Safjan, K.; D'amico, V.; Bültmann, D.; Martín-Sacristán, D.; Saadani, A.; Schöneich, H. (2011). Assessing 3GPP LTE-Advanced as IMT-Advanced Technology: The WINNER+ Evaluation Group Approach. IEEE Communications Magazine. 49(2):92-100. doi:10.1109/MCOM.2011.5706316.

Assessing 3GPP Long Term Evolution (LTE)-Advanced as IMT-Advanced technology: the WINNER+ Evaluation Group approach

Krystian Safjan, *Nokia Siemens Networks – Research, Poland*

Valeria D'Amico, *Telecom Italia, Italy*

Daniel Bültmann, *ComNets Research Group, RWTH Aachen University, Germany*

David Martín-Sacristán, *iTEAM Research Institute, Universidad Politécnica de Valencia, Spain*

Ahmed Saadani, *Orange-Labs, France*

Hendrik Schöneich, *Qualcomm CDMA Technologies GmbH, Germany*

Abstract: This article is describing the WINNER+ approach to performance evaluation of 3GPP LTE-Advanced proposal as IMT-Advanced technology candidate. Official registered WINNER+ Independent Evaluation Group evaluated this proposal against ITU-R requirements. First part of the article gives an overview on ITU-R evaluation process, criteria and scenarios. Second part is focused on the working method of the evaluation group emphasising simulator calibration approach. Finally the article contains exemplary evaluation results based on analytical and simulation approaches. The obtained results allow WINNER+ to confirm that the 3GPP LTE Release 10 & Beyond (LTE-Advanced) proposal satisfies all the IMT-Advanced requirements, thus it qualifies as IMT-advanced system.

Keywords: mobile communication, LTE, Long Term Evolution, ITU, IMT-Advanced, evaluation, performance assessment, simulation, calibration, 3GPP, OFDM, MIMO, CoMP, beamforming, end-to-end performance evaluation, system-level simulation, link-level simulation.

1. Introduction

Fast growing mobile traffic volume was one of the main reasons why the so-called 4th generation mobile communication systems are being investigated and standardized. For that reason a call for submission of system candidates towards IMT-Advanced was opened by ITU-R, while independent groups were encouraged to register to ITU-R to evaluate candidate systems. The IMT-A systems are meant to support low to high user mobility, various data rates, support for multiple environments while having capabilities for high quality multimedia applications and provide a significant improvement in performance and quality of service [1].

Predecessors of WINNER+ project, the WINNER I and II projects, had an important impact on the Long Term Evolution (LTE) roadmap. The WINNER I system concept represented an important contribution towards LTE, while WINNER II was involved in preparation of World Radiocommunication Conference 2007 (WRC-07) and had impact on IMT-A requirements in terms of spectrum demand, minimum requirements and evaluation methodology.

Shortly after WRC-07, ITU-R issued the Circular Letter [2] with call for submission of IMT-Advanced Radio Interface Technology proposals to ITU-R. Since WINNER+ predecessors were involved in ITU-R process, WINNER+ is covering both competence and tools for performing evaluations. In November 2008 WINNER+ registered as Independent Evaluation Group (IEG) at ITU-R for IMT-Advanced with a focus on evaluating the 3GPP LTE-Advanced proposal. Finally 14 IEGs from Americas, Asia and Europe registered at ITU-R.

By highlighting the WINNER+ IEG approach to simulator calibration, evaluation and providing exemplary evaluation results, this article attempts to address the challenge of how to pursue a system-level performance check supplying relevant and reliable performance indicators while keeping the performance analysis feasible and practical. WINNER+ is a consortium of project partners, therefore many different tools are used for evaluation. Thus, a relevant question appears: is it possible to assess similar performance results using different simulation tools of a complex communication system? In this paper we present the WINNER+ evaluation group approach on how to harmonize the “orchestra” of simulators while aligning different organizations with a variety of tools to produce converging system performance evaluation results.

We also shortly describe a limited set of test scenarios used in the evaluations that directly correspond to a typical usage scenario of the system under consideration. Finally a full evaluation of the 3GPP LTE Release 10 & Beyond (LTE-Advanced) candidate is performed, confirming that the proposal satisfies all the IMT-Advanced requirements.

2. ITU-R framework and evaluation process

The path towards IMT-Advanced has officially started in March 2008, when the Circular Letter was sent out by the ITU-R to invite submissions of IMT-Advanced technology proposals. The ITU-R schedule spans over the 2008-2011 timeframe and is shown in the following Figure 1, as in [3].

