R&S®TS 8980 test system analyzes LTE quality indicators: CQI, PMI and RI

LTE stands for fast and reliable data transmission. Accurately measuring the channel quality with the user equipment plays a major role. The R&S®TS 8980 RF conformance test system can analyze this measurement with new test cases while scrutinizing the CQI, PMI and RI quality indicators of the LTE standard.

Three LTE quality indicators in detail

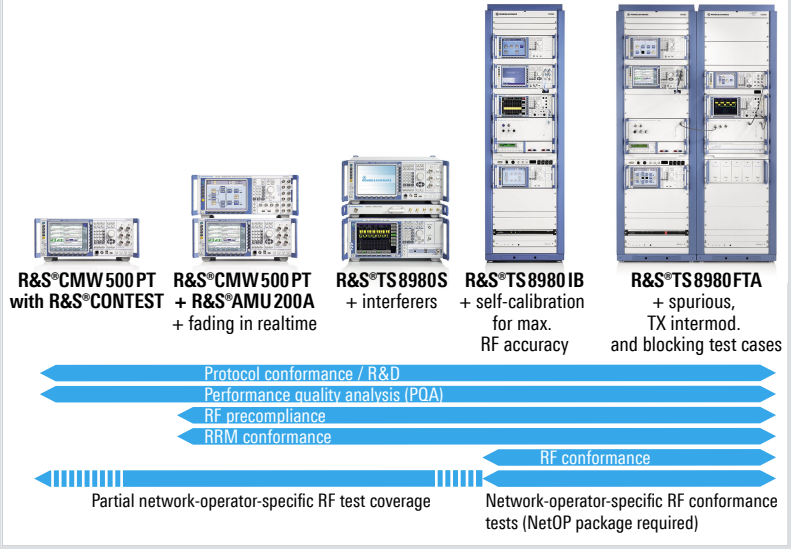
The LTE standard [1] defines three quality indicators that serve as a benchmark for the transmission quality in the downlink: CQI, PMI and RI (channel state information – CSI). The user equipment (UE) can measure all three and transmit the information in the uplink to the base station (BS), which then adapts the signal transmission in the downlink accordingly, although this is not mandatory. To actually improve transmission quality through a modification in the downlink, the statistical properties of the channel must remain constant between the time a quality indicator is reported to the BS and the time the transmission is modified (coherence time).

Channel quality indicator (CQI)

The CQI indicates the highest modulation and the code rate at which the block error rate (BLER) of the channel being analyzed does not exceed 10 %. The CQI accepts discrete values between 0 and 15 (FIG 1). Index 0 indicates that the UE has not received any usable LTE signals and that the channel is inoperable. The CQI report for the UE has a wide variety of settings. As an example, the UE can use one of two methods to send the CQI value to the BS via the uplink:

- periodically via the PUCCH or PUSCH channels,
- aperiodically via the PUSCH channel. In this case, the BS explicitly requests the UE to send a CQI report.

R&S®TS 8980 scalable test system family



With the new R&S®TS 8980 scalable RF conformance test systems for LTE and WCDMA/HSPA+, Rohde&Schwarz is paving the way for its customers to develop broadband wireless user equipment, from design to the fastest possible market introduction. The extremely high level of flexibility to configure and scale the systems means that they are easily and quickly adapted to individual requirements. The R&S®TS 8980 test system family offers room for individual expansion, from the R&S®CMW 500 PT protocol tester combined with the R&S®CONTEST software for development tasks in the lab to the R&S®TS 8980 FTA test system for full-scale RF user equipment certification. A detailed article (R&S®TS 8980 test system family for LTE and WCDMA/HSPA+) can be found on the Internet ("News&Events", "R&S News Magazine", No. 202).

CQI index	Modulation	Target code rate	Imcs	Information bit payload (subframes 1, 2, 3, 4, 6, 7, 8, 9)	Binary channel bits per subframe (subframes 1, 2, 3, 4, 6, 7, 8, 9)	Actual code rate
0	out of range	out of range	DTX	–	12600	–
1	QPSK	0.0762	0	1384	12600	0.1117
2	QPSK	0.1172	0	1384	12600	0.1117
3	QPSK	0.1885	2	2216	12600	0.1778
4	QPSK	0.3008	4	3624	12600	0.2895
5	QPSK	0.4385	6	5160	12600	0.4114
6	QPSK	0.5879	8	6968	12600	0.5549
7	16QAM	0.3691	11	8760	25200	0.3486
8	16QAM	0.4785	13	11448	25200	0.4552
9	16QAM	0.6016	16	15264	25200	0.6067
10	64QAM	0.4551	18	16416	37800	0.4349
11	64QAM	0.5537	21	21384	37800	0.5663
12	64QAM	0.6504	23	25456	37800	0.6741
13	64QAM	0.7539	25	28336	37800	0.7503
14	64QAM	0.8525	27	31704	37800	0.8394
15	64QAM	0.9258	28	31704	37800	0.8394

FIG 1 CQI indexes with the associated transport formats (source: [4], conditions: 50 resource blocks allocated, SIMO, Imcs = modulation and coding scheme index).

