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Beyond Conformance Testing in 3GPP LTE

White Paper

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1. ABSTRACT

The 3rd Generation Partnership Project (3GPP) Long Term Evolution (LTE) standard was formally frozen in March 2009. The freezing of the standard speeds up LTE product development and testing. This White Paper introduces the 3GPP LTE technology and discusses the conformance and beyond conformance test aspects. The paper describes how LTE products, systems and applications are tested in a realistic wireless environment – not in the field but in a laboratory.

The benefits of beyond conformance testing compared to standard conformance testing are explained. LTE terminal and base station manufacturers as well as operators are recommended to go beyond basic testing and carry out performance measurements already in the early phases of LTE product development. The White Paper also discusses the different testing methods and introduces key radio channel models which can be used in the testing process.

ABBREVIATIONS

3GPP	3rd Generation Partnership Project
AoA	Angle of Arrival
AoD	Angle of Departure
AWGN	Additive White Gaussian Noise
B3G	Beyond 3G
BER	Bit Error Rate
BLER	BLock Error Rate
BSC	Base Station Controller
CDL	Clustered Delay Line
eNodeB	evolved Node B (LTE base station)
EPA	Extended Pedestrian A channel model
ETU	Extended Typical Urban channel model
EVA	Extended Vehicular A channel model
HSDPA	High Speed Downlink Packet Access
HSPA	High Speed Packet Access
HSPA+	HSPA evolution
Flash-OFDM	Fast Low-latency Access with Seamless Handoff – OFDM
GSCM	Geometry-based Stochastic Channel Model
IMT-2000	International Mobile Telecommunications (global 3G standard)
IMT-Advanced	IMT-Advanced (global 4G standard)
IPTV	Internet Protocol Television
ITU	International Telecommunication Union
ITU-R	ITU Radiocommunication sector
LoS	Line of Sight
LSP	Large Scale Parameter
LTE	Long Term Evolution (3.9G)
LTE-Advanced	Long Term Evolution Advanced (4G)
MIMO	Multiple-Input Multiple-Output (any multi-antenna system)
NLoS	Non Line of Sight
OFDM	Orthogonal Frequency Division Multiplexing
OFDMA	Orthogonal Frequency Division Multiple Access
PAPR	Peak to Average Power Ratio
QoS	Quality of Service
RNC	Radio Network Controller
RRM	Radio Resource Management
SAE	System Architecture Evolution
SC-FDMA	Single Carrier Frequency Division Multiple Access
SCM	Spatial Channel Model
SCME	SCM Extended
TDL	Tapped Delay Line
UE	User Equipment
UMTS	Universal Mobile Telecommunications System
WCDMA	Wideband Code Division Multiple Access
WINNER	Wireless world INitiative NEw Radio (project name)

2. INTRODUCTION

In the past few years mobile data usage has experienced a remarkable growth. Mobile subscribers are increasingly using the cellular networks to access the Internet and other data services. This trend is showing no signs of slowing. Figure 1 illustrates an estimation of the total data growth in mobile networks for the near future. Many telecom operators have been reporting a 6- to 14-fold increase in mobile data consumption from 2007. [Source: Rysavy Research, EDGE, HSPA and LTE - Broadband Innovation, November 2008].

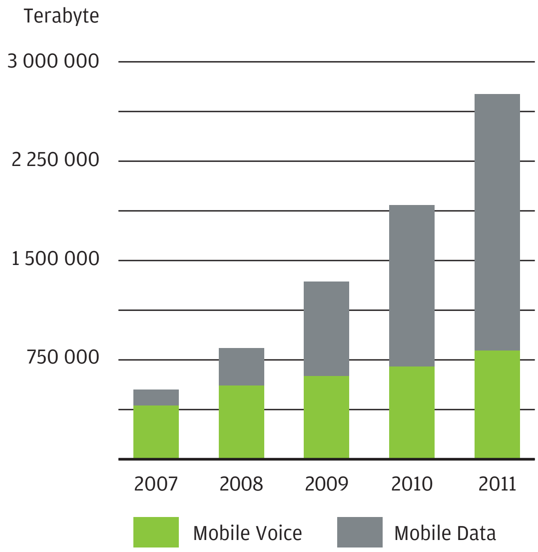

Figure 1. Traffic growth estimation in mobile networks.

2.1 Mobile Data Business Drivers

The key business driver for the significant growth in mobile data consumption is the recent breakthrough of broadband wireless access (broadband wireless access) technologies such as WLAN, UMTS/HSPA, LTE and WiMAX. The increase in the data traffic from cellular subscribers is driven by easy and ubiquitous access from laptop computers with cellular USB dongles, as well as new laptop models featuring built-in cellular interfaces. This access method is made feasible by the flat rate billing model that is becoming increasingly popular with operators. The increased data rates also make it possible to introduce many new, innovative services.

Although the broadband wireless access trend provides many business opportunities for mobile broadband internet service providers, it does not come without some serious challenges. The key challenge for cellular operators in providing a flat-rate broadband wireless access subscription is the cost per bit offered. As the data rates increase, it is becoming increasingly evident that the cost per bit figures offered by current third generation (3G) technologies cannot scale to the widespread adoption of high speed broadband wireless access subscriptions. This is due to the complexity of the current cellular network infrastructure and the limitations of the radio interface technology. To overcome the above-mentioned challenges, LTE provides interesting opportunities for high data rate applications.

2.2 LTE – Next Generation of Mobile Data

Many traditional cellular operators are looking towards another emerging technology as a way to evolve their networks. This technology is called Long Term Evolution (LTE). LTE is specified by the Third Generation Partnership Project (3GPP). The same organization currently oversees the development of the other "GSM family" of technologies. The GSM family is illustrated in Figure 2.

The 3GPP LTE is specified in Release 8 of 3GPP specifications. LTE has been designed to be interoperable with the other GSM family of technologies. Therefore it provides a logical evolution path for existing GSM and WCDMA operators.

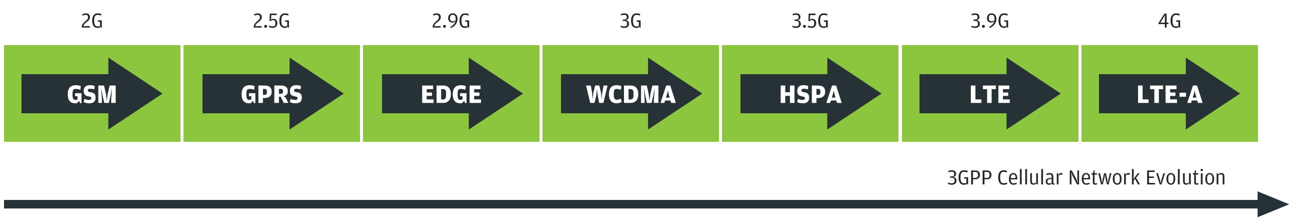

Figure 2. GSM family of technologies

LTE covers a new radio interface and enhanced core network architecture (SAE) that is based completely on IP transport. LTE is expected to substantially improve cell capacity, end-user throughput, provide enhanced Quality of Service (QoS) and reduce the latency experienced by the user. These features are expected to finally make mobile broadband a reality and bring with it a significantly improved user experience. These features allow LTE to support new, more demanding services, such as IPTV, music and video sharing, interactive gaming and other multimedia applications. Some key features of LTE are listed below.

