Estimation of Link-Layer Quality Parameters in a System-Level LTE Simulator

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***Abstract*—The Long-Term Evolution (LTE) is the next generation of current mobile telecommunication networks. LTE has a new flat radio-network architecture and a significant increase in spectrum efficiency. In this paper a link level implementation in a system-level LTE simulator is proposed. There are two important functions at link level to increase the network capacity: Link Adaptation and Dynamic Scheduling. These functions are based on user connection quality. A physical layer abstraction is performed to predict link-layer performance with a low computational cost. In this manner, realistic OFDM (Orthogonal Frequency Division Multiplexing) channel realizations with multi-path fading propagation conditions are generated at this layer to obtain an accurately value of Signal-to-Interference Ratio (SIR) for each subcarrier. Thus, a method to aggregate SIR measurements of several OFDM subcarriers into a single scalar value is described. Finally, the previously calculated SIR is then used to estimate Block Error Rate (BLER), which is used in the Link Adaptation and Dynamic Scheduling functions.**

I. Introduction

In order to satisfy the increasing traffic demand, the *3G Partnership Project* (3GPP) has developed a new standard as the evolution of the current network architecture of mobile communications, GSM/HSPA. The new system, called *Long-Term Evolution* (LTE), has been optimised for the packet transmission and it represents a substantial change in the development of new services.

A primary objective of the LTE standard is to define a set of specifications of a new radio access technology with the purpose of achieving data transmission rates higher than the existing, low latency and a better spectral efficiency [1].

LTE is capable of supporting different transmission bandwidths from 1.4 to 20 MHz and it supports both data transmission modes, the Frequency Division Duplex (FDD) and the Time Division Duplex (TDD). The media access technique used is the Orthogonal Frequency Division Multiple Access (OFDMA) for the downlink and the Single-Carrier Frequency Division Multiple Access (SC-FDMA) for the uplink [2].

On the other hand, LTE defines a set of advanced functions of radio resource management in order to achieve an efficient use of the available resources. These functions include the resource scheduling and the link adaptation. The former allows the users to transmit on those frequency bands which have a better channel response, depending on the characteristics of the environment. The latter maximises the spectral efficiency based on channel conditions. During the execution of these functions measurements are needed in order to obtain information about the channel state and the quality connection.

In this work a general scheme of an LTE system-level simulator based on the radio access technology specified by the 3GPP is presented. It focuses on the calculation of those parameters of interest that serve as input to the radio resource management functions. A well-known parameter which gives an estimate of the quality connection is the Block Error Rate (BLER), obtained from the Signal-to-Interference Ratio (SIR). In the calculation of these parameters a set of OFDM channel realizations is generated with the purpose of characterizing accurately the radio channel, including the multipath fading.

The rest of the paper is organised as follows. Section II presents the general simulator structure. Section III focuses on the calculation of the different OFDM channel realizations needed for the resource scheduling. The calculation of the propagation loss, the interference and the SIR included in the simulator are detailed in Section IV. Section V briefly introduces the management functions of link adaptation and resource scheduling. Finally, conclusions are presented in section VI.

II. Simulator General Structure

The proposed LTE simulator is focused in modeling the radio access network of a LTE mobile communication network. In Fig. 1, the main functional blocks of the simulator are shown.

Firstly, the parameters linked to the different functions of the simulator should be configured and initialized. During this

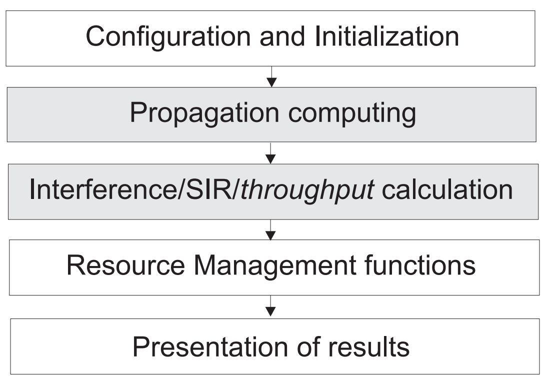

Fig. 1. Block diagram of the LTE simulator

procedure, a warm-up distribution of users is generated, which allows to start the simulation with a steady situation according to the configuration and to obtain meaningful network statistics from the very beginning. Furthermore, in this first stage, the OFDM channel samples are generated for each user. This channel samples will be subsequently used by other functions in the simulator.

