ETSI TR 103 554 V1.1.1 (2018-08)

TECHNICAL REPORT

**Rail Telecommunications (RT);
Next Generation Communication System;
LTE radio performance simulations and
evaluations in rail environment**

Reference

DTR/RT-0047

Keywords

LTE, railways

ETSI

650 Route des Lucioles
F-06921 Sophia Antipolis Cedex - FRANCE

Tel.: +33 4 92 94 42 00   Fax: +33 4 93 65 47 16

Siret N° 348 623 562 00017 - NAF 742 C
Association à but non lucratif enregistrée à la
Sous-Préfecture de Grasse (06) N° 7803/88

Important notice

The present document can be downloaded from:
http://www.etsi.org/standards-search

The present document may be made available in electronic versions and/or in print. The content of any electronic and/or print versions of the present document shall not be modified without the prior written authorization of ETSI. In case of any existing or perceived difference in contents between such versions and/or in print, the only prevailing document is the print of the Portable Document Format (PDF) version kept on a specific network drive within ETSI Secretariat.

Users of the present document should be aware that the document may be subject to revision or change of status. Information on the current status of this and other ETSI documents is available at
https://portal.etsi.org/TB/ETSIDeliverableStatus.aspx

If you find errors in the present document, please send your comment to one of the following services:
https://portal.etsi.org/People/CommiteeSupportStaff.aspx

Copyright Notification

ETSI

Contents

Intellectual Property Rights

Essential patents

IPRs essential or potentially essential to normative deliverables may have been declared to ETSI. The information pertaining to these essential IPRs, if any, is publicly available for **ETSI members and non-members**, and can be found in ETSI SR 000 314: *"Intellectual Property Rights (IPRs); Essential, or potentially Essential, IPRs notified to ETSI in respect of ETSI standards"*, which is available from the ETSI Secretariat. Latest updates are available on the ETSI Web server (https://ipr.etsi.org/).

Pursuant to the ETSI IPR Policy, no investigation, including IPR searches, has been carried out by ETSI. No guarantee can be given as to the existence of other IPRs not referenced in ETSI SR 000 314 (or the updates on the ETSI Web server) which are, or may be, or may become, essential to the present document.

Trademarks

The present document may include trademarks and/or tradenames which are asserted and/or registered by their owners. ETSI claims no ownership of these except for any which are indicated as being the property of ETSI, and conveys no right to use or reproduce any trademark and/or tradename. Mention of those trademarks in the present document does not constitute an endorsement by ETSI of products, services or organizations associated with those trademarks.

Foreword

This Technical Report (TR) has been produced by ETSI Technical Committee Railway Telecommunications (RT).

Modal verbs terminology

In the present document "**should**", "**should not**", "**may**", "**need not**", "**will**", "**will not**", "**can**" and "**cannot**" are to be interpreted as described in clause 3.2 of the ETSI Drafting Rules (Verbal forms for the expression of provisions).

"**must**" and "**must not**" are **NOT** allowed in ETSI deliverables except when used in direct citation.

Executive summary

In order to assess 3GPP LTE radio performance in a rail environment, three scenarios have been defined: Rural, Hilly and Urban, representing various radio conditions typical to rail environment. Each scenario has been defined with its radio parameters, load condition and train speeds.

UIC and E-UIC spectrum bands have been assumed, with bandwidth of 1,4 MHz, 3 MHz and 5 MHz, corresponding to possible deployments with LTE and GSM-R co-existence and deployment with a standalone LTE.

Three different studies are described. One is based on simulation with a software chain tool using a Monte-Carlo statistical approach, including multiple cells in a linear deployment along the track. The two others are based on laboratory radio test bench, featuring hardware communication devices and wireless channel emulators, but not taking into account multiple cells interferences.

The present document includes results from software chain tool study and from one of the two laboratory radio test bench study.

In the present document, only results for LTE using a channel bandwidth of 1,4 MHz with maximum UE power of 23 dBm in the 900 MHz band are provided. A set of initial conclusions has been drawn from these partial results; however a final conclusion will need the completion of the analysis with results for 3 MHz and 5 MHz channel bandwidths and for maximum UE powers of 26 and 31 dBm. Furthermore, the impact of using a TDD mode in other frequency bands will need to be added to the report.

