ECC Report 355

Measurement-based compatibility studies assessing interference from Very Low Power (VLP) Wireless Access Systems including Radio Local Area Networks (WAS/RLAN) operating in 5945-6425 MHz to Communication Based Train Control (CBTC) systems operating in 5915-5935 MHz

approved 10 May 2024

0 EXECUTIVE SUMMARY

ECC Report 302 [1] and CEPT Report 75 [3] studied the coexistence between Wireless Access Systems including Radio Local Area Networks (WAS/RLAN) operating above 5945 MHz and Communication Based Train Control (CBTC) operating below 5935 MHz. ECC Decision (20)01 [5] harmonises the use of WAS/RLAN in the 5945-6425 MHz band, including Very Low Power (VLP) portable use, with maximum mean[1] 25 mW e.i.r.p., that may operate both indoor and outdoor. VLP WAS/RLAN devices are in the scope of this Report.

ECC Decision (20)01 [5] as published in November 2020 mentioned that "It should be noted that the -45 dBm/MHz OOB limit below 5935 MHz for VLP would allow VLP initial market to take up. CEPT also agreed that this OOB limit should be valid in time only until 31 December 2024 and be re-examined with regard to an opportunity to relax it based on the real IEEE and DSSS Urban Rail interference situation. In absence of the justified evidence, a value of -37 dBm/MHz, for the OOB limit below 5935 MHz, will be adopted from 1 January 2025." ECC Decision is expected to be amended in due course.

This Report gathers findings of laboratory and field measurement campaigns as well as additional studies with the aim of re-examining the OOB emission limit below 5935 MHz for VLP WAS/RLAN devices operating in the 6 GHz band. The measurement campaigns were conducted thanks to the help of the French administration ANFR, the German administration BNetzA, the JRC, and CBTC and WAS/RLAN industry stakeholders.

These measurement campaigns provided new technical elements relevant for interference to a single CBTC link. The studies in the Report first analyse single link interference scenarios. Then based on these analyses, the Report provides probabilistic assessments of the overall risk of interference to the CBTC system. No measurement was performed on the overall resilience of the system to interference.

This Report considered the following four scenarios:
- Scenario 1: impact of a VLP WAS/RLAN operated on a platform to CBTC Access Point (AP);
- Scenario 2: impact of a VLP WAS/RLAN operated on a platform to CBTC Train Unit (TU);
- Scenario 3: impact of a VLP WAS/RLAN operated onboard a train to CBTC TU;
- Scenario 4: impact of a VLP WAS/RLAN operated onboard a train to CBTC AP.

Studies conducted in this Report include:
- Coupling loss approach: VLP OOB emissions potential impact on CBTC through an I/N analysis;
- Coupling loss approach: VLP OOB emissions potential impact on CBTC through an SINR analysis;
- Coupling loss approach: VLP in-band and OOB emissions potential impact on CBTC through a protection ratio analysis;
- Statistical assessments of the overall risk of interference to the CBTC system.

From these studies, it was observed that the critical scenario for the studied RER train is Scenario 2 (VLP on platform vs CBTC TU), while the critical scenario for the studied metro types[2] (labelled as MP14, MP89, and MP05) is Scenario 3 (VLP onboard vs CBTC TU).

0.1 RESULTS OF COUPLING LOSS STUDIES

Some studies demonstrated that VLP with OOB emission levels at both -37 dBm/MHz and -45 dBm/MHz can lead, for some scenarios, to degradation of performance of a single CBTC radio link. The risk of interference is shown to be increased by relaxing the OOB emissions from -45 dBm/MHz to -37 dBm/MHz.

[1] The "mean e.i.r.p." refers to the e.i.r.p. during the transmission burst, which corresponds to the highest power, if power control is implemented.

[2] For the definition of RER trains and metro trains refer to section 2.4.2

Some other studies demonstrated that with both OOB emission levels there is no degradation of performance of a single CBTC radio link, except for one studied metro type (MP14), lacking a margin of less than 1 dB due to its lower measured coupling loss[3].

The different results mainly come from the variation in the assumptions used for the noise floor, the minimum CBTC signal level, the modulation and the body loss. It was also observed that the coupling loss between the passenger cabin and the CBTC TU can vary significantly between trains. Therefore, the variation in the coupling loss has a significant impact on the coexistence between VLP WAS/RLAN and CBTC.

0.2 RESULTS OF STATISTICAL STUDIES

Noting that an emergency brake is automatically triggered if a train is not able to receive and successfully demodulate the movement authority message for a period of typically 2.5 s, statistical studies were conducted.

A first statistical analysis further analysed the MP14 case and showed that the likelihood of interference is low.

A second statistical analysis on the impact from a VLP WAS/RLAN on platform to a CBTC TU showed that the risk of single link interference is increased from 2.5% to 43% of trains entering a platform when relaxing OOB emissions from -45 dBm/MHz to -37 dBm/MHz, and could be mitigated by transmit power control. It is expected some interference would affect the useful link of a TU, therefore the CBTC system would be affected, although still able to cope in most cases (nominal mode). The system would become more exposed in case of double failures, and in those very rare but critical events, there could be instances of partial or total loss of CBTC communication. A sensitivity analysis showed that with a minimum CBTC signal level of -77 dBm/MHz over the platforms there is no interference with the OOB emissions of -37 dBm/MHz.

A third statistical analysis on the impact from a VLP WAS/RLAN onboard to a CBTC TU showed that the number of interference events per 24 hours (lasting more than 1 second) is low for OOB emissions at -45 dBm/MHz, but substantially increased with OOB emissions relaxed to -37 dBm/MHz (70-fold increase). The study also showed that VLP with OOB emissions at -37 dBm/MHz are unlikely to produce harmful interference to CBTC under the following conditions:

- A VLP would select lower channels below 6105 MHz only if the spectrum access mechanism has failed with the upper channels. When channels below 6105 MHz are used, the channel selection would be reassessed approximately every 100 seconds, for example;
- Transmit Power Control (TPC) would be able to reduce the total power from VLP maximum transmit power P_{max} down to at least P_{max} – 6 dB.

Some possible mitigation techniques on both VLP WAS/RLAN and CBTC and their possible implications are described in section 8.

It has to be noted that the one CBTC receiver with 10 MHz bandwidth measured (Annex 5) responds heterogeneously to changes of OOB emission levels and WAS/RLAN bandwidths. The laboratory measurements did not highlight a CBTC receiver selectivity issue. The measurements of characteristics of this receiver were conducted specifically for the purpose of this study and are not meant to be used or referenced outside the scope of this Report.

[3] Metro MP14 exhibits a 44.2 dB coupling loss while metros MP89 and MP05 exhibit 50.1 dB and 54.2 dB, respectively

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LIST OF ABBREVIATIONS

Abbreviation	Explanation
ACR	Adjacent Channel Rejection
ACS	Adjacent Channel Selectivity
AGC	Automatic Gain Control
ANFR	Agence Nationale des Fréquences (National Frequency Agency, France)
AP	Access Point (WAS/RLAN or CBTC)
AV-burst	Average burst. In the context of an RF level, this value represents the RMS signal power during a burst time.
BL	Body Loss
BMI	Body mass indicator
BNetzA	Bundesnetzagentur (Federal Network Agency, Germany)
BPSK	Binary phase-shift keying
CBTC	Communication Based Train Control
CDF	Cumulative Distribution Function
CEPT	European Conference of Postal and Telecommunications Administrations
CL	Coupling Loss
C/I_{adj}	Carrier to interference ratio (also called “protection ratio”). When levels are given in logarithmic units, this is the difference of wanted level minus interfering level.
DC	Duty Cycle
DL	Downlink. This is the direction from the “server” to the DUT. For the measured system, it is the direction from the access point to the onboard unit.
DSSS	Direct-Sequence Spread Spectrum
DUT	Device under test
ECC	Electronic Communications Committee
e.i.r.p.	Effective Isotropic Radiated Power
EMSL	European Microwave Signature Laboratory
ETSI	European Telecommunications Standards Institute
FCC	Federal Communications Commission
FEC	Forward Error Correction
IEEE	Institute of Electrical and Electronics Engineers
I/N	Interference to noise ratio
ITS	Intelligent Transport System
I/Q	In-/Quadrature phase signals are mathematically complex

Abbreviation	Explanation
I_{adj}	The interfering power in a channel adjacent to the victim channel (in our case, VLP wanted emissions)
JRC	Joint Research Centre of the European Commission
LAN	Local Area Network
LPI	Low power indoor WAS/RLAN devices according to ECC Decision (20)01 [5]
MCL	Minimum Coupling Loss
MTBF	Mean Time Between Failures
MTTR	Mean Time To Repair
NG	Next Generation
OBU	Onboard unit of the CBTC system
OOB	Out-of-band. This is the frequency range immediately starting on the lower and upper channel border and expands to a frequency offset of 250% of the channel bandwidth.
OTA	Over the air
PR	Protection Ratio
QAM	Quadrature Amplitude Modulation
QPSK	Quadrature phase-shift keying
RF	Radio Frequency
RLAN	Radio Local Area Network
RMS	Root Mean Square. If used as a detector, it specifies the average power level in a certain measurement time.
RSSI	Received Signal Strength Indicator
Rx	Receiver
SINR	Signal to interference plus noise ratio
TCP/IP	Transmission Control Protocol/Internet Protocol
TDD	Time Division Duplex. Both uplink and downlink transmit/receive on the same frequency in different time slots. This feature results in bursted emissions.
TPC	Transmit Power Control
TU	Train Unit
Tx	Transmitter
UDP	User datagram protocol
UL	Uplink. This is the direction from the DUT to the “server” For the measured system, it is the direction from the onboard unit to the access point.
USB	Universal Series Bus
VLP	Very Low Power WAS/RLAN devices according to ECC Decision (20)01 [5]
WAS	Wireless Access Systems

1 INTRODUCTION

ECC Report 302 [1] and CEPT Report 75 [3] studied the coexistence between Wireless Access Systems including Radio Local Area Networks (WAS/RLAN) operating above 5945 MHz and Communication Based Train Control (CBTC) operating below 5935 MHz. ECC Decision (20)01 [5] harmonises the use of WAS/RLAN in the 5945-6425 MHz band, including Very Low Power (VLP) portable use, with maximum mean[4] 25 mW e.i.r.p., that may operate both indoor and outdoor.

ECC Decision (20)01 [5] as published in November 2020 mentioned that "It should be noted that the -45 dBm/MHz OOB limit below 5935 MHz for VLP would allow VLP initial market to take up. CEPT also agreed that this OOB limit should be valid in time only until 31 December 2024 and be re-examined with regard to an opportunity to relax it based on the real IEEE and DSSS Urban Rail interference situation. In absence of the justified evidence, a value of -37 dBm/MHz, for the OOB limit below 5935 MHz, will be adopted from 1 January 2025." ECC Decision is expected to be amended in due course.

This Report considers additional information including findings of measurement campaigns to finalise the ECC studies on VLP OOB emission requirements below 5935 MHz.

[4] The "mean e.i.r.p." refers to the e.i.r.p. during the transmission burst, which corresponds to the highest power, if power control is implemented.

2 METHODOLOGY AND FIELD MEASUREMENTS

2.1 INTRODUCTION AND CONTEXT

When developing the technical studies that led to the elaboration of ECC Report 290 [2] and ECC Report 302 [1], ECC Decision (20)01 [5] and ECC Decision (08)01 [6] and CEPT Report 75 [3], it appeared that the CBTC receiver performance was not standardised. At the time of writing of this Report, CBTC standardisation work was still ongoing within ETSI.

