

LTE and EPC Test

An Overview of Test Concepts and Tools for Trials

Table of Contents

Specific LTE Test Areas	3
Overview	3
Gaining deeper insights	4
Performance testing	5
Single-user throughput testing	5
Cell performance verification with multi-user throughput testing	6
Realistic multi-user throughput testing	8
Idle-to-active transition times	9
Latency testing	10
KPI verification and calculation	10
Validating LTE voice	12
Signaling validation	13
Voice QoS and QoE (MOS)	13
Testing QoS and QoE of LTE streaming video	14
Evaluating LTE MIMO and frequency-selective scheduling	15
Testing network coverage	16
Testing LTE handover	16
Validating LTE backhaul	18
Verifying LTE handset IOT	18
Validating device configuration	18

Appendix: Outline for a Basic Phase 1 LTE Test Plan	20
Overview	20
Achievable data rates and latency: single-user throughput for UL/DL and TCP/UDP	20
Achievable data rates and latency: cell throughput and MU throughput for UL/DL and TCP/UDP. . .	21
Achievable data rates and latency: latency.	21
Intra-LTE mobility: mobility and handover performance	21
Achievable data rates and latency: application performance	22
Coverage and capacity radio features efficiency and gain assessment: link budget	22
Coverage and capacity radio features efficiency and gain assessment: scheduler.	22
Evaluation of antenna configuration options	23
Self-configuration and self-organizing network features	23
Evaluation of frequency reuse: one deployment scenario	23
Basic QoS: user differentiation between non-GBR users with different QCI	24
Basic QoS: user-differentiation between GBR and non-GBR users	24
Basic application performance: web browsing, streaming, voice calls, e-mail, VPN, on-line gaming . .	25
References	26
EPS specification references	26
3GPP references	26
NGMN reference	28
ETSI reference.	28
Glossary	29

Specific LTE Test Areas

Overview

Creating an overall framework for the testing, evaluation, and optimization of LTE and SAE is a large and complex topic. This document provides a starting point that covers the topic at a relatively high level.

Looking across the lifecycle of a technology such as LTE/SAE, the tools, processes, and measures must be tailored to suit organizational priorities at specific times within the lifecycle (Figure 1). JDSU provides a cost-effective set of solutions that enable reusing assets across the lifecycle. This ensures not only complete coverage but also the reuse of results and assets, leading to a solid return on investment (ROI).

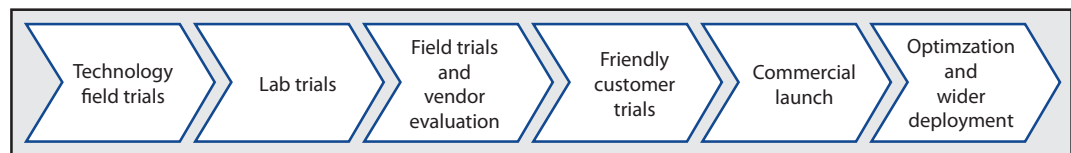


Figure 1. A simple model of the LTE deployment lifecycle

The examples listed below address different aspects of testing at various stages in the rollout of LTE/SAE. These are offered as an overview of the major elements of the LTE deployment lifecycle.

- Technology field trials
 - Evaluate the technology against NGMN or other industry requirements
 - Test and validate technology implementations
 - Adopt a process that is more open than fully closed bilateral field trials
- Lab testing
 - Evaluate eNodeB scheduling performance
 - Evaluate security and billing policies
 - Evaluate service performance in controlled environments
 - Evaluate UE performance
 - Evaluate MIMO performance gains
- Field trials and vendor evaluation
 - Evaluate end-to-end (E2E) performance
 - Evaluate network coverage
 - Evaluate cell and node performance under loaded conditions
 - Evaluate self-optimizing network capabilities
 - Evaluate IRAT capabilities and performance
 - Perform KPI monitoring and benchmarking

- Friendly customer trials
 - Understand end-user QoE/QoS
 - Confirm historic troubleshooting capabilities
 - Test handset IOT, conformance and pre-conformance
 - Monitor handset performance
 - Include trending, statistics and VIP reporting
- Commercial launch
 - Perform service- and access technology-aware monitoring
 - Verify E2E visibility and troubleshooting capabilities
 - Validate and understand subscriber behavior
 - Understand overall network and IRAT handover (HO) performance
 - Include integration with node-logging capabilities
- Optimization and wider deployment phase
 - Validate and ensure SON capabilities are working
 - Locate areas for expansion
 - Monitor backhaul performance impact on end-user QoE
 - Benchmark service performance between macro and femto roll-out

The remainder of this document focuses on the “field trials” portion of the process. Each section describes the test cases most operators will want to undertake and also outlines the tools that will ensure effective performance of such tests. It is assumed that not all operators will perform all steps so will need to match the test cases (and possible solutions) to unique needs.

Gaining deeper insights



For years, personnel from across Agilent Technologies have been involved with technology standardization and test development for LTE and SAE. Since 2008, Agilent has actively provided tools to help developers take LTE/SAE forward to the marketplace. In April 2009, the company published a comprehensive book called *LTE and the Evolution to 4G Wireless: Design and Measurement Challenges* (ISBN: 978-0-470-68261-6). This resource has received significant and widespread positive feedback from the wireless industry. In May 2010, JDSU acquired the Network Solutions Division from Agilent. With this acquisition, several contributing authors to this LTE book—including the author of this application note—transitioned from Agilent to JDSU. The book is just one example of how Agilent—and now JDSU—contribute to the overall landscape of the LTE and SAE industry. As a companion to the book, this application note contains relevant references to the LTE book, which can be studied separately in pursuit of a deeper understanding of the various topics and concepts involved in LTE testing.

Performance testing

With LTE, much of the focus has been on increasing system performance in areas such as end-user throughput, latency, and idle-to-active transitions. Although these improvements—along with significantly impressive single-user data rates—are important for marketing reasons, in themselves they play a limited role in how real users will utilize a deployed LTE network. Thus, measurements are needed for both single-user peak rates and multi-user throughput. In analyzing multi-user throughput and overall cell capacity, it is important to understand the impact of a cell's real distribution of users as well as the mobility and usage patterns of those users.

Single-user throughput testing

In theory, single-user throughput testing is quite simple. However, in reality it can prove to be quite tricky. As an example, the first aspects to understand are *what to measure and how to benchmark the result*.

Looking at the public results of the LTE SAE Trial Initiative (LSTI) Proof of Concept (PoC) group, it can be seen that peak rates will vary from a few hundred kilobits per second at the cell edge to over 150 Mbps in very good radio conditions (for example, in a 20 MHz 2x2 MIMO system). In practice, measuring this wide range of rates could be performed with a dedicated hardware traffic generator that will have guaranteed performance and will produce traffic precisely according to an anticipated traffic profile. Such a profile could include varying data rates, different types of traffic, and delay characteristics such as jitter. Other alternatives include software-based traffic generators (for example, iperf) or simply generating the traffic from existing standard application servers used for FTP or video streaming.

If a software-based traffic generator is used, it is important to understand the conditions under which it will deliver reliable results. In general, currently available software-based traffic generators produce a correct average throughput; however, the instantaneous variations could be significant. To generate high rates, dedicated CPU resources must be consistently available to the generator. Should other processes start on the traffic PC, and this is often the case with certain operating systems, there may be complicated side effects in the EPC or the eUTRAN because buffering might occur unexpectedly. Consequently, there may be a gap in the generated traffic and thus nothing to transfer over the air interface for a given TTI.

If not managed properly, the use of an existing application server (for example, an FTP server) to generate the traffic could also produce unexpected side effects. For example, an FTP server normally accesses a file from a traditional hard disk. If multiple users try to download the same file at the same time, there could be a bottleneck caused by the FTP server rather than the LTE air interface (in good radio conditions). It is possible to setup an FTP server to manage this if proper care is taken and the appropriate disk system is applied; however, oversights as simple as an improperly configured disk can skew the overall results.

