CHAPTER V
SIMULATION MODEL

This section presents the simulation model which is considered as Macro-femto cell deployment (heterogeneous LTE Network) and focuses on main parameters used in the simulation model

5.1 SIMULATION NETWORK LAYOUT

We consider a heterogeneous LTE network deployed according to the models described in [29] and in line with [25]. 19-hexagonal macrocell are dropped with an inter site distance (ISD) of 500m. Each macro node cell site includes three cells (sectors) with antenna boresights pointing in the three horizontal directions separated by 120 degrees as shown in figure 5.1.

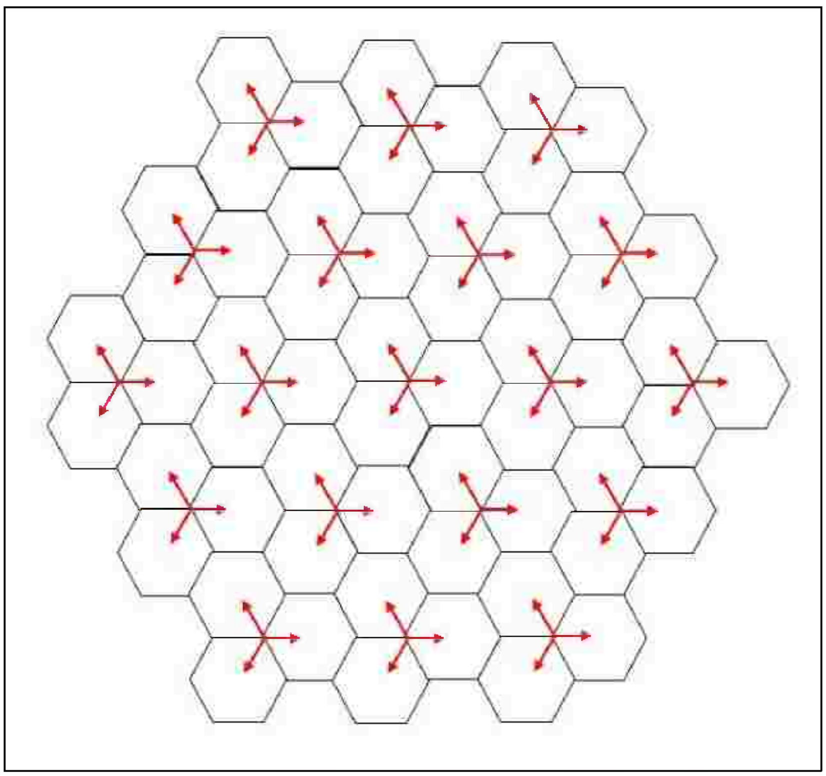

Figure 5.1 Network Layout

25 macro UEs are dropped randomly following a uniform distribution within the cell site area. Dual strips model of HeNBs are randomly dropped in each cell, dual strips are composed of two building separated by one strip as shown in figure 5.2.

