Simulation Analysis of the Long Term Evolution

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Abstract. *In this paper a simulation-software is presented, which allows system-level analysis of 3GPP Long Term Evolution (LTE) networks. The application is based on a detailed system-level model of LTE, including scheduling algorithms and MIMO (Multiple Input Multiple Output) operation. The model implemented in the software contains realistic description of a live network. These modelling parameters include the channel models and an IP-level traffic-generator, mobility modelling, OFDM (Orthogonal Frequency Division Multiplexing) operation and adaptive modulation and coding.*

This paper presents the capabilities of the simulator and some numerical results on packet level QoS attained by using different scheduling algorithms.

Keywords

LTE, simulation, MIMO, scheduling, Walfish-Ikegami, SUI

1. Introduction

The first release of LTE standards was issued by 3GPP in 2007. This standard aims higher data rates, quality of services of faster moving mobiles, lower delay between the UE (user equipment) and the network and more efficient and flexible use of the spectrum [1]. The physical layer of the LTE is based on OFDMA (Orthogonal Frequency-Division Multiple Access) scheme. The main advantages of the OFDMA are the simple generation and processing of baseband signal by FFT (Fast Fourier Transformation) and IFFT (Inverse FFT) methods and its resistance to the interference caused by multipath propagation. The system architecture of the LTE is changed with the new notion SAE (System Architecture Evolution). It specifies a new, all-IP based core network and a new access network layout. The RNCs (Radio Network Controller) are gone, and its functions got into the new base station, named eNodeB (Evolved NodeB). The eNodeB is responsible for maintaining the connection between the mobile and the BS, for scheduling and for handover [1].

In our days, in some countries the novel LTE are currently being developed for commercial purposes. A software, that models LTE operation under realistic circumstances, and that is capable of estimating user received QoS is hence very useful for network dimensioning and capacity planning processes. This was the motivation that led to the development of such software. First, the application fits in many aspects of the standard. It applies the physical layer of LTE, MIMO and HHO (Hard Handoff) to achieve full mobility. In addition, there are three implemented scheduling algorithms in the simulator. These are the round-robin, the proportional-fair and the Max-C/I. Secondly, it tries to model the traffic of the cellular networks and the characteristic of the radio channel, hence, the program includes a traffic generator and two channel models: the SUI (Stanford University Interim) model, which is recommended through OFDM (Orthogonal Frequency-Division Multiplexing) and the COST-231 – Walfish-Ikegami model with urban features.

The paper is structured as follows. The next section describes the system model along with basic concepts, like the physical layer and MIMO, and scheduling algorithms. Next, in Section 3, other important parts of the simulator are introduced: the channel models and the traffic-generator. Then the main operation of this application is described. The program capabilities are discussed and numerical results are presented in Section 4, while Section 5 concludes this work.

2. System model of the LTE

The physical layer of the LTE is based on OFDMA scheme as mentioned before. This multiple access method divides the frequency-domain into smaller pieces, named subcarriers, which are orthogonal to each other, and divides the time-domain into basic units, the OFDMA symbols. Six or seven symbols (depending on the length of the cyclic prefix) are transmitted in a slot. Two slots make up a subframe and ten subframes create a frame, which has the duration of ten milliseconds. Scheduling decision is made for every 10 ms frames that allocate the time and frequency resources to different connections. The subcarriers and the symbols together are called the resource grid. Every slot on twelve neighbouring subcarriers means a PRB (Physical Resource Block), which is in practice the smallest schedulable unit of the resource grid. Each PRB contains special signals to convey the physical control information between the mobile and the BS (base station).

The MIMO is a multiple antenna technique, with different possible means of operation. However, often in the literature, and so in this paper, we refer to the spatial multiplexing as MIMO. The standard specifies other methods too, like the beam-forming and diversity. The spatial multiplexing uses multiple antennas at both the receiver and the transmitter. It creates “parallel” channels on the same frequency-band to achieve higher data rates [3].

The standard suggests two types of handover to maintain mobility and reduce or avoid the loss of the packets in the air. The simpler is the hard handoff. In this case, the UE measures the SNR (Signal-to-Noise Ratio) and report it to the BS. If the quality of the channel decays, the base station instructs the mobile to change BS. In this case, the packet loss is prevented by the BS forwarding packets to the new position (new BS) of the user until the handoff process is not finished completely. The other method is the soft handover, which tries to avoid the loss of the packets. This process affects more BS and complicated according to HHO, however, it offers high quality of service [1].