In the next stage, the function that performs propagation computing is executed. This function calculates the propagation loss suffered by each user in the signal transmitted by each base station. The simulator includes a slow-fading model and the OFDM samples previously obtained, which take into account the fast-fading. As a result, the power received by each user from the different base stations is obtained.

The interference received by each user is determined by the power received from the other base stations. Once interference values are calculated, the Signal-to-Interference Ratio (SIR) is computed. From SIR, the Block Error Rate (BLER) is calculated, which is an indicator of the connection quality. Lastly, the *throughput* experienced by each user is calculated.

The set of radio resource management functions includes, at network level, admission control, mobility management and quality of service management. At link level, it includes link adaptation and dynamic resource scheduling. The link adaptation function selects the modulation and coding scheme for each user depending on the quality experienced in the communication and on the requirements of the service, maximizing spectral efficiency. Resource scheduling determines the distribution of the physical resources among the users, according to a given assignment policy. In LTE, the channel characterization is a key factor for scheduling.

Lastly, the simulator contains a block which displays the main results and statistics.

This paper is focused on the functions included in the simulator which are related to propagation and interference calculation, SIR and *throughput*, as it is shown in Fig. 1.

III. OFDM Channel Realizations

The radio propagation channel can be characterized as a linear system and therefore it has a impulse response associated, which expresses the amplitudes of the different multipath components and their respective delays. However this impulse response is different at every moment of observation, i.e., it is time-varying. Hence, the impulse response function will be two-dimensional, depending on both variables: the delay and the observation time. Mobile communications standards define only the dependence on the observation time variable, providing the so-called channel power profiles which appear in tables B.2.1-2 to B.2.1-4 in [3]. In order to obtain the aforementioned two-dimensional impulse response, the dependence on the observation time variable is generated using the model described in [4]. This model assumes that each multipath component follows an independent temporary variation which is associated with complex Gaussian random processes, whose spectral density function is limited to the maximum Doppler frequency deviation of the propagation scenario considered, among which it is proposed the standard included in Table I. An example of the impulse response so generated is shown in Fig. 2, where it is represented both the independent variation of each multipath component with respect to the observation time and the different delay values of all multipath components at any given time.

The channel models considered in the simulator are defined in Table I.

The frequency response of a linear system can be calculated mostly by transforming its impulse response into the frequency domain. In this manner, applying the Fourier Transform to the delay variable of the two-dimensional channel impulse response, the frequency response is obtained, which also depends on the observation time, i.e., the frequency response is time-varying and an example of this is shown in Fig. 3. This function provides information about the channel behavior for the different frequencies within the OFDM signal bandwidth and its temporary variation over different observation times during the simulation.

IV. Propagation Computing and SIR

A. Radio Propagation Model

The radio propagation model included in the simulator is the COST 231 extension of Okumura-Hata model [5]. This model is applicable for frequencies in the range 1500 to 2000 MHz. The effective height of the base station (eNB) antenna has been set to 30 meters, while the effective height of the mobile station antenna has been set to 1.5 meters. With these assumptions and setting the operating frequency to 2 GHz, the

TABLE I
Channel model parameters

Model	Maximum Doppler frequency
EPA 5Hz	5Hz
EVA 5Hz	5Hz
EVA 70Hz	70Hz
ETU 70Hz	70Hz
ETU 300Hz	300Hz

