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Foreword

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

The present document is part 1 of a multi-part deliverable covering radio performance simulations and evaluations in rail environment, as identified below:

Part 1: "Long Term Evolution (LTE)";

Part 2: "5G New Radio (NR)".

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).

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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.

The impact of using a TDD mode in other frequency bands will need to be added to the present document.

Introduction

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.

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.

1 Scope

The present document:

- Defines 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.
- Collects and analyse the simulation results of an LTE system in the rail environment operating in the 900 MHz frequency band (UIC and E-UIC bands).
- Identifies limitations of an LTE system in the rail environment.

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.

[i.10] ETSI TR 145 050 (V15.0.0) (07-2018): "Digital cellular telecommunications system (Phase 2+) (GSM); GSM/EDGE Background for Radio Frequency (RF) requirements (3GPP TR 45.050 version 15.0.0 Release 15)".

[i.11] Kapsch CarrierCom: "Power limitations in the extension part of the ER-GSM band", Contribution to CEPT FM56(17)047, December 2017.

NOTE: Available at https://cept.org/Documents/fm-56/39947/fm56-17-047_power-limitations-in-the-extension-part-of-the-er-gsm-band.

[i.12] Loïc Brunel, Hervé Bonneville, Akl Charaf and Émilie Masson: "System-Level Evaluation of Next-Generation Radio Communication System for Train Operation Services", Proceedings of 7^{th} Transport Research Arena TRA 2018, April 16-19, 2018.

3 Definition of terms, symbols and abbreviations

3.1 Terms

Void.

3.2 Symbols

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

λ	wave length

3.3 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 the present document, 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 MHz, 3 MHz and 5 MHz)

- Consideration of TDD and FDD duplex modes
- Consideration of different subscriber and train densities and distributions
- Consideration 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.