In addition, the frequency domain resolution in the CQI report can be varied. Apart from the wideband CQI for the entire channel bandwidth, there are different subband CQIs, each of which indicates the transmission quality for a specific frequency subrange. All previously mentioned setting alternatives are verified using tests specified in [1].

The CQI index reported to the BS by the UE is derived from the quality of the downlink signal. In contrast to other mobile radio systems such as HSDPA, the LTE CQI index is not directly associated with the measured signal-to-noise ratio. Instead, it is also influenced by the signal processing in the UE. With the same channel, a UE featuring a powerful signal processing algorithm is able to forward a higher CQI index to the BS than a UE that has a weak algorithm.

Precoding matrix indicator (PMI)

The precoding matrix determines how the individual data streams (called layers in LTE) are mapped to the antennas. Skillfully selecting this matrix yields a maximum number of data bits, which the UE can receive together across all layers. However, this requires knowledge of the channel quality for each antenna in the downlink, which the UE can determine through measurements. If the UE knows what the allowed precoding matrices are, it can send a PMI report to the BS and suggest a suitable matrix.

Rank indicator (RI)

The channel rank indicates the number of layers and the number of different signal streams transmitted in the downlink. When using a single input multiple output (SIMO) or a transmit diversity configuration, only one layer is utilized. In contrast, 2×2 MIMO (multiple input multiple output) with spatial multiplexing (see [2] and [3]) uses two layers. The goal of an optimized RI is to maximize the channel capacity across the entire available downlink bandwidth by taking advantage of each full channel rank.

RI is not the sole benchmark for the state of the channel when using LTE. CQI and PMI are taken into account as well, since the value of the RI also influences the allowed precoding matrices and CQI values. In contrast, the BS can only utilize the CQI reporting to adapt the downlink channel (assuming the RI does not change such as in pure SIMO mode).

The BS is not forced to react to the feedback from the UE and modify the signal in the downlink accordingly. In most cases, it nevertheless makes sense to do this in order to reduce the error rate and increase the data throughput. However, inaccurate feedback from the UE regarding the state of the channel can lead to exactly the opposite situation. For this reason, it is vital to ensure that the UE accurately indicates the state of the channel by means of the CQI, PMI and RI parameters. To address this requirement, the test specification [1] defines several test cases that are used to verify if a UE accurately determines the CQI, PMI or RI values (CSI values) even under difficult conditions such as additive white Gaussian noise (AWGN) and fading. These test cases can be carried out with the R&S®TS8980 RF test system family. The R&S®CMW500 wideband radio communication tester assumes the role of the base station while the R&S®AMU200A fading simulator simulates the channel.

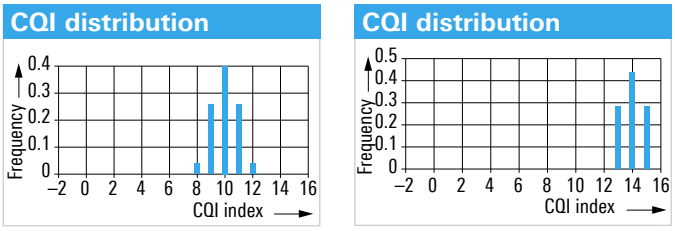


FIG 2 Example of a CQI distribution across 2000 samples sent to the BS by the UE (left: test 1, SNR = 10 dB, right: test 2, SNR = 16 dB). The distributions show that based on the analysis of the channel state by the UE, the BS should utilize the CQI index 10 and 14 respectively.

For median CQI +1, the error rate **must be equal to or greater than 10 %** (FIG 4), since in this case a lower code rate and – depending on the CQI value – a higher order modulation that is more susceptible to errors is selected. If the error rate is less than 10 %, the channel state tends to correspond to the median CQI +1 value. In this case, the UE would not have passed the test, since:

- a higher data rate can be achieved by utilizing the median CQI +1, where the error rate is less than 10 %,
- this also means that the median CQI produced from the CQI distribution, which was sent to the BS by the UE, did not reflect the real state of the channel. This error reduces the data rate that is possible with the current channel quality.