When it comes to measuring the performance, one essential rule of thumb is to understand the basic aspects that will control the results. For example, an understanding of the underlying radio layer transport settings is crucial. HARQ provides an example: if HARQ is not enabled, the link will actually deliver a higher throughput in good radio conditions compared to times when HARQ is not switched on. On the other hand, reliable transport depends on HARQ being switched on. If not, problems such as a significant amount of TCP retransmission will crop up, leading to a very poor effective throughput. Even if HARQ is switched on, the amount of HARQ retransmission can be configured. Setting this to a very low value will increase the instantaneous throughput but will lead to a poor effective throughput under non-ideal radio conditions.

For a detailed understanding of bearer throughput, measurements should be made at different layers in the protocol stack—MAC layer, IP layer and UDP or TCP layers—after applicable retransmissions. During these measurements, it is important to understand and record the actual settings that were configured for the MAC layer and the TCP layer, and if any specific service or application layer settings have been applied (for example, if the application using TCP had one or multiple TCP flows).

In some very specific cases it may be useful to measure the highest possible bit rate that the LTE air interface can deliver. For this measurement, the recommended approach is to measure the lossless (for example, zero packet-loss throughput) of a sustained UDP stream. In such cases, the specific MAC layer settings should be recorded as well as the UDP packet size. It could add substantial value to perform an RFC 2544 test over the LTE connection; this will step through several different packet sizes and throughput rates to locate the lossless throughput for each relevant packet size.

To understand why throughput is changing in different environments at different times, the best approach is to record a set of LTE-relevant parameters while performing the throughput test. These parameters should include the inputs to the eNodeB scheduling decisions (for example, CQI for all of the ranks (wideband and sub-band), the PMI, and the rank indicator) and information about the resulting eNodeB scheduling decisions (for example, selected modulation and coding, MIMO mode, etc.). When testing uplink performance, the relevant power-control information should also be logged.

JDSU provides all of the tools and processes needed to plan, perform, evaluate results, and provide reports for single- and multi-user throughput testing. This includes both tools to generate E2E traffic as well as tools to log data from handsets and relevant network interfaces. For testing in the field, signal sources available from other vendors emulate uplink interference and loading caused by users in other cells. Because loading has a significant impact on throughput rates it should be included as part of any realistic evaluation. The generated interference should ideally be representative of an LTE air interface in both UL and DL. Although white noise was acceptable for UMTS, which uses a noise-like CDMA air interface, it does not represent the power variations across frequency and time that characterize LTE's OFDM and SC-FDMA modulation schemes. Rapid variations may trick schedulers into making either optimistic or pessimistic predictions of the channel conditions and subsequent modulation and coding scheme that can be reliably transmitted. JDSU tools provide the means to evaluate this impact before networks become heavily loaded.

Cell performance verification with multi-user throughput testing

Measuring the performance of an LTE system in a single-user case provides a basic understanding upon which a more realistic analysis of the multi-user case can be performed. It should be understood that, in many cases, single-user peak throughput performance will be much higher than even the aggregate cell throughput with several users actively downloading. From industry studies performed by LSTI and others, DL cell throughput is expected to be around 35-40 Mbps (assuming 20 MHz with 2x2 MIMO) with 10 users spread over the cell, all with full buffer downloads and a proportional fair scheduler.^{1,2}

1. These expectations are relatively consistent with previous 3GPP simulations.

2. The term "full buffer" refers to the idea that the eNodeB is constantly scheduling data from the S1 interface. The buffer must always contain enough data to fully saturate the link even in the case of a perfect RF environment and the highest throughput rate.

When basic multi-user testing is performed, the results may vary greatly, spanning from values below the anticipated numbers to rates near the single-user peak performance. The reason for this wide variation is due to two key factors: the overall behavior of the eNodeB's scheduling and the environment for each individual user. It is therefore important to set up the test in a repeatable way to ensure that results are useful on their own and can be compared against similar tests in either adjacent cells in the same network or with cells that use network equipment from another vendor.

The process of setting up a test to verify cell performance with multiple users has too many steps to present here in detail. In outline form, here are the key steps:

1. Evaluate the distribution of signal quality in the network through exhaustive drive or walk testing to build a CDF.
 - a. If the CDFs for different cells are significantly different, the end result will be significantly different.
 - b. The distribution will depend on the type of terrain covered and where the walk or drive test is performed. For example, including indoor locations will produce lower signal qualities than outdoor-only drive testing.
 - c. It is expected that roughly 80 percent of the LTE data traffic will be generated indoors.
2. Distribute the UEs according to the signal quality CDF to obtain a proper traffic profile.
 - a. The choice of distribution should match not only the measured CDF but also the anticipated distribution of real users in the real network. For example, if it is anticipated that several users are located in a group in a public location (for example, an airport or café) then it is advisable to place some of the users in similar patterns.
 - b. Different MIMO conditions might be stressed due to this type of distribution (for example, multi-user gains from MIMO).
3. In the real network, locate the users according to the planned distribution.
 - a. Note that it will be nearly impossible to get an exact match so it is important to instead locate the users in an area similar to the one identified. Make sure that the actual radio conditions of the chosen locations are logged and stored for the complete duration of the test.
 - b. For cases in which some of the users will be in a moving environment, make sure that this can be managed in a controlled way.
4. Ensure OCNB is enabled in the DL for the adjacent cells to create DL loading in the cell.
5. Ensure realistic UL loading is generated from UEs in adjacent cells.
6. Generate traffic to the test UEs and ensure that each UE is setup to receive or transmit traffic with full buffers.
7. Log all of the relevant parameters as identified earlier including the location (latitude and longitude) of each UE.
 - a. Log all relevant traffic from the network interfaces to ensure that full buffers were present for all UEs in all conditions.
 - b. Verify that all UEs were active and that the individual UE throughput rates are realistic compared to expectations.
8. Correlate the UE's entire individual throughput for MAC, IP, and UDP or TCP layers.
 - a. If one or several of the UEs were moving, the aggregated throughput may change over time depending on the scheduling and specific radio performance of each device's environment.

It should be noted that this is not a realistic way to test a cell's actual performance in a real network scenario when buffers are not always full. Instead, it is a test of how the eNodeB would behave in a very specific scenario. This could normally be considered a worst-case scenario for a specific distribution of users.

Realistic multi-user throughput testing

Despite the complexity, there are still limitations in multi-user testing that uses full buffer downloads and uploads. In a realistic traffic scenario, users are expected to have bursty traffic profiles, possibly comprising HTTP, voice, FTP, IM, e-mail, etc. In the full-buffer case, users with good connections download more data than users with low data rates, which biases results. Although this is partly true, users tend to do more with a faster connection—the full-buffer case is perhaps too extreme. The question, then, is what would be a more realistic traffic model? Would it be valuable to pursue this testing and, if so, what is the added value? The answer depends on which phase of the technology the specific operator is in at the time. If the operator is about to perform vendor selection, this could prove to be an essential test to ensure that the equipment behaves appropriately in terms of scheduling, ability to deliver the desired QoS, and overall fairness to the different users.

It is also important to understand that delivering the expected QoS or being able to provide fairness in the system is not necessarily a difficult task for an eNodeB. In practice, the difficulty is the ability to deliver the expected QoS with a minimum of overhead factors that impact the overall cell capacity.

The following is a proposed test to highlight certain possible deficiencies in a system.

1. QoS overhead provisioning analysis
 - a. Setup a static multi-user cell download with 6 to 10 users performing full-buffer downloads.
 - b. Measure the overall cell capacity.
 - c. Reassign one user as a mobile user with a fixed-rate UDP stream with the same megabit-per-second rate that was achieved in the full-buffer download.
 - i. Set the QoS parameters for this user to match the fixed rate of the UDP stream.
 - ii. Verify that the throughput rate is in the range of 2 to 5 Mbps.
 - d. Measure the overall cell capacity.
 - e. Move the user from medium to poor radio condition in five steps and repeat the cell-capacity measurements for each step.
 - f. Move the user to the cell edge for the specific data rate that was provisioned.
 - g. Measure the overall cell capacity.

Compare the cell capacity first with and then without the QoS provisioned for the bandwidth that can be delivered without any actual impact on the overall cell capacity. Then compare, step by step, the overall impact of user mobility on cell capacity and guaranteed QoS.

