



Sudan University for Science and Technology



Graduate Studies College

Msc PROGRAM in TELECOMMUNICATION ENGINEERING

Performance Improving for Indoor Users in LTE

Networks Using Femtocells

تحسين الأداء لمستخدمي شبكات التطور على المدى البعيد داخل المباني باستخدام

الخلايا الصغيرة جداً

THESIS

Submitted in partial fulfillment of the requirements for the degree of Master of
Science in Telecommunication Engineering

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2014

DEDICATION

To my family

ACKNOWLEDGMENT

This master thesis was held and completed at Sudan University for Science and Technology in March 2014, I am deeply grateful to my supervisors Dr. Sara Aljack, who have been my instructors for my thesis work. I am grateful for her help and Co-operation, encouragement and invaluable guidance throughout the thesis. I must extend my gratitude to the internal examiner Dr. Fateh Elrhman, external examiner Dr. Masoud, and my workmates for being always so supportive and cooperative.

I am deeply and forever obliged to my family for their love, support and encouragement throughout my entire life.

ABSTRACT

The exponential growth of mobile data traffic affects not only the capacity requirements of the mobile networks, but even the expected quality of service. The introduction of LTE improved the situation to some extent. However, as a high percent of mobile data traffic is generating from indoors, LTE operating at higher frequencies cannot really meet the ever-increasing demand of data traffic and reasonable quality of service. This Thesis provides an analysis of the network throughput with LTE technology. In this regard a system level simulation environment was developed that included macro and indoor traffic distribution pattern. Simulation results show that with increasing percentage of indoor traffic the aggregated throughput of the macro network decreases significantly. Lately, two scenarios emerged to offload the indoor traffic, by Femtocell.

LTE is designed to provide multi-megabit bandwidth, more efficient use of the radio network, latency reduction, and a lower cost per bit. This combination aims to enhance the user's experience and further drive the demand for mobile multimedia services. With LTE, people will more readily access their Internet services from mobile devices, including real time and on demand television, blogging, social networking and interactive gaming.

Femtocells are low-power access points that operate in licensed spectrum and provide mobile coverage and capacity over internet-grade backhaul. Femtocell applications include residential, enterprise, indoor hotspot, and outdoor hotspot deployments. Femtocells are lower in cost than typical macrocells while retaining full operator management even if they are located on the customer premises.

المستخلص

إن النمو المتسارع لحركة البيانات المتنقلة لم يؤثر فقط على متطلبات سعة شبكات المحمول ، ولكنه أثر حتى في نوعية و جودة الخدمة المتوقعة من قبل المستخدمين.

إن ظهور خدمة الجيل الرابع أو تكنولوجيا التطور على المدى الطويل أدى إلى تحسن الوضع إلى حد ما ومع ذلك، فإن نسبة عالية من حركة البيانات المتنقلة يولد من المستخدمين الموجودون داخل المباني.

إن خدمات الجيل الرابع تعمل على ترددات أعلى و لا يمكنها حقا تلبية الطلب المتزايد على حركة البيانات و جودة الخدمة المعقولة و المتوقعة

توفر هذا الرسالة تحليلا لسرعة و حجم بيانات الشبكة للمستخدمين داخل المباني مع تقنية الجيل الرابع.

في هذا الصدد تم تطوير بيئة محاكاة مستوى النظام التي شملت الشبكة الكلية و نمط توزيع حركة المرور في الأماكن المغلقة. تظهر نتائج المحاكاة أنه مع نسبة متزايدة من حركة المرور في الأماكن المغلقة فإن حجم البيانات المجمعة للشبكة الكلية يقل بشكل ملحوظ ، تم عمل سيناريوهين لافراغ حركة المرور في الأماكن المغلقة بواسطة الخلايا الصغيرة.

لقد تم تصميم تكنولوجيا التطور على المدى الطويل لتوفير عرض النطاق الترددي للبيانات المتعددة، ولإستخدام أكثر كفاءة لشبكة الراديو والحد من الكمون ، و أقل تكلفة لكل بت بيانات، ويهدف هذا الدمج لتعزيز تجربة المستخدم و كذلك دفع الطلب على خدمات الوسائط المتعددة المتنقلة .

مع خدمة الجيل الرابع سيتمكن المستخدمون من الوصول بسهولة أكبر لخدمات الإنترنت الخاصة بهم من الأجهزة المحمولة ، بما في ذلك تطبيقات الوقت الحقيقي وخدمة التلفزيون عند الطلب ، والمدونات ، والشبكات الاجتماعية و الألعاب التفاعلية.

إن الخلايا الصغيرة جداً هي نقاط الوصول المنخفضة الطاقة و التي تعمل في الطيف المرخص و توفر تغطية للهاتف النقال و قدرة على الوصول للإنترنت.

وتشمل تطبيقات الخلايا الصغيرة جداً المناطق السكنية و المشاريع و النقاط الساخنة في الأماكن المغلقة ، ويمكن نشر النقاط الساخنة في الأماكن المفتوحة.

إن الخلايا الصغيرة جداً أقل تكلفة من الخلايا الكبيرة و نموذجية مع الإحتفاظ بإدارة المشغل الكامل حتى لو كانت تقع في مباني العملاء.

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ABBREVIATIONS

| | |
|--------|---|
| AMCS | Advance Modulation and Coding Scheme |
| BLER | Block Error Rate |
| BPL | Building Penetration Loss |
| CQI | Channel Quality Indicator |
| CP | Cyclic Prefix |
| CSG | Close Subscriber Group |
| CapEx | Capital Expenditure |
| EESM | Exponential Effective Signal to Interference and Noise Ratio Mapping |
| E-UTRA | Evolved Universal Terrestrial Radio Access |
| eNodeB | Evolved NodeB |
| FAP | Femto Access Point |
| FDD | Frequency Division Duplex |
| 3GPP | 3 rd Generation Partnership Project |
| 4G | Fourth Generation |
| HRPD | High Rate Packet Data |
| HSPA | High Speed Packet Access |
| ITU | International Telecommunication Union |
| IMT | International Mobile Telecommunications |
| iPAD | internet Packet Assembler Disassembler |
| LTE | Long Term Evolution |
| LMSC | LAN/MAN Standard Committee |
| LMMSE | Linear Minimum Mean Square Error |
| MRC | Maximum Ratio Combining |
| MIESM | Mutual Information Effective Signal to Interference and Noise Ratio Mapping |

| | |
|--------|---|
| MIMO | Multiple Input Multiple Output |
| MME/GW | Mobility Management Entity/Gateway |
| OFDMA | Orthogonal Frequency Division Multiple Access |
| OSG | Open Subscriber Group |
| OpEx | Operational Expenditure |
| PRBs | Physical Resource Blocks |
| PGW | Packet Data Gateway |
| PDN | Packet Data Network |
| QoS | Quality of Service |
| RNC | Radio Network Controller |
| SCFDMA | Single Carrier Frequency Division Multiple Access |
| SIM | Subscriber Identity Module |
| SISO | Single Input Single Output |
| SINR | Signal to Interference and Noise Ratio |
| SGW | Serving Gateway |
| TDD | Time Division Duplex |
| TTIs | Transmission Time Intervals |
| UE | User Equipment |
| USB | Universal Serial Bus |
| VNI | Visual Networking Index |
| WCDMA | Wideband Code Division Multiple Access |
| WiMAX | Worldwide Interoperability for Microwave Access |

CHAPTER 1

INTRODUCTION

1.1 Background:

According to International Telecommunication Union (ITU); total mobile cellular subscriptions reached almost 6 billion by end 2012; corresponding to a global penetration of 86%, and the number of mobile-connected devices exceeded the world's population in 2013[4] [11].

Last year's mobile data traffic was eight times the size of the entire global Internet in 2000. Global mobile data traffic in 2011 (597 peta bytes per month) was over eight times greater than the total global Internet traffic in 2000 (75 peta bytes per month), and Mobile video traffic was 52 percent of traffic by the end of 2011[9].

The Cisco Visual Networking Index (VNI) Global Mobile Data Traffic Forecast announced that; Mobile video traffic exceeded 50% for the first time in 2011. Mobile video traffic was 52% of traffic by the end of 2011[9]. Two-thirds of the world's mobile data traffic will be video by 2016. Mobile video will increase 25-fold between 2011 and 2016, accounting for over 70 percent of total mobile data traffic by the end of the forecast period.

In 2012, a fourth-generation (4G) connection generated 28 times more traffic on average than a non-4G connection [9]. Although 4G connections represent only 0.2% of mobile connections today, they already account for 6% of mobile data traffic.

The mature market is not growing from number of subscribers point of view rather this section of market is growing from data traffic point of view. Due to this, the global access of mobile broadband connection reached about 20% in developing countries, and in the developed world 75% by the end of 2013[11].

The dominating part of the mobile broadband traffic is coming from laptops with in-built or USB modem and from smart phones, and it is originating mostly from indoor, the higher percentage of indoor traffic is due to the increasing usage of video applications on mobile devices.

The exponential growth of mobile data traffic affects not only the capacity requirements of the mobile networks, but even the expected quality of service. The introduction of Long Term Evolution (LTE) improved the situation to some extent. However, as a high percent of mobile data traffic is generating from indoors, a realistic experience shows that in mature market about 70% traffic is generated from the indoor users.

LTE operating at higher frequencies and great bandwidth (1.25 to 20 MHz) cannot really meet the ever-increasing demand of data traffic and reasonable quality of service.

The higher percentage of indoor traffic is due to the increasing usage of video applications on mobile devices. Introduction of the LTE technology enhanced the capacity of the network [7] and provided a solution to the capacity hungry network to some extent. But the ever-increasing trend of

indoor traffic contribution to overall mobile data traffic still degrades the user's quality of service all over the network. It requires offloading such enormous contribution of indoor traffic from the macro networks to indoor networks [1].

Recently the possible solution is to deploy femtocells inside buildings that face huge penetration loss.

The penetration loss through the obstacles depends on the number of materials and material of the building used [2].

1.2 Emergence of New Devices

The high capabilities of innovative devices play a vital role in paradigm shifts in application's usage on the mobile devices. The current mobile devices are equipped with high-resolution cameras. They contain higher processing power, data storage facility and multiple wireless connectivity. A usual e-reader was initially thought to consume text-only contents. But nowadays e-books or e-newspapers also contain rich multimedia contents. Lately iPad and smart phones goes beyond these readers by supporting much additional functionalities. The large screen terminals such as personal computers are consuming the highest volume of wireless network capacity.

It has been observed that a single laptop can generate as much traffic as 1300 basic-feature phones.

Currently cellular operator's business model supports use of SIM cards (through USB modem) with Laptop or Net book. It is seen that Laptops and Net books would alone contribute to 70% of all mobile data traffic by 2014 [9].

1.3 Problem Statement:

The high indoor penetration loss at higher LTE frequencies decreases the overall capacity of the cell hence results poor quality of service for indoor users. This is a big challenge for operators to improve the capacity and quality of service of the network.

In addition the thesis discuss the network cost (capital expenditure + operation expenditure) and its effectiveness in the cost per bit. Also the thesis tries to give optimum number of femtocells in a network to save the cost.

1.4 Proposed Solutions for Efficient Service of Indoor Users:

The thesis tries to find better solution for LTE indoor users by deploying the femtocells or Home evolved Node Base station (HeNBs).

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.

Femtocells also allow operators to create a more compelling LTE business case as they can considerably lower the delivery cost per bit through significant savings in cell site installation, maintenance and backhaul costs [12].

1.5 The Objective:

The goal of the thesis is to provide performance evaluation of LTE network throughput, also shows effective offloading by femtocells which is a point of interest from operator's business perspective, and give cost analysis for the system by computing the optimum number of the femtocells required, as Femtocells can be utilized as a tool which is offered to mobile operators to improve business cases.

1.6 Methodology and Simulation:

The performance of an existing network can be measured, but these measurements reflect only the current state of the network and do not consider the changes in behavior of applications and users, which are changing over time. Therefore network operators must constantly modify and improve the network time to time.

The thesis tries to manage the problem of indoor users in LTE network by deploying new small cells inside the buildings which leads to improvement in capacity and hence QoS.

Two basic scenarios are considered, in first scenario, indoor users are being increased while no femtocells are deployed for indoor users to serve them and the performance of macrocells is evaluated through the throughput; capacity and number of users. In the second scenario, femtocells will be deployed indoors and both performance of macro and Femtocells are estimated.

In order to implement LTE parameters equations and relations to get results the thesis uses LTE System Level Simulator.

In this research a system level simulation environment is developed that includes macro; a cellular network comprises of 7 Evolved NodeBs (eNodeBs) or Base Stations, and indoor traffic distribution pattern.

The LTE System Level Simulator doesn't give the total aggregated throughput for all UEs in the network, it gives the throughput value for individual users, therefore the values of throughput are taken manually for all the indoor users; and laid out in an Excel sheet table and then the plots of throughput for all indoor users in the two scenarios are obtained and figured.

Results show that with increasing percentage of indoor traffic the aggregated throughput of the macro network decreases significantly. Later, the same work is performed in the presence of femtocells for serving the indoor

users and showing that aggregated throughput of macro network increased significantly when femtocells are deployed for indoor users

1.7 Thesis layouts:

This work is organized in six chapters; first one is an introductory which contains a preface to the work, problem statement that describes the problem of the thesis is described, proposed solution which suggests solution to the mentioned problem, and methodology which shows the method followed in order to implement the solution suggested.

In chapter two and as a literature review the work illustrates some general and important concepts and describes the LTE network architecture which is desirable to understand the basic idea beyond the networks fundamentals.

Chapter two also presents the main problem which play magnificent rule in attenuation the mobile signal inside building for indoor users due to The Building Penetration Loss BPL.

In chapter three the thesis discuss the proposed solution by using femtocells technique and define several benefits are expected from deployment of femtocells, starting from an increased network capacity.

Chapter four highlights the available simulation tool, and simulation environment setup for the computation of LTE macro and femto network throughput and the performance evaluation of simulation results.

Finally conclusion of the work with the highlights of future works in order to improve this; is given in chapter five.

CHAPTER 2

LITERATURE REVIEW

2.1 LTE Network Architecture

2.1.1 Historical Background

The cellular wireless communications industry witnessed tremendous growth in the past decade with over four billion wireless subscribers worldwide. The first generation (1G) analog cellular systems supported voice communication with limited roaming. The second generation (2G) digital systems promised higher capacity and better voice quality than did their analog counterparts. Moreover, roaming became more prevalent thanks to fewer standards and common spectrum allocations across countries particularly in Europe. The two widely deployed second-generation (2G) cellular systems are GSM (global system for mobile communications) and CDMA (code division multiple access).

As for the 1G analog system, 2G system were primarily designed to support voice communication. In later releases of these standards, capabilities were introduced to support data transmission. However, the data rates were generally lower than that supported by dial-up connections. The ITU-R initiative on IMT-2000 (international mobile telecommunications 2000) paved

the way for evolution to 3G. A set of requirements such as a peak data rate of 2 Mb/s and supports for vehicular mobility were published under IMT-2000 initiative [1].

Both the GSM and CDMA camps formed their own separate 3G partnership projects (3GPP and 3GPP2, respectively) to develop IMT-2000 compliant standards based on the CDMA technology. The 3G standard in 3GPP is referred to as wideband CDMA (WCDMA) because it uses a larger 5MHz bandwidth relative to 1.25MHz bandwidth used in 3GPP2's cdma2000 system. The 3GPP2 also developed a 5MHz version supporting three 1.25MHz subcarriers referred to as cdma2000-3x. In order to differentiate from the 5 MHz cdma2000-3x standard, the 1.25 MHz system is referred to as cdma2000-1x or simply 3G-1x

The first release of the 3G standards did not fulfill its promise of high-speed data transmissions as the data rates supported in practice were much lower than that claimed in the standards. A serious effort was then made to enhance the 3G systems for efficient data support [1] [3]. The 3GPP2 first introduced the HRPD (high rate packet data) system that used various advanced techniques optimized for data traffic such as channel sensitive scheduling, fast link adaptation and hybrid ARQ.

The HRPD system required a separate 1.25MHz carrier and supported no voice service. This was the reason that HRPD was initially referred to as cdma2000-1xEVDO (evolution data only) system. The 3GPP followed a similar path and introduced HSPA (high speed packet access) enhancement to the WCDMA system. The HSPA standard reused many of the same data-optimized techniques as the HRPD system. A difference relative to HRPD, however, is that both voice and data can be carried on the same 5MHz carrier in HSPA. The voice and data traffic are code multiplexed in the downlink. In

parallel to HRPD, 3GPP2 also developed a joint voice data standard that was referred to as cdma2000-1xEVDV (evolution data voice). Like HSPA, the cdma2000-1xEVDV system supported both voice and data on the same carrier but it was never commercialized [1].

In the later release of HRPD, VoIP (Voice over Internet Protocol) capabilities were introduced to provide both voice and data service on the same carrier. The two 3G standards namely HSPA and HRPD were finally able to fulfill the 3G promise and have been widely deployed in major cellular markets to provide wireless data access.

2.1.2 Beyond 3G systems

While HSPA and HRPD systems were being developed and deployed, IEEE 802 LMSC (LAN/MAN Standard Committee) introduced the IEEE 802.16e standard for mobile broadband wireless access. This standard was introduced as an enhancement to an earlier IEEE 802.16 standard for fixed broadband wireless access. The 802.16e standard employed a different access technology named OFDMA (orthogonal frequency division multiple access) and claimed better data rates and spectral efficiency than that provided by HSPA and HRPD.

Although the IEEE 802.16 family of standards is officially called Wireless MAN in IEEE, it has been dubbed WiMAX (worldwide interoperability for microwave access) by an industry group named the WiMAX Forum. The mission of the WiMAX Forum is to promote and certify the compatibility and interoperability of broadband wireless access products. The WiMAX system supporting mobility as in IEEE 802.16e standard is referred to as Mobile WiMAX. In addition to the radio technology advantage, Mobile WiMAX also employed a simpler network architecture based on IP protocols [1].

The introduction of Mobile WiMAX led both 3GPP and 3GPP2 to develop their own version of beyond 3G systems based on the OFDMA technology and network architecture similar to that in Mobile WiMAX. The beyond 3G system in 3GPP is called evolved universal terrestrial radio access (evolved UTRA) and is also widely referred to as LTE (Long-Term Evolution) while 3GPP2's version is called UMB (ultra mobile broadband) as depicted in Figure 1.1. It should be noted that all three beyond 3G systems namely Mobile WiMAX, LTE and UMB meet IMT-2000 requirements and hence they are also part of IMT-2000 family of standards [1] [7].