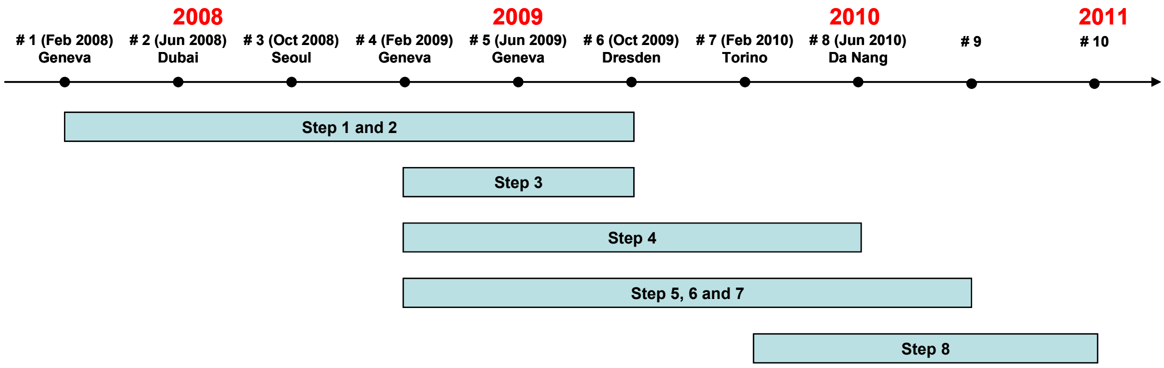

Figure 1: The ITU-R schedule for the IMT-Advanced process mapped to ITU-R WP5D meetings.

The radio interface development process is covered in several steps, the first one represented by the issuance of the Circular Letter (Step 1), after which Step 2 copes with the development of candidate Radio Interface Technologies (RIT) and Set of Radio Interface Technologies (SRIT). Step 3 represents the submission/reception of the RIT and SRIT proposals (and acknowledgement of receipt) to Working Party 5D (WP5D), the group within ITU-R responsible for IMT-Systems. Step 4 indicates the phase in which evaluation of candidate RITs or SRITs by evaluation groups is carried on. Step 5, Step 6 and Step 7 respectively refer to the review and coordination of outside evaluation activities, to the review to assess compliance with minimum requirements and, finally, to the consideration of evaluation results, consensus building and decision. Step 8 will then refer to the development of radio interface Recommendation(s).

The timing of these phases can partially overlap, as it is clear from the above schedule, and not all the phases are treated within ITU-R. In particular, step 4 is external to the ITU-R. Organizations willing to become an IEG have been invited to register with ITU-R.

In November 2008, the European Eureka Celtic project WINNER+ has registered as an IEG at ITU-R. WINNER+ has been very active in the IMT-Advanced process since its early stages. WINNER+ has participated to both rounds of workshops organized by the IMT-Advanced proponents in years 2009 and 2010 and to the relevant ITU-R WP5D meetings, by submitting several contributions and sharing the adopted work method, intended work plan and calibration assumptions and results. A dedicated website was activated by WINNER+ [4] so to share the updated calibration data status in real time with all the other IEGs. The calibration methodology proposed by WINNER+ has represented a basic guideline for all the IEGs. The alignment of such results across different evaluation groups has been verified, being beneficial for the robustness of the entire ITU-R process. A correspondence group was also initiated on the ITU-R website to address questions to the proponents and exchange comments among the different evaluation groups. WINNER+ has had a high level of communication with others through this tool.

The WINNER+ project, in its 30 months lifetime, has produced consistent research work [5] on optimisation of the radio interface concepts for IMT-Advanced systems, also thanks to the heritage of the activities carried out in the former European Union Framework Program 6 projects WINNER I and WINNER II. In particular, WINNER II has strongly influenced the channel model definition for IMT-Advanced[6]. Based on the expertise in IMT-Advanced radio technology concepts and in link- and system-level simulation tools, the WINNER+ Evaluation Group has considered the 3GPP LTE Release 10 & Beyond (LTE-Advanced) SRIT proposal consisting of a Time Division Duplexing (TDD) RIT and a Frequency Division Duplexing (FDD) RIT [7]. The WINNER+ group has evaluated all minimum requirements for IMT-Advanced systems by means of analytical, inspection and simulation activities in order to perform a full evaluation of the LTE-Advanced candidate technology.

For simulation purposes, in order to guarantee the reliability of the results, evaluated characteristics have been assessed by a plurality of partners. During the course of the work, great emphasis has been given to reflect a realistic behaviour of the system under consideration, by modelling non-ideal aspects including, e.g., effects of channel estimation errors, CQI measurement errors and feedback delay as well as a correct modelling of the overhead in the system. Simulators of different partner organizations have been calibrated in order to provide consistent results. The adopted calibration approach, detailed calibration results together with the requirements assessment will be provided in the following Section 4

3. Performance Criteria and Evaluation Scenarios

According to the evaluation process of ITU-R, IMT-Advanced candidate proposals need to fulfil a set of 13 requirements related to technical performance for IMT-Advanced radio interface(s) [8]. The requirements ensure that candidate systems fit to the framework of IMT systems.

It is to be checked by IEGs by inspection of the proposal whether the candidate system supports scalable bandwidths in the IMT-Advanced spectrum, supports a wide range of services and supports inter-system handover with at least one IMT-2000 system.

Furthermore, candidate systems should be designed to reach certain performance requirements under best-case conditions. Calculations should prove that peak spectral efficiency requirements can be reached and that user-plane, and control-plane latency as well as handover interruption times are meeting the requirements.