2. Test the impact of realistic traffic behavior on the overall scheduling
 - a. Setup a group of users (6 to 10) with a realistic traffic profile for the type of users envisioned for the LTE network. The following are examples of use scenarios.
 - i. Download five web pages with a 30-second delay between each download. Each page contains 20 objects for a total of 1.4 MB per page.
 - ii. Receive an e-mail message with a large (for example, 10 MB) attachment.

- iii. Send 10 e-mail messages, four with 2-MB attachments and six small ones with only 50 KB of data in each.
- iv. Listen to Internet radio (256 Kbps).
- v. Perform a background FTP download of seven large files (total of 100 MB, similar to a monthly operating system update).
- vi. Make one VoIP call using 12.2 Kbps on a guaranteed QoS bearer.

Note that the test conditions must be set up such that the radio interface will be congested in certain conditions during test execution. Use the previously measured anticipated cell capacity numbers to select the correct test-case parameters.

- b. The sequence of events occurs in parallel for each user; however, the users are separated in time by 10 seconds each.
- c. Each user would be located in a specific radio environment defined by the CDF for the specific cell.
- d. Let the test run to completion while logging all data from both the trace UEs and the network based probes. If possible, also log the data from the LTE Uu interface.

The data should then be analyzed to reveal actual behavior during congested conditions. One should specifically study the impact of the scheduler on both the guaranteed QoS traffic (VoIP) and the static RTP stream for the Internet radio because these two services are the most likely to degrade.

A simple and basic measure is to benchmark the total time of completion for the test sequence (excluding the Internet radio stream and the VoIP session, which could run indefinitely). The minimum completion time should be relatively easy to calculate based on the previously measured performance for the multi-user and full-buffer download scenarios. The difference from this minimum time should be analyzed to understand the overall efficiency of the system.

Adding mobility to this test case would allow for further analysis. However, it would probably add so much complexity that it could not be justified as a basic case.

All aspects of the scheduling and performance of the radio environment should be analyzed to understand the efficiency in each layer and during each process. This will also help reveal which conditions lead to successful scheduling results and which cause scheduling issues.

JDSU can provide the tools and the processes to execute and analyze the results from these types of tests. JDSU tools can help characterize the behavior and allow for both competitive benchmarking and regression testing when a “laundry list” must be maintained for a specific supplier.

Idle-to-active transition times

One of the main expectations of LTE is to provide an “always connected” experience for end users. This is achieved in part by ensuring a swift transition between the idle and active modes. The overall RRC state machine has been optimized and the number of possible states has been minimized to ensure reduced complexity, lower power consumption, and faster transition times.

To measure the idle-to-active transition times one must be able to either fully control UE behavior or be able to log all of the associated signaling to ensure the data is available to be measured from the overall traffic.

JDSU tools can measure idle-to-active time as well as other relevant transaction and procedural times. These measurements can be performed using either data from a trace mobile alone or data combined from the LTE and EPC network links to enable true correlated E2E measurements.

Latency testing

The overall experience is more than the specific bandwidth that an end user can receive and how quickly the network will enable switching between the idle and active modes. The experience also depends on the E2E latency of a packet transitioning through the complete EPC and eUTRAN.

KPI verification and calculation

The JDSU book *LTE and the Evolution to 4G Wireless: Design and Measurement Challenges* includes an extensive section about KPIs, the calculation methods, and the overall methodology (please refer to Chapter 6). As a result, the KPI material covered here is kept to a minimum.

It is unfortunate that the phrases “key performance indicator” and “KPI” have become commonly misunderstood and misused. At the most basic level, a KPI is nothing more than a statistic or a measurement. However, it is the test objective or market requirement for a given service that allows a particular statistic or measurement to be considered as a key indicator of performance.

Even the term “performance” can mean very different things depending on the testing context. For example, service performance for VoIP may be measured in terms of jitter, latency, and dropped packets. Network performance may be measured by the number concurrent VoIP users that can be served with an acceptable level of jitter, latency, and packet loss. Thus, when measuring quality or performance, one of the key challenges is agreeing on definitions that enable consistent interpretations of results.

According to 3GPP, KPIs generally fit into one of five categories: accessibility, retainability, integrity, availability, and mobility. The list is sometimes expanded to include the categories of utilization and usability.

3GPP KPI standardization efforts are largely focused on measurements related to the end user’s perceived QoS. These metrics tend to be more operator-centric as they relate specifically to measuring the ability of customers to obtain and maintain a connection to the network and thereby make use of one or more available services.

KPIs are best understood in the context of the actual objective of the measurement. Each part of the network has different responsibilities associated with delivering a single service. Therefore, LTE-specific KPIs focus on the eUTRAN itself and, in many cases, rely on the eNodeB to actually measure its own performance. One challenge for an NEM is defining a way to verify that KPIs calculated by the eNodeB are correct, especially when running at high load or full capacity. Another challenge for both NEMs and WSPs is making the shift from simply looking at KPIs to troubleshooting and identifying the root causes of problems.

For each KPI category, each service may have a different QoS profile or QCI label. To identify the performance of each type of service being accessed, the measurements should be made on a per-QCI basis. Additional KPIs in each of these categories should be considered in order to evaluate the end-to-end usability and manageability of a service.

Key aspects of a well-designed end-to-end test system are the data sources and the possible monitoring points that exist in an LTE and SAE network. Some of the topics discussed here are already part of the industry standards. Other areas may or may not be part of future standardization efforts by 3GPP, ETSI, or other industry bodies.

Fundamental to the topic of data sources and monitoring points is an understanding of measurement theory, basic physical laws, and how the LTE/SAE technology works and is deployed. Consider the following example common to both LTE/SAE and UMTS in which two engineers need to measure the RRC connection success ratio in the network.

- The first engineer, who is experienced in drive testing, commissions a targeted drive-test campaign, measuring the RRC connection setup success ratio for a wide area. Clearly, the number of measurement points is directly related to the duration of the testing and the number of actual attempts per unit of time. For this example, the engineer concluded that the RRC connection success ratio was 98.5 percent.
- The second engineer is accustomed to network counters and link-monitoring tools. As a result, he extracts logs from the system. This provides him with a report of all of the RRC connection attempts for the full network; his measured RRC connection success ratio is 99.5 percent.

Why is there a difference of nearly one full percentage point? The answer is fundamental to the rest of this discussion.

The difference in the results is not due to flaws in the data source, be it the drive test, the network counters, or the link-monitoring tools. The disparity is caused by the two engineers measuring different network procedures from different angles.

- The drive-test method analyzes network performance as seen from a single handset at specific physical points in the network at distinct points in time.
- The network counters and link-monitoring tools record all of the traffic and all of the occurrences of signaling and user traffic they are designed to monitor. This is a different frame of reference: it analyzes network performance as seen on the network and at the network monitoring points.

Differences begin to accumulate if any drive-test locations are well outside the actual, and potentially, intended network coverage area. As a result, RRC connection requests made outside of the network coverage area will be recorded by the drive-test system but not by the network counters or link-monitoring solutions. This highlights a key point: an extensive drive-test campaign provides additional information beyond what network counters or link-monitoring tools can provide.

In the optimization community, it is generally agreed that KPIs should be compared to each other only when they are derived from the same data source or when they are normalized to remove any bias due to method or source. This is especially true if comparisons show unexpected results. Today, the lack of proper comparisons is one of the largest contributors to unsound optimization decisions in the mobile industry. Valid comparisons and meaningful optimization can be ensured only if a stringent and coherent agreement on data sources and monitoring points has been settled in advance.³

Whether engaged in the R&D process or the optimization phase, one must often choose between several different strategies when developing an LTE test plan. Selecting the most cost-effective and results-effective strategy is one of the most important decisions to be made early in each phase of the work. Once a strategy is selected, the boundary conditions of its applicability must be established. It is important to note that a strategy that is appropriate for one phase of the work probably has significant shortcomings in any other phase. In other words, it is seldom a good idea to use the same fundamental KPIs because the data sources will provide different results in different phases of a network's deployment and maintenance.