Introduction

The present document outlines the study conducted within TC RT on LTE radio performance simulations and evaluations in rail environment.

1   Scope

3GPP LTE radio access is one candidate for the radio access technology to be used for the Future Rail Mobile Communications System (FRMCS). In the present document, the term FRMCS refers -unless stated otherwise- to the radio part of the communication system.

The present document is intended to:

- Define the simulation parameters relevant to rail environment relating to 3GPP LTE radio performance. This includes in particular operating frequency bands, bandwidths, deployment scenario (inter-site distance), and antenna characteristics, transmit powers and channel models, along with relevant metrics to be evaluated.

- Collect and analyse the simulation results of an LTE system in the rail environment.

- Identify limitations of an LTE system in the rail environment.

Radio performance evaluation of an LTE system could be done by simulation, through software and processing resources only, or through a test bench incorporating pieces of equipment emulating parts of the chain, e.g. the RF. In both cases, it is important to align the parameters and the assumptions made in the simulation and in the evaluation chain to be able to reflect better a deployment in a rail environment, and to better compare and understand the simulation and the evaluation results.

2   References

2.1   Normative references

Normative references are not applicable in the present document.

2.2   Informative references

References are either specific (identified by date of publication and/or edition number or version number) or non-specific. For specific references, only the cited version applies. For non-specific references, the latest version of the referenced document (including any amendments) applies.

NOTE: While any hyperlinks included in this clause were valid at the time of publication ETSI cannot guarantee their long term validity.

The following referenced documents are not necessary for the application of the present document but they assist the user with regard to a particular subject area.

[i.1]   ETSI TS 145 005 (V14.4.0) (04-2018): "Digital cellular telecommunications system (Phase 2+) (GSM); GSM/EDGE Radio transmission and reception (3GPP TS 45.005 version 14.4.0 Release 14)".

[i.2]   ETSI TS 136 104 (V14.7.0) (04-2018): "LTE; Evolved Universal Terrestrial Radio Access (E-UTRA); Base Station (BS) radio transmission and reception (3GPP TS 36.104 version 14.7.0 Release 14)".

[i.3]   ETSI TS 136 101 (V14.7.0) (04-2018): "LTE; Evolved Universal Terrestrial Radio Access (E-UTRA); User Equipment (UE) radio transmission and reception (3GPP TS 36.101 version 14.7.0 Release 14)".

[i.4]   Recommendation ITU-R M.2135-1 (12-2009): "Guidelines for evaluation of radio interface technologies for IMT advanced".

[i.5]   IST-4-027756 Winner II D1.1.2 V1.2 Winner II Part I: "Channel Models", European Commission, Deliverable IST-WINNER D.

[i.6]   Ikuno, J. Colom, Martin Wrulich, and Markus Rupp.: "Performance and modelling of LTE H-ARQ." Proc. International ITG Workshop on Smart Antennas (WSA 2009), Berlin, Germany 2009.

[i.7]   ETSI TS 136 211 (V14.6.0) (04-2018): "LTE; Evolved Universal Terrestrial Radio Access (E-UTRA); Physical channels and modulation (3GPP TS 36.211 version 14.6.0 Release 14)".

[i.8]   Recommendation ITU-R M.1225 (1997): "Guidelines for evaluation of radio transmission technologies for IMT-2000".

[i.9]   European Integrated Railway Radio Enhanced Network System Requirements Specification, UIC CODE 951, GSM-R Operators Group, December 2015.

3   Abbreviations

For the purposes of the present document, the following abbreviations apply:

ACS   Adjacent Channel Selectivity
AMC   Adaptive Modulation and Coding
AWGN   Additive White Gaussian Noise
BS   Base Station
BTS   Base Transceiver Station
BW   Bandwidth
CDF   Cumulative Distribution Function
CDL   Clustered Delay Line
COST   Cooperation of Scientific and Technical
CP   Cyclic Prefix
DL   Down Link
EIRENE   European Integrated Railway radio Enhanced NEtwork
eNB   evolved Node B
ETU   Extended Typical Urban model
E-UTRA   Evolved UMTS Terrestrial Radio Access
FDD   Frequency Division Duplex
FEC   Forward Error Correction
FRMCS   Future Rail Mobile Communications System
FSTD   Frequency Switched Transmit Diversity
GSM   Global System for Mobile communications
GSM-R   Global System for Mobile communication for Railway application
HARQ   Hybrid Automatic Repeat-Request
HO   Hand Over
HST   High Speed Train
IMT   International Mobile Telecommunications
IP   Internet Protocol
ISD   Inter Site Distance
ISI   Inter-Symbol Interference
ITU-R   Internail Telecommunication Union - Radiocommunication sector
LOS   Line Of Sight
LTE   Long Term Evolution
MAC   Media Access Control
MCS   Modulation and Coding Scheme
MIMO   Multiple Input, Multiple Output
MISO   Multiple Input, Single Output
MOS   Mean Opinion Score
MRS   Mobile Relay Station
NLOS   Non Line Of Sight
OFDM   Orthogonal Frequency Division Multiplexing
PBCH   Physical Broadcast Channel
PDCCH   Physical Downlink Control Channel
PDCP   Packet Data Convergence Protocol
PDP   Power Delay Profile
PER   Packet Error Rate

PHY   PHYsical layer
PUCCH   Physical Uplink Control Channel
QAM   Quadrature Amplitude Modulation
QCI   QoS Class Identifier
RB   Resource Block
REC   Railways Emergency Call
RF   Radio Frequency
RLC   Radio Link Control
RT   Rail Telecommunications
SFBC   Space-Frequency Block Coding
SGW   Serving Gateway
SIMO   Single Input, Multiple Output
SINR   Signal to Interference-plus-Noise Ratio
SISO   Single Input, Single Output
SNR   Signal to Noise Ratio
SRS   System Requirement Specification
TC   Technical Committee
TCP   Transmission Control Protocol
TDD   Time Duplex Division
UDP   User Datagram Protocol
UE   User Equipment
UIC   Union Internationale des Chemins de fer
UL   Up Link
UMTS   Universal Mobile Telecommunications System
USB   Universal Serial Bus

4   Assumptions and parameters for simulations and evaluations

4.1   Introduction

In the scope of this study, the following points are addressed:

- Simulations take into account railway specifics

- Simulations are flexible in order to simulate different system configurations, parameter settings and scenarios

- Consideration of different carrier band-widths (at least 1,4, 3 and 5 MHz)

- Consideration of TDD and FDD duplex modes

- Consideration of different subscriber and train densities and distributions

- Considerations of FRMCS system parameters (e.g. Cyclic Prefix)

- Different power classes of FRMCS equipment

- Different antenna radiation patterns and tilts

- SISO, SIMO, MISO und MIMO

- Different installation heights of antennas

- Different distances and densities of fixed transmitter equipment (eNB)

- Different specified and appropriate coding and modulation schemes

- Different 3GPP Releases (e.g. LTE: ≥ 13) to take into account new features, e.g. performance improvements for high speed.

4.2   Simulation tools

Software simulations are made at radio level, i.e. above the physical layer as depicted in Figure 1. Overheads like pilots and cyclic prefixes are taken in to account, but not the overheads that are added by layers above PHY, in particular PDCP and IP headers.