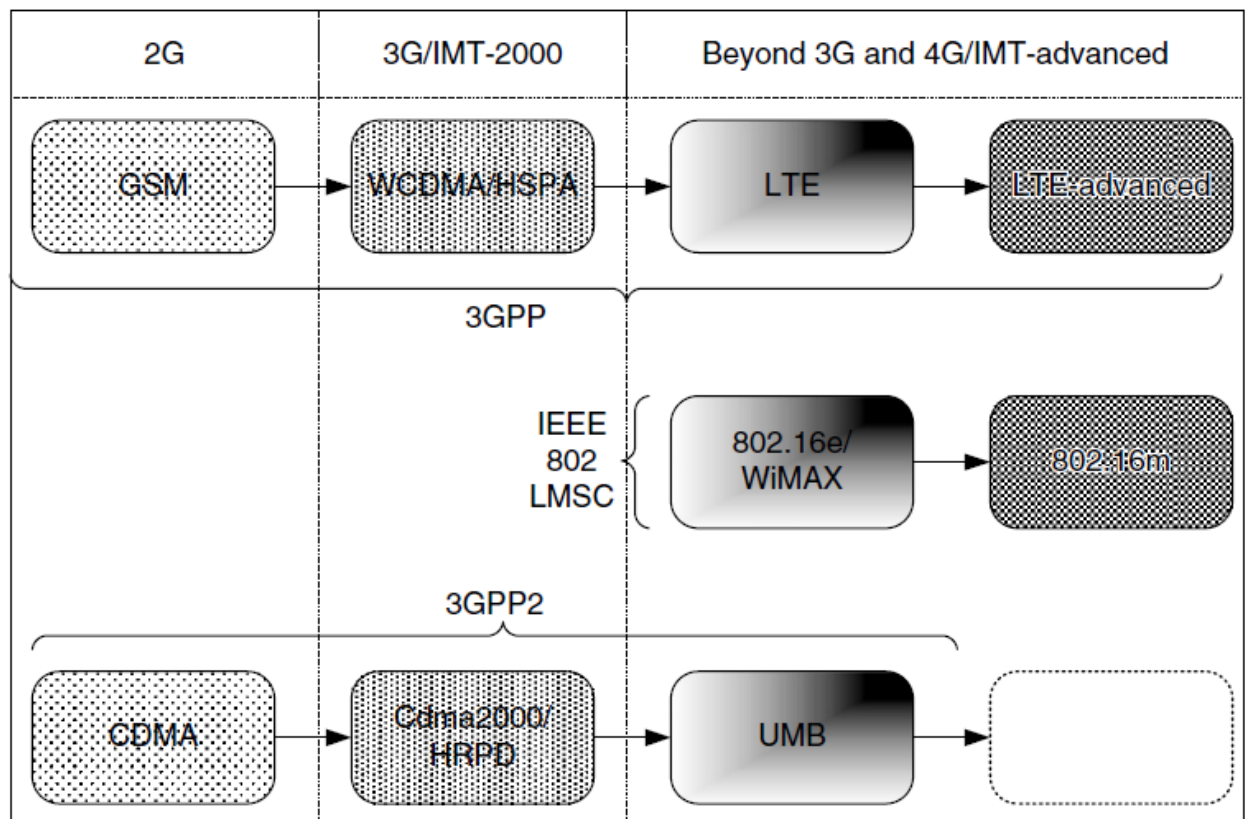


Figure 1.1 cellular systems evolution

2.1.3 Long-Term Evolution (LTE):

The goal of LTE is to provide a high-data-rate, low-latency and packet-optimized radio access technology supporting flexible bandwidth deployments. In parallel, new network architecture is designed with the goal to support packet-switched traffic with seamless mobility, quality of service and minimal latency.

The air-interface related attributes of the LTE system are summarized in Table 1.1. The system supports flexible bandwidths thanks to OFDMA and SC-FDMA access schemes. In addition to FDD (frequency division duplexing) and TDD (time division duplexing), half duplex FDD is allowed to support low cost UEs. Unlike FDD, in half-duplex FDD operation a UE is not required to transmit and receive at the same time [12]. This avoids the need for a costly duplexer in the UE. The system is primarily optimized for low speeds up to 15 km/h. However, the system specifications allow mobility support in excess of 350 km/h with some performance degradation. The uplink access is based on single carrier frequency division multiple access (SC-FDMA) that promises increased uplink coverage due to low peak-to-average power ratio (PAPR) relative to OFDMA.

Table 1.1 LTE system attributes

| | | |
|--------------------------|----------|---|
| Bandwidth | | 1.25–20 MHz |
| Duplexing | | FDD, TDD, half-duplex FDD |
| Mobility | | 350 km/h |
| Multiple access | Downlink | OFDMA |
| | Uplink | SC-FDMA |
| MIMO | Downlink | $2 \times 2, 4 \times 2, 4 \times 4$ |
| | Uplink | $1 \times 2, 1 \times 4$ |
| Peak data rate in 20 MHz | Downlink | 173 and 326 Mb/s for 2×2 and 4×4 MIMO, respectively |
| | Uplink | 86 Mb/s with 1×2 antenna configuration |
| Modulation | | QPSK, 16-QAM and 64-QAM |
| Channel coding | | Turbo code |
| Other techniques | | Channel sensitive scheduling, link adaptation, power control, ICIC and hybrid ARQ |

The system supports downlink peak data rates of 326 Mb/s with 4×4 MIMO (multiple input multiple output) within 20MHz bandwidth. Since uplink MIMO is not employed in the first release of the LTE standard, the uplink peak data rates are limited to 86 Mb/s within 20MHz bandwidth. In addition to peak data rate improvements, the LTE system provides two to four times higher cell spectral efficiency relative to the Release 6 HSPA system. Similar improvements are observed in cell-edge throughput while maintaining same-site locations as deployed for HSPA. In terms of latency, the LTE radio-interface and network provides capabilities for less than 10 ms latency for the transmission of a packet from the network to the UE [1].

2.1.4 Evolution to 4G

The radio-interface attributes for Mobile WiMAX and UMB are very similar to those of LTE given in Table 1.1. All three systems support flexible bandwidths, FDD/TDD duplexing, OFDMA in the downlink and MIMO schemes. There are a few differences such as uplink in LTE is based on SC-FDMA compared to OFDMA in Mobile WiMAX and UMB. The performance of the three systems is therefore expected to be similar with small differences.

Similar to the IMT-2000 initiative, ITU-R Working Party 5D has stated requirements for IMT-advanced systems. Among others, these requirements include average downlink data rates of 100 Mbit/s in the wide area network, and up to 1 Gbit/s for local access or low mobility scenarios. Also, at the World Radio communication Conference 2007 (WRC-2007), a maximum of a 428MHz new spectrum is identified for IMT systems that also include a 136MHz spectrum allocated on a global basis [1] [11].

Both 3GPP and IEEE 802LMSC are actively developing their own standards for submission to IMT-advanced. The goal for both LTE-advanced and IEEE 802.16m standards is to further enhance system spectral efficiency and data rates while supporting backward compatibility with their respective earlier releases. As part of the LTE-advanced and IEEE 802.16 standards developments, several enhancements including support for a larger than 20MHz bandwidth and higher-order MIMO are being discussed to meet the IMT-advanced requirements.

2.1.5 LTE network architecture

The LTE network architecture is designed with the goal of supporting packet-switched traffic with seamless mobility, quality of service (QoS) and minimal latency. A packet-switched approach allows for the supporting of all services including voice through packet connections.

The result is a highly simplified flatter architecture with only two types of node namely evolved Node-B (eNB) and mobility management entity/gateway (MME/GW). This is in contrast to many more network nodes in the current hierarchical network architecture of the 3G system [1].

One major change is that the radio network controller (RNC) is eliminated from the data path and its functions are now incorporated in eNB. Some of the benefits of a single node in the access network are reduced latency and the distribution of the RNC processing load into multiple eNBs. The elimination of the RNC in the access network was possible partly because the LTE system does not support macro-diversity or soft-handover [17].

All the network interfaces are based on IP protocols. The eNBs are interconnected by means of an X2 interface and to the MME/GW entity by means of an S1 interface as shown in Figure 2.1.

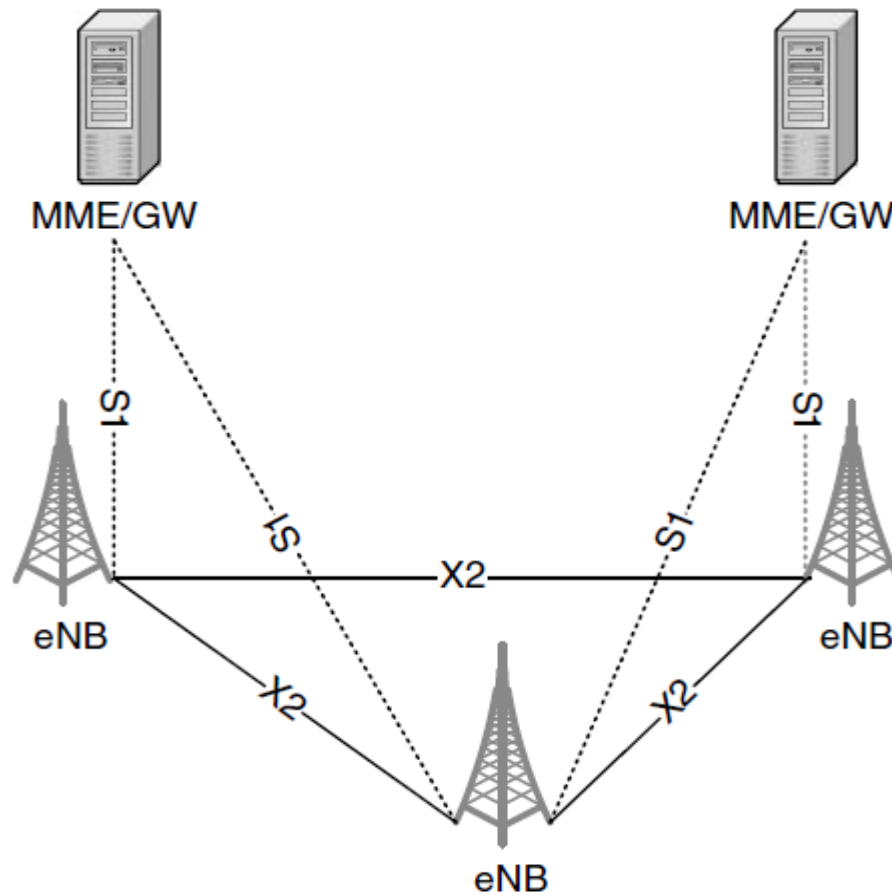


Figure 2.1 LTE Network architecture

The S1 interface supports a many-to-many relationship between MME/GW and eNBs. The functional split between eNB and MME/GW is shown in Figure 2.2

Two logical gateway entities namely the serving gateway (S-GW) and the packet data network gateway (P-GW) are defined. The S-GW acts as a local mobility anchor forwarding and receiving packets to and from the eNB serving the UE. The P-GW interfaces with external packet data networks (PDNs) such

as the Internet and the IMS. The P-GW also performs several IP functions such as address allocation, policy enforcement, packet filtering and routing.

The MME is a signaling only entity and hence user IP packets do not go through MME. An advantage of a separate network entity for signaling is that the network capacity for signaling and traffic can grow independently. The main functions of MME are idle-mode UE reach ability including the control and execution of paging retransmission, tracking area list management, roaming, authentication, authorization, P-GW/S-GW selection, bearer management including dedicated bearer establishment, security negotiations and NAS signaling, etc [1] [17].

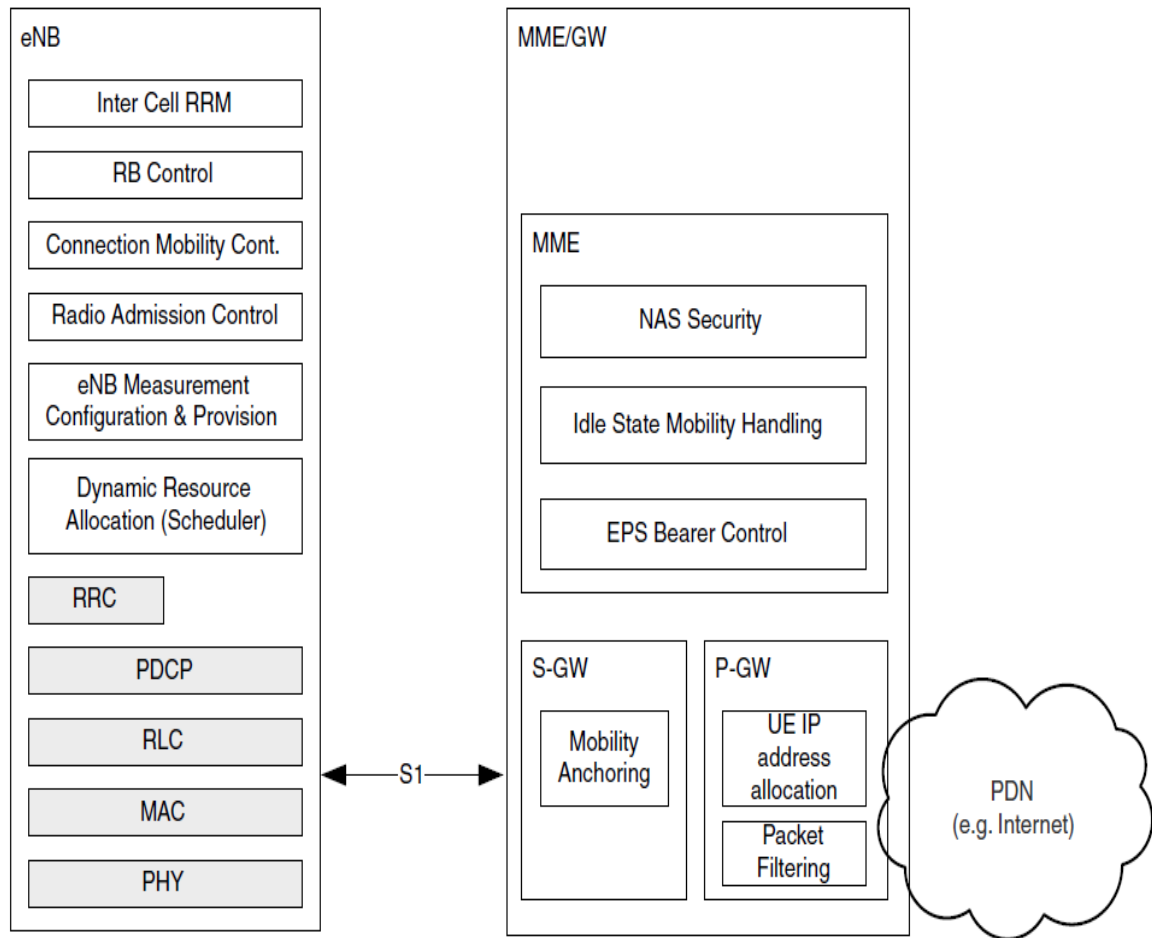


Figure 2.2 Functional split between eNB and MME/GW

Evolved Node-B implements Node-B functions as well as protocols traditionally implemented in RNC. The main functions of eNB are header compression, ciphering and reliable delivery of packets. On the control side, eNB incorporates functions such as admission control and radio resource management. Some of the benefits of a single node in the access network are reduced latency and the distribution of RNC processing load into multiple eNBs.

2.1.6 Downlink access

The current 3G systems use a wideband code division multiple access (WCDMA) scheme within a 5MHz bandwidth in both the downlink and the uplink. In WCDMA, multiple users potentially using different orthogonal Walsh codes are multiplexed on to the same carrier [1].

In a WCDMA downlink (Node-B to UE link); the transmissions on different Walsh codes are orthogonal when they are received at the UE. This is due to the fact that the signal is transmitted from a fixed location (base station) on the downlink and all the Walsh codes are received synchronized. Therefore, in the absence of multi-paths, transmissions on different codes do not interfere with each other. However, in the presence of multi-path propagation, which is typical in cellular environments, the Walsh codes are no longer orthogonal and interfere with each other resulting in inter-user and/or inter-symbol interference (ISI).

The multi-path interference can possibly be eliminated by using an advanced receiver such as linear minimum mean square error (LMMSE) receiver. However, this comes at the expense of significant increase in receiver complexity. The multi-path interference problem of WCDMA escalates for larger bandwidths such as 10 and 20MHz required by LTE for support of higher data rates. This is because chip rate increases for larger bandwidths and hence more multi-paths can be resolved due to shorter chip times. Note that LMMSE receiver complexity increases further for larger bandwidths due to increase of multi-path intensity. Another possibility is to employ multiple 5MHz WCDMA carriers to support 10 and 20MHz bandwidths. However, transmitting and receiving multiple carriers add to the Node-B and UE complexity. Another concern against employing WCDMA for LTE was lack of flexible bandwidth support as bandwidths supported can only be multiples of

5MHz and also bandwidths smaller than 5MHz cannot be supported. Taking into account the LTE requirements and scalability and complexity issues associated with WCDMA, it was deemed necessary to employ a new access scheme in the LTE downlink [1].

2.1.7 Orthogonal frequency division multiplexing (OFDM)

Orthogonal frequency division multiplexing (OFDM) approach was first proposed more than four decades ago by R. W. Chang. The scheme was soon analyzed by Saltzberg. The basic principle of OFDM is to divide the available spectrum into narrowband parallel channels referred to as subcarriers and transmit information on these parallel channels at a reduced signaling rate. The goal is to let each channel experience almost flat-fading simplifying the channel equalization process. The name OFDM comes from the fact that the frequency responses of the subchannels are overlapping and orthogonal. An example of five OFDM subchannels or subcarriers at frequencies f_1, f_2, f_3, f_4 and f_5 is shown in Figure 2.3. The subchannel frequency $f_k = k\Delta f$, where Δf is the subcarrier spacing. Each subcarrier is modulated by a data symbol and an OFDM symbol is formed by simply adding the modulated subcarrier signals.

The modulation symbol in Figure 2.3 is obtained by assuming that all subcarriers are modulated by data symbols 1's. An interesting observation to make is that the OFDM symbol signal has much larger signal amplitude variations than the individual subcarriers [7].

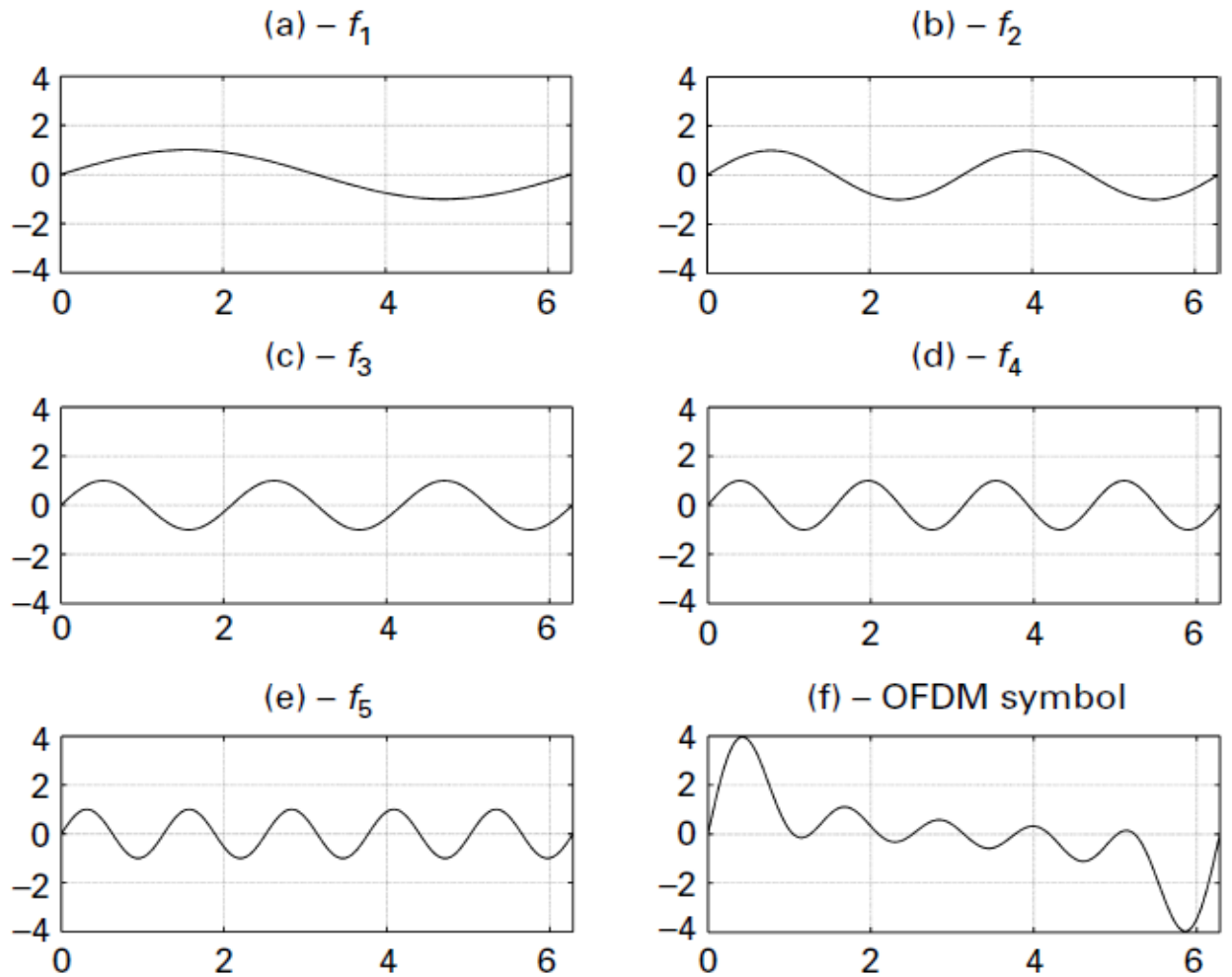


Figure 2.3 An illustration of subcarriers and OFDM symbol

The orthogonality of OFDM subcarriers can be lost when the signal passes through a time-dispersive radio channel due to inter-OFDM symbol interference. However, a cyclic extension of the OFDM signal can be performed to avoid this interference. In cyclic prefix extension, the last part of the OFDM signal is added as cyclic prefix (CP) in the beginning of the OFDM signal as shown in Figure 2.4.