3. Please note that this is simply a matter of fundamental measurement theory. It is not intended to be a discussion about the potential risk of results being incorrect due to a certain measurement tool not working as defined.

To illustrate this idea, consider a case in which QoS is contrasted with QoE. Monitoring the end-user IP traffic on a mobile network provides a full and detailed understanding of the traffic flows (TCP or UDP), the applications (voice, video, HTTP, e-mail, etc.), and potentially performance. Some believe that the monitoring of only the UDP or TCP flows will provide enough information about the end-user QoS to be able to deduce a good approximation of the end-user QoE. As the following scenario shows, this is not the case for applications such as streaming video.

- A user is watching streaming video on his handset, but the radio quality is not sufficient to deliver the full bandwidth over the air interface. When the UDP stream is measured in the core network, no degradation of the RTP/UDP stream is observed. Three other locations provide a better place to observe the degradation: on the air interface, on the user's handset, or between the two end points of the RLC entity (in the UTRAN between the UE and the RNC or in the LTE eUTRAN between the UE and the eNodeB). The network monitoring tool in the core would report a high and stable bit rate (good QoS); however, the end user would report a poor QoE.
- Shifting the scenarios, assume that the end user's application is quality-aware and, due to the radio conditions, signals that the video streaming server should change the bit rate of its codec. When this new RTP/UDP bit stream appears on the network, the network monitoring tool will associate the change with a lower QoS stream because it has a lower bit rate. On the other hand, the radio conditions are good enough to deliver this adapted bit stream, and the end user QoE has now increased.

This scenario shows that the crucial element in the QoE is not the bit rate measured in the core network, but rather the end-to-end ability to deliver a specific service to the end user. The application domain will, in this case, ensure that the best possible QoE is achieved. Therefore, the monitoring tool must be application-aware to deliver correct QoS measurements that lead to the correct estimation of end-user QoE.

Validating LTE voice

One of the to-be-defined items for the EPS is how circuit-switched services such as voice, CS UDI video, SMS, LCS, and USSD will be managed. Four alternatives are commonly considered.

- Circuit-switched fallback (CSFB)
- Voice over LTE generic access (VoLGA)
- Voice over IMS (VoIMS)
- Proprietary options

CSFB and VoLGA are both standardized and could be readily implemented. VoIMS is likely to follow and is anticipated to be a widespread, long-term solution. Among these, CS fallback in EPS is described in detail below; the other options are covered in brief.

Another aspect that is not yet specified in 3GPP R8 is the use of a voice codec. Several different options are at hand; however, due to a lack of agreement, this part of the standardization might be delayed until R10. One key reason for the delay is the lack of clarity on the objective: should the quality be improved or should the capacity be improved by the choice of codec? It is likely that a choice of codec for initial EPS deployments will be based on a mutual bilateral agreement between the UE vendors, the operators, and the EPS provider. It would not be a surprise if AMR and AMR-WB were used initially.

It is crucial to understand that the ITU has already moved ahead with the definition of the G.718 codec. G.718 is built on the AMR-WB foundation and, for the most part, provides the quality of AMR-WB at 12.65 Kbps on the same capacity as AMR 7.95 Kbps. Overall, this means that G.718 provides a 57 percent increase in capacity with a very limited impact on speech delay. A detailed description is outside the scope of this paper so the reader is encouraged to study ITU-T Rec. G.718 in full to further understand this topic.

Signaling validation

Figure 2 is a typical example of an IMS call flow for LTE interacting with the SS7 network. As will be shown, this is far from “only SIP” and some of the critical aspects cannot easily be seen in this simplified view. One example is the lack of visibility into the choice of the bearers that have been set up and how they map to a certain QCI, etc.

Any short-term analysis of a voice-over-LTE implementation will most probably be impacted by one or several shortcuts even if the intention is to be standards compliant. This should be considered when performing analysis and drawing conclusions. Key aspects to consider are the usage of ROHC for the air interface; the usage of a codec for E2E speech and the integration of a paging procedure when the UE is in idle mode; and, how the mobility between access technologies would be managed.

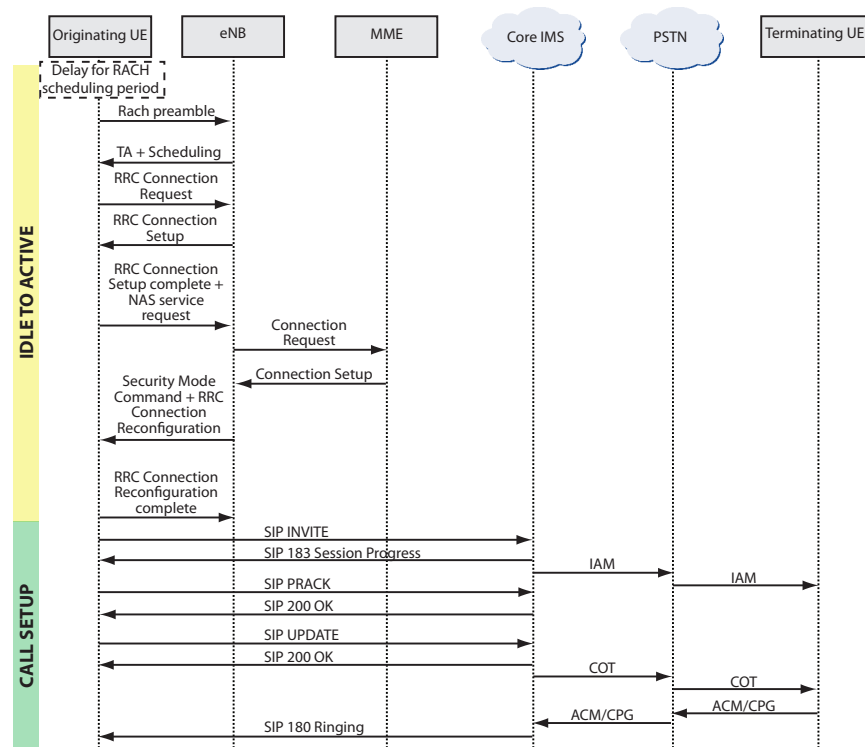


Figure 2. Typical IMS call flow for LTE interacting with SS7

Voice QoS and QoE (MOS)

Voice QoS and the resulting QoE is a topic of many good publications and thus this section will not go into too many details.

Overall, one must be careful about what is tested under which conditions, and one must be aware of the governing factors that control the outcome. If a certain voice service is tested with a bearer delivering a specific QoS, then the resulting voice quality will be limited by the quality delivered by the bearer.

JDSU provides all of the relevant tools to monitor video QoS and QoE from either a passive perspective or from an active perspective (Figure 4). Support is provided for both standard IPTV and for MSTV.

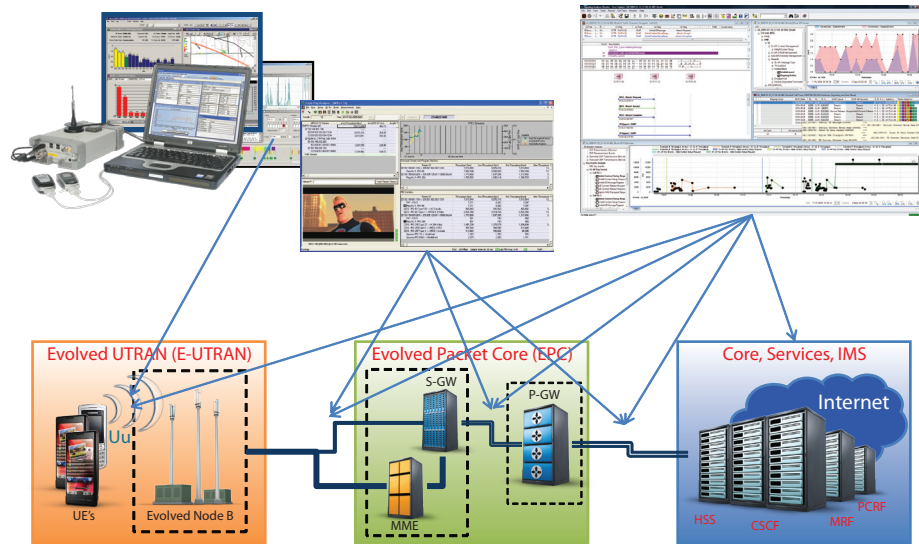


Figure 4. Tools for monitoring end-to-end LTE QoS and QoE (VoIP, IPTV, data)

Evaluating LTE MIMO and frequency-selective scheduling

Compared to HSPA systems, much of the value in LTE comes from the effective usage of both MIMO and frequency-selective scheduling (FSS). In many aspects these are technologies that have yet to be proved in terms of adding real tangible value to the customer in a field environment. Their real value depends on three things: the actual deployment scenario; the overall traffic modeling; and, the specific implementation and configuration of the system.

