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ERTMS/GSM-R Quality of Service Test Specification

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EVOLUTION SHEET

Version	Date	Author	Modification
0.1	3 June 2003	QoS Working Group	First draft version, based on a QoS Working document created by GSM-R/UNISIG.
0.2	13 June 2003	QoS Working Group	Updated after GSM-R internal review.
0.3	21 July 2003	QoS Working Group	Update after comments from UNISIG.
0.4	25 July 2003	QoS Working Group	Update after comments of Unisig and GSM-R internal review.
1.0	11 September 2003	QoS Working Group	Final approved version.
1.1	16th September 2005	GSM-R QoS Working Group	Update after new release of Subset093 and new definition of transmission interference metric.
1.2	7th July 2006	GSM-R QoS Working Group	Update after terrain feedback about the transmission interference and the network registration metrics. Addition of an appendix proposing a sample size for KPI validation.
2.0	30th October 2006	GSM-R QoS Working Group	Generic improvement of QoS parameter definitions, prerequisites, algortihms and statistics through interim document versions 1.2a to 1.2i.
2.01	22nd November 2006	OG meeting #26	Comments of OG meeting included.
3.0	19th February 2007	ERIG/IG/UNISIG/EEIG	Specification update approved issue

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1 INTRODUCTION

1.1 Purpose

This document is a test specification for the Quality of Service requirements based on [SUBSET-093] and proposes a standardized set of acceptance tests to allow comparable QoS behaviour of GSM-R communication networks.

It contains:
- Detailed definitions of the QoS parameters for the bearer service.
- The interfaces on which the bearer service and the QoS parameters are applicable.
- The methods of measuring and verification of QoS parameter values.

Remark: it is intended to include in a future release of this document the methods of monitoring QoS parameters in operational situations.

When complying with the tests in this document it will be possible:
- To demonstrate that the end-to-end communication system for ETCS complies with -requirements.

1.2 References

[SUBSET-093]	UNISIG Subset-093, v 2.3.0
[EUR FFFIS]	Radio Transmission FFFIS for EuroRadio, A 11 T 6001 12
[EIRENE FRS]	EIRENE Functional Requirement Specification, v15
[EIRENE SRS]	EIRENE System Requirement Specification, v7
[ISO/IEC 13239:2002]	Information technology — Telecommunications and information exchange between systems — High-level data link control (HDLC) procedures, Third edition 2002-07-15

1.3 Abbreviations and definitions

Abbreviations

ASCII	American Standard Code for Information Interchange. ASCII code is the numerical representation of a character such as 'a' or '@' etc.
ERTMS	European Rail Traffic Management System
ETCS	European Train Control System
KPI	Key Performance Indicator
IMSI	International Mobile Subscriber Identity
LUP	Location Update (GSM term). MT performs LUP when switched on and off, periodically and when entering into a new Location Area defined by the network.
MT	Mobile Termination
NT	Network Termination
OBU	On-Board Unit
PLMN	Public Land Mobile Network
QoS	Quality of Service

RBC	Radio Block Center
TI	Transmission Interference

Definitions

Byte	1 start bit + 8 data bits + 1 stop bit
Call	Refers to GSM-R network only
Connection	Refers to end-to-end data call
Confidence	Confidence level is the confidence in the measurement result, please see Appendix A, Clarification on Statistics
Data frame	A frame is defined as 30 consecutive bytes.
I_{FIX}	The interface between ETCS and GSM-R on fixed side, refer to [EUR FFFIS]
I_{GSM}	The interface between ETCS and GSM-R on mobile side, refer to [EUR FFFIS]
I_{Um}	The GSM-R radio interface,
Octet	8 data bits
Probability	Unitless, e.g. percentage
Rate	Value per time unit, e.g. per hour
Bearer Service User	ETCS (the service is the bearer service provided by GSM-R).
User	In this document, User means test operator

2 INTERFACES AND OTHER ASPECTS

2.1 System and Measurement Architecture

In order to define and to clarify the different QoS aspects, a reference system architecture is needed. Both the operational system architecture and the measurement architecture are shown below.

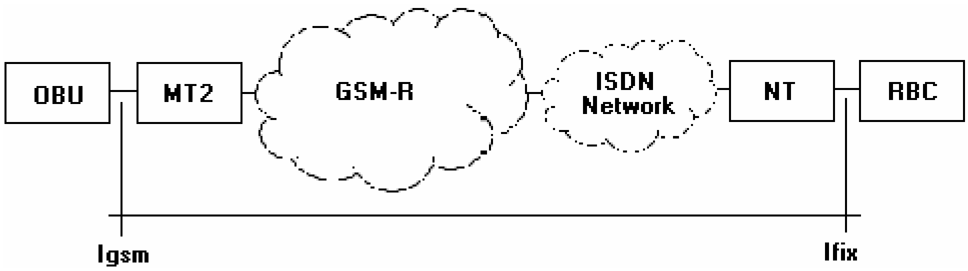


Figure 1: System Architecture

In the system architecture, the most important GSM-R related communication networks and elements are shown. It consists of:

- The GSM-R mobile termination, MT2.
- The GSM-R network.
- The fixed network between the GSM-R network and the network termination.
- The GSM-R fixed network termination, NT.

Important notices:

1. The implementation of the GSM-R PLMN network is a national matter. Interoperability will be guaranteed when this network is compliant with the EIRENE specifications.
2. The implementation of the fixed network is a national matter and does not affect interoperability directly. However, the behaviour of this network must be taken into account for the end-to-end QoS.
3. The choice of the MT (MT2 or MT0) is a responsibility of the railway operator and shall not affect the interoperability for ETCS. For reference purposes, this document uses only MT2.

For testing purposes, the following differences are allowed compared with the System Architecture shown in Figure 1.

- $I_{GSM(T)}$ can differ from I_{GSM} in the sense that the test equipment does not always includes an MT2.
- The interface between Test mobile and Test application complies with the recommended interface implementation as described in [EUR FFFIS].
- $I_{FIX(T)}$ differs from I_{FIX} in the sense that the terminal adapter (i.e. ISDN Modem) is included.
- I_{Um} is added for GSM-R network only tests and for (possibly) measures of fault finding.

Although the differences above exist, no difference in performance shall be allowed.

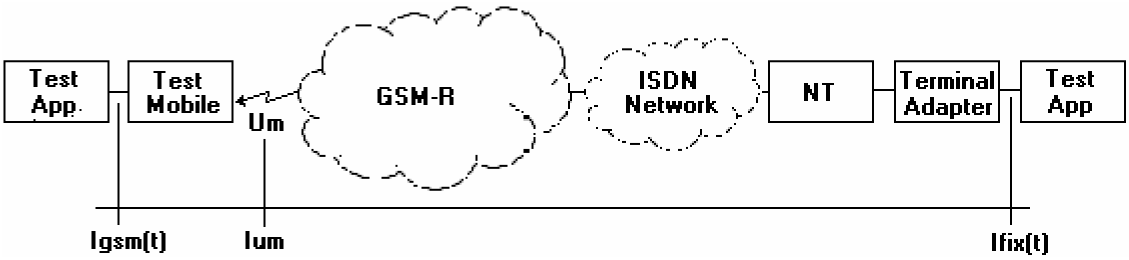


Figure 2: Measurement Architecture

2.2 Prerequisites and clarifications

2.2.1 General

The purpose of these tests is to test the correct behaviour of the GSM-R subsystem. EuroRadio protocol stacks according to [subset 037] are not used during testing. Measurement applications are used to collect the QoS result.

The tests shall be performed using the same bearer service(s) as the ETCS operational system.
Although a data frame in the operational system consists of octets, all test descriptions use bytes, since test tools are more likely to handle bytes and ASCII characters.
For some QoS tests, 30 bytes long data frames shall be used. These frames are providing a model for HDLC protocol which is using data frames consisting of 30 octets.

The test area is defined as the area with ETCS service. ETCS service boundaries are usually marked by a ETCS "announcement" balise.
The test shall be performed under conditions similar to nominal operational conditions. Tests shall be done using the highest commercial available train speed (according to the line status: new line, on-going upgrades,). All equipment is in normal operational use. Non-availability due to technical defects is excluded, unless stated otherwise.

Measuring for a higher data transfer rate also qualifies the test area for the lower rates (e.g. measuring at 9.6 kbps also qualifies 4.8 and 2.4)

Requirements are normally specified with a Confidence Level. This allows calculation of the number of samples needed before a test can be considered as completed. If feasible, all parameters shall be verified up to the Confidence Level specified on a national or operator basis. See Appendix D, Recommendation of minimum sample sizes for ETCS QoS parameter validation (informative) and Appendix A, Clarification on Statistics.