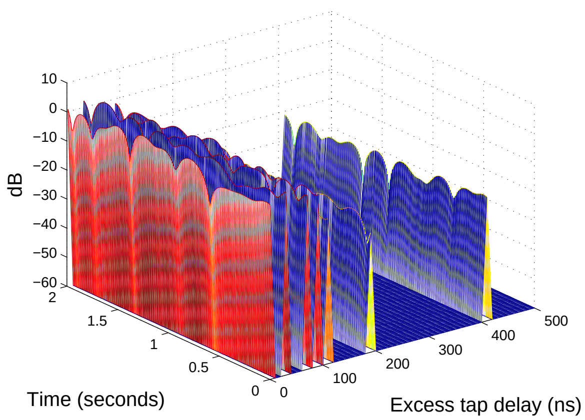

Fig. 2. Two-dimensional impulse response for EPA 5 channel model

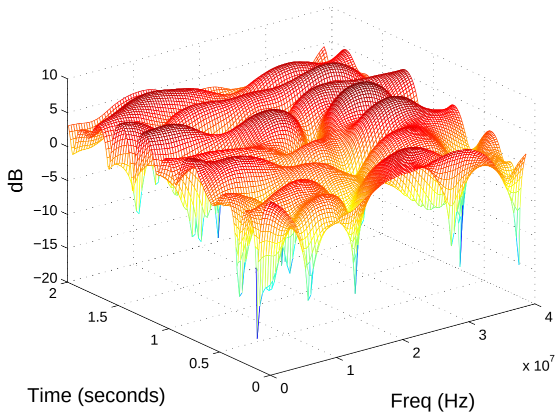

Fig. 3. Time-variant transfer function for EPA 5 channel model

expression which calculates the propagation loss as a function of the distance is given by:

$$L = 134.79 + 35.22 \log d \tag{1}$$

where d represents the distance in km between the user and the eNB which the user is connected to.

As mentioned above, in addition to the propagation loss, the simulator includes a slow fading model based on the fact that the local average of the radio signal envelope can be modelled by a lognormal distribution, i.e., the local average, in dB, is a Gaussian random variable. The standard deviation of the distribution depends on the considered environment. A typical value for the macrocell urban area analyzed is 8 dB [1].

The dynamic nature of the simulator leads to the implementation of a correlation model between the successive samples which represent the slow fading. An ARMA(1,1) model [6] has been selected for the simulator in this work:

$$z_t = \theta z_{t-1} + (1-\theta) a_t \tag{2}$$

where z_t represents the slow fading sample at the current simulation step, z_{t-1} is the slow fading sample at the previous simulation step, a_t is a Gaussian random variable uncorrelated with z_t and θ and $(1-\theta)$ are the coefficients of the ARMA(1,1) model.

The coefficients of this model are determined from the probability that a user terminal suffers fading provoked by the same obstacle at the time interval Δ/v. That probability can be modelled as an exponential distribution:

$$\theta = P(\tau < \Delta/v) = \exp(-\Delta \cdot \lambda) \tag{3}$$

where Δ is the distance moved by the user terminal at a time interval, v is the user terminal velocity and λ is the interruption rate of the line of sight. The interruption rate of the line of sight, λ, is the inverse of the correlation distance. A typical value of the correlation distance for the macrocell urban area simulated is 20 m [7].

Finally, the Gaussian random variable, a_t, must be defined based on its mean and standard deviation. This variable provides a statistical distribution of zero mean and a standard deviation, σ_a, that relates to the standard deviation of the slow fading, σ_z, as follows:

$$\sigma_z^2 = \frac{\sinh(\Delta \cdot \lambda/2)}{\cosh(\Delta \cdot \lambda/2)} \cdot \sigma_a^2 \tag{4}$$

B. SIR calculation

In order to calculate the SIR, it is necessary firstly calculate the interference which each user suffers. This requires having the value of the signal received by each user from all interfering cells. It is assumed that intracell interference is cancelled in LTE because users are scheduled at different frequencies or time slots, hence only intercell interference due to the transmitted power by those interfering cells which use the same frequency band than the user to transmit is considered. The computation of the interference does not include the multipath effect so that channel realizations for each user and base station are not required. Consequently, only the propagation loss and the slow fading are considered in the calculation of the interference.

The SIR calculation for a given subcarrier k, γ_k, is computed using the expression proposed in [8],

$$\gamma_k = P(k) \times \bar{G} \times \left(\frac{N}{N+N_p} \right) \times \frac{R_D}{N_{SD}/N_{ST}} \tag{5}$$

where $P(k)$ represents the frequency-selective fading power profile value for the k^{th} subcarrier, $\bar{G}$ includes the propagation loss, the slow fading, the thermal noise and the experienced interference, N is the FFT size used in the OFDM signal generation, N_p is the length of the cyclic prefix, R_D indicates the percentage of maximum total available transmission power allocated to the data subcarriers, N_{SD} is the number of data subcarriers per Transmission Time Interval (TTI) and N_{ST} is the number of total useful subcarriers per TTI.