A feature such as FSS makes it theoretically possible to add significant performance to the system. In practice, however, performance is limited by the algorithm used to control scheduling. This is due to operational tradeoffs such as reducing significant uplink traffic for sub-band CQI reporting, or technical factors such as the practical available computational performance in the eNodeB.

As far as MIMO is concerned, it should be understood that MIMO usage or the measurements leading to a specific MIMO configuration for specific transmissions to a user during a specific TTI is typically not a static behavior. What's more, any expectation that MIMO can be controlled, modeled, or understood from one or a few measurements is typically unrealistic. As a result, it is important to identify two key elements: those aspects of the technology that should be evaluated from a statistical behavior point of view; and, those parameters that can be analyzed from a single discrete measurement without looking at a larger sample.

It is vital to understand and characterize the actual behavior of both MIMO and FSS to ensure the proper dimensioning of the cells, the backhaul, and the QoS provisioning. The statistical nature of MIMO and FSS can be well understood on a detailed TTI level only if the right tools and process are applied. These capabilities are all available using JDSU tools and methods. The tools allow a detailed analysis and characterization, enabling a clear understanding of actual behavior.

Testing network coverage

During network planning, modeling is performed and assumptions are made. If these are at all inaccurate, the undesirable consequences include either unplanned coverage holes or unwanted signal leakage into adjacent cells. Early in the planning and tuning process, a clear understanding of actual network coverage versus the planned network layout enables the planning and engineering team to develop a strong methodology that allows for very cost-effective network deployment and tuning. Early verification of the coverage will allow creation of a CDF of the network performance and allow for proper testing of cell performance.

JDSU provides detailed RF coverage measurements including RSSI, RSRP, RSRQ, and RS_CINR. These capabilities can effectively cover a large number of bands in very complex network topologies. The results from the measurements can be post-processed with either custom software or any of the industry-standard post-processing applications.

Testing LTE handover

Coverage testing is closely linked to the characterization of HO validation and performance. To fully grasp HO performance, one has to first study and understand the overall procedures and processes that underlie the handover in LTE. As is widely understood, no soft handover is present in LTE. As a result, the handover is always a hard “break before make” transition. The resulting impact on end-user QoE must be understood and optimized. It is also important to understand the handover’s overhead impact on the eNodeB because LTE handovers can be used to proactively manage service loading in a specific area.

Several different types of handovers are present: those between cells in the same eNodeB; those between cells in different eNodeBs without any X2 data forwarding; and, those in which X2 data forwarding is ensuring a minimum interruption of data traffic. It is commonly understood that the X2 data forwarding feature might be implemented in later releases of the eUTRAN software; however, some vendors might make this capability available early in the lifecycle.

A UE can normally discriminate between the types of handovers by monitoring the SFN around the HO time and check if the SFN is jumping or is continuous.

Figure 5 is a good example of a handoff between two cells in a single eNodeB. The plot shows that the BLER is increasing the moments before the HO and that this results in degraded throughput on the MAC layer. After the HO is performed (for example, an RRC connection reconfiguration), MAC layer throughput is increased and no BLER is reported.

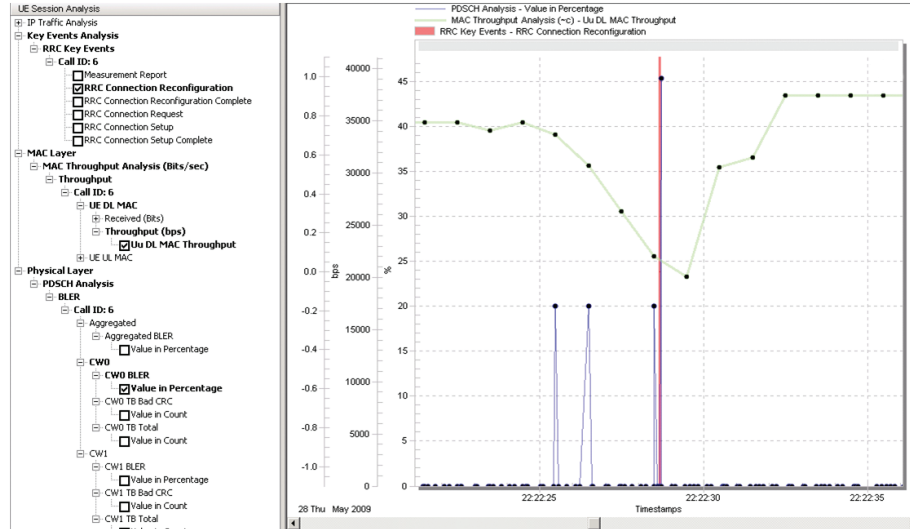


Figure 5. MAC throughput (green line) sags before an RRC event but recovers immediately after.

Following this from a signaling perspective, the call trace (Figure 6) reveals the resulting HO interruption time, which is on the order of 12 to 35 ms. Note that this analysis requires access to both the protocol logs from the UE (or from a passive Uu probe or from a eNodeB feed) with those from the network links (for example, S1, X2, etc.).

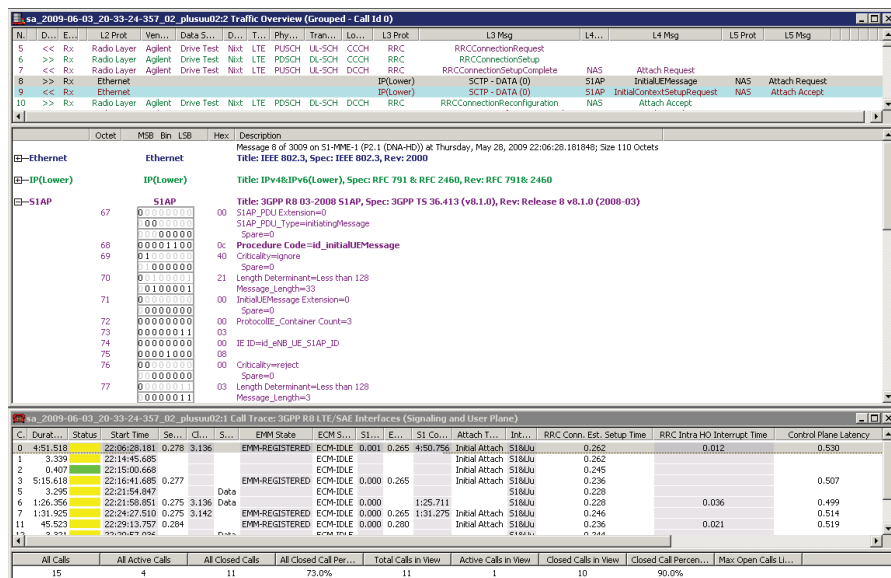


Figure 6. A call trace can reveal the resulting HO interruption time

As in all mobile technologies, it is relatively straightforward to achieve successful handovers. However, achieving an optimized network with optimized handovers requires great insight and tremendous skill in the art of optimization.

Validating LTE backhaul

LTE offers greatly increased bandwidth to the end user. In turn, it is very important that this bandwidth capability is available through every part of the network. One of the big areas of focus for this is the mobile backhaul network, typically Ethernet, between the cell site (eNodeB) and the core network.