Tests are fulfilling data bearer requirements, as specified in [SUBSET-093].
The network configuration and the parameters shall be described within test cases and logged during test execution.

2.2.2 Mobile equipment

The mobile shall be registered to the GSM-R network, if not stated otherwise in testing conditions.

The test mobile performance shall be equal to an MT2 on the relevant parameters in the different test cases. ETCS data communication is tested using only 8W mobiles. The MT2 test mobile must be compliant with the EIRENE specifications.
The mobile must report classmark 2 information element, with a SIM Card not configured for subscription to VBS/VGCS services, as described in [EUR FFFIS], to avoid disturbance of ASCI notification.

2.2.3 GSM-R and ISDN network

The GSM-R network shall be well designed, e.g. in terms of handover interval, and in accordance with EIRENE requirements.
Requirements and values are considered for a network without congestion/overload. Overload shall be prevented with good initial design and preventive measures such as capacity enhancements.
The configuration of network specific parameters is a national matter, but it is recommended to have Authentication activated on Location Update (LUP) only. Additionally, ETCS has its own end-to-end authentication and encryption.

2.2.4 Fixed network interface

ISDN connections compliant with [EUR FFFIS] shall be used.
On the fixed side, the ISDN network may or may not consist of other network/transmission elements. In either case, it must be compliant with [EIRENE SRS] (which states a maximum delay 250 ms for fixed networks).
ISDN network can be designed according to national requirements as long as it complies with EIRENE.

2.3 Test plan

Testing and tuning the network is usually part of larger and partially national project efforts. One can use QoS testing for a step-by-step or layer-by-layer integration of ETCS.

Basic testing of QoS for ETCS will be necessary or at least helpful for tuning and optimising the network that will operate ETCS. QoS test equipment will here be used as "test application", integration of which will show possible network or mobile deficiencies and lead to an optimised transmission system. Fundamental as well as local problems can be disclosed.

After this it should be easier to integrate the real ETCS application consisting of EURORADIO equipment, RBC, OBU into the GSM-R system. Nevertheless, it can be necessary to perform additional QoS testing in this phase, e.g. to raise the confidence level in view of forthcoming railway operation.

Therefore the extent of testing, and for what purpose, is a decision of the national projects.

2.3.1 Typical testing phases

Here are the typical testing phases foreseen for an ETCS project:

- **Phase 0** – RF tuning, ensuring that the sole air interface is performing well. GSM-R only parameters are measured. This phase is meant to be performed prior to start the QoS tests specified within this document.
- **Phase 1** – End-to-end testing and optimisation.

- **Phase 2** – ETCS integration tests using real components like RBC, OBU and EuroRadio protocol stack.
- **Phase 3** – In-service continuous monitoring of the performances (not covered by this document).

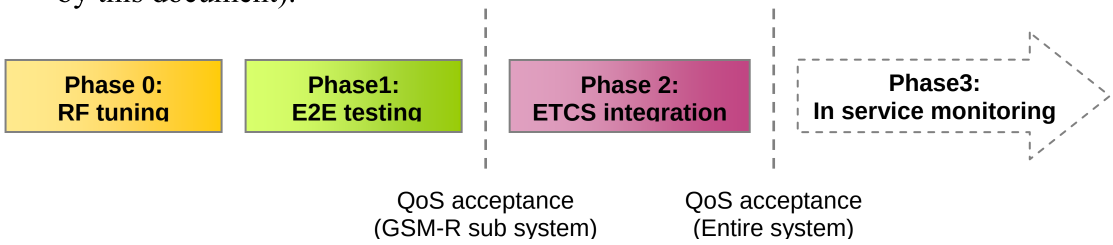


Figure 3, Testing phases

3 ACCEPTANCE TEST SPECIFICATION OF MOBILE ORIGINATED CALLS

3.1 Connection establishment delay

3.1.1 Definition:

This is the value of the elapsed time between the connection establishment request and the indication of successful connection establishment on the requesting side.

3.1.2 Pre-conditions for measurement:

Measurement interfaces are $I_{GSM(T)}$ and $I_{FIX(T)}$, measurement point is $I_{GSM(T)}$.
Only MSISDN numbers shall be used, and not Functional Numbers (FN).
Only successfully established connections, refer to 3.2, shall be evaluated in order to avoid double counting.
Terminal is registered to the GSM-R network, is in Idle mode, and is located in its Home-PLMN. A delta delay for Visited-PLMN calls shall be measured by laboratory tests.
Automatic answering for B-party shall be as fast as possible.
Call re-establishment as defined by ETSI shall not be considered.

3.1.3 For measurement:

At $I_{GSM(T),}$ the elapsed time between the delivery of the command ATD xxx to the MT2/MT and the later of the two following events is measured at $I_{GSM(T)}$:

- Indication of successful connection establishment by CONNECT yyy
- Transition of circuit 109 (DCD) to ON

To ensure proper cell reselection, a sufficient time between each attempt shall be used, typically 30 seconds.

3.1.4 Recommended tools:

Test application for control of terminal and automation (scripting).
Test terminal for tracking possible failure in automated test, and/or
Abis protocol analyser for tracking possible failure.
GPS for position information.

3.2 Connection establishment error ratio

3.2.1 Definition:

This is the ratio of the number of unsuccessful attempts for connection establishment to the total number of connection establishment attempts.

3.2.2 Pre-conditions for measurement:

Measurement interfaces are $I_{GSM(T)}$ and $I_{FIX(T)}$, measurement point is $I_{GSM(T)}$.
Terminal is registered to the GSM-R network and is in Idle mode.
The B-party is reachable.
For Call set-up a valid phone number is used.
The user must not release the connection establishment before a successful connection is indicated or within the period specified as maximum delay.
For measurement:

At $I_{GSM(T)}$ test is initiated by issuing ATD xxx
As soon as the connection establishment indication (CONNECT or DCD) is received, small data units have to be transmitted in both directions (uplink/downlink) to confirm the successful establishment of the connection. In case no data is received on I_{GSM} or I_{FIX} the connection establishment is considered as failed.
All connection establishment requests (ATD xxx) and all unsuccessful connection establishment attempts are counted.
Unsuccessful cases are:

- All responses except CONNECT yyy, if the connection establishment error is not caused by the service user.
- If successful connection establishment is not signalised within the period specified as maximum delay.
- If neither a connection establishment indication nor an error indication is received up to the maximum time of connection establishment, the attempt is counted as unsuccessful.

The failure probability is calculated as the ratio between ‘number of failed attempts’ and ‘total number of attempts’

3.2.3 Recommended tools:

Test application for control of terminal and automation (scripting).
Test terminal for tracking possible failure in automated test, and/or
Abis protocol analyser for tracking possible failure.
GPS for position information.

3.3 Connection loss rate

3.3.1 Definition:

The number of connections released unintentionally per total accumulated connection time.

3.3.2 Pre-conditions for measurement:

Measurement interfaces are $I_{GSM(T)}$ and $I_{FIX(T)}$, measurement point is $I_{GSM(T)}$
The connection is successfully established and data is transmitted in both directions end-to-end.
Connection duration refers to the end-to-end data transmission phase of a connection and consequently the connection establishment delay shall be withdrawn from the measured time (delay to be withdrawn is between CONNECT & ATH).
A minimum connection duration shall be defined (5 min).
Connection losses caused by the service user are not counted.
The test results are only concerning number of losses per time unit, it is therefore independent of the number of connections made and connection duration. The only thing of importance is the total measured time to reach sufficient confidence in the measurements.

3.3.3 For measurement:

At $I_{GSM(T)}$, if one of the following events is detected, a connection loss is assumed and counted:

- Indication of ERROR
- Transition of circuit 109 (DCD) to OFF
- Indication of NO CARRIER

- When the continuous end-to-end data transmission in either direction is unintentionally interrupted. Transmission interruption is considered if the duration of the interruption exceeds a threshold (typical example: 10 s).

Notes

1. The first occurrence of such event whichever comes first is sufficient to assume a connection loss.
2. A combination of these events occurring in sequence before starting connection re-establishment is counted as only one connection loss.

The single connection duration for this connection established is accumulated to the total connection duration.

3.3.4 Recommended tools:

Test application for control of terminal and automation (scripting).
Test terminal for tracking possible failure in automated test, and/or
Abis protocol analyser for tracking possible failure.
GPS for position information.

3.4 Transfer delay of user data frame

3.4.1 Definition:

This is the value of the elapsed time between the request for transfer of a data frame and the indication of successfully transferred end-to-end data frame.