- Downlink peak data rates of more than 100 Mbps and uplink peak data rates in the range of 50 Mbps.
- Radio interface based on OFDMA and SC-FDMA with support for high order modulation (64-QAM).
- Support for flexible carrier bandwidths ranging from 1.25 MHz up to 20 MHz.
- Support for a wide variety of new and existing spectrum bands.
- Support for FDD and TDD deployments.
- Support for seamless handovers to existing 3GPP cellular networks.
- Support for multi-antenna MIMO configurations both in the terminal and in the base station.

LTE coverage will most likely be provided for urban centers first, where it will complement the existing 2G and 3G network coverage.

2.3 LTE Radio Fundamentals

The LTE radio interface carries data and control signals between the LTE terminal and the base station, more specifically known as the evolved Node B (eNodeB). In GSM/WCDMA systems the base station is only responsible for the physical layer processing, and the BSC/RNC handles critical Radio Resource Management (RRM) related tasks. In LTE the base station is solely responsible for all radio-related processing.

The LTE downlink radio transmission is based on Orthogonal Frequency Division Multiplexing (OFDM). OFDM is a so-called multicarrier modulation technique, in which the channel bandwidth is divided into a number of subcarriers (Figure 3). Each subcarrier is individually modulated with a part of the overall bit stream to be transmitted. OFDM provides several benefits that make it a suitable choice for wireless transmission. OFDM-based receivers are less complex than WCDMA receivers, which directly relates to the development costs of UE and making OFDM well suitable for downlink. OFDM provides good protection against Inter-Symbol Interference (ISI), as well as against narrowband interference in general. In addition, implementation of the flexible channel bandwidth is relatively easy with OFDM-based systems. The bandwidth can be scaled by simply changing the number of subcarriers used for transmission. OFDM is also used in WLAN and WiMAX.

What separates OFDM from normal frequency division multiplexing is the subcarrier spacing. By carefully selecting the correct parameters the subcarriers are made orthogonal or non-interfering to each other. This allows the subcarriers to be placed closer to each other in the frequency domain, thus increasing the spectral efficiency of the transmission.

LTE radio uses OFDM somewhat differently in the downlink and in the uplink. In the downlink the basic OFDM functionality is extended to also provide the means for multiple access. This variation of OFDM is called Orthogonal Frequency Division Multiple Access (OFDMA). With OFDMA the LTE base station transmits to different users by using different sets of subcarriers, as illustrated in Figure 4.

The subcarrier allocation can be changed rapidly in order to adapt to changing radio channel conditions. The LTE base station makes the radio resource allocation decision by employing RRM algorithms. The uplink and downlink resources are allocated independently of each other. The allocation criterion is not specified in the 3GPP specifications, but it could be based on the channel quality feedback reported by the mobile terminals, for example.

One of the drawbacks of OFDMA is the relatively high Peak to Average Power Ratio (PAPR). The OFDMA symbols can

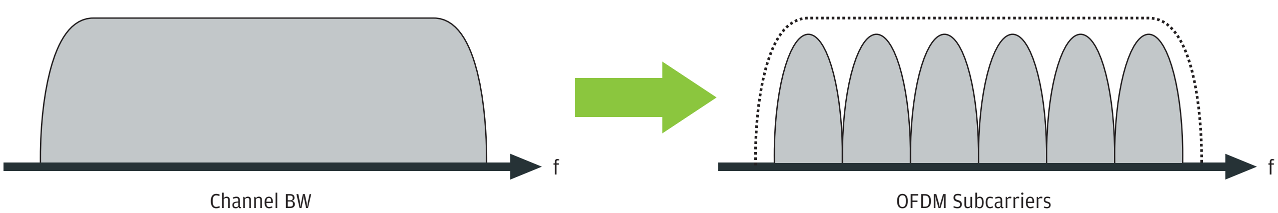

Figure 3. Illustration of OFDM technology. The channel bandwidth is divided to closely spaced orthogonal sub-carriers.

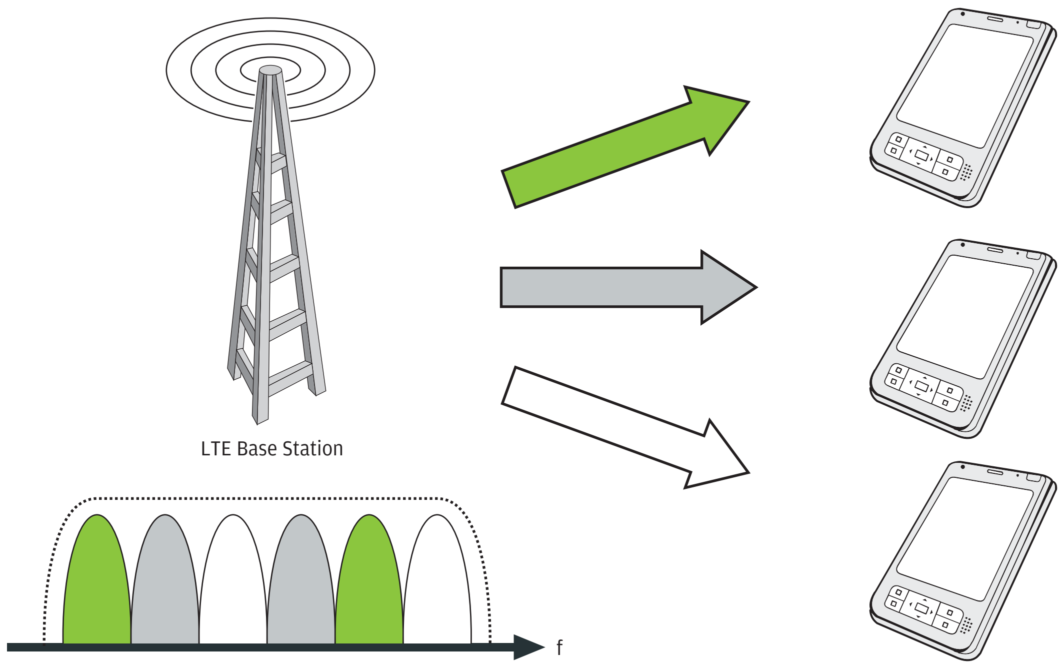

Figure 4. Multiple access in OFDMA is done by assigning different subcarriers to individual users.

have high amplitude peaks, which requires advanced linear power amplifiers and in practice leads to power inefficiency. OFDM modulation was deemed unfeasible for LTE terminal transmission. Therefore, a more power-efficient transmission scheme, known as Single Carrier Frequency Division Multiple Access (SC-FDMA), was developed for the uplink transmission. SC-FDMA is in principle quite similar to OFDMA. The main difference is that with SC-FDMA data is transmitted effectively on a symbol-by-symbol basis. This approach produces a PAPR level which is significantly smaller than that of OFDMA.