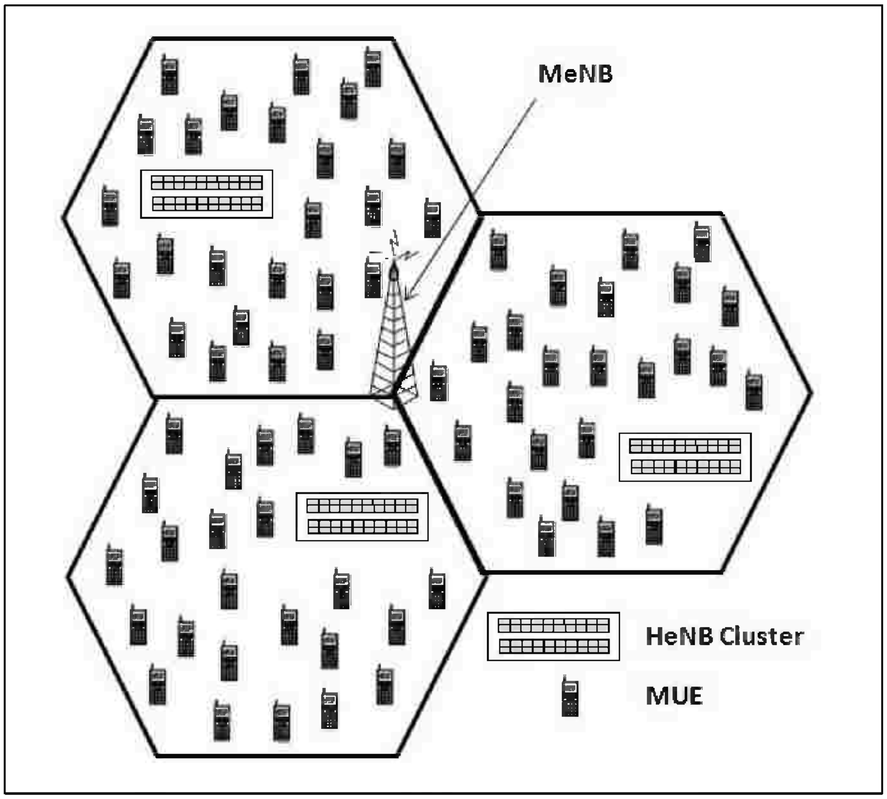

Figure 5.2 Cell site area

Each building is composed of 10x2 apartments; the apartments are 10mx10m as shown in figure 5.3. Only single-story buildings are considered. For simplicity, we assume that all HeNBs are perfectly synchronized in both time and frequency domain among each other as well as with the macro sectors. For each apartment, a biased coin toss is carried out to decide whether a femto is deployed within that apartment or not. If it is, HeNB and an associated UE are dropped in random locations within the apartment. The bias factor in the coin toss is determined by the product of penetration factor and activity ratio, and in this paper the value 0.2 is used

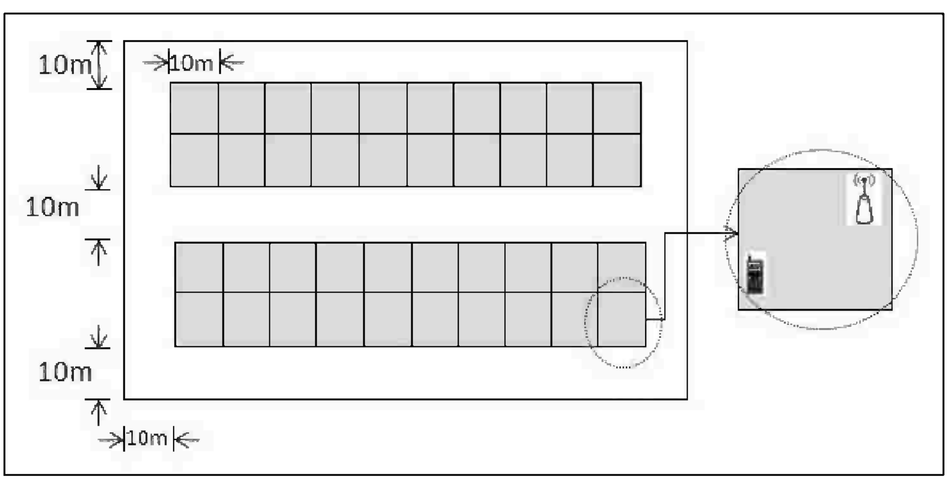

Figure 5.3 Dual Strip Cluster [25]

5.2 HETEROGENEOUS SIMULATION PARAMETERS

The system bandwidth is 10 MHz; corresponding to 50 RBs (Resource blocks) per subframe. Macro transmission power in each cell equals to 46 dBm. For each cell, 25 macro users are dropped randomly with minimum separation between any user and base station of 35 meters. HeNB and associated HUE are dropped in random location with minimum separation 3 m for each apartment.

HeNB are assumed to be closed subscriber group (CSG) cells. It may be configured with restricted access i.e. only the members of closed subscriber group (CSG) are allowed to access it. We assume two transmit antennas at the eNBs and two receive antennas at the UEs. UEs are assumed to be served using closed-loop spatial multiplexing, also known as transmission mode 4 (TM4) in the LTE terminology.

The maximum HeNB transmission power is 20dBm; most of the HeNBs may have a transmission power remarkably lower than this value as the result of power control. Both macro eNBs and HeNBs, transmit on the same DL channel (i.e., co-channel deployment). A TU-3 radio channel model is used to capture the frequency-selectivity of the channel. The cells are assumed to periodically receive subband channel state information (CSI) reports from all associated UEs. Since the mobile speed is assumed to be very low (3m/s), 5ms reporting periodicity is assumed, which allows a fairly accurate channel knowledge at the eNB side.