3.4.2 Pre-conditions for measurement:

Measurement interfaces are $I_{GSM(T)}$ and $I_{FIX(T)}$, measurement point is $I_{GSM(T)}$
Only successfully received user data frames (ie data frames received with a correct CRC check sum) are evaluated.
The length of data frame shall be 30 bytes.
The fixed side responding application is a test application responsible for echoing all incoming data frames back to the sender.
The response time of the test application shall be very small and negligible.

3.4.3 For measurement:

Round trip delay is an allowed measurement procedure.
The test is performed by sending and receiving bytes and in the test application represented by ASCII characters.
At $I_{GSM(T)}$, value of the half of elapsed time between start of transmission of a user data frame and end of reception of the same frame echoed back from B-subscriber terminal application is evaluated as transfer delay. The term 'user' refers to the user of the GSM-R bearer service.

3.4.4 Recommended tools:

Test application for control of terminal and automation (scripting).
Test terminal for tracking possible failure in automated test, and/or
Abis protocol analyser for tracking possible failure.
GPS for position information.

3.5 Data transmission interference

3.5.1 Definition:

The purpose of this KPI is to test the correct sending of data frames across the GSM-R subsystem. The statistical distributions of transmission interferences and error-free periods will be then built and finally assessed against [Subset093] targets using separately uplink and downlink distributions.

Transmission recovery period T_{REC}

- T_{REC} starts with the first error-free data frame.
- T_{REC} ends before the first erroneous data frame.

Transmission interference period T_{TI}:

- T_{TI} starts with the first erroneous data frame. An erroneous data frame is a 30 bytes frame bearing at least one bit in the received data stream that does not comply with the associated bits of the transmitted data frame.
- T_{TI} ends before the first error-free data frame. An error-free data frame is a 30 bytes data frame bearing no bit in the received data frame that does not comply with the associated bits of the transmitted data frame.

In case a connection loss (see chapter 3.3.3 page 12), the last continuous interference period prior to the connection loss shall not be taken in account for T_{TI} cumulated distribution function, since such an event is already counted within the connection loss rate.
In case of a T_{REC} period equal or less than 4 consecutive error-free data frames, this short error free period shall be counted as one error period and shall be merged with the adjacent Transmission interference period $T_{TI.}$ A T_{REC} period always starts with 5 or more consecutive error-free data frames.

<u>KPI assessment</u>:

- The statistical events defining the QoS targets for transmission interference specified in [Subset093] are the transmission recovery periods and transmission interference periods.

3.5.2 Pre-conditions for measurement:

Measurement interfaces are $I_{GSM(T)}$ and $I_{FIX(T)}$, measurement points are both $I_{GSM(T)}$ and $I_{FIX(T).}$
The connection is successfully established.

3.5.3 For measurement:

The parameter Transmission interference is measured without use of HDLC. However, the parameter and its requirements are derived from the characteristics of HDLC.
The test is performed by sending and receiving a data stream in the test application represented by ASCII characters.
To collect as many sample as possible within a limited number of train test runs, data frames shall be sent only separated by a small delay (up to10 ms) between 2 consecutive frames.

The data frame pattern is set at the sending side, with the following pattern:
[7E] [random data payload] [sequence number] [CRC-16] (= 30 octets in total)
where:

- *[7E] is the octet flagging the start of the frame, as in HDLC*
- *[random data payload] is a 25 octet random payload*
- *[16 bits sequence nbr] is a 2 octets sequence number marking the frame*
- *[CRC-16] is a 2 octets CRC-16 check sum to detect valid data frames on the receiving application (CRC Hamming distance is very good for a 30 octets data frame)*

The receiving side shall synchronise with sent frames.
The time reference for interference duration and recovery measurement shall be on the receiving application only (Channel latency is measured independently).
The measurement results are updated following verification of the data frame sequence number.

The data streams must be stored to files on both sending and receiving sides (at both $I_{GSM(T)}$ and $I_{FIX(T)}$).
The result is either calculated by comparison and analysis of the differences in these files or detecting CRC errors in the received data.
The transmission interference test shall be performed using separate applications for uplink and downlink (no round-trip data).
The uplink and downlink may be tested simultaneously depending on test application capabilities.
Cumulated distribution functions for both T_{REC} and T_{TI} shall be built over the measured area.
Some typical examples are shown below:

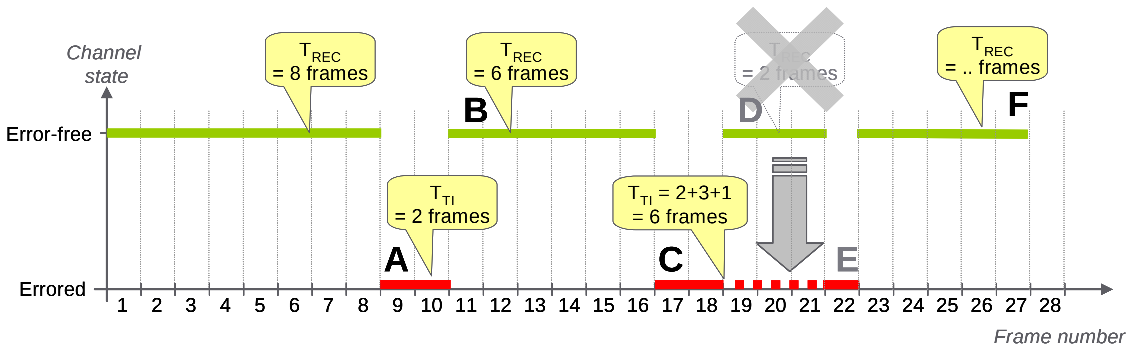


Figure 4, Example of transmission interference

A. An interference, 2 frames from first to last erroneous frame.
B. An error-free series of frames longer than or equal to 5 frames, T_{TI} = 2 frames and T_{REC} = 6 frames
C. An interference, 2 frames from first to last erroneous frame
D. An error-free series of frames shorter than 5 frames, consider D as an interfered period and merged it with C and E
E. An isolated interference of 1 frame.
F. Back to a series of error-free frames longer than or equal to 5 frames, T_{TI} is incremented with the sum of C+D+E, considered as a single interfered period. T_{TI} = 6 frames. T_{REC} is incremented until the next erroneous frame.

An algorithm for Transmission Interference calculation is proposed in Appendix B, Algorithm for Transmission Interference calculation (informative). The algorithm itself is for information, but the calculation methodology and the definition of the parameters shall be adhered to.

Note that from a practical point of view (i.e. in life networks where handovers occur) there is a natural balance between Transmission Interference and Recovery. Very short interferences (<0.8 sec.) contribute to a better performance on Transmission Interference, but typically decreases performance on Recovery. Extremely long Recovery periods (which typically decreases Recovery performance) do not exist since the occurrence of handovers prevents this.

3.5.4 Recommended tools:

Test application for control of terminal and automation (scripting).
Test application capable of transmitting and receiving a data stream.
Test terminal for tracking possible failure in automated test, and/or
Abis protocol analyser for tracking possible failure.
GPS for position information.

3.6 GSM-R network registration delay

3.6.1 Definition:

The elapsed time between the registration request "+COPS=1,2," network2select" and the indication of successful registration onto GSM-R network "+CREG: 1" or "+CREG: 5".

3.6.2 Pre-conditions for measurement:

Measurement interface is $I_{GSM(T)}$ and measurement point is $I_{GSM(T)}$.

3.6.3 For measurement:

The scenario is registration in manual mode from a registration in manual mode on a forbidden network
Perform manual registration onto a forbidden network, i.e. a network to which no roaming exists.
At $I_{GSM(T)}$, the elapsed time between the delivery of the command AT+COPS=1,2,"network2select" and the result "+CREG=1" or "+CREG=5". (Note that the result +CREG=1 is only applicable on home PLMN and +CREG=5 for roaming PLMNs).
This parameter shall be tested on certain locations (static test) to confirm the nominal value. No "drive-test" necessary.

For border crossing scenarios both directions shall be verified, i.e. using the sequence described above with:

- For outbound border crossing, "network2select" = Visited PLMN.
  Test location: In coverage from Visited PLMN.
- For inbound border crossing, "network2select" = Home PLMN.
  Test location: In coverage from Home PLMN.

A command script is proposed in Appendix C, Command script for GSM-R network registration delay measurement (informative)

3.6.4 Recommended tools:

Test application for control of terminal and automation (scripting).
Test terminal for tracking possible failure in automated test, and/or
Abis protocol analyser for tracking possible failure.
GPS for position information.

4 ACCEPTANCE TEST SPECIFICATION OF MOBILE TERMINATED CALLS

Mobile Terminated connections are currently not used by the ETCS application, thus no test specification exists. This is to be defined when needed.