If the multipath fading magnitudes and phases are assumed to be constant over the observation interval, the frequency-selective fading power profile value for the k^{th} subcarrier can be calculated using the following expression:

$$P(k) = \left| \sum_{p=1}^{paths} M_p A_p \exp\left(j\left[\theta_p - 2\pi f_k T_p\right]\right) \right|^2 \tag{6}$$

where p is the multipath index, M_p and θ_p represent the amplitude and the phase values of the multipath fading respectively, A_p is the amplitude value corresponding to the long-term average power for the p^{th} path, f_k is the relative frequency offset of the k^{th} subcarrier within the spectrum, and T_p is the relative time delay of the p^{th} path. Additionally, the fading profile is assumed to be normalised such that $E[P(k)] = 1$.

The value of $\bar{G}$ is calculated from the expression:

$$\bar{G} = \frac{P_{max} \frac{g_n(UE) \times g_{UE}}{PL_{UE,n} \times SH_{UE,n}}}{P_{noise} + \sum_{k=1,k\neq n}^{N} P_{max} \times \frac{g_k(UE) \times g_{UE}}{PL_{UE,k} \times SH_{UE,k}}} \tag{7}$$

where $g_n(UE)$ is the antenna gain of the serving base station in the direction of the user UE, g_{UE} is the antenna gain of the user terminal, P_{noise} is the thermal noise power, $PL_{UE,k}$ is the propagation loss between the user and the eNB k, $SH_{UE,k}$ is the loss due to slow fading between the user and the eNB k and N is the number of interfering eNBs considered.

Taking into account these channel conditions, effective SIR can then be computed as:

$$SIR_{eff} = -\beta \ln \left(\frac{1}{N_u} \sum_{k=1}^{N_u} \exp\left(-\frac{\gamma_k}{\beta} \right) \right) \quad (8)$$

where β is a parameter that depends on the modulation and coding scheme used in the transmission [9] and N_u indicates the number of subcarriers used to evaluate the effective SIR. The value of β for a particular modulation and coding scheme is shown in Table II.

The value of the effective SIR for each user is then calculated considering the subset of subcarriers that the user uses during a time interval for the transmission. Once the effective SIR has been calculated, the Block Error Rate (BLER), which provides information about the connection quality, can be derived. There are curves that establish the relationship between the values of SIR and BLER defined for an AWGN channel for every modulation and coding rate combination. It is possible to use these curves in order to calculate the BLER if the intercell interference is assumed to be modelled as AWGN [8].

The Hybrid Automatic Repeat reQuest (H-ARQ) is a function at link level that allows to perform retransmissions directly at physical or MAC layer in LTE systems. A low-complexity model capable of accurately predicting the H-ARQ gains on the physical layer is derived in [10]. When a H-ARQ retransmission occurs, an improvement of the BLER is expected. The result is that the BLER curves based on AWGN channel model are shifted providing a Signal to Noise Ratio (SNR) gain due to H-ARQ. Hence, the new SIR can be calculated as follows:

$$SIR(i) = SIR + SNR_{gain}(i) \quad (9)$$

where i represents the i^{th} retransmission. The value of SNR_{gain}, which depends on the redundancy version index i and the given Modulation and Coding Scheme (MCS), can be derived from a specific table given in [10].

Once the value of BLER has been obtained and taking into account the modulation and coding scheme used in the transmission, it is possible to calculate the value of *throughput*, T_i, for each user as follows:

$$T_i = (1 - BLER(SIR_i)) \times \frac{D_i}{TTI} \quad (10)$$

where D_i is the data block *payload* in bits [11], which depends on the MCS selected for the user in that time interval, TTI is the transmission time interval and $BLER(SIR_i)$ is the value of BLER obtained from the effective SIR.

