ETSI TR 103 865 V1.1.1 (2024-09)

Rail Telecommunications (RT);
Future Railway Mobile Communication System (FRMCS);
Radio performance aspects

Reference

DTR/RT-0079

Keywords

FRMCS, radio parameters

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 - APE 7112B
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Sous-Préfecture de Grasse (06) N° w061004871

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Foreword

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

Modal verbs terminology

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Executive summary

The goal of the present document is to help railway infrastructure managers identifying features and techniques recommended to optimize radio network performance of a Future Railway Mobile Communication System (FRMCS) in different railway contexts. Several topics have been studied, such as interference mitigation, TDD operation, Doppler effect or impact on time synchronization of sub-carrier spacing and of speed, and a conclusion has been drawn for each of them.

Introduction

3GPP 5G NR is the radio access technology to be used in the Future Railway Mobile Communication System (FRMCS). Some performance evaluations of NR in typical railway deployments have been made in ETSI TR 103 5542 [i.1]. Furthermore, the need has been identified to clarify some technical aspects and assumptions that have been made in ETSI TR 103 554-2 [i.1]. Although ETSI TR 103 554-2 [i.1] highlighted the importance of mitigating interferences to guarantee enough throughput at any location of the train in a cell, especially at cell edge, further study and clarification of possible mitigation techniques was deemed beneficial.

The allocation of a TDD spectrum band for train services in Europe raised some additional questions specific to TDD deployment, in particular when considering continuous operation across country borders, with each country having deployed its own FRMCS network.

The present document has several objectives. A first objective is to provide clarifications about some technical aspects such as Doppler effect impact, impact of sub-carrier spacing and impact of train speed on time synchronization. The second goal is to provide an analysis and a comparison of some different features and techniques that are included in 3GPP specifications regarding interference mitigation techniques in the context of railway-specific deployment scenarios. A third point is to provide an analysis of TDD operation implications regarding synchronization and cross-border coordination.

Overall, the aim of the present document is to help railway infrastructure managers with identifying features and techniques recommended to optimize radio network performance in different railway contexts.

1 Scope

The present document analyses and provides additional information on 5G NR radio performance for FRMCS operation limited to RMR bands 900 MHz (FDD) and 1 900 MHz (TDD).

Starting from the most representative FRMCS use cases defined in ETSI TR 103 554-2 [i.1], the efficiency of different interference mitigation techniques is compared. Further, given the availability of a TDD band for RMR, some aspects related to performance when operating in TDD are explored. Finally, miscellaneous technical aspects affecting radio performance (Inter System Interference, consideration of Doppler effect, impact of the Sub Carrier Spacing (SCS), etc.) are studied.

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 TR 103 554-2: "Rail Telecommunications (RT); Next Generation Communication System; Radio performance simulations and evaluations in rail environment; Part 2: New Radio (NR)".

[i.2] Loïc Brunel, Hervé Bonneville, Akl Charaf and Émilie Masson: "System-Level Evaluation of Next-Generation Radio Communication System for Train Operation Services", Proceedings of 7th Transport Research Arena TRA 2018, April 16-19, 2018.

[i.3] G. B., N. H. M., T. B. S., P. M., Fernando M. L. Tavares: "On the Potential of Interference Rejection Combining in B4G Networks".

[i.4] 3GPP TR 36.884: "Performance requirements of MMSE-IRC receiver for LTE BS".

[i.5] ETSI TS 136 423: "LTE; Evolved Universal Terrestrial Radio Access Network (E-UTRAN); X2 Application Protocol (X2AP) (3GPP TS 36.423)".

[i.6] ETSI TS 136 300: "LTE; Evolved Universal Terrestrial Radio Access (E-UTRA) and Evolved Universal Terrestrial Radio Access Network (E-UTRAN); Overall description; Stage 2 (3GPP TS 36.300)".

[i.7] Shangbin Wu and Yinan Qi: "Centralized and distributed schedules for non-coherent joint transmission".

