology, Austria is used [16]. System Level Environment is built on top of it to simulate Real LTE usage Scenarios, in MATLAB. Working model in the form of the flow chart is shown in the figure.

The core parts of the simulator are the link measurement model and link performance model [16].

The link measurement model abstracts the measured link quality used for link adaptation and resource allocation. On the other hand the link performance model determines the link Block Error Ratio (BLER) at reduced complexity. As an output the simulator calculates throughput and Block Error Rate (BLER) in order to check the performance. The simulation is performed by defining a Region of Interest (ROI) in which the eNodeBs (evolved NodeB) and UEs are positioned. Length of simulation is measured in Transmission Time Intervals (TTIs) [16].

4.1.1 Matlab-based System Level Simulator

Implementation-wise, the simulator flow executes in the following way [Figure 4-1].

For each TTI the UE is moved, when UE goes outside the ROI then UE are re-allocated randomly in the ROI. Every eNodeB receives a feedback after each feedback delay. For scheduling the UEs, simulator does the following tasks [16].

- Channel state → link quality model → SINR
- SINR, Modulation and Coding Scheme (MCS) → link performance model → BLER
- Send UE feedback
Where "→" represents the data flow of the simulator

The macroscopic pathloss between an eNodeB’s transceiver and UE is used to model the propagation pathloss by using the distance and the antenna gain. The Shadow fading is caused by the obstacles between the eNodeB and UE.
4.2 Simulation Scenarios

4.2.1 Scenario 1

This scenario reflects the impact of increasing the number of indoor users (with extra penetration loss) on the throughput a user gets. This impact is analyzed with 10 sub-scenarios each containing 10% increased number of indoor users around the edge of the cell than the previous scenario. (10% indoor users, 20% indoor users, 30%....100% indoor users)

Outdoor users are spread over the cells randomly whereas the indoor users are placed around the edge of the hexagonal cell.

In this scenario [Figure 4-2], we increased the number of users at the border of the cell keeping the number of users per cell same. This was done in 10 steps increasing 10% of user at the border of the cell.

![Figure 4-2: Hexagonal Cell structure showing users at the cell edge [22]](image-url)
4.2.2 Scenario 2

This Scenario [Figure 4-3] comprises of a situation where the indoor users, located at the edge of the cell are served by Femto cell. Indoor users were increased in a similar fashion as in Scenario 1. Impact of serving the indoor users with Femto cell on the cumulative throughput of the Macro cell was analyzed. As Macro and Femto cells use the same bandwidth, it is of great interest to evaluate the impact of indoor users as the interference between the two networks becomes indispensable.

Figure 4-3: Cell edge Users served by Femtos [22]
4.2.3 Scenario 3

This scenario resembles with Scenario 2 in its deployment. However, in this scenario, instead of using a shared spectrum, where both femto and macro cells were using the same bandwidth, the spectrum is split in a way [Figure 4-4] that both macro and femto network have dedicated bandwidth of 15MHz and 5MHz, respectively. Using this technique, it is intended to avoid the interference between the macro and femto network which would have a negative impact on the network throughput.

![Figure 4-4: Partitioning of Spectrum](image)

**20 MHz eNodeB -- Femto**

**5MHz- Femto**

**15MHz- eNodeB**
4.3 Common Simulation Parameters [15]

For all three scenarios, following describes the Common simulation environment entities/parameters.

**Macroscopic Pathloss:**

Macroscopic model defined by Technical Specification ‘TS25814’ with urban setting is deployed.

\[ L = I + 37.6 \times \log_{10} R \]  \hspace{1cm} \text{Eq.3}

Where \( R \) is the base station-UE separation in km and \( I = 128.1 \) when using a 2 GHz carrier

**Shadow Fading:**

Log normally-distributed 2D space-correlated shadow fading with a mean value of 0 dB and standard deviation of 10 dB, shown in Figure 4-5 as described by Claussen [23] is used.