Other simulations, e.g. hardware simulations and laboratory tests, could have a reference point at application level.
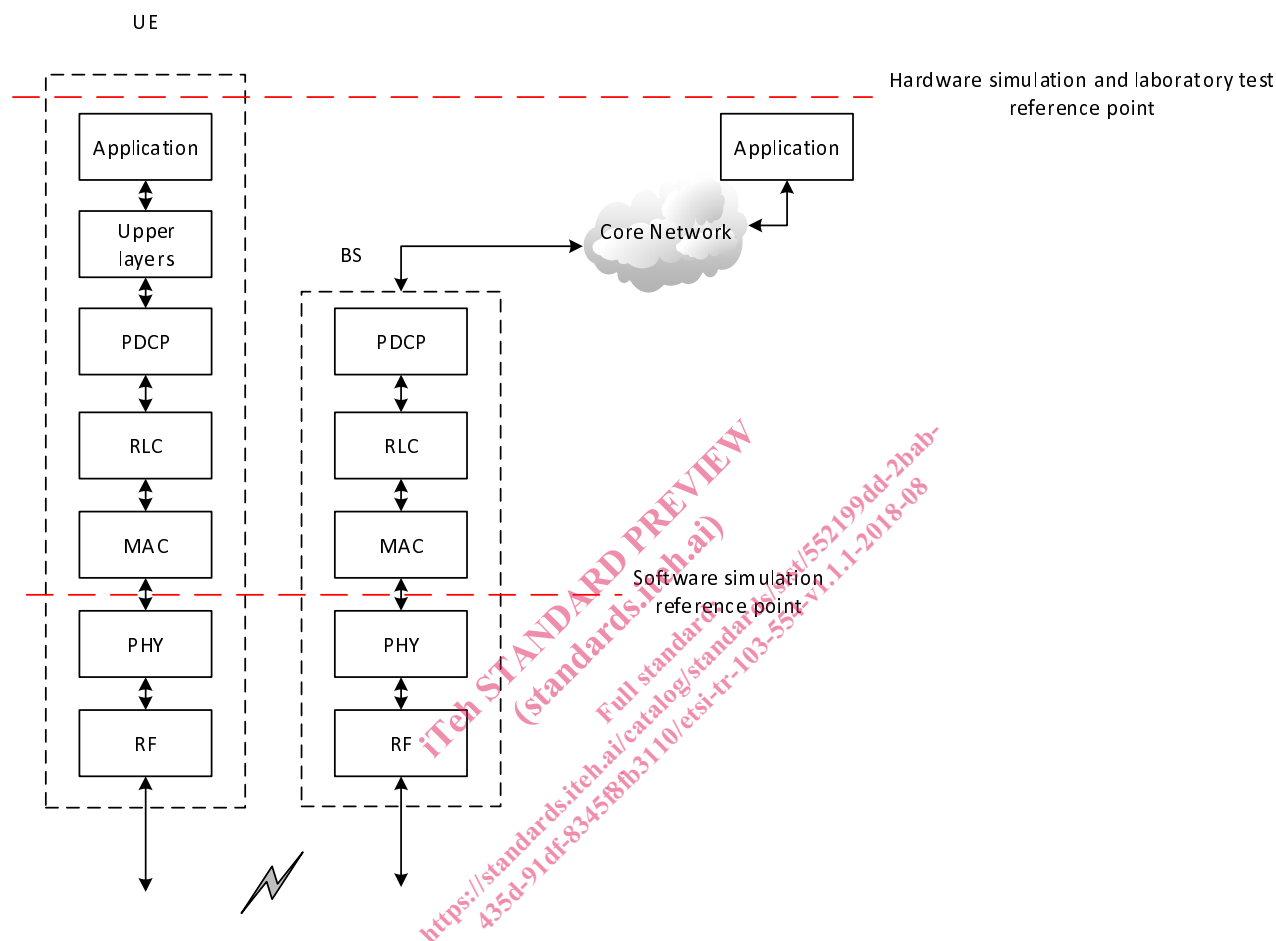

Figure 1: Reference point for the software simulations

4.3   Scenarios

The objective is to define the minimum number of scenarios which cover the majority of the radio environment.

Three scenarios have been retained: Urban, Rural, and Hilly. Urban is relative to areas where train density is high, but move at moderate speed. Rural scenario typically intends to model high speed lines. Hilly scenario intends to handle more complex situations from radio propagation point of view, with in particular extensive multi-path propagation.

Tunnels are complex scenarios, since they depend widely on tunnel shape and tunnel/train relative geometry. They are not considered in this study as they would require a more long and thorough work.

Only train-ground communications are considered in this study. Handset or shunting area scenarios are for further study.

Whether it is possible to have several antennas on trains roof tops and what could be their characteristic needs further discussions.

4.4 Bandwidth and transmit power

4.4.1 Bandwidths

Three scenarios are considered, on bandwidths of 1,4 MHz, 3 MHz and 5 MHz in the UIC and E-UIC bands, as depicted in Figure 2:

1) Scenario 1 considers GSM-R in UIC band as per today, with the addition of a 1,4 MHz LTE carrier in the upper part of E-UIC band. This scenario corresponds to a migration phase, with co-existence of both GSM-R and LTE systems.

