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Public Mobile Wideband Networks Interference Impact Assessment on Railways GSM-R Network

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***Abstract*—This paper presents a field study relating to the impact that public operator cellular networks such as UMTS (Universal Mobile Telecommunication System), LTE (Long-Term Evolution), and 5G-NR (5G - New Radio) have on railway GSM-R (Global System for Mobile Communications – Railway) networks. The validation of the interference calculation relied on actual network measurements taken along railway lines using a dedicated probe. Emissions from public networks, in some scenarios, have been shown to affect GSM-R networks to a large extent. The developed algorithm is currently being used in real GSM-R network planning to mitigate this negative effect on base station coverage and service performance.**

***Index Terms*—GSM-R; UMTS; Interference; Railway Communications; Frequency Planning**

I. Introduction

Railways are typically heavy users of mobile communication systems due to various aspects involved in their operations, coupled with trains' high speed and mobility. Therefore, GSM-R in the 900 MHz band has been adopted by most railway infrastructure operators to support voice and data communications. This system is the one supporting mobile rail communications. It is mandatory and interoperable at the European level and is used by infrastructure and railway operators. These systems are regarded as critical given their importance in railway operations and safety, especially ETCS (European Train Control System) level 2 and above, which involve signaling transmission via GSM-R. Communication criticality means that reliability, availability, and safety are crucial aspects and challenges to be considered on any rail communication network.

Given the widespread adoption of GSM-R technology, some operators have started to identify operational limitations in their networks caused by interference generated by public networks, and both are increasing in use this interference also increases, making it necessary to mitigate this phenomenon effectively, and enabling the networks to coexist. In this scenario, algorithms that predict this interference need to be used to make optimal reuse of the spectrum available for each technology when planning is performed, not only for public networks but also for rail networks.

This work studies the impact that public networks have on a GSM-R network implemented at Cascais-Lisbon, Portugal railway lines. Results are computed using the developed algorithm and validated by measures performed on the same railway line. The guidelines represented in the [1] and [2] reports are merely theoretical, while this paper puts them into practice on real networks.

This paper is organized as follows: Section II presents the characterization of the interference and all its parameters, in Section III the case study is presented, Section IV explains the methodology for calculating the interference, and Section V analyses the results obtained. Finally, conclusions are drawn in Section VI.

II. Interference Characterisation

A. GSM-R spectrum and requirements

Recently, some European rail operators using GSM-R have reported problems caused by interfering signals from the adjacent band (880-915 / 925-960 MHz) [1], Fig. 1.

These problems have been attributed mainly to the decision by European regulators to allow UMTS and LTE technologies to operate in the E-GSM band, previously reserved for GSM technology [1].

Interference exists regardless of the strength of the received signal and cannot be attributed to either intermodulation or jamming effects alone, so other effects must be taken into

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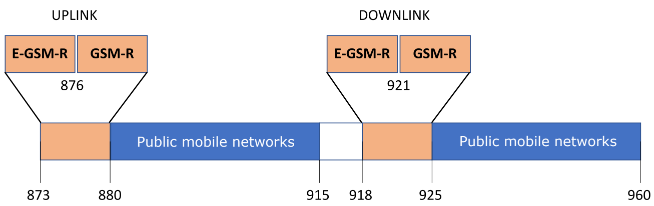


Fig. 1. Spectrum usage between 873 and 960 MHz.

account, such as broadband noise. Three types of mechanisms can be identified by which interfering signals can considerably affect the receiver's performance:

- **Receiver Desensitization** - the signal can not be decoded, due to the presence of interfering signals, which is related to the power ratio between the desired signal and its interfering counterpart (C/I). These interfering signals may originate from out-of-band emissions from other emitters or intermodulation products, especially those of the 3rd and 5th order.
- **Receiver Blocking** - effect caused by a strong out-of-band interfering signal from the receiver which makes it impossible to detect a desired low power signal.
- **Receiver Overload** - effect caused by the presence of two strong signals on the antenna resulting in intermodulation products on non-linear devices in the reception chain.