In the development of this Report, some of the CBTC parameters were measured providing better insights in the CBTC systems. The CBTC receiver performance in ECC Report 302 was based on theoretical values while measurements would give a better insight on the actual CBTC receiver performance and implementations.

The field measurements aim to qualify the CBTC receiver characteristics, link budget elements, VLP patterns and body loss, that would allow to re-calculate the appropriate VLP out-of-band (OOB) emission limits established previously in a theoretical manner.

Thus, some measurement campaigns provided new information:

- on coupling loss for different scenarios in the context of RER trains, between the assumed worst case VLP position and CBTC antennas;
- on coupling loss for different scenarios in the context of Parisian metros, between the CBTC antennas and the potential VLP positions in the front of the train where on board CBTC antennas are located;
- on laboratory characterisation of one CBTC receiver in the presence of interference in adjacent frequencies in terms of sensitivity and C/I_{adj} [5];
- on the radiation pattern of Very Low Power (VLP) WAS/RLAN devices;
- on body loss;
- on elements on OOB emissions of a specific VLP device;
- on the received wanted signal levels over two actual CBTC lines.

Additional information was provided on:

- minimum signal level at the antenna connector during the commercial service and modulation for a number of different CBTC lines;
- statistics on CBTC Access Point (AP) deployment on one line.

2.1.1 General model

CBTC systems incorporate several simultaneous radio links. Those redundancies exist to accommodate a challenging propagation environment and also to guarantee continued operation under degraded modes which happen regularly due to the large population of equipment (e.g. a CBTC radio equipment failure). Studies in this Report focus on single-link interference as measurements of impact at system level were not conducted: this was partly due to the difficulty to measure impact on very high availability systems (e.g. of the order of 5 min unavailability per year). Such single-link studies must be interpreted in the larger context of the overall CBTC system including CBTC network planning, equipment redundancy and the combined impact with respect to sharing and VLP OOB emission levels.

The main criterion for the design and deployment of a CBTC system is the availability of the complete line. CBTC systems implement redundancy to reach the required availability. Redundancy approach can vary between vendors, products and project requirements, but typically information is transmitted twice, once via the front and once via the back of the train. This redundancy compensates for any single component failure.

In case of failure of a component, the system may operate in degraded mode (see Figure 2 and Figure 3), during which any interfering effects may have a bigger impact on the availability of the line, since a lower number of redundant links is available under such circumstances.

[5] I_{adj} denotes the interfering power in a channel adjacent to the victim channel (in our case, VLP wanted emissions)

Considering redundant transmission via both ends of the train, the possibility that a single VLP device disturbs both transmissions can be excluded. Therefore, section 4, section 5 and section 6 consider the potential interference effect of VLP on a single transmission, whereas section 7 takes into account the impact at system level.

The probability of degraded mode events was estimated based on the MTBF (Mean Time Between Failures) specification of train unit (TU) and AP devices. As a typical example, MTBF values of 40000 h for TU and 50000 h for AP (project in Paris) are assumed in this Report. When considering the whole system, despite the high reliability of individual components, the amount of time the line is operated in degraded mode (system operating but not all radio links are nominal) may not be negligible. For example, a typical line with 50 trains and 30 km length with an AP distance of 400 m and a MTTR (Mean Time To Repair) per TU of 14 hours would result in the duration of operation in degraded mode of 24 h/month for TU failures and 29 h/month for AP failures. An appropriate selection of individual component MTBF and redundancy level enables an operator to achieve the overall reliability of the line. For example, some lines consider an overall maximum unavailability of 5 min per year.

In degraded mode, only one TU or one AP are connected at a time. Due to the short headway of trains, an emergency brake of a single train affects operation of the whole line. For instance, an emergency brake is automatically triggered if a train is not able to receive and successfully demodulate the movement authority message for a period of typically 2.5 s, including all retransmission capabilities of the CBTC system.

Two IEEE based CBTC variants are currently used and differ in the way redundancy and handover are managed:

- In the first variant, each train-end is equipped with two radios. Each radio is assigned a single radio channel. Two successive APs use two different frequencies. One train-end is therefore successively connected through either one of its two radios;
- In the second variant, each train-end is equipped with one single radio. Two successive APs use distinct radio channels, and train radio swaps channels accordingly. Doubled radios are used at each AP site, and both radios use the same radio channel, shared in time.

Figure 1, Figure 2 and Figure 3 describe one typical implementation of the CBTC radio design for the first IEEE based system variant.

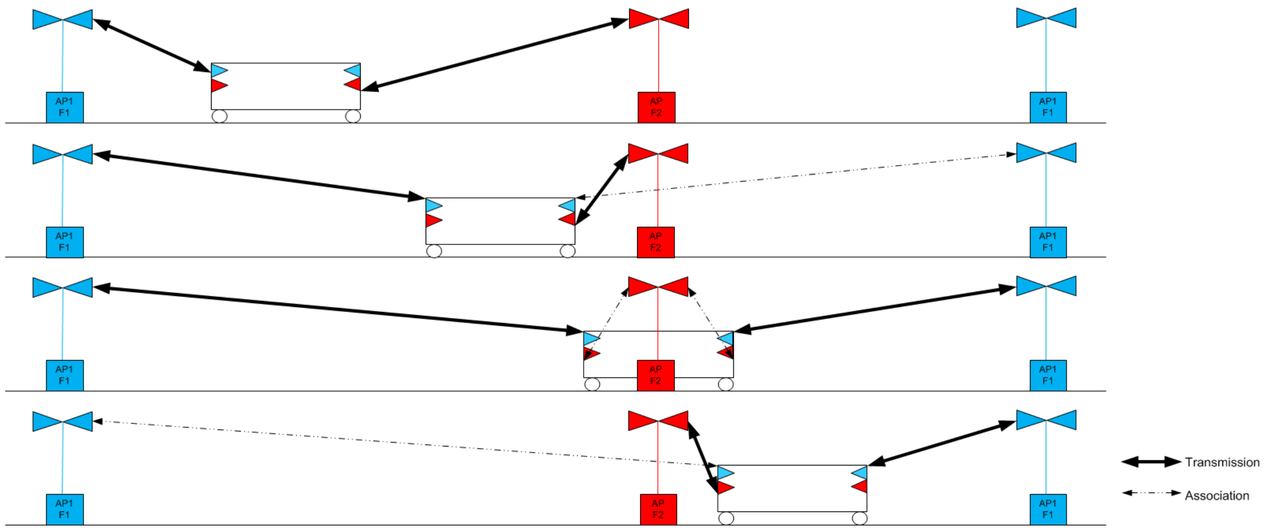

Figure 1: Nominal mode for IEEE radio CBTC

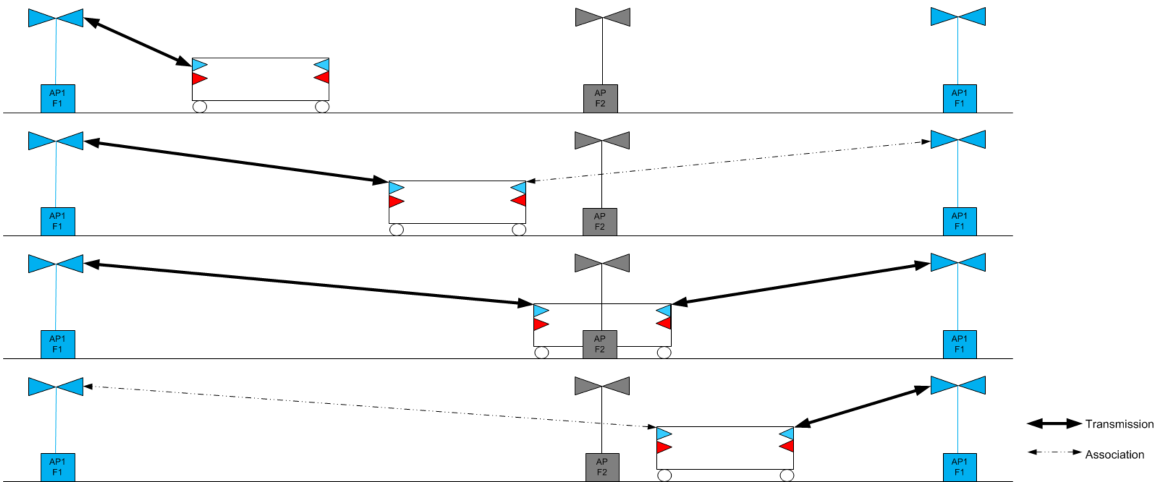

Figure 2: Degraded mode – AP failure

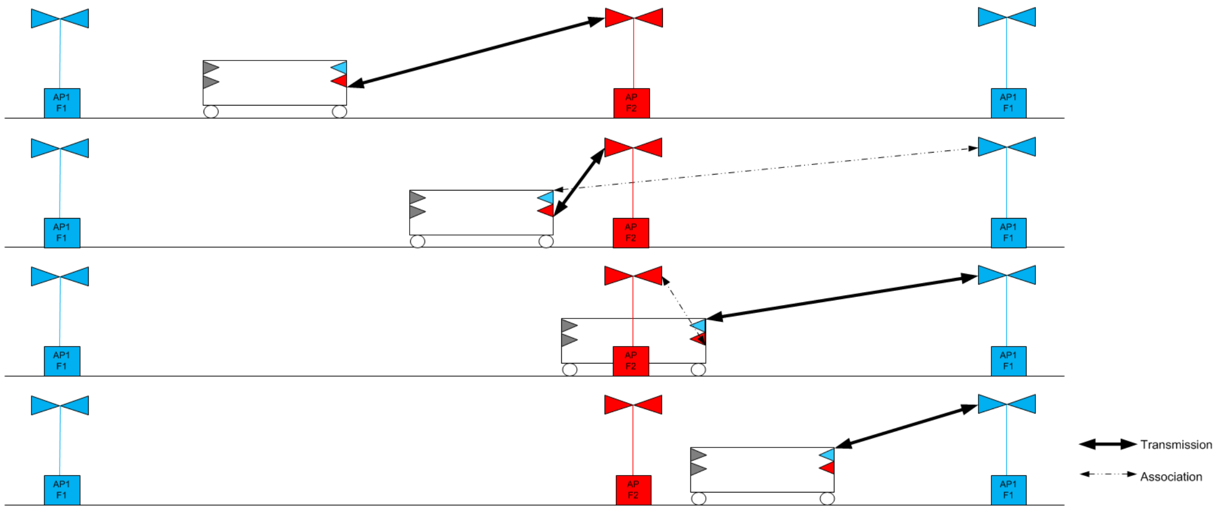

Figure 3: Degraded mode – TU failure

The risk of interference is typically reduced by implementation of specific measures, including diversity measures such as front/rear onboard equipment with four antennas, intelligent use of the frequency spectrum and a repetition of telegrams when indicated [9].

Onboard radio units establish multiple wireless connections to the access points along the track. Handover from one radio cell to the next (roaming) is seamless. To avoid signal data packet loss, the radio system uses a controlled roaming algorithm, with at most one roaming radio module at a time while the other active radio module stays tuned to the currently linked access points. The central system router managing communications is linked to the radio backbone network. The network is connected to the access points via parallel fibre-optic cables [9].

ETSI TR 103 442 [10] indicates: "It is common to combine 3 to 4 types of diversity. One type is generally kept for redundancy, e.g. a whole communication channel. The other types are devoted to improving availability: frequency diversity, polarisation diversity, MIMO, spatial diversity (head & end of train) and macro diversity using simultaneous connections to several successive AP's. The last one is very efficient in tunnels, when trains are masking each other at a moderate distance from the current AP. All types of diversities being combined […] the wireless coverage should be continuous".