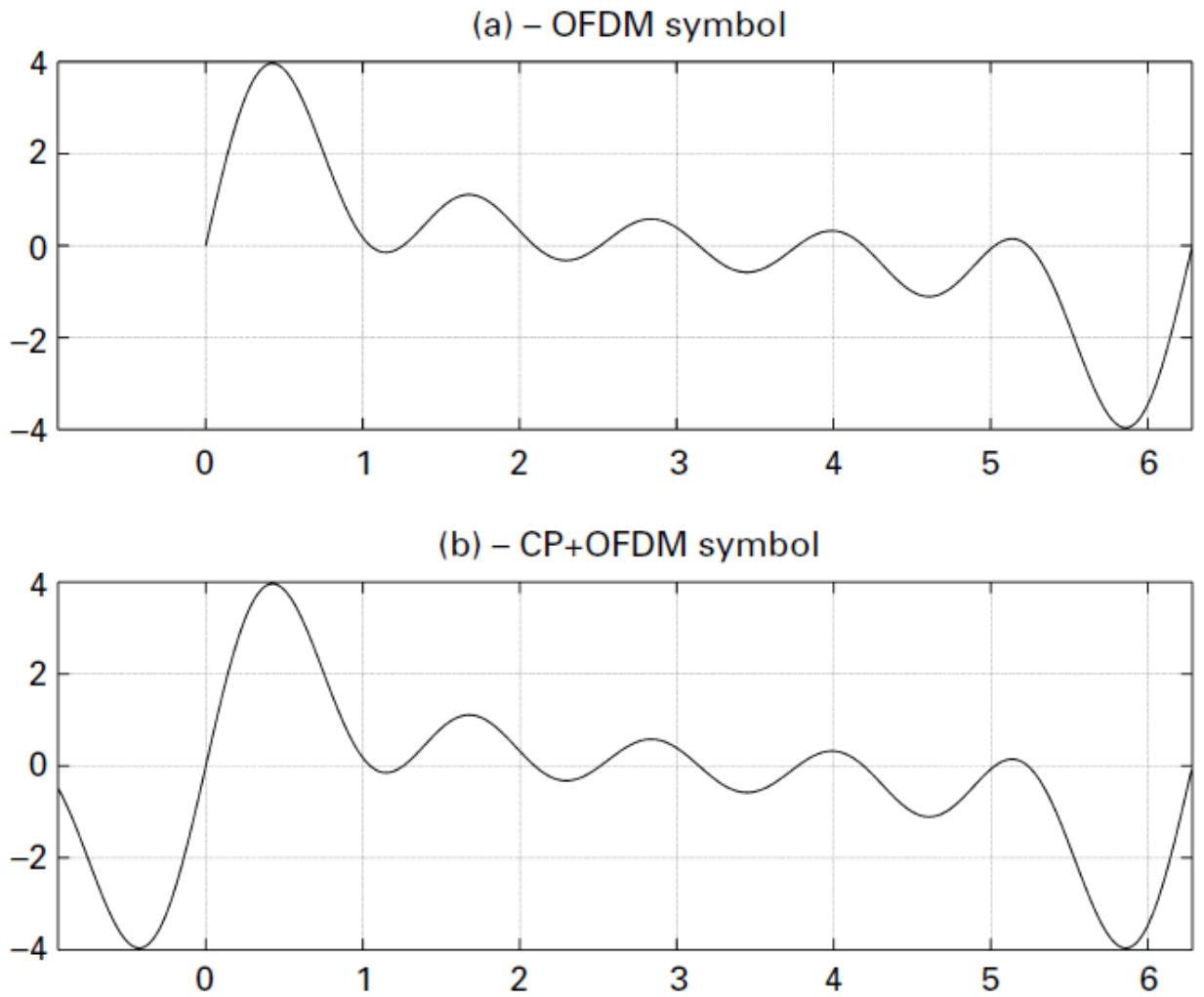


Figure 2.4 an illustration of cyclic prefix extension of OFDM symbol

The cyclic prefix length is generally chosen to accommodate the maximum delay spread of the wireless channel. The addition of the cyclic prefix makes the transmitted OFDM signal periodic and helps in avoiding inter-OFDM symbol and inter-subcarrier interference as explained later. The baseband signal within an OFDM symbol can be written as:

$$s(t) = \sum_{k=0}^{(N-1)} X(k) \times e^{j2\pi k \Delta f t}, \quad (2.1)$$

Where N represents the number of subcarriers, $X(k)$ complex modulation symbol transmitted on the k th subcarrier $e^{j2\pi k \Delta f t}$ and Δf subcarrier spacing as shown in Figure 2.5. The OFDM receiver model is given in Figure 2.6. At the receiver, the estimate of the complex modulation symbol $X(m)$ is obtained by multiplying the received signal with $e^{-j2\pi m \Delta f t}$ and integrating over OFDM symbol duration [1].

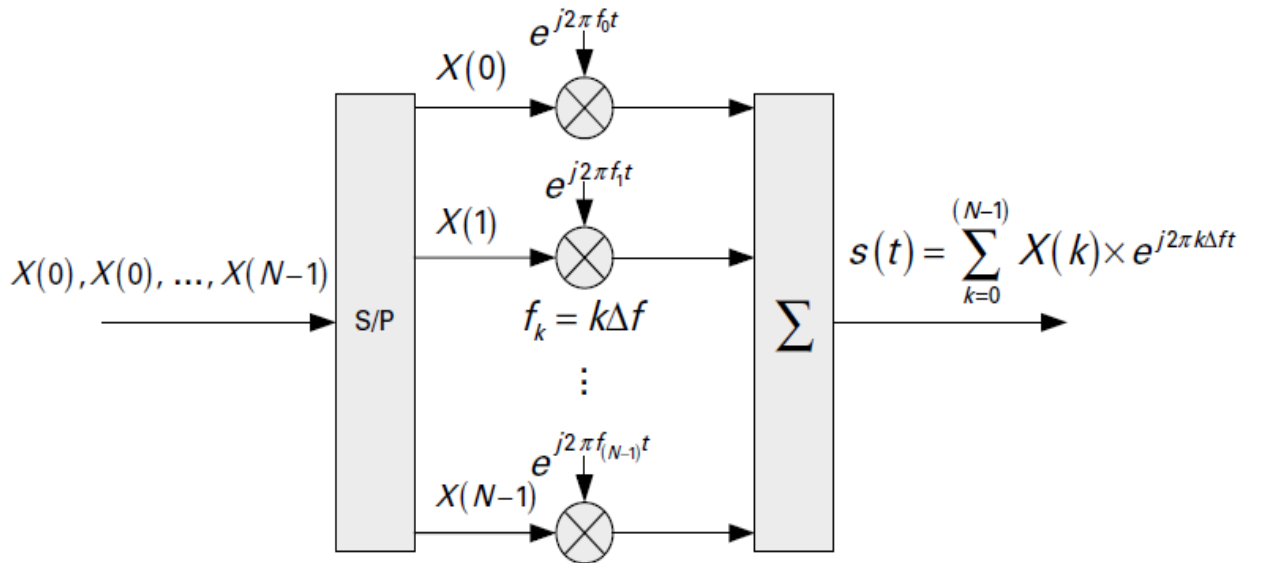


Figure 2.5 OFDM continuous-time transmitter model using banks of subcarrier oscillators

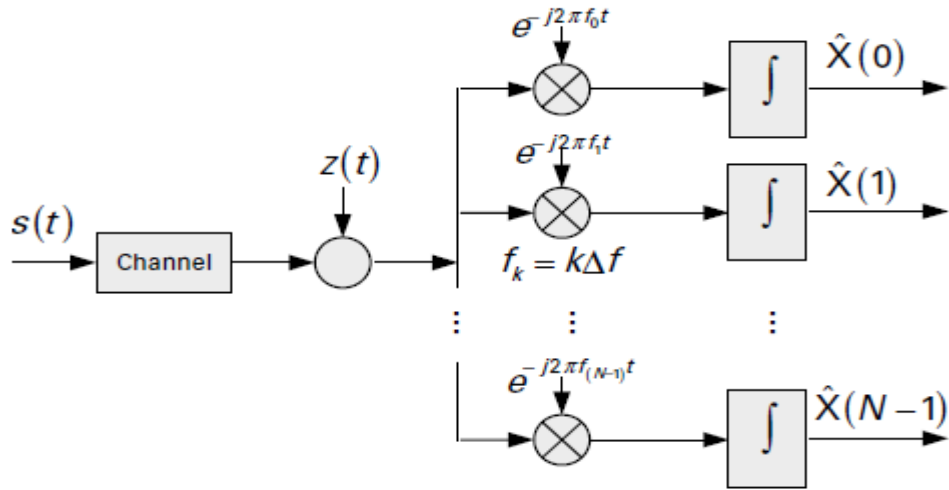


Figure 2.6 OFDM continuous-time receiver model using banks of subcarrier oscillators

2.1.8 Uplink access

The design of an efficient multiple access and multiplexing scheme is more challenging on the uplink than on the downlink due to the many-to-one nature of the uplink transmissions. Another important requirement for uplink transmissions is low signal peakiness due to the limited transmission power at the user equipment (UE). The current 3G systems use the wideband code division multiple access (WCDMA) scheme both in the uplink and in the downlink. In a WCDMA downlink (Node-B to UE link) the transmissions on different Walsh codes are orthogonal when they are received at the UE. This is due to the fact that the signal is transmitted from a fixed location (base station) on the downlink and all the Walsh codes received are synchronized. Therefore, in the absence of multi-paths, transmissions on different codes do not interfere with each other. However, in the presence of multi-path propagation, which is typically the case in cellular environments, the Walsh codes are no longer orthogonal and interfere with each other resulting in inter-user and/or inter-symbol interference (ISI).

The problem is even more severe on the uplink because the received Walsh codes from multiple users are not orthogonal even in the absence of multi-paths. In the uplink (UE to Node-B link), the propagation times from UEs at different locations in the cell to the Node-B are different. The received codes are not synchronized when they arrive at the Node-B and therefore orthogonality cannot be guaranteed. In fact, in the current 3G systems based on WCDMA, the same Walsh code though scrambled with different PN (pseudo-noise) sequences is allocated to multiple users accessing the system making the uplink transmissions non-orthogonal to each other [1].

The simultaneous transmissions from multiple users interfering with each other contribute to the noise rise seen by each of the users. In general, the noise rise at the base station is kept below a certain threshold called the rise-over-thermal (RoT) threshold in order to guarantee desirable capacity and coverage. The RoT is defined as:

$$\text{RoT} = \frac{I_0 + N_0}{N_0}, \quad (2.2)$$

Where I_0 is the received signal power density (including both the inter-cell and intra-cell power) and N_0 is the thermal noise (also referred to as the background noise) density. The RoT threshold limits the amount of power above the thermal noise at which mobiles can transmit. The RoT can be related to the uplink loading by the following expression:

$$\text{RoT} = \frac{I_0 + N_0}{N_0} = \frac{1}{1 - \eta_{\text{UL}}}, \quad (2.3)$$

Where η_{UL} represents uplink loading in a fraction of the CDMA pole capacity. In general uplink loading in a CDMA system is tightly controlled for system stability and coverage [1] [7].

Assuming 70% loading, a noise rise of 5.2 dB is obtained. It can be noted that 5.2 dB is also the maximum SINR (or chip energy to noise-plus-interference spectral density, E_c/N_t) that can be observed if there is no inter-cell and intra-cell interference i.e. a single user transmitting in the system. However, in a realistic scenario, the maximum E_c/N_t seen by a user would be much smaller due to inter-cell, intra-cell and multi-path interference. Therefore, the noise rise constraint limits the maximum achievable E_c/N_t that in turn limits the maximum achievable data rate in a CDMA uplink.

The noise rise constraint is a result of the near-far problem in a non-orthogonal WCDMA uplink. However, if the uplink can somehow be made orthogonal (e.g. using synchronous WCDMA), the noise rise constraint can be relaxed. Synchronous WCDMA requires subchip level synchronization and thus puts very strict requirements on uplink timing control in a mobile environment. The subchip level synchronization required in synchronous CDMA makes it undesirable in a mobile wireless system. It is also possible to improve the performance of a WCDMA uplink by using a more complex successive interference cancellation (SIC) receiver.

In a WCDMA uplink the number of Walsh codes used for uplink transmission from a single user is limited to a few codes. This is to limit the uplink signal peakiness to improve the power amplifier efficiency. With a single code transmission, WCDMA provides low signal peakiness due to its single-carrier property.

The goal for the LTE uplink access scheme design is to provide low signal peakiness comparable to WCDMA signal peakiness while providing orthogonal access not requiring an SIC receiver. The two candidate technologies for orthogonal access are OFDMA (orthogonal frequency division multiple access) and SC-FDMA (single-carrier frequency division multiple access) [4].

2.1.9 Single-carrier FDMA

Single-carrier FDMA scheme provides orthogonal access to multiple users simultaneously accessing the system. Another attractive feature of SC-FDMA is low signal peakiness due to the single carrier transmission property. In one flavor of SC-FDMA scheme referred to as IFDMA in, the user's data sequence is first repeated a predetermined number of times. Then the repeated data sequence is multiplied with a user specific phase vector. Another way of looking at this approach is Fourier Fast Transform FFT precoding of the data sequence and then mapping of the FFT- precoded data sequence to uniformly spaced subcarriers at the input of IFFT (Inverse FFT). The uniform spacing is determined by the repetition factor Q . The multiplication of the repeated data sequence with a user-specific phase vector can be seen as frequency shift applied in order to map transmissions from multiple users on non-overlapping orthogonal subcarriers. It should be noted that each data modulation symbol is spread out on all the subcarriers used by the UE. This can provide a frequency-diversity benefit in a frequency-selective channel. However, there may be some impact on performance as well due to loss of orthogonality or noise enhancement when data subcarriers experience frequency selective fading. We will refer to the IFDMA scheme as distributed FDMA (DFDMA) from now on. The mapping of FFT-precoded data sequence to contiguous subcarriers results in a localized transmission in the frequency domain. Similar to distributed mapping or DFDMA, localized mapping also results in a low PAPR signal. The

distributed and localized mapping of FFT pre-coded data sequence to OFDM subcarriers is sometimes collectively referred to as DFT-spread OFDM.

2.1.10 Frame and slot structure

In the LTE system, uplink and downlink data transmissions are scheduled on a 1 ms sub-frame basis. A sub-frame consists of two equal duration (0.5 ms) consecutive time slots with sub-frame number i consisting of slots $2i$ and $(2i + 1)$. All the time durations are defined in terms of the sample period $T_s = 1/f_s$, where $f_s = 30.72$ Msamples/sec [1]. Some of the control signals such as synchronization and broadcast control in the downlink are carried on a 10 ms radio frame basis, where a radio frame is defined to consist of 10 subframes as shown in Figure 2.7.

The transmission of the uplink radio frame number i from a UE starts $N_{TA} \times T_s$ seconds before the start of the corresponding downlink radio frame at the UE, where N_{TA} represents the timing offset between uplink and downlink radio frames at the UE in units of T_s . This timing offset N_{TA} is adjusted for each UE in order to make sure that signals from multiple UEs transmitting on the uplink arrive at the eNodeB at the same time. Each slot is further divided into $N_{\text{symb}}^{\text{UL}}$ SC-FDMA symbols or $N_{\text{symb}}^{\text{DL}}$ OFDM symbols for the uplink and downlink respectively.

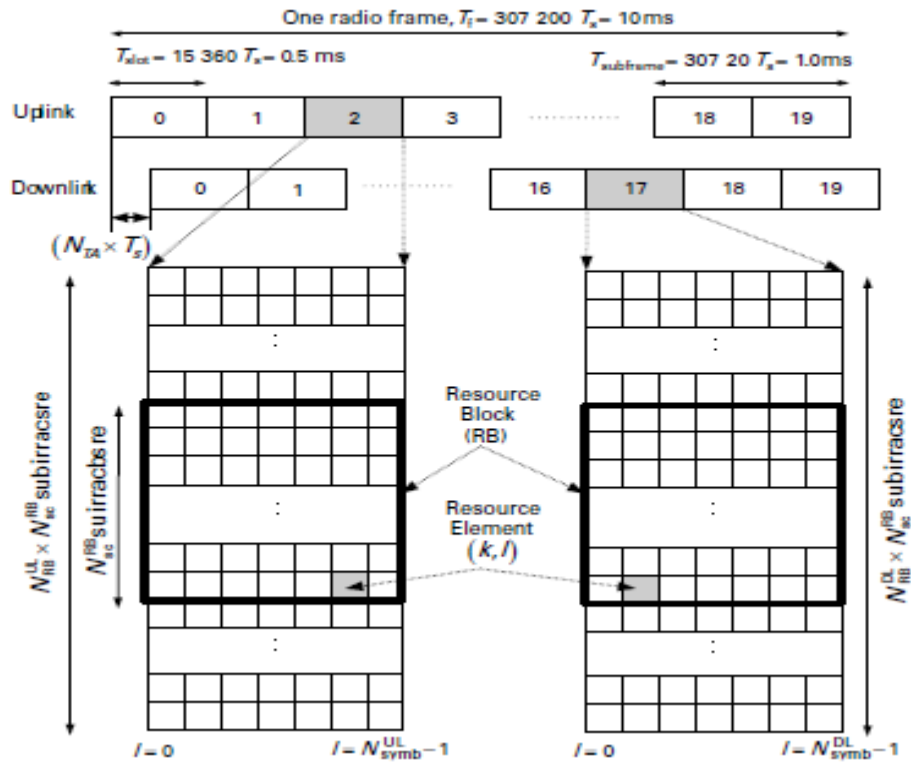


Figure 2.7 downlink and uplink frame structure

2.2 Building Penetration Losses (BPLs)

Mobile traffic demand has substantially grown over the last years partially because of commercial launch of flat rates. New mobile communication systems must fulfill higher average and cell-edge user throughput requirements, while at the same time average revenues per user are continually decreasing. Therefore, the key success of future wireless systems will be the provision of mobile broadband access but at lower costs-per-bit for the operators than previous systems.

Growth of mobile traffic demand is not the only problem, but also that this demand is mainly generated from indoors. According to Cisco VNI; more than 70% of the mobile traffic is generated in indoors [9]. The problem with indoor users is that they suffer from poor signal-to-interference and noise ratio (SINR) due to in building penetration losses (BPLs), so that they require more resources to achieve acceptable throughput, i.e., more spectrum, what undoubtedly degrades the network performance.

Femtocells are regarded as a cost-efficient solution to this problem and have become one important research topic since it seems to be a promising alternative to reduce network costs. Femtocells show, however, several challenges not only regarding technical aspects, but also in economic and regulatory issues.

The possibilities of deployment offered by femtocells are very diverse so that the scenarios to analyze are numerous. Residential femtocells are installed at user's home and make fixed-mobile convergence possible. Enterprise femtocells aim at satisfying indoor traffic demand with quality of service (QoS) at companies and they can offer additional functionalities, as the integration with a private branch exchange. Operators can also benefit from femtocells for saving coverage gaps or specific capacity problems. Finally, femtocells can

provide broadband access in remote places with a satellite backhaul, for example, inside an airplane.

2.2.1 Building Penetration Loss Models

The building penetration loss is defined as the power loss that an electromagnetic wave undergoes as it propagates from outside a building towards one or several places inside this building. This parameter is determined from the comparison between the external field and the field present in different parts of the building where the receiver is located. Penetration loss models, being integrated into the coverage prediction tools, must take into account the environment around the buildings which is under consideration [2].