5 MONITORING OF QUALITY OF SERVICE DURING OPERATION

When an ERTMS system is in operation, there will still be a need to monitor the performance of the network part. Possible performance degradation can be identified and corrected before there is any impact on the signalling application. This can be done by repetition of the Acceptance test procedure, but even better is to have continuous feedback of performance.

Continuous monitoring of network performance is to be done with statistical call-related counters available in the GSM-R network.

Next level of details can be achieved with the commonly available IMSI Trace, which is a way to collect call details on specific calls, i.e. on subscribers identified by their IMSI number.

Details of parameters to be continuously monitored are to be agreed on a national or contract basis as required.

6 APPENDIXES

6.1 Appendix A, Clarification on Statistics

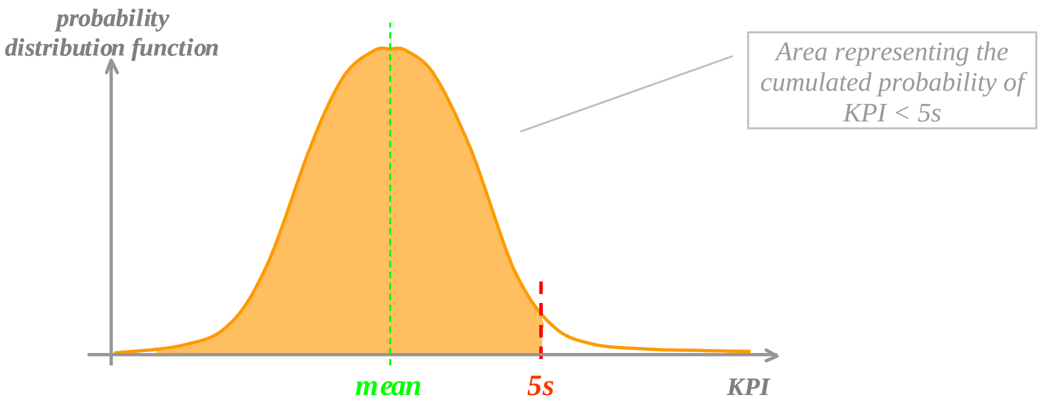
The QoS requirements available in [SUBSET-093] shall be completed together with Confidence Level at national or contractual level.
This term is further explained below.
For ease of understanding, illustrations and explanations are based on the following example:

“t<5sec (95%) with a confidence level of 90%”

This example is based on a continuous set of values. Similar illustrations can be drawn on discrete set of values.

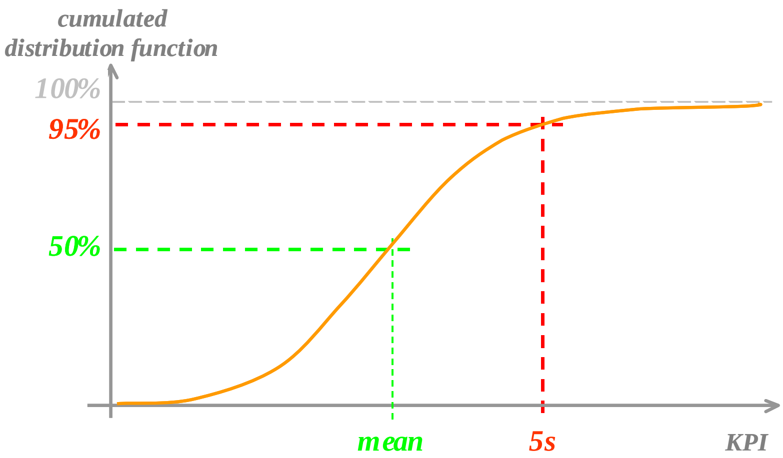
6.1.1 Quantiles:

A statement t<5sec (95%) means that for the KPI to evaluate, the following is valid: 95% of all values are smaller than 5s.



Equivalent to the above statement is that the area under the distribution function is enclosed in the interval [0s;5s].

The cumulated statistic is often used to visualise whether the KPI target is met:

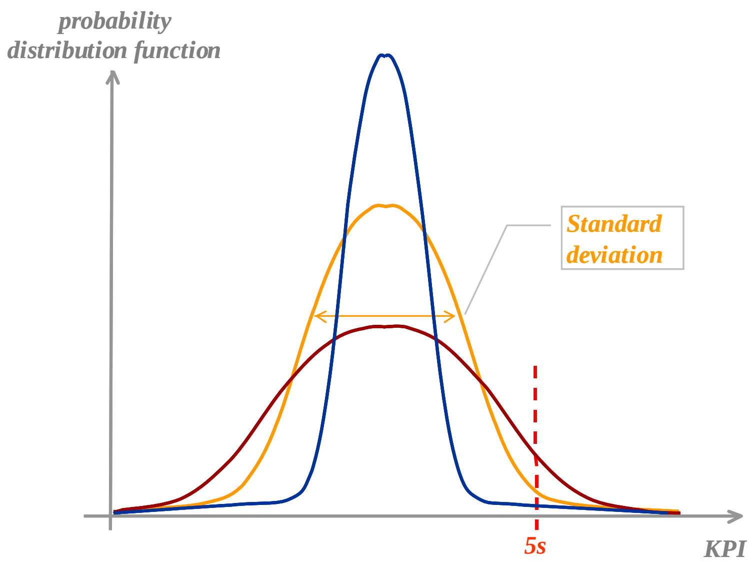


Note

The mean value of the KPI is often different from the KPI target.

6.1.2 Standard deviation:

The standard deviation shows the spreading of a statistical law.



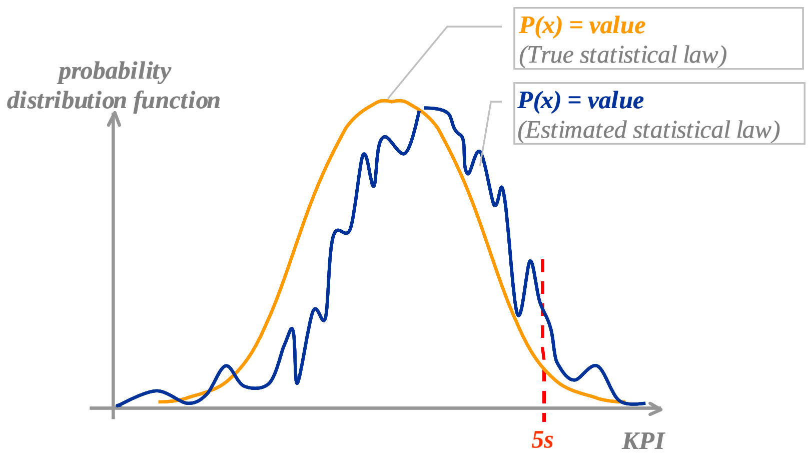
Note

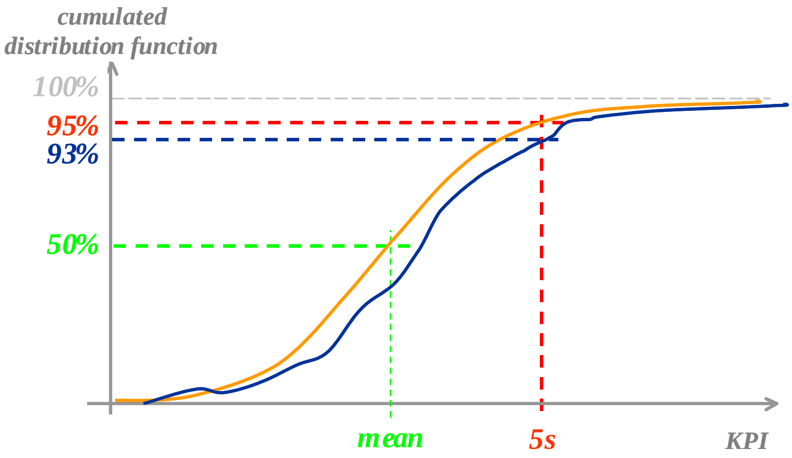
There is no relationship between the standard deviation and “errors” and confidence intervals. The standard deviation is a property of the statistical law, whereas the confidence interval is related to measured estimations.

6.1.3 Confidence Intervals:

The true probability law represents the statistical properties of the entire set of KPI values.

For practical reasons, it is only possible to collect a limited set of measurements. Unfortunately, the subset’s properties often differ from the true probability law:





Although it is impossible to determine precisely this difference*, estimation of the probability that the subset is within x% of the true statistical can be made: it is called the confidence interval.