[i.8] ETSI TS 138 104 (V17.6.0): "5G; NR; Base Station (BS) radio transmission and reception (3GPP TS 38.104 version 17.6.0 Release 17)".

[i.9] ETSI TS 138 101-1 (V17.6.0): "5G; NR; User Equipment (UE) radio transmission and reception; Part 1: Range 1 Standalone (3GPP TS 38.101-1 version 17.6.0 Release 17)".

[i.10] Bernd Holfeld, Moritz Lossow, Maksym Tyrskyy, Said Mehira, Lourdes Garcia, Simon Biemond, and Christoph Bach: "Field Study on Multi-Antenna Radio Technologies for Future Railway Communications at 1.9 GHz", August 2021.

[i.11] ETSI TS 138 211: "5G; NR; Physical channels and modulation (3GPP TS 38.211)".

[i.12] ETSI TS 138 214: "5G; NR; Physical layer procedures for data (3GPP TS 38.214)".

[i.13] Lars Lindbom (Ericsson®), Robert Love, Sandeep Krishnamurthy (Motorola® Mobility), Chunhai Yao (Nokia® Siemens® Networks), Nobuhiko Miki (NTT DOCOMO), Vikram Chandrasekhar (Texas Instruments®): "Enhanced Inter-cell Interference Coordination for Heterogeneous Networks in LTE-Advanced: A Survey", December 7, 2011.

[i.14] Zainab Zaidi, Vasilis Friderikos, Zarrar Yousaf, Simon Fletcher, Mischa Dohler and Hamid Aghvami: "Will SDN be part of 5G?", February 2018.

[i.15] CEPT ECC Report 353 (16 June 2023): "Cross-border coordination and synchronisation for Railway Mobile Radio (RMR) networks in the 1900-1910 MHz TDD frequency band".

[i.16] 3GPP TR 38.828: "Cross Link Interference (CLI) handling and Remote Interference Management (RIM) for NR".

[i.17] ETSI TS 138 300: "5G; NR; NR and NG-RAN Overall description; Stage-2 (3GPP TS 38.300)".

[i.18] 3GPP TR 36.878: "Study on performance enhancements for high speed scenario in LTE".

[i.19] CEPT ECC Recommendation (23)01 (16 June 2023): "Cross-border coordination for Railway Mobile Radio (RMR) in the 1900-1910 MHz TDD frequency band".

[i.20] IEEE™ Volume 17 - Issue 1: "Interference rejection combining in LTE networks", Y. Léost, M. Abdi, R. Richter and M. Jeschke. In Bell Labs Technical Journal, pp. 25-49, June 2012, doi: 10.1002/bltj.21522.

[i.21] Fernando M. L. Tavares, Gilberto Berardinelli, Nurul H. Mahmood, Troels B. Sørensen, and Preben Mogens: "On the Potential of Interference Rejection Combining in B4G Networks".

[i.22] Haifan Yiny, Haiquan Wang, Yingzhuang Liuy, David Gesbert: "Dealing with the Mobility Problem of Massive MIMO using Extended Prony's Method".

[i.23] Kien T. Truong and Robert W. Heath Jr: "Effects of Channel Aging in Massive MIMO Systems".

[i.24] ETSI TS 138 133: "5G; NR; Requirements for support of radio resource management (3GPP TS 38.133)".

[i.25] ETSI TS 138 213: "5G; NR; Physical layer procedures for control (3GPP TS 38.213)".

3 Definition of terms, symbols and abbreviations

3.1 Terms

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

cell centre: geographical area where a terminal experiences a good radio link quality (e.g. high SINR values)

cell edge: geographical area where a terminal experiences a poor radio link quality (e.g. low SINR values)

3.2 Symbols

Void.