When considering the potential interference caused by VLP OOB emissions to a CBTC receiver (TU or AP) for a single CBTC link, it is useful to address this complexity by considering separately the following three dimensions:

1 Interfering link (I): this models the link from the interfering VLP to the victim CBTC receiver. In previous studies, this interfering link was modelled with geometrical assumptions on where the VLP is located with respect to the CBTC receiver and on assessing representative physical parameters for the coupling loss between the two, based on antenna patterns, propagation, additional losses stemming from boxing and body loss, etc. Studies considered only one VLP interfering at a time, a simplification which can be justified in case of very low WAS/RLAN duty cycle and given the WAS/RLAN polite protocols to access the medium.

2 Wanted link (C): this models the link from the active CBTC transmitter to the victim CBTC receiver. In ECC Report 302 [1], the wanted link was not modelled and the analysis was conducted by focusing on receiver sensitivity and potential desensitisation, i.e. I/N approach. Statistics on CBTC deployment can also provide guidance on the minimum wanted link signal level in a typical CBTC deployment, therefore enabling a SINR or protection ratio analysis. However, generic propagation models do not always match the losses experienced in various tunnel environments. Additional protection ratio analyses are provided based on different CBTC wanted signal levels.

3 CBTC receiver behaviour in the presence of VLP interference: this models how the CBTC receiver demodulation will be impacted by the emission of the VLP WAS/RLAN device, including the OOB emissions. In previous studies, this was determined based on CBTC receiver typical characteristics (ACR, ACS, etc.) provided by manufacturers and assuming the VLP OOB is an additive white noise. However, the coexistence situation is also impacted by the real level and shape of the VLP unwanted emissions and by the real performance (selectivity, protection ratio) of the CBTC receiver.

2.1.2 Approach followed

Because of the practical difficulty of carrying out measurements addressing the three dimensions mentioned above simultaneously in a statistically representative way, the following was provided:

- field measurements of coupling loss, relevant for the interfering link;
- statistics of distance between two adjacent access points distinguishing tunnels and outdoor for one example of CBTC line;
- field measurements of the received wanted signal level, at the CBTC RF card antenna port, or minimum wanted signal level expected during the commercial service for various CBTC projects in Europe;
- laboratory measurements to determine the protection ratios between the CBTC signal in 5915-5935 MHz and the WAS/RLAN VLP signal in 5945-6425 MHz.

No measurement was performed on the overall resilience of the system to interference. This Report provides an analysis on interference to a single link, if any. No measurement was conducted to determine how such single link interference would potentially lead to service outage.

The single link interference analyses are then combined through statistical analyses to provide insight on the possible impact on service outage.

2.2 COEXISTENCE SCENARIOS

The following scenarios were investigated (please see Annex 1 for further details):

- Scenario 1: impact of a WAS/RLAN VLP operated on a platform to CBTC AP;
- Scenario 2: impact of a WAS/RLAN VLP operated on a platform to CBTC TU;
- Scenario 3: impact of a WAS/RLAN VLP operated onboard a train to CBTC TU;
- Scenario 4: impact of a WAS/RLAN VLP operated onboard a train to CBTC AP.

2.3 WANTED SIGNAL LEVEL

During the design phase of each CBTC project, a radio planning is done to define the location of each AP. The radio link budget for this planning includes margins for propagation assumptions, fading and possible conditions for shadowing, including masking effect by other trains. The radio planning results in the placement of APs with varying AP distances to accommodate specific track topologies, varying tunnel characteristics (e.g. single tube or double tubes) and other constraints.

2.3.1 Access points placement in stations

For a particular urban rail line implementation, the actual placement of CBTC AP in stations in relation to the platforms has been studied. For most stations studied, the AP is either outside the platforms or at their extremity, although there are cases where it can be located on the platform.

This suggests that out of the two scenarios on the platforms (Scenario 1 and Scenario 2), the most likely interference situation could arise from a WAS/RLAN VLP interfering with the TU (Scenario 2).

A WAS/RLAN VLP interfering with an AP on a platform is however a possibility in some stations, although a more typical situation for Scenario 1 would be an access point at the station extremity, for instance at a tunnel entrance.

2.3.2 Statistics on CBTC access points

For the characterisation of the CBTC wanted link, information on the placement of CBTC APs in a practical RF planning can help better anticipate real life situations to plan measurements or design realistic simulations.

Based on the geographical placement of the various APs in one example of urban rail line, it was found that distances up to 325 m can be observed between two APs in tunnels, whereas on outdoor locations along this line distances up to 519 m can be seen. The inter-site distance however varies significantly depending on field considerations (such as tunnel shapes, etc.).

Table 1: Statistics on adjacent APs along one line

Item (dimension)	Tunnels	Outdoor
Number of samples	65	56
Min. distance (km)	0.112	0.108
Max. distance (km)	0.325	0.519
Average distance (km)	0.250	0.274
90% centile (km)	0.313	0.433
95% centile (km)	0.318	0.498

Section 2.3.2.1 and section 2.3.2.2 provide the CBTC wanted signal level based on theoretical propagation models and the minimum signal level at the antenna connector on some existing CBTC lines respectively.

2.3.2.1 CBTC wanted signal level from theoretical channel models

The CBTC wanted signal level calculated from theoretical channel models is the basis for Study 1 in section 4.1, section 5.1 and section 6.1 (see Table 2). In a nominal scenario, the worst propagation situation is when the train is between (i.e. in the middle of) two Access Points (that is 160 m in tunnels and 250 m outdoors). However, CBTC networks are also designed so that operation can still be maintained in the case of a failure of one access points or train unit. In this degraded scenario, the worst propagation situation happens when the train is at the position of the failed CBTC AP (in which case the distance to then next AP is around 320 m in tunnels and 500 m outdoors).

Table 2: Derivation minimum CBTC signal level at CBTC TU in degraded mode

Parameter	Value		
Maximum e.i.r.p. (dBm/MHz)	23		
Maximum e.i.r.p. in 5930-5935 MHz (dBm)	30		
Channel	**Free-Space**	**Recommendation ITU-R P.1411 [4] Street Canyon**	**Tunnel Model I [8]**
Maximum distance (m)	500	500	320
Pathloss (dB)	101.9	102.7	106.4
Minimum Signal level at TU antenna (dBm)	-71.9	-72.7	-76.4
Minimum Signal at TU Receiver (dBm)	-63.9	-64.7	-68.4

2.3.2.2 *Minimum signal level during the commercial service*

The minimum signal level during the commercial service is the basis for Study 2 in section 4.2, section 5.2 and section 6.2 (see Table 3) shows examples of minimum signal level targets used for various European CBTC projects.

Table 3: Minimum signal level target at the RF port of the radio equipment during the commercial service

City/Line	Minimum Signal Level Target	Comments
Frankfurt Airport People Mover	-84 dBm	IEEE, 16 QAM FEC ½
Grand Paris	-87 dBm	IEEE, 16 QAM FEC ½
Paris Line 14	-84 dBm	IEEE, 16 QAM FEC ½
Paris NEXTEO Line E	-84 dBm	IEEE, 16 QAM FEC ½
Rennes B	-87.5 dBm	IEEE, 16 QAM FEC ½

Below this minimum signal level, a reliable CBTC transmission cannot be guaranteed anymore. Also, below this level a new connection cannot be reliably established anymore. On the other hand, above that level, a single link must work, and the radio planning must guarantee that this level is reached or exceeded. The compatibility studies should therefore be based on these minimum signal levels for the CBTC wanted signal level.

It must be noted that high order modulation such as 16 QAM rate ½ are commonly used, which requires a higher protection ratio than BPSK and even QPSK signals. The measurements based on QPSK ¾ modulation are the closest configuration used in the laboratory measurements performed for this Report.

When commissioning the line, received power levels of each CBTC radio are measured with the train moving along the track. A validation criterion for acceptance is that the measured power level shall reach a defined signal level all along the tracks. This target signal level is obtained from the sensitivity of the receivers combined with margins for e.g. Doppler effects, hardware tolerances (like cable loss, connectors, antenna gain) and masking.

Thereafter, the minimum signal level at the CBTC RF port of CBTC radio equipment (AP and TU) is defined as the minimum signal level expected during the commercial service, i.e. when the radio propagation conditions are realistically poor.

The following two series of figures (Figure 4 and Figure 5) show the received power levels at the CBTC RF port of one train unit, for two different examples of underground lines. In each series, the top plot corresponds to the RSSI (sampled in time) for the first RF channel (e.g. a “blue” receiver in Figure 1). The middle plot corresponds to the RSSI of the second RF channel (e.g. a “red” receiver in Figure 1). The bottom plot shows the RSSI actually experienced by the train unit (i.e. the RSSI of the serving radio): at any location it's given by either the blue or red curve, depending on the selection operated by the train unit, noting that the other radio also needs to be connected in anticipation of the next handover.

The first series show a situation where all APs are working (i.e. nominal mode). The second series shows a degraded mode where one AP out of 2 is down. Qualification of the system includes such a test, as this could happen in real life if one fibre connecting half of the APs is down (or in case of a higher layer backhaul network breakdown).

These curves have been gathered from on-site measurements in unobstructed tunnels. During commercial service, the received power would regularly be about 5 dB lower due to a masking train effect (typical value for large monotube tunnels). It is important to note that the masking penalty often impairs both links from the same TU as both signals are correlated since they are typically subject to the same masking train.

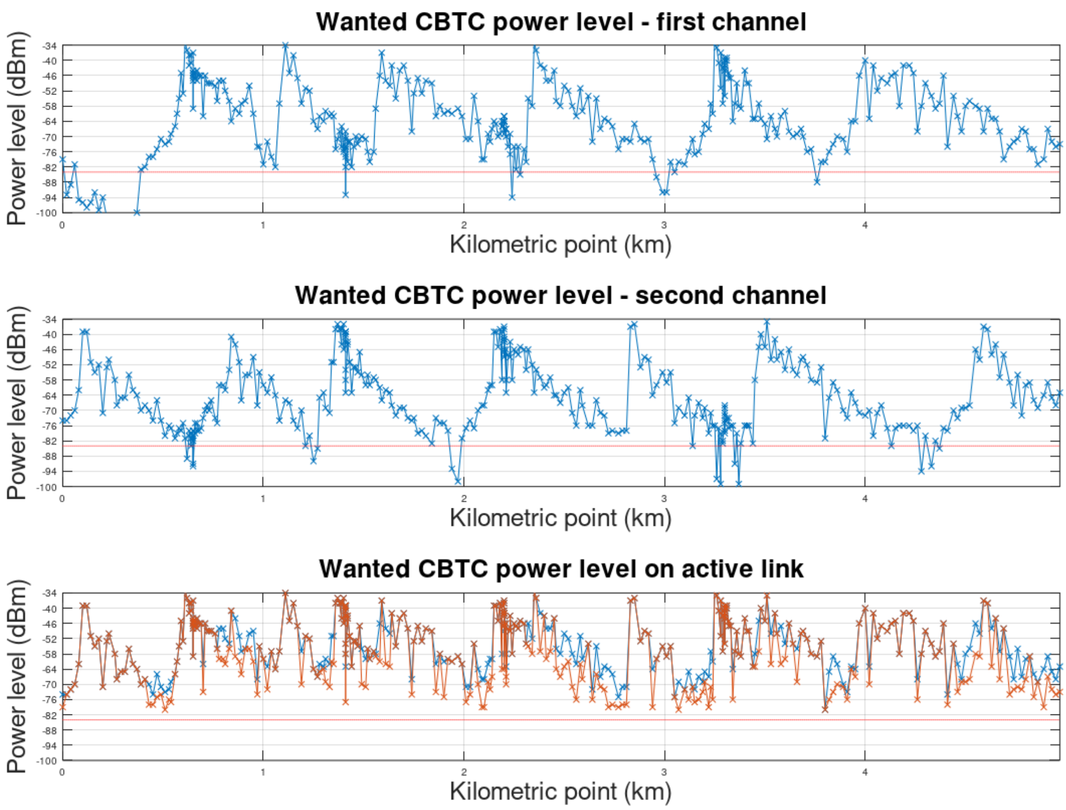

Figure 4: Wanted power level received by a train unit (TU, i.e. one train end) on Paris line 1. The horizontal red line corresponds to the minimum signal level target