R&S®TS8980 combined with R&S®CONTEST

Using the current LTE software for the R&S®TS8980, all test cases are carried out with the easy-to-use graphical interface of the R&S®CONTEST software. The software displays the CQI distributions in the report in the form of bargraphs at runtime (FIG 2). A wide selection of test parameter settings allows users to analyze the CQI, PMI and RI measurements of the UE across different channels, even outside of the official RF test specification. The individual parameters can be configured in a window in R&S®CONTEST (FIG 3). Individual test sequences (test plans) can then be easily put together with a mouse click. The reports from R&S®CONTEST are sorted according to various criteria and analyzed. Additional features of R&S®CONTEST are described in [5].

A brief explanation of the individual test cases for CSI reporting for FDD based on the test specification [1] is provided in the following sections. In the future, the R&S®TS8980 will feature the capability to use similar test cases for TDD as well.

Test cases 9.2.x: CQI under AWGN conditions

For this group of test cases, the R&S®TS8980 test system, functioning as a BS, first sets a modulation and a code rate that correspond to a CQI index of 8. The UE then determines the state of the channel and sends a corresponding CQI for the entire bandwidth (wideband CQI) back to the BS. The software produces a CQI distribution from 2000 received CQI indexes, which the BS uses to calculate a median CQI (FIG 2).

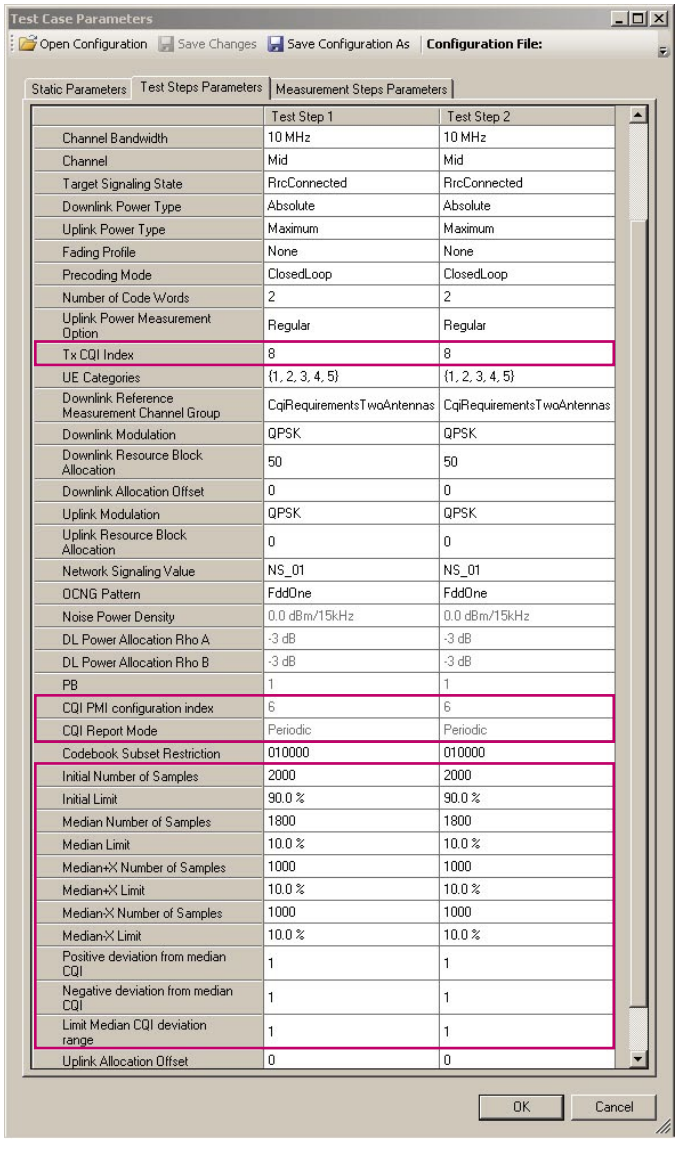
In the next step, the downlink is configured with three different CQI indexes: with the median CQI and the ±1 deviations from the median CQI. In all three cases, the block error rate

$$BLER = NACK/(ACK + NACK) \quad \text{(formula 1)}$$

is measured and compared to a predefined upper and lower threshold of 10 %:

$$BLER_{Median\ CQI\ -1} \leq 0.1 \leq BLER_{Median\ CQI\ +1} \quad \text{(formula 2)}$$

FIG 3 R&S®CONTEST provides a clear and concise list of all test parameters. The specific parameters for the channel state information tests are framed by a red border.