Multiple-Input-Multiple-Output (MIMO) technology has received much attention in recent years due to its potential to drastically increase the capacity of the system in which it is deployed. The basic concept behind MIMO is to use multiple antennas both in the base station and in the user terminal for signal transmission and reception. MIMO technology will have a key role in improving the spectral efficiency of future wireless communication systems. HSPA+, WiMAX and LTE all take advantage of MIMO.

MIMO can be used to serve many purposes, one such purpose being Spatial Multiplexing. With spatial multiplexing different data streams are transmitted simultaneously in parallel through different transmit antennas. In theory, assuming ideal MIMO radio channels, doubling the number of transmit and receive antennas will double the transmission capacity of the system. The spatial multiplexing principle is illustrated in Figure 5.

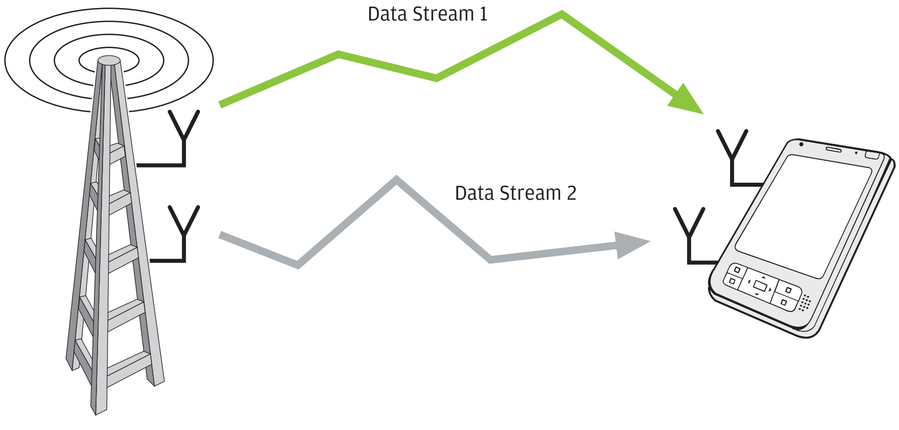

Figure 5. In spatial multiplexing paralel data streams are used for increasing the link capacity.

As both the transmitting antennas and the receiving antennas have spatial separation between them, the transmissions will fade differently at different antennas when propagating through the radio channel. The receiver can use this “spatial signature” to differentiate between the different data streams.

The receiver has to have knowledge about the fading characteristics of each spatial channel prior to data transmission. This knowledge is provided by sending pilot signals, which are known for both the transmitter and the receiver, individually from each transmitting antenna. The fading of the pilot signal conveys the “signature” of that particular spatial path. As the channel conditions are constantly changing the pilot signals need to be transmitted periodically in order to update the receiver.

2.4 LTE-Advanced

While LTE is not yet even deployed the 3GPP has already begun thinking about how to further evolve it. This evolution of LTE currently goes by the name of LTE-Advanced.

The International Telecommunication Union (ITU) is the internationally recognized entity that will produce the official definition of the fourth generation cellular networks. The ITU Radiocommunication Sector (ITU-R) is currently establishing a globally accepted definition of 4G wireless systems. This initiative is more commonly called IMT-Advanced. It is a logical continuation of the work done in IMT-2000, which provided a standard definition and set of requirements for the 3G technologies.

Although the specifications have not yet been finalized, the current consensus for the data rates in IMT-Advanced is a very ambitious one: 100 Mbps for high mobility subscribers and up to 1 Gbps for low mobility subscribers with channel bandwidths up to 100 MHz. Clearly the data rates provided by LTE fall short of the IMT-Advanced requirements. Many players in the telecom industry thus regard LTE to be more of a “3.9G” technology – better than current 3.5G systems, but not quite 4G.

The main driver for the development of LTE-Advanced is to meet, or even exceed, the IMT-Advanced requirements for a 4G wireless system. The bandwidth of LTE-Advanced will most probably be a multiple of 20 MHz LTE-type slots, i.e., 20, 40, 60, 80 and 100 MHz. The LTE-Advanced specification is expected to be included in the 3GPP Release 10. A similar evolution is being realized for WiMAX technology in the form of the IEEE 802.16m standard, which will be the base for WiMAX 2.0.

3. PRODUCT TESTING IN LTE

LTE product testing includes basic conformance testing, beyond conformance testing, and field testing. Radio channel emulation can be efficiently utilized in different product testing phases.

3.1 Field Testing

In order to guarantee the product performance for real-life operation the testing should mimic real-life scenarios as closely as possible. The LTE equipment can be field tested in a test setup that matches the intended use scenario. This could include for example performing drive testing with a measurement device through a coverage area of a live network. Field testing is an essential part of product, system and application development.

Traditional field testing of wireless telecommunication systems has some drawbacks. Field testing is generally a labor-intensive, time-consuming and expensive process. When performing testing in the field, testing of different environments requires physically moving the testing equipment to another geographical location. Field testing results are specific to the environment, location and time. They are non-repeatable, even under the exact same test setup, location and test scenario conditions. This is due to the fact that with field testing there is no real control over the natural environment or the radio channel effects. As a transmission signal propagates through the radio channel it is affected by many different phenomena, such as path loss, shadowing, multipath fading, delay spread, Doppler spread, angle spread, polarization effects as well as the addition of interference. These phenomena are somewhat random and depend on the time and place the test is performed.

3.2 Radio Channel Emulation

A more sophisticated approach to testing LTE products compared to field tests is to emulate the radio channel in a controlled laboratory environment. With this approach the real radio channel is replaced with a radio channel emulator, which takes all the radio channel phenomena into account. The radio channel emulator is a test and measurement device connected between the transmitter and the receiver. The transmission passes through the emulator, which recreates e.g., path loss, shadowing, multipath fading, delay spread, Doppler spread, angle spread, polarization effects as well as the addition of noise and interference. Figure 6 illustrates the principle of radio channel emulation testing.

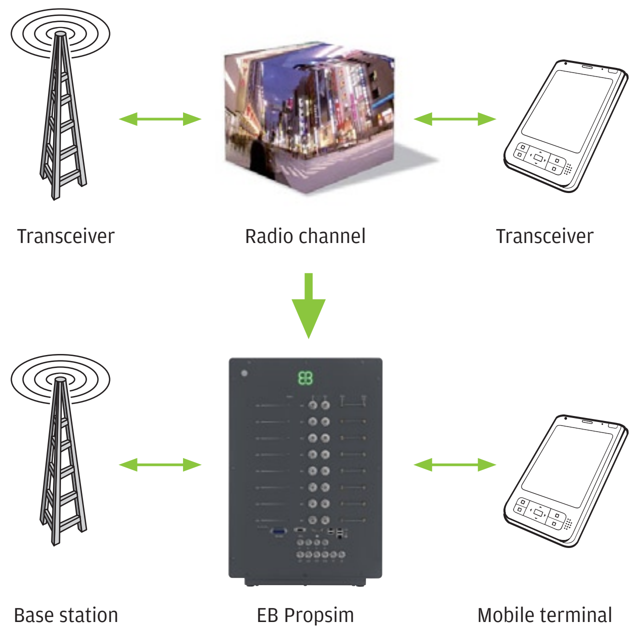

Figure 6. How real-world radio channel environments can be emulated in lab: the principle of radio channel emulation.