The electromagnetic field inside buildings is subject to the influence of different parameters, including the position of the building with respect to the emitter and to other buildings or the architectural characteristics of the building, for instance the materials, the interior layout or the size of the windows. Values obtained for a given building should not, therefore, be generalized to any kind of building when performing coverage predictions. While a database integrating a large enough number of characteristics would help improving the precision of building penetration loss models, the development on a large scale of such a database remains difficult.

The value of the building penetration loss is influenced by a number of different physical parameters, whose effects intermingle most of the time. Among these different parameters the following are traditionally distinguished:

- The near environment: a distinction is drawn between districts with high towers more or less separated from each other and more traditional districts with buildings of average height,

- The reception depth in buildings: the amplitude of the field decreases as the mobile moves from the front of the building towards a room located inside it, while the influence of the inhomogeneities decreases as the penetration depth inside building increases. Waves penetrate more easily through window panes than through brick walls. Accordingly, the paths followed by radio waves will be more or less attenuated, and might even be occulted. The building penetration loss is generally 6 dB lower for glazed walls compared with non glazed walls. Although the level of attenuation is higher in the back of buildings, it is also much more homogeneous there.

- The incidence angle, which determines the reflection and transmission coefficients at a surface,

- The reception height, more commonly described as ‘floor effect’. This parameter induces effects in the form of a reduction of the building penetration loss or of a relative power gain, as compared with the lower floor. The calculation starts therefore from the consideration of the building penetration loss at the ground floor, as determined from a comparison with the external field. In small cell, power gains are typically of the order of approximately 2 to 3 dB per floor at the 900 and 1800 MHz frequencies. However the great diversity of situations results in a scattering of these gains per floor; values ranging from 4 to 7 dB have already been measured in practice. The lower floors are illuminated by rays reflected and diffracted at the roofs and in the street, whereas the upper floors are generally under stronger illumination, and even sometimes under direct line-of-sight illumination. As a consequence, the

values of the building penetration loss vary between the lower floors and the upper floors.

- The distance between the transmitter and the receiver, when the building where the mobile is located is in line-of-sight of the transmitting antenna. The building penetration loss in this case depends on distance as predicted by the free space propagation law.

- The height of the emitting antenna,

- The frequency,

- The nature of the materials. The attenuation that electromagnetic waves undergo varies from 4 dB in the case of wood to 10 dB in the case of concrete walls (COST231).

Several different measurement techniques have been developed in order to characterize the building penetration loss associated with the materials of the buildings. In particular, the method based on the use of two reverberation rooms can be mentioned here.

The most classical models draw on the Motley-Keenan model (Motley 1988) used for the study of propagation inside buildings. The parameters considered in these models for the determination of the building penetration loss include:

- The distance between the emitter and the external wall of the building where the receiver is located,

- The distance between the external wall and the receiver,

- The number of internal walls present along the emitter-receiver profile,

- The floor effect,

- The attenuation due to the external walls of the building,
- The attenuation due to the internal walls of the building.

The loss path L is expressed as the sum of the free-space loss L_0 , of the losses due to the obstacles present along the direct line-of-sight path (tiles, walls, doors, windows) and of a constant L_c (Motley 1988). Databases can be used for differentiating between the different obstacles to which specific attenuation values are attached. This model is the most commonly used.

$$L = L_0 + L_c + \sum_{j=1}^N N_j L_j + N_f L_f \quad (3.1)$$

Where N_j is the number of walls of type j present along the line-of-sight path, L_j is the losses due to walls of type j , N is the number of types of walls, N_f is the number of tiles present along the line-of-sight path and L_f is the losses due to tiles. Typical values of transmission losses for different types of materials used for the external walls in the 2 GHz frequency band are summarized in Table 3.1 (COST 231) [2].

Table 3.1 Transmission losses for external walls made of different types of materials in the 2 GHz frequency band

| Materials | Losses [dB] |
|--|-------------|
| Porous concrete | 6.5 |
| Reinforced glass | 8 |
| Concrete (30 centimetres) | 9.5 |
| Thick concrete wall (25 centimetres) with large glazed panes | 11 |
| Thick concrete wall (25 centimetres) without glazed panes | 13 |
| Thick wall (> 20 centimetres) | 15 |
| Tile | 23 |

The main disadvantage of these models lies in the empirical evaluation of the parameters. These parameters, for instance the value of the wall attenuation, may indeed present significant fluctuations from one building to another, which results in a reduction of the degree of precision of the prediction of the field strength. Furthermore, the internal architecture of buildings is not at the present time integrated by any database. Even though this solution could be considered for certain specific buildings, it is doubtful that it could ever be implemented on a large scale [2].

Building penetration loss BPL models can be enhanced through the use of micro profiles joint the indoor mobile to external reference points.

The information relating to the external environment and to the interior of buildings and extracted from the micro profiles allows determining the total attenuation, which consists of two terms: a building penetration loss and an outdoor path loss between the base station and the building (COST 231).

2.2.2 Indoor Propagation Models

The propagation of radio waves in buildings depends primarily on the nature of the environment. The propagation environment can be characterized as either dense (office type buildings), open (office type buildings, offices with large capacity), broad (buildings with very large rooms, for instance warehouses, airports or railway stations) and corridor (in the case where the emitter and the receiver are located in the same corridor). Indoor propagation is also multipath: the predominant propagation mechanisms are reflection, transmission, diffraction and scattering [2].

CHAPTER (3)

FEMTOCELLS THE PROPOSED TECHNIQUES

3.1 Efficient Solutions for indoor users

The solution for efficient service of indoor users can be better using femtocells; Femtocells can be defined as "a personal mobile network in a box". Femtocells use a low power Femto Access Point (FAP) that utilizes fixed broadband connections to route femtocells 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 [10] [14].

Femtocells represent, nowadays, a low-cost attractive solution for improving both coverage and capacity of broad-band cellular networks. Market forecasts are expecting a massive increase in data traffic generated by mobile users in upcoming years so that emerging broadband technologies (i.e., WiMAX, LTE, and LTE-A) require significant architectural improvements to become able to satisfy this ever growing user demands. In this perspective, the support of high data-rate indoor traffic becomes fundamental, since it is estimated that most of the voice calls and data sessions will take place in indoor environment during the next years [4]. The deployment of cellular network composed by very small cells (i.e., femtocells) represents today the smartest

solution for boosting cellular network services, especially in indoor scenarios [3]. Femtocells in LTE environment is obtained using a Home evolved Node B (HeNB), that is a low-power and small-range cellular base station, typically designed for home or small business environment. It has plug-and-play capabilities to be straightly set up by end-users; moreover, it is connected to the core network through the DSL line available at consumers' houses or offices.

Several benefits are expected from deployment of femtocells, starting from an increased network capacity [7]. The market of femtocells is expected to be very attractive for both mobile operators and consumers. From one side, they can guarantee a better coverage to those areas which are currently provided with an unsatisfactory service if served by macro cells. On the other hand, users could take advantage from the reduction of costs related to their generated traffic.

According to [13], in fact, the cost per GByte of the traffic handled inside a femtocell is expected to be less than the one managed by a macro cell. Nevertheless, several issues have still to be investigated, especially in the area of the Radio Resource Management (RRM). Among others, interference management, as matter of fact, becomes a major issue in conditions of uncoordinated deployment of HeNBs.

In fact, when the operator cannot perform a centralized frequency planning, both co-layer (femto-to-femto) and cross layer (femto-to-macro) interference take place. This problem appears even more complex when restricted access policies are used at HeNBs.

3.2 Network Management with Femtocells

Femtocells can be utilized as a tool [14] which is offered to mobile operators to improve business cases:

- Network Savings:
 - deployed for indoor coverage to reduce cell site.

- offload macro network traffic,
- reduces Capital Expenditure (CapEx) and Operational Expenditure (OpEx).
- deployed in phase, brings require capacity.
- Customer Hold:
 - improved customer satisfaction
 - brings incentive value suggestion for households
- Compatible for next generation networks:
 - supports high frequencies e.g. LTE-A
 - provides high data rates e.g. LTE-A

Usually price per volume of data traffic is lower than that of voice traffic; the cost of managing data dominated network will soon become unsustainable in future. It is because the revenues they generate can no longer support such a high growth of data traffic.

The investment required for the expansion of data dominated network is higher than its voice dominated counterpart simply because of the enormous growth of data traffic. It has been observed already that mobile data traffic will be dominated by video traffic. To give an example, an average length YouTube video can generate the same amount of traffic to the network as 500,000 short messaging service (SMS) do [14].

3.3 Growing Demand for Mobile Traffic

Mobile traffic has been increasing rapidly as a result of growing demand for smartphones. Mobile service providers face an urgent need to expand the capacity of their mobile networks. One resolution in addressing this increased traffic is improving the spectral efficiency by applying LTE, which uses the latest wireless access technology. Another resolution is the “small cell approach”, which is deploying a lot of femtocells in order to improve communication quality owing to the reduction of the propagation length

between smartphones and femtocells, and in order to increase the chance to occupy wireless resource of femtocells.

LTE femtocell is a small and lightweight base station that offers easy installation interface and excellent communication quality. First technology is a plug-and-play function that enables simple automatic installation when the unit is connected to a broadband network. Second technology is an interference control function which can reduce radio interference among outdoor macrocells, indoor picocells and femtocells. Third technology is an inter-system handover function which performs seamless handover between LTE and the Wi-Fi based on the traffic congestion and realizes dynamic traffic offloading.

As a result, the LTE Femtocell delivers high-quality, high-capacity mobile networking for consumers [14] [17].

3.4 Mathematical modeling:

In OFDM, there is no multi-path interference due to use of a cyclic prefix and 1-tap equalization of OFDM subcarriers. Therefore, the sources of SINR degradation in an OFDMA system are the other-cell interference and the background noise. The SINR in an OFDM system is then approximated as:

$$\rho_{OFDM} = \frac{P}{f \cdot P + N_0}.$$

P is the received power, f represents the ratio between other-cell and own-cell signal, N_0 single path.

We note that SINRs in an OFDM system and a WCDMA system are the same for a single-path frequency-flat fading channel [1]. The capacity limit of an OFDM system is given as:

$$C_{\text{OFDM}} = \log_2 \left(1 + \frac{P}{fP + N_0} \right) = \log_2 \left(1 + \frac{\rho}{\rho \cdot f + 1} \right) \quad [\text{b/s/Hz}].$$

We also need to take into account the cyclic prefix overhead for the OFDMA case. Therefore, the capacity of an OFDM system is scaled-down to account for CP overhead as below:

$$C_{\text{OFDMA}} = \left(1 - \frac{\Delta}{T_s} \right) \cdot \log_2 \left(1 + \frac{\rho}{\rho \cdot f + 1} \right) \quad [\text{b/s/Hz}]$$

Where T_s is the OFDM symbol duration and f is the cyclic prefix duration.

It can be noted that the SINR in an OFDM system degrades with increasing f . In general, f is larger for cell-edge users experiencing high interference from neighboring cells and lower for cell-center users receiving little interference from the neighboring cells. Therefore, users closer to the cell with low f are expected to benefit more from OFDMA than users at the cell edge. The performance of cell edge users is generally dominated by interference from a neighboring cell rather than the multi-path interference. Therefore, OFDMA is expected to provide relatively smaller gains for the cell-edge users [1].

Like OFDMA, SC-FDMA avoids intra-cell interference in the uplink. However, SC-FDMA can also benefit from frequency diversity because a given modulation symbol is transmitted over the whole bandwidth allocated to the UE. However, the downside of this approach is that performance of SC-FDMA suffers in a frequency-selective fading channel due to noise enhancement. This is because the IDFT operation after frequency-domain equalization at the receiver spreads out the noise over all the modulation symbols. It should be noted that noise enhancement results in inter-symbol-interference (ISI) and not the inter-user interference, that is, there is no intra-cell interference among UEs transmitting over orthogonal frequency resources. The losses of SC-FDMA link

performance relative to OFDMA have been estimated ranging from no loss or a slight gain due to diversity at low SINR for QPSK modulation to about 1 dB for 16-QAM and 64-QAM modulations typically used at higher SINR [1]. Therefore, the uplink capacity limit for an SC-FDMA system is given as:

$$C_{\text{SC-FDMA}} = \left(\frac{T_s}{T_s + \Delta} \right) \times \log_2 \left(1 + \frac{KP}{fKP + N_0} \times \frac{1}{10^{(L_{\text{SC-FDMA}}/10)}} \right) [\text{b/s/Hz}],$$

Where $L_{\text{SC-FDMA}}$ represents the SC-FDMA link loss in dBs relative to OFDMA, K is the number of users. This loss occurs at higher SINR when frequency-domain linear equalization is used. It should be noted that some or all of this loss can be recovered by using a more advanced receiver at the eNodeB at the expense of additional complexity.

It can, however, be argued that lower PAPR is more desirable for power-limited UEs using QPSK modulation. In general, QPSK is used at relatively lower SINR where capacity scales approximately linearly with SINR. This means that additional power that becomes available due to lower PAPR directly translates into higher data throughputs. However, higher order modulations such as 16-QAM and 64-QAM are used at relatively higher SINR where channel capacity scales logarithmically with SINR [1]. Therefore, the additional power that becomes available due to lower PAPR translates into only marginal improvements in data rates.

Let us assume the path-loss model for 2 GHz frequency:

$$PL_s = 128.1 + 37.6 \times \log_{10}(r) \text{ dB s},$$

Where r is the distance between the UE and eNodeB in kilometers. In addition, we assume in-building penetration loss of 20 dB. The same path-loss model is assumed for the interferer eNB2.

$$PL_i = 128.1 + 37.6 \times \log_{10}(2R - r) \text{ dB s}.$$

The SINR experienced by the UE can be written as:

$$\rho_{ICI} = \frac{P \left(10^{\frac{PL_s}{10}} \right)}{N_0 W + P \left(10^{\frac{PL_f}{10}} \right)}.$$

When the Inter Cell Interference ICI is not present, the SINR experienced by the UE can be written as:

$$\rho_{No-ICI} = \frac{P \left(10^{\frac{PL_s}{10}} \right)}{N_0 W}.$$

The lower SINR happens when r approaches R , which is the case for cell-edge UEs, and in case for femtocell the value of r is small and hence good SNIR value is expected.

CHAPTER (4)

IMPLEMENTATIONS AND RESULTS DISCUSSIONS

4.1 Simulation Tools

The performance management of modern communication network is the key parameter from any operator's point of view for reviewing its Quality of Service (QoS) against its contestants.

The performance of an existing network can be measured, but these measurements reflect only the current state of the network and do not consider the changes in behavior of applications and users, which are changing over time. Therefore network operators must constantly modify and improve the network time to time. However, changing a network to meet new goals is a very complex process and is difficult to be analyzed with theoretical point of view by using mathematical methods. One solution is to analyze the simulation with the help of any appropriate simulating tool. Simulation can be described as building a model of network under consideration, inside a computer and introducing traffic into that model. The computer then provides some statistical parameters as output and these results are then used by operator as basis for determining, what must be done to change the network.

The better option is LTE system level simulator, it is open source and used for network simulations.

The core parts are link measurement model and link performance model. 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 and UEs are positioned. Length of simulation is measured in Transmission Time Intervals (TTIs).

4.2 Simulation Scenarios for Performance Evaluation

The thesis I tries to manage the problem of indoor users in LTE network by deploying new small cells inside the buildings which leads to improvement in capacity and hence QoS. It tries also to evaluate the performance for indoor users.

Two basic scenarios are considered, in first scenario, indoor users are being increased while no femtocells are deployed for indoor users to serve them and the performance of macrocells is evaluated through the uplink throughput and capacity; number of users. In the second case, femtocells will deployed indoor and both performance of macro and Femtocells are estimated.

The system level environment is built on top of LTE System Level Simulator provided by the Vienna University of Technology, Austria [15], [16] for real LTE usage scenario is set up in MATLAB. The Simulation uses TS36942 with urban environment as macroscopic Pathloss model. TS36942 [12], [15] is Technical Specification provided for the future development work within 3rd Generation Partnership Project (3GPP) for Evolved Universal Terrestrial Radio.

Access (E-UTRA) operation primarily with respect to the radio transmission and reception including the Radio Resource Management (RRM) aspects. Whereas log normally-distributed 2D space-correlated shadow fading with a mean value of 0 dB and standard deviation of 10 dB, as described by Claussen [15], [16] is used. The resolution of map is set to 5 meters/pixel. The

algorithm also counts the number of neighbors which is fixed to 4 and 8, means 4 or 8 pixels from center of eNodeB. The correlation between sectors of site is fixed to 1, which means exactly the same pathloss map is generated for each sector of eNodeB. Correlation could either be 0 or 1, where 0 means absolutely different maps. Fast fading model [12], [13] is generated according to the speed of the user and the mode used for the transmission. The channel model type used is PedB, ITU pedestrian, it is the specification of link-level simulation, part of LTE Link Level Simulator, and other options of channel model type are also available.

The channel trace length in seconds could be chosen depending upon the available memory, as it will be loaded by the simulator for later use. 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. TS36.942 antenna specification is used for eNodeBs in the simulation with a gain of 15dBi. Other options are also available, depending upon the environment and frequencies.

Single Input Single Output (SISO) is used as the transmission mode. The SINR averaging algorithm, Exponential Effective Signal to Interference and Noise Ratio Mapping (EESM), other options could be Mutual Information Effective Signal to Interference and Noise Ratio Mapping (MIESM). The users are set according to Table 4.1 [11], [15]. The simulation is run for 100 Transmission Time Interval (TTIs).

4.3 LTE Network layout:

The network layout shown in Fig. 4.1 consists of 7 eNodeBs each containing 3 sectors and users are randomly distributed in the whole macro network with 10 UEs per sector/cell.

The value of SINR decreases with the increase in distance from eNodeB towards the edge due to increased path loss and high interference from neighboring cells. To sum up, edge users experience poor SINR and hence poor quality of service.

Indoor environment is created at the edge of cells and then UEs are taken indoors from these randomly distributed users. Worst case scenario is considered for indoor UEs which are at edge of the cells and facing an extra 20 dB indoor penetration loss.