TABLE II
VALUES OF β DEPENDING ON THE MODULATION AND CODING SCHEME

Modulation	Codification	β factor
QPSK	1/3	1.49
QPSK	2/5	1.53
QPSK	1/2	1.57
QPSK	3/5	1.61
QPSK	2/3	1.69
QPSK	3/4	1.69
QPSK	4/5	1.65
16QAM	1/3	3.36
16QAM	1/2	4.56
16QAM	2/3	6.42
16QAM	3/4	7.33
16QAM	4/5	7.68
64QAM	1/3	9.21
64QAM	2/5	10.81
64QAM	1/2	13.76
64QAM	3/5	17.52
64QAM	2/3	20.57
64QAM	17/24	22.75
64QAM	3/4	25.16
64QAM	4/5	28.38

V. RADIO RESOURCE MANAGEMENT

A. Link Adaptation

The 3GPP has standardized a parameter denominated Channel Quality Indicator (CQI) that represents the connection quality in a subband of the spectrum. The CQI index needs 4 bits to be transmitted, although a differential CQI value can be transmitted to reduce the CQI signaling overhead. Hence, there is only a subset of possible modulation and coding schemes that corresponds to a CQI value [12]. This correspondence between the channel coding rate value and modulation scheme and the CQI index is given in Table III. Also the value of efficiency is shown for each CQI value, taking into account the number of bits per symbol given by the modulation and the coding rate.

The link adaptation function selects the most appropriate modulation and coding scheme to transmit the information on the physical downlink shared channel (PDSCH) depending on the propagation conditions of the environment. In order to execute this function it is necessary to know the link quality for each user and for each subband of the spectrum. This information is given by the CQI index. If the experimented BLER value is required to be smaller than a specific value given by the service, it is possible to establish a SIR-to-CQI mapping [13]. On the other hand, the standard 3GPP defines a 5-bit modulation and coding scheme field of the downlink control information to identify a particular MCS. This leads to a greater variety of possible modulation and coding schemes. For simplicity, the LTE simulator includes only the same set of MCS given by the CQI index. From the effective SIR value, the index CQI is calculated and the modulation and coding scheme can be determined for the next time interval.

B. Resource Scheduling

The resource scheduling can be decomposed into a time-domain and frequency-domain scheduling. On the one hand it is necessary to determine which user transmits at the following time interval. For simplicity, a Round-Robin scheduling policy will be employed in a first stage of the simulator development. The Round-Robin scheduling assigns the time equally between the users. The algorithm is both simple and easy to implement. On the other hand, the frequency-domain scheduling selects those subcarriers within the system bandwidth whose channel response is more suitable for the user transmission. In this case it is necessary to know the channel response for each user and for each subcarrier of the system bandwidth. This information is given from the channel realizations generated in the initialization phase of the simulation. In order to select the most appropriate frequency subband for the user, the index CQI is used.

VI. Conclusion

In this paper a general scheme of an LTE system-level simulator is presented. This simulator includes the main characteristics of the radio access technology as well as the radio resource management algorithms which provide notable improvements in the efficient use of the available radio resources with respect to the current radio access technology. This work focuses on the calculation of several indicators with the purpose of evaluating the connection quality in a mobile communication. Those indicators are required in the execution of radio resource management functions. Hence, it is essential that these indicators reflect accurately the behavior of a real network. To achieve this goal, an OFDM channel model has been performed to characterize the temporary and frequency variation of the radio transmission environment for each user during the simulation. As a result of this process, a set of realizations including the multipath fading effect is generated and therefore a more realistic physical channel representation is accomplished from which quality indicators are obtained.

TABLE III
Relationship between the 4-bit CQI and the MCS

CQI index	Modulation	Coding rate	Efficiency (bits per symbol)
0		Out of range	
1	QPSK	78/1024	0.15
2	QPSK	120/1024	0.23
3	QPSK	193/1024	0.38
4	QPSK	308/1024	0.60
5	QPSK	449/1024	0.88
6	QPSK	602/1024	1.18
7	16QAM	378/1024	1.48
8	16QAM	490/1024	1.91
9	16QAM	616/1024	2.47
10	64QAM	466/1024	2.73
11	64QAM	567/1024	3.32
12	64QAM	666/1024	3.90
13	64QAM	772/1024	4.52
14	64QAM	873/1024	5.12
15	64QAM	948/1024	5.55

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