LTE-Advanced System Level Simulation Platform for IMT-Advanced Evaluation

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Abstract

International Mobile Telecommunications (IMT)-Advanced is the new global standard defined by the International Telecommunication Union (ITU) for the fourth generation of mobile communication systems. Several technologies like Long Term Evolution (LTE)-Advanced have been proposed as IMT-Advanced candidates. In order to achieve this consideration, evaluations must ensure the achievement of a set of ITU requirements. Some of them can be analytically evaluated but others are based on simulative methods. Therefore, novel simulation platforms have been developed recently to perform IMT-Advanced evaluation.

In this paper it is presented a system level simulation platform developed to assess the performance of LTE-Advanced in the framework of IMT-Advanced evaluation. First, the main building blocks of this simulator are presented, including their main features, possible implementation and interactions. Second, the calibration process conducted to ensure the validity of the results obtained with the System level simulation platform is explained and the results of this process are shown. These results demonstrate that the simulation platform developed is well calibrated. Finally, results for one of the IMT-Advanced test scenarios are shown as an example of how this simulator can be used in the IMT-Advanced evaluation process.

Keywords

LTE-Advanced, system level simulation, IMT-Advanced evaluation

1. Introduction

International Telecommunication Union (ITU) is involved in the definition of a global standard for the fourth generation of mobile communication systems known as International Mobile Telecommunications (IMT)-Advanced. One of the technologies included in this global standard is the Long Term Evolution (LTE)-Advanced based on a previous technology known as LTE. Both technologies were presented in a previous paper [1]. LTE-Advanced has been proposed by the Third Generation Partnership Project (3GPP) that standardized Universal Mobile Telecommunication System (UMTS) in the framework of IMT-2000.

IMT-Advanced systems must fulfill a set of requirements specified by ITU in [2]. A first set of requirements is checked through inspection of the proposal. These requirements include the support of scalable bandwidths in the IMT-Advanced spectrum, a wide range of services and inter-system handover with at least one IMT-2000 system. A second set of requirements is checked analytically, that is, conducting numerical calculations. This is the case of the peak spectral efficiency, user plane and control plane latency and handover interruption times. The third, and last, set of requirements is too complicated to be evaluated analytically and then simulative methods are needed. These requirements are cell spectral efficiency, cell edge user spectral efficiency, mobility and Voice over Internet Protocol (VoIP) capacity.

In order to reduce simulation complexity, simulations are often divided into two stages or levels of abstraction known as link level and system level. Link level simulations are used to assess the performance of the physical layer and those higher layer aspects directly related to the radio interface, such as combining of retransmissions. At the link level a continuous radio link is modeled, including in the simulation specific features like synchronization, modulation, channel coding, channel fading, channel estimation, demodulation, multi-antenna processing, etc. On the other hand, a system level simulator allows evaluating the performance of a global network. At this level, system modeling encompasses a set of base stations (BSs) and all their associated mobile terminals (MTs). Both the signal level received by each user and other users' interferences are modeled taking into account the propagation losses and channel fading effects. Signal to Interference plus Noise power Ratio (SINR) is calculated for each active user taking into account the current network configuration. These SINR values can be then translated to Block Error Rate (BLER) or effective throughput values using models whose development is based on the results obtained in the link level simulations. This interaction between link and system level simulators is usually referred to as Link-to-System (L2S) mapping, L2S interface or link abstraction models.

Guidelines and deployment scenarios to perform IMT-Advanced evaluation are detailed in [3]. Following these guidelines a LTE-Advanced system level simulation platform has been implemented, which is fully compliant with 3GPP specifications. Specifically, the downlink (DL) of the system, that is, the link from the BS to the MT is emulated, since this is the most demanding link. It is appropriate to say that implementation is focused on the Frequency Division Duplex (FDD) version of the technology because it is envisaged that this version will be the predominant one.

After a first stage of simulation development a calibration process has been performed. This second stage is of paramount importance to ensure the validity of the results obtained with the simulation platform. Calibration is performed through comparison of the outcomes of the developed simulator with the outcomes of the simulation platforms of other research institutions. This work has been performed in the framework of the European project Wireless World Initiative New Radio + (WINNER+).

After calibration of the simulation platform the capabilities of LTE and LTE-Advanced have been evaluated. The focus of this assessment is on the achievement of IMT-Advanced requirements. Therefore, the methodology and the key performance indicators used in this assessment follow the guidelines that ITU defined for the IMT-Advanced evaluation.