A third set of requirements refers to the efficient use of the radio spectrum under normal operation conditions. Link and system level simulations need to demonstrate high cell spectral efficiency while ensuring basic service for cell edge users. A high number of simultaneous voice calls must be supported and the system should operate at user speeds of up to 300 km/h.

For these simulations the ITU-R gives detailed guidelines for evaluation of radio interface technologies for IMT-Advanced [9] to ensure comparable simulation results across evaluation groups. According to [10] minimum requirements need to be fulfilled in three of four specific test environments that reflect future use cases of IMT-Advanced systems. Each environment is associated with a deployment scenario that specifies the simulation setup, e.g. inter-site-distance, carrier frequency, maximum transmit powers, channel model, etc.

In particular, the deployment scenarios defined in [9] are:

- **Indoor Hotspot** (InH): Small isolated cells at offices or hotspot areas. Targets high user throughput or user density for pedestrian users. Two base stations operating at 3.4 GHz with omni-directional antenna setup are mounted on the ceiling of a long hall with adjacent offices (cell coverage area 3000m^2).
- **Urban Micro-cell** (UMi): High traffic and user density for city centers and dense urban areas. Outdoor and outdoor to indoor propagation characteristics for pedestrian users are assumed. Continuous hexagonal deployment is used with 3 sectors per cell and below rooftop antenna mounting. Base stations operate at 2.5GHz and have an inter-site distance of 200m (cell coverage area 0.035km^2).
- **Urban Macro-cell** (UMa): Targets ubiquitous coverage for urban areas. A similar hexagonal deployment is used with larger inter-site distance of 500m and antennas mounted clearly above rooftop. Non line-of-sight or obstructed propagation conditions is common for this scenario. Only vehicular users at moderate speed are assumed, suffering from an additional outdoor to in-car penetration loss. Base stations operate at 2GHz (cell coverage area 0.22km^2).

- **Rural Macro-cell** (RMa): Similar to UMa, but targets larger cells with support for high-speed vehicular users. Base stations have an inter-site-distance of 1732m and operate at 800MHz which is more suitable for large cells (cell coverage area 2.59km²).
- **Suburban Macro-cell** (SMa): This is an optional scenario for the same test environment as of the UMa scenario. The key difference is an increased inter-site-distance of 1299m and a mix of indoor and high-speed vehicular users (cell coverage area 1.46km²).

During the evaluation phase, the Indian evaluation group TCOE India has proposed in [10] an additional optional scenario reflecting an important use case to serve rural areas. It can be characterized by:

- **Rural Indian Open Area**: This is a large-cell coverage scenario. Some parameters of the scenario may take several values, e.g. the carrier frequency, the terminal antennas height, the inter-site distance. The inter-site-distance is 30km-50km corresponding to typical distance between villages in India. In this scenario terminals are in fixed positions with rooftop directional antennas. Base stations operate at 312MHz-2300MHz (cell coverage area is up to 1962 km²).

4. Working method of the WINNER+ evaluation group

4.1 Assessment of the 3GPP technology candidate

In 2008, 3GPP held two “3GPP IMT-Advanced Workshops”. The goal of these workshops was to investigate what were the main changes that could be brought forward to enhance the Evolved Universal Terrestrial Radio Access Radio Interface as well as the Evolved Universal Terrestrial Radio Access in the context of IMT-Advanced.
In particular, the LTE-Advanced Study Item was initialized in order to study the evolution of LTE, based on new performance targets. This initiative has been collecting operator's and manufacturer's views in order to develop and test innovative concepts that will satisfy the needs of the next-generation communications. The resulting Technical Report was published in June 2008 and a contribution was sent to ITU-R covering the work in 3GPP RAN on LTE-Advanced towards IMT-Advanced. Finally 3GPP has contributed to the ITU-R towards IMT-Advanced via its proposal “3GPP LTE Release 10 & Beyond (LTE-Advanced)” [7].
The new technical features of LTE-Advanced are defined in [13]. Main technical features are the following:

- **Support of wider bandwidth**

  Carrier aggregation, where two or more component carriers, each with a bandwidth up to 20 MHz, are aggregated, is considered for LTE-Advanced in order to support downlink transmission bandwidths larger than 20 MHz, e.g. 100 MHz.
- **Extended Multi-Antenna configurations**

  Extension of LTE downlink spatial multiplexing is considered. LTE-Advanced supports spatial multiplexing of up to eight layers for the downlink direction and up to four layers for the uplink direction. Enhanced Multi-User MIMO (MU-MIMO) transmission is supported in LTE-Advanced.
- **Coordinated Multiple Point transmission and reception**

  Coordinated multi-point (CoMP) transmission/reception is considered for LTE-Advanced as a tool to improve the coverage of high data rates, the cell-edge throughput and/or to increase system throughput. Downlink CoMP transmission implies dynamic coordination among multiple geographically separated transmission points. The 3GPP currently considers the following two categories: Joint Processing and Coordinated Scheduling/Coordinated Beamforming. Downlink CoMP transmission should include the possibility of coordination between different cells. Two implementations of CoMP can be considered: inter-site CoMP and intra-site CoMP. Initially the focus of CoMP will be on intra-site schemes. In fact for Release 10, there will be no new standardised interface communication for support of inter-site CoMP, therefore no additional features are specified to support downlink CoMP. Uplink CoMP reception is expected to have very limited impact on the specifications. Uplink CoMP reception can involve joint reception of the transmitted signal at multiple reception points and/or coordinated scheduling decisions among cells to control interference.