These mentioned features are implemented in the simulator. The program models the operation of the eNodeB, which maintains the connection with UEs through management signals, schedules the mobiles (this is based on the physical layer), and decides about HHO. The UEs are receiving packets and moving during a simulation. The program includes the MIMO with 2x2 antennas. Many parameters describe the exact system, like the topology, the scheduling algorithm (see the next subsection), the nominal bandwidth, etc.

2.1 Scheduling algorithms

This subsection describes the three main scheduling algorithms, what was implemented in the software. Every BS uses the same type of algorithm during a simulation, but each basestation has its own scheduling (depending on the connected mobiles), see Figure 2.

The simplest algorithm is the round-robin (RR) scheduler. First, it selects the schedulable UEs, and then it makes a priority list. The highest priority is set for the UE that was scheduled the longest time ago. Finally, it tries to give as many PRBs from the resource grid for every schedulable UE as required. If some PRBs are not scheduled, the mobiles with higher priority will get them. The channel conditions are not taken into account in this algorithm; hence, this algorithm reaches the lowest performance, although, it is fair in terms of physical resource usage. Moreover, its implementation is very simple.

The second algorithm is the Max-C/I scheduler. It makes the priority list on the reported SINR (Signal to Interference and Noise Ratio) values from the schedulable mobiles. The highest priority is set for the UE with the highest SINR value (meaning the best channel quality). The resource allocation is as follows. The first mobile gets as many PRBs as required and so on. This continues until the last PRB is scheduled. This algorithm depends on the instantaneous quality of the channel. Note that it maximizes the throughput of the system and the implementation is also not complex. However, in a high-loaded cell there will be famished mobiles; in other words, there will be UEs, which can’t communicate in a useful way. This can happen at cell edge, where the SNR value is low.

The last implemented algorithm is the proportional-fair (PF) scheduler. It maintains the average data rates, tries to give fair service in terms of achieved throughputs and tries to forecast the data rate if the mobile is scheduled. The priority of an UE is defined with these two values. This algorithm is fair, it allocates PRBs for every schedulable mobile, and hence, the case mentioned at Max-C/I can’t occur. It is harder to implement in a real network as the other two algorithms, but it achieves the best performance in many aspects. In some ways, PF joins the advantages of the RR and Max-C/I schedulers.

3. The simulator

This section describes the main operation of the software. To this end two independently developed, but important parts are presented: the traffic-generator and the channel models.

The traffic-generator is made for generic use. It emulates of the generation of IP packets for the mobiles. The generation mechanism includes probability variables to achieve real distributions of the different type of packets. There are six types of traffic implemented. These are web, e-mail, VoIP (Voice over IP), peer-to-peer, network games and VBR (Variable Bit Rate) media stream.

The use of channels-models is based on [2]. There are two implemented channel-models in the application. One of them is the SUI model. It is a simple empirical model, which was developed at Stanford University, especially for OFDM based systems. The path loss of an OFDM signal depends on the distance between the transmitter and the receiver. The path loss is calculated as follows.

$$L = A + 10\gamma \log\left(\frac{d}{d_0}\right) + L_f + L_h + s \tag{1}$$

$$A = 20 \log\left(\frac{4\pi d_0}{\lambda}\right) \tag{2}$$

$$\gamma = a - bh_b + \frac{c}{h_b} \tag{3}$$

$$L_f = 6.0 \log\left(\frac{f}{2000}\right) \tag{4}$$

$$L_h = \begin{cases} -10.8 \log\left(\frac{h_r}{2000}\right), if\ Terrain\ Type\ A\ or\ B \\ -20.0 \log\left(\frac{h_r}{2000}\right), if\ Terrain\ Type\ C \end{cases} \tag{5}$$

where d is the distance between the BS and the UE, d_0 is the reference distance (default 100 m), s is the shadowing effect, λ is the wavelength of the carrier, h_b is the height of the basestation’s antenna, h_r is the height of the mobile’s antenna, f is the carrier frequency. The a, b and c parameters' values are in the Table 1.

Model Parameter	**Terrain Type A**	**Terrain Type B**	**Terrain Type C**
a	**4,6**	**4,0**	**3,6**
b	**0,0075**	**0,0065**	**0,005**
c	**12,6**	**17,1**	**20**

Table 1. The values of the parameters depend on the terrain type [2]

The other implemented channel model is the COST-231 – Walfish-Ikegami model. It is an empirical model too, and it fits to urban environment. Figure 1 shows the parameters of the model, namely, height of the buildings h_{roof}, the height of the BSs h_b, the height of the mobiles h_m, the width of the roads w, building separation b and road orientation with respect to the direct radio path φ.