The BS (Base Station) and the MS (Mobile Station) admit a certain level of interference from adjacent channels without significantly impairing the performance of the established radio link. The ability to tolerate interference is affected by the receiver's characteristic selectivity, representing the equipment's ability to filter out signals located in adjacent bands.

Therefore, it is crucial to determine a minimum signal rejection capability for adjacent bands, which is usually described by the parameter ACIR (Adjacent Channel Interference Ratio). This parameter is defined as the ratio between the total power emitted by a given source (MS or BS) and the power received by the receiving equipment (victim). This ratio depends essentially on the ACLR (Adjacent Channel Leakage Ratio) of the transmitter and the ACS (Adjacent Channel Selectivity) of the receiver.

B. Interference Rejection

The adjacent channel signals rejection is represented by the ACIR parameter defined as the ratio between the power transmitted on one channel and the total interference received by a receiver on the adjacent channel due to imperfections in the transmitter and receiver. To calculate this parameter, (1), it is necessary to take into account the selectivity of the GSM-R filters (ACS), the ACLR of the BS, and the MS in UMTS, LTE and 5G-NR 900.

$$ACIR = \frac{1}{\frac{1}{ACLR} + \frac{1}{ACS}} \tag{1}$$

Fig. 2 compares ACIR in UMTS, LTE and 5G 900. To facilitate this comparison, only 5 MHz channel will be demonstrated for LTE and 5G in order to be comparable with UMTS.

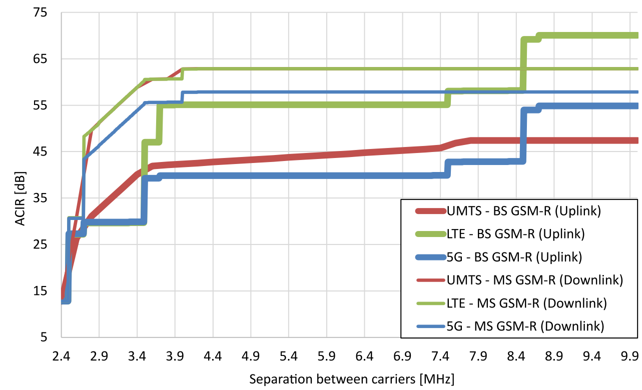


Fig. 2. ACIR comparison for GSM-R BS when interfered by UMTS, LTE and 5G 900 networks.

Fig. 2 shows that compared to 5G networks, UMTS and LTE networks are more harmful to GSM-R uplink, i.e. when other networks' base station interfere with the GSM-R mobile terminal.

C. Public Networks OBE (Out of Band Emissions)

To determine the level of interference from the BS and MS it is necessary to characterize the maximum allowed standard of out-of-band emissions, therefore requiring a calculation of the ACLR from both the BS and the MS.

The ACLR, also known as the Adjacent Channel Power Ratio (ACPR), is defined as the ratio of the power transmitted within the bandwidth of the allocated channel to the power of unwanted emissions transmitted on adjacent channels. Each wireless technology has adjacent channels located at different frequencies.

The ACLR values for BS and MS defined in GSM-R standards were obtained through the spectral masks defined for GSM-R [3], [4], for UMTS [5], [6], for LTE [2], and finally for 5G [7], [8].

Once the ACLR has been calculated, it is possible to define the OBE power levels defined in Eq. (2).

It should be noted that out-of-band emissions cannot be reduced without affecting the corresponding data/signals quality transmission.

$$OBE = P_{rx} - ACLR_{200\ kHz} \tag{2}$$

where, P_{rx} is equivalent to the receiving power (dBm).

Fig. 3 shows the projection of the power transmitted over the GSM-R 200 kHz band, assuming that the BS of the respective technology is transmitting at its maximum power (worst case). Fig. 3 shows the 19 GSM-R carriers in order to facilitate the observation of out-of-band emissions and their impact. In order to compare the three technologies (UTMS, LTE and 5G), a bandwidth of 5 MHz and a carrier of 927.6 MHz were used in this study

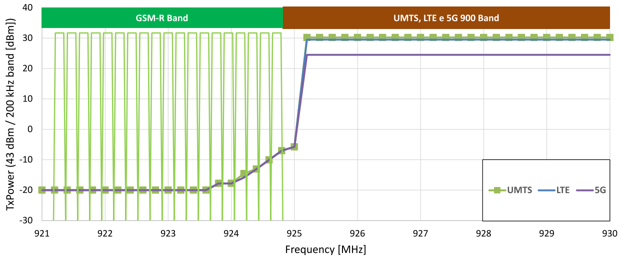


Fig. 3. Comparison between the out-of-band emissions of a UMTS, LTE and 5G 900 BS over a 200 kHz band.