- **Relaying functionality**

  Relaying is considered for LTE-Advanced as a tool to improve the coverage of high data rates, group mobility, temporary network deployment, the cell-edge throughput and/or to provide coverage in new areas. Relay nodes are placed throughout the macro-cell layout, hence modifying the reference layout specified in [9]. Moreover the channel model to be used to model relay backhauling transmission link was not defined in [9]. For these reasons relay nodes have not been considered as advanced feature to be used when assessing IMT-Advanced requirements.

The evaluation guidelines published by ITU-R in [9] are helpful for IMT-A systems evaluation but evaluating Beyond Rel.10 systems is still challenging since there is a need for specifying reference scenarios and missing parameters for new features like e.g. CoMP or multilayered networks.

4.2 Splitting the work: analytical, inspection and simulation approaches

In its "Guidelines for evaluation of radio interface technologies for IMT-Advanced" [9] the ITU-R defined the characteristics for evaluating IMT-Advanced candidate proposals. The characteristics can be classified based on the three different methods for evaluation:

1. Analytical
2. Inspection
3. Simulation (link-level or system-level).

Analytical evaluation comprises all characteristics that can be calculated. It is performed for the characteristics peak spectral efficiency, control and user plane latency as well as intra- and inter-frequency handover interruption time. Inspection is a non-numerical check by the IEG that certain requirements are fulfilled and certain capabilities are provided. The characteristics bandwidth, inter-system handover, deployment in at least one of the identified IMT bands, channel bandwidth scalability, and support for a wide range of services are evaluated by inspection.

Numerical characteristics that are too complicated to be calculated are evaluated by simulative methods. These characteristics are cell spectral efficiency, cell edge user spectral efficiency, mobility, and VoIP capacity. The simulations results should respect the guidelines and the deployment scenarios detailed in [9].

4.3 Preparing the work: calibration of the simulators

In the WINNER+ project the evaluations have been performed by several partners using different simulation tools. To ensure that all tools yield coherent results, key components were calibrated among partners. Specifically, the channel model implementation, that is technology agnostic, and a basic setup of the baseline LTE Release 8 communication system were aligned among partners. The calibration process was implemented using a stepwise approach with three steps: channel model large scale parameters calibration, channel model small scale parameters calibration and the baseline system calibration. Such calibration work provided high reliability to the WINNER+ IEG main evaluation work that was focused on the full assessment of the 3GPP LTE Release 10 & Beyond (LTE-Advanced) proposal.

The channel model proposed by ITU-R in [9] is far from being simple to implement. This is why the WINNER+ IEG addressed a channel model implementation calibration from the beginning. The channel model calibration process was divided in two steps: the large scale parameters calibration and the small scale parameters calibration.

Large Scale Calibration (LSC) is focused on the calibration of the channel model implementation without multipath effects, that is, only with large scale fading. The metrics used in this calibration are the pathgain and the wideband signal to interference plus noise power ratio (SINR). The pathgain is defined as the average signal attenuation between a user terminal and its serving base station. The measure includes distance attenuation, shadowing and antenna gains (both at the base station and at the user terminal) while the effects from fast fading are excluded. The downlink wideband SINR, sometimes also called the geometry, is the average power received from the serving cell in relation to the average interference power received from all other cells plus noise. In addition to the evaluation principles and assumptions in [9] and the channel model clarifications that followed, additional assumptions concerning the cell selection mechanism, feeder loss and base station antenna tilt have been used to derive the pathgain and wideband SINR distributions. Exact values are included in [12].

Small Scale Calibration (SSC) is focused on the calibration of the multipath part of the channel model. Given that the channel model is a stochastic geometric model, the stochastic distributions of several geometric characteristics are calibrated. These characteristics include the delay spread, the departure and arrival angular spread at the base station and at the user terminal respectively (also known as angle of departure, or AoD, and angle of arrival, or AoA). The root mean square delay spread and the circular angular spread at the base station and at the user terminal are calculated for a large number of radio links and in the calibrations the corresponding distributions are compared. Mathematical definitions of these spread measures are included in [12]. The calibrations are performed separately for line of sight (LoS), non line of sight (NLoS) and outdoor-to-indoor (OtoI) propagation conditions.

As an example of the calibration data collected in this phase we provide curves obtained in the UMi deployment scenario in Figure 2. Results of several partners are included and also the averaged curves of the group. It can be concluded that the calibration is achieved. The complete calibration data obtained by WINNER+ is available in the WINNER+ IMT-Advanced evaluation web page [4].