The benefits of radio channel emulation are that it enables accurate, controllable and fully repeatable test runs to be performed in a laboratory environment. Testing through radio channel emulation can be used to complement – or in some cases even replace – traditional field testing. Emulator testing significantly reduces the testing time and cost for a variety of standard and specific radio environments. With a radio channel emulator it is possible to test product performance during one test session in any environment such as indoor, metropolitan, highway, rural and mountainous areas. Faster testing cycles lead to shorter development cycles, which in turn will lead to shorter time to market for new products.

3.3 Conformance Testing

LTE conformance tests are used to verify that the LTE products conform to 3GPP standards and that the transmitter and receiver performance fulfill the minimum requirements set by 3GPP. Conformance tests are technology specific. Usually the conformance tests are specified by the same organization that developed the technology itself. The 3GPP has product conformance tests for the existing technologies it has developed, such as WCDMA and HSPA. The 3GPP has also specified conformance tests for testing LTE terminals and base stations [1]–[2]. The conformance tests are typically performed by an external organization, such as a certified conformance test laboratory.

Although both the LTE terminals and base stations are developed according to 3GPP specifications, ambiguity within the standards allows some freedom of interpretation. For example, the LTE standards only define the main functionality and tasks of RRM. The actual RRM algorithms design is left to the manufacturers. The same applies to physical layer receiver algorithms, which causes performance deviations between different vendors. Conformance testing is vital to ensure that any differences in implementation do not cause disturbance to the network or problems visible to the end user.

Conformance tests cover the basic transmitter and receiver characteristics for both the mobile terminal and the base station and the minimum performance requirements (for both FDD and TDD modes). Related to radio channel modeling, they include measurements on e.g.

- Receiver diversity characteristics
- Reference sensitivity power level
- Receiver performance requirements
  - Single antenna port performance
  - Transmit diversity performance
  - Open loop spatial multiplexing performance
  - Closed loop spatial multiplexing performance
- Reporting of channel state information
  - AWGN radio channel
  - Frequency selective radio channel
  - Frequency non-selective radio channel
- Reporting of Pre-coding Matrix Indicator.

LTE conformance tests are mandatory for any terminal or base station product. The conformance tests are designed with a pass/fail criterion. Products that pass the conformance tests gain a formal approval to be deployed in commercial networks.

An example of a 2x2 MIMO UE conformance testing setup is shown in Figure 7. The channel model is a tapped delay line model with a fixed per-channel correlation matrix, see section 4.1.

3.4 Beyond Conformance Testing

The purpose of conformance testing is not to secure optimal product operation in the field, but merely to validate that the various products in the LTE network conform to the basic requirements and that they do not cause unexpected problems when operating in the network. Because of the "pass" or "fail" criterion of LTE conformance tests, these tests do not measure the true performance of a product accurately. They only give an indication whether or not a tested product performs above or below a specified threshold.

LTE terminal and base station manufacturers need a method to quantify the true performance of their equipment in realistic radio channel conditions. Only by obtaining accurate and reliable performance data it can be ensured that the goals set for the product quality are met. In order to obtain this data, testing that goes beyond the basic conformance testing needs to be performed. This type of testing is also known as performance testing. Performance testing allows the manufacturer to optimize the air interface performance and to maximize the achievable system throughput before launching products on the market. Optimization can be performed for example on the following key areas:

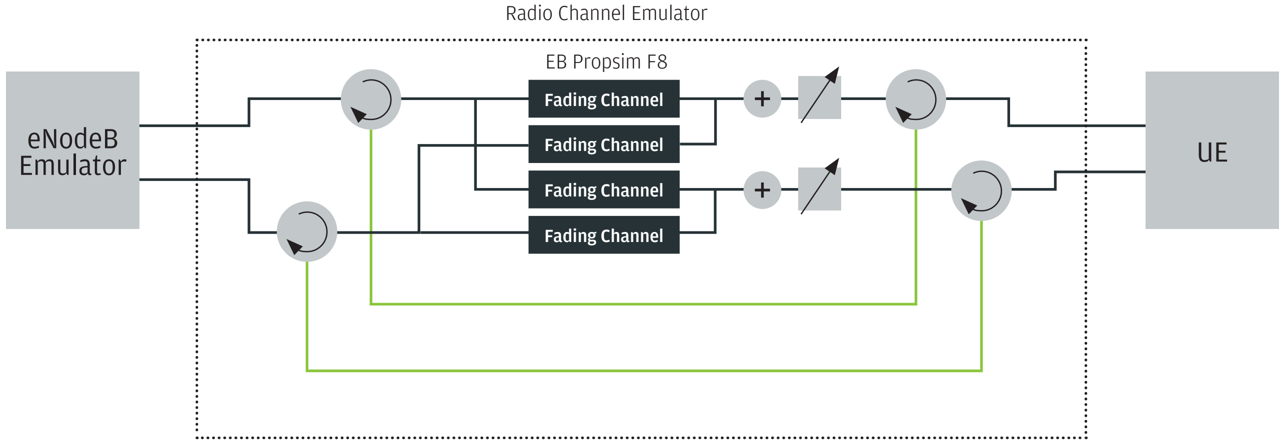

Figure 7. UE conformance test setup showing connections for 2x2 MIMO downlink.

- Adaptive modulation and coding
- Channel equalization
- Frequency domain scheduling
- Handovers
- MIMO configurations
- Adaptation between different MIMO modes
- Closed loop pre-coding MIMO
- Interference cancellation
- RRM algorithms (e.g. multi-user scheduling).

Advanced performance testing is beneficial for marketing and business purposes as well. Competition in the wireless industry is tough, and device manufacturers are forced to find ways to differentiate themselves from their competitors. Product performance is one key differentiator. Because the result of conformance testing does not express the true performance of the product, it cannot be used as a differentiating factor between different manufacturers' products. By validating products with reliable performance testing manufacturers and operators can gain a competitive advantage on the LTE market.

The key benefits that can be achieved by performing beyond conformance testing are listed below:

- Improved network performance and coverage
- Faster deployment
- Avoiding over- and under-specifying the product
  - optimizing product performance and development costs
  - demonstrating the performance of the product in realistic user scenarios
- Reducing the need for extensive field tests
- Realistic performance figures for physical layer and system throughput
  - e.g. bit error rate (BER) and block error rate (BLER)
- Better risk management.

An example of a beyond conformance MIMO handover test setup is shown in Figure 8. In the test setup, there are two eNodeBs with two antenna each, and one UE with two antennas each. Uplink and downlink can operate at the same or different frequencies (TDD or FDD). The radio channel model can be, e.g., SCME or WINNER (see sections 4.2.2 and 4.2.4).

The next section defines the radio channel models used in LTE conformance and beyond conformance testing.