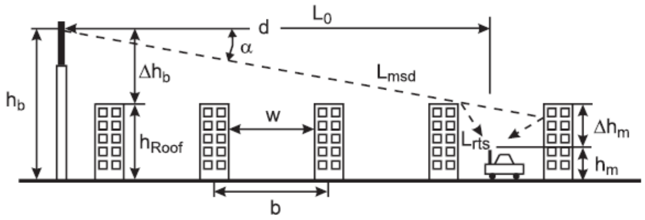

Figure 1. Parameters of the COST-231 – Walfish-Ikegami model [2]

This model distinguishes between the line-of-sight (LOS) and non-line-of-sight (NLOS) cases. For LOS, the total path loss is:

$$PL = 42.6 + 26 \log d + 20 \log f_c \qquad (6)$$

for $d \geq 0.02$ m. Here d is in units of kilometres, and f_c is the carrier frequency in MHz.

For the non-LOS case, path loss consists of three terms: the free space path loss L_0, the multi-screen loss L_{msd} along the propagation path, and attenuation from the last roof edge to the MS, L_{rts} (rooftop-to-street diffraction and scatter loss):

$$PL = \begin{cases} PL_0 + L_{rts} + L_{msd} & for\ L_{rts} + L_{msd} > 0 \\ PL_0 & for\ L_{rts} + L_{msd} \leq 0 \end{cases} \qquad (7)$$

$$PL_0 = 32.4 + 20 \log d + 20 \log f_c \qquad (8)$$

$$L_{rts} = -16.9 + 10 \log w + 10 \log f_c + 20 \log \Delta h_m + L_{ori} \qquad (9)$$

Here w is the width of the street, and Δh_m is the difference between the building height h and the height of the mobile h_m.

Orientation of the street is taken into account by an empirical correction factor L_{ori}:

$$L_{ori} = \begin{cases} -10 + 0.354\varphi & for\ \ 0° \leq \varphi \leq 35° \\ 2.5 + 0.075(\varphi - 35) & for\ 35° \leq \varphi \leq 55° \\ 4.0 - 0.114(\varphi - 55) & for\ 55° \leq \varphi \leq 90° \end{cases} \qquad (10)$$

where φ is the angle between the street orientation and the direction of incidence in degrees.

The multi-screen loss L_{msd} is obtained by modelling building edges as screens.

$$L_{msd} = L_{bsh} + k_a + k_d \log d + k_f \log f_c - 9 \log b \qquad (11)$$

where b is the distance between two buildings.

$$L_{bsh} = \begin{cases} 18 log(1 + \Delta h_b) & for\ h_b > h_{roof} \\ 0 & for\ h_b \leq h_{roof} \end{cases} \qquad (12)$$

$$k_a = \begin{cases} 54 & for\ h_b > h_{roof} \\ 54 - 0.8\Delta h_b & for\ d \geq 0.5\ km\ and\ h_b \leq h_{roof} \\ 54 - \frac{0.8\Delta h_b d}{0.5} & for\ d < 0.5\ km\ and\ h_b = h_{roof} \end{cases} \qquad (13)$$

$$\Delta h_b = h_b - h_{roof} \qquad (14)$$

$$h_d = \begin{cases} 0.7\left(\frac{f_c}{925} - 1\right) & for\ medium - size\ cities \\ 1.5\left(\frac{f_c}{925} - 1\right) & for\ metropolitan\ areas \end{cases} \qquad (15)$$

The application doesn't calculate the parameter φ through performance cause. It is set to the default 90°, so L_{ori} is a fixed value (see Equation 10).

The Walfish-Ikegami model allows of handling real areas, so an LTE network can be analysed in realistic environment. The program can process appropriate map files. These include the basic parameters of buildings and streets; hence, the application can calculate the needed variables of the model. This ability makes the simulator very useful. However, the generation of the map files is not automated yet, and this channel model reduces the performance of the simulator significantly (increases the runtime).