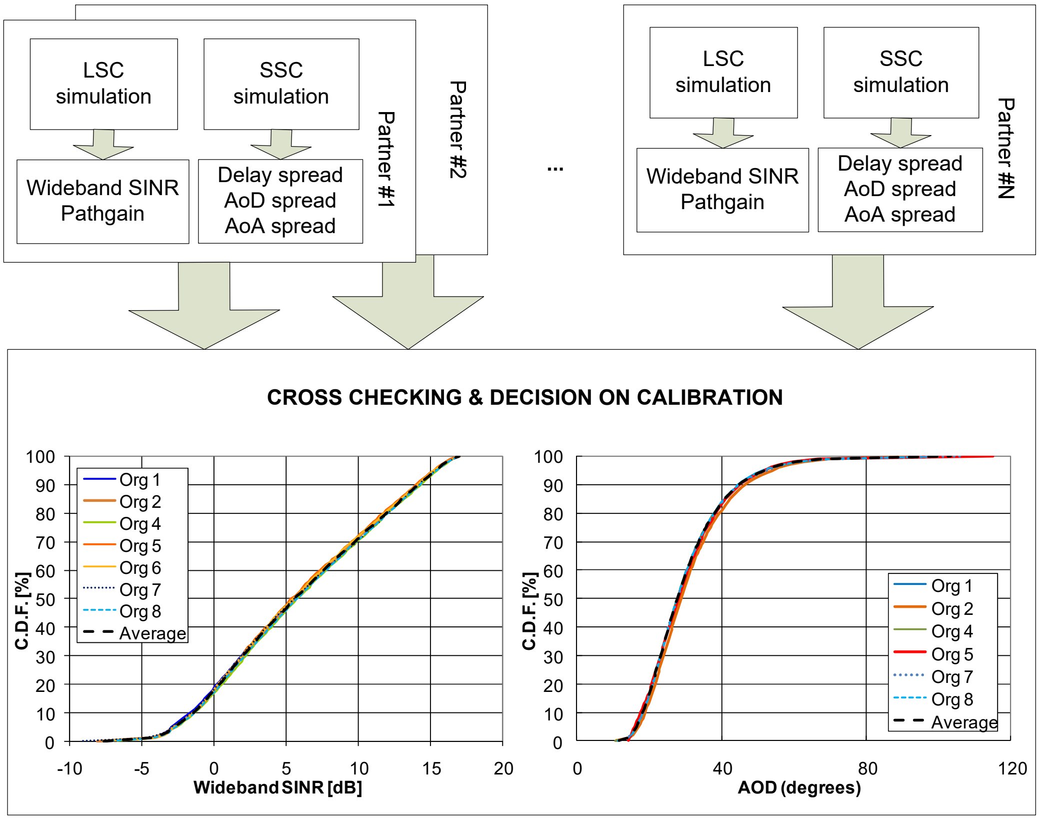

Figure 2: Channel model calibration (steps 1 and 2 of the calibration process) with examples of wideband SINR (left) and Angle of Departure (right) distributions in the UMi NLoS scenario

WINNER+ has focused on evaluating the 3GPP LTE Release 10 & Beyond (LTE-Advanced) proposal and, in order to prepare the system level evaluations, a simulator **calibration for the baseline configuration** was performed in the third step of the calibration process. The reference baseline configuration is illustrated in Figure 3 and the detailed simulation parameters can be found in [13].

Simulation Parameter	Value
Duplex Method	FDD
Traffic	Full Buffer
Downlink Scheduling	Round Robin (TDMA)
Uplink Scheduling	Round Robin (FDMA)
Uplink Power Control	P0 = 106.0 dBm Alpha = 1.0
...	...

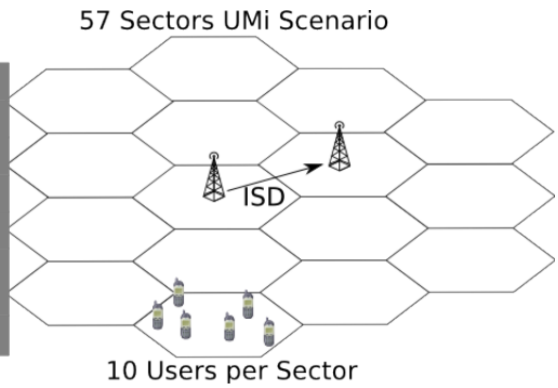

Figure 3: Baseline system calibration scenario and parameters

Harmonization of simulators was done by comparing uplink and downlink spectral efficiencies (both cell and cell edge) for a baseline setup. Implementations of all major parts of an LTE compliant protocol stack such as H-ARQ retransmissions, channel status feedback loop, power control, scheduling and receiver setup were included. For non-standardized algorithms baseline assumptions were made. By comparing the normalized downlink and uplink user throughput (user spectral efficiency) distributions in Figure 4 it can be seen that a good alignment between WINNER+ partners was achieved.