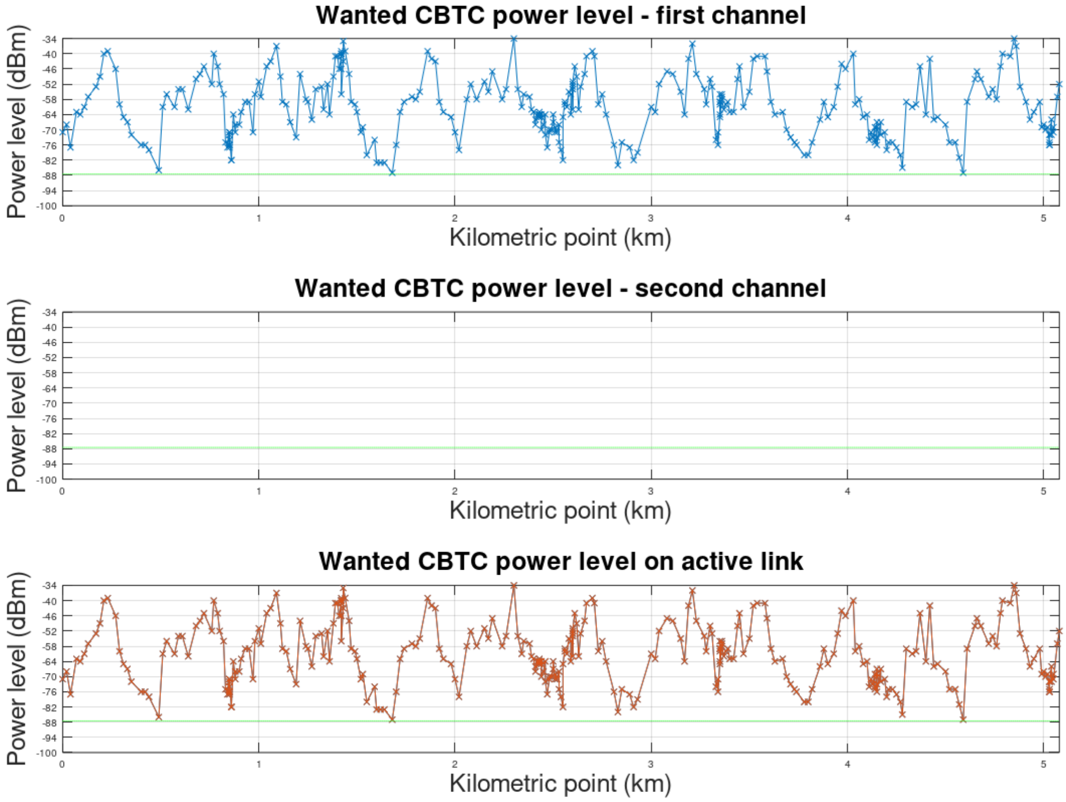

Figure 5: Wanted power level received by a train unit (TU, i.e. one train end) on Rennes B, emulating a degraded mode with down APs. The horizontal green line corresponds to the minimum signal level target

2.4 INTERFERING LINK

Characterisation of the interfering link has been achieved through coupling loss measurements performed on two different urban rail environments:

- Coupling loss measurements of a suburban train environment (the measurement campaign is described in Annex 2);
- Coupling loss measurements of a dense urban train environment (the measurement campaign is described in Annex 4).

2.4.1 Coupling loss definition

The Coupling Loss (CL) is defined as the difference between the power received at the antenna connector of the CBTC receiver equipment and the e.i.r.p. transmitted by a VLP. Minimum Coupling Loss (MCL) is the minimum CL that can occur in a realistic situation representing the worst case.

These measurements results do not include any non-deterministic losses such as body loss, reduction in gain of the VLP towards the CBTC relative to the max e.i.r.p. or any VLP power back off, but they include the CBTC receiver antenna gain towards the assumed VLP position.

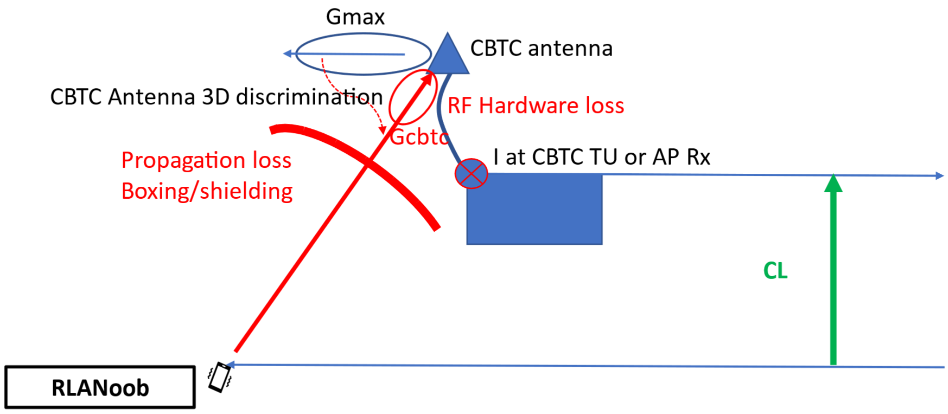

Figure 6: Relation between OOB emission limits, interference power and the Coupling Loss

For instance, knowing the maximum OOB emission limits and the MCL, it is possible to determine the interference power that could be received from the VLP by a CBTC receiver:

$$I\ (dB) = RLAN_{OoB} - MCL$$

Where:

- $RLAN_{OoB}$ stands for the VLP OOB e.i.r.p. level in the CBTC channel bandwidth, not accounting for any non-deterministic losses such as body loss, reduction in gain of the VLP towards the CBTC relative to the max e.i.r.p. or any VLP power back off.

2.4.2 MCL measurement results

The measurement results for the different scenarios and environments are summarised in the following tables (for more details see Annex 2, Annex 3 and Annex 4).

RER trains are urban rail trains of high capacity (e.g. 3000 passengers in a 220 m long double train with two decks). They service high traffic node stations in the metropolis and suburban stations in the surrounding area. RER trains are currently equipped with a driver's cabin physically isolated from the passenger's compartment even if part or all of driving is automated through CBTC.

Metro trains are also high capacity but smaller, lighter trains (e.g. 600 to 950 passengers in a single deck 90-120 m long train). They service a dense network of stations within the metropolis and close suburbs. In automatic metro lines, there is no driver’s cabin and passengers can seat or stand up very close to the front and rear windscreen extremities of the train.

Platform 1 is RER outdoor platform located in Gagny, France. Platform 2 is a metro indoor platform on the Paris line 1.

Table 4: Scenario 1 - VLP on platform interfering with CBTC AP

Environment	Minimum coupling loss (dB)
Platform 1: Suburban environment, open air	78 (Note 1)
Platform 2: Tunnel, Urban metro line	< 74.6 $\pm$ 5
Note1: This value may not be representative of the MCL, as the measurement area was limited at 10 m from the AP and consequently the measurement point was outside of AP main lobe. ECC Report 302 indicated theoretical MCL value of 68.9 dB.	

Table 5: Scenario 2 - VLP on platform interfering with CBTC TU

Environment	Minimum coupling loss (dB)
RER train	56.3 ± 2 (Note 1)
Note 1: The measurement was not repeated in the underground environment.	

Table 6: Scenario 3 - VLP onboard interfering with CBTC TU

Environment	Measured MCL (dB)	Measured CL with estimated correction of the measurement antenna gain (dB)
RER train	92.0 ± 5 (Note 2)	71.3 ± 5 (Note 1) 92.0 ± 5 (Note 2)
Urban metro type MP14 - Metro 1	44.2 ± 5	47.2 ± 5 (Note 3)
Urban metro type MP89 - Metro 2	50.1 ± 5	48.1 ± 5 (Note 3)
Urban metro type MP05 - Metro 3	54.2 ± 5	51.0 ± 5 (Note 3)
Note 1: VLP in driver's cabin Note 2: VLP in passenger deck Note 3: Measurement performed at antenna height 137 cm		

Table 7: Scenario 4 - VLP onboard interfering with CBTC AP

Environment	Minimum coupling loss (dB)
Tunnel, Urban metro type MP14 - Metro 1	59 ± 5
Tunnel, Urban metro type MP05 - Metro 3	62

From these measurements, it can be concluded that the critical scenario for RER train is Scenario 2 (VLP on platform vs CBTC TU), while the critical scenario for Metro 1, 2 and 3 is Scenario 3 (VLP onboard vs CBTC TU).

3 CBTC AND VLP DEVICE CHARACTERISTICS

3.1 CBTC CHARACTERISTICS

When developing the technical studies that led to the elaboration of ECC Report 290 and ECC Report 302 [1], ECC Decision (20)01 [5], ECC Decision (08)01 and CEPT Report 75 [3], it appeared that the CBTC receiver performance was not standardised. At the time of writing of this Report, CBTC standardisation work was still not finalised and ongoing within ETSI.

3.1.1 CBTC receivers

This section provides assumptions for CBTC receiver characteristics used in the studies.

The studies of ECC Report 290 [2] and ECC Report 302 use values taken from the IEEE specification for the CBTC systems using this technology. The specific receiver measured by BNetzA (see Annex 5) exhibit better performance, i.e. lower sensitivity and lower protection ratio. As can be expected, some of the CBTC equipment currently used in the field have different characteristics compared to the CBTC characteristics assumed in ECC Report 302 and ECC Report 290.

ECC Decision (08)01 [6] harmonises the use of Safety-Related Intelligent Transport Systems (ITS) in the 5875-5935 MHz frequency band, and considering z) states that Urban Rail ITS receivers should be robust against WAS/RLAN emissions in 5945-6425 MHz.

Table 8: CBTC characteristics for studies in this Report

Study	Parameter	Value	Reference
Study 1	Modulation	BPSK ½	ETSI TR 103 580, section B.5.2 [7]
	Noise floor	-94 dBm / 5 MHz	ECC Report 302 [1]
	SINR threshold BPSK ½	4 dB	IEEE 802.11-2020
	CBTC Protection Ratio (C/I_{adj})	-33 dB	BPSK ½ CBTC at 5930MHz, 40MHz RLAN with -37 dBm/MHz OOB emissions (see Annex 5)
Study 2	Modulation	QPSK ¾	Deployment in existing lines
	Noise floor	-101 dBm / 5 MHz	Noise Floor calculated using sensitivity and protection ratio measurements provided in Annex 5
	SINR threshold QPSK ¾	9 dB	IEEE 802.11-2020
	CBTC Protection Ratio (C/I_{adj})	For VLP OOB emissions at -37 dBm/MHz: -28 dB for CBTC at 5930 MHz or -33 dB for CBTC at 5920 MHz For VLP OOB emissions at -45 dBm/MHz: -35 dB for CBTC at 5930 MHz or -38 dB for CBTC at 5920 MHz	QPSK ¾ CBTC, 40 MHz WAS/RLAN (see Annex 5)

3.1.2 Laboratory measurements of CBTC vs RLAN protection ratio

Several WAS/RLAN signals were used to determine the dependency of the C/I_{adj}[6] on the following parameters (see Annex 5).