3.3 Abbreviations

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

ACLR	Adjacent Channel Leakage Ratio
BBU	Base Band Unit
BS	Base Station
CDMA	Code-Division Multiple Access
CE	Control Element
CJT	Coherent Joint Transmission
CLI	Cross Link Interference
CLI-RSSI	Cross Link Interference - Received Signal Strength Indicator
CoMP	Coordinated Multi-Point
CP	Cyclic Prefix
CSI	Channel State Information
CSI-RS	Channel State Information - Reference Signals
DIP	Dominant Interferer Portion
DL CoMP	DownLink CoMP

NOTE: NCJT, CJT.

DL	DownLink
DMRS	Demodulation Reference Signal
DPS	Dynamic Point Selection
DSRC	Dedicated Short-Range Communications
FDD	Frequency Division Duplex
F-NCJT	Fully overlapped NCJT
gNB	5G Node B
GP	Guard Period
GSM	General System for Mobile communication
HFR	Hard Frequency Reuse
ICI	Inter-Carrier Interference
ISD	Inter-Site Distance
LOS	Line Of Sight
LTE	Long Term Evolution
MAC	Media Access Control
MAC-CE	Medium Access Control - Control Element
MCS	Modulation and Coding Scheme
MFCN	Mobile/Fixed Communications Network
MIMO	Multiple Input Multiple Output
MMSE-IRC	Minim Mean Square Error - Interference Rejection Combining
MRC	Maximum Ratio Combining
NCJT	Non-Coherent Joint Transmission
NF-NCJT	Non-Fully overlapped NCJT
NLOS	Non-Line Of Sight
NR	New Radio
O&M	Operation and Maintenance
OFDM	Orthogonal Frequency Division Multiplex
PFR	Partial Frequency Reuse
PRACH	Physical Random Access CHannel
PRB	Physical Resource Block
QAM	Quadrature Amplitude Modulation
QPSK	Quadrature Phase Shift Keying
RB	Resource Block
RF	Radio Frequency
RIM	Remote Interference Management
RMR	Railway Mobile Radio
RRC	Radio Resource Control
RSSI	Radio Signal Strength Indication
SCS	Sub-Carrier Spacing
SFN	Single Frequency Network
SFR	Soft Frequency Reuse

SINR	Signal-to-Noise plus Interference Ratio
SNR	Signal-to-Noise Ratio
SRS	Sounding Reference Signal
SRS-RSRP	SRS - Reference Signal Received Power
SSB	Synchronization Signal Block
TDD	Time Division Duplex
TP	Transmit Power
TRP	Transmission Reference Point
UE	User Equipment
UL CoMP	UpLink CoMP
UL	UpLink

4 Interference Mitigation

4.1 Frequency Reuse Techniques

4.1.1 Presentation

4.1.1.0 Introduction

Hard Frequency Reuse, Soft Frequency Reuse and Partial Frequency Reuse are three different frequency reuse techniques depicted in Figure 1 and described hereafter.

4.1.1.1 Hard Frequency Reuse

Hard frequency reuse consists of assigning different fractions of a frequency band to each cell of a group of cells. This is described by a hard reuse factor. The geographical separation between cells using the same frequency chunk in two different groups is larger, hence the cochannel interference is reduced. In hard frequency reuse the frequency band is divided in a static manner between cells of a group. This provides frequency orthogonality between cells but reduces cell capacity since the allocation is limited to a fraction of the carrier bandwidth (e.g. half of the carrier bandwidth for a hard reuse factor of 2), even in low cell load situation or in absence of interference from neighbouring cells.

4.1.1.2 Soft Frequency Reuse

Using soft frequency reuse, neighbouring cells dynamically coordinate their allocation of frequency resources and transmit power to users based on their knowledge of their radio conditions. This exploits the difference in path loss between different users in the cell by allocating a given fraction of the band with reduced power in a region close to the cell centre while the other part is allocated for cell edge users with higher power. A neighbouring cell does the same but swaps the frequency fractions to maximize the separation and avoid interference. The whole bandwidth is reused in every cell. Soft frequency reuse scheme avoids interference to some extent. Only a fraction of the band is allocated for a given user, but from a network perspective, cell spectrum utilization is much higher compared to a hard frequency-reuse scheme.