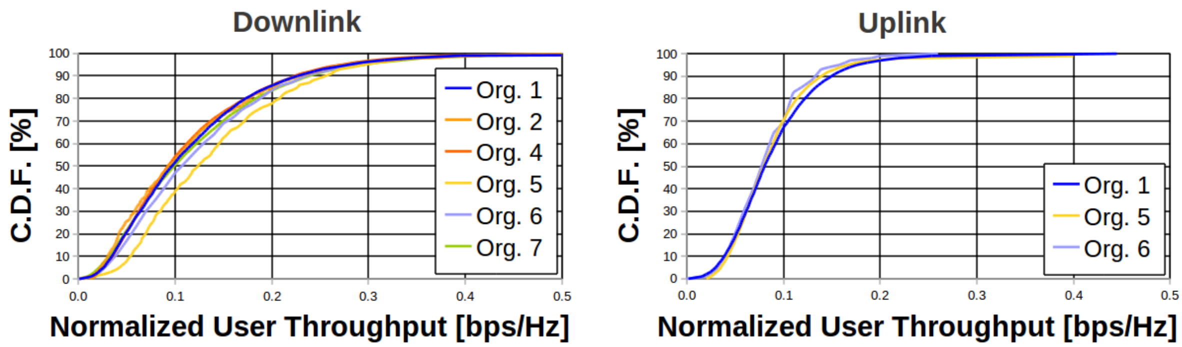

Figure 4: Baseline system calibration (step 3 of the calibration process) for UMi scenario

The presented information and benchmark data has been derived for all IMT-Advanced deployment scenarios and it has been shared with the other IEGs during the evaluation period, in order to foster the required coordination and unification of results.

4.4 LTE-Advanced technology candidate results

This section gives an introduction to a subset of evaluation characteristics addressed by the WINNER+ IEG for the 3GPP LTE Release 10 & Beyond (LTE-Advanced) proposal assessment. The peak spectral efficiency is presented as an example for the analytical method. This is followed up by simulation results based on the aforementioned calibration outcome.

Analytical results

The peak spectral efficiency (PSE) is defined in [8]. It is basically the highest theoretical data rate normalised by bandwidth assignable to a single mobile station assuming error-free conditions. The WINNER+ IEG evaluated PSE for LTE-Advanced FDD mode and TDD mode in uplink and downlink. In addition to evaluation configuration parameters provided in [9] with up to 4 Rx and 4 Tx antennas at the base station and up to 4 Rx and 2 Tx antennas at the mobile station, also configurations with up to 8 antennas were investigated for informative purposes.

From a mathematical point of view the PSE calculation is not demanding. It is simply the number of data bits that can be transmitted divided by the bandwidth and the time needed for that transmission.

But LTE-Advanced, as any other mobile radio system, needs overhead that does not contribute to the data rate. Reference and synchronization signals as well as broadcast channels and control signalling with channels carrying different indicators and control information form such overhead. Depending on the mode and the direction of transmission, different overhead types have to be taken into account. In TDD mode the guard period (GP) which separates downlink and uplink transmission in time domain adds additional overhead. For the PSE calculation one may additionally distinguish between different overhead types that add to the data rate or not. This topic was raised during a workshop organised by 3GPP for all IEGs end of 2009 and finally clarified by ITU-R in a liaison statement in 2010. A further topic was the handling of the GP duration in TDD mode and its influence on the time normalisation for PSE calculation.

The WINNER+ IEG provided multiple PSE calculations for LTE-Advanced and all of them clearly fulfilled the IMT-A requirements. The results for 4-layer spatial multiplexing are summarised in Table 1.

Table 1: Requirements and analytical PSE results for FDD and TDD RIT.

PSE in bit/s/Hz	ITU-R Requirement	FDD RIT Assessment	TDD RIT Assessment
Downlink	15	16.3	15.8
Uplink	6.75	8.4	7.9

As it is clearly beyond the scope of this paper to go into technical details the interested reader is referred to the final evaluation report [12] where the calculation is explained in detail.

Simulation results

Simulations have been derived by the organisations and results are compared to the ITU-R requirements. The assessment is done in different ITU-R environments and for FDD and TDD RIT. The ITU-R guidelines impose that for DL, the number of antennas to be used should be higher or equal to n = 4 for the transmitter and m = 2 for the receiver. However for the UL, only the receiver should use at least m = 2 antennas. The use of different transmitting schemes allowed by the LTE-Advanced and constraint given by the antenna number, leads to different simulation results. The following definitions for the transmission schemes hold:

- SIMO: the transmitter uses 1 antenna and the receiver m antennas. This scheme is called 1 × m Single Input Multiple Output.
- BF: the transmitter uses n and the receiver m antennas. The transmitter exploits the n antennas to orientate the transmitting power of the transmitted data stream to the receiver favourite direction. The scheme is called n × m Beam Forming.
- SU-MIMO: the transmitter uses n and the receiver m antennas. The transmitter uses all n antennas to transmit for only one receiver one or several data streams. This schemes is called n × m Single User (SU)- MIMO.
- MU-MIMO: several receivers having m antennas share the n transmitting antenna to be served on the same time-frequency resources. This scheme is called Multi-user (MU) MIMO.