** If it would be known, we could compute the true statistical law!*

Note

The larger the number of samples within the subset, the smaller the confidence interval. For a Gaussian law, as an approximation, the size of the confidence interval decreases with $\frac{1}{(\text{number of samples})^2}$.

This means to increase the confidence from 90% to 99% keeping the same interval, 100 times more samples are needed!

The knowledge of the confidence interval and the type of statistical law allow computing the number of samples needed.

A confidence level of 90% means that there is 10% of chance to fall out of the interval [0, measured KPI for t<5s].

It does NOT mean that the "error" on the measurement is 10%.

6.2 Appendix B, Algorithm for Transmission Interference calculation (informative)

6.2.1 Sending side

```
/frame formatting procedure/
1. insert 7E flag
2. append 25 bytes of random data
3. append sequence number (2 bytes); update Snr
4. calculate and append CRC (2 bytes)
5. send data frame
6. wait for xx ms
   /xx: value of delay between 2 consecutive frames, up to 10 ms/
```

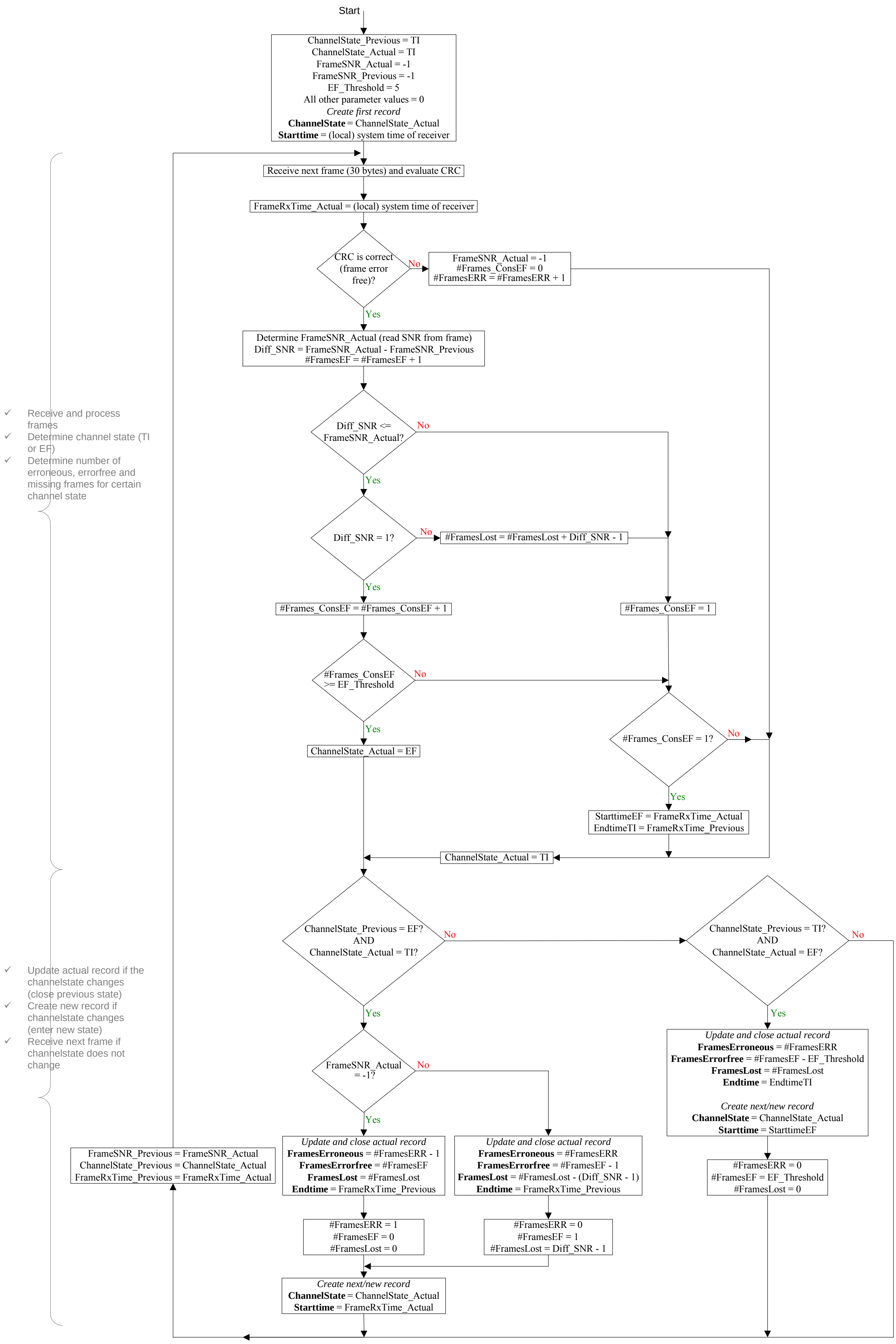
6.2.2 Receiving side

The purpose of the Transmission Interference algorithm is to receive and evaluate frames in order to build a table where each record has the following fields and contents (example):

ChannelState	Startime	Endtime	FramesErroneous	FramesErrorfree	FramesLost
EF	01:00:00.234	01:10:00.834	0	1525	0
TI	01:10:00.934	01:11:08.555	13	5	3
…					
EF	01:30:30.523	01:50:10.523	0	30127	0

ChannelState indicates the type of interval. The interval is either Error Free (EF) or Transmission Interfered (TI). Startime and Endtime indicate the beginning respectively the end of an EF- or TI-interval (format: hour:minute:second.milisecond). FramesErroneous indicates the number of frames received in error during the interval, FramesErrorfree indicates the number of correctly received frames during the interval. FramesLost indicates the number of lost frames during the interval. Lost frames occur when two consecutively received error free frames do not have consecutive sequence numbers.
The algorithm uses the following variables:

Parameter	Description
FrameRxTime_Actual	Time of reception of the actual or current frame. This time is derived from the operating system of the receiver (receiver local time).
FrameRxTime_Previous	Time of reception of the previous frame.
FrameSNR_Actual	Sequence number of the actual or current frame. If the actual frame is not error free FrameSNR_Actual = -1.
FrameSNR_Previous	Sequence number of the frame received just before the actual or current frame. If the previous frame is not error free FrameSNR_Previous = -1.
#Frames_ConsEF	Number of consecutive received error free frames since the last erroneous or lost frame.
EF_Threshold	EF_Threshold indicates how many consecutive error free frames should have been received before the channel state changes from TI to EF. Its default value is 5.
ChannelState_Actual	The actual or current state of the transmission channel. The channel resides either in TI- or EF-state. If a lost frame is detected or an erroneous frame is received, the channel state changes to TI. If EF_Threshold consecutive error free frames have been received, the channel state changes to EF.
ChannelState_Previous	The state of the transmission channel just before the reception of the actual frame (i.e. the channel state at reception of the previous frame).
Diff_SNR	Contains the difference between the sequence numbers of the actual and previous frame.
#FramesLost	Contains the total number of lost frames in a certain TI-interval. The value of the parameter is incremented with Diff_SNR –1 if two consecutive error free frames are received which sequence numbers differ more than 1. Its value is reset every time ChannelState changes.
#FramesERR	Contains the total number of erroneous frames in a certain TI-interval. Its value is reset every time ChannelState changes.
#FramesEF	Contains the total number of error free frames in a certain TI- or EF-interval. Its value is reset every time ChannelState changes.