The organization of the paper is as follows. In Section 2 a functional description of the LTE-Advanced simulation platform developed is provided. The main steps of the calibration process are presented in Section 3. Finally, the main results of the LTE-Advanced evaluation in the framework of IMT-Advanced evaluation are given in Section 4.

2. Simulation platform functional description

A logical structure of the LTE-Advanced simulation platform is shown in Figure 1. Special interactions among functional entities are shown as connections among blocks in Figure 1. Main features of each functional entity have been included within the block representing this functional entity. The components shown in this figure and their interactions are described in the following subsections.

2.1 Network layout

The network layout is a logical entity whose main function is to store the location of each. Additionally this module stores the interfering relations among base stations, that is, which BSs produce interference to the users served by each BS.

Two BS layouts are considered in IMT-Advanced simulations. The first one is a layout with BSs placed in a regular grid, following hexagonal layout. The network consists of 19 sites, each of 3 cells. Wrap around technique is used to avoid border effect. The second one is the indoor hotspot scenario that consists of one floor of a building. The floor contains 16 rooms of 15 m × 15 m and a long hall of 120 m × 20 m. Two sites are placed in the middle of the hall at 30 m and 90 m with respect to the left side of the building. Users are distributed uniformly over the whole area and in IMT-Advanced evaluations its position is kept fixed during a simulation run.

2.2 Channel

This module is a generic entity employed by any wireless link established in the simulation that models the radio propagation conditions between a BS and a MT.

The IMT-Advanced channel model defined by the ITU-R is a stochastic and geometric model that allows creating a bidirectional radio channel [3] consisting of a plurality of rays. Although it is a geometric based model that knows the exact location of transmitting and receiving elements, it does not specify the position of the scatterers, rather only ray directions are known.

Figure 2 shows a transmitter and receiver and all existing rays between them. Moreover, this figure represents the concept of cluster, or propagation path – in space, time and angle – that consists of a set of rays affected by nearby scatterers. The figure also includes the concept of Angle of Departure (AoD) and Angle of Arrival (AoA), both at cluster and ray level.