- Overload or saturation effects and threshold of the CBTC receiver;
- Dependency on the WAS/RLAN bandwidth;
- Dependency on the out-of-band level of the WAS/RLAN VLP signals;
- Dependency on the WAS/RLAN channel occupancy;
- Dependency on the WAS/RLAN timing (burst/pause length).

A real CBTC onboard receiver unit was available for the measurements. The results may be applicable to CBTC access points also, because their RF design is expected to be identical to the onboard units. The CBTC system was configured for a bandwidth of 10 MHz and tested on 5920 and 5930 MHz at data rates of 3 and 9 Mbit/s. It should be noted that the deployed CBTC analysed in this Report uses a bandwidth of 5 MHz.

The interfering WAS/RLAN VLP signals were always on the lowest usable channel in the band above 5945 MHz.

In summary, the main results are as follows:

- The sensitivity of the CBTC receiver was between -94 and -91 dBm, depending on the data rate;
- The required C/I_{adj} for CBTC operation on 5930 MHz is around -35 dB, and for CBTC operation on 5920 MHz around -33 dB;
- The tested CBTC receiver showed a high dependency of the required C/I_{adj} on wanted signal level. Higher wanted signal levels result in higher C/I_{adj} values. This may indicate the implementation of some sort of automatic gain control at a very early RF stage, levelling down the signal as a reaction of even short interference peaks;
- The dependency of the C/I_{adj} on different channel occupancies of the interfering WAS/RLAN VLP signal is surprisingly low. A WAS/RLAN signal with 1% channel occupancy typically requires only about 4 to 6 dB less C/I_{adj} than a fully loaded interferer with nearly 100% channel occupancy;
- The dependency on different out-of-band levels from WAS/RLAN VLP emissions is noticeable, especially at low wanted signal levels and at CBTC frequency 5930 MHz. The less stringent OOB requirement for future VLP devices results in 6 to 7 dB more protection requirement.
- In absence of out of band emissions, the measured C/I_{adj} values are low, significantly below the measured C/I_{adj} in presence of out of band emissions: there is no compatibility issue when the WAS/RLAN OOB emissions are suppressed.

It should be noted that the results presented here are only based on measurement of one specific, although typical, CBTC receiver.

3.2 VLP CHARACTERISTICS

3.2.1 Out-of-band emission limits

Two values of maximum OOB emission levels are considered in this Report, i.e. -37 dBm/MHz and -45 dBm/MHz.

As such, the OOB emission level in 5930-5935 MHz cannot exceed respectively -30 and -38 dBm/5MHz for respectively -37 and -45 dBm/MHz.

In practice, the OOB emission limit corresponds to emission peaks. The VLP OOB emissions are tested in peak/max-hold, meaning that the actual OOB emissions must remain below this level in time and within each MHz. The maximum OOB emission level is unlikely to be reached over 5 MHz simultaneously.

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[6] I_{adj} denotes the interfering power in a channel adjacent to the victim channel (in our case, VLP wanted emissions)

Furthermore, VLP devices leverage antenna with non-uniform gain. The OOB emission limit is fulfilled in the direction of maximum gain, but will be much lower in other directions.

3.2.2 Body loss

Measurements in Annex 6 indicate that 6 GHz proximity/body loss for laptops/tablets can be estimated as 5.5 dB in average.

Similarly, external regulatory bodies[7] indicate that "a mean attenuation of 4 dB for body and/or clutter loss" which "would follow a gaussian distribution is appropriate".

The studies in Annex 6 were not conducted specifically for the use cases considered in this Report and therefore do not always perfectly match: for instance, in these studies measurements were conducted including for laptops on desks, while VLP are portable devices and train stations are not areas where people would typically sit to work with their VLP device on a table. It is rather anticipated that smartphone, smart glasses, headphones, and other wearables devices would be predominant in the metro environment and have not been measured. The body loss experienced in reality is also expected to vary depending on the respective locations of the WAS/RLAN VLP antenna and the CBTC antenna.

A single value however allows initial assessment of interference cases. The studies in this Report considering a single average value for body loss assume either a 5.5 dB (Study 1) or 0 dB (Study 2) body loss. Sensitivity and probability analysis consider the distribution of body loss, not just a single average value (see section 3.2.4).

3.2.3 Power control

VLP devices may implement power control to save battery, leading to a further reduction of the OOB emissions while power control is active.

The FCC requests Transmit Power Control (TPC) which shall be able to reduce the total power from its maximum -5 dBm/MHz down to at least -11 dBm/MHz. In doing so, the FCC expects a mean power reduction of 3 dB[8]. In CEPT, the current maximum power density allowed for VLP operating in channels of 20 MHz or above is 1 dBm/MHz [5].

3.2.4 Probability considerations for radiation pattern and body loss

This section discusses the additional attenuation purely due to body loss (BL) and radiation pattern and does not take into account power control, which would reduce the OOB emissions further and is taken into account separately.

The probabilistic studies in section 7.1 take into account the radiation pattern of VLP devices and body loss, adopting the e.i.r.p. distribution of VLP devices, with the limitations described in section 3.2.2, as defined in Table 9.

Table 9: Estimated distribution of OOB emissions taking into account radiation pattern and body loss

% VLP	e.i.r.p. with BL (dBm)	Estimated OOB emission (dBm/MHz)
61.78	0	-51 dBm/MHz
37.53	11	-40 dBm/MHz
0.69	14	-37 dBm/MHz

[7] see https://docs.fcc.gov/public/attachments/FCC-23-86A1.pdf, paragraph 40 page 24

[8] idem, paragraph 56 page 34

As indicated in Table 9, a small fraction of VLP devices would transmit at the OOB emission limit, while the vast majority would transmit at much lower level. This distribution is derived by considering the measurement in Annex 6 for all devices, including laptops on tables, tablet handheld by a human, and all directions around the user.

The probabilistic studies in section 7.2 and section 7.3 consider the body and antenna pattern loss distribution to assess the probability of interference according to the distribution in Table 10. This distribution is derived by considering the measurement from Annex 6 for the tablet handheld by a human. It is then modified to cover a scenario where the body of the user tends not to be between the CBTC antenna and the active VLP device. In the absence of spatial distribution data, an assumption was made that only the 50% lowest combined body and antenna loss of the CDF may represent the half space directed to the antenna without body obstruction and were used to derive the distribution below. This also assumes that the device will always be held in the same orientation with line of sight towards the victim receiver. This modified distribution is not intended for use outside this Report.

Table 10: Distribution for VLP combined antenna gain/body loss effect

Percentage of occurrence	Body loss + antenna pattern loss
10%	0 dB
10%	3.5 dB
20%	5 dB
20%	6.5 dB
20%	8 dB
20%	9.5 dB

4 I/N ANALYSIS

The analysis in this section considers the impact of a VLP device interference on the CBTC receiver sensitivity, i.e. an I/N analysis (as per ECC Report 302), based on the MCL measured for the different scenarios and trains.

4.1 STUDY 1

Study 1 considers:

- Body loss of 5.5 dB;
- CBTC noise floor of -94 dBm/5 MHz (from ECC Report 302 [1]);
- Coupling loss measurement, using the direct measurement data (see section A4.2);
- VLP OOB emission level of -37 dBm/MHz.

4.1.1 Scenario 1: VLP on platform - CBTC AP

Table 11: VLP on platform - CBTC AP

Scenario 1	Platform 1	Platform 2
VLP OOB emission (dBm/MHz)	-37	-37
VLP Interference emitted in 5930−5935 MHz (dBm) (Note 1)	-30	-30
Body Loss (dB)	5.5	5.5
Measured coupling loss (dB)	78 (Note 2)	74.6
Interference at CBTC AP receiver (dBm) (Note 1)	-113.5	-110.1
Noise at CBTC AP receiver (dBm) (Note 1)	-94	-94
Noise + Interference at CBTC receiver (dBm) (Note 1)	-93.9	-93.9
Desensitisation (dB)	0.1	0.1

Note 1: The power levels are expressed in dBm within the 5 MHz bandwidth of the CBTC receiver.
Note 2: The measured coupling loss may not represent the minimum coupling loss. While this value was the minimum value measured during the campaign, it was identified during the campaign that the participants probably did not manage to measure the minimum coupling loss.

A VLP device on the platform is unlikely to interfere a CBTC AP.

4.1.2 Scenario 2: VLP on platform - CBTC TU

Table 12: VLP on platform - CBTC TU

Scenario 2	RER train
VLP OOB emission (dBm/MHz)	-37
VLP interference emitted in 5930−5935 MHz (dBm) (Note 1)	-30
Body loss (dB)	5.5
Measured coupling loss (dB)	56.3
Interference at CBTC AP receiver (dBm) (Note 1)	-91.8
Noise at CBTC AP receiver (dBm) (Note 1)	-94

Scenario 2	RER train
Noise + Interference at CBTC receiver (dBm) (Note 1)	-89.7
Desensitisation (dB)	4.2
Note 1: The power levels are expressed in dBm within the 5 MHz bandwidth of the CBTC receiver.	

A VLP on the platform may desensitise one of the antennas of a CBTC TU by less than 5 dB. However, such desensitisation would be limited to the exact point in time and space where the coupling loss between the VLP and the CBTC TU is minimal.

4.1.3 Scenario 3: VLP onboard - CBTC TU

Table 13: VLP onboard - CBTC TU

Scenario 3	RER train	Metro MP14	Metro MP89	Metro MP05
VLP OOB emission (dBm/MHz)	-37	-37	-37	-37
VLP interference emitted in 5930−5935 MHz (dBm) (Note 1)	-30	-30	-30	-30
Body loss (dB)	5.5	5.5	5.5	5.5
Measured coupling loss (dB) (Note 2)	92	44.2	50.1	54.2
Interference at CBTC AP receiver (dBm) (Note 1)	-127.5	-79.7	-85.6	-89.7
Noise at CBTC AP receiver (dBm) (Note 1)	-94	-94	-94	-94
Noise + Interference at CBTC receiver (dBm) (Note 1)	-94	-79.5	-85	-88.3
Desensitisation (dB)	0	14.5	9.0	5.7
Note 1: The power levels are expressed in dBm within the 5 MHz bandwidth of the CBTC receiver. Note 2: This measured coupling loss does not assume that the signal comes from a single direction and therefore does not include post processing of antenna gain measurements, assuming the measurement antenna pattern is flat. This value was the minimum value measured during the campaign.				

The result range for metros MP14, MP89 and MP05 suggests that some metros are more susceptible to interference than others. Results suggest that some trains with low coupling loss could be susceptible to emission levels as low as -52 dBm/MHz.

4.1.4 Scenario 4: VLP onboard - CBTC AP

Table 14: VLP onboard - CBTC AP

Scenario 4	Metro MP14	Metro MP05
VLP OOB emission (dBm/MHz)	-37	-37
VLP interference emitted in 5930-5935 MHz (dBm) (Note 1)	-30	-30
Body loss (dB)	5.5	5.5
Measured coupling loss (dB)	59	62
Interference at CBTC AP receiver (dBm) (Note 1)	-94.5	-97.5

Scenario 4	Metro MP14	Metro MP05
Noise at CBTC AP receiver (dBm) (Note 1)	-94	-94
Noise + interference at CBTC receiver (dBm) (Note 1)	-91.2	-92.4
Desensitisation (dB)	2.8	1.6
Note 1: The power levels are expressed in dBm within the 5 MHz bandwidth of the CBTC receiver.		