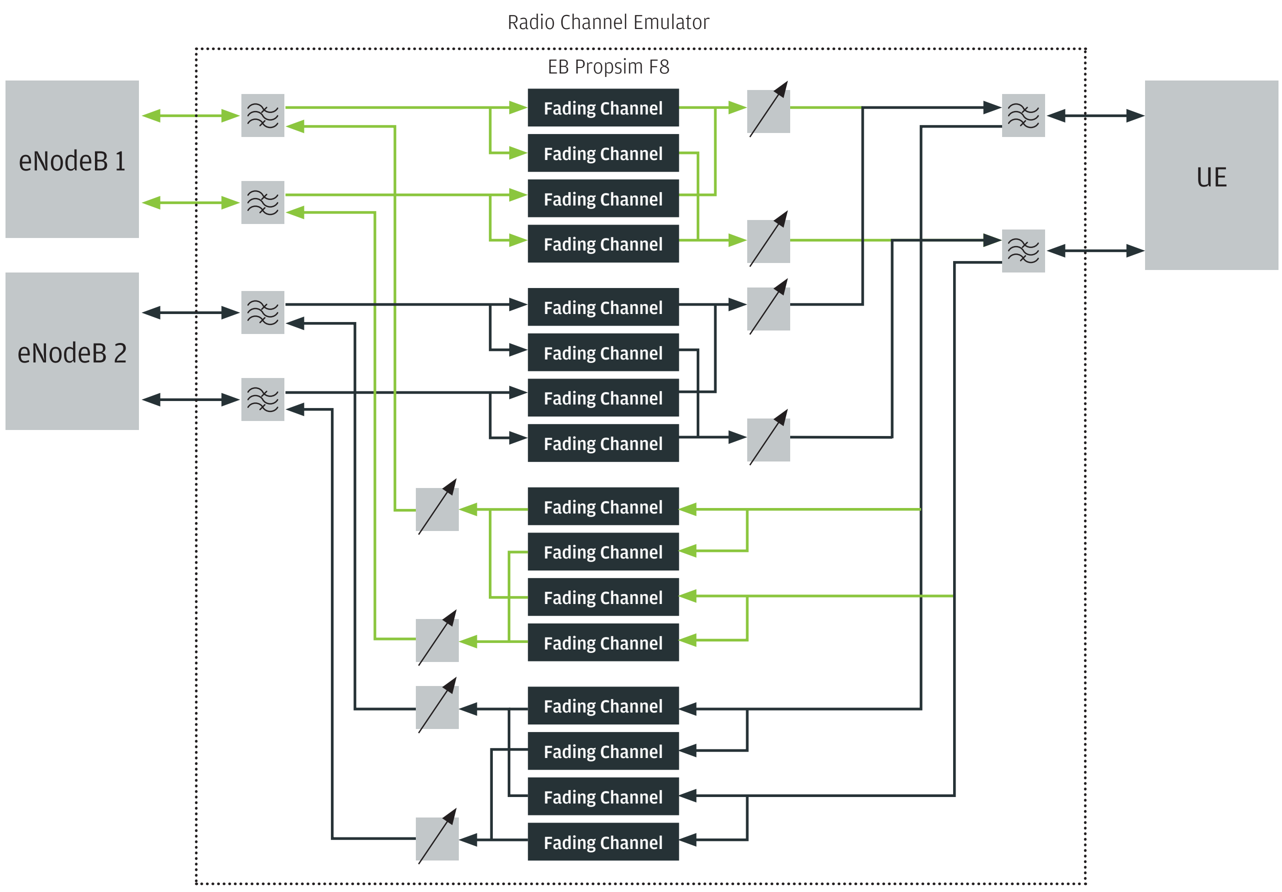

Figure 8. Example of 2x2 MIMO handover test

4. RADIO CHANNEL MODELS

The only way to guarantee that a product will function as expected in the real environment is to test it in conditions that are close to reality. When performing testing through emulations, the radio channel emulator requires accurate channel models to run the emulations. The reliability and accuracy of emulation results are directly linked to the accuracy of the channel model used to obtain those results. The closer the radio channel model is to reality the more reliable the results will be.

In addition to being accurate, the model used should be flexible enough so it can be used to emulate many different types of environments. The effects of the radio channel are dependent on the environmental conditions – an urban city center presents a different challenge from rural countryside or an indoor meeting room. Each radio environment requires a specific adaptation in the LTE equipment. By testing device performance across a range of conditions expected in a cellular system we can ensure that the device is not only optimized for a few environments.

Many different radio channel models have been created by different organizations for testing the various cellular technologies. These models are introduced in the following sections.

4.1 Radio Channel Models for LTE Conformance Testing

The 3GPP has defined the LTE conformance tests and the parameters for the radio channel models in TS 36.141 (eNodeB) and TS 36.521 (UE) [2].

The channel models that are used in LTE conformance testing are relatively simple, especially for MIMO applications. The models are extended ITU models (EPA, EVA, ETU) having 7 to 9 fading paths each and the same correlation matrix to all the multipath components [3]. Each fading path corresponds to one signal propagation path from TX antenna to RX antenna with a specific delay. The correlation between different antenna signals is only artificially defined as high, medium, and low. It does not provide the level of detail needed to reliably measure product performance limits.

4.2 Radio Channel Models for Beyond Conformance Testing

In general, there are three fundamental approaches to performing channel modeling: deterministic, stochastic, and geometry-based stochastic.

With the deterministic approach the full environment has to be modeled in detail (building materials, trees, ground

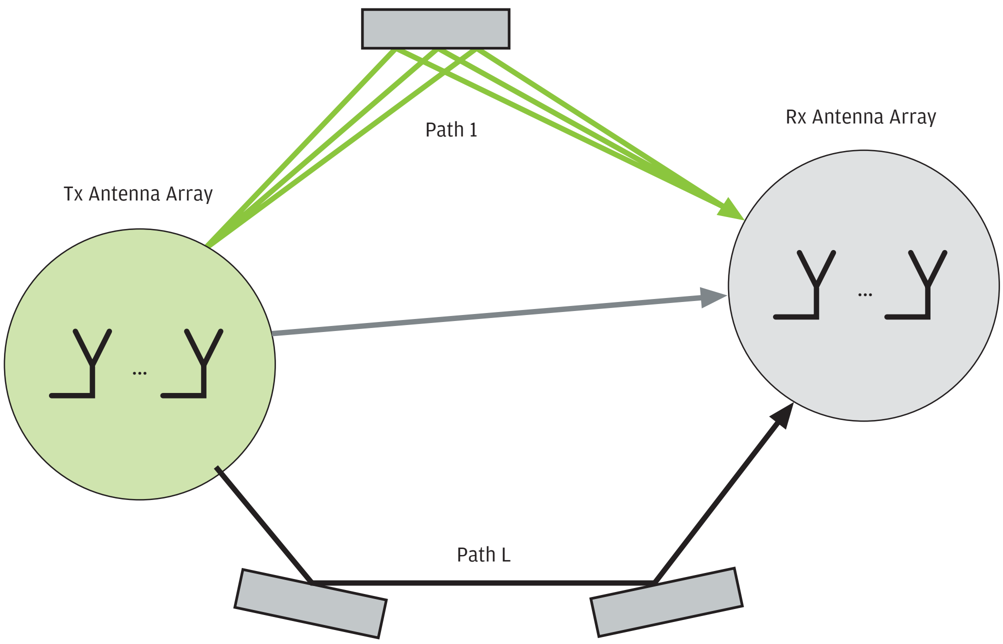

Figure 9. Single link description of GSCM -model showing TX and RX antenna arrays and geometric properties of the propagation.

within the accuracy of millimeters) based on wave propagation theory (Maxwell's equations). In practice, it would need a different model for each location of the mobile at each given time. Each model requires trillions of operations to calculate the propagation characteristics. Therefore, the modeling of the environment is intractable.