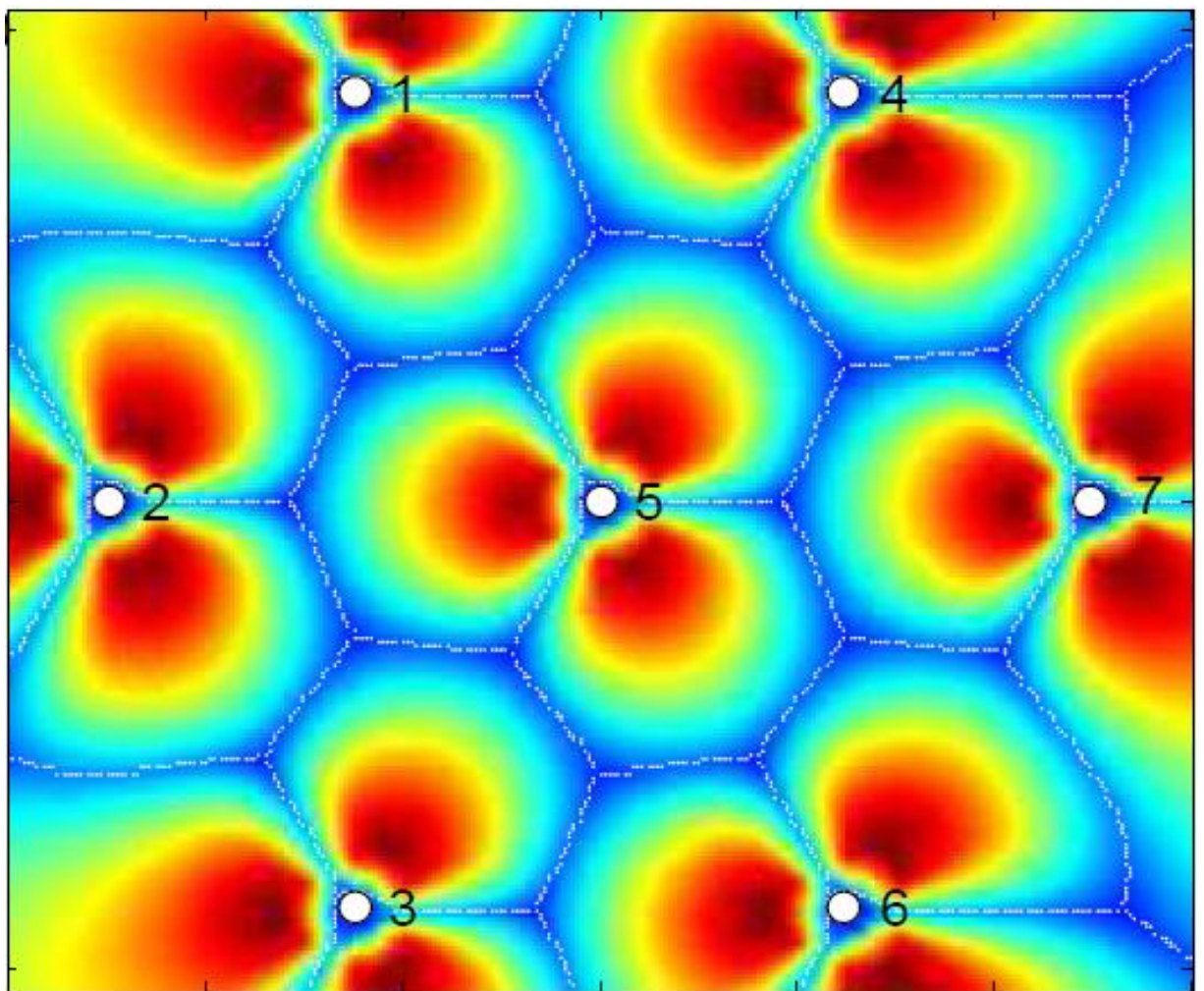


Figure 4.1 LTE Network layout

The basic parameters for LTE simulation environment are shown in table 4.1 below:

Table 4.1: basic parameters for LTE simulation environment

| Parameter | Value |
|--------------------------|----------------------------------|
| Frequency | 2.1 GHz |
| Receiver noise figure | 9 dB |
| System Bandwidth | 20MHz |
| Thermal noise density | -174 dBm/Hz |
| Lognormal Shadowing | 10dB |
| Inter eNodeB distance | 500 m |
| UE Power | 23dBm |
| Macroscopic pathloss | $128.1 + 37.6 \log_{10}(R)$ [15] |
| Number of UEs per sector | 10 |
| eNodeB TX Power | 46 dBm [14] |
| Penetration Loss | 20dB |
| UE speed | 5 Km/h |
| BS antenna gain | 15 dBi [14] |
| Traffic type | Full buffer Traffic |
| Cell Layout | Hexagonal grid, 3sectors/eNodeB |

Two basic scenarios are considered, in first scenario, indoor users are being increased while no femtocells are deployed for indoor users to serve them and the performance of macrocells is evaluated. In the second case, femtocells are also deployed indoor and both performance of macro and femtocells are estimated. The basic simulation Parameters are set according to Table 4.1 [11], [15], [16]. These parameters will remain the same for all simulation scenarios.

4.4 Without Deployment of Femtocells:

Initially, when the simulation is run, users are randomly distributed in the whole macro network with 10 UEs per sector/cell. As described in previous chapter, indoor environment is created at the edge of cells and then UEs are taken indoors from these randomly distributed users. Worst case scenario is considered for indoor UEs which are at edge of the cells and facing an extra 20 dB indoor penetration loss.

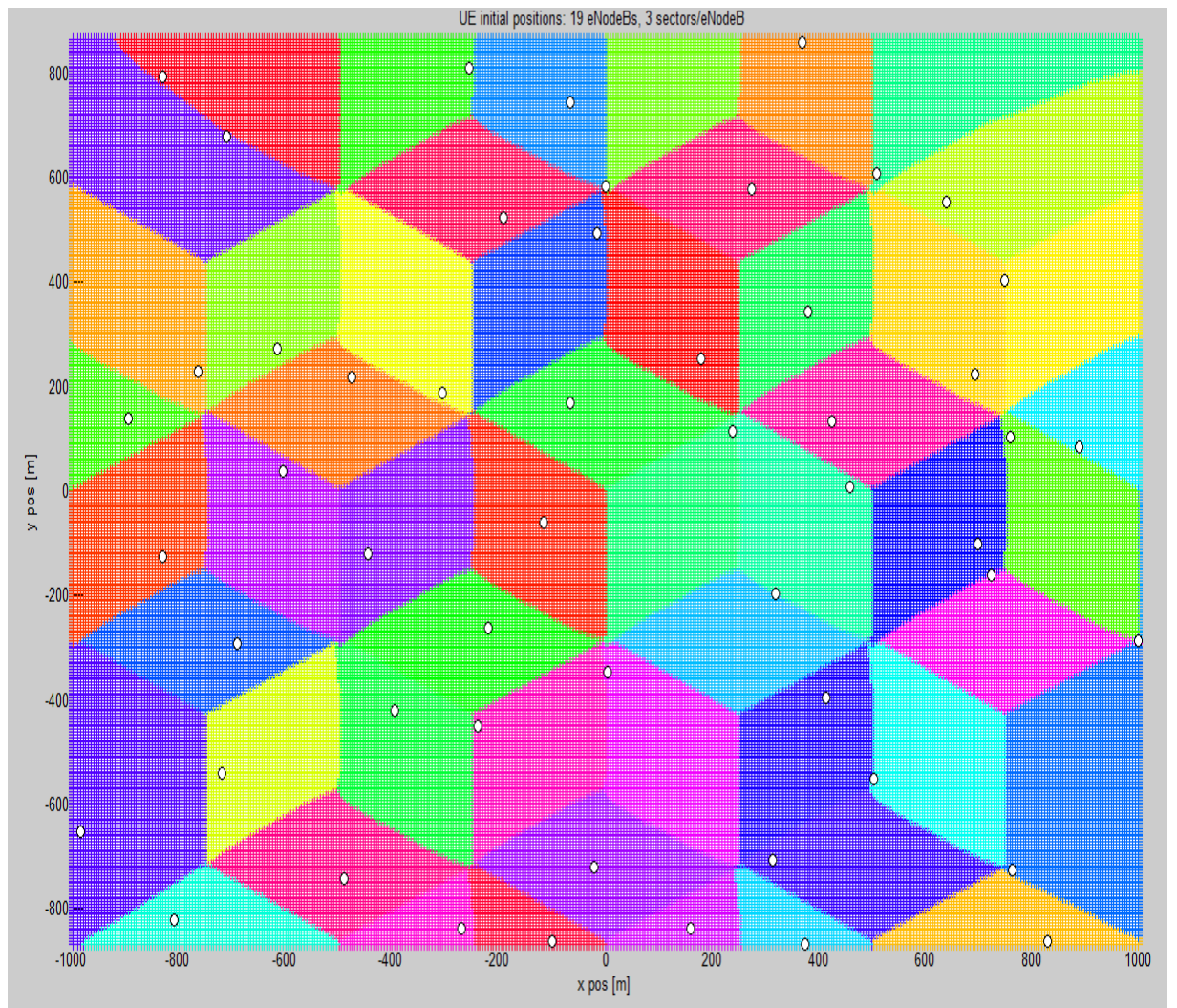


Fig. 4.2 UE initial positions: 3 sectors/eNodeB

To see the impact of indoor users on throughput, indoor users are increased from 0% to 100% with a step increase of 10%. The resulting total aggregated macro network throughput is computed for all cells.

4.5 Simulation Results:

The network layout shown in Fig. 4.3 consists of 7 eNodeBs each containing 3 sectors.

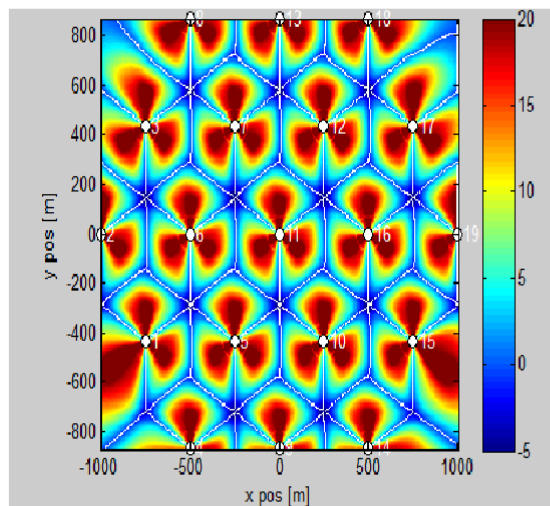


Figure 4.3 Network layouts with pathloss, eNodeBs with different SINR values

The SINR map after the application of pathloss as shown in Fig. 4.3 represents the distribution of SINR for the whole ROI. High SINR values, as expected, are observed in the region closer to the eNodeBs and hence excellent quality of service is assured for UEs present in this region. The value of SINR

decreases with the increase in distance from eNodeB towards the edge due to increased pathloss and high interference from neighboring cells. To sum up, edge users experience poor SINR and hence poor quality of service.

As shown in Fig. 4.4, a clear degradation in throughput of the total macro network is observed with increasing percentage of indoor users. This decreasing trend in the throughput is in accordance with eq. 1 as the indoor users at the edge have lower SINR value shown in Fig. 10, which leads to the lower capacity and hence lower throughput. Fig. 4.4 represents the percentage decrease of total network throughput with percentage increase of indoor users.

Currently the indoor traffic makes up about 70% [9] of the overall traffic which in coming years is expected to increase and is the cause of the increased data volume. Statistically speaking, the behavior of the network around this percentage becomes hugely important. From Fig. 4.4 we observe a degradation of about 35% to 45% in the macro network throughput when the indoor users increase from 70% to 90%. From an operator's point of view, almost half of the macro network throughput is lost due to indoor users [8] which are a point of concern to meet quality of service requirements and to compete in the ever growing market.

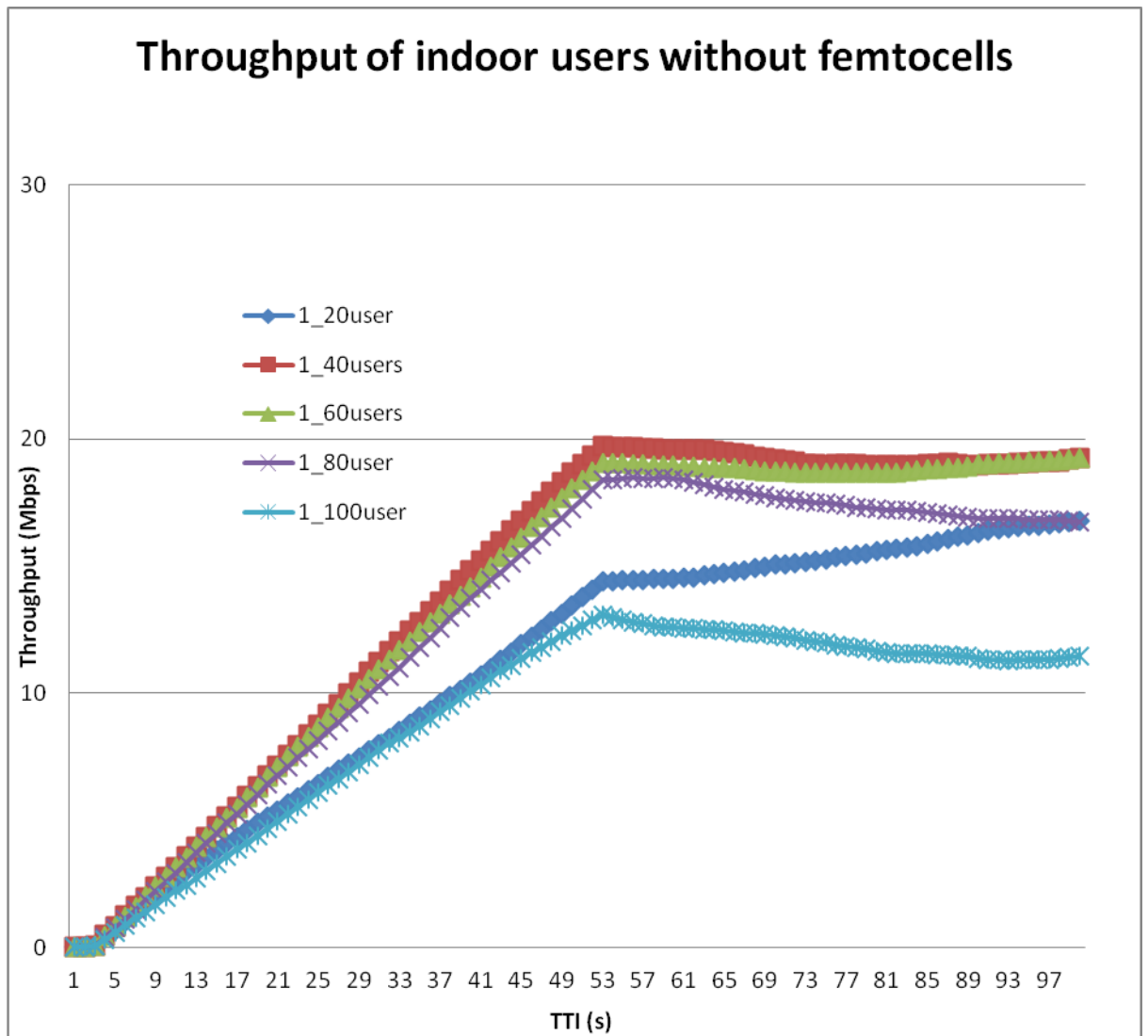


Figure 4.4 Throughput of indoor users without femtocells

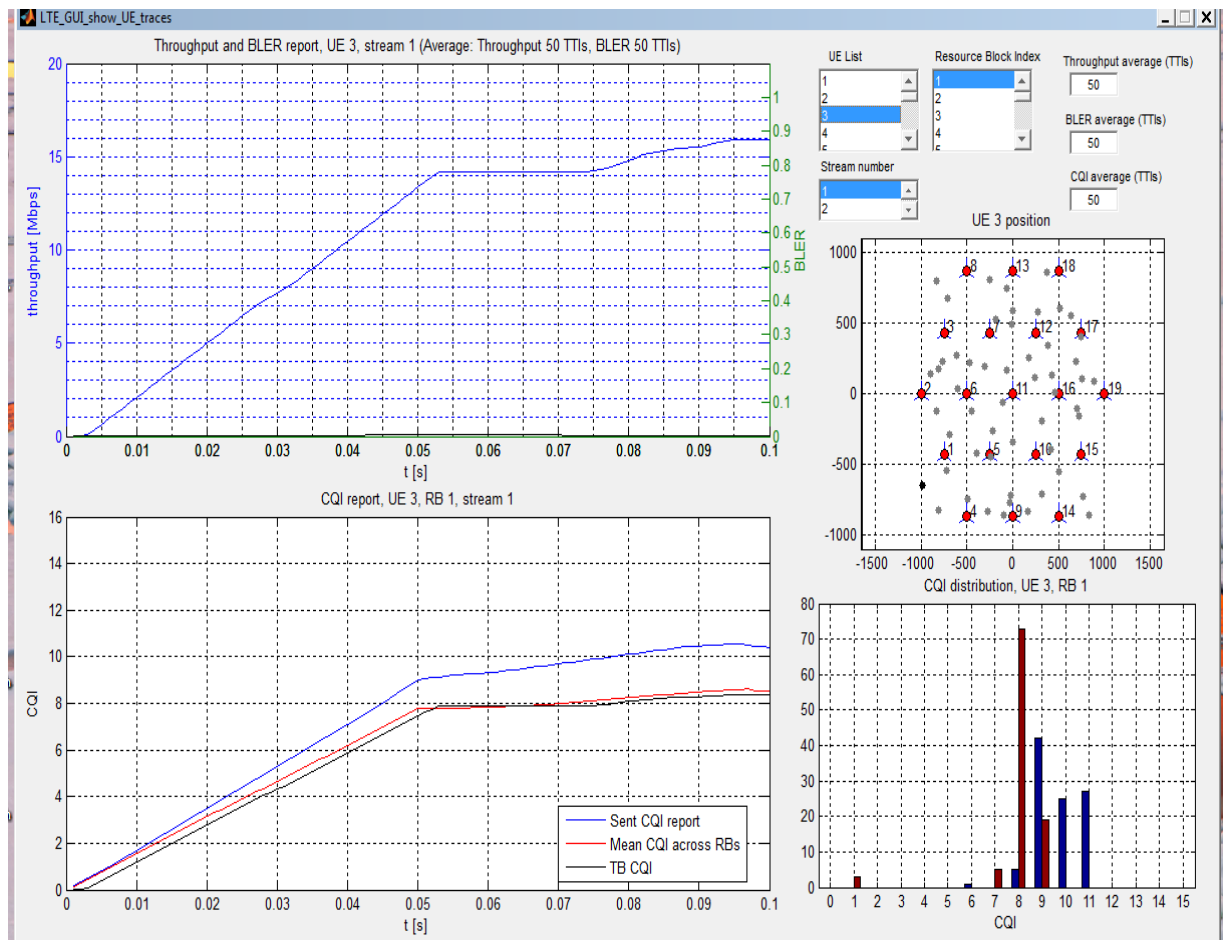


Figure 4.5 LTE GUI show UE traces without femtocells

Figure 4.5 above illustrate LTE Geographical User Interface GIU to show UE throughput in Mbps for the selected stream and UE depicts in blue line in the upper left graph; in the plot it appear to be about 15 Mbps before deployment of the femtocell. Also the system shows the UE position in the Region Of Interest (ROI).

In the same plot also the simulator shows the sent Channel Quality Indicator (CQI) report for the selected RB and stream (blue), mean CQI for the whole frequency band (red) and CQI of the Transport Block (TB) sent to the UE, if scheduled.

Also we can see the distribution of the CQIs for the selected UE and Resource Blocks (RB) during the simulation time (blue), and of the TB CQIs (red).

4.6 Dense Deployment of Femtocells:

Basic simulation parameters for femtocells are summarized in Table 4.2. Femtocell is using single transceiver and its antenna gain is 5 dBi. One femtocell serves about 8 users [10]. The effective coverage of a femtocell is 10 meter in radius. The same setting is ensured for all femtocells.

As previously mentioned that number of users per sector is 10 so total of 210 users exist in the whole macro network. We need a total of 27 femtocells in order to accommodate all the indoor users (8 user/femtocell). Main parameters for femtocells are assigned according to Table 4.2 [15], [16].

Table 4.2 Basic parameters for femtocells environment

| Parameter | Value |
|--------------------------------|----------------------------------|
| Frequency | 2.1 GHz |
| Receiver noise figure | 9 dB |
| System Bandwidth | 20MHz |
| Thermal noise density | -174 dBm/Hz |
| Lognormal Shadowing | 10dB |
| Cell Radius | 10 m |
| UE Power | 23dBm |
| Macroscopic pathloss | $128.1 + 37.6 \log_{10}(R)$ [15] |
| Average Number of UEs per Cell | ≈ 8 users |
| HeNodeB TX Power | 21 dBm [14] |
| Penetration Loss | 20dB |
| UE speed | 5 Km/h |
| BS antenna gain | 5 dBi [14] |
| Traffic type | Full buffer Traffic |
| Cell Layout | Circular cell , 1sectors/HeNodeB |

4.7 Simulation Results

The total aggregated throughput of all femtocells is computed against the increased percentage of indoor users as shown in Fig. 4.6. It is clearly shown that the aggregated throughput is increasing almost linearly by increasing the percentage of indoor users. When more users move indoor, the traffic on macrocells offloads; this offloaded traffic is efficiently served by the operational femtocells, which results in getting maximum aggregated throughput. Hence better QoS is ensured. Comparing to our previous scenario, in the absence femtocells, users were facing poor quality of signals from eNodeBs due to cell edge and extra indoor penetration loss of 20 dB so the aggregated throughput was also degraded.