A VLP device on the train is unlikely to interfere a CBTC AP.

4.1.5 Conclusion of I/N Study 1

The study takes into account body loss and some of the CBTC characteristics considered in ECC Report 290 [2] and ECC Report 302 [1]. The study does not take into account VLP radiation patterns and power control, which would further reduce the OOB emissions from VLP devices.

Based on the coupling loss measurements available, it can be concluded that:

- VLP on a platform is unlikely to interfere a CBTC AP;
- VLP on the train is unlikely to interfere a CBTC AP;
- VLP on a platform may desensitize one antenna of a CBTC TU by less than 5 dB. However, this would only occur if the VLP transmits at full power, with maximum e.i.r.p. in the direction of the CBTC TU antenna, at the moment the coupling loss between the CBTC TU antenna and the VLP device is minimum. Such situation is not only rare but also transient in nature as the train is moving;
- Contrary to the RER train measured, the VLP onboard metros MP14, MP89 and MP05 may desensitise one antenna of a CBTC TU. The result range for metros MP14, MP89 and MP05 suggests that some metros are more susceptible to interference than others. Results suggest that some trains with low coupling loss could be susceptible to emission levels as low as -52 dBm/MHz.

4.2 STUDY 2

Study 2 considers:

- Body loss of 0 dB;
- CBTC noise floor calculated using sensitivity and protection ratio laboratory measurements provided in Annex 5;
- Coupling loss measurement, with post processing of antenna gain measurements (see section A4.2);
- VLP OOBE levels of -37 dBm/MHz and -45 dBm/MHz.

4.2.1 Scenario 1: VLP on platform - CBTC AP

Table 15: VLP on platform - CBTC AP

Scenario 1	Platform 1	Platform 2	Platform 1	Platform 2
VLP OOB emission (dBm/MHz)	-37	-37	-45	-45
VLP interference emitted in 5930−5935 MHz(dBm) (Note 1)	-30	-30	-38	-38
Body loss (dB)	0	0	0	0
Measured coupling loss (dB)	78 (Note 2)	74.6	78 (Note 2)	74.6

Scenario 1	Platform 1	Platform 2	Platform 1	Platform 2
Interference at CBTC AP receiver (dBm) (Note 1)	-108	-104.6	-116	-112.6
Noise at CBTC AP receiver (dBm) (Note 1)	-101	-101	-101	-101
Noise + interference at CBTC receiver (dBm) (Note 1)	-100.2	-99.4	-100.9	-100.7
Desensitisation (dB)	0.8	1.6	0.1	0.3

Note 1: The power levels are expressed in dBm within the 5 MHz bandwidth of the CBTC receiver.
Note 2: The measured coupling loss may not represent the minimum coupling loss. While this value was the minimum value measured during the campaign, it was identified during the campaign that the participants probably did not manage to measure the minimum coupling loss.

For the scenario of a CBTC AP interfered by a VLP on a platform, it can be concluded that the risk of interference is low (noting that the cases of specific deployments like APs close to the platform ends are not covered in this analysis).

4.2.2 Scenario 2: VLP on platform - CBTC TU

Table 16: VLP on platform - CBTC TU

Scenario 2	RER train	RER train
VLP OOB emissions (dBm/MHz)	-37	-45
VLP interference emitted in 5930-5935 MHz (dBm) (Note 1)	-30	-38
Body loss (dB)	0	0
Measured coupling loss (dB)	56.3	56.3
Interference at CBTC TU receiver (dBm) (Note 1)	-86.3	-94.3
Noise at CBTC TU receiver (dBm) (Note 1)	-101	-101
Noise + interference at CBTC receiver (dBm) (Note 1)	-86.1	-93.5
Desensitisation (dB)	14.8	7.5

Note 1: The power levels are expressed in dBm within the 5 MHz bandwidth of the CBTC receiver.

For Scenario 2, the desensitisation is significant. This scenario is therefore studied further in this Report.

4.2.3 Scenario 3: VLP onboard - CBTC TU

Table 17: VLP onboard - CBTC TU, -37 dBm/MHz case

Scenario 3	RER train	Metro MP14	Metro MP89	Metro MP05
VLP OOB emissions (dBm/MHz)	-37	-37	-37	-37
VLP interference emitted in 5930−5935 MHz (dBm)(Note 1)	-30	-30	-30	-30
Body loss (dB)	0	0	0	0
Measured coupling loss (dB) (Note 2)	92	47.2	48.5	49

Scenario 3	RER train	Metro MP14	Metro MP89	Metro MP05
Interference at CBTC TU receiver (dBm) (Note 1)	-122	-77.2	-78.5	-79
Noise at CBTC AP receiver (dBm) (Note 1)	-101	-101	-101	-101
Noise + interference at CBTC receiver (dBm) (Note 1)	-101.0	-77.2	-78.5	-79
Desensitisation (dB)	0	23.8	22.5	22.0
Note 1: The power levels are expressed in dBm within the 5 MHz bandwidth of the CBTC receiver. Note 2: This coupling loss includes post processing of antenna gain measurements, assuming that the signal comes mainly from a single direction.				

Table 18: VLP onboard - CBTC TU, -45 dBm/MHz case

Scenario 3	RER train	Metro MP14	Metro MP89	Metro MP05
VLP OOB emission (dBm/MHz)	-45	-45	-45	-45
VLP Interference emitted in 5930−5935 MHz (dBm) (Note 1)	-38	-38	-38	-38
Body Loss (dB)	0	0	0	0
Measured coupling loss (dB) (Note 2)	92	47.2	48.5	49
Interference at CBTC TU receiver (dBm) (Note 1)	-130	-85.2	-86.5	-87
Noise at CBTC AP receiver (dBm) (Note 1)	-101	-101	-101	-101
Noise + Interference at CBTC receiver (dBm) (Note 1)	-101.0	-85.1	-86.3	-86.8
Desensitisation (dB)	0	15.9	14.6	14.2
Note 1: The power levels are expressed in dBm within the 5 MHz bandwidth of the CBTC receiver. Note 2: This coupling loss includes post processing of antenna gain measurements, assuming that the signal comes mainly from a single direction.				

For Scenario 3, the desensitisation is significant for the metro trains MP14, MP89 and MP05. This scenario is therefore studied further in this Report.

4.2.4 Scenario 4: VLP onboard - CBTC AP

Table 19: VLP onboard - CBTC AP

Scenario 4	Metro MP14	Metro MP05	Metro MP14	Metro MP05
VLP OOB emissions (dBm/MHz)	-37	-37	-45	-45
VLP interference emitted in 5930−5935 MHz (dBm) (Note 1)	-30	-30	-38	-38
Body loss (dB)	0	0	0	0
Measured coupling loss (dB)	59	62	59	62
Interference at CBTC AP receiver (dBm) (Note 1)	-89	-92	-97	-100
Noise at CBTC AP receiver (dBm) (Note 1)	-101	-101	-101	-101

Scenario 4	Metro MP14	Metro MP05	Metro MP14	Metro MP05
Noise + interference at CBTC receiver (dBm) (Note 1)	-88.7	-91.5	-95.5	-97.5
Desensitisation (dB)	12.3	9.5	5.4	3.5
Note 1: The power levels are expressed in dBm within the 5 MHz bandwidth of the CBTC receiver.				

For Scenario 4, the desensitisation is significant. This scenario is therefore studied further in this Report.

4.2.5 Conclusion for I/N Study 2

Under the assumptions of the I/N Study 2, reflected in Table 15 - Table 19, the following can be concluded:

- VLP on a platform is unlikely to interfere a CBTC AP;
- For Scenario 2, the desensitisation is significant. Results suggest that receivers could be susceptible to emission levels as low as -52 dBm/MHz;
- For Scenario 3, the desensitisation is significant for the metro trains MP14, MP89 and MP05 Results suggest that receivers could be susceptible to emission levels as low as -60.9 dBm/MHz;
- For Scenario 4, the desensitisation is significant. Results suggest that receivers could be susceptible to emission levels as low as -50.4 dBm/MHz;
- These I/N results therefore called for additional analyses (see section 5 and section 6).

5 SINR ANALYSIS (VLP OOB EMISSIONS ONLY)

5.1 STUDY 1

Study 1 considers:

- Body loss of 5.5 dB;
- VLP OOBE level of -37 dBm/MHz
- CBTC signal level of -77 dBm (AP) and -76 dBm (TU) in line with ECC Report 290 with system margins (both within the 5 MHz bandwidth and at the AP/TU RF port);
- Coupling loss measurement, using the direct measurement data (see section A4.2);

While the study does not specify the SINR threshold, the conclusions of the study consider the SINR threshold of 4 dB corresponding to "Preferred data rate" from ETSI TR 103 580 [7], i.e. BPSK 1.5 Mbps.

Since Scenarios 1 and 4 of Study 1 (section 4.1) did not lead to significant desensitisation, the SINR analysis focuses on Scenarios 2 and 3.

5.1.1 Scenario 2: VLP on platform - CBTC TU

Table 20 compares the noise and interference at the CBTC TU receiver (see Table 12) with the minimum signal level at the CBTC TU receiver.

Table 20: VLP on platform - CBTC TU

Scenario 2	RER train
Noise + Interference at CBTC receiver (dBm) (Note 1)	-89.7
Minimum signal level (dBm)	-76
Minimum SINR (dB)	13.7
Note 1: The power levels are expressed in dBm within the 5 MHz bandwidth of the CBTC receiver.	

The SINR remains above 13.7 dB for Scenario 2, i.e. significantly above the 4 dB minimum SINR.

5.1.2 Scenario 3: VLP onboard - CBTC TU

Table 21 compares the noise and interference at the CBTC TU receiver (see Table 13) with the minimum signal level at the CBTC TU receiver.

Table 21: VLP onboard - CBTC TU

Scenario 3	RER train	Metro MP14	Metro MP89	Metro MP05
Noise + Interference at CBTC receiver (dBm) (Note 1)	-94	-79.5	-85	-88.3
Minimum signal level (dBm)	-76	-76	-76	-76
Minimum SINR (dB)	18	3.5	9	12.3
Note 1: The power levels are expressed in dBm within the 5 MHz bandwidth of the CBTC receiver.				

The SINR analysis confirms that RER train, metros MP89 and MP05 would not suffer interference, even under worst-case conditions, due to the higher signal level.

In the specific location where the signal level is at its minimum (-76 dBm), the SINR for metro MP14 would fall to 3.5 dB, under the worst-case condition where the VLP device transmits at maximum e.i.r.p. exactly in the direction of the CBTC TU antenna, and the CBTC TU is using a single antenna. While the SINR falls slightly below the 4 dB SINR threshold, the analysis is conducted under a number of worst-case assumptions (VLP maximum e.i.r.p., CBTC signal at minimum level, VLP signal fully colliding with CBTC signal) making this situation unlikely. This likelihood is further studied in Section 7.1.

5.1.3 Conclusion of SINR Study 1

When considering the CBTC signal level of -76 dBm at the CBTC TU as per ECC Report 290 (with system margin), the SINR under Scenario 2 (VLP on the platform to CBTC TU) remains well above the 4 dB SINR threshold, even under worst-case assumptions.