Start
ChannelState_Previous = TI
ChannelState_Actual = TI
FrameSNR_Actual = -1
FrameSNR_Previous = -1
EF_Threshold = 5
All other parameter values = 0
Create first record
ChannelState = ChannelState_Actual
Starttime = (local) system time of receiver
Receive next frame (30 bytes) and evaluate CRC
FrameRxTime_Actual = (local) system time of receiver
CRC is correct (frame error free)?
No
FrameSNR_Actual = -1
#Frames_ConsEF = 0
#FramesERR = #FramesERR + 1
Yes
Determine FrameSNR_Actual (read SNR from frame)
Diff_SNR = FrameSNR_Actual - FrameSNR_Previous
#FramesEF = #FramesEF + 1
Diff_SNR <= FrameSNR_Actual?
No
Yes
Diff_SNR = 1?
No
#FramesLost = #FramesLost + Diff_SNR - 1
Yes
#Frames_ConsEF = #Frames_ConsEF + 1
#Frames_ConsEF = 1
#Frames_ConsEF >= EF_Threshold
No
Yes
ChannelState_Actual = EF
#Frames_ConsEF = 1?
No
Yes
StarttimeEF = FrameRxTime_Actual
EndtimeTI = FrameRxTime_Previous
ChannelState_Actual = TI
Receive and process frames
Determine channel state (TI or EF)
Determine number of erroneous, errorfree and missing frames for certain channel state
ChannelState_Previous = EF? AND ChannelState_Actual = TI?
No
ChannelState_Previous = TI? AND ChannelState_Actual = EF?
No
Yes
Update and close actual record
FramesErroneous = #FramesERR
FramesErrorfree = #FramesEF - EF_Threshold
FramesLost = #FramesLost
Endtime = EndtimeTI
Create next/new record
ChannelState = ChannelState_Actual
Starttime = StarttimeEF
#FramesERR = 0
#FramesEF = EF_Threshold
#FramesLost = 0
Update actual record if the channelstate changes (close previous state)
Create new record if channelstate changes (enter new state)
Receive next frame if channelstate does not change
Yes
FrameSNR_Actual = -1?
No
Yes
Update and close actual record
FramesErroneous = #FramesERR - 1
FramesErrorfree = #FramesEF
FramesLost = #FramesLost
Endtime = FrameRxTime_Previous
Update and close actual record
FramesErroneous = #FramesERR
FramesErrorfree = #FramesEF - 1
FramesLost = #FramesLost - (Diff_SNR - 1)
Endtime = FrameRxTime_Previous
FrameSNR_Previous = FrameSNR_Actual
ChannelState_Previous = ChannelState_Actual
FrameRxTime_Previous = FrameRxTime_Actual
#FramesERR = 1
#FramesEF = 0
#FramesLost = 0
#FramesERR = 0
#FramesEF = 1
#FramesLost = Diff_SNR - 1
Create next/new record
ChannelState = ChannelState_Actual
Starttime = FrameRxTime_Actual

6.2.3 Validation of Transmission Interference parameters

From the table in par. 6.2.2 (Receiving side), T_{REC} & T_{TI} are obtained by subtracting Starttime from Endtime for each interval. The Transmission Interference parameters shall then be calculated using the formulas below. The parameters are applicable (and shall be calculated) for both up- and downlink separately.

$$Percentage_{TI\_0.8} = \frac{NumberOf\ T_{TI}\ Intervals <= 0.8\sec}{TotalNumberOf\ T_{TI}\ Intervals} * 100\%$$

$$Percentage_{TI\_1} = \frac{NumberOf\ T_{TI}\ Intervals <= 1\sec}{TotalNumberOf\ T_{TI}\ Intervals} * 100\%$$

$$Percentage_{REC\_7} = \frac{NumberOf\ T_{REC}\ Intervals >= 7\sec}{TotalNumberOf\ T_{REC}\ Intervals} * 100\%$$

$$Percentage_{REC\_20} = \frac{NumberOf\ T_{REC}\ Intervals >= 20\sec}{TotalNumberOf\ T_{REC}\ Intervals} * 100\%$$

Successful validation is achieved if all percentage PERC values exceed the corresponding 95%- and 99% percentages of subset-093.

6.3 Appendix C, Command script for GSM-R network registration delay measurement (informative)

6.3.1 Command script for inbound border crossing

```
// select a forbidden network
AT+COPS=1,2,"ForbiddenNetwork"
// wait for +CREG: 3

// select “network2select” = Home PLMN
AT+COPS=1,2," network2select"
// measurement [1] begins
// wait for +CREG: 1
// measurement [1] ends.
```

6.3.2 Command script for outbound border crossing

```
// select a forbidden network
AT+COPS=1,2,"ForbiddenNetwork"
// wait for +CREG: 3

// select “network2select” = Visited PLMN
AT+COPS=1,2," network2select"
// measurement [2] begins
// wait for +CREG: 5
// measurement [2] ends.
```

6.4 Appendix D, Recommendation of minimum sample sizes for ETCS QoS parameter validation (informative)

6.4.1 Introduction

This annex recommends sample sizes and validation procedures for performance tests to validate ETCS QoS parameters.
Since ETCS QoS parameters differ on statistical characteristics and target values, sample sizes for individual parameters also differ. Furthermore, the choice for a particular sample size is to a large extent arbitrary. It is a compromise between costs (time and effort to perform validation tests), precision (reproducibility) and confidence level.
ETCS QoS parameters can be subdivided into four categories. Each category requires a particular statistical approach to determine a suitable sample size. The categories as discussed in the next paragraphs are:

1. Connection Establishment Delay (CED), Transfer Delay (TD), Network Registration Delay (NRD)
2. Connection Loss Rate (CLR)
3. Transmission Interference (TI)
4. Connection Establishment Error Ratio (CER)

6.4.2 Summary

The table below provides an overview of ETCS QoS parameters. It lists minimum required sample sizes and validation procedures as derived in the following paragraphs.

ETCS QoS parameter	Requirement (Subset-093)	Minimum recommended sample size (95% confidence level)	Validation procedure
Connection Establishment Delay (CED)	<8.5s (95%) ≤10s (100%)	100 samples	Parameter successfully validated if the 95th-percentile is less than 8.5s
Trasnfer Delay (TD)	≤0.5s (99%)	100 samples	Parameter successfully validated if the 99th-percentile is less than 0.5s
Network Registration Delay (NRD)	≤30s (95%) ≤35s (99%) ≤40s (100%)	100 samples (inbound border crossing) 100 samples (outbound border crossing)	Parameter successfully validated if the 95th-percentile is less than 30s and if the 99th-percentile is less than 35s
Connection Loss Rate (CLR)	$<10^{-2}$/h	300 hours	Parameter successfully validated if no connection loss occurs within 300 hours
Transmission Interference (TI)	TI period: <0.8s (95%) <1s (99%) EF period: >20s (95%) >7s (99%)	1500 samples per kilometer (uplink) 1500 samples per kilometer (downlink)	Refer to Annex B, par. 6.2.3
Connection Establishment Error Ratio (CER)	$<10^{-2}$	1078 samples	Parameter successfully validated if the number of Connection Establishment Errors is less than or equals 16

Note 1:
For CED and CER a sample or event is defined as a call set up (attempt). For TD and TI a sample or event is defined as the transmission/reception of a data frame. For NRD a sample or event is defined as a network registration session as described in par. 6.3 (Appendix C, Command script for GSM-R network registration delay measurement (informative).

For CLR, the sample size is expressed as the duration of the measurement. A connection loss should typically not occur.

Note 2:
For Transmission Interference the parameters of interest are T_{REC} and T_{TI} rather than the immediate result of transmission/reception of data frames. With a sample size of 1500 frame transmissions per kilometre however, adequate reproducibility of the average probability of a frame transmitted in error is achieved (see par. 6.4.5). The assumption is that this sample size also implies adequate reproducibility of T_{REC} and T_{TI}. These parameters are validated over a substantial ETCS area (covered by at least 5 GSM-R cells) by 1 up to 3 round-trip test runs depending on the speed of the measurement train (see par. 6.4.5).

Note 3:
In this annex, sample sizes are calculated for a confidence level of 95%. Decreasing the confidence level while maintaining the same confidence interval, typically results in a decreased sample size (and hence in a reduction of measurement time and costs). The choice for a particular confidence level and sample size is a national matter.

6.4.3 Connection Establishment Delay (CED), Transfer Delay (TD), Network Registration Delay (NRD)

Sample size (theoretical background)
From a statistical perspective, the parameters CED, TD and NRD can be described by a mean delay μ, a standard deviation σ and some kind of statistical distribution (not necessarily a normal distribution).
Since the true standard deviation σ is not known and the sample size may be small (n<30), the Student t distribution is used to statistically model these QoS parameters. The standard deviation σ is then replaced by the standard deviation of the sample s. One of the properties of the t distribution is the degree of freedom (df). The degree of freedom corresponds with the sample size (i.e. df = n – 1).
The t distribution approaches the standard normal distribution with increasing df.
The confidence interval is denoted as:

$$\bar{x} \pm t^* . \frac{s}{\sqrt{n}} \qquad (1)$$

Where:

$\bar{x}$ =	is the sample mean (best estimate of the population mean μ)
s =	standard deviation of the sample
n =	sample size
t* =	t-parameter (df = n – 1)

Note that t* depends on n.
For a two-sided interval with a confidence level of 95%, t* = 2 (n=60), for a two-sided interval with a confidence level of 90% t* = 1.67 (n=60).