Analysing Fig. 3, it can be seen that the 4 top carriers are substantially more affected by signals from the first carriers of the technologies concerned. It will only be possible to effectively quantify the disturbance felt after the selectivity of the GSM-R terminal has been determined.

D. Selectivity

Adjacent channel selectivity is a measure that characterizes the ability of a radio receiver to receive a signal on the desired channel band in the presence of another signal on an adjacent frequency or channel. The ACS can therefore be defined as the capacity that a filter present in the receiver has to suppress signals present in adjacent channels.

III. Study Case: Cascais Railway

The Portuguese Cascais Railway line was used for this study. Public and GSM-R networks were measured in order to compare them with the theoretical model and approach.

A. GSM-R Network

Cascais Railway, represented in Fig. 4, has the following characteristics:

- 25 km long,
- 9 stations and 8 halts,
- 5 GSM-R BS and urban environment.

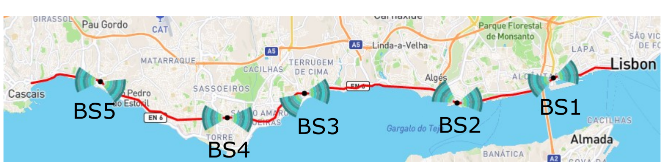


Fig. 4. Cascais Railway.

Table I shows GSM-R BS configuration in operation. Note that this configuration is not the one currently used by the Portuguese GSM-R operator, it was only a pilot scenario

B. Measurement setup

Taking into account the scenario described above, field tests were performed in order to obtain signals from the GSM-R and UMTS networks on the Cascais Railway. These tests were performed through a probe installed in the train driver's cabin.

TABLE I: GSM-R Carriers used in Cascais Railway.

Cell ID	BS	Channel BCCH	Channel TCH
014C	BS1	955	955 / 961
02DC	BS2	959	959 / 965
0534	BS3	969	963 / 969
0660	BS4	967	967 / 973
06C4	BS4	955	955 / 961
091C	BS6	959	959

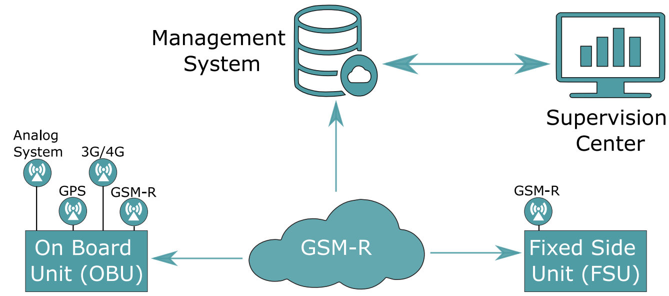


Fig. 5. Measurement collection platforms.

Fig. 5 shows the diagram flow implemented in the measurement data collection tool.

Here, tests are performed between two devices: the On Board Unit (OBU) and the Fixed Side Unit (FSU), using as access service the GSM-R network. In this way, it is possible to collect a series of radio parameters not only from GSM-R but also from UMTS of public operators. Furthermore, several GPS parameters are also collected in order to identify the train location.

C. Received signal level and quality

Measurements over GSM-R and UMTS were collected and are presented in Fig. 6. Here, signal averages per Kilometric Point (KP) and per GSM-R carrier are shown. It should be noted that the measurements performed in UMTS were made for the 932.6 MHz carrier.