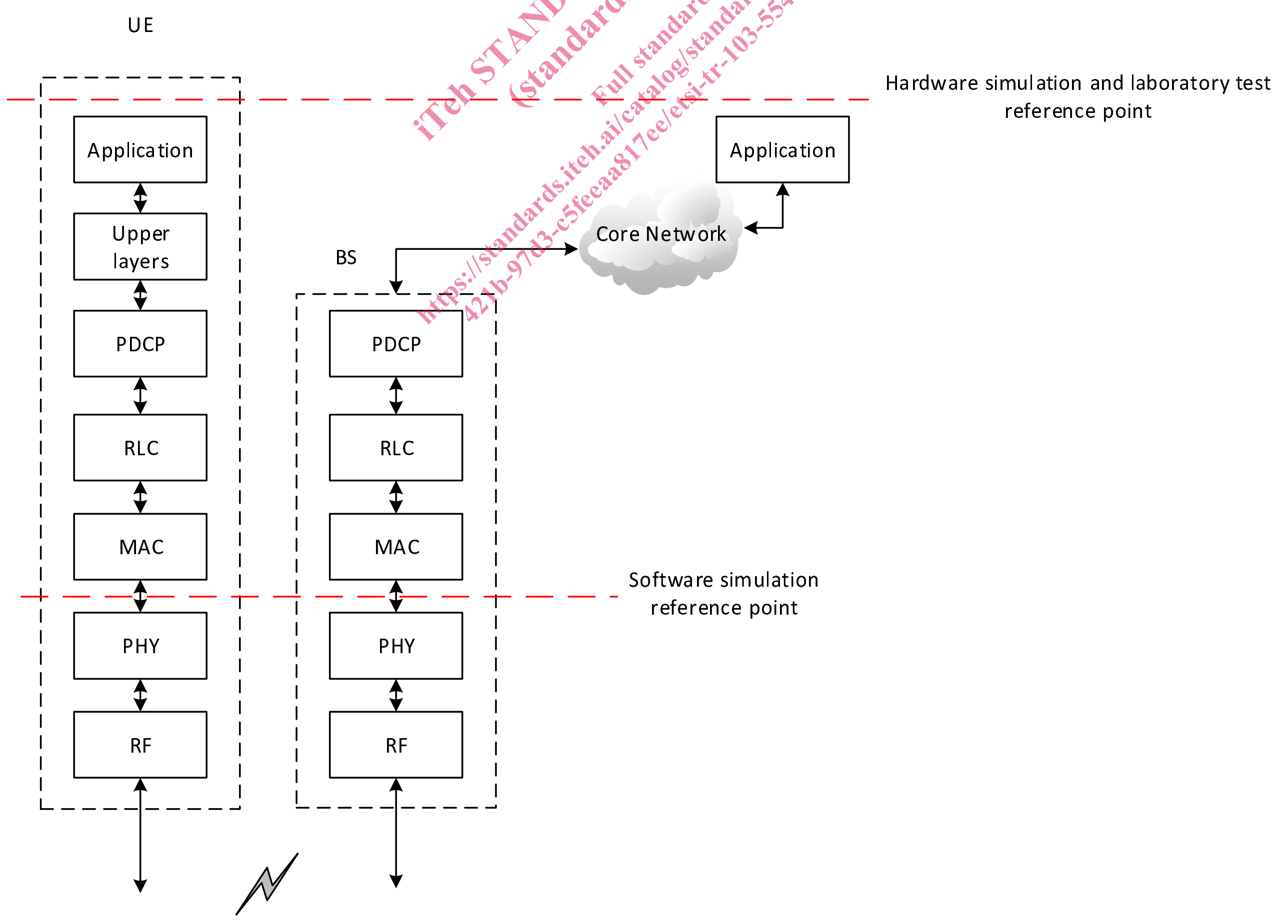

Figure 1: Reference point for the software simulations

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 the present document as they would require a more long and thorough work.

Only train-ground communications are considered in the present document. 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 is an extension of scenario 1 with an LTE carrier extended to 3 MHz in the E-UIC band.

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

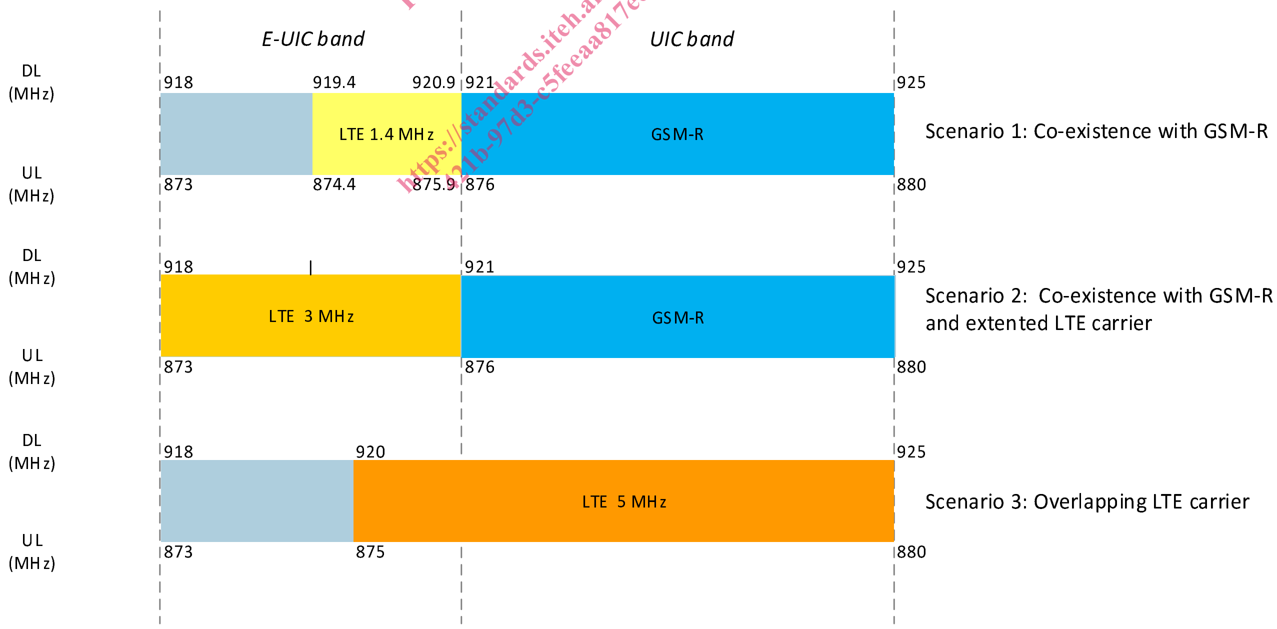

Figure 2: Carriers and bandwidths in the deployment scenarios considered

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. Power limitations and ACS (Adjacent Channel Selectivity) have been found as not relevant for the present document.

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.

More detailed information can be found in [i.11].

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

4.5.2 Antenna diagrams at the UE

The on-board antenna is considered as being omnidirectional with vertical polarization in case of one mounted antenna, and with vertical polarization and a separation > 10 λ in case of two mounted antennas.

It is assumed that the UE antenna gain at low angles of elevation compensates the feeder loss.

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 ETSI TR 145 050 [i.10])

2) ITU-R 1997 for IMT 2000 (see Recommendation ITU-R M.1225 [i.8]) and LTE specified scenarios (see ETSI TS 136 104 [i.2] and ETSI TS 136 101 [i.3])

3) ITU-R for IMT advanced (see Recommendation ITU-R M.2135-1 [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 the present document.

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 in bold.

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 1)	MRS 1 to 2 km 20 km for Rural (see note 1)
	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	Δ*hb* = 0 to 50 m, i.e. up to 46 m for 4 m train antenna height (see note 2)	**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 1: Delays are shorter than what can be expected with such ISD. NOTE 2: Δ*hb* is the height difference between base station and train antennas.						

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