In stochastic modeling the channel parameters are determined randomly based on statistical distributions. A typical example of a stochastic model is the traditional tapped delay line (TDL) model, which has been used to test narrowband, single antenna systems. TDL models are not suitable for testing the new cellular MIMO systems due to the fact that the model lacks directional information of the propagation paths.

Radio channel models recommended for LTE beyond conformance testing belong to the family of Geometry-based Stochastic Channel Models (GSCM). The GSCM approach accurately models the spatial characteristics of the MIMO radio channel. They are measurement-based, multi-dimensional models covering all the necessary dimensions (time, frequency, space, and polarization) of the radio channel. Figure 9 simplifies the single link model of the GSCM and figure 10 shows the physical interpretation of the GSCM model.

GSCMs determine certain channel model variables according to statistical distributions. These variables include for example the angle of arrival (AoA) and the angle of departure (AoD) of the transmitted and received signal components. The geometry-based stochastic channel models can be used to model a wide range of environments and systems supporting various MIMO technologies, such as beamforming and spatial multiplexing. Due to these properties these models have been found to be well suited to mobile environments and can be used to perform beyond conformance testing. The following sections introduce the key GSCM-based channel models.

4.2.1 SCM Model

The 3GPP and 3GPP2 initially specified the Spatial Channel Model (SCM) as a joint venture for testing 3G systems [4]. The main driver for the SCM model was to define realistic MIMO channel characteristics. These characteristics were required in order to evaluate different MIMO schemes for HSDPA technology.

Both simple TDL models for calibration purposes and a GSCM for system-level simulations are included in the SCM. The channel parameters in the SCM model are determined stochastically. These parameters are then used to establish the propagation characteristics for a particular channel realization. Parameters incorporated by the SCM include, e.g., path loss, power delay profile, shadow fading, delay spread, angle spread at UE, angle spread at base station, UE speed, and antenna patterns. There are three different scenarios included in the SCM, namely suburban macro-cell, urban macro-cell, and urban micro-cell. Each scenario represents a unique environment and a unique set of conditions for MIMO testing. The different scenarios are modeled by using the same approach but different parameters. The model takes into account the antenna spacing in transmitter and receiver arrays and then specifies path characteristics to establish the fading and correlation behavior between different antenna elements.

The SCM model uses a system-level approach to emulate performance across a range of conditions expected

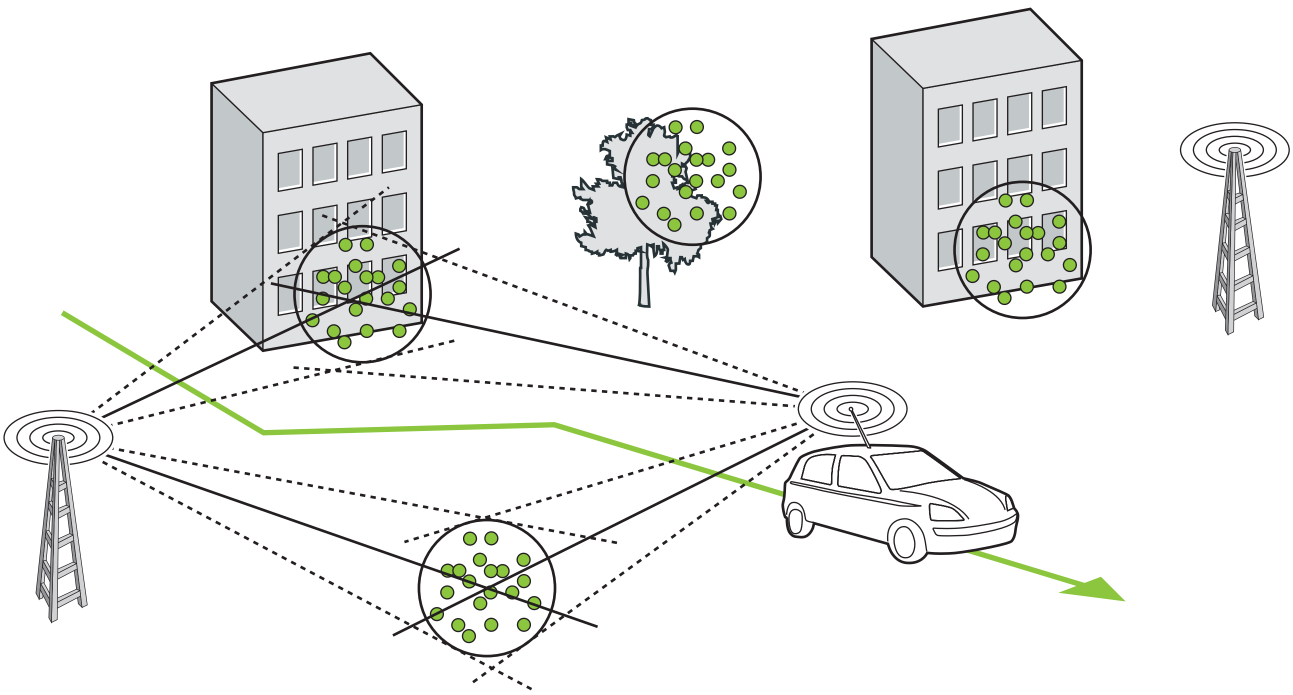

Figure 10. Physical interpretation of GSCM model.

in a cellular system. With system-level testing the scenario is similar to the deployments in a real network, with many base stations and user terminals active at the same time. In comparison to link-level testing, where a link between a single terminal and a single base station is tested, system-level testing provides more realistic results.

The system-level testing with SCM enables the total performance of both the uplink and the downlink to be tested at the same time. Emulations with the SCM model may use multiple base stations, each with multiple sectors and each sector with multiple antennas. These base stations can be connected to multiple terminals, each having multiple antennas. Each connection between a terminal and a base station is modeled with 6 paths, where each path can have unique characteristics. In order to keep the computational load manageable in such a complex emulation, the SCM system level model uses a "drop" concept. A user terminal is placed or "dropped" in different locations in the network and the performance of the system is evaluated in each position. Each drop reflects a short snapshot of the fading channel. The results gathered from all the drops mirror the overall system performance.

The SCM system-level model can provide results that are much closer to reality than the LTE conformance model. It is a good candidate for beyond conformance testing purposes and is used today for WCDMA, HSPA, WiMAX and LTE system-level evaluation and performance verification. However, the SCM model has some limitations that may make it unsuitable for certain scenarios of LTE testing.