![Figure 4-5: Log-Normal shadow fading](image)

**Fast Fading Model:**

Fast fading model is generated according to the speed of the user and the mode used for the transmission. Users are moving with the speed of 5km/hour (walking) and the transmission mode used is SISO. (Single input Single Output)

**Region of Interest (ROI) Specifications:**

ROI comprises of 7 eNodeBs with 3 sectors each. Whole region (size depending upon inter eNodeB distance) is divided into pixels. Path Loss, shadow fading and fast fading is computed on pixel level.
Schedulers:

The environment uses Best Channel Quality Indicator (CQI) scheduler for Physical Resource Blocks (PRBs) allocation. Other available options are round robin, proportional fair, as proportional fair has been tested and contains some bugs.

Transmission Time Interval:

Each simulation is run for 200TTIs.

4.3.1 eNodeB Parameters

eNodeB parameters used in all of the three Scenarios are listed in the Table 2.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency</td>
<td>2.0 GHz</td>
</tr>
<tr>
<td>Receiver noise figure</td>
<td>9 dB</td>
</tr>
<tr>
<td>System Bandwidth</td>
<td>10MHz</td>
</tr>
<tr>
<td>Thermal noise density</td>
<td>-174 dBm/Hz</td>
</tr>
<tr>
<td>Lognormal Shadowing</td>
<td>10dB</td>
</tr>
<tr>
<td>Inter eNodeB distance</td>
<td>500m</td>
</tr>
<tr>
<td>UE Power</td>
<td>23dBm</td>
</tr>
<tr>
<td>Macroscopic pathloss</td>
<td>$128.1 + 37.6 \log_{10}(R)$</td>
</tr>
<tr>
<td>Number of UEs per sector</td>
<td>10</td>
</tr>
<tr>
<td>eNodeB TX Power</td>
<td>46 dBm</td>
</tr>
<tr>
<td>Penetration Loss</td>
<td>20dB</td>
</tr>
<tr>
<td>UE speed</td>
<td>5 km/h</td>
</tr>
<tr>
<td>BS antenna gain</td>
<td>15 dBi</td>
</tr>
<tr>
<td>Traffic type</td>
<td>Full buffer Traffic</td>
</tr>
<tr>
<td>Cell Layout</td>
<td>Hexagonal grid, 3sectors/eNodeB</td>
</tr>
</tbody>
</table>

Table 2: Configuration parameters for eNodeB
4.3.2 Femto cell parameters

Femto cell parameters are defined by the Table 3. Area of the indoor block is set to be 100m$^2$ containing 4 users served by one Femto cell.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency</td>
<td>2.0 GHz</td>
</tr>
<tr>
<td>Receiver noise figure</td>
<td>9 dB</td>
</tr>
<tr>
<td>System Bandwidth</td>
<td>20MHz</td>
</tr>
<tr>
<td>Thermal noise density</td>
<td>-174 dBm/Hz</td>
</tr>
<tr>
<td>Lognormal Shadowing</td>
<td>10dB</td>
</tr>
<tr>
<td>Cell Radius</td>
<td>10 m</td>
</tr>
<tr>
<td>UE Power</td>
<td>23dBm</td>
</tr>
<tr>
<td>Macroscopic pathloss</td>
<td>$128.1 + 37.6 \log_{10}(R)$</td>
</tr>
<tr>
<td>Average number of Users per Cell</td>
<td>3 OR 4</td>
</tr>
<tr>
<td>HeNB TX Power</td>
<td>21 dBm</td>
</tr>
<tr>
<td>Penetration Loss</td>
<td>20dB</td>
</tr>
<tr>
<td>UE speed</td>
<td>5 km/h</td>
</tr>
<tr>
<td>BS antenna gain</td>
<td>5 DBI</td>
</tr>
<tr>
<td>Traffic type</td>
<td>Full Buffer Traffic</td>
</tr>
<tr>
<td>Cell Layout</td>
<td>Circular cell, 1 sector/femto</td>
</tr>
</tbody>
</table>

Table 3: Configuration parameters for Femto Access Point (FAP)

As there are 10 UEs per sector which makes up to 210 Users in the ROI and one Femto cell can cover up to 4 UEs, a maximum of 53 Femto Cells were required to serve 100% of Indoor users. Same setting as in Table 3 was ensured for all of the Femto Cells.
5 Performance Evaluation

5.1 Without Femto cell deployment (Scenario 1)

Figure 5-1 shows the Signal to Noise and Interference Ratio (SINR) after applying the signal macroscopic path Loss in the Region of Interest (ROI). It shows 7 eNodeBs, each with 3 sectors covering 120 degrees. The region closer to the eNodeB (Red Region) is the high SINR region and as we move away from the center towards the edges, the interference from the neighboring cell increases and thus the SINR value decreases.