TX CQI #0 Used	11
Requested Samples	1000
Measured Samples	2000
Measured ACK (CQI #0)	1780
Measured NACK (CQI #0)	220
Measured StatDTX (CQI #0)	0
Measured NACK/(ACK+NACK) (CQI #0)	0.110
Lower Limit NACK/(ACK+NACK)	0.100
Result	Inside

TX CQI #0 Used	9
Requested Samples	1000
Measured Samples	2000
Measured ACK (CQI #0)	1820
Measured NACK (CQI #0)	180
Measured StatDTX (CQI #0)	0
Measured NACK/(ACK+NACK) (CQI #0)	0.090
Upper Limit NACK/(ACK+NACK)	0.100
Result	Inside

FIG 4 Excerpt from the R&S®CONTEST report, which is displayed on the R&S®TS8980 during a test run. The table on the left contains the measurement results for median CQI +1; the table on the right shows median CQI –1.

The CQI feedback of the UE under 2 × 2 MIMO is also tested. The test concept is similar to the one described above, with the exception that 2 × 2 MIMO operates with two data streams. The BS records a CQI distribution for each individual stream. The CQI indexes for both code words must adhere to the BLER conditions (formula 2) in order for the UE to pass the test.

Test cases 9.3.x: CQI under fading conditions

This series of tests utilizes various, and for the most part frequency-selective interference to analyze the CQI indexes of the entire frequency range, as well as those of the individual subbands. The various transmission conditions in the subbands also lead to different CQI distributions.

When there is a single CQI index for all subbands, the data throughput must be less than when there are multiple CQI indexes, each of which the UE recommends for a specific subband. Only then will the UE pass the test. The ratio of the data throughputs measured by the R&S®TS8980 is a benchmark for what is gained by utilizing the individual CQI values for each subband.

Test case 9.3.3.1.1 has another special feature. In addition to fading, the average power of the AWGN noise is frequency-selective and varies depending on the subband. In this way, the UE is tested to determine how it deals with interference signals that have power levels similar to the signal from the BS in the downlink.

Test cases 9.4.x: precoding matrix indicator (PMI)

The UE can use the PMI reporting to recommend a downlink precoding matrix to the BS that will achieve the highest data throughput for the given channel state. Test cases 9.4.x calculate the ratio γ between the throughput under randomly selected but equally distributed PMIs, and the throughput when utilizing PMIs that have been configured in accordance with the feedback of the UE. If the PMIs have been adapted, the throughput must increase by 10 % and 20 % respectively in order for the UE to pass the test.

One unique feature of the tests from the 9.4.x series involves the UE-dependent configuration of the signal-to-noise ratio (SNR). The SNR is individually configured for each UE, such that the throughput is between 58 % and 62 % when randomly selected PMIs are utilized. This levels out the throughput for all UEs. Whether the UE has passed the test depends solely on the ratio γ, and not on its performance at a specific SNR.

Test case 9.5.1.1: rank indicator (RI)

Test case 9.5.1.1 checks all quality indicators (CQI, PMI, RI) in the report of the UE at the same time. The extent to which the three indicators are interdependent can also be tested. If the UE changes the RI value, then the CQI and PMI must be changed accordingly.

Summary

In addition to TX, RX, performance and MIMO test cases under LTE, the R&S®TS8980 test system family can now also be used to test the CQI, PMI and RI quality indicators. Manufacturers and test houses can now ensure that the prerequisites are in place for high data rates and reliable transmission with the LTE standard. The versatile capabilities of the test systems are far from being exhausted however. The systems can also execute LTE radio resource management tests and throughput measurements under real conditions for LTE / HSPA+ / WCDMA. Moreover, the NetOP package for the R&S®TS8980IB and R&S®TS8980FTA test systems provides applications tailored specifically to network operators.

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References

[1] 3GPP 36.521-1 V9.3.0 test specification, "User equipment (UE) conformance specification, radio transmission and reception, part 1: conformance testing".

[2] From SISO to MIMO – taking advantage of everything the air interface offers (2). News from Rohde&Schwarz (2007) No. 194, pp. 4–7.

[3] Radio conformance test systems ready for MIMO. NEWS (2010) No. 200, pp. 6–8.

[4] 3GPP 36.521-1 V9.3.0 test specification, "User equipment (UE) conformance specification, radio transmission and reception, part 1: conformance testing", table A. 4–3, p. 382.

[5] R&S®TS8980 RF conformance test system family for LTE and WCDMA / HSPA+. Article available on the Internet ("News&Events", "R&S News Magazine", No. 202).