The main operation of the program is as follows. After the initialization, the traffic-generator begins to generate the packets for the mobiles. These packets get into a puffer at the BS. When an UE is in range and connected, the BS marks as a schedulable mobile. In the next scheduling period, the scheduler allocates some PRBs to the UE (depending on the scheduling algorithm). The eNodeB fragments the IP-packets into MAC (Medium Access Control) packets, and sends it over the mentioned PRBs. Finally, the BS logs some important data. Meanwhile, the mobiles are moving, changing their positions. The SINR values are calculated after each movement of the mobiles. The calculation is based on the mobiles position and on the channel model. The SINR values are used by the eNodeB (and by the scheduling algorithm). The achievable data rates depend on the channel's quality. The BS chooses the appropriate transport format based on the reported SINR values. The transport format includes the modulation and the error protection coding. If the mobile receives the packet, it logs some data. With all the logged information the simulator calculates system parameters, like throughput and delay. These operation runs the duration of a simulation. The Figure 3 shows the main functions.

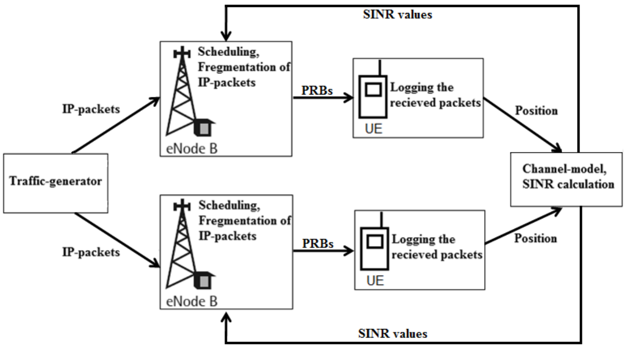

Figure 2. The simple block diagram of the simulator with the main functions

4. Numerical results

This section describes some simulation results. Two simulation scenarios were selected to show the generic analysis of a system. The main aspects are the scheduling algorithms, the MIMO and the movement speed of the mobiles. In each scenario, there are three BSs and they are located smoothly. The initial positions of the mobiles are random. The duration of the simulated time is one hour; the nominal bandwidth is 5 MHz.

The first scenario was executed with the use of the SUI model, without MIMO. In this case, the main focus is on the performance of the scheduling algorithms. The variables are the movement speed (0-120 km/h) and the number of the mobiles (50-200 UE). The first diagram (Figure 3) shows the average throughput of the system, when the velocity of the UEs is between 0 and 30 km/h. As we can see, the average throughput is increasing with the mobiles' number. However, in the case of 150 and 200 UE, the difference among the scheduling algorithms is reduced. The cause is that so many mobiles can saturate the capacity of the system. On the other hand, there is a bigger step between 50 and 75 mobile. 50 UE can't fill capacity, so there are enough resources to serve 25 more mobiles.

Otherwise, the scheduling algorithms perform as expected. The RR is the worst, although, the differences are not significant. The Max-C/I reaches the highest average throughput, but the average delays are the highest here, too (see Figure 4). The PF' values are between the other two algorithms.

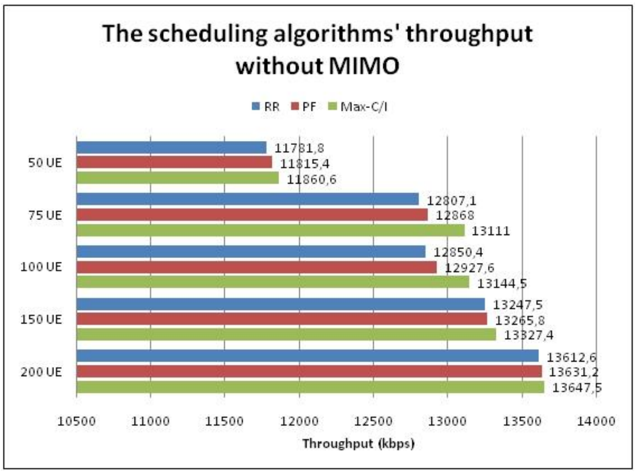

Figure 3. The average system throughput of the scheduling algorithms on 0-30 km/h movement speed, without MIMO, in function of the number of the mobiles

Figure 4 shows the average delay of the system, when 75 UEs are in it and the movement speed of the mobiles increases. The most conspicuous is the high values at the Max-C/I. As mentioned, this algorithm uses the instantaneous quality of the channel and it can famish mobiles, hence these mobiles get hardly any service, destroying the average delay values. The other two algorithms perform better. It is interesting, that the RR achieves the lowest values all the time. It is caused by the equal resource portions. Other remark, the increasing movement speed of the mobiles causes the growth of the delay values, so the QoS is decreased at higher velocity.