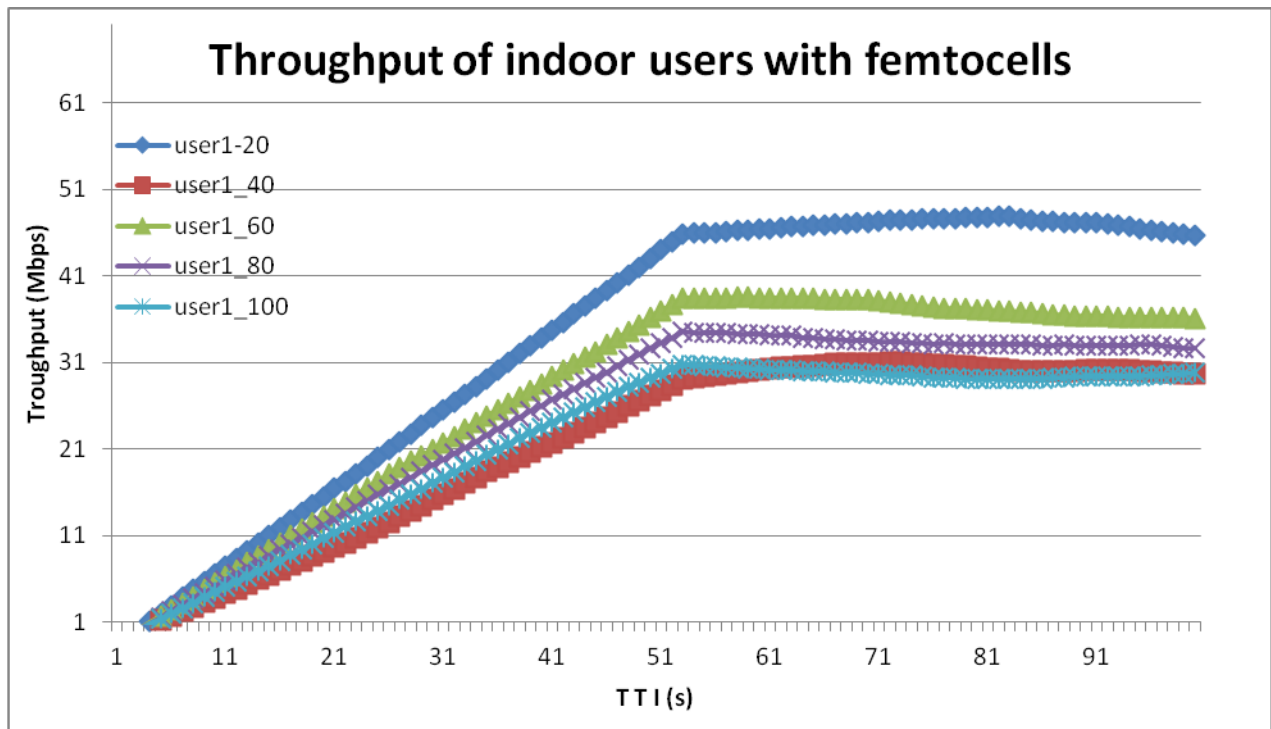


Figure 4.6 throughputs of indoor users with femtocells

When number of users being moved indoor is increased, the total aggregated throughput of the macro network is also increasing. The reason is that now indoor users are being served by femtocells and getting good SINR by the serving femtocells. A clear difference in throughput is shown in the figure 4.6 which is basically depicting the offloading behavior of femtocells. The figure is rather giving a clear picture and showing the increase in percentage. Here the maximum peak value of macro network throughput is 75% when the indoor users reach to 80%. The percentage increase or decrease shows the difference in general for evaluation purposes.

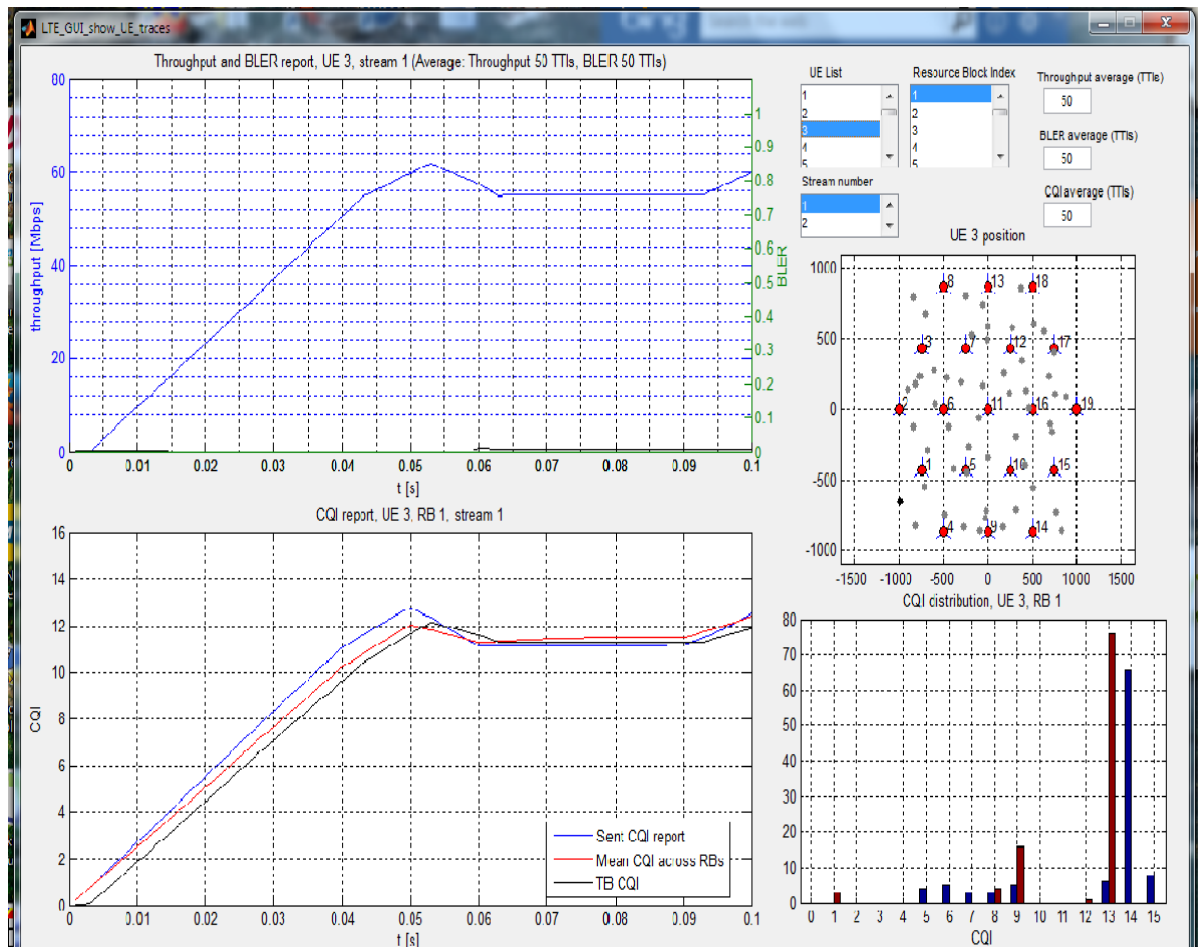


Figure 4.7 LTE GUI show UE traces with femtocells

Figure 4.7 shows the same UE throughput after deployment of the femtocells in the network; now the performance is improved and throughput close to 60 Mbps represent more than 100% comparing to the same UE in figure 4.6.

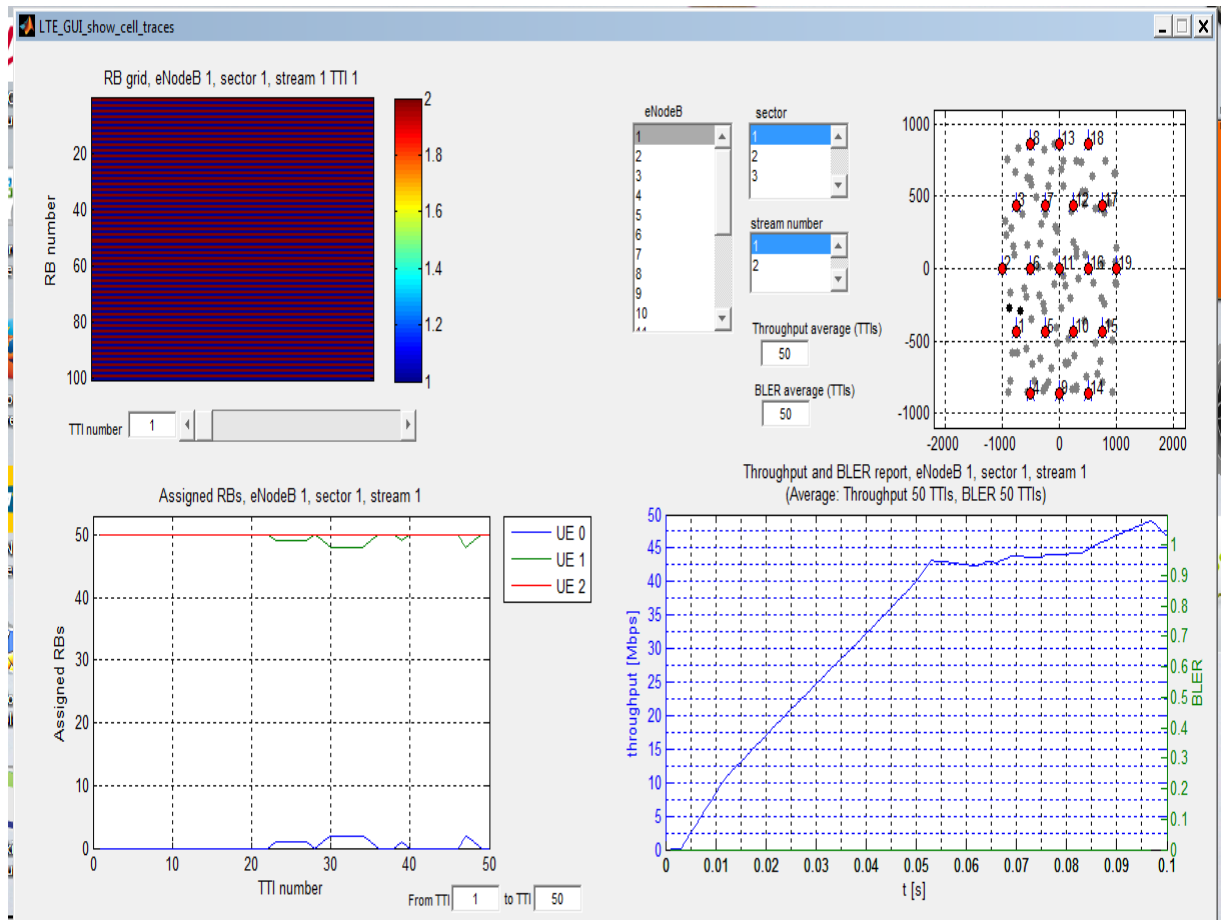


Figure 4.8 LTE GUI show cell trace before femtocells

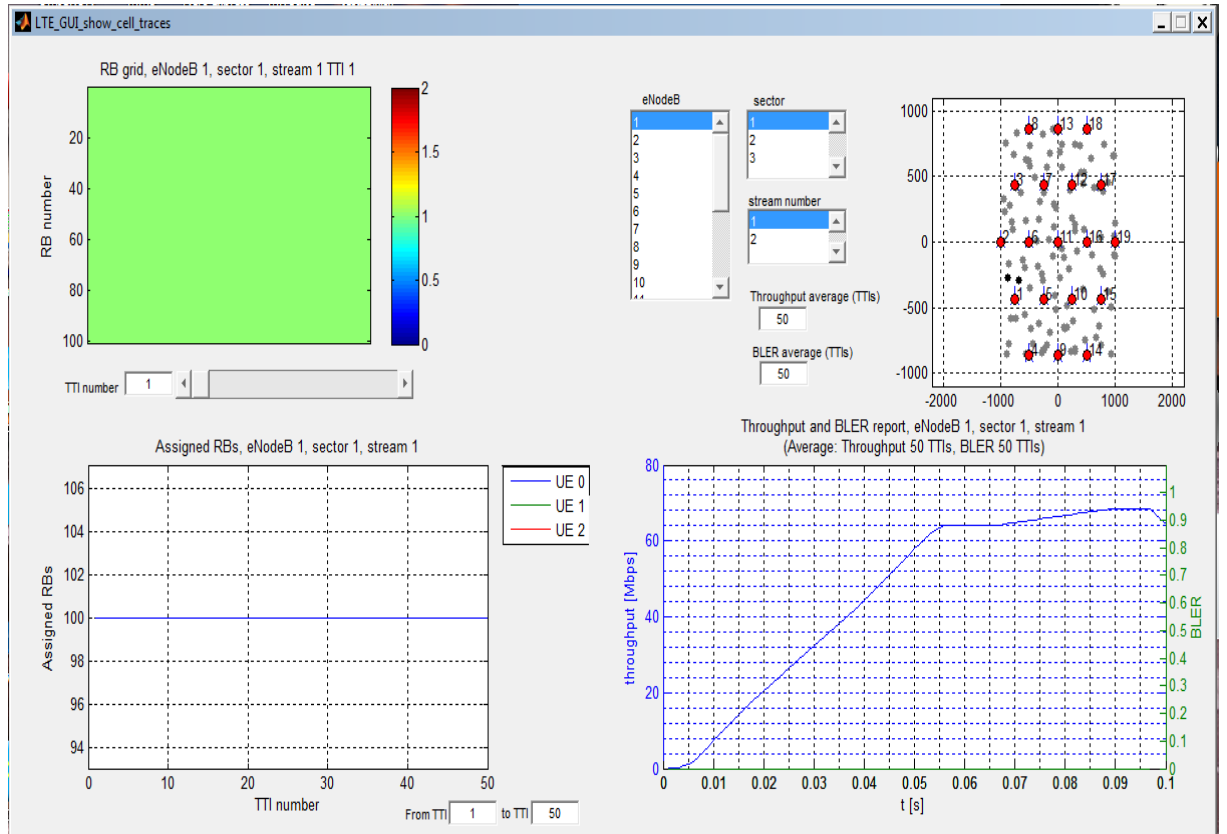


Figure 4.9 LTE GUI show cell trace after femtocells

The above two figures 4.8 and 4.9 illustrate GUI of LTE cells trace throughput and BLER for the selected stream number. Throughput and BLER are averaged using a rectangular window of configurable length. In order to make the post-processing faster, the cell throughput is calculated with the acknowledged (ACKed) data from the UEs instead of checking the throughput of every attached UE. Thus, the uplink delay makes you lose the value for some TTIs.

Fig. 4.10 summarizes a detailed comparison of macro network aggregated throughput for different percentage of indoor users. It basically

shows the required number of operational femtocells for different percentage of indoor users which will effectively offload macro network traffic and leads to high aggregated macro network throughput. This sort of performance evaluation is highly important from business model perspective to network operators.

Operators need to know the effective number of operational femtocells required which effectively offload the increased traffic and to enhance the capacity performance of macrocells. Figure shows when a network contains 50% indoor users, the effective offloading takes place when to serve only 60% indoor users amongst them by femtocells instead of serving 100% indoor users.

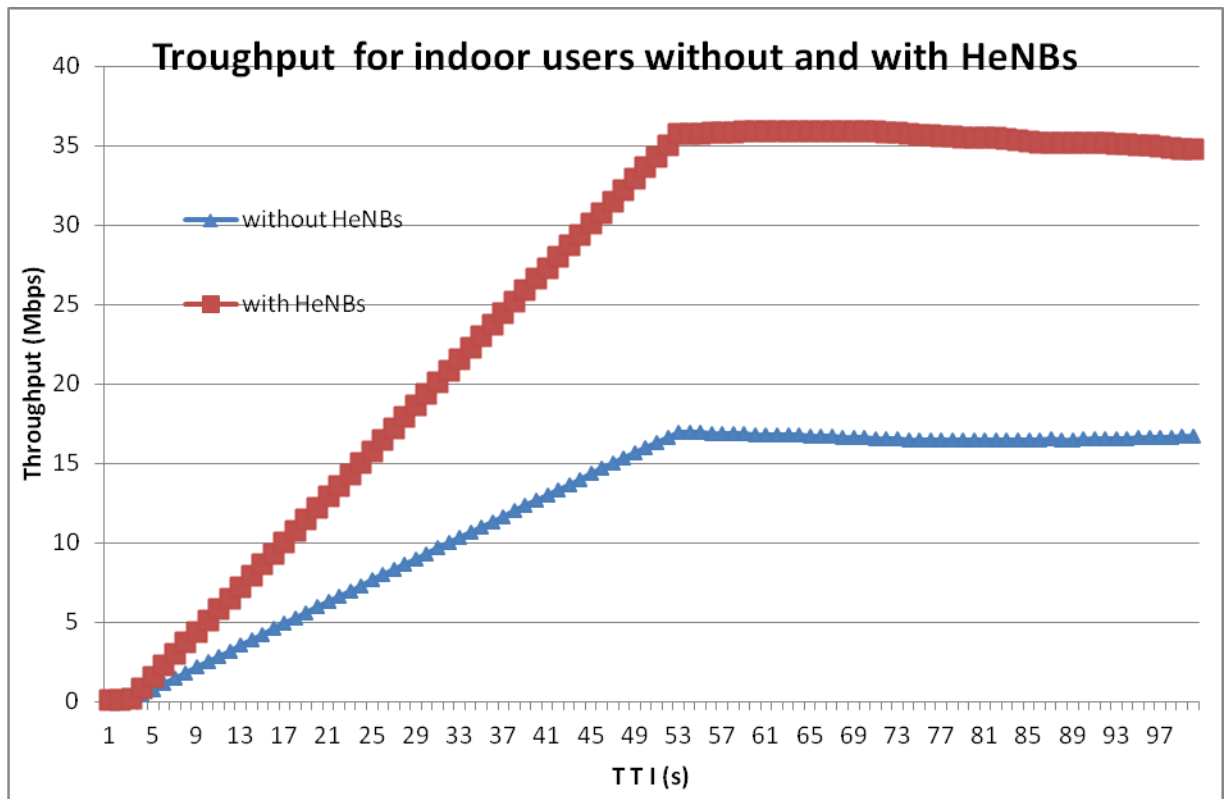


Figure 4.10 Throughput for indoor users without and with femtocell (HeNB)

The effective offloading statistical value is different in case of 40% indoor users, where this value is 45%. Similarly for 70% indoor users, this value is 100%. Interesting point occurs for 90% indoor users for which the favorite value is also 100% instead of 70% as for both the maximum throughput is almost the same, so the desired value for operators is to serve only 50-52%. Finally for 90% of indoor users using HeNBs are double throughput of that without HeNBs. In 100% indoor users' case the throughput change over to femtocells and shows that the macro network is under loaded and all users are now being served by femtocells.

In the previous analysis when there was no femtocell, it is shown that great degradation occurs when indoor users are in deep buildings facing about 20 dB penetration losses.

4.8 Network Costs Analysis:

The annualized network costs (CAPEX + OPEX) of maintaining each macro cell, consists of annual capital loan repayment, costs of associated infrastructure, maintenance costs, site rental costs as well as backhaul costs.

Since femto-cells are customer-premise deployed and have a small footprint, they generally do not incur site rental or energy costs.

Fundamentally, both the macro-cell and femto-cell are designed to support some given number of users. Hence, the number of cells that need to be deployed will depend on the number of active users in a given area which will leads to improve capacity and changing user traffic demands by using several modulation techniques to modulate data and control information. These modulation techniques include: QPSK (2 bits per symbol), 16 QAM (4 bits per symbol), and 64 QAM (6 bits per symbol).

A modulation technique is selected based on the measured Signal to Interference plus Noise Ratio SINR. Each modulation scheme has a threshold SINR. Subscribers located farther from the eNodeB and deep indoor buildings facing more attenuation (with lower SINR values) use a more robust modulation scheme (lower throughput), while subscriber closer to the eNodeB or indoor users having femtocells or HeNB (with higher SINR values) can use less robust modulation scheme (higher throughput)

Both the eNB and the UE measure signal quality using the Reference Signal, this signal carry a known (pseudo-noise) bit pattern at a boosted power level.

The eNB always controls and selects the modulation and coding scheme for both the downlink and uplink.

With LTE products becoming commercially available, the decision on the right timeframe will depend on several factors unique to each operator and market such as:

- Capacity growth rate as the traffic per subscriber and number of connections increases

- Spectrum availability and regulatory environment
- Service provisioning strategy
- Availability of suitable backhaul options
- Competitors' movements

4.8.1 Cost per bit:

One of the main goals for LTE was to reduce the network cost per bit as the data traffic growth is outpacing the corresponding growth in revenue.