Table 2 summarizes the main results in Urban-Micro Cell and Urban-Macro Cell environments for FDD RIT. The results presented in this table for cell spectral efficiency and cell edge spectral efficiency are averaged over results coming from different organizations, evaluated using the same transmission scheme. We note that different LTE advanced transmission schemes permit the requirement achievement for UL and DL. The UMi and UMa deployment scenarios are the most challenging ones since there is a need to use MU-MIMO to achieve the downlink requirements. However, InH and RMa requirements are met using SU-MIMO configuration. Uplink requirements are less demanding than downlink requirements since them can be achieved with SIMO configurations.

For the mobility assessment, the traffic channel link data rate and the support of the mobility classes are addressed. It is also shown that their requirements are also achieved for the considered environments. Finally the VoIP capacity is assessed and it is shown that the required number of active users/sector/MHz is achieved by the LTE-Advanced technology.

Table2: Requirements and simulation results in UMi and UMa environments for FDD RIT

	UMi		**UMa**	
	Requirement	**Assessment results**	**Requirement**	**Assessment results**
Cell spectral efficiency in DL (bit/s/ Hz/cell)	2.6	**2.88*** (4x2 MU-MIMO)	2.2	**2.38*** (4x2 MU-MIMO)
Cell spectral efficiency in UL (bit/s/ Hz/cell)	1.8	2.07* (1x4 SIMO) 2.41* (2x4 BF) **2.59*** (2x4 SU-MIMO)	1.4	1.60* (1x4 SIMO) **2.94** * (2x4 BF) 1.97 * (2x4 SU-MIMO
Cell edge spectral efficiency in DL (bit/s/ Hz/cell)	0.075	**0.089*** (4x2 MU-MIMO)	0.06	**0.067*** (4x2 MU-MIMO
Cell edge spectral efficiency in UL (bit/s/ Hz/cell)	0.05	0.082* (1x4 SIMO) 0.124* (2x4 BF) **0.127*** (2x4 SU-MIMO)	0.03	0.073* (1x4 SIMO) **0.092*** (2x4 BF) 0.091* (2x4 SU-MIMO
Mobility Traffic channel link data rates in UL (bits/s/Hz)	0.75	**1.27*** (1x4 SU-MIMO)	0.55	**1.36*** (1x4 SU-MIMO)
Mobility classes supported	Stationary, pedestrian, Vehicular (up to 30 km/h)	YES	Stationary, pedestrian, vehicular	Yes
VoIP capacity (Active users/sector/MHz)	40	**83***	40	**66***

* *Mean value of all contributing organizations for the given antenna configurations. Note that the mean value does **not** represent the performance of one particular system setup. Values in bold (maximum values in case of multiple antenna configurations) are taken as main results.*

In general, the addressed requirements are achieved by simulations in all environments for FDD and TDD RIT. A complete set of assessment results for all ITU-R deployment scenarios derived by WINNER+ IEG is described is [12]. The obtained results have confirmed that the 3GPP LTE Release 10 & Beyond (LTE-Advanced) proposal satisfies all the IMT-Advanced requirements.

5. Conclusions

The WINNER+ project responded to the ITU-R call to form an IEG and created its own evaluation group. The evaluation effort has different flavours ranged from careful study of the proponent proposal (Inspection) through calculation (Analytical) to the link-level and system-level simulations (Simulation). Evaluations by simulations were preceded by calibration. The stepwise calibration exercise appeared to be a complex and demanding task. During this step, communication among independent evaluation groups was relevant. Making results of the WINNER+ IEG publicly available has enabled discussions and the possibility to compare results among other IEGs. Furthermore WINNER+ gave a hint on one possible approach on how to cope with calibration.

WINNER+ IEG also promptly reacted on proposed scenarios suggested by other IEG, as in the case of “Rural Indian Open Area” additional test scenario. The WINNER+ IEG response can be an example of agile approach to the evaluation activity.

The WINNER+ evaluation Group completed its assessment of the 3GPP LTE-Advanced proposal and submitted its final evaluation report to ITU-R WP5D in June 2010. The main conclusion drawn from the results is that 3GPP LTE Release 10 & Beyond (LTE-Advanced) proposal satisfies all the IMT-Advanced requirements thus it qualifies as IMT-advanced system.

There is an expectation that further LTE evolution beyond Rel.10 will provide even better performance since multiple features considered in further releases e.g. Relaying, Coordinated Multipoint Transmission and reception (CoMP) were not a part of evaluated proposal.