There are two different sets of channel param-

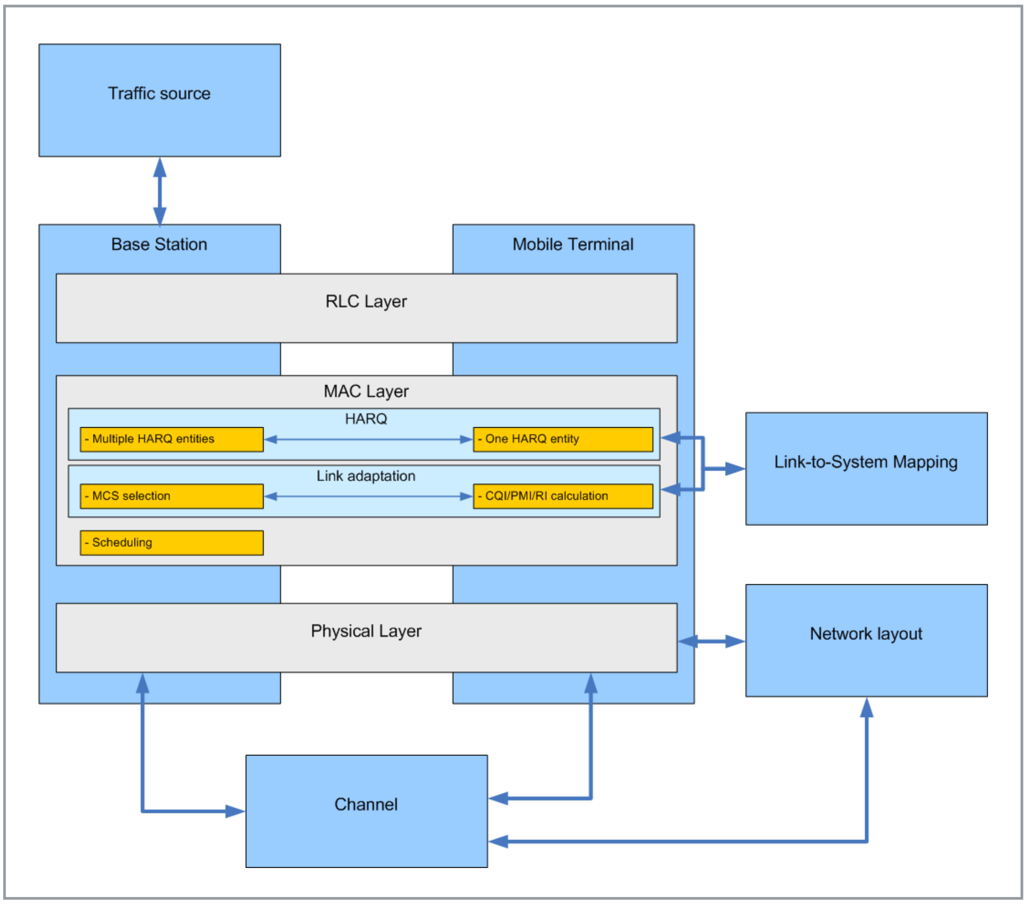

Figure 1. *Simulation platform functional scheme.*

ITU is involved in the definition of a global standard for the fourth generation of mobile communication systems, IMT-Advanced.

eters in the IMT-Advanced channel model. The first one is related to the large scale parameters, such as shadow fading (SF) and path loss. The second one concerns small scale parameters, including Angle of Arrival (AoA) and Departure (AoD) or delay of the rays.

In order to generate channel samples between one transmitter and one receiver, mobility and exact location of both ends must be known. Based on this information all large scale parameters are generated, followed by the small scale parameters. All these parameters are kept constant during the whole simulation. Channel samples are obtained by adding the contributions of all involved rays.

There are five different scenarios and thus channel models: indoor hotspot (InH), urban microcell (UMi), urban macrocell (UMa), suburban

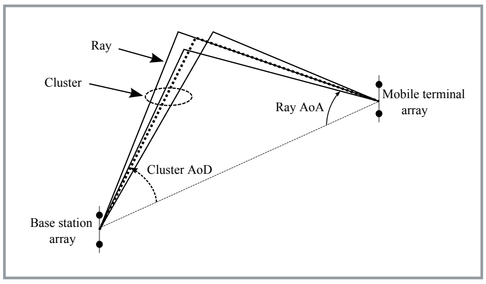

Figure 2. *IMT-Advanced MIMO channel*

macrocell (SMa) and rural macrocell (RMa). Different models are characterized by different parameters of the statistical distributions used to generate the channel samples.

2.3 Link-to-System Mapping

Link-to-system mappings are developed through link level simulations to provide an abstraction of the complex processes that occur at link level. In a system level simulator, link abstraction models are used to translate channel quality measures, such as SINR values, to transmission quality values, such as BLER or throughput.

IMT-Advanced technologies are based on Orthogonal Frequency Domain Multiplexing (OFDM) that is a multicarrier modulation. Then, the outcomes of SINR measurements performed over the air interface are vectors whose elements represent the SINR of each carrier. This fact has made link-to-system mapping developed for single carrier systems to be useless for IMT-Advanced. Instead, a family of methods known as Effective SINR Mapping (ESM) is commonly used. These methods map an instantaneous set of SINR samples into a scalar value, which is called effective SINR. The general formula used to obtain the effective SINR is:

$$SINR_{eff} = \alpha_1 \Phi^{-1}\left(\frac{1}{N}\sum_{n=1}^{N}\Phi\left(\frac{SINR_i}{\alpha_2}\right)\right)$$

being the number of SINR samples, $\Phi(\bullet)$ an $\Phi^{-1}(\bullet)$ information measure function and its inverse and α_1 and α_2 two configurable parameters. Once the effective SINR value, $SINR_{eff}$, has been calculated, a look up table obtained through simulations conducted in an AWGN scenario is used to translate the effective SINR value to, for instance, a BLER value. With this aim, an AWGN look up table must be obtained for each Modulation and Coding Scheme (MCS).

For each MCS, α_1 and α_2 must be calibrated through link level simulations to minimize the error between real BLER (obtained through simulation) and predicted BLER (obtained through the ESM). If the model was perfect, the $SINR_{eff}$ would be the scalar SINR value that in a AWGN scenario would produce the same BLER obtained in the multicarrier scenario with the measured SINR vector.