The number of simultaneous users supported on each femtocell is typically between 4 and 32. Management of the femtocells is shared by the operator (for mobile network related parameters using a TR-069 system) and the enterprise (e.g. to control user access to enterprise applications via the femtocell).

Network capacity could be improved by adding cell sites to the congested areas. The traffic distribution depends on the network deployment, country geography and number of users. Typically, more users lead to a more equal traffic distribution between sites. Traffic is also not equally distributed over a 24 hour period.

Depending on the configuration, including backhaul, no site rental, power consumption and radio network software and hardware maintenance; the cost per bit in the femtocells will be reduced and in low price or tariff.

The cost of delivering a gigabyte of data per subscriber can be less in tariff if total data use is high enough. LTE networks can lower the cost per bit, especially when macrocells spectrum is fully utilized, because adding LTE capability to existing sites costs much less than adding new macrocells sites. However, for this to be viable, sufficient LTE terminal penetration is needed to drive traffic onto the LTE network.

CHAPTER (5)

FUTURE WORK AND CONCLUSION

The analysis of LTE based network roll-out demonstrates that the macro network capacity drops by about 45% for 90% of users being indoors. This high amount of indoor users is very typical for LTE users. A further analysis needs to be performed in order to estimate the business perspective for mobile and fixed operators.

5.1 Conclusion:

In order to meet the requirements of high bandwidth consuming applications and devices, paradigm shift towards high frequencies is foreseen. The increasing network traffic, whose most part is data traffic, is originating from the indoor; to solve this dilemma the thesis used LTE System Level Simulator Tool with required environment such like frequency, system bandwidth, cell radius, eNB transmit power, etc... then the indoor environment is created at the edge of the cells and then UEs are taken indoors from these randomly distributed users, then two scenarios are considered; first indoor users are being increased while no femtocells are deployed, and second one the femtocells deployed indoor and throughput evaluated and obtained acceptable results and the throughput improvement is exceeded 100%.

This explosive growth of indoor data traffic poses a big challenge for the operators in the mature market from capacity and quality of service point of view. Hence in order to sustain the quality of service requirements and ensure high data rates, deployment of femtocells for indoor users with consideration of

optimum number of femtocells can lead to optimization coverage and then offloading the indoor data traffic becomes a necessity.

Deployment of Femtocells in this regard can surely be of great interest to both users and operators providing users with good quality of service and operators with low Capital Expenditure CapEx and Operation Expenditure OpEx while providing the high revenue.

Deducting the running costs such like power, site rental, leasing the wired backhaul connection to the base stations and maintenance; the cost per bit delivered to the users expected to be less in price and tariff comparing to the price in the macrocells.

5.2 Future Work

In future there is expecting to demonstrate the business impact of the mass deployment of indoor base stations. The thesis sees the importance of developing a business model that motivates both the users and the mobile operators to go for a large scale deployment of indoor base stations.

Another area of interest is to mitigate interference created by mass deployment of femtocells, and the future work can include a comprehensive cost model to evaluate the costs of deploying a femtocells network in coverage-limited scenarios. The internal architecture of buildings is not at the present time integrated by any database. Even though this solution could be considered for certain specific buildings in the future.

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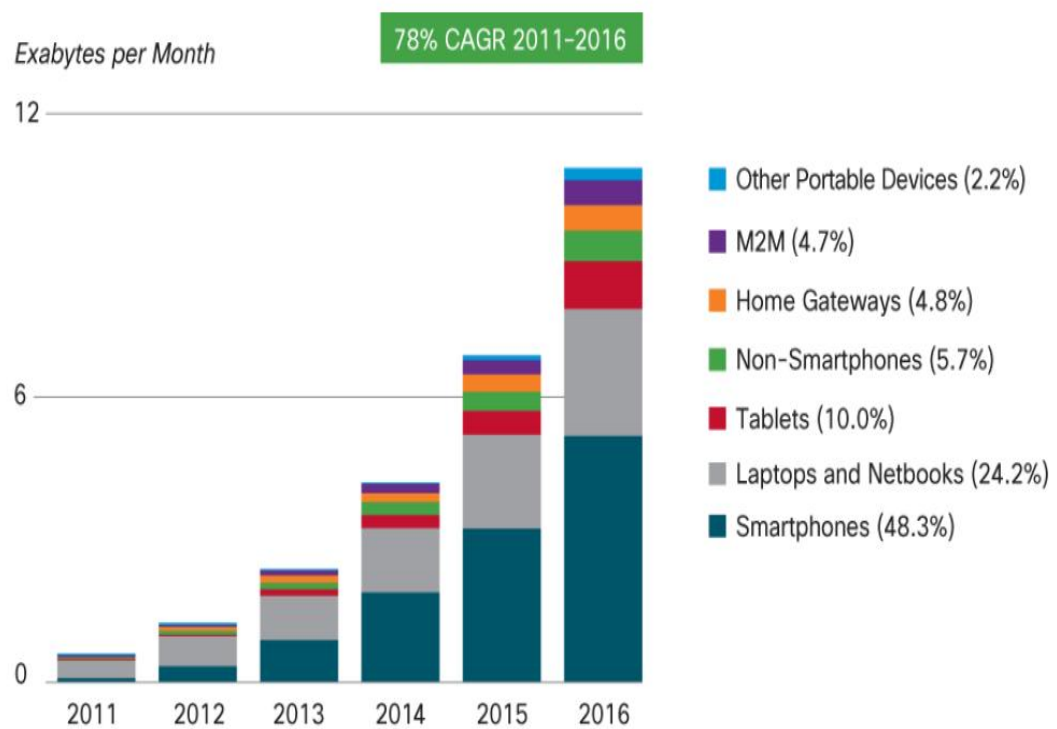
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APPENDIX A



Figures in legend refer to traffic share in 2016.
Source: Cisco VNI Mobile, 2012

Figure 7.1 Smart phones and Laptops Lead Traffic Growth

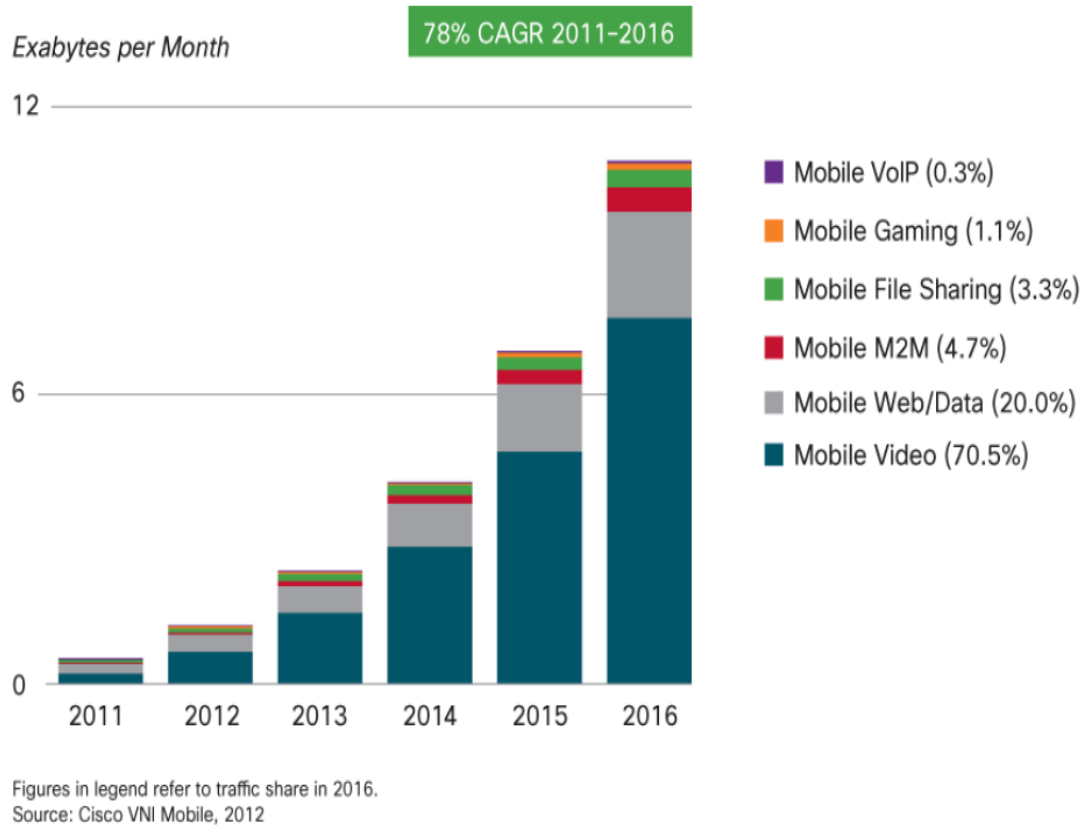
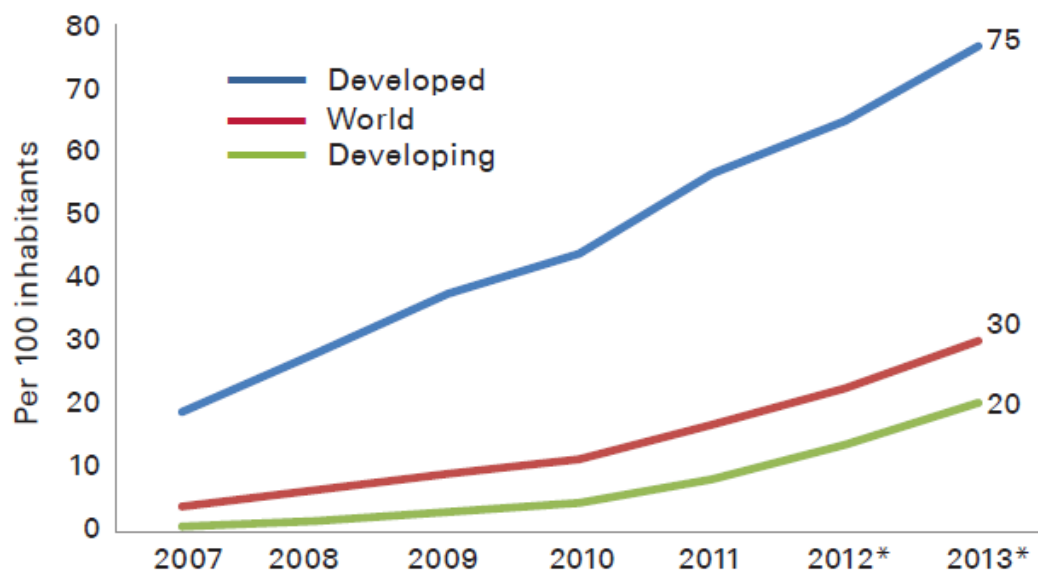


Figure 7.2 Mobile Video Will Generate Over 70 Percent of Mobile Data Traffic by 2016



Source: ITU World Telecommunication /ICT Indicators database

Figure 7.3 Active Mobile Broadband Subscriptions 2007 – 2013*

APPENDIX B

Configured Simulation Parameters

```
% Load the LTE System Level Simulator config parameters
% (c) Josep Colom Ikuno, INTHFT, 2011
% www.nt.tuwien.ac.at

global LTE_config;

%% Debug options
LTE_config.debug_level = 1; % 0=no output
                           % 1=basic output
                           % 2=extended output

%% Plotting options
LTE_config.show_network = 1; % 0= show no plots
                             % 1= show some plots
                             % 2= show ALL plots (moving UEs)
                             % 3=plot even all of the pregenerated fast
fading

%% General options
LTE_config.frequency      = 2.14e9;          % Frequency in Hz
LTE_config.bandwidth      = 20e6;           % Frequency in Hz

LTE_config.UEs_only_in_target_sector = false; % Whether you want UEs to
be places on the whole ROI or only in the target sector
LTE_config.target_sector = 'center';         % 'auto' for specifying
the target sector to be the center one
                                                % a [eNodeB_id sector_id]
vector otherwise
LTE_config.nTX            = 2;
LTE_config.nRX            = 2;
LTE_config.tx_mode        = 4;

LTE_config.always_on      = false; % Controls whether the eNodeB is
always radiating power (dafault and worse-case scenario) or no power is
used when no UEs are attached

%% Random number generation options
LTE_config.seedRandStream = false;
LTE_config.RandStreamSeed = 0;      % Only used if the latter is set to
'true'

%% Simulation time
LTE_config.simulation_time_tti = 100; % Simulation time in TTIs

LTE_config.latency_time_scale = 25; % Number of TTIs used to
calculate the average throughput (exponential filtering)
                                   % See: P. Viswanath, D. Tse and
R. Laroia, "Opportunistic Beamforming using Dumb Antennas", IEEE
Transactions on Information Theory, vol. 48(6), June, 2002.
```

```

%% Cache options. Saves the generated eNodeBs, Pathloss map and Shadow
fading map to a .mat file
LTE_config.cache_network = false;
%LTE_config.network_cache = 'capesso_mka_lte';%'auto';
LTE_config.network_cache = 'auto';
LTE_config.delete_pathloss_at_end = false; % Reduces the amount needed
to store the traces by deleting the pathloss data and shadow fading data
(when present) from the results file
LTE_config.delete_ff_trace_at_end = true; % Reduces the amount needed
to store the traces by deleting the fading parameters trace from the
results file
LTE_config.UE_cache      = false; % Option to save the user position
to a file. This works in the following way:
                                % - cache=true and file exists:
read position from file
                                % - cache=true and file does not
exist: create UEs and save to cache
                                % - cache=false: do not use cache
at all
LTE_config.UE_cache_file = 'auto';

%% How to generate the network. If the map is loaded, this parameters
will be overridden by the loaded map
% Use network planning tool Capesso by placing 'capesso'
LTE_config.network_source = 'capesso';

% Configure the network source. Overridden if a pregenerated network
pathloss map is used.
switch LTE_config.network_source
case 'generated'
    % Network size
    LTE_config.inter_eNodeB_distance = 500; % In meters. When the
network is generated, this determines the
                                % distance between the
eNodeBs.
    LTE_config.map_resolution = 5; % In meters/pixel. Also the
resolution used for initial user creation
    LTE_config.nr_eNodeB_rings = 0; % Number of eNodeB rings
    LTE_config.minimum_coupling_loss = 70; % Minimum Coupling Loss:
the parameter describing the minimum
                                % loss in signal [dB]
between BS and UE or UE and UE in the worst
                                % case and is defined as
the minimum distance loss including
                                % antenna gains measured
between antenna connectors.
                                % Recommended in TS
36.942 are 70 dB for urban areas, 80 dB for rural.
% is

    % Models to choose
    % Available are:
    % 'free space': (more something for testing purposes than to
really use it...)
    % 'cost231'
    % 'TS36942': Recommended by TS 36.942, subclause 4.5
    % 'TS25814': Recommended by TS 25.814 (Annex). The same as in
HSDPA
    LTE_config.macroscopic_pathloss_model = 'TS25814';

```

```

        % Additional pathloss model configuration parameters. Will
depend on which model is chosen.
        % Available options are:
        % 'urban_micro' (COST231)
        % 'urban_macro' (COST231)
        % 'suburban_macro' (COST231)
        % 'urban' (TS36942)
        % 'rural' (TS36942)
LTE_config.macroscopic_pathloss_model_settings.environment =
'urban_macro';

        % eNodeB settings
LTE_config.eNodeB_tx_power = 46; % eNodeB's transmit power, in
Watts.
                                % Recommended by TS.36.814
are:                                % 43 dBm for 1.25, 5 MHz
carrier                                % 46/49 dBm for 10, 20 MHz
carrier

        % Add here cases for other sources (eg. network planning tools)
case 'capesso'
        % Define basic parameters needed also in functions different
from network generation
        % All other parameters defined in
"LTE_init_generate_capesso_network"

        % warning('Check maps resolution when using data from example
maps and Capesso data');
        LTE_config.map_resolution = 5; % In meters/pixel. Use for
default scenario

        LTE_config.manually_set_ROI = false; % If needed, false by
default
        LTE_config.rescale_factor = 1; % Resolution rescale factor for
ROI
        LTE_config.macroscopic_pathloss_model = 'Capesso';
        LTE_config.macroscopic_pathloss_model_settings.environment =
'';

        % eNodeB's transmit power, in Watts -> Read from file

        % Configure Capesso import params
LTE_config.capesso_params.planning_tool =
'capesso';
        LTE_config.capesso_params.pathloss_data_folder =
'./data_files/CapessoExample/pathloss';

        LTE_config.capesso_params.enable_dtm = true;
% 'false' for debugging
        LTE_config.capesso_params.dtm_folder =
'./data_files/CapessoExample/dtm';
        LTE_config.capesso_params.dtm_file_name =
'exampleDTM.bil';
        LTE_config.capesso_params.dtm_hdr_file_name =
'exampleDTM.hdr';

        LTE_config.capesso_params.kathrein_antenna_folder =
'./data_files/KATHREIN_antenna_files/txap';

```

```

        % CapessoExample
        LTE_config.capesso_params.cell_atoll_filename      =
'exampleCluster_Cell.txt';
        LTE_config.capesso_params.site_atoll_filename      =
'exampleCluster_Sites.txt';
        LTE_config.capesso_params.transmitter_atoll_filename =
'exampleCluster_Transmitter.txt';

        LTE_config.capesso_params.rx_height                = 1.5; %
Height of receiver in meter from ground level
        LTE_config.capesso_params.use_default_tilt_value    = false; %
Use common mechanical tilt value for all sites. When not using this
option, values will be extracted from Capesso data
        LTE_config.capesso_params.default_mechanical_tilt    = 0; %
Default mechanical tilt in degree - usage decreases simulation time
significantly
        LTE_config.capesso_params.eNodeB_ROI_increase_factor = 0; %
Increase ROI relative to size

        % Debugging and plotting
        LTE_config.capesso_params.plot_antenna_gain_patterns = 1; % 0
... false, 1 ... true - don't use boolean values
        LTE_config.capesso_params.enable_debug_plotting      = false; %
This is the extended DEBUG plotting for each of the subfunctions. Probably
A LOT of plots!!!
        LTE_config.capesso_params.number_of_sectors          = 3 ; %
Chosen static for now. In the future, an arbitrary number of
sectors/eNodeB may be supported

        % NOTE: are these parameters needed?
        LTE_config.nr_eNodeB_rings = 0; % Number of eNodeB rings
        otherwise
        error([LTE_config.network_source ' network source not
supported']);
        end

        %% Generation of the shadow fading
        LTE_config.shadow_fading_type = 'none'; % Right now only 2D space-
correlated shadow fading maps implemented

        % Configure the network source
        switch LTE_config.shadow_fading_type
        case 'claussen'
            LTE_config.shadow_fading_map_resolution = 5; % Recommended
value for 8 neighbors
            LTE_config.shadow_fading_n_neighbors    = 8; % Either 4 or 8
            LTE_config.shadow_fading_mean           = 0;
            LTE_config.shadow_fading_sd             = 10;
            LTE_config.r_eNodeBs                    = 0.5; % inter-site
shadow fading correlation
        case 'none'
            % do not use shadow fading
            LTE_config.shadow_fading_map_resolution = 5; % Recommended
value for 8 neighbors
            LTE_config.shadow_fading_n_neighbors    = 8; % Either 4 or 8
            LTE_config.shadow_fading_mean           = 0;
            LTE_config.shadow_fading_sd             = 0;
            LTE_config.r_eNodeBs                    = 0; % inter-site
shadow fading correlation