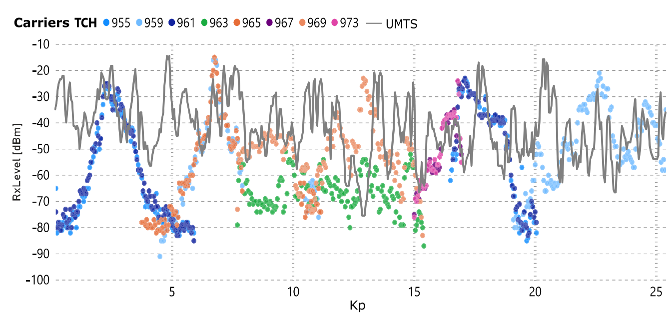


Fig. 6. GSM-R and UMTS coverage on the Cascais Railway.

As can be seen in Fig. 6, the UMTS signal received on the Cascais Railway is quite significant, having the potential to generate interference over adjacent channels.

During the drive tests the parameter RxQual was also measured, as shown in Fig. 7.

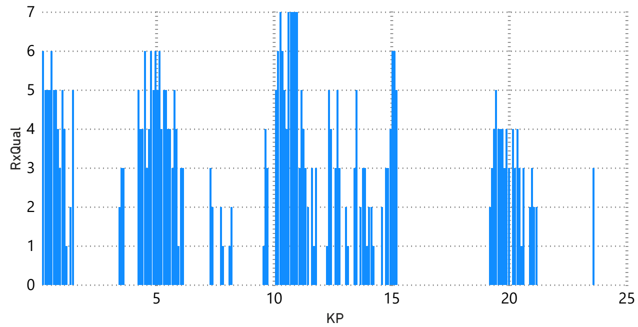


Fig. 7. RxQual on the Cascais Railway.

Analysing RxQual, it is possible to see that paralleling with Fig. 6, when the UMTS signal is higher than the GSM-R signal the interference increases.

IV. GSM-R QoS Estimation

The main objective of this research is to measure the impact that UMTS networks have on GSM-R networks. Therefore, it is necessary to estimate the Inter and Intra Network interference (Intra + Inter Network interference) separately, to clarify which one has more impact.

A. Intra-network C/I

For the interference calculation, there are two basic parameters that have to be analysed: the carriers' frequencies (both victims and interfering carriers), and the power, which in this specific case reaches the same point of the railway, coming from all the BS's used for the analysis.

It is therefore necessary to distinguish the victim's carrier (f_{Victim}) from the interfering carrier ($f_{Interfering}$), as can be seen in (3).

$$\Delta f = |f_{Victim} - f_{Interfering}| \quad (3)$$

Depending on the deviation calculated above (Δf), the interfering power value (P_{int}) has to be determined, represented in (4).

$$P_{int} = 10^{(P_{rxI} - ACIR)} \quad (4)$$

It is then possible to calculate the total interfering power ($P_{int}\ Total$), represented in (5).

$$P_{int}\ Total_{Intra} = P_{int} + N_f \quad (5)$$

where N_f corresponds to the noise power [1].

Finally, it is possible to calculate the C/I by subtracting the receiving power at the mobile terminal from the victims (P_{rxV}) with the total interfering power ($P_{int}\ Total$) , as represented in (6).

$$C/I = P_{rxV}/P_{int}\ Total \quad (6)$$

B. Inter-network C/I

To calculate the UMTS Inter Network interference in GSM-R the same methodology described above is followed, and then the interference caused by GSM-R itself is added. Therefore, the only change is the substitution of (5) by (7).

$$P_{int}\ Total_{Inter} = P_{int}\ GSM-R + N + P_{int}\ UMTS \quad (7)$$

C. RxQual estimation

Once C/I has been calculated, it must be converted to $RxQual$ by means of the mapping represented in Table II.

TABLE II: Mapping table from $RxQual$ to C/I [9].

$RxQual$	C/I
0	[20, $+\infty$[
1	[18, 20[
2	[16, 18[
3	[14, 16[
4	[11, 14[
5	[9, 11[
6	[4, 9[
7	]$-\infty$, 4[

V. Results Analysis

C/I was computed for the worst case scenario, with the minimum signal strength from the victim BS' reaching each point on the line and the maximum signal strength in the case of interfering stations (GSM-R and public operators) and the results are shown in Fig. 8.