Originally, the SCM model was specified for systems operating in the 2 GHz range. However, LTE offers much more flexibility with regard to the operating frequency band compared to the WCDMA / HSPA systems. The current specifications enable LTE deployment in any of the IMT-2000 frequency bands, ranging from 700 MHz up to 2.7 GHz and beyond. A requirement for LTE products is that the same level of RF performance is provided in all bands. Since many of the phenomena that affect signal propagation are operating frequency dependent, the model used in beyond conformance testing for LTE should take into account the full range of possible deployments.

The SCM model was specified for channel bandwidths up to 5 MHz. LTE enables scaling the channel bandwidth up to 20 MHz. With increasing bandwidth the effects of frequency selective fading are enhanced. Due to the above-mentioned reasons, the SCM model might not provide truthful results for LTE. Thus there are some justified concerns with using the SCM model for all types of LTE testing.

4.2.2 SCME Model

In order to address some of the shortcomings of SCM the pan-European Wireless World Initiative New Radio (WINNER) project proposed an extension to the original SCM model [5]. This new model became known as the SCM Extended (SCME). The SCME model is intended for Beyond 3G (B3G) system testing.

The SCME duplicates most of the work done for the original SCM, but changes some of the path characteristics to produce a more realistic model for B3G systems. The SCME model allows distributing each SCM path into 3-4 distinct "mid-paths" that have slightly different powers and delays. If all of the original 6 paths of the SCM are modeled with 3 mid-paths the resulting model will have 18 paths. "This path distribution produces an improved frequency correlation compared to the original SCM model. New contributions in the SCME model include extending the operating frequency range from 2 GHz up to 6 GHz, as well as artificially expanding the channel bandwidth from 5 MHz up to 100 MHz. These parameters are more aligned with the parameters that LTE will use. Since the SCME model provides good correlation to real LTE network scenarios, it can be used in performance testing to find the real performance limits of LTE terminal and base station products.

4.2.3 LTE Evaluation Model

As LTE was developed it became apparent that an LTE-specific channel model was needed in order to evaluate the user terminal and the LTE base station performance requirements, radio resource management requirements, as well as other system concepts. This model became known as the LTE Evaluation model.

The SCME model was initially proposed to be used as the LTE Evaluation model. However, it was later decided that the SCME model would not be used directly, but a simplified version of it would be created for LTE Evaluation purposes. The first simplification came with the decision to use the SCME Tapped Delay Line (TDL) model – which had initially been created for calibration and comparison purposes only – as the model for performing system level emulation. The more precise and realistic SCME model, based on a stochastic drop concept, was discarded. Secondly, the MIMO characteristics were simplified by describing them by correlation matrices, instead of directional propagation parameters.

4.2.4 WINNER Models

The WINNER group was created to define key concepts needed for a B3G wireless communication system. WINNER has many ongoing research activities on various B3G topics. One major task WINNER has adopted is the investigation of radio propagation conditions and the development of advanced radio channel models. In addition to creating the SCME model WINNER has come up with other advanced models as well.

The channel model creation within the WINNER projects was from the start divided into three phases. In each phase a more accurate channel model is produced as the end deliverable. The outcome of this approach has been 3 models: WINNER I, WINNER II and WINNER+ (still under development). The WINNER channel model timeline is illustrated in Figure 11.

A key feature of the WINNER models is that they are based on both radio channel measurements and data obtained from literature. For example, unlike the SCME model, which artificially expands the model to 100 MHz, the WINNER model is based on real 100 MHz channel measurements. The WINNER models also provide more flexibility for testing by specifying more scenarios than the SCM/SCME models. The WINNER II model includes 13 different scenarios, which are obtained by adjusting the channel model parameters. The model includes polarization and supports multi-user, multi-cell, and multi-hop networks. Because of the level of detail included in the WINNER models they represent the real-life radio channel with unprecedented accuracy. For each scenario, there are both GSCM for simulation purposes and reduced-variability Clustered Delay Line (CDL) models for calibration purposes, most of them having both Line-of-Sight (LOS) and Non-LOS (NLOS) features.

The channel modeling work as part of the WINNER project is aimed not only for WINNER internal purposes. The developed channel models are generic enough to also be used in other projects and in standardization activities [6]-[7]. An example of this is that the WINNER II model has had considerable influence on the definition of the IMT-Advanced channel models. The WINNER models will most likely play a part in the LTE-Advanced channel models as well.

4.2.5 IMT-Advanced Channel Models

The IMT-Advanced channel model (primary module) for the evaluation of IMT-Advanced candidate radio interface technologies is based on the WINNER II channel model, but channel model parameters were adjusted based on several contributions from different countries. In addition, some simplifications were made. There are four mandatory channel models, namely urban macro-cell (UMa), urban micro-cell (UMi), indoor hotspot (InH), and rural macro-cell (RMa), and one optional suburban macro-cell (SMa). A more detailed description of the models is available on the ITU web site [8].

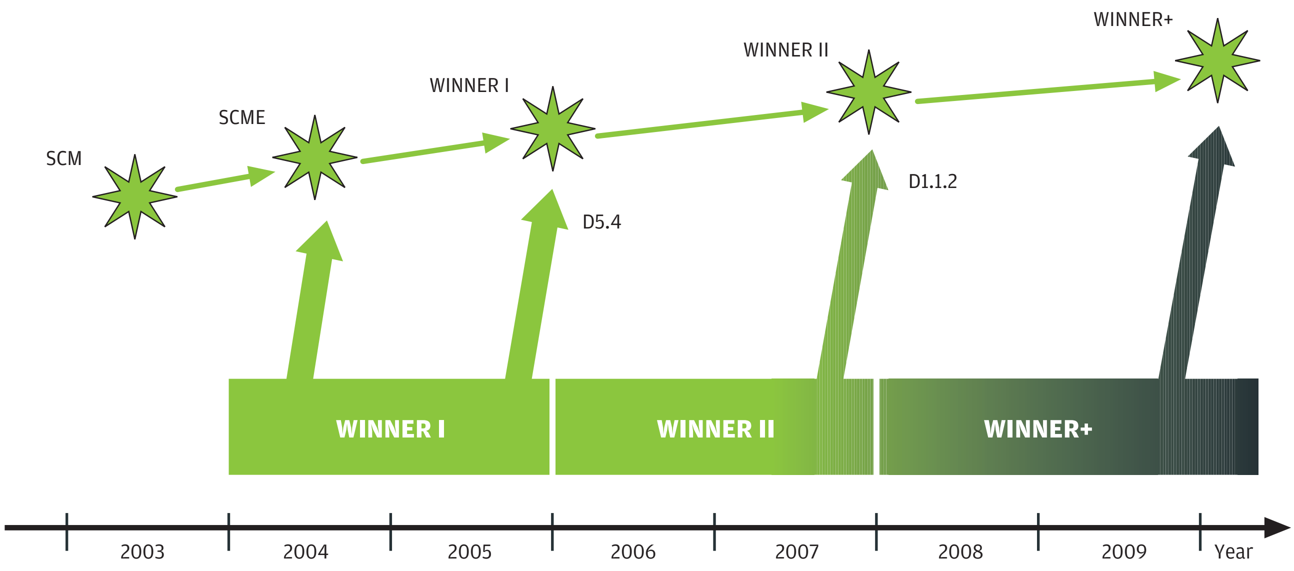

Figure 11. WINNER project timeline.