2) Scenario 2 assumes is an extension of scenario 1 with a LTE carrier extended to 3 MHz in the E-UIC band.

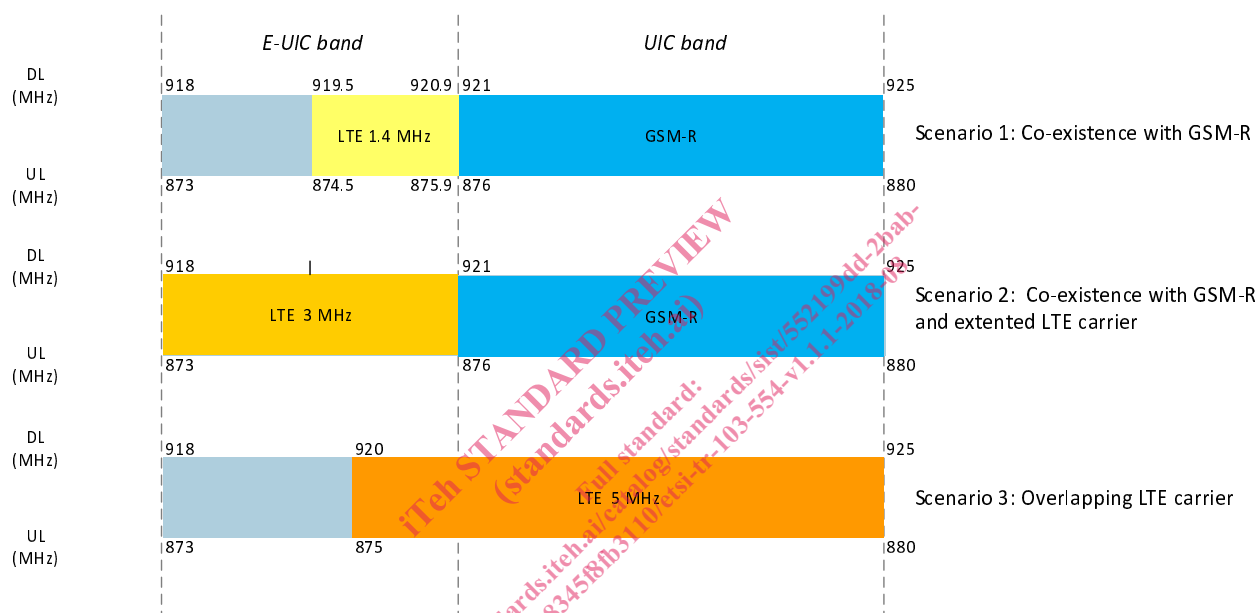3) Scenario 3 assumes a deployment with no GSM-Rand one LTE 5 MHz carrier in UIC band, overlapping the E-UIC band.

Figure 2: Carriers and bandwidths in the deployment scenarios considered

Scenario 1 is of highest priority.

4.4.2 Transmit powers

Transmit power in the E-UIC band is subject to limitations in case of FRMCS system deployment uncoordinated with commercial systems operating in neighbouring bands.

The method to compute the maximum transmit power derives the impact from the adjacent channel selectivity related specifications (wideband blocking and narrow band blocking), takes into account applicable effects (0,8 dB desensitization, slope of the filtering, etc.) as well as corrections resulting from spurious emissions from base station transmission and from UE. ACS (Adjacent Channel Selectivity) has been found as not relevant for this study.

Summary of the acceptable maximum transmit power of a FRMCS system in case of uncoordinated deployment is shown in Table 1.

Table 1: FRMCS acceptable transmitted power at eNB connector taking into account impact of BS Tx spurious emissions and Noise Rise from UE

FRMCS 1,4 MHz channel centre frequency (MHz)	918,7			920,3		
Standard under consideration in adjacent bands	UMTS	LTE	Multi-Standard	UMTS	LTE	Multi-Standard
FRMCS acceptable Tx power (dBm)	24,2	22,2	22,2	48,8	45,8	48,8

In coordinated scenario, the maximum transmit power at 918,7 MHz can be the same than at 920,3 MHz.