For Scenario 3 (VLP in the train interfering CBTC TU), the RER train, metro MP89 and metro MP05 maintain an SINR above the 4 dB SINR threshold. While the SINR for metro MP14 can fall to 3.5 dB, due its lower coupling loss compared to other trains, it is important to consider that such situation only occurs under the following conditions:

- The VLP device is transmitting at full power, with maximum e.i.r.p. in the exact direction of the TU receiver antenna;
- The CBTC system is operating in degraded mode, i.e. a CBTC AP is not operating;
- The CBTC signal propagation is experiencing a 15 dB fading compared to its usual value;
- The study considered CBTC TUs that do not use antenna diversity;
- The interference has an effect on the overall CBTC system, suggesting that the train is stopped in front of the platform, exactly in the signal minimum location, with the VLP continuing to transmit at maximum power exactly in the direction of the CBTC antenna. Should the train be moving, the interference would be transient and not affect the overall system.

Overall, the SINR analysis demonstrates that VLP with OOB emissions at -37 dBm/MHz are extremely unlikely to create interference to CBTC, under realistic scenarios. It must be noted that CBTC train design can play a significant role in maintaining SINR above the threshold, irrespective of the type of train considered.

5.2 STUDY 2

Study 2 considers:

- Body loss of 0 dB;
- VLP OOBE levels of -37 dBm/MHz and -45 dBm/MHz;
- CBTC signal level of -87 dBm within the 5 MHz bandwidth at the AP/TU RF port (the minimum signal level used for various European CBTC lines);
- Coupling loss measurement, with post processing of antenna gain measurements (see section A4.2);
- QPSK ¾ modulation;
- CBTC Noise Floor calculated using sensitivity and protection ratio laboratory measurements provided in Annex 5.

5.2.1 Scenario 1: VLP on platform - CBTC AP

Table 22: MCL study for VLP on a platform - CBTC AP, -37 dBm/MHz

Parameter	Platform 1	Platform 2
Measured coupling loss (dB)	78 (Note 1)	74.6
OOB $eirp_{RLAN}$ (dBm/MHz)	-37	-37
OOB $eirp_{RLAN}$ (dBm) (Note 2)	-30	-30

Parameter	Platform 1	Platform 2
C (dBm) (Note 2)	-87	-87
Noise at CBTC TU receiver (dBm) (Note 2)	-101	-101
SINR (dB)	13.2	12.4
Note 1: The measured coupling loss may not represent the minimum coupling loss. While this value was the minimum value measured during the campaign, it was identified during the campaign that the participants probably did not manage to measure the minimum coupling loss. Note 2: The power levels are expressed in dBm within the 5 MHz bandwidth of the CBTC receiver.		

The SINR remains significantly above the 9 dB minimum SINR for QPSK ¾.

Table 23: MCL study for VLP on platform - CBTC AP, -45 dBm/MHz case

Parameter	Platform 1	Platform 2
Measured coupling loss (dB)	78 (Note 1)	74.6
OOB $eirp_{RLAN}$ (dBm/MHz)	-45	-45
OOB $eirp_{RLAN}$ (dBm) (Note 2)	-38	-38
C (dBm) (Note 2)	-87	-87
Noise at CBTC TU receiver (dBm) (Note 2)	-101	-101
SINR (dB)	13.9	13.7
Note 1: The measured coupling loss may not represent the minimum coupling loss. While this value was the minimum value measured during the campaign, it was identified during the campaign that the participants probably did not manage to measure the minimum coupling loss. Note 2: The power levels are expressed in dBm within the 5 MHz bandwidth of the CBTC receiver.		

The SINR remains significantly above the 9 dB minimum SINR for QPSK ¾.

5.2.2 Scenario 2: VLP on platform - CBTC TU

Table 24: MCL study for VLP on platform - CBTC TU

Parameter	RER train	RER train
Measured coupling loss (dB)	56.3	56.3
OOB $eirp_{RLAN}$ (dBm/MHz)	-37	-45
OOB $eirp_{RLAN}$ (dBm) (Note 1)	-30	-38
C (dBm) (Note 1)	-87	-87
Noise at CBTC TU receiver (dBm) (Note 1)	-101	-101
SINR (dB)	-0.8	6.5
Note 1: The power levels are expressed in dBm within the 5 MHz bandwidth of the CBTC receiver.		

With a VLP OOB level of -37 dBm/MHz, the SINR falls well below the 9 dB minimum SINR for QPSK ¾, while with a VLP OOB level of -45 dBm/MHz, the SINR falls 2.5 dB below the threshold.

This scenario was only studied with RER trains, in the absence of measurements for the underground trains.

5.2.3 Scenario 3: VLP onboard - CBTC TU

Table 25: MCL study for VLP onboard RER - CBTC TU

Parameter	RER train	RER train
Measured coupling loss (dB) (Note 1)	92	92
OOB $eirp_{RLAN}$ (dBm/MHz)	-37	-45
OOB $eirp_{RLAN}$ (dBm) (Note 2)	-30	-38
C (dBm) (Note 2)	-87	-87
Noise at CBTC TU receiver (dBm) (Note 2)	-101	-101
SINR	14.0	14.0
Note 1: This coupling loss includes post processing of antenna gain measurements, assuming that the signal comes mainly from a single direction. Note 2: The power levels are expressed in dBm within the 5 MHz bandwidth of the CBTC receiver.		

For RER trains, the SINR remains significantly above the 9 dB minimum SINR for QPSK ¾.

Table 26: MCL study for VLP onboard metros - CBTC TU, -37 dBm/MHz case

Parameter	Metro MP14	Metro MP89	Metro MP05
Measured coupling loss (dB) (Note 1)	47.2	48.5	49
OOB $eirp_{RLAN}$ (dBm/MHz)	-37	-37	-37
OOB $eirp_{RLAN}$ (dBm) (Note 2)	-30	-30	-30
C (dBm) (Note 2)	-87	-87	-87
Noise at CBTC TU receiver (dBm) (Note 2)	-101	-101	-101
SINR (dB)	-9.8	-8.5	-8
Note 1: This coupling loss includes post processing of antenna gain measurements, assuming that the signal comes mainly from a single direction. Note 2: The power levels are expressed in dBm within the 5 MHz bandwidth of the CBTC receiver.			

Table 27: MCL study for VLP onboard metros - CBTC TU, -45 dBm/MHz case

Parameter	Metro MP14	Metro MP89	Metro MP05
Measured coupling loss (dB) (Note 1)	47.2	48.5	49
OOB $eirp_{RLAN}$ (dBm/MHz)	-45	-45	-45
OOB $eirp_{RLAN}$ (dBm) (Note 2)	-38	-38	-38
C (dBm) (Note 2)	-87	-87	-87
Noise at CBTC TU receiver (dBm) (Note 2)	-101	-101	-101
SINR (dB)	-1.9	-0.6	-0.2

Parameter	Metro MP14	Metro MP89	Metro MP05
Note 1: This coupling loss includes post processing of antenna gain measurements, assuming that the signal comes mainly from a single direction. Note 2: The power levels are expressed in dBm within the 5 MHz bandwidth of the CBTC receiver.			

For metros, with a VLP OOB level of either -45 dBm/MHz or -37 dBm/MHz, the SINR falls well below the 9 dB minimum SINR for QPSK ¾.

5.2.4 Scenario 4: VLP onboard - CBTC AP

Table 28: MCL study for VLP onboard metros - CBTC AP, -37 dBm/MHz case

Parameter	Metro MP14	Metro MP05
Measured coupling loss (dB)	59	62
OOB $eirp_{RLAN}$ (dBm/MHz)	-37	-37
OOB $eirp_{RLAN}$ (dBm) (Note 1)	-30	-30
C (dBm) (Note 1)	-87	-87
Noise at CBTC TU receiver (dBm) (Note 1)	-101	-101
SINR (dB)	1.7	4.5
Note 1: The power levels are expressed in dBm within the 5 MHz bandwidth of the CBTC receiver.		

Table 29: MCL study for VLP onboard metros - CBTC AP, -45 dBm/MHz case

Parameter	Metro MP14	Metro MP05
Measured coupling loss (dB)	59	62
OOB $eirp_{RLAN}$ (dBm/MHz)	-45	-45
OOB $eirp_{RLAN}$ (dBm) (Note 1)	-38	-38
C (dBm) (Note 1)	-87	-87
Noise at CBTC TU receiver (dBm) (Note 1)	-101	-101
SINR (dB)	8.5	10.5
Note 1: The power levels are expressed in dBm within the 5 MHz bandwidth of the CBTC receiver.		

With a VLP OOB level of -37 dBm/MHz, the SINR falls well below the 9 dB minimum SINR for QPSK ¾ while with a VLP OOB level of -45 dBm/MHz, the SINR is around the threshold.

6 PROTECTION RATIO ANALYSIS

The following compatibility studies in this section are based on measurements contained in Annex 5, which give values for protection ratios. The studies also use the coupling loss measured in various scenarios (within different types of trains and metros, or on a platform) contained in section 2.

The protection ratio is between the CBTC signal in 5915-5935 MHz and the WAS/RLAN VLP signal in 5945-6425 MHz. It thus combines the effects of blocking and of out-of-band emissions. The ratio values are noted C/I_{adj}.

While the C/I_{adj} measurements are conducted on 10 MHz channels, the analysis below assumes that the protection ratio remains valid for 5 MHz channels for which the analysis is conducted.

6.1 STUDY 1

Study 1 considers:

- Body loss of 5.5 dB;
- CBTC signal level of −77 dBm (AP) and −76 dBm (TU) in line with ECC Report 290 with system margin (both within the 5 MHz bandwidth and at the TU/AP RF port);
- Coupling loss measurement, using the direct measurement data (see section A4.2).

The conclusions of the study consider the threshold C/I_{adj} of −33 dB corresponding to a 3 Mbps (BPSK ½) CBTC system operating on the channel closest to WAS/RLAN with WAS/RLAN bandwidth of 40 MHz and OOB emissions at −37 dBm/MHz.

6.1.1 Scenario 1: VLP on platform - CBTC AP

Table 30: VLP on platform - CBTC AP

Scenario 1	Platform 1	Platform 2
VLP e.i.r.p. (dBm) in 5945−5985 MHz (Note 1)	14	14
Body loss (dB)	5.5	5.5
Measured coupling loss (dB)	78 (Note 2)	74.6
VLP signal at CBTC AP receiver (dBm) (Note 1)	-69.5	-66.1
CBTC minimum signal level at CBTC AP receiver (dBm) (Note 3)	-77	-77
Minimum C/I_{adj} (dB)	-7.5	-10.9
Note 1: The power levels are expressed in dBm within the 40 MHz bandwidth of the WAS/RLAN VLP transmitter. Note 2: The measured coupling loss may not represent the minimum coupling loss. While this value was the minimum value measured during the campaign, it was identified during the campaign that the participants probably did not manage to measure the minimum coupling loss. Note 3: The power levels are expressed in dBm within the 5 MHz bandwidth of the CBTC receiver.		

A VLP device on the platform is unlikely to interfere a CBTC AP because the minimum C/I_{adj} remains well above the threshold C/I_{adj} of −33 dB.

6.1.2 Scenario 2: VLP on platform - CBTC TU

Table 31: VLP on platform - CBTC TU

Scenario 2	RER train
VLP e.i.r.p. (dBm) (Note 1)	14
Body loss (dB)	5.5
Measured coupling loss (dB)	56.3
VLP signal at CBTC AP receiver (dBm) (Note 2)	-47.8
CBTC minimum signal level at CBTC TU receiver (dBm) (Note 2)	-76
Minimum C/I_{adj} (dB)	-28.2
Note 1: The power levels are expressed in dBm within the 40 MHz bandwidth of the WAS/RLAN VLP transmitter. Note 2: The power levels are expressed in dBm within the 5 MHz bandwidth of the CBTC receiver.	