In LTE field trials we have witnessed to date, the wireless backhaul network is brought on-line prior to implementation of the LTE-specific test cases. Commissioning the Ethernet backhaul quickly and easily is vital to keeping an LTE field trial on schedule. The JDSU NetComplete Service Assurance Solution for Wireless Backhaul verifies Ethernet service operation to trial cell sites in advance of the LTE trial execution. Adherence to RFC-2544 standards is maintained with cost-saving derived through automation and efficient deployment of technicians even across multiple cell sites. However, since such testing is not unique to an LTE field trial, it is beyond the scope of this application note. General information is available such as the IETF's RFC 2544 (1999), the IEEE, and the ITU which define test and performance monitoring methodologies for Ethernet network interface devices.

Verifying LTE handset IOT

For each operator in the early phases of bringing LTE to market, it is essential to ensure proper interoperability of LTE handsets or data cards. Of course, these are early devices that will continue to evolve rapidly over time. Consequently, it is important to understand the capabilities and ensure interoperability between the handset and the relevant network elements. It will not be possible to simply rely on pre-conformance or conformance test results because these will seldom reflect actual user behavior or issues found in the early phases of network deployment.

Industry forums such as LSTI have defined a minimum feature set and a corresponding IoDT and IOT test plan. These are available only to LSTI members and may be used only for LSTI purposes. As a result, non-members must rely on other means to secure handset interoperability. As an LSTI member, Agilent has made significant contributions to the IoDT and IOT phases. Through this experience personnel in both Agilent and JDSU are better able to contribute effectively to the wider industry.

JDSU provides monitoring tools such as the Signaling Analyzer that provide the capability to analyze and correlate information from each interface and highlight any discrepancies versus the anticipated behavior on a signaling level. The JDSU NiXT application can actively stimulate a handset to execute different applications and tasks. This correlates to control of the relevant RF parameters (for example, fading, MIMO profiles, etc.) and an effective LTE handset interoperability environment can be provided. If appropriately and effectively automated, this will ensure that cost-effective and reliable testing is performed, thereby maximizing asset utilization.

Validating device configuration

One part of LTE is yet to be fully standardized and widely agreed upon: the effective performance of device configuration. Even if significant interoperability testing has been performed, any operator launching an LTE service early will be required to remotely update handsets and parameters such as network settings, software, or other relevant parameters during operation of the network.⁴

4. Many of the traditional OTA systems are based on short message services (SMS) that are not easily supplied in an LTE environment without the use of either CSFB IMS or VoLGA, both of which are relatively complex and error-prone technologies.

It is essential to provide full visibility into device behavior during pre-configuration, configuration, and post-configuration phases—and to comprehend the full E2E signaling needed to deliver the configuration environment. With JDSU tools, the pre-configuration state can be analyzed both qualitatively (for example, the performance of all operational services) and in simple go/no-go testing (which services work or don't work). Specific network behaviors that identify incorrectly configured devices can be analyzed and documented to be used in subsequent network-wide monitoring systems. During the configuration procedure, different types of positive and negative testing can be performed to stimulate error conditions and to prove that the configuration is successful if certain conditions are met. The negative conditions are especially critical because it is often difficult to evaluate the state of an end-user device in a real network.

Appendix: Outline for a Basic Phase 1 LTE Test Plan

Overview

This section contains a basic set of test cases that can be used in two ways: to evaluate LTE as a technology; and, to assess the basic performance of LTE infrastructure vendors.

The basic test plan described here is well-aligned with the thinking of most infrastructure vendors. It is also consistent with their detailed test plans. As a result, this section can be useful to operators too. They can use this plan when asking vendors to create a detailed outline that spells out how testing will be conducted. The operator could then validate that the detailed test plan meets the intention and basic expectations of the plan. The overall test execution, data collection, analysis, and reporting can be managed with integrity, ensuring a valid evaluation.

Subsequent phases of a test plan can be provided that will allow the operator to move toward vendor selection and network roll-out.

The suggested test plan has eight major sections.

- Achievable data rates and latency: single-user throughput for UL/DL and TCP/UDP
- Intra-LTE mobility
- Coverage and capacity
- Evaluation of antenna configuration options
- Self-configuration and self-organizing network features
- Evaluation of frequency reuse
- Basic QoS
- Basic application performance

Below, “Achievable data rates and latency” has four subsections and “Coverage and capacity” has two. Each of the 13 total entries presents a basic test overview that can be easily leveraged into a test plan.

Achievable data rates and latency: single-user throughput for UL/DL and TCP/UDP

Basic test overview

- Evaluate single-user throughput across a range of radio conditions. Generate UL and DL loading of 70 percent from adjacent cells.
- Perform separate UL and DL throughput tests individually with TCP and UDP. Measure average throughput for 30 seconds during stationary conditions. The TCP and UDP tests should measure lossless throughput rather than raw throughput.
- Log all appropriate parameters and conditions including full traces of the control and user planes from the network and UE sides.
- Provide raw and normalized results according to the common test description.

Achievable data rates and latency: cell throughput and MU throughput for UL/DL and TCP/UDP

Basic test overview

- Generate a CDF of the cell according to the common test description. Place 10 UEs according to the CDF distribution.
- Verify placement of the 10 UEs in appropriate and representative locations.
- Generate UL and DL loading of 70 percent from adjacent cells.
- Perform separate UL and DL throughput tests individually with TCP and UDP. Measure average throughput for 30 seconds during stationary conditions. The TCP and UDP tests should measure lossless throughput rather than raw throughput.
- Log all appropriate parameters and conditions including full traces of the control and user planes from the network and UE sides.
- Provide raw results and normalized results according to the common test description.

Achievable data rates and latency: latency

Basic test overview

- Evaluate the end-to-end latency in a range of radio conditions and loading scenarios.
- No-load scenario
 - Perform end-to-ping in a range of radio conditions for a minimum of 100 samples per location and packet size (32, 1000, 1500 bytes).
- With-load scenario
 - Generate UL and DL loading of 70 percent from adjacent cells.
 - Generate same-cell DL load from one UE in good radio conditions with full UDP download.
 - Generate same-cell UL load from 1 UE in poor radio conditions with full UDP upload.
 - Perform end-to-end ping (32, 1000, 1500 bytes) in a range of radio conditions for a minimum of 100 samples per location and packet size.
- Log all appropriate parameters and conditions including full traces of control and user plane from the network and UE sides.
- Provide RAN and EPC latency and, if relevant, the backhaul transmission latency.
- Provide raw results plus minimum, maximum and average values for each radio condition and packet size.

Intra-LTE mobility: mobility and handover performance

Basic test overview

- Test and compare results for handover based on both S1 alone and on X2 forwarding; test same cell loaded and unloaded.
 - Same methodology for both (S1 and X2) test cases
 - Repeat test for at least 20 HO of each type.
 - Perform the test with DL and UL TCP and UDP traffic subsequently.
 - Measure and report HO success rate.
 - Measure and report control plane HO time.
 - Measure and report user plane HO interruption time and packet loss.

- Log all appropriate parameters and conditions including full traces of control and user plane from the network and UE sides.
- For loaded HO performance, test add two UEs in good radio conditions in both cells performing full-buffer DL and UL.
- Other cell load should be 70 percent in DL. In the mobility case, note that UL loading is not required due to practical issues.

Achievable data rates and latency: application performance

Basic test overview

- From idle mode, connect and download the Copernicus website (see common test description) and measure the download time in a range of radio conditions. A minimum of five repetitions at each location is required. A minimum of five (10 is recommended) different radio conditions should be covered from good radio conditions to cell-edge conditions.
- The other cell load should be 70 percent in UL and DL.
- Log all appropriate parameters and conditions including full traces of the control and user planes from the network and UE sides.

Coverage and capacity radio features efficiency and gain assessment: link budget

Basic test overview

- Test first in static locations:
 - The UE is located close to the cell center. A UDP DL transfer with full buffer is initiated.
 - The user moves away from the base station, so path loss increases. Repeat the measurements at the new location.
 - This is repeated for at least 10 different locations across the cell. A majority of the locations should be in poor radio conditions; continue until coverage is lost.
- Repeat the same test while in mobile conditions: drive from cell center to cell edge and repeat several times.
- Log all appropriate parameters and conditions including full traces of control and user planes from the network and UE sides.