The most common ESM model in IMT-Advanced evaluation is the Mutual Information Effective SINR Mapping (MIESM). That uses as its information measure the so called mutual information [4]. A good comparison of MIESM with other ESM methods is presented in [5].

2.4 Base Station and Mobile Terminal

BSs and MTs are the main simulation entities. Both entities present a layered architecture consisting of three main layers: the physical layer, Medium Access Control (MAC) layer and Radio Link Control (RLC) layer. Next, functions and peculiarities of these layers are described.

2.4.1 Physical layer

The main function of the simulation platform physical layer is the calculation of the SINR obtained in the MT after the receiver filter and before the decoder. To this end, the physical layer has an interface with the channel module, to know the state of the channel links, and also with the network layout, since interfering relations are contained in this module. Both the SINR of reference signals and data packets sent by the BSs are calculated.

Different receiver filters have been modeled: for Single Input Multiple Output (SIMO) the Maximum Receiver Combining (MRC) is used while for Multiple Input Multiple Output (MIMO) the Minimum Mean Square Error (MMSE) receiver with interference suppression or interference cancellation is considered.

2.4.2 MAC layer

The MAC layer of the simulation platform presents three main functions:

a. HARQ management

Hybrid ARQ (HARQ) with soft combining is a technique that deals with retransmission of data in case of errors. In an ARQ scheme, the receiver uses an error-detecting code to check if the decoded packet contains errors or not. The transmitter is informed by a NACK or ACK, respectively. In case of a NACK, the packet is retransmitted. Since ARQ is a stop-and-wait protocol, it can be more efficient to have multiple ARQ processes in parallel. HARQ consist of a combination of ARQ and a Forward Error Correction (FEC). The concept of soft combining means that when a packet is erroneously received it is stored in a buffer and later combined with the retransmission(s) to obtain a single packet that is more reliable than its constituents.

In LTE-Advanced, full Incremental Redundancy (IR) is applied, which means that the retransmitted packets are typically not identical with the first transmission but carry complementary information. Besides, in LTE-Advanced, there is a HARQ entity in the MT that manages multiple parallel HARQ processes to implement a multichannel stop-and-wait HARQ protocol. The BS has as many HARQ entities as users being served by this BS. Then, each HARQ entity in the BS has a pair entity in the MS.

The developed LTE-Advanced simulator emulates in detail all the HARQ functionality. In the simulation platform, each time a packet is transmitted from a BS, the MT receives HARQ information (e.g. MCS of this packet) from its pair entity and SINR information from the physical layer. All this information is translated into a BLER value thanks to the L2S Mapping. Randomly, and taking into account the BLER calculated, the transmitted block can be erroneously received. Soft combining is implemented by each HARQ process through the combination of SINR values of retransmitted packets.

b. Link adaptation

One of the key techniques of LTE-Advanced is the link adaptation that allows the transmitter to adapt the transmission format, including the MCS, transmission rank and precoder among other parameters, to the channel quality variations. As the simulator implements a FDD system, in which uplink (UL) and DL are separated in frequency, DL quality cannot be estimated directly by the BS through measurements of the UL channel. Instead, the MT must report the BS which is the channel state that it is experiencing.

Several methods are allowed to perform the channel state report. First, explicit channel estimates can be reported to the BS. For example, one channel estimated can be reported per subcarrier. To reduce the overhead of such a transmission only channel correlation matrices could be transmitted. Besides these methods, other kind of non-explicit information could be transmitted. In fact, this approach is common in LTE. Following this approach, the MT performs SINR measurements and calculates the most suitable format for transmission. This information includes which is the most suitable MCS, multi-antenna scheme, and precoding matrices and rank in case of spatial multiplexing. This information is conveyed in a set of reports known as Channel Quality Indicator (CQI), Precoder Matrix Indicator (PMI) and Rank Indicator (RI). In this process, it is necessary to have an interface with the physical layer to know the channel state and also with the link abstraction model to be able to translate the channel state into a transmission quality estimate.

An additional source of information used to perform the link adaptation is the HARQ feedback sent by the MT to the BS. For instance, if a negative acknowledgement is received by the BS, it means that the transmission format used in a previous transmission was incorrect and adaptation is needed.