Sample size proposal
Rather good reproducibility is achieved if we choose n such that $\bar{x}$ does not deviate more than a small percentage from one measurement campaign to another with a high confidence level. Using (1) and making a choice for a deviation of $\bar{x}$ of 10% results in:

$$0.1\bar{x} = t^* . \frac{s}{\sqrt{n}} \qquad (2)$$

Solving for n yields: $n = \left(\frac{st^*}{0.1\bar{x}} \right)^2$ (3)

Measurements in the Netherlands have shown that $s/\bar{x}$ is much smaller than 0.5 for all parameters (i.e. CED, TD and NRD).
Taking a worst case value of $s/\bar{x} = 0.5$, a confidence level of 95% (two sided confidence interval) and applying equation (3) results in n = 100.

Consequences for measurement in practice
If for validating CED and TD a single round-trip drive-test is performed, a sample size of n = 100 is easily achieved.
NRD is defined under standstill conditions. A validation test with a sample size of n = 100 can be performed in less than 2 hours.

Validation of parameters CED, TD and NRD
Compliancy with the requirements is demonstrated by taking the 95^{th}-percentile from the measurement data set for CED, taking the 99th-percentile from the measurement data set for TD and the 95^{th} and 99^{th} percentiles from the measurement data set for NRD.
The k-th percentile is defined as that value of the measurement data set which corresponds to a cumulative frequency of n.k/100. With n=100, the 95th/99th-percentile is simply the $95^{th}/99^{th}$ value of the measurement data set (when sorted in ascending order).If a percentile of a particular parameter is less than the corresponding value as specified in Subset-093, the parameter is successfully validated.

6.4.4 Connection Loss Rate (CLR)

Sample size (theoretical background)
Assuming that the Connection Loss Rate is characterized by:

1. The number of connection losses is proportional to the measurement time
2. The probability of a connection loss is almost zero over a short period of time
3. Connection losses are independent events

then the CLR is reasonably modeled by a Poisson distribution.
Note that it is not sensible to speak about a sample size here, but rather of a certain measurement time interval in which a connection loss may (or may not) appear.
For a Poisson distribution the following formula applies:

$$P(k) = (Rt)^k . \frac{e^{-Rt}}{k!} \qquad (4)$$

Where:

P(k) = The probability that k failures occur within a measurement time interval t if the Connection Loss Rate is R.

k = Number of connection losses in measurement time interval t

R = Connection Loss Rate (connection losses per hour)

t = Measurement time interval (hours)

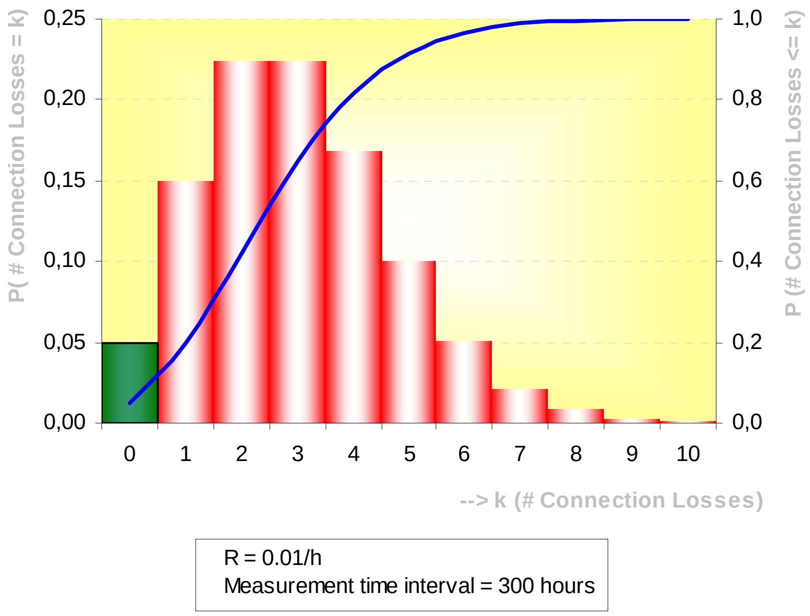
Note that for a Poisson distribution both the mean and the variance are equal to Rt.

Measurement time interval proposal

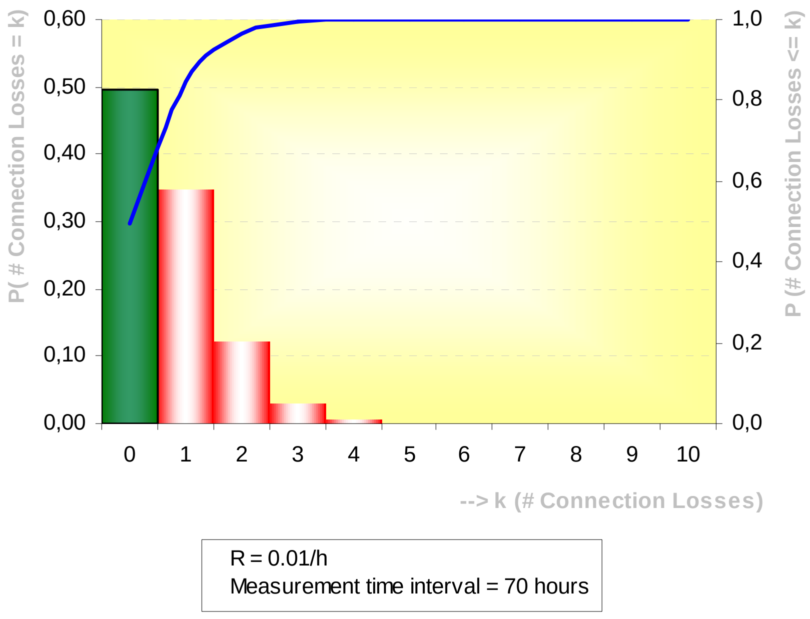
The question is then how to choose the size of the measurement time interval t.
If we choose a confidence level of 95% and define that as the probability that 1 or more connection losses occur in a measurement time interval t under the pre-condition that the Connection Loss Rate is truly R=0.01/hour (i.e. as specified in Subset-093), the measurement time interval t can be calculated. The probability of having 1 or more connection losses in a measurement time interval t is:

$$P(k >= 1) = 1 - P(k = 0) = 1 - e^{-0.01t} = 0.95 \qquad (5)$$

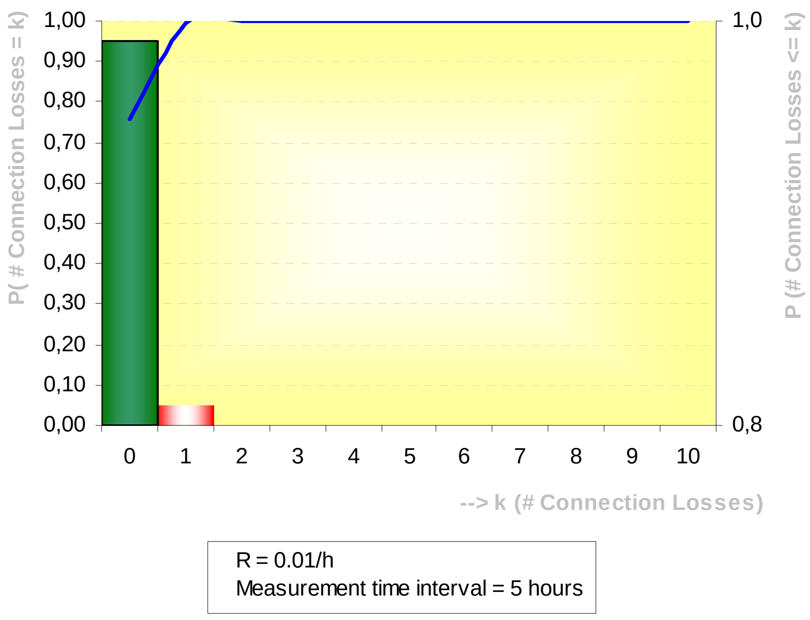
Solving (5) results in: t = 300 hours.
Or alternatively stated: if the Connection Loss Rate is truly R=0.01/h and is measured for a period of 300 hours then the probability of experiencing no connection loss at all is 5%. This situation is shown in the figure below.



There is a trade off between confidence level and measurement time interval. Two examples demonstrating this trade off are given below. In both cases the starting point is that the true CLR = 0,01/h.
If the measurement time interval is 70 hours, the probability of no connection loss is about 50%.



Finally if the measurement time interval is 5 hours, the probability of one or more connection losses is only about 5%.



Consequences for measurement in practice

The parameter CLR obviously requires several test runs. Measurement time is decreased by using multiple mobile measurement sets per test run. The number of test runs may be further decreased by performing measurements as part of commercial train operation.

Validation of parameter CLR
CLR is successfully validated if no connection losses occur in a measurement time interval of 300 hours. If one or more connection losses occur, validation has failed.