A VLP device on the platform is unlikely to interfere a CBTC TU because the minimum C/I_{adj} remains above the threshold C/I_{adj} of −33 dB.

6.1.3 Scenario 3: VLP onboard - CBTC TU

Table 32: VLP onboard - CBTC TU

Scenario 3	RER train	Metro MP14	Metro MP89	Metro MP05
VLP e.i.r.p. (dBm) (Note 1)	14	14	14	14
Body loss (dB)	5.5	5.5	5.5	5.5
Measured coupling loss (dB) (Note 2)	92	44.2	50.1	54.2
VLP signal at CBTC AP receiver (dBm) (Note 2)	-83.5	-35.7	-41.6	-45.7
CBTC minimum signal level at CBTC TU receiver (dBm) (Note 3)	-76	-76	-76	-76
Minimum C/I_{adj} (dB)	7.5	-40.3	-34.4	-30.3
Note 1: The power levels are expressed in dBm within the 40 MHz bandwidth of the WAS/RLAN VLP transmitter. Note 2: This measured coupling loss does not assume that the signal comes from a single direction and therefore does not include post processing of antenna gain measurements, assuming the measurement antenna pattern is flat. Note 3: The power levels are expressed in dBm within the 5 MHz bandwidth of the CBTC receiver.				

A VLP device onboard the train is unlikely to interfere a the CBTC TU of RER or MP05 because the minimum C/I_{adj} remains above the threshold C/I_{adj} of −33 dB.

The C/I_{adj} for metro MP14 falls to −40.3 dB, i.e. 7.3 dB lower than the required −33 dB, while the C/I_{adj} for metro MP89 falls to -34.4 dB, i.e. 1.4 dB lower than the required −33 dB.

It is important to stress that such link degradation would only impact the overall CBTC system under the following conditions:

- The VLP device is transmitting at full power, with maximum e.i.r.p. in the exact direction of the TU receiver antenna;
- The CBTC system is operating in degraded mode, i.e. a CBTC AP is not operating;

- The CBTC signal propagation is experiencing a 15 dB fading compared to its usual value;
- The study considered CBTC TUs that do not use antenna diversity.

6.1.4 Scenario 4: VLP onboard - CBTC AP

Table 33: VLP onboard - CBTC AP

Scenario 4	Metro MP14	Metro MP05
VLP e.i.r.p. (dBm) (Note 1)	14	14
Body loss (dB)	5.5	5.5
Measured coupling loss (dB)	59	62
VLP signal at CBTC AP receiver (dBm) (Note 1)	-50.5	-53.5
CBTC minimum signal level at CBTC AP receiver (dBm) (Note 2)	-76	-76
Minimum C/I_{adj} (dB)	-25.5	-22.5
Note 1: The power levels are expressed in dBm within the 40 MHz bandwidth of the WAS/RLAN VLP transmitter. Note 2: The power levels are expressed in dBm within the 5 MHz bandwidth of the CBTC receiver.		

A VLP device on the train is unlikely to interfere a CBTC AP because the minimum C/I_{adj} remains above the threshold C/I_{adj} of −33 dB.

6.1.5 Conclusion of C/I_{adj} Study 1

The C/I_{adj} analysis suggests that VLP are unlikely to interfere CBTC links under Scenarios 1, 2 and 4.

For Scenario 3 (VLP onboard to CBTC TU), VLP are unlikely to interfere RER train and metro MP05. For metro MP14 (respectively MP89), the achieved C/I_{adj} is 7.3 dB (respectively 1.4 dB) below the threshold C/I_{adj} under the conditions listed in section 6.1.3. Such a degradation may only happen under these conditions and the risk is not present in all train designs as demonstrated by metro MP05.

6.2 STUDY 2

Study 2 considers:

- Body loss of 0 dB;
- CBTC signal level of -87 dBm within the 5 MHz bandwidth at the AP/TU RF port (the minimum signal level used for various European CBTC lines);
- Coupling loss measurement, with post processing of antenna gain measurements (see section A4.2);
- C/I_{adj} thresholds from laboratory measurements, for QPSK ¾, i.e. −28 dB and −35 dB for respectively WAS/RLAN VLP OOB emissions of −37 dBm/MHz and −45 dBm/MHz;
- CBTC system operating on the channel closest to WAS/RLAN with WAS/RLAN bandwidth of 40 MHz.

6.2.1 Scenario 1: VLP on platform - CBTC AP

Table 34: MCL study for VLP on platform - CBTC AP

Parameter	Platform 1	Platform 2
$eirp_{RLAN}$ (dBm) (Note 1)	14	14
Measured coupling loss (dB)	78 (Note 2)	74.6

Parameter	Platform 1	Platform 2
I_{adj} (dBm) (Note 1)	-64	-60.6
C (dBm) (Note 3)	-87	-87
C/I_{adj} (dB)	-23	-26.4
Note 1: The power levels are expressed in dBm within the 40 MHz bandwidth of the WAS/RLAN VLP transmitter. Note 2: The measured coupling loss may not represent the minimum coupling loss. While this value was the minimum value measured during the campaign, it was identified during the campaign that the participants probably did not manage to measure the minimum coupling loss. Note 3: The power levels are expressed in dBm within the 5 MHz bandwidth of the CBTC receiver.		

The C/I_{adj} results are higher than both thresholds (-28 dB and -35 dB for respectively VLP OOB emissions of -37 dBm/MHz and -45 dBm/MHz). Although VLP OOB emissions of up to -37 dBm/MHz seem not to be problematic for this scenario, it is recommended to carry out site specific studies before deploying CBTC APs in stations and on platforms, if the coupling losses between the AP and VLP could be in the range of 73 dB or less. A theoretical analysis shows that this is likely to happen at distances of around 15 m.

6.2.2 Scenario 2: VLP on platform - CBTC TU

Table 35: MCL study for VLP on platform - CBTC TU

Parameter	RER train
$eirp_{RLAN}$ (dBm) (Note 1)	14
Measured coupling loss (dB)	56.3
I_{adj} (dBm) (Note 1)	-42.3
C (dBm) (Note 2)	-87
C/I_{adj} (dB)	-44.7
Note 1: The power levels are expressed in dBm within the 40 MHz bandwidth of the WAS/RLAN VLP transmitter. Note 2: The power levels are expressed in dBm within the 5 MHz bandwidth of the CBTC receiver.	

This scenario was only studied with RER trains, in the absence of measurements for the metro trains.

Results suggest that a WAS/RLAN VLP located on a platform could cause interference to CBTC train unit.

The C/I_{adj} values are 16.7 dB and 9.7 dB lower than the C/I_{adj} thresholds for respectively VLP OOB emissions at −37 dBm/MHz and −45 dBm/MHz.

6.2.3 Scenario 3: VLP onboard - CBTC TU

Table 36: MCL study for VLP onboard RER - CBTC TU

Parameter	RER train
$eirp_{RLAN}$ (dBm) (Note 1)	14
Measured coupling loss (dB)	92
I_{adj} (dBm) (Note 1)	-78
C (dBm) (Note 2)	-87

Parameter	RER train
C/I_{adj} (dB)	-9
Note 1: The power levels are expressed in dBm within the 40 MHz bandwidth of the WAS/RLAN VLP transmitter. Note 2: The power levels are expressed in dBm within the 5 MHz bandwidth of the CBTC receiver.	

For the VLP on the passenger deck, the C/I_{adj} results are higher than both C/I_{adj} thresholds (−28 dB and −35 dB for respectively VLP OOB emissions at −37 dBm/MHz and −45 dBm/MHz). VLP OOB emissions of up to −37 dBm/MHz do not seem problematic for RER train with driver's cabin.

Table 37: MCL study for VLP onboard metros - CBTC TU

Parameter	Metro MP14	Metro MP89	Metro MP05
$eirp_{RLAN}$ (dBm) (Note 1)	14	14	14
Measured coupling loss (dB) (Note 2)	47.2	48.5	49
I_{adj} (dBm) (Note 1)	-33.2	-34.5	-35
C (dBm) (Note 3)	-87	-87	-87
C/I_{adj} (dB)	-53.8	-52.5	-52
Note 1: The power levels are expressed in dBm within the 40 MHz bandwidth of the WAS/RLAN VLP transmitter. Note 2: This coupling loss includes post processing of antenna gain measurements, assuming that the signal comes mainly from a single direction. Note 3: The power levels are expressed in dBm within the 5 MHz bandwidth of the CBTC receiver.			

Results suggest that a WAS/RLAN VLP located onboard a metro could cause interference to the CBTC TU. The C/I_{adj} is up to 25.8 dB and 18.8 dB lower than the C/I_{adj} thresholds for respectively VLP OOB emissions at −37 dBm/MHz and −45 dBm/MHz.

6.2.4 Scenario 4: WAS/RLAN VLP operated onboard a train to CBTC AP

Table 38: MCL study for VLP onboard metros - CBTC AP

Parameter	Metro MP14	Metro MP05
$eirp_{RLAN}$ (dBm) (Note 1)	14	14
Measured coupling loss (dB)	59	62
I_{adj} (dBm) (Note 1)	-45	-48
C (dBm) (Note 2)	-87	-87
C/I_{adj} (dB)	-42	-39
Note 1: The power levels are expressed in dBm within the 40 MHz bandwidth of the WAS/RLAN VLP transmitter. Note 2: The power levels are expressed in dBm within the 5 MHz bandwidth of the CBTC receiver.		

Results suggest that a WAS/RLAN VLP located onboard a metro could cause interference to a CBTC AP. The C/I_{adj} is up to 14 dB and 7 dB lower than the C/I_{adj} thresholds for respectively VLP OOB emissions at −37 dBm/MHz and −45 dBm/MHz.

It is also worth recalling that the wanted signal "C" originates from distant trains (VLP is within a train in the proximity of the CBTC AP, while the CBTC AP is also communicating with another distant train).

6.2.5 Conclusion of C/I_{adj} Study 2

This study considered metro trains (see Figure 21 in ANNEX 1:). The critical interference scenario appears to be a train passenger sitting behind the front window. For trains with a driver's cabin, no measurement was made as this case was not deemed critical. Table 39 summarises the results and gives the difference between the C/I_{adj} calculated and the C/I_{adj} threshold for the two values of WAS/RLAN VLP OOB emission levels considered.

Table 39: C/I_{adj} summary table

VLP location	Victim	Environment / Train	C/I_{adj} analysis (dB)	Delta to C/I_{adj} for QPSK ¾ with WAS/RLAN VLP OOB emissions at −37 dBm/MHz (i.e. −28 dB)	Delta to C/I_{adj} for QPSK ¾ with WAS/RLAN VLP OOB emissions at −45 dBm/MHz (i.e. −35 dB)
Platform	AP	Outdoor	-23 (Note 1)	5	12
Platform	AP	Tunnel	-26.4	1.6	8.6
Platform	TU	RER train	-44.7	-16.7	-9.7
Onboard	TU	RER train	-9	19	26
Onboard	TU	Metro MP14	-53.8	-25.8	-18.8
Onboard	TU	Metro MP89	-52.5	-24.5	-17.5
Onboard	TU	Metro MP05	-52	-24	-17
Onboard	AP	Metro MP14	-42	-14	-7
Onboard	AP	Metro MP14	-39	-11	-4
Note 1: The measured coupling loss may not represent the minimum coupling loss. While this value was the minimum value measured during the campaign, it was identified during the campaign that the participants probably did not manage to measure the minimum coupling loss.					

7 PROBABILITY OF INTERFERENCE

ETSI TR 103 