```

```

        otherwise
            error([LTE_config.shadow_fading_type ' shadow fading type not
supported']);
        end

%% Microscale Fading Generation config
% Microscale fading trace to be used between the eNodeB and its
attached UEs.
LTE_config.channel_model.type = 'winner+'; % 'PedB' 'extPedB' --> the
PDP to use
LTE_config.channel_model.trace_length = 30; % Length of the trace in
seconds. Be wary of the size you choose, as it will be loaded in memory.
LTE_config.channel_model.correlated_fading = true;
LTE_config.pregenerated_ff_file = 'auto';
LTE_config.pregenerated_ff_file =
fullfile('./data_files','winner+_2x2_CLSM_20MHz_5Kmph_1s');

% With this option set to 'true', even if cache is present, the channel
trace will be recalculated
LTE_config.recalculate_fast_fading = false;

%% UE (users) settings
% note that for reducing trace sizes, the UE_id is stored as a uint16,
so
% up to 65535 users in total are supported. To change that, modify the
scheduler class.
% When using user density traffic maps
LTE_config.UE.use_traffic_map = false; % Use traffic maps for
user generation
LTE_config.UE.receiver_noise_figure = 9; % Receiver noise figure
in dB
% LTE_config.UE.thermal_noise_density = -131.59; % Thermal noise
density in dBm/Hz (-174 dBm/Hz is the typical value) - use this (-131.59)
for the SISO LL-SL comparison
% LTE_config.UE.thermal_noise_density = -134.89; % Thermal noise
density in dBm/Hz (-174 dBm/Hz is the typical value) - use this (-134.89)
for the MIMO LL-SL comparison
LTE_config.UE.thermal_noise_density = -174; % Thermal noise density in
dBm/Hz (-174 dBm/Hz is the typical value)
LTE_config.UE_per_eNodeB = 1; % number of users per eNodeB sector
(calculates it for the center sector and applies this user density to the
other sectors)
LTE_config.UE_speed = 5/3.6; % Speed at which the UEs move. In
meters/second: 5 Km/h = 1.38 m/s

%% eNodeB options
% LTE_config.antenna.antenna_gain_pattern = 'berger';
% LTE_config.antenna.antenna_gain_pattern = 'kathreinTSAntenna'; %
Additional parameters needed
LTE_config.antenna.antenna_gain_pattern = 'TS 36.942'; % As defined in
TS 36.942. Identical to Berger, but with a 65° 3dB lobe

% LTE_config.antenna.max_antenna_gain = 14; % For a berger antenna
% LTE_config.antenna.max_antenna_gain = 15; % LTE antenna, rural area
(900 MHz)
LTE_config.antenna.max_antenna_gain = 15; % LTE antenna, urban area
(2000 MHz)
% LTE_config.antenna.max_antenna_gain = 12; % LTE antenna, urban area
(900 MHz)

```

```

%% Load the linear approximations to the BICM curves (necessary for
scheduling)
load('./+utils/BICM_k_d_MSE.mat','k','d');
% load('./+network_elements/MI_data/Efficiency_k_d_MSE.mat','k','d');
LTE_config.MI_data.k = k;
LTE_config.MI_data.d = d;

% Additional parameters needed when using 'kathreinTSAntenna'
% This section refers to the generic use of Kathrein antennas without
% having additional information from network planning tool
if strcmp(LTE_config.antenna.antenna_gain_pattern, 'kathreinTSAntenna')
    % Default values used for each site
    LTE_config.site_altitude = 0; % Altitude of site
[m]
    LTE_config.site_height = 20; % Height of site
[m]
    LTE_config.rx_height = 1.5; % Receiver height
[m]
    LTE_config.antenna.mechanical_downtilt = 0; % [°]
    LTE_config.antenna.electrical_downtilt = 6; % [°]
    LTE_config.antenna.kathrein_antenna_folder =
    './data_files/KATHREIN_antenna_files/txap';
    LTE_config.antenna.file_format = 'txap';
    % Kathrein Antenna Type : Extensions possible
    LTE_config.antenna.antenna_type = '742212';
    % LTE_config.antenna.antenna_type = '742215';
    LTE_config.antenna.frequency = 2140;
end

%% Scheduler options
LTE_config.scheduler = 'round robin'; % 'round robin', 'best
cqi', 'max min', configured 'max TP', 'resource fair', 'proportional fair' or
'prop fair Sun'
LTE_config.scheduler_params.k = LTE_config.MI_data.k; % to map from
CQI to spectral efficiency
LTE_config.scheduler_params.d = LTE_config.MI_data.d; % to map from
CQI to spectral efficiency
LTE_config.scheduler_params.av_window = LTE_config.latency_time_scale;
% size of the throughput averaging window
LTE_config.scheduler_params.fairness = 0.5; % fairness for the variable
fairness scheduler
% LTE_config.scheduler_params.alpha = 1; % Additional
configuration parameters for the scheduler (defau
% LTE_config.scheduler_params.beta = 1;
LTE_config.power_allocation = 'homogeneous;'; % 'right now no power
loading is implemented, so just leave it as 'homogeneous'

%% CQI mapper options
LTE_config.CQI_mapper.CQI2SNR_method = 1; % 1 to use less conservative
method to map from CQI back to SNR
% uses the value in the
middle of the SNR interval corresponding to a CQI instead of the lower
boarder value
% this value will just be
used in connection with quantized CQI feedback

%% Uplink channel options
LTE_config.feedback_channel_delay = 3; % In TTIs

```

```

LTE_config.unquantized_CQI_feedback = false;

%% SINR averaging options

% MIESM config
LTE_config.SINR_averaging.algorithm = 'MIESM';
LTE_config.SINR_averaging.BICM_capacity_tables =
'data_files/BICM_capacity_tables_20000_realizations.mat';
LTE_config.SINR_averaging.betas =
[3.85,2.85,0.66,1.04,0.98,1,0.85,0.95,1,0.99,1.02,0.94,1.03,1,1]; % MIESM

% EESM config
% LTE_config.SINR_averaging.algorithm = 'EESM';
% LTE_config.SINR_averaging.MCSs      = [0  1  2    3    4    5    6    7
8    9   10   11   12   13   14   15];
% LTE_config.SINR_averaging.betas    =
[4,3.96,2.77,0.93,1.38,1.44,1.56,3.62,4.73,6.09,11.59,16.35,21.45,26.5,30.
75,33.5]; % EESM

%% Where to save the results
LTE_config.results_folder      = './results';
LTE_config.results_file       = 'auto'; % NOTE: 'auto' assigns a
filename automatically

%% Values that should not be changed
LTE_config.antenna_azimuth_offsett = 30; % This controls the antenna
layout that will be generated. 0 degrees generates hexagonal cells,
% while 30 degrees
hexagonal sectors.

LTE_load_params_dependant;

```


APPENDIX C

Implementation Parameters

Below there is a list of the parameters that can be configured in the `LTE_load_params` file:

A. General parameters:

`_LTE_config.debug_level`: configures how much debug text output is shown. Options are:

- 0: no output.
- 1: basic output.
- 2: extended output.

`_LTE_config.show_network.`: configures how much plots are shown. Options are:

- 0: no plots shown.
- 1: show some plots.
- 2: show all plots, which includes one showing the moving User Equipments (UEs), which may slow down simulations significantly.
- 3: show also the plots of the generated micro scale fading traces.

`_LTE_config.frequency.`: frequency in which the system is operating [Hz].

`_LTE_config.bandwidth.`: system bandwidth. Allowed values are 1.4 MHz, 3MHz, 5 MHz, 10 MHz, 15 MHz, and 20 MHz. This bandwidths are equivalent to 6, 15, 25, 50, 75, and 100 Resource Blocks (RBs) respectively.

`_LTE_config.UEs_only_in_target_sector`: defines whether UEs are created in the whole Region Of Interest (ROI) or just in the target sector. for the case where the UEs are just positioned in one sector, the other transmitters radiate at maximum power, just acting as interferers.

`_LTE_config.target_sector`: if UEs are only to be set in the target sector, this setting specifies which one that is. Set it to center for specifying the target sector to be the center one. [eNodeB_id sector_id] otherwise.

`_LTE_config.nTX`: number of transmit antennas. Used to generate the micro scale fading trace.

`_LTE_config.nRX`: number of receive antennas. Used to generate the micro scale fading trace.

`_LTE_config.tx_mode`: the transmission modes are defined in TS 36.213.

– 1: single antenna.

– 2: Transmission Diversity (TxD).

– 3: Open Loop Spatial Multiplexing (OLSM). Spatial multiplexing with Large Cyclic Delay Diversity (CDD).

– 4: Closed Loop Spatial Multiplexing (CLSM).

– 5: Multiuser MIMO (not yet implemented).

`_LTE_config.seedRandStream`: in order to allow repeatability, it is possible to seed MATLAB's default random number generator. Set it to either true or false.

`_LTE_config.RandStreamSeed`: if the above is set to true, it specifies the seed. Seeds must be an integer between 0 and 232.

_LTE_config.simulation_time_tti: length of the simulation in Transmission Time Intervals (TTIs).

_LTE_config.latency_time_scale: the simulator keeps track of average UE throughput filtered with an exponential window. This averaged throughput is basically used by the proportional fair scheduler to obtain the average throughput.

B. Cache options

_LTE_config.cache_network: whether you want to save the generated eNodeBs, Pathloss map and Shadow fading map to a .mat file. Either true or false. All cache options work in the following way:

- cache=true and file exists: read cache file.
- cache=true and file does not exist: create and then store data in cache file.
- cache=false: do not use cache at all.

_LTE_config.network_cache: the name of the cache file. set it to auto if you want the simulator to assign a name automatically (eg. data_files/network_1_rings_5m_res_TS25814_2.00GHz_freq.mat).

_LTE_config.delete_ff_trace_at_end: since the micro scale fading trace takes up large amounts of space, when doing the final save command, it is preferable to delete it, so as not to have too large result files.

_LTE_config.UE_cache: whether to save the user position to a file. Either true or false.

_LTE_config.UE_cache_file: the name of the cache file. set it to auto if you want the simulator to assign a name automatically

(eg. data_files/UE_cache_1rings_target_sector_only_20UEs_sector_20100301_114247.mat).

C. Network layout and macroscopic pathloss parameters

`_LTE_config.network_source`: Available options

- generated: A hexagonal grid of equidistantly-spaced eNodeB sites with three sectors each will be created.

- capesso: eNodeB position, configuration, and pathloss data are read from data exported from and written from the Capesso TM planning tool (see Section VII). When using this source, shadow fading data is not generated, as the imported pathloss maps should already have it incorporated.

1) Generated network:

`_LTE_config.inter_eNodeB_distance`: in meters. When the network is generated, this determines the distance between the eNodeBs.

`_LTE_config.map_resolution`: in meters/pixel. Also the resolution used for initial user creation.

`_LTE_config.nr_eNodeB_rings`: number of eNodeB rings.

`_LTE_config.minimum_coupling_loss`: describes the minimum loss in signal [dB] between Base Station (BS) and UE or UE and UE in the worst case and is defined as the minimum distance loss including antenna gains measured between antenna connectors. Recommended values [6] are 70 dB for urban areas, 80 dB for rural.

`_LTE_config.macroscopic_pathloss_model`: sets what macroscopic pathloss model is to be used.

Depending on the choice, different choices are available for `LTE_config.macroscopic_pathloss_model_settings.environment`.

The available macroscopic pathloss models are:

- cost231: COST231 pathloss model. The possible options for

LTE_config.macroscopic_pathloss_model_settings.environment are:

_urban_micro: microcell LOS and NLOS pathloss based on the COST231 Walfish-Ikegami model, see TR25.996 and COST 231 book.

_urban_macro: urban macro cell pathloss based on the COST 231 extended Hata model, see 3GPP TR25.996 and COST 231 book.

_suburban_macro: suburban macro cell pathloss based on the COST 231 extended Hata model, see 3GPP TR25.996 and COST 231 book.

log10(R) \square $18 \log{10} (D_{hb}) + 21 \log_{10} (f) + 80$ dB. Where R is the base station-UE separation in km, f the carrier frequency in MHz and D_{hb} is the base station antenna height in metres, measured from the average rooftop level.

Suburban: $L = 69.55 + 26.16 \log{10} (f) + 13.82 \log_{10} (H_b) + [44.9 \square 6.55 \log_{10} (H_b)] \log_{10} (R) \square 4.78 (\log_{10} (f))^2 + 18.33 \log_{10} (f) \square 40.94$. Where R is the base station-UE separation in km, f the carrier frequency in MHz and H_b is the base station antenna height above ground in metres.

– TS25814: see [7] for more information. $L = I + 37.6 \log_{10} (R)$. Where R is the base station-UE separation in km and I = 128.1 when using a 2 GHz carrier and I = 120.9 for 900 MHz.

_LTE_config.eNodeB_tx_power: eNodeB's transmit power, in Watts. Recommended are:

– 43 dBm for 1.25, 5MHz carrier

– 46/49 dBm for 10, 20MHz carrier.

D. Shadow fading (only for generated networks)

_LTE_config.shadow_fading_type:

– clausen: It generates a lognormal-distributed 2D space-correlated shadow fading map.

– none: No shadow fading map. For simplicity reasons this is implemented as a shadow fading map with a constant value.

_LTE_config.shadow_fading_map_resolution: map resolution for the shadow fading pathloss map (metres/pixel).

_LTE_config.shadow_fading_n_neighbors: specifies the number of neighbors the algorithm takes into account when space-correlating the shadow-fading maps. Possible options are 4 and 8, which use R5 and R9 [9] respectively.

_LTE_config.shadow_fading_mean: mean (__) of the lognormal distribution.

_LTE_config.shadow_fading_sd: standard deviation (__) of the lognormal distribution.

_LTE_config.r_eNodeBs: inter-site shadow fading correlation. The correlation between the sectors in a site is fixed to 1 (same shadow fading map).

E. Microscale fading

Microscale fading trace to be used between the eNodeB and its attached UEs.

_LTE_config.channel_model.type: which PDP to use for the channel generation. Available options are:

– PedA: ITU Pedestrian A channel [10].

– PedB: ITU Pedestrian B channel [10].

– extPedB: Extension of the ITU channel models for wideband (OFDM) systems.

– VehA: ITU Vehicular A channel [10].

– VehB: ITU Vehicular B channel [10].

`_LTE_config.channel_model.trace_length`: length of the channel trace in seconds. Be wary of the size you choose, as it will be loaded in memory.

`_LTE_config.pregenerated_ff_file`: where to save the channel trace. If the specified file exists, it will be loaded.

For the auto or inexistent filename cases, a new trace will be generated.

e.g. `ff_60.0s_2x2_PedB_5.0MHz_5Kmph_20100205_121257`.

`_LTE_config.channel_model.correlated_fading`: true or false. Activates or deactivates the channel time correlation.

`_LTE_config.recalculate_fast_fading`: whether generate the trace even if the file already exists (force a new trace).

F. UE settings

`_LTE_config.UE.receiver_noise_figure`: receiver noise figure in dB. Set to 9 dB.

`_LTE_config.UE.thermal_noise_density`: thermal noise density in dBm/Hz.

`_LTE_config.UE_per_eNodeB`: number of UEs per sector.

`_LTE_config.UE_speed`: speed at which the UEs move. In meters/second.

`_Traffic map related parameters`: Related to the importing of Capesso-generated maps. See Section VII for a detailed explanation of the parameters.

G. eNodeB settings

`_LTE_config.antenna_gain_pattern`: gain pattern of the antenna attached to each sector. Only valid for generated networks. For Capesso-imported networks, these values are not used, as they are read from the cell description files.

Available options are:

– berger: $A(_) = \square \text{ min}$

– TS 36.942: $A(_) = \square \text{ min}$

– KathreinTSAntenna: Antenna pattern to be read from an antenna pattern file. It needs of the following parameters:

_LTE_config.site_altitude: Altitude of site (terrain altitude) [m]

_LTE_config.site_height: Height of site [m].

_LTE_config.rx_height: Receiver height [m].

_LTE_config.antenna.mechanical_downtilt: Antenna mechanical down tilt [°].

_LTE_config.antenna.electrical_downtilt: Antenna electrical down tilt [°].

_LTE_config.antenna.kathrein_antenna_folder: Folder to scan for the antenna pattern files.

_LTE_config.antenna.file_format: either msi or txap, depending on the format of your antenna pattern files.

_LTE_config.antenna.antenna_type: The name of the antenna you want to use. e.g. '742212'.

_LTE_config.antenna.frequency: The frequency at which the pattern should be used [MHz]. It is not automatically set to the frequency being used because it could happen that all you are interested is the pattern itself, not whether it would correspond with the actual frequency used.

_LTE_config.mean_antenna_gain: antenna gain, in dB. Recommended values are: 15 dBi (rural area 900 MHz, urban area 2 GHz) and 12 dBi (urban area 900 MHz).

_LTE_config.scheduler: the type of scheduler to use. Supported schedulers are round robin, best cqi (Max C/I), and proportional fair. Please note that the proportional fair scheduler has not been thoroughly tested and may be buggy.

_LTE_config.power_allocation: only homogeneous is supported right now. H. Uplink channel options

_LTE_config.feedback_channel_delay: uplink delay in TTIs. When set to 0 TTIs, only the Channel Quality Indicator (CQI) reports experience zero delay. ACK reports have a minimum delay of one TTI.

_LTE_config.unquantized_CQI_feedback: there is an option to send unquantized feedback, which is de-facto sending the measured Signal to Interference and Noise Ratio (SINR), as then afterwards the CQI is not mapped.

I. SINR averaging

_LTE_config.SINR_averaging.algorithm: what subcarrier averaging algorithm is to be used. For each option, the specific configuration parameters will vary. Possible options are [12]:

– EESM: use Exponential Effective Signal to Interference and Noise Ratio Mapping (EESM).

The following configuration parameters are needed:

_LTE_config.SINR_averaging.MCSs: the Modulation and Coding Schemes (MCSs) defined.

_LTE_config.SINR_averaging.betas: the calibration _ parameters that fit the EESM function to the Additive White Gaussian Noise (AWGN) Block Error Ratio (BLER) curves.

– MIESM: use Mutual Information Effective Signal to Interference and Noise Ratio Mapping (MIESM). Please note that MIESM has not yet been thoroughly tested with the simulator. Some bugs may be present. A .mat file containing the Bit Interleaved Coded Modulation (BICM) capacity tables for the relevant modulations and bit mappings must be provided. One is included with the simulator:

`_LTE_config.SINR_averaging.BICM_capacity_tables`: location of the BICM capacity tables.

One is already provided: `data_files/BICM_capacity_tables_10000_realizations.mat`.

J. Saving of the results

`_LTE_config.results_folder`: folder where to save the results.

`_LTE_config.results_file`: results filename. auto assigns a filename automatically.

eg. `2.00GHz_freq_5.00_bw_200TTIs_20100304_103218_proportional_fair_r230.mat`.

K. Values that should not be changed

`_LTE_config.RB_bandwidth`: Bandwidth of a RB. 180 KHz and should not be changed. It basically used for throughput calculations.

`_LTE_config.TTI_length`: length of a TTI (subframe) in seconds.

`_LTE_config.cyclic_prefix`: set to normal. It is used to calculate the number of available bits in each subframe, so it will not realistically reflect the effect of using another cyclic prefix length.

`_LTE_config.maxStreams`: maximum number of codewords per TTI. Set to two.

L. Optional configuration parameters

The following parameters, to allow for backwards-compatibility, are optional. If you do not specify them, they will take a default value, which is described here.

`_LTE_config.always_on`: If no UEs are attached to the eNodeB, when set to false, the eNodeB will not radiate power. i.e. not generate interference (see `_LTE_config.signaling_ratio` also). Defaults to true.

`_LTE_config.traffic_map_upscaling`: When specifying traffic maps, this value up scales the traffic map. i.e. it allows you to test a UE density distribution and then upscale it without needing to generate a new map. Defaults to 1 (no up scaling).

`_LTE_config.delete_pathloss_at_end`: To save some space, if set to true, it will delete the pathloss maps from the results file. Defaults to false.

`_LTE_config.additional_penetration_loss`: It allows you to set an additional amount of macroscopic pathloss that will be applied, in addition to the set maps. Useful to add an indoor or similar pathloss to the UEs. Defaults to 0.

It also accepts the following strings as inputs, which are equivalent to the following values:

– deep indoor: 23 dB

– indoor: 17 dB

– incar: 7 dB

– outdoor: 0 dB

`_LTE_config.output_filename_suffix`: Allows you to specify a suffix that will be appended to the end of the simulation results file. Defaults to '' (empty string).

`_LTE_config.signaling_ratio`: Allows you to set a ratio of power that is to be dedicated non-data channels. It is set to simulate pilots and other control channels that, even if no UE is attached, would continue to be sent. i.e. a ratio of the total power which is always radiating and interfering other neighboring eNodeBs. Must be between 0 and 1. Defaults to 0.