4.1.1.3 Partial Frequency Reuse

Using partial frequency reuse, the frequency band is divided into three fractions:

- one fraction used by all cells with relatively low power expected to serve users in cell centre;
- two other equal fractions allocated to neighbouring cells where each fraction is exclusively used by one of the two cells with a high transmission power.

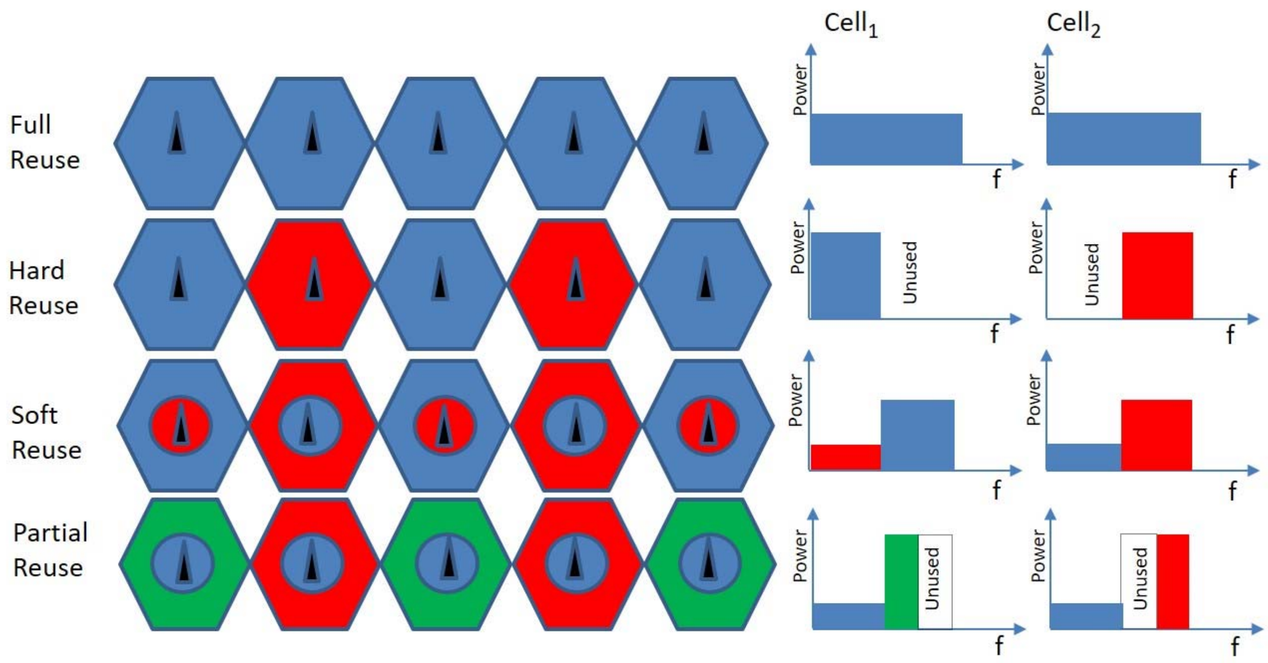

Figure 1: Interference mitigation through frequency reuse

4.1.2 Remarks and Potential Implementation of Frequency-Reuse Techniques

4.1.2.1 Introduction

For clarity, some definitions are provided hereafter. For more details, refers to ETSI TS 138 211 [i.11] and ETSI TS 138 214 [i.12].

Sounding Reference Signals (SRS) are uplink signals designed to infer the uplink channel state information. Sounding Reference Signals are UE-specific and scheduled by BS to gather channel quality on specific RBs. UEs are configured to transmit UL SRS so that the BS can estimate the channel quality in the UL.

Channel State Information Reference Signals (CSI-RS) are DL signal which allows BS to gather Channel State Information. CSI-RS are UE-specific and can be used and configured to fulfil different purposes. They can be multiplexed in time or frequency while they may also be periodic, semi-periodic or aperiodic. It should be noted that, in 5G New Radio, all reference signals are scheduled by the BS.