Coverage and capacity radio features efficiency and gain assessment: scheduler

Basic test overview

- Locate four UEs in good radio conditions as close as possible to equal radio conditions. Ensure that all UEs have the same priority and QoS settings.
- Setup DL loading of UDP with the following traffic characteristics: UE1=X; UE2=2*X; UE3=3*X; UE4=4*X. Ensure X is chosen so that the aggregated throughput of the users exceeds the cell capacity.
- Measure the resulting behavior.
- Locate the UEs at four different locations and generate the same UDP stream throughput to each UE. Ensure aggregated throughput of the users exceeds the cell capacity.
- Measure the resulting behavior.
 - Log all appropriate parameters and conditions including full traces of the control and user planes from the network and UE sides.

Evaluation of antenna configuration options

Basic test overview

- Perform the single-user throughput test case and the multi user cell capacity test case with the following antenna configurations:
 - SIMO
 - 2x2 MIMO
 - 4x4 MIMO (Optional: Perform if possible for the vendor)

Self-configuration and self-organizing network features

Basic test overview

- Ensure at least two eNodeBs are operational and no neighbors exist in the target cell.
- Verify in the O&M system that no neighbors or X2 interfaces are configured.
- Activate ANR in eNodeB.
- Turn on the UE in a cell where no neighbors are defined. After UE reporting of signal strengths of surrounding sectors, the ANR function shall add neighbors to the neighbor list.
- Perform a handover.
- Verify in the O&M system that all correct neighbors and X2 interfaces have been added.
- Perform an HO to and from the new neighbor.
- Log all appropriate parameters and conditions including full traces of the control and user planes from the network and UE sides.

Evaluation of frequency reuse: one deployment scenario

Basic test overview

- Locate a UE at the cell edge (in 100 percent other cell load) and prepare full-buffer downloads.
 - Without other cell load, measure average throughput for 30 seconds for both TCP and UDP.
 - With 50 percent other cell load, measure the average throughput for 30 seconds for both TCP and UDP.
 - With 70 percent other cell load, measure the average throughput for 30 seconds for both TCP and UDP.
 - With 100 percent other cell load, measure the average throughput for 30 seconds for both TCP and UDP.
- Log all appropriate parameters and conditions including full traces of the control and user planes from the network and UE sides.
- Compare the cell-edge performance under the various loading conditions and compare the measured SINR for each loading condition at the same physical location.

Basic QoS: user differentiation between non-GBR users with different QCI

Basic test overview

- One UE (A) should have a full-buffer download of UDP traffic in good radio conditions and with the QCI of lowest priority.
- One UE (B) should have a download of a UDP stream of 10 Mbps and be located in medium radio conditions with a QCI of second-lowest priority.
- One UE (C) should have a download of a UDP stream of 10 Mbps and be located in medium radio conditions with a QCI of highest priority.
- Measure the resulting throughput and packet loss (on UE B and C) and report the actual received throughput and the S1 and SGi throughput.
- Other cell load should be 70 percent in UL and DL.
- Log all appropriate parameters and conditions including full traces of control and user plane from the network and UE sides.

Note: To ensure that congestion occurs, it may be necessary to normalize the throughput of UE B and C.

Basic QoS: user-differentiation between GBR and non-GBR users

Basic test overview

User	UE1	UE2	UE3	UE4
GBR DL (Mbps)	X1	X2	X3	X4
GBR UL (Mbps)	Y1	Y2	Y3	Y4
MBR DL (Mbps)	A1	A2	A3	A4
MBR UL (Mbps)	B1	B2	B3	B4
ARP (Allocation and Retention Priority is NOT equal for all flows)	N1	N2	N3	N4

Assume: $N1 > N2 > N3 > N4$ (User 1 has the highest priority and User 4 has the least priority)

- Locate four UE in good radio conditions. Configure DL bearers with GBR values for UE1, UE2, UE3, and UE4. Ensure that X1, X2, X3, and X4 DL throughputs are aggregated above the cell capacity at all UE locations but that X1, X2, and X3 aggregated are below the cell capacity.
- Generate UDP DL traffic to clients UE1, UE2, UE3, and UE4.
- Stop DL transfer after at least 30 seconds of data transfer to the UE clients.
- Measure DL throughput.
- Verify that the DL rates for UE1, UE2, and UE3 are no less than their predefined GBR values (X1, X2, and X3, respectively).
- Verify that UE4 (lowest-priority traffic) was the most negatively affected (the DL bit rate failed to achieve X4, which is the desired DL-GBR for UE4).
- Change the ARP setting of UE4 to be the highest priority (N1).
- Repeat with simultaneous DL transfer to all four UE clients.
- Verify that the DL data rate to UE3 (lowest priority among all UEs) is most negatively affected (its data rate will be lower than its desired DL-GBR).

- Perform the same test but limit the S1 downlink performance to cause congestion at a level below the RF cell capacity but above the aggregated X1, X2, and X3. Verify throughput is below the S1 peak throughput limitation.
 - The limitation can be achieved via VLAN tuning.

Basic application performance: web browsing, streaming, voice calls, e-mail, VPN, on-line gaming

Basic test overview

- Identify the relevant services for each local environment.
 - Select a heavily trafficked local website:
 - 1-5 MB for the main page (including images)
 - Select a VoIP application supported by the operator and the local environment (for example, Skype, Google Chat, MSN, etc.).
 - Select a local corporate customer using a VPN in a mobile environment; the VPN connection should have a data rate on the order of 2-10 Mbps end-to-end.
 - Identify three local, well-recognized services:
 - A high-requirement (low-latency) online game
 - A high performance fixed-line Internet service (for example, xDSL, packet cable, etc.)
 - A streaming video (RTP/UDP) service
- Execute and compare the application performance on the following access technologies:
 - HSPA (best local commercial available service)
 - Fixed-line Internet service
 - LTE in good, medium, and poor radio conditions
- Log all appropriate parameters and conditions including full traces of the control and user planes from the network and UE sides for LTE and, if possible, for HSPA and the fixed-line Internet service.
 - For the voice service, measure and compare MOS.
 - For the streaming video service, measure and compare video MOS or a subjective quality comparison with friendly users.
 - For the online game, get a subjective statement from an experienced gamer and an E2E latency measurement.
- Report the absolute and relative performance between the different access technologies.

References

EPS specification references

3GPP TS	Title	Protocol	Interface(s)
24.301	Non-Access-Stratum (NAS) Protocol for Evolved Packet System (EPS); Stage 3	EPS NAS	S1-C
36.413	E-UTRAN: S1 Application Protocol (S1AP)	S1-AP	S1-C
36.423	E-UTRAN: X2 Application Protocol (X2AP)	X2-AP	X2-C
29.118	Mobility Management Entity (MME) -Visitor Location Register (VLR) SGs Interface Specs.	SGsAP	SGs
29.168	Cell Broadcast Center Interfaces with the Evolved Packet Core; Stage 3	SBC-AP	SBC
29.272	MME Related Interfaces Based on Diameter Protocol	Diameter+	S6a, S6d, S13
29.274	Evolved General Packet Radio Service (GPRS) Tunneling Protocol for Control plane (GTPv2-C);	GTPv2-C	S3-C, S4-C, S5/8-C, S10, S11-C
29.275	Proxy Mobile IPv6 (PMIPv6) based Mobility and Tunneling Protocols; Stage 3	PMIPv6	S5, S8 (PMIP)
29.276	Optimized Handover Procedures and Protocols between EUTRAN Access and cdma2000 HRPD	S101-AP	S101
29.277	Optimized Handover Procedures and Protocols between EUTRAN Access and 1xRTT Access	S102-AP	S102
29.280	3GPP EPS Sv Interface (MME to MSC) for SRVCC	Sv	Sv
29.281	GPRS Tunneling Protocol User Plane (GTPv1-U)	GTPv1-U	S1-U, X2-U, S4-U, S5/8-U, S12-U

3GPP references

3GPP TS 23.272: Circuit Switched Fallback in Evolved Packet System; Stage 2

3GPP TS 24.301: Non-Access-Stratum (NAS) protocol for Evolved Packet System (EPS); Stage 3