![SINR Map](image)

Figure 5-1: SINR Map for 7 eNodeBs [16]

The outdoor users are randomly distributed over the whole region whereas the indoor users, depending upon the sub scenario (10%, 20%...and so on) are placed around the edges of the cell. Only the worst case scenario is considered for the simulation, as we are placing the Indoor UEs only at the bad coverage area (edges of the cell).
Figure 5-2: Scenario showing 20% indoor users

Figure 5-2 represents the sub-scenario of 20% indoor UEs located around the edge of the cells. This snapshot of the ROI represents the path loss added with the shadow fading of the region.

Figure 5-3 shows the scenario with 90% of the Indoor users.
Each sub scenario was run for 200 TTI and the corresponding downlink Throughput was measured.

Figure 5-4(a) shows the numerical value of the Throughput while the Figure 5-4(b) shows the percentage decrease in the Throughput.

The total aggregated macro network throughput is plotted versus percentage increase of indoor users in Figure 5-4(a). The results are only computed for downlink traffic. Throughput is computed using eq.

\[
\text{Throughput} = \frac{\text{Acknowledged Data}}{\text{Time}} \quad \text{(Bits/Sec)}
\]  

\text{Eq. 4}
This decreasing trend of the throughput is in accordance with the Eq. 1. Since within the indoor environment, which is created at edges of the macro cell, SINR value is quite low due to 1) UE being at the farthest distance from the eNodeB and 2) the extra added penetration loss of 20dB, this leads to an overall low Capacity and hence the degraded throughput.

As the number of indoor UEs increase, the throughput begins to decrease and for the value of 80-90% indoor users, the throughput decreases by 45% of its original value. This figure is a point of focus for all the wireless and mobile operators (also referred to as OpCos) since the study [4] shows the number of Indoor users in next few years are going to increase to that value and loosing 45% of the network throughput is a point of concern for the OpCos to
meet their Quality of Service (QoS) requirements and compete in the market against each other.

5.2 With deployment of Femto Cells (Scenario 2)

Like Scenario 1, the number of Indoor users was increased with the step of 10% but instead, they are served by a femto cell, which is defined by the parameters listed in Table 3.

The point of focus here is not the effective throughput of the femto cell but its effect on the macro network throughput. Hence the comparison of Scenario 1 and Scenario 2 was made on the basis of the network throughput in Figure 5-5.

![Comparison of Macro Network Throughput with and without femtos](image)

![Percentage Increase in Throughput of Macro Network with Femtos](image)

*Figure 5-5: Increase in throughput when users are served with femtocells*
Macro network throughput always stays higher for every percentage of Indoor Users. This is due to the fact that since the indoor users with low SINR are offloaded to Femto cell, the outdoor users could be served better by the eNodeBs. With the ‘full buffer’ traffic model, where UEs always have something to download from the eNodeB, as more and more UEs with Low SINR were offloaded to the femto cell, macro network throughput kept on increasing until the macro network was under loaded. This effect can be understood better from the Figure 5-5(b), which represents the percentage increase in the throughput of macro network.

Unlike the Scenario 1, where macro network lost about 40% of its throughput (TP) for 80% of indoor users, an increase of about 75% is observed in the throughput. The percentage increase or decrease shows the difference in general for evaluation purposes. The throughput is dropped to zero when the percentage of indoor users reaches a value of 100, showing that all users are moved indoors and now being served by femto cells.

Another interesting aspect to focus on at this point is the interference between the macro and femto cells [Figure 5-6]. femto-femto interference is ignored mainly because of very low Transmitting power of the Femto cell and the added high Path loss of 40dB between two femto cell environments would have negligible effect on each other.
Block Error Rate is a fair measure to evaluate the interference level. BLER is computed at eNodeB using the following Equation:

\[ BLER = \frac{\text{No.of Blocks Sent} - \text{No.of Blocks Correctly Received}}{\text{Total Number of Blocks Sent}} \]  

Eq. 5

In Figure 5-6, BLER increases for couple of steps, before following a decreasing curve till the end. One explanation for such pattern could be that at 10% not enough UEs are offloaded and femto cells, which use the same frequency band, were introduced causing an increase in the Interference level at eNodeB and hence the BLER, but as more UEs with low SINR value are taken indoors and served with femto cells, the Interference level began to decrease and hence the block error ratio (BLER) diminishes.