6.4.5 Transmission Interference

Sample size (theoretical background)
Let's assume that successful/erroneous transfer of frames follows a binomial statistical law. This is the case if individual frame transfer events are mutually independent and the a-priori probability of a successful transfer is the same for every frame transfer. The probability of an erroneous frame transfer is denoted as p. The probability of a successful transfer of a frame is denoted as 1-p. The sample size is denoted as n.

Then:

- the mean number of erroneous transfers is: $Mean = np$;
- and the standard deviation is: $SD = \sqrt{np(1\text{-}p)}$.

If the sample size is large (i.e. np >= 5 and n(1-p) > 9) p follows a normal distribution with mean $\hat{p} = x/n$ (x is the number of erroneous frame transfers and n is the sample size, where $\hat{p}$ is the best estimate of p). The standard deviation of $\hat{p}$ is

$$SD_{\tilde{p}} = \sqrt{\frac{\tilde{p}(1\text{-}\tilde{p})}{n}}$$

The confidence interval for p is $\tilde{p} \pm z^*SD_{\tilde{p}}$ (where z* is the standardised- or z-value of the normal distribution). For a two-sided interval with a confidence level of 95%, z* = 1.96, for a two-sided interval with a confidence level of 90% z* = 1.65.

The error margin of $\tilde{p}$ is denoted as $m = z^* \sqrt{\frac{\tilde{p}(1\text{-}\tilde{p})}{n}}$

If we choose $m = 0.5\tilde{p}$ then solving for n yields:

$$n = \left(\frac{z^*}{m}\right)^2 \tilde{p}(1-\tilde{p}) = 4(z^*)^2 \frac{1-\tilde{p}}{\tilde{p}} \qquad (6)$$

Sample size proposal
Analysis of data obtained during performance tests for the HSL line in the Netherlands shows that $\tilde{p}$ is of the order of 1% (on average 1% of the frames are transferred in error).
If we choose a confidence level of 95% then (6) results in:

$$n = 4(1.96)^2 \frac{1-0.01}{0.01} = 1521 \qquad (7)$$

This means that if we perform the same test with a sample size of n = 1521 over and over again, we find a value of $\tilde{p}$ in the range of 0.5% to 1.5% in 95% of all tests carried out. This seems to be quite a reasonable approach with rather good reproducibility.
The sample size should be constrained to a certain geographical- or (measurement) time unit in order to discriminate between ETCS lines of different length.
It is proposed to (at least) take 1500 samples (1521 rounded down) over 1 km of track (750 samples in each direction of travel).

Since the behaviour of downlink frame transfer and uplink frame transfer is quite different, a sample size of 1500 is applicable to both uplink- and downlink measurement.

Note that the assumption that the transfer of frames follows a binomial statistical law may not be true since the a-priori probability of transferring a frame in error may not be the same for every frame transfer (it is probably dependent on train speed and location). During a GSM-R hand over for example, the data transfer may be disturbed over several consecutive frames.
Therefore the area over which the 1500 samples are taken is limited to 1 km.
In any case, the results of real-live performance tests are needed to evaluate the strength of the analysis and the underlying assumptions.

Consequences for measurement in practice
The analysis of the measurement data of the HSL line in the Netherlands also shows that after completion of the transfer of a frame in the uplink direction, the average time it takes before the next frame is starting to transmit is about 10 msec. It takes (1+8+1)*30/9600*1000 = 31.25 msec. to transfer a single 30-byte frame (including start- and stop-bit) with 9600 bps. So the average frame transfer rate is 25 per second (i.e. actually 1/(31.25+10)*1000 = 24.24).
For the downlink the frame transfer rate is higher (it takes only 1 msec. on average in between two frame transfers). The rate on the downlink is 1/(31.25+1)*1000 = 31 frames per second.
The table below shows the practical consequences in terms of the number of recommended test runs:

Average speed of test train along the track	Duration to travel 1000 meter (seconds)	Number of samples obtained during 1000 meter with frame transfer rate = 25 per second	Number of test runs recommended with sample size 1500 (with 2 measurement sets per train (1 set for uplink, 1 set for downlink)
56 km/hr (15 m/s)	66.66	1666.50	2 (0.9) *
108 km/hr (30 m/s)	33.33	833.25	2 (1.8)
216 km/hr (60 m/s)	16.67	416.75	4 (3.6)
324 km/hr (90 m/s)	11.11	277.78	6 (5.4)

** 2 runs (1 return trip) is the minimum number of runs that is needed. This is due to the GSM mobility management mechanisms that have hysteresis and therefore it is required to travel at least once both ways to check the correct sending of data frames*

Note
The test for validation of Transmission Interference shall comprise a substantial ETCS test area including at least 5 GSM-R cells.

<u>Example</u>:
If you have a 100 km ETCS line with an *average* operational train speed of 216 km/h, it is recommended to use a measurement train equipped with 2 measurement sets (1 for uplink- and 1 for downlink measurements) and to perform 2 round trip test runs.

Validation of TI parameters
For a description of the validation procedure and the definition of TI parameters refer to par. 6.2.3.

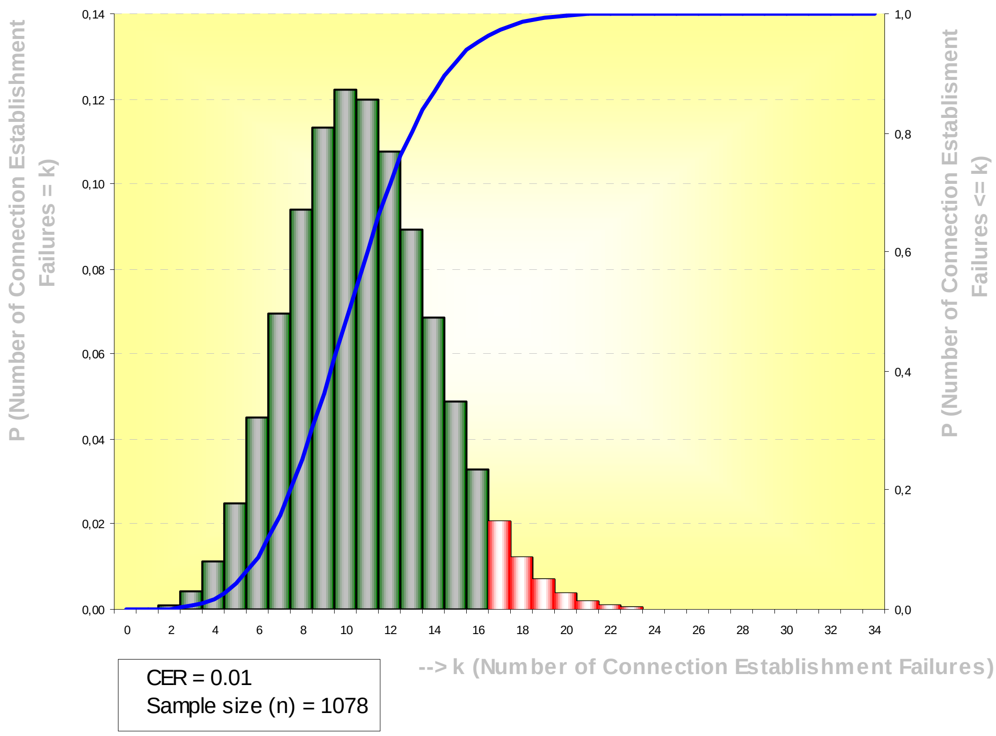
6.4.6 Connection Establishment Error Ratio

Sample size (theoretical background)
The theoretical background is described in section 6.4.2.

Sample size proposal
With CER = 0.01 (as specified in Subset-093) and with formula (6 and 7) a sample size of n=1521 is required (with a (two-sided) confidence level = 95%). The 95% confidence interval then ranges from 0.5% to 1.5%.
With a one-sided interval with confidence level = 95% however, formula (6) results in n=1078 (note that z*=1.65 in this case). Since the requirement is CER < 0.01 and not CER = 0.01, a one-sided confidence interval is most appropriate.

Consequences for measurement in practice
Assuming that a call can be set up every 30 seconds on average, about 9 hours of test time is required (n=1078).

Validation of parameter CER
If the number of connection establishment failures is less than or equals 16, the maximum measured CER = 16/1078 = 1.48%, just results in a successful validation of CER. If the number of connection establishment failures equals or exceeds 17, the minimum measured CER = 17/1078 = 1.58% and validation of CER fails (i.e. the measured CER is outside the one-sided confidence interval).



The figure above illustrates the binomial distribution for CER=0.01 and n=1078. The red area at the tail corresponds with a cumulative probability of about 5%, which is the probability that the number of connection establishment failures is 17 or more.

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