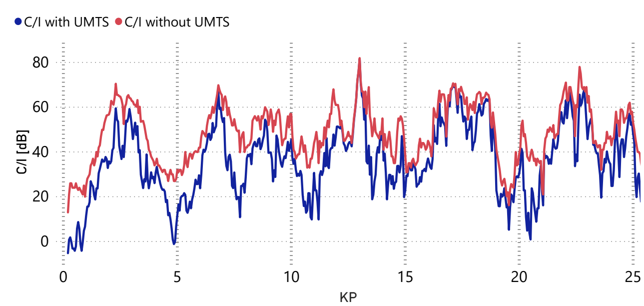
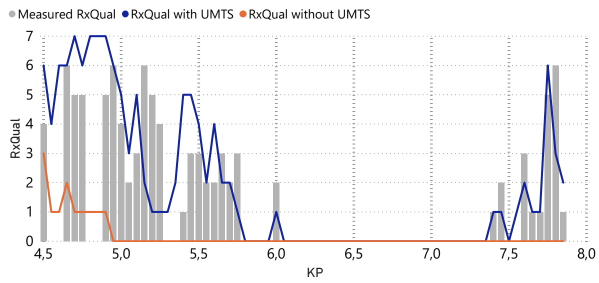


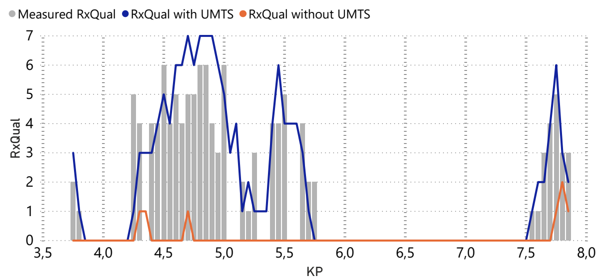
Fig. 8. C/I with and without signal from UMTS network.

As can be seen in Fig. 8, the impact of public networks on GSM-R is quite significant, given that a $C/I < 9$ renders communication very difficult. In order to better highlight this impact, Fig. 9 compares the measured RxQual with the calculated RxQual (with and without external public networks) per site and carrier.

By looking at Fig. 9, it is possible to confirm that UMTS has a negative impact on GSM-R. It is also shown that the calculated RxQual is validated by the measurements, and that there are differences that relating to the delay that may exist between measurements and other external parameters which are not being taken into account in the theoretical calculations, as we do not have access to the internal code of the modem that collects the data. In Fig. 10 it is possible to observe the

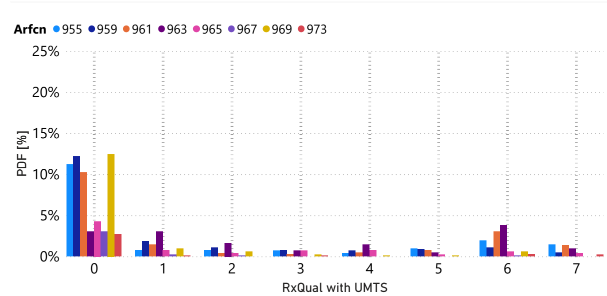


(a) Carrier 959.

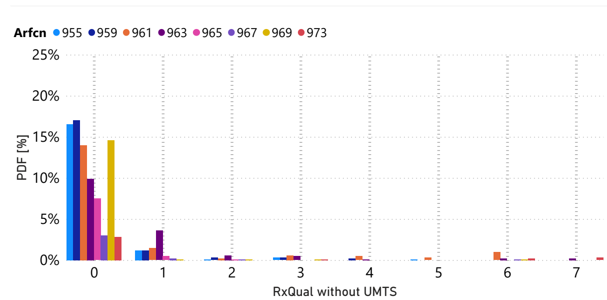


(b) Carrier 965.

Fig. 9. RxQual for Pedrouc¸os site.



(a) With UMTS.



(b) Without UMTS.

Fig. 11. RxQual histogram per site.

RxQual for the entire scenario in question, testing once again the theoretical Rxqual against the practical one.