A UE is notified via RRC messages about the resources on which it is scheduled to receive CSI-RS or through MAC-CE for aperiodic CSI-RS.

Non-Zero Power (NZP-CSI-RS) and **Zero Power (ZP-CSI-RS)** are configured for a given UE so it can estimate the CSI and provide feedback to the base station.

CSI Interference Measurement (CSI-IM) are blank resources used for interference measurement. The BS does not transmit any signals on CSI-IM so that a UE can measure on these configured resources interference signals from other cells.

Measurements that are performed using the above reference signals can be used to exchange information between BS for coordination between cells or on a centralized common scheduler so that the interference can be minimized.

4.1.2.2 Performance of frequency reuse

In [i.2] it is shown how partial frequency reuse outperforms hard reuse and soft reuse and combines their respective advantages. At cell edge partial reuse offers better interference mitigation than soft reuse since the resources used on cell edge by the neighbouring cell are unused (blanked). On the other hand, with partial reuse all cells keep enough bandwidth (reused resources with low power) for mid-cell and cell centre so that the cell capacity is not penalized.

Frequency reuse techniques described above have not been considered in 3GPP specifications for 5G NR. They can potentially be implemented, including hard reuse, at scheduling or RRC level. They could be negotiated dynamically between base stations but could also be configured more statically by O&M, and thus be part of a deployment configuration. However, the detailed implementation impacts (i.e. which components would be impacted and to what degree) have not been studied within the present document.

4.1.2.3 Dynamic Frequency-Reuse implementation

For LTE, 3GPP has defined standardized messages allowing base stations from different vendors to coordinate dynamically their resource allocations through frequency-reuse technique. This can be done:

- in frequency domain:
  - High Interference Indicator (HII);
  - Overload Indicator (OI);
  - Relative Narrowband Transmit Power (RNTP); and also
- in time domain:
  - Almost Blank Subframes (ABS) (ETSI TS 136 423 [i.5] and ETSI TS 136 300 [i.6]).

The standardized signalling is transported between base stations through X2 interface, which has a latency typically of the order of a tens of milliseconds. Hence, the dynamic of a frequency-reuse technique could be expected to be in the order of a few hundred of milliseconds [i.13].

The coordination interface described above for LTE has not been defined in NR specifications but left up to vendor implementation. This means that dynamic frequency reuse could be feasible between NR base stations provided by a single vendor and implementing a vendor-specific coordination messages/interface. Hence, a dynamic frequency-reuse technique is not guaranteed to be inter-vendor inter-operable by the 3GPP NR specifications as of today.

It is also worth noting that for deployment options where one Base Band Unit (BBU) controls several transmission/reception points, a dynamic frequency-reuse technique could be implemented at BBU level for the whole set of transmission/reception points. However, the interference problem remains between zones controlled by different BBUs.

4.1.2.4 Static Frequency-Reuse implementation

Frequency-reuse techniques could also be implemented without the need of inter-base stations communication by providing each of them (e.g. through O&M) some allocation rules for cell-edge UEs. Hard-reuse is typically one possibility, but partial and soft-reuse techniques could also be configured.

For example, one possible implementation of the soft frequency reuse technique is that schedulers in base stations serving two adjacent cells can be configured to allocate the resource blocks for cell-edge users starting from a different edge of the carrier bandwidth. In low load situation and a low data traffic (moderate payload size) condition, this would avoid interference between the two adjacent cells. However, when load and/or data traffic become greater, the two allocations may overlap since they are not aware of each other, and the resulting interference may significantly degrade the performance on both sides.

4.1.2.5 Frequency-Reuse techniques and RMR operating bands

For both 900 MHz and 1 900 MHz bands, soft reuse and partial reuse techniques rely on a single carrier, hence with one Synchronization Signal Bloc (SSB). They could be implemented in a vendor-specific manner, with possible impacts on scheduler and/or other internal functions.