Link adaptation algorithms are not included in the LTE-Advanced specifications. Therefore, each developer uses a different solution to obtain the best system performance.

c. Scheduling

Scheduling is one of the main functions of the Radio Resource Management (RRM) and is carried at the BS. Scheduling decides how to allocate resources to the users in each transmission, that is, at a fast pace (once per millisecond). Additionally, the scheduling process includes not only the selection of the resources devoted to each user, but it also decides for each selected user which HARQ process will carry the transmission. This implies that the scheduler decides if the transmission carried is a retransmission or a new one.

Given a utility function (for example, the cell spectral efficiency), the problem of performing an optimum scheduling decision to maximize this utility function is usually a Non-deterministic Polynomial-time (NP)-hard problem. That is, it is not feasible to obtain the optimum solution in a limited amount of time and with a limited amount of computational resources. Instead, suboptimal algorithms are designed to get the most of the available resources.

Opportunistic scheduling is a term that includes the group of algorithms that use the channel state information reported by the users to allocate each resource to the user with better channel state at that resource.

Scheduling algorithms are not included in the LTE-Advanced specifications. In the simulation platform, different kind of schedulers are implemented including the Round Robin algorithm that allocates resources equally among the users, the MaxCQI algorithm that allocates each resource to the user with best quality and the Proportional Fair algorithm that allocates the resources to the users with a priority that is directly proportional to the channel quality of this user but inversely proportional to the throughput experienced in the past by this user.

A good survey about scheduling in LTE technology can be found in [6].

2.4.3 RLC layer

In the BS, the RLC entity receives packets from higher layers and multiplexes or divides them to adapt packet sizes to MAC layer needs. In the MT, the RLC entity receives packets from the MAC and reassembles the original packets to pass them to higher layers.

The implemented data transfer mode in the RLC sublayer is the Acknowledged Mode (AM) [7]. RLC headers are added to form the RLC Packet DataUnits (PDUs) in order to provide a reliable in sequence delivery service and enable the segmentation and reassembly or concatenation and demultiplexation tasks. In case of MAC transmission failure, retransmissions are carried out at RLC level. Moreover, the RLC entity performs RLC Service Data Unit (SDU) discarding when the maximum time delay set for upper layer packets is exceeded.

2.5 Traffic source

Two traffic models are used for evaluation of proposed IMT-Advanced technologies: full buffer traffic model and VoIP model.

In the full buffer traffic model there is an infinite amount of data bits waiting for transmission to each receiver entity. Although this model is not realistic it can be used to get interesting insights of the spectrum efficiency of each system.

The VoIP model used in IMT-Advanced evaluation is detailed in [3]. It assumes a codec rate of 12.2 kbps, and an encoder frame length of 20 ms. It is also important to note that a voice activity factor of 50% has been considered.

3. Simulator platform calibration

In order to ensure the validity of the results obtained with the simulation platform, it is necessary to conduct a calibration process after the development phase. In this process, several tests are defined and outcomes of different simulators are cross-checked to detect incoherencies. If results are aligned, the simulators are considered well calibrated. Otherwise, more work is needed to achieve calibration. It is important to define properly the calibration tests to ensure that the key building blocks of the simulation are calibrated.

A stepwise calibration methodology was followed in the framework of the WINNER+ project. This process consists of three steps: calibration of the large scale parameters of the channel model, calibration of the small scale parameters of the channel model and calibration of a baseline system configuration. The first two steps involve mainly the calibration of the channel model, that is, a technology-agnostic building block, while the last step is focused on the calibration of the MAC layer and link abstraction model that are technology dependent.

Scheduling is one of the main functions of the Radio Resource Management (RRM) and is carried at the BS.

3.1 Channel Model Calibration

In the calibration of the large scale parameters of the channel model, all the multipath effects are neglected. Simulations are conducted to obtain for each user a path gain and a wideband SINR value. The path gain is defined as the average signal gain between a MT and its serving BS. It includes distance attenuation, shadowing and antenna gains. The wideband SINR is the ratio of the average power received from the serving cell and the average interference power received from other cells plus noise. Sometimes this measure is called geometry factor since it presents a great dependency with the position of the user in relation to the position of the BSs. Then, the calibration of this measure ensures not only the calibration of the channel model but also the calibration of the network layout. In addition, it involves the calibration of the physical layer considered in the simulation platform functional description, since the SINR is calculated in this layer. In addition to the evaluation principles and assumptions in [3] the assumptions shown in Table 1 have been considered.