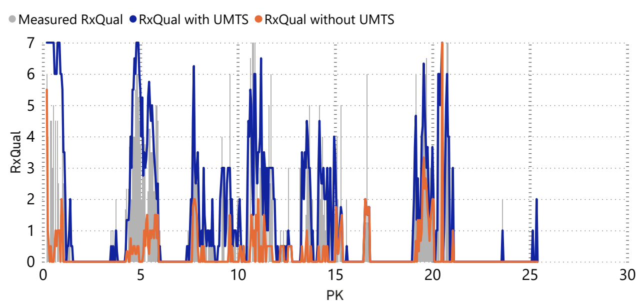


Fig. 10. RxQual for the entire scenario.

In Fig. 11, the RxQual comparison histogram with and without UMTS are represented per site, allowing an analysis of the impact of UMTS.

By analysing Fig. 11, it can be shown that the impact of UMTS is quite significant. It is observed that Alcântara and Paço d'Arcos sites suffer more from both GSM-R and UMTS. This is reinforced if we do the same analysis as before, but this time for the carriers, the most affected being those used by the aforementioned sites, as expected.

VI. Conclusions

Before any implementation, it has been demonstrated through theoretical analysis that the connection that most affects GSM-R, is the downlink connection. There was also analysis on which of the three networks (UMTS, LTE and 5G - NR) had the most negative impact for coexistence with GSM-R and it was concluded that it would depend on carrier to carrier deviations, with deviations above 2.8 MHz being almost equal, and those for deviations below 2.8 MHz UMTS the most adverse in almost its entire domain (from 0 to 2.8 MHz).

This research, results on a tool for calculating interference, is validated by measurements taken in railway environments. In order to measure the impact that UMTS has on GSM-R, two sets of tests were performed in which all the results were validated with the measures mentioned above.

In the first test, Intra-Network interference was calculated in order to measure only the impact that GSM-R has on itself. Results shows that, it is possible to identify a situation close to PK 0 (Cais do Sodré) where the C/I is close to 9 dB, which can cause dropped calls.

In the second test, Inter Network interference, caused by UMTS in GSM-R is calculated in addition to the interference calculated in the first test. This shows that Inter Network interference is much more harmful than Intra Network interference, reinforcing the argument that the public operators' networks are the cause of many problems in the networks used by railway operators in urban environments. Consequently, it was concluded that the interference on the Cascais Railway is not caused by GSM-R itself but by UMTS.

VII. Acknowledgment

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REFERENCES

[1] E.C.C.E. within the European Conference of Postal and T.A. (CEPT), ECC Report 162 - Pratical Mechanism to Improve the Compatibility Between GSM-R and Public Mobile Networks and Guidance on Pratical Coordination. ECC, CEPT, May 2011.

[2] E.C.C.E. within the European Conference of Postal and T. A. (CEPT), ECC REPORT 41 - Compatibility Study for LTE and WiMAX Operating within the Bands 880-915 MHz/925-960 MHz and 1710-1785 MHz/1805-1880 MHz (900/1800 MHz bands). ECC, CEPT, November 2010.

[3] ETSI, 145 005 Digital Cellular Telecommunications System (phase 2+); Radio Transmission and Reception (3GPP TS 45.005 Version 12.5.0 Release 12), Sophia Antipolis Cedex, April 2015.

[4] ETSI, 3GPP TR 45.050 V9.0.0 (2009-12) Technical Specification Group GSM/EDGE, Radio Access Network; Base Station (BS) Radio Transmission and Reception (FDD). 3GPP, 2010.

[5] ETSI, 3GPP TS 25.104 (Rel-9) Base Station (BS) Radio Transmission and Reception (FDD). 3GPP, 2018.

[6] ETSI, 3GPP TS 25.101 (Rel-9) User Equipment (UE) Radio Transmission and Reception (FDD). 3GPP, 2019.

[7] ETSI, 5G; NR; Base Station (BS) Radio Transmission and Reception (3GPP TS 38.104 version 15.2.0 Release 15). 3GPP, 2018.

[8] ETSI, 5G; NR; User Equipment (UE) Radio Transmission and Reception; Part1:Range 1 Standalone (3GPP TS 38.101-1 version 15.3.0 Release 15). 3GPP, 2018.

[9] F.Hägglund, Improved power control for GSM/EDGE, 2005.