Table 5.1 Heterogeneous simulation baseline parameters

Parameter	**Value**
Bandwidth	10 MHz
Cellular Layout	Hexagonal grid
Macro eNB	19 sites, 3 sectors/site
Inter Side Distance (ISD)	500 m
Frequency	2 GHz
Mobile Speed	3 m/s
Macro BS Power	46 dBm
Femto BS Power	20 dBm
Antenna gain	14 dB (macros), 5 dB (femtos), 0 dB (UEs)
Minimum Distance Between MNB and UE	10 m
Outdoor Walls Loss (L_{ow})	20 dB
Indoor Walls Loss (L_{iw})	5 dB
Subcarrier Spacing	15 kHz
Transmission mode	4 (CLSM)
Target block error rate	10%
CQI reporting	5ms (periodic)

The frequency-selective CSI at the eNB side is used by the downlink scheduler, which is based on the proportional fairness (PF) criterion, to come up with scheduling decisions, including which UEs to schedule on each subband and the corresponding modulation and coding scheme (MCS).

We also point out that the throughput results shown in this section account for the LTE physical layer overheads, due to PDCCH (assumed to occupy the first 3 OFDM symbols of each subframe) and the CRS.

5.3 INTERFERENCE SCENARIOS

5.3.1 Indoor to Indoor Interfernce Scenarios

There will be cases of femto-to-femto, and femto-to-macro interference [49]. The femto-to-femto interference can actually happen due to interference stemming from imperfect isolation of apartments. Since a HeNB UE can only associate to the HeNB within the same apartment or to a macro (depending on received power), the interference which coming from neighbor apartments' HeNBs can be strong. Hence, HeNB UEs may also experience outage, even if the propagation characteristics to the HeNB they associate to may be very benign.

The femto-to-macro interference is the case of interference from femtocell BS to nearby macrocell UE. It must be commented that the last one is the most harmful. The reasons are the high transmitted power of the macro UE to reach the macro BS to overcome indoor-to-outdoor propagation path loss, and the high received power from the femto BS by the macro UE in comparison to the power received from the macro BS (outdoors and usually further). Figure 5.4 shows indoor-to-indoor interference scenarios.

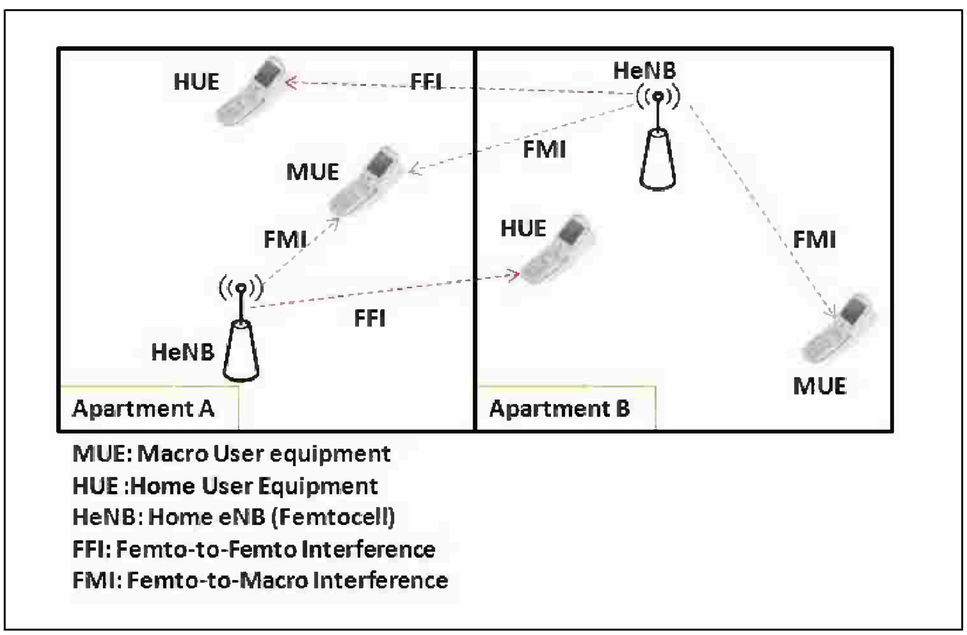

Figure 5.4 Indoor to indoor interference scenario

5.3.2 Indoor to Ourtdoor interference Scenario

There will be a case of femto-to-macro interference; interference from femtocell BS to macrocell user equipment (MUE) as shown in figure 5.5. In closed subscriber group (CSG) femtocells deployed in the same band as the macrocell (co-channel deployment), signals coming from the femtocells will cause downlink interference to nearby macrocell UEs. If this interfering signal is strong enough, dead zones will appear in the macrocell. Dead zones are regions with low pilot Carrier to Interference and Noise Ratio (CINR) due to path loss. The femtocell coverage areas of can be considered as dead zones from a macrocell perspective because macrocell users located in those regions will suffer extremely high noise levels and will not be able to get any service.