3GPP TS 29.118: Mobility Management Entity (MME) – Visitor Location Register (VLR) SGs interface specification

TS 23.401: General Packet Radio Service (GPRS) enhancements for Evolved Universal Terrestrial Radio Access Network (E-UTRAN) access

3GPP TS 21.905: Vocabulary for 3GPP specifications

3GPP TS 22.278: Service requirements for the Evolved Packet System (EPS)

3GPP TS 43.318: Generic Access Network (GAN); Stage 2

TS 23.401: General Packet Radio Service (GPRS) enhancements for Evolved Universal Terrestrial Radio Access Network (E-UTRAN) access

TS 24.301: Non-Access-Stratum (NAS) protocol for Evolved Packet System (EPS); Stage 3

TS 29.272: Evolved Packet System; MME and SGSN related interfaces based on Diameter protocol

TS 33.102: 3G Security; Security architecture

TS 33.203: Access security for IP-based services

TS 33.210: 3G Security; Network Domain Security; IP network layer security

- TS 33.401:** 3GPP System Architecture Evolution (SAE): Security Architecture;
- TS 36.300:** Evolved Universal Terrestrial Radio Access (E-UTRA) and Evolved Universal Terrestrial Radio Access Network (E-UTRAN); Overall description; Stage 2
- TS 23.401:** General Packet Radio Service (GPRS) enhancements for Evolved Universal Terrestrial Radio Access Network (E-UTRAN) access
- TS 24.301:** Non-Access-Stratum (NAS) protocol for Evolved Packet System (EPS); Stage 3
- TS 29.272:** Evolved Packet System; MME and SGSN related interfaces based on Diameter protocol
- TS 33.102:** 3G Security; Security architecture
- TS 33.203:** Access security for IP-based services
- TS 33.210:** 3G Security; Network Domain Security; IP network layer security
- TS 33.401:** 3GPP System Architecture Evolution (SAE): Security Architecture;
- TS 36.300:** Evolved Universal Terrestrial Radio Access (E-UTRA) and Evolved Universal Terrestrial Radio Access Network (E-UTRAN); Overall description; Stage 2
- TS 36.420:** X2 layer 1 general aspects and principles
- TS 36.421:** X2 layer 1
- TS 36.422:** X2 signalling transport
- TS 36.423:** X2 Application Protocol (X2AP)
- TS 36.424:** S2 data transport
- TS 29.281:** GPRS Tunneling protocol for user plane (GTPv1-U)
- TS 23.401:** General Packet Radio Service (GPRS) enhancements for Evolved Universal Terrestrial Radio Access Network (E-UTRAN) access
- TS 36.300:** Evolved Universal Terrestrial Radio Access (E-UTRA) and Evolved Universal Terrestrial Radio Access Network (E-UTRAN); Overall description; Stage 2
- TS 29.305:** Interworking Function (IWF) between MAP-based and Diameter-based interfaces
- TS 29.274:** Tunneling protocol for Control plane (GTPv2-C); Stage 3
- TS 23.060:** General Packet Radio Service (GPRS); service description; Stage 2
- TS 36.410:** S1 layer 1 general aspects and principles
- TS 36.412:** S1 signalling transport
- TS 36.413:** S1 Application protocol (S1AP)
- TS 36.414:** S1 data transport
- TS 29.281:** GPRS Tunneling protocol for user plane (GTPv1-U)

TS 24.301: Non-Access-Stratum (NAS) protocol for Evolved Packet System (EPS); Stage 3

3GPP TR 22.968: Study for requirements for a Public Warning System (PWS)

3GPP TS 22.168: Earthquake and Tsunami Warning System (ETWS) requirements; Stage 1

3GPP TR 23.828: Earthquake and Tsunami Warning System (ETWS), requirements and solutions

TS 23.060: General Packet Radio Service (GPRS); service description; Stage 2

TS 23.107: Quality of Service (QoS) concept and architecture

TS 23.203: Policy and Charging Control Architecture

TS 23.401: General Packet Radio Service (GPRS) enhancements for Evolved Universal Terrestrial Radio Access Network (E-UTRAN) access

TS 36.300: Evolved Universal Terrestrial Radio Access (E-UTRA) and Evolved Universal Terrestrial Radio Access Network (E-UTRAN); Overall description; Stage 2

TS 23.002: Network architecture

TS 23.003: Numbering, addressing and identification

NGMN reference

www.ngmn.org/uploads/media/White_Paper_NGMN_Beyond_HSPA_and_EVDO.pdf

ETSI reference


ETSI TS 102 250-1: *Speech Processing, Transmission and Quality Aspects (STQ); QoS aspects for popular services in GSM and 3G networks: Part 1: Identification of Quality of Service aspects*

Glossary

AAA	authentication, authorization, and accounting
AMR	adaptive multi-rate
AMR-WB	adaptive multi-rate wideband
APN	access point name
ASP	application service provider
BICC	bearer-independent call control
BLER	block error rate
BSC	base station controller
BTS	base transceiver station
CAPEX	capital expenditures
CDF	cumulative distribution function
CDMA	code division multiple access
CLID	calling line identification
CLIP	calling line identification presentation
CS UDI	circuit-switched unrestricted digital information
CSFB	circuit-switched fallback
DL	downlink
DMT	data mining toolkit
E2E	end-to-end
eNodeB	evolved NodeB; Node B is a UMTS base transceiver station (BTS)
EPC	evolved packet core
EPS	evolved packet system
ESN	electronic serial number
ETSI	European Telecommunications Standards Institute
eUTRAN	evolved UMTS terrestrial radio access network; also abbreviated as E-UTRAN or EUTRAN
FSS	frequency-selective scheduling
GGSN	gateway GPRS support node
GPRS	general packet radio service
GUI	graphical user interface
HA	home agent
HARQ	hybrid automatic repeat request
HLR	home location register
HO	handover
HTTP	hypertext transfer protocol
IM	instant messaging
IMS	instant messaging service
IMSI	international mobile subscriber identity

IP-TV	Internet protocol television
IOT	inter-office trunk
IP	Internet protocol
IRAT	inter-radio access technology
KPI	key performance indicator
LCS	location services
LSTI	LTE SAE trial initiative
LTE	Long term evolution
MGW	media gateway
MIMO	multiple-input/multiple-output
MSC	mobile switching center
MSC-S	mobile switching center server
MSS	mobile softswitch
MSTV	Maximum Service Television
NAI	network address indicator
NE	network element
NEM	network equipment manufacturer
NGMN	next-generation mobile networks
OCNG	OFDMA channel-noise generation
OFDM	orthogonal frequency-division multiplexing
OPEX	operating expenses
OLAP	online analytical processing
PCF	packet control function
PDSN-FA	packet data serving node, foreign agent
PDSN-HA	packet data serving node, home agent
PoC	proof of concept
PSTN	public switched telephone network
QCI	QoS class identifier
QoE	quality of experience
QoS	quality of service
QoS M	Quality of Service Manager
RNC	radio network controller
ROHC	robust header compression
RRC	radio resource control
SAE	System Architecture Evolution
SC-FDMA	single-carrier frequency-division multiple access
SCTP	Standard Control Transmission Protocol
SFN	single-frequency network
SGSN	serving GPRS support node

SIP	session initiation protocol
SMS	short messaging service
SON	self-optimizing network
STP	signaling transfer point
TDR	transaction detail record
TTI	transmission time interval
UE	user equipment
UMTS	Universal Mobile Telecommunications System
UL	uplink
URI	uniform resource indicator
USSD	unstructured supplementary service data
VIP	very important person
VoIMS	voice over instant messaging service
VoLGA	voice over LTE generic access
WAP	Wireless Application Protocol
WSP	wireless service provider



Test & Measurement Regional Sales

NORTH AMERICA TEL: 1 866 228 3762 FAX: +1 301 353 9216	LATIN AMERICA TEL: +1 954 688 5660 FAX: +1 954 345 4668	ASIA PACIFIC TEL: +852 2892 0990 FAX: +852 2892 0770	EMEA TEL: +49 7121 86 2222 FAX: +49 7121 86 1222	WEBSITE: www.jdsu.com/test
---	--	---	---	--