Effective Offloading:

In Scenario 2 all of the indoor users were served by Femto cell (e.g. 20% indoor – all of those 20% were served by femto cells) but now we want to analyze the impact if only a part of indoor users are offloaded. This is also a point of focus for OpCos, since it might not be practical to offload ‘ALL’ of the indoor users but only a part of them. Figure 5-7 represents this scenario. Each line in the figure represents the percentage of users within the indoor environment, x-axis represents the percentage of indoor users severed by femto cell and y-axis represents the macro network throughput.

![Effective Offloading of Macro Network](image)

Figure 5-7: Effective Offloading

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In Figure 5-8 it can be seen that indoor users in the range from 15% to 40% do not show any significant drop in the peak value of throughput as the number of indoor users increase. This is because that macro network is not fully loaded by indoor users and the increase in traffic does not reach the threshold yet, which basically does not show their offloading nature.

![Effective Offloading of Macro Network (II)](image)

**Figure 5-8: Effective Offloading (50-100%)**

In Scenario 1, when there were no femtocells deployed, it was shown that major degradation occurred when indoor users were in the range of 70% to 90%. Figure 5-8 rather gives a clearer picture of indoor users in the range from 50% to 100%.

If we analyze the graph closely, it can be seen that, depending upon the percentage of indoor users, serving a certain amount of indoor users with femto cells can bring optimal results in terms of the maximum value of the Throughput of the macro network which is shown by the peaks for every percentage of indoor user. For 100% indoor users, it is optimum to offload about 45% of those indoor users to femto cells, whereas, for 90% indoor users, the optimum value is 60%.
5.3 Effect of Interference Management (Scenario 3)

If we look at Figure 5-9, the Throughput value at 0% indoor users is less for Scenario 3 as compared to Scenario 1 [Figure 5-4]. This is because only 15MB bandwidth is available for the macro network as compared to 20MB for Scenario 1.

![Graph showing TP of Macro Network without Femtos and with Partitioned Spectrum Femtos](image)

![Graph showing Impact on Throughput in percentage](image)

Figure 5-9: Scenario showing Femtocells throughput by partitioning spectrum

The overall increasing trend is identical to Scenario 2, as we offload the macro network by taking the users indoor but the percentage increase in the Throughput is relatively low in this scenario. In scenario 1, about 75% increase in the Throughput was observed for 80% of indoor users whereas only about 50% increase was observed in this scenario.
Interesting to note in Figure 5-10 is that the BLER remains almost the same as the number of indoor users increases and, also, the value of BLER at 0% indoor user is low as compared with Figure 5-6, which is expected since femto and macro network are using non-overlapping partitioned bandwidth and have a very low interference level.

Though we observe lower BLER in this scenario as compared to Scenario 2 and yet the gain in macro network Throughput is lower. One possible explanation is since capacity is also dependent on the amount of bandwidth available, in scenario 2 we have more bandwidth available than in scenario 3.

Since in this simulation Scenario, we placed femto cells only at the edge of the circle, the area where the received-signal strength from eNodeB is very low (Low SINR) and hence the interference level between femto and macro network is low. For such scenario, Shared Spectrum technique is more suitable as macro network restores more capacity as compared to Slip Spectrum technique.

Split Spectrum Technique would be more suited for the scenario where Indoor users are placed randomly or closer to the eNodeBs, where the interference level between femto and macro network would be relatively higher and splitting the spectrum would make more sense.
6 Conclusion and Future Work

Macro network alone cannot support the ever growing demand of the bandwidth hungry applications for the indoor users. Without any assistance, Macro network loses up to 50% of its actual capacity (QoS) and poses serious concerns for maintaining QoS for the Telcom OpCos. Femto cells provide an attractive solution for meeting capacity requirements of the network. Simulation results show offloading the traffic via femtocells restores the Macro Network capacity. Also, for current position of indoor users, shared spectrum yeilds better results than paritioned spectrum.

Future work would include the Investigation of the effect of distance between eNodeB and femto cells and to find the right combination of the split and shared spectrum.

7 References