Table 1. Feature comparison of GSCMs.

Feature	SCM	SCME	WINNER I	WINNER II	IMT-Advanced
Bandwidth ≥ 100 MHz	No	Yes	Yes	Yes	Yes
Indoor scenarios	No	No	Yes	Yes	Yes
Outdoor-to-indoor scenario	No	No	No	Yes	Yes
AoA/AoD elevation	No	No	Yes	Yes	No
Intra-cluster delay spread	No	Yes	No	Yes	Yes
TDL/CDL model based on the generic model	No	Yes	Yes	Yes	Yes
Cross-correlation between LSPs	Yes	Yes	Yes	Yes	Yes
Time evolution of model parameters	No	Yes	No	Yes	No

Table 2. Numerical comparison of GSCMs.

Parameter	Unit	SCM	SCME	WINNER I	WINNER II	IMT-Advanced
Max. bandwidth	MHz	5	100*	100**	100**	100**
Frequency range	GHz	2	2 - 5	2 - 6	2 - 6	2 - 6***
No. of scenarios		3	3	7	12	5
No. of clusters		6	6	8-24	8-20	10-20
No. of mid-paths per cluster		1	3 - 4	1	1 - 3	1 - 3
No. of sub-paths per cluster		20	20	10	20	20
No. of taps		6	18 - 24	8 - 24	12 - 24	14 - 24
eNodeB angle spread	°	5 - 19	5 - 18	3 - 38	3 - 58	6 - 42
UE angle spread	°	68	62 - 68	10 - 53	16 - 55	30 - 74
RMS delay spread	ns	160 - 660	231 - 841	2 - 235	16 - 630	20 - 365
Shadow fading standard deviation	dB	4 - 10	4 - 10	1 - 8	3 - 8	3 - 8

* artificial extension from 5 MHz bandwidth ** based on 100 MHz measurements *** Rural macro-cell 0.45 - 6 GHz.

4.2.6 Comparison of GSCM Models

A feature and a numerical comparison of the geometry-based stochastic channel models introduced in this White Paper are illustrated in Table 1 and in Table 2, respectively. The comparison shows that the SCME, WINNER II and IMT-Advanced models are well suitable for LTE and LTE-Advanced beyond conformance testing.

The evolution of the various channel models introduced in this White Paper is illustrated in Figure 12. The SCM represents the first widely used GSCM model, and SCME, WINNER I, WINNER II, and WINNER+ are based on the same principles, further evolving the features and reality since much channel measurement and propagation research was done to improve the model. The standardized models are often simplified to minimize the complexity and to make the description shorter in the specifications.

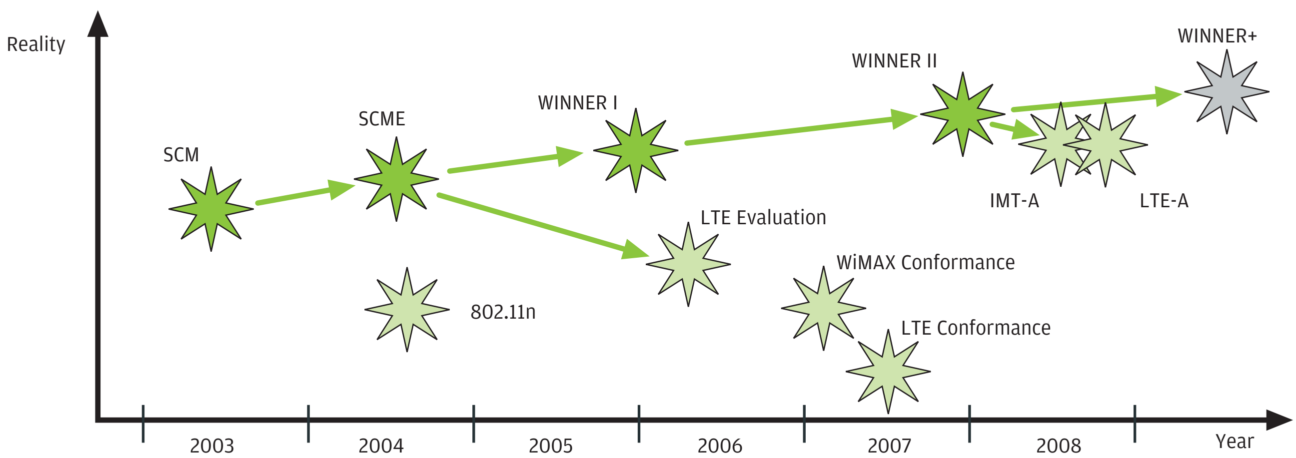

Figure 12. Channel model evolution

5. SUMMARY

LTE conformance tests help to ensure that products conform to the standard and do not cause serious problems when operating in a real network. However, LTE product verification with conformance testing alone is not adequate to assess product quality. Before manufacturers launch their products on the market, it is necessary to perform testing beyond the basic conformance level in order to quantify the true performance of their products.

Those LTE product manufacturers who choose to perform LTE laboratory channel emulation with advanced channel models – for example SCM, SCME or the WINNER models – will gain a competitive advantage in the LTE market. By going beyond conformance testing the LTE terminal and base station manufacturers can verify the product performance throughout the product development cycle, as well as show the exact product capabilities to operators.

Beyond conformance testing also provides benefits from the operators' perspective. The service quality experienced by the subscribers can greatly affect the end user loyalty to the operator. In end-to-end service delivery, the efficiency of the air interface plays a critical role. By specifying their own detailed performance test scenarios the operators can find the highest quality base station and mobile terminal products and therefore provide better service to end customers.

6. EB SOLUTIONS

EB is a global technology leader in test tools for measuring, modeling and emulating wireless environments. EB is actively involved in the development and definition of industry standards for wireless communications and utilizes this work for its customers by designing and implementing the conformance and beyond conformance testing requirements in its testing solutions. The EB Propsim™ family of radio channel emulators is used in testing wireless products throughout the entire product development cycle.

In past years, EB has actively contributed spatial channel models to a number of different standards such as ITU-R IMT-Advanced, 3GPP, IEEE 802.16m and WiMAX Forum. EB has acted as a leader of a channel model work package in the European Wireless World Initiative New Radio (WINNER) project and as chairman of a channel model drafting group in ITU-R IMT.EVAL. Recently, WINNER-based models were adopted by ITU, 3GPP and IEEE.

EB Propsim radio channel emulators enable the creation of real-world-like wireless communication scenarios allowing for all the aspects of a radio channel to be included in the emulation, and therefore the testing is more realistic. The highest performance available in the market for channel emulation and 100 percent repeatability of test scenarios are the key features of EB Propsim products that guarantee realistic radio channel emulation for wireless communications applications.

For further information visit the EB website: www.elektrobit.com/what_we_deliver/wireless_test_tools/applications/spatial_channel_modeling and www.elektrobit.com/ebpropsim.

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