Cell selection	1 dB of handover margin			
Feeder loss	2 dB			
BS antenna tilt	InH	UMi	UMa	RMa
	0º	12º	12º	6º

Table 1. *Additional simulation assumptions.*

Figure 3 shows the cumulative density function (CDF) of the path gain (left) and wideband SINR (right) obtained from a set of simulations conducted with the LTE-Advanced simulation platform. It has been shown the CDF for each one of the test scenarios considered in IMT-Advanced evaluations. Comparison of the presented results with these obtained in the WINNER+ project [8] and these obtained by the 3GPP [9] proves the calibration of the presented simulator.

Comparison of the presented results with these obtained in the WINNER+ project and these obtained by the 3GPP proves the calibration of the presented simulator.

In the calibration of the small scale parameters of the channel model, the set of characteristics whose distributions are investigated include the delay spread and the departure and arrival angular spread at the BS and MT, respectively. The root mean square delay spread (DS) and circular angular spread at the BS (angle of departure, AoD) and MT (angle of arrival, AoA) are calculated for a large number of radio links. Mathematical definitions of these spread measures are included in [8]. The calibration is performed separately for Line of Sight (LoS), Non Line of Sight (NLoS), and Outdoor-to-Indoor (OtoI) propagation conditions. For simplicity, this calibration step assumes omni-directional antennas at both the BS and the MT. Delay spread distributions for each test scenario in LoS and NLoS are shown in Figure 4, while in Figure 5 and Figure 6 the AoA spread and AoD spread are shown. The distributions of the small scale parameters have been compared with the results of other partners in the framework of the WINNER+ project [8], proving the correct implementation of the IMT-Advanced channel model in the LTE-Advanced simulation platform.

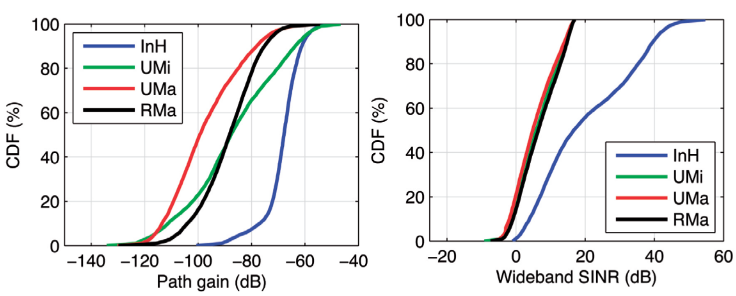

Figure 3. *Distribution of path gain (left) and distribution of wideband SINR (right) in the channel model large scale parameters calibration step.*

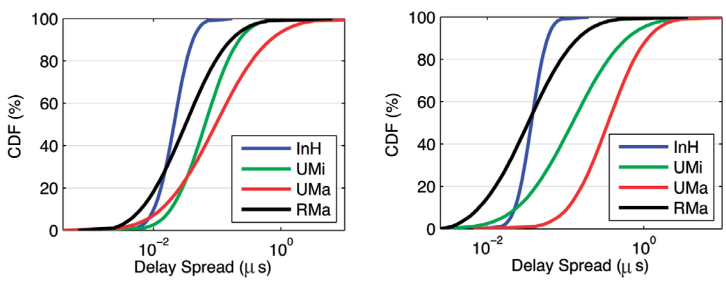

Figure 4. *Distribution of delay spread for LoS (left) and NLoS (right) in the channel model small scale parameters calibration step.*

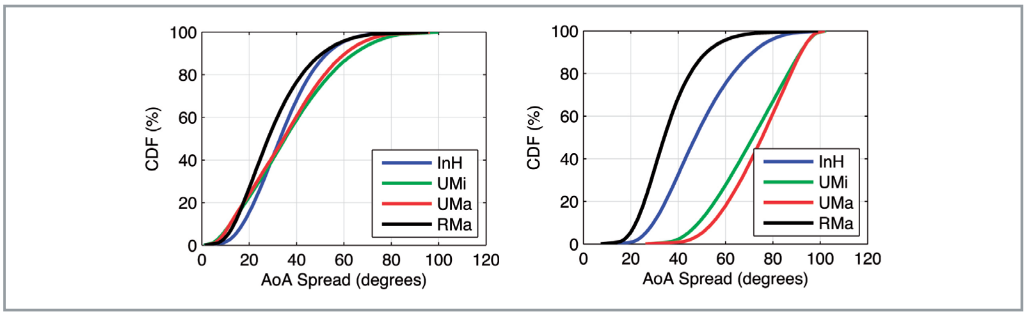

Figure 5. *Distribution of angle of arrival spread for LoS (left) and NLoS (right) in the channel model small scale parameters calibration step.*