4.5 Antenna diagrams

4.5.1 Antenna diagrams at the base station

Different types of antennas are deployed depending on the area. For the study, two different antennas are selected: One with a horizontal beam angle of 65°, devoted to Non Line Of Sight (NLOS) situations - typically hilly terrains and urban areas, and one more directive, with a horizontal beam angle of 30°, more suited to Line Of Sight (LOS) situations - typically rural areas.

Antenna characteristics are summarized in Table 2 and an extended description is provided in Annex D.

Table 2: Summary of base station antenna patterns

Horizontal Polarization	Vertical Polarization	Gain	Polarization	Usage
65°	7°	18 dB	±45°	NLOS
30°	8,5°	20,5 dB	±45°	LOS/NLOS

4.6 Radio propagation aspects

4.6.1 Radio propagation model

Simulations have to be based on railway specific time-variant channel impulse responses of the radio channel in order to take into account multi-path radio propagation and Doppler-effects.

Four families of standards have been considered:

1) Okumura-Hata, Cost 207-GSM, COST 231 models and GSM specified models (see [i.1])

2) ITU-R 1997 for IMT 2000 (see [i.8]) and LTE specified scenarios (see [i.2] and [i.3])

3) ITU-R for IMT advanced (see [i.4])

4) Winner II (see [i.5])

Recent propagation models and multipath profiles have been aimed at being used for wireless systems with a small or medium range. This is coherent since 3G and 4G standards have been developed for capacity rather than for coverage. Early defined models such as COST 207 or 231 were derived at a time when coverage was the main priority rather than high speed operation which is of particular significance within the scope of this study.

Most relevant parameters in rail environment are then:

- Frequency range

- Delays in Cluster Delay Line models

- Geometry, most of models are considering 1,5 m for handheld User Equipment

- Inter Site Distances (ISD)

- LOS scenarios are using Ricean factor with high domination of the direct path

Characteristics of models are summarized in the following Table 3, discrepancies are highlighted in red.

Table 3: Summary of model characteristics

		Railway current	Okumura-Hata, COST 207-GSM COST 231	ITU-R IMT 2000	ITU-R IMT advanced	Winner II
Propagation aspects	Frequency range	Band 8 (900 MHz)	150 to 1 500 MHz	2 000 MHz	Rural: 450 MHz to 6 GHz	Rural: 2 GHz to 6 GHz
	Inter Site Distance	Up to 12 km	Range up to 100 km	Max = 1 732 m	20 km for Rural (RMa) (see note)	MRS 1 to 2 km 20 km for Rural (see note)
	Path clearance	LOS, Ricean < 3 dB	Ricean Factor = 0 dB air	ETU has no direct path, HST has only direct path	LOS, Ricean factor = 6 dB	LOS, Ricean factor = 6 dB
	Delayed paths	Up to 20 µs	HTx: up to 20 µs	Max delay = 5 µs	Max delay = 0,22 µs (not in line with 20 km ISD)	Max delay < 0,5 µs (not in line with 20 km ISD)
	Train speed	360 km/h, projection to 500 km/h	Max = 250 km/h in R 1, no double Doppler	Max = 350 km/h with double Doppler	Max = 350 km/h	Max = 350 km/h
Geometry	Base Station Antenna Height	10 to 45 m	30 to 200 m	Δhb = 0 to 50 m, i.e. up to 46 m for 4 m train antenna height	Up to 35 m	20 to 70 m
	Train Antenna Height	4 m to 4,5 m	1 to 10 m		1,5 m	1,5 m / 2,5 m
NOTE: Delays are shorter than what can be expected with such ISD.						

Indeed, propagation and geometry parameters that are deemed particularly relevant for Railways are summarized below.

Table 4: Main characteristics of Railway context

Propagation aspects	Frequency range	Band 8 (900 MHz)
	Inter Site Distance	Up to 12 km
	Path clearance	LOS, Ricean < 3 dB
	Delayed paths	Up to 20 µs
	Train speed	360 km/h, projection 500 km/h
Geometry	Base Station Antenna Height	10 m to 45 m
	Train Antenna Height	4 m to 4,5 m

The Ricean factor taken here corresponds to worst case scenario. In actual deployments, higher values could be encountered, leading to more favourable channel conditions.

4.6.2 Conclusion

Okumura-Hata models and COST 207-GSM COST 231 family (see [i.1]) are taken as the basis.