6. ACKNOWLEDGMENT

This work has been performed in the framework of the CELTIC project CP5-026 WINNER+. The authors would like to acknowledge the contributions of their colleagues in the WINNER+ consortium. The authors wish to thank colleagues from Ericsson Per Skillermark and Johnan Nyström for their effort in leading simulations part of WINNER+ evaluation group. The work of David Martín-Sacristán was supported by a FPU grant of the Spanish Ministry of Education

7. References

[1] Doc IMT-ADV/1-E “Background on IMT-Advanced”

[2] ITU-R Circular Letter 5/LCCE/2 and addendums: “Invitation for submission of proposals for candidate radio interface technologies for the terrestrial components of the radio interface(s) for IMT-Advanced and invitation to participate in their subsequent evaluation”

[3] ITU-R Doc IMT-ADV/2 Rev1 “Submission and evaluation process and consensus building”

[4] http://projects.celtic-initiative.org/winner+/WINNER+%20Evaluation%20Group.html

[5] WINNER+ D4.2 “Final conclusions on end-to-end performance and sensitivity analysis”, June 2010 Available:http://projects.celtic-initiative.org/winner+/WINNER+%20Deliverables/D4.2_v1.0.pdf

[6] IST-WINNER D1.1.2 P. Kyösti, et al., "WINNER II Channel Models", ver 1.1, Sept. 2007. Available: https://www.ist-winner.org/WINNER2-Deliverables/D1.1.2v1.1.pdf

[7] Doc IMT-ADV/8 “Acknowledgement of candidate submission from 3GPP proponent (3GPP organization partners of ARIB, ATIS, CCSA, ETSI, TTA AND TTC) under Step 3 of the IMT-Advanced process (3GPP technology)”, October 2009

[8] ITU-R M.2134 “Requirements related to technical performance for IMT-Advanced radio interface(s)”, November 2008

[9] ITU-R M.2135 “Guidelines for evaluation of radio interface technologies for IMT-Advanced”, November 2008

[10] ITU-R IMT-ADV/16 “Evaluation of IMT-Advanced candidate technology submissions in documents IMT-ADV/4 and IMT-ADV/8 by TCOE India”, 2010

[11] ITU-R M.2133 “Requirements, evaluation criteria and submission templates for the development of IMT-Advanced”

[12] Doc. IMT-ADV/22 “Evaluation of IMT-Advanced candidate technology submissions in Documents IMT-ADV/6, IMT-ADV/8 and IMT-ADV/9 by WINNER+ Evaluation Group”, available at: http://www.itu.int/ITU-R/index.asp?category=study-groups&rlink=rsg5-imt-advanced&lang=en

[13] 3GPP TR 36.814 “Evolved Universal Terrestrial Radio Access (E-UTRA); Further advancements for E-UTRA physical layer aspects”, v.9.0.0, March 2010.

Author Biographies

Krystian Safjan graduated Wroclaw University of Technology, Wroclaw, Poland, Faculty of Electronics, Specialization of Telecommunications / Digital Signal Processing in 2004. After the graduation he joined current Nokia Siemens Networks Sp z o.o., Poland, where he is involved in research and development of B3G systems within the Department of Radio System Technology. His main research interests are concentrated on advanced radio resource management methods.

Valeria D'Amico received a MSc degree in Electronics Engineering from the University of Catania, Italy. After an internship in ST Microelectronics, she joined Marconi Mobile. Since 2001 she is with Telecom Italia where she has been involved in several activities targeting future generation communications, contributing to the Italian-funded FIRB PRIMO project and to the Eureka Celtic WINNER+ project. Currently she is involved in the EU ARTIST4G project, leading the work package on interference avoidance.

Dipl.-Ing. **Daniel Bültmann**, received his Diploma degree in electrical engineering from RWTH Aachen University in 2004. Since January 2005, he is employed as Research Assistant with the Research Group ComNets, RWTH Aachen University where he is working towards his Ph.D. degree. The focus of his research is on LTE-Advanced radio resource management. He was involved in WINNER II and WINNER+ projects

David Martín-Sacristán received his M.S. degree in telecommunications engineering from the Polytechnic University of Valencia (UPV) in 2006. Nowadays, he is a Ph.D student in the Institute of Telecommunications and Multimedia Applications (iTEAM), UPV. His research interests are focused on beyond 3G networks including modeling and simulation, resource management and link adaptation.

Ahmed Saadani received his Engineering degree from Tunisia Polytechnic School in 1999, his Masters degree in 2000 and the PhD degree in digital communications in 2003 from the Ecole National Supérieure des Télécommunications (ENST), Paris, France. He then joined Orange Labs, Issy les Moulineaux, in France as a research engineer where he worked on advanced receivers and MIMO schemes for 3G/3G+ systems. His current research interests are in cooperative communications, relaying and distributed MIMO for 4G systems.

Hendrik Schöneich received his Dipl.-Ing. degree in 2001 for a diploma thesis on co-channel interference cancellation in the GSM system. He joined the Information and Coding Theory Laboratory (ICT) in 2001, where he worked as a research assistant on different research topics with a focus on interleave-division multiple access (IDMA). He received his Dr.-Ing. degree for a thesis on adaptive IDMA in mobile radio communication systems. Since 2006 he has been with Qualcomm CDMA Technologies GmbH Nuremberg. His research interests include iterative interference cancellation, turbo equalization and decoding, semi-blind channel estimation, and related resource allocation strategies.