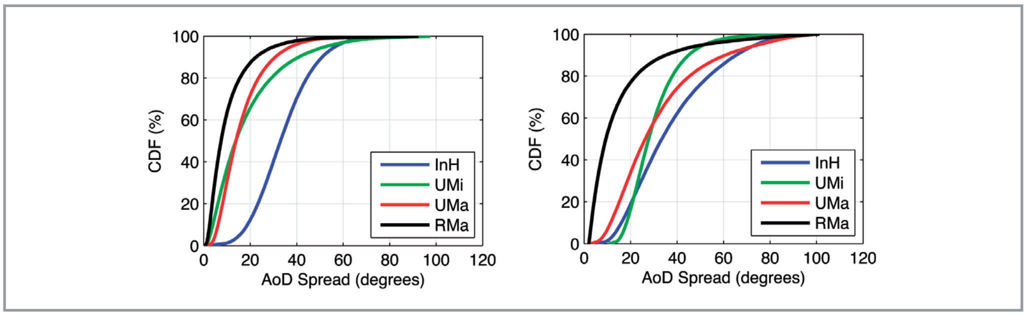

Figure 6. *Distribution of angle of departure spread for LoS (left) and NLoS (right) in the channel model small scale parameters calibration step.*

3.2 Baseline Configuration Calibration

In a third stage, spectral efficiencies, user throughput distributions and SINR distributions have been obtained and compared using a basic LTE configuration. In this configuration, baseline assumptions are made for non-standardized algorithms. For example, the chosen downlink scheduler is the Round Robin algorithm with full bandwidth allocation, that is, the whole set of resources is allocated to one of the users served by a cell in each transmission time. The DL transmission scheme is SIMO with one antenna at the transmitter side and two antennas at the receiver side. The antennas are vertically polarized with 0.5 wavelength separation at UE. In order to get a gain from diversity, MRC is used at the receiver. Link adaptation is achieved through a wideband CQI sent with a 5ms periodicity and without measurement errors. Channel estimation is also ideal.

In this calibration stage, the focus of the calibration is for the first time on the MAC layer and link abstraction model.

Results of this stage are presented in terms of three performance indicators. First, cell spectral efficiency is calculated as the total amount of bits correctly transmitted by the BS per unit of time and frequency. Second, the cell-edge user spectral efficiency is the spectral efficiency met by at least the 95% of the simulated MTs. Both performance indicators are heavily affected by the number of active users in the scenario under test. A user density of 10 MTs per cell has been considered in the simulations. The third performance indicator is the post antenna combination SINR, that is, the SINR obtained after the MRC

	Scenario				
Metric	Evaluator	InH	UMi	UMa	RMa
Cell spectral efficiency (b/s/Hz)	iTEAM	2.60	1.20	0.98	1.14
	3GPP	2.3	1.2	1.0	1.2
Cell-edge user spectral efficiency (b/s/Hz)	iTEAM	0.082	0.026	0.021	0.025
	3GPP	0.082	0.028	0.022	0.027

Table 2. *Cell and cell-edge user spectral efficiencies.*

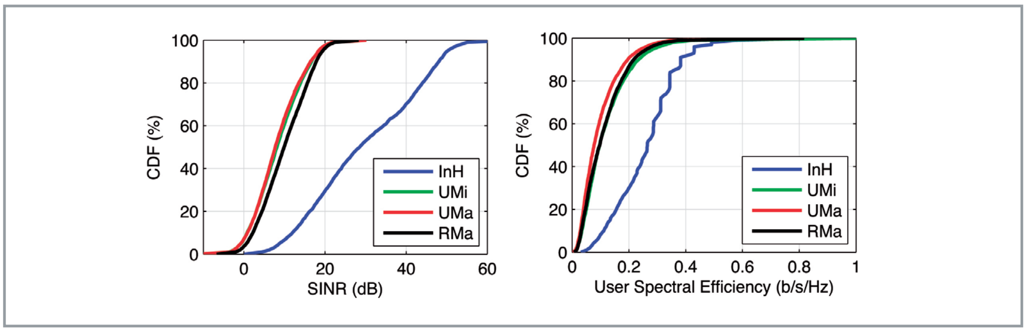

Figure 7. *Distribution of SINR after antenna combination (left) and distribution of user spectral efficiency (right).*

receiver and before the decoder. A unique SINR value is obtained through linear averaging over time and frequency for each user. Spectral efficiencies are presented in Table 2 while SINR and user spectral efficiency distributions are shown in Figure 7. Again, results obtained with the LTE-Advanced simulation platform are consistent with those obtained in the WINNER+ project [8] and in the 3GPP [9].

4. LTE-Advanced Performance

Once the system level simulation platform is calibrated, it is possible to assess the LTE-Advanced technical features that imply a simulative methodology.

Simulations have been conducted using full buffer traffic sources to obtain cell spectral efficiencies and cell edge user spectral efficiencies. Results are focused on the indoor hotspot scenario. The main simulation parameters are shown in Table 3.

Table 4 presents the results of the LTE-Advanced performance assessment for the indoor hotspot scenario. The IMT-Advanced requirement (Req), the mean results of the WINNER+ assessment (WINNER+) and the performance obtained with the presented simulation platform (ITEAM) are indicated. It can be observed that requirements are fulfilled in this scenario with the considered configuration.

Feature	Value
Scheduler	Proportional Fair
Downlink transmission scheme	Basic Release 8 (Codebook based precoded adaptive rank MIMO)
Receiver type	MMSE with interference cancellation
HARQ scheme	Incremental redundancy
Channel estimation	Ideal
Link adaptation	Non ideal, based on delayed feedback:
Channel state reports	Wideband PMI, subband CQI (5 resource blocks) CQI error per RB: N(0,1) PMI and CQI periodicity: 5 ms
Antenna configuration	BS: 4 antennas, vertically polarized, separated 4 wavelengths UE: 2 antennas, vertically polarized, separated 0.5 wavelengths
Control channel overhead	3 OFDM symbols per TTI for PDCCH

Table 3. *System configuration in indoor hotspot simulations.*

Performance indicator	Requirement	iTEAM	3GPP+	WINNER+
Cell spectral efficiency (b/s/Hz)	3.0	4.36	4.00	4.10
Cell-edge user spectral efficiency (b/s/Hz)	0.1	0.21	0.20	0.17

Table 4. *Cell and cell-edge user spectral efficiencies.*

5. Conclusions

It has been presented a LTE-Advanced compliant simulation platform developed according to the guidelines of the ITU for IMT-Advanced evaluation.

The main building blocks of the simulation platform have been explained. Some of these blocks are technology-agnostic, that is, they can be used in any IMT-Advanced simulator independently of the evaluated technology. This is the case of the network layout, channel module and the traffic sources. The link abstraction model is similar for different technologies but for each technology it is needed to calibrate the model parameters and also to have link level look-up-tables. Finally, it is proposed to use a layered model for the base station and mobile terminal entities. This layered model reflects the layers specified in the technology under study and hence these entities are also technology-dependent. In the LTE-Advanced simulator, the layered model includes three layers: physical, MAC and RLC. The main functions of these layers included in the specifications have been modeled such as the MIMO processing at the physical layer or the HARQ, link adaptation and scheduling at the MAC layer.

The simulator calibration process has been presented. In a first stage the channel model (and the network layout) has been validated. This validation has been achieved through cross-checking of the small scale and large scale parameters distributions obtained with the presented simulator and by other IMT-Advanced evaluators in reference scenarios. In this first stage technology-agnostic blocks have been involved. In a second stage a reference LTE configuration has been considered to calibrate technology-dependent simulator blocks. Again, calibration has been obtained comparing the results obtained with the presented simulator with those obtained by other researchers. The calibration process ensures the validity of the results obtained with the simulator.

Finally, the evaluation of several IMT-Advanced requirements has been performed through simulation for the indoor hotspot scenario. The obtained results show that LTE-Advanced meets the requirements set by ITU in this particular scenario.

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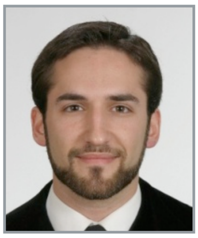
Biographies



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