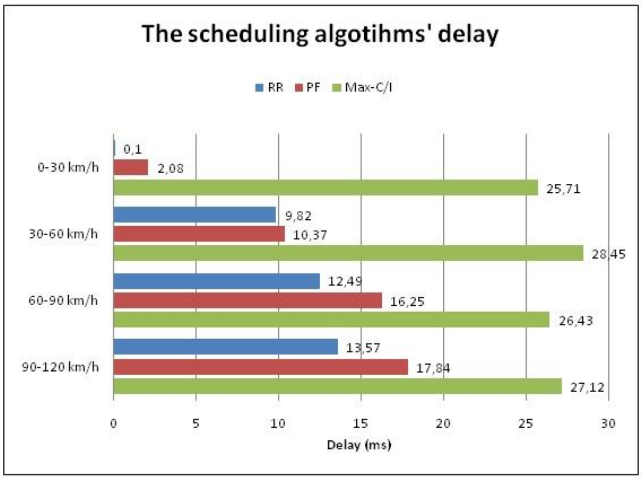

Figure 4. The average system delay of the scheduling algorithms with 75 UE, without MIMO, in function of the movement speed of the mobiles

The second scenario is simpler. Here, the focus is on the performance of the Max-C/I and the PF algorithms with 2x2 MIMO. There is two quantity of mobiles, 50 and 100, and they are moving with velocity between 0 and 30 km/h. The main difference between the simulations before (along with MIMO) is the use of the Walfish-Ikegami model. In this case, the program works with a map, urban environment within.

Figure 5 shows the average system throughput of the Max-C/I and PF algorithms with and without 2x2 MIMO. First, the use of the MIMO is worth it. It increases the average throughput significantly (up to about 50%); however, the theoretical maximum is never reached. Secondly, the algorithms behave as before, the Max-C/I achieves higher average throughput, but causes big delays (see Figure 6). Contrarily, the PF offers smooth performance.

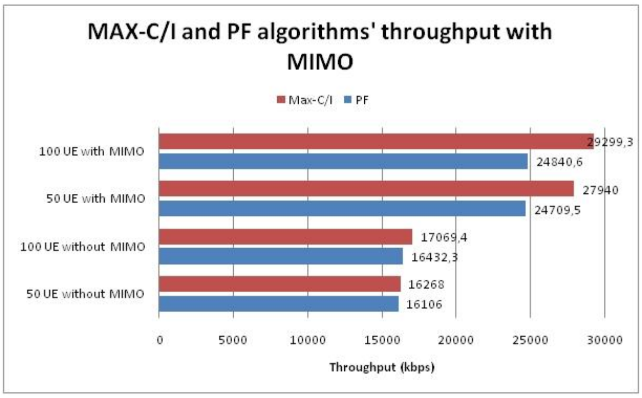

Figure 5. The average system throughput of the Max-C/I and PF algorithms with and without 2x2 MIMO, in function of the number of the mobiles

The Figure 6 shows the average system delay of the Max-C/I and PF algorithms with and without 2x2 MIMO. The use of MIMO doesn't affect the average delay significant. As mentioned, the values of the Max-C/I are multiple of the PF's values.

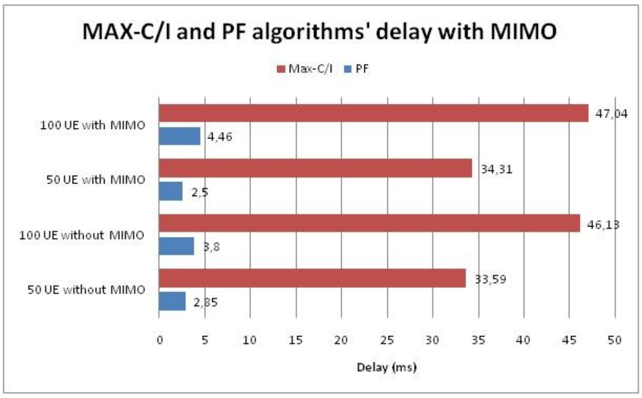

Figure 6. The average system delay of the Max-C/I and PF algorithms with and without 2x2 MIMO, in function of the number of the mobiles

5. Conclusion

I introduced an own developed simulation software, which allows system-level analysis of an LTE network. The main features of it are the physical layer of LTE, MIMO, HHO, channel-models and packet-level observations. The application is capable of handling real areas through COST-231 – Walfish-Ikegami model.

After the numerical results, the overall conclusion can be: the proportional fair scheduling algorithm is the best from the user's aspect. It ensures high quality of service in exchange for fewer throughputs. However, the implementation in real systems is not the simplest.

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