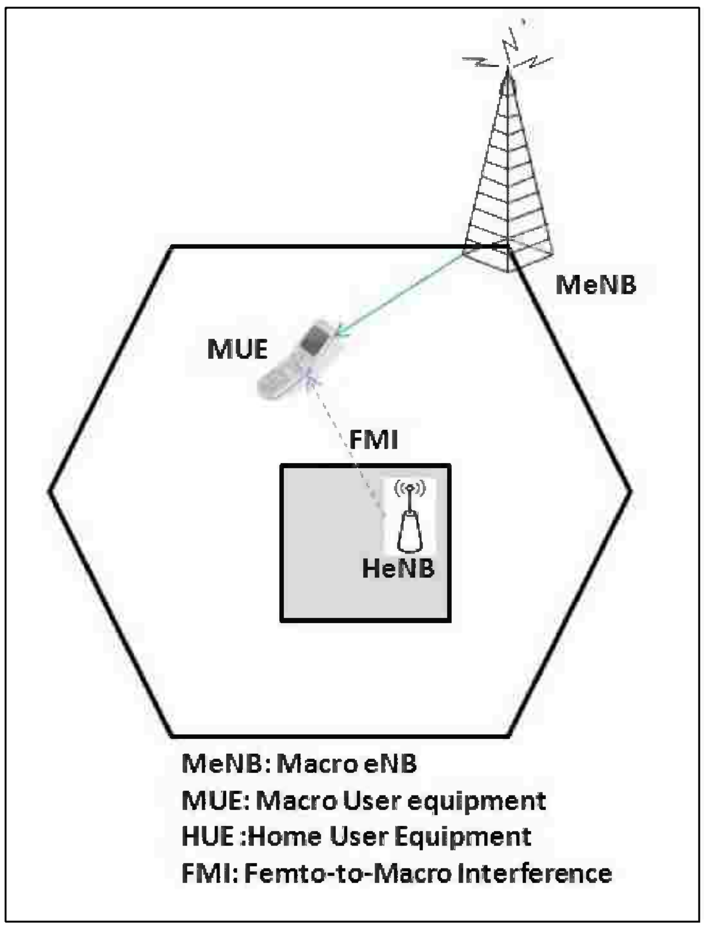

Figure 5.5 Indoor to outdoor interference scenario

5.4 PATH LOSS MODEL

In order to estimate the SINR, we need first to calculate the path loss between a macro BS and User Equipment (UE) and between a femto BS and a UE.

The path loss for various scenarios in an urban area can be determined as follows [29]

Case 1: User Equipment (UE) to Macro eNB

- ***User Equipment (UE) is outside***

Path loss between Macro eNB and User Equipment (UE)

$$PL_{LOS}\ (dB) = 30.8 + 24.2\ \log_{10}(R) \tag{5.1}$$

$$PL_{NLOS}\ (dB) = 2.7 + 42.8\ \log_{10}(R) \tag{5.2}$$

Where R is the distance between the transmitter (T_x) and the receiver (R_x) in meters, and probability of LOS and NLOS is calculated as follows:

$$\text{Prob}(R) = \min\left(\frac{18}{R}, 1\right) * \left(1 - e^{\left(\frac{-R}{63}\right)}\right) + e^{\left(\frac{-R}{63}\right)} \tag{5.3}$$

- ***User Equipment (UE) is inside an apartment***

$$PL_{LOS}\ (dB) = 30.8 + 24.2\ \log_{10}(R) + L_{ow} \tag{5.4}$$

$$PL_{NLOS}\ (dB) = 2.7 + 42.8\ \log_{10}(R) + L_{ow} \tag{5.5}$$

Where R in meters, and L_{ow} is the penetration loss of an outdoor wall. Probability of LOS and NLOS is calculated as follows:

$$\text{Prob}(R) = \min\left(\frac{18}{R}, 1\right) * \left(1 - e^{\left(\frac{-R}{63}\right)}\right) + e^{\left(\frac{-R}{63}\right)} \tag{5.6}$$

Case 2: User Equipment (UE) to Home eNB (HeNB)

- ***Path loss between HeNB and UE in the same apartment***

The path loss between a femto BS and a UE that are in the same apartment stripe are calculated by the following equation:

$$PL\ (dB) = 38.46 + 20\ \log_{10}R + 0.7\ d_{2D,indoor} + q * L_{iw} \tag{5.7}$$

Where R in meters, $d_{2D,indoor}$ is the distance inside the apartment, q is number of walls separating apartments between UE and HeNB, and L_{iw} is the penetration loss of the wall separating apartments.

- ***Path loss between HeNB and outdoor UE***

The case of path loss between an outdoor user and femto BS is calculated by following equation:

$$PL\ (dB) = \max\ (2.7 + 42.8\ \log_{10}R,\ 38.46 + 20\ \log_{10}R) + q * L_{iw} + L_{ow} \qquad (5.8)$$

L_{ow} is penetration loss of an outdoor wall.

- ***Path loss between HeNB and UE in different apartment***

In dual strip model, the path loss where UE is inside a different apartment from femto BS calculated as:

$$PL\ (dB) = \max\ (2.7 + 42.8\ \log_{10}R,\ 38.46 + 20\ \log_{10}R) + q * L_{iw} + L_{ow,1} + L_{ow,2} \qquad (5.9)$$

$L_{ow,1}$ and $L_{ow,2}$ are the penetration losses of outdoor walls for two apartments.

5.5 POWER CONTROL

Transmission power control of CSG HeNBs is a viable way to improve performance of UEs that are affected by strong interference from HeNBs. An autonomous power control method is employed in our simulation based on a variant of the smart power control algorithm described in [24]. The proposed method relies upon measurements at HeNB side and does not require complicated backhaul negotiation among the HeNBs, and thus it could be considered a baseline Release 8/9 interference management technique. The goal is to minimize the interference to the macro network and yet ensure HeNB coverage according to a specific targeted path loss value. Since the path loss value is a design parameter which determines the desired HeNB coverage area, it should be set to the maximum path loss for any link between HeNB and HUE in the same apartment, namely we target a coverage area coinciding with the apartment.

The target pathloss value in simulations is 60dB in the power control formula, and we assessed the sensitivity to this parameter. The maximum transmit power of HeNB is limited to 20dBm, while the minimum transmit power is -10dBm. The following equation represents the power control algorithm applied by the HeNB [25]:

$$P_{TX} = \max\ (\ P_{TXmin}\ ,\ \min\ (P_{TXmax}\ ,\ P_{RX} + PL - \lambda)) \qquad (4.10)$$

Where P_{TX} is HeNB transmission power, P_{TXmin} , P_{TXmax} are the minimum and maximum transmission powers which values are -10 dBm and 20 dBm, respectively. P_{RX} is the power received from the strongest macro (MNB), PL is the assumed pathloss in dB, and λ is the target minimum C/I value in dB. The target is to minimize interference to macro network, while the pathloss determines the desired HeNB coverage; it should be set to maximum pathloss for any link between HeNB and its HUE in same apartment (the value used in simulation is 60dB).

5.6 ALMOST BLANK SUBFRAME

The basic idea is to have some subframe in which femtocell is not allowed to transmit data. This scheme is called almost blank subframe (ABS) [21]. As described in chapter 2, the ABS is TDM (time domain multiplexing) scheme for enhanced inter-cell-interference coordination (eICIC).To alleviate this issue, subframe resources are split among macro and femto cells to improve reliability of both the DL and UL data channels and to allow macro advanced UEs to penetrate deeply within the coverage area of a HeNB while still maintaining connection and reliable communication with the macro node. In this particular example, which reflects the scenario considered in the subsequent throughput simulation results; macro nodes can use all subframes while HeNBs can use only half [50].

This scheme entails a throughput reduction for HeNBs due to the available resources being halved. But on the other hand allows macro UEs to penetrate deeply into femto coverage areas while still maintaining data communication with macro node, provided that the DL scheduler is aware of the subframes partitioning and the channel quality experienced by UEs on the different subframe types. This scheme motivated the design of an updated CQI reporting methodology at the UE, where CQI on the two subframe types are separately estimated and fed back to the eNB.

In this scenario, a macro UE very close to an aggressor HeNB may report a low CQI on the unprotected subframes, where HeNBs is allowed to transmit, and thus will be scheduled on protected subframes only, where HeNBs is silent and the UE is not subject to strong interference. On the other hand, an outdoor UE far enough from all clusters will experience approximately the same channel quality on both subframe types, since the power leaking from HeNBs is negligible, and can therefore be scheduled on any subframe.

5.7 ADAPTIVE MODULATION AND CODING

5.7.1 Link Adaptation

Link adaptation is based on the Adaptive Modulation and Coding (AMC). AMC can adapt modulation scheme and code rate in the following way:

- Modulation scheme: if the SINR (Signal-to-Interference plus Noise Ratio) is sufficiently high, higher-order modulation schemes with higher spectral efficiency (hence with higher bit rates) like 64QAM are used. In the case of poor SINR a lower-order modulation scheme like QPSK, which is more robust against transmission errors but has a lower spectral efficiency, is used.

- Code rate: for a given modulation scheme, an appropriate code rate can be chosen depending on the channel quality. The better the channel quality, the higher the code rate and of course the higher the data rate.

In LTE for data channels a Turbo encoder with a mother code rate of 1/3 is assumed. There is a Rate Matching (RM) module following the Turbo encoder, which makes it possible to get other code rates, if desired. Increasing and decreasing the code rate is done via puncturing and repetition, respectively. Both, puncturing and repetition are integrated in the Rate Matching module of LTE physical layer.

5.7.2 CQI Feedback

The quality of channel is measured in the UE and sent to the eNodeB in the form of so-called CQIs (Channel Quality Indicator). The quality of the measured signal depends not only on the channel, the noise and the interference level but also on the quality of the receiver, e.g. on the noise figure of the analog front end and performance of the digital signal processing modules. That means a receiver with better front end or more powerful signal processing algorithms delivers a higher CQI. The signal quality measurements are done using reference symbols.

Depending on the SNR (Signal-to-Noise Ratio) a combination of modulation scheme and code rate is selected to ensure that the BLER (Block Error Rate) is less than 0.1. This can be seen in Figure.5.6 [8].

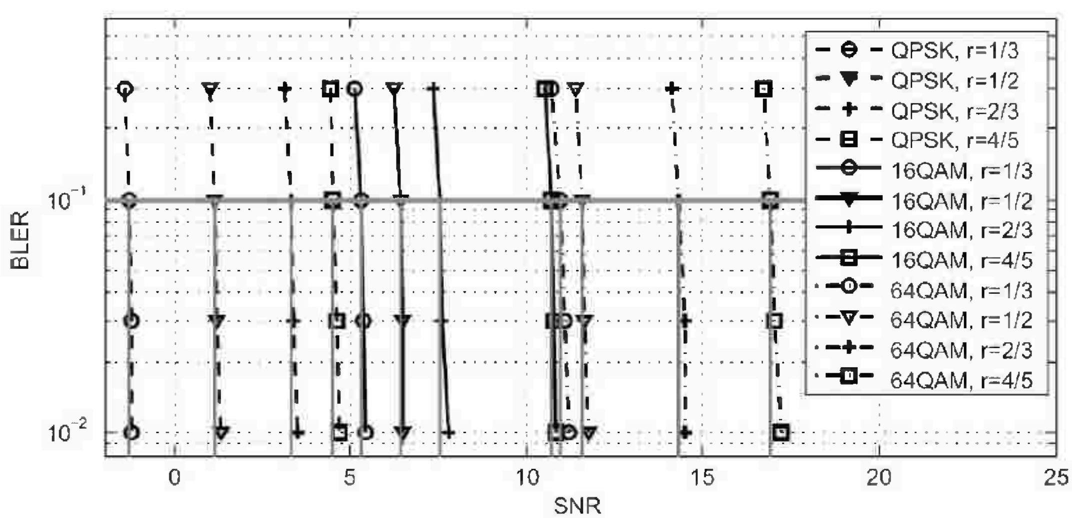

Figure 5.6 BLER versus SNR for various combinations of modulation scheme and code rate [8]

In Table 5.2 a list of 5-bit MCSs corresponding to the 29 possible combinations of modulation scheme and code rate. This table is indexed using a 5-bit index (with some reserved entries).Typically, a higher MCS index offers a higher spectral efficiency which translates to a higher potential data rate but requires a higher SNR to support it. Using curves of BLER versus

SNR from [51], the appropriate MCS index value for a particular channel condition can be determined.

With increasing channel quality, higher order modulation schemes and higher code rates can be selected. The highest order of modulation and highest code rate, which can be selected are 64QAM and 0.925 respectively. In the above discussions it is assumed, that the considered channel is a slow fading channel. In other words, between two CQI measurements, channels behavior does not change or the coherent time of the channel is at least as long as the CQI measurement period.

Here, only the link adaptation for downlink is discussed. The link adaptation in uplink is very similar. The difference is that eNodeB estimates channel quality by evaluating the channel using two types of reference signals (RS), also known as pilots. LTE foresees two types of pilots for the uplink transmission- demodulation reference signal (DMRS) and sounding reference signal (SRS) – which serve different purposes.

- ✓ DMRS
  It is used to determine - with high accuracy - the channel transfer function in the specific resource blocks (RBs) used by a UE for data transmission; it is used for equalization at the receiver.

- ✓ SRS
  It enables the eNodeB to estimate the wideband frequency-domain channel response over a large portion of the system bandwidth, and, thus, enables scheduling.

Table 5.2 5-bit MCS table [51]

MCS	Spectral efficiency	Modulation	Rate	SIR
1	0.305664063	QPSK	0.15283	-4.075
2	0.376953125	QPSK	0.18848	-3.15
3	0.489257813	QPSK	0.24463	-2.075
4	0.6015625	QPSK	0.30078	-1
5	0.739257813	QPSK	0.36963	0
6	0.876953125	QPSK	0.43848	1
7	1.026367188	QPSK	0.51318	2
8	1.17578125	QPSK	0.58789	3
9	1.326171875	QPSK	0.66308	4
10	1.326171875	16QAM	0.33154	4.5
11	1.4765625	16QAM	0.36914	5
12	1.6953125	16QAM	0.42383	5.95
13	1.9140625	16QAM	0.47852	6.9
14	2.16015625	16QAM	0.54004	7.9
15	2.40625	16QAM	0.60156	8.9
16	2.568359375	16QAM	0.64209	9.875
17	2.568359375	64QAM	0.42773	10.1
18	2.73046875	64QAM	0.45508	10.85
19	3.026367188	64QAM	0.50439	11.725
20	3.322265625	64QAM	0.55371	12.6
21	3.612304688	64QAM	0.60205	13.475
22	3.90234375	64QAM	0.65039	14.35
23	4.212890625	64QAM	0.70215	15.25
24	4.5234375	64QAM	0.75391	16.15
25	4.819335938	64QAM	0.80322	17.15
26	5.115234375	64QAM	0.85254	18.15
27	5.334960938	64QAM	0.88916	19.075
28	5.5546875	64QAM	0.92578	19.72
29	5.646	64QAM	0.941	20

5.8 SCHEDULING ALGORITHM

Over the last years many works were published about scheduling in multi-carrier based systems. As it can be read in literature, resource allocation schemes can be divided in two main classes: Margin Adaptive (MA), and Rate Adaptive (RA).

The margin adaptive allocation has the object of minimizing the total transmit power while providing each user with its required quality of service. The object of rate adaptive allocation is to maximize the total data rate of the system taking into account the constraint on the total transmit power.

- *Proportional Fair*:

  Proportional Fair is a compromise between Maximum Rate and Round Robin [52].It pursues the maximum rate, and meanwhile assure that none of terminals is starving. The terminals are ranked according to the priority function. Then scheduler assigns resources to terminal with highest priority. Repeat the last two steps until all the resources are used up or all the resources requirements of terminals are satisfied. The priority function is following

  $$R_{requeted}/\ R_{served} \tag{5.11}$$

  Where $R_{request}$ is the instantaneous requested rate based on SINR and R_{served} is the average served data rate up to the previous TTI.

5.9 SINR ESTIMATION

Each MUE is interfered by all neighboring macrocells and femtocells. Intra-cell interference is eliminated due to the orthogonality characteristics of OFDMA. The downlink signal to interference and noise ratio (SINR) for any MUE served by a sector S in macrocell B can be formulated as follows:

$$SINR_{MUE} = \frac{P_R^{S,B}}{\sum_{b=1}^{19}\sum_{s=1_{s\neq S}}^{3} P_R^{s,b} + \sum_{f=1}^{N_f} P_R^{f}} \tag{5.12}$$

Where $P_R^{S,B}$ is the received power from sector S of serving macrocell B, $P_R^{s,b}$ is the received power from interfering sector s associated with macrocell b, and P_R^{f} is the received power from interfering femtocell f, N_f is number of femtocells.

The power received P_R is directly calculated from the simple formula as follows

$$P_R\,(dBm) = P_T\,(dBm) - P_{TL}\,(dB) \tag{5.13}$$

Where P_T is the macrocell transmission power in dBm and P_{TL} is the total loss encountered by the signal in dB such that

P_{TL} (dB) = P_L (dB) - G_T (dB) (5.14)

Where P_L and G_T are the macroscopic pathloss and transmitting antenna gain in dB respectively.

Similarly, each FUE is also interfered by all neighboring macrocells and femtocells that use the same sub bands assigned to its serving femto BS. The downlink SINR for a FUE served by a femtocell F is:

$$SINR_{FUE} = \frac{P_R^F}{\sum_{b=1}^{19}\sum_{s=1}^{3} P_R^{s,b} + \sum_{f=1_{f \neq F}}^{Nf} P_R^F} \quad (5.15)$$

Where P_R^F is the received power from serving femtocell (F). The theoretical user capacity (bps) for any UE can be formulated as follows (assuming a static AWGN scenario or average SINR in case of fading channels):

$$C_{MUE/FUE} = W \log_2 (1 + SINR_{MUE/FUE}) \quad (5.16)$$

Where W is the total bandwidth of the sub-carriers available for this UE in Hz

5.10 TRAFFIC MODEL

Two FTP (File Transfer Protocol) traffic models are considered as non-full buffer traffic models, Table 5.3 and 5.4 show the parameters for FTP traffic model 1, and model 2, respectively [29].

Table 5.3 FTP Traffic Model 1 [29]

Parameter	**Statistical Characterization**
File size, S	2 Mbytes (0.5 Mbytes optional) (one user downloads a single file)
User arrival rate λ	Poisson distributed with arrival rate λ (1second)

Table 5.4 FTP Traffic Model 2 [29]

Parameter	**Statistical Characterization**
File size, S	0.5 Mbytes
Reading Time (D)	Exponential Distribution, Mean = 5 seconds
Number of users	Fixed

Figure 5.7 and 5.8 illustrate the user arrival of traffic model 1 and 2, respectively. The traffic model employed for these simulations is based on packets of size 2 Mbytes and adaptive Poisson arrivals with average inter-arrival time of 1s.

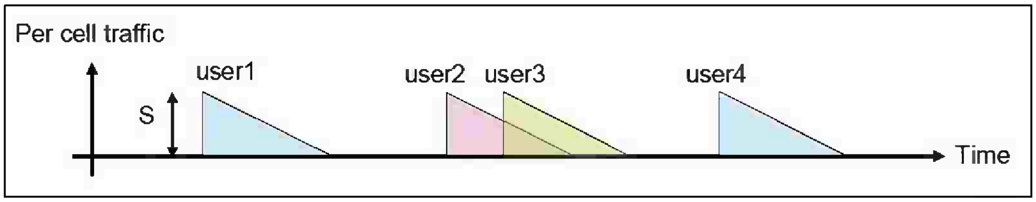

Figure 5.7 Traffic generation of FTP model 1 [29]

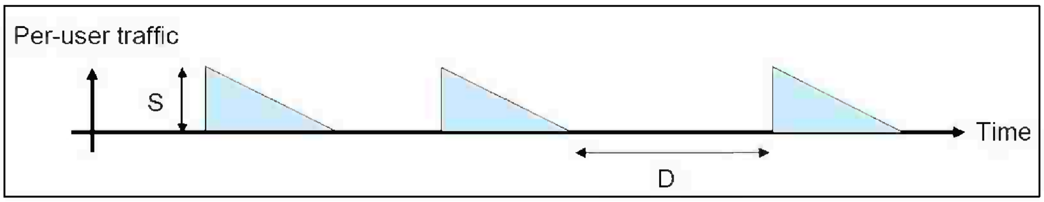

Figure 5.8 Traffic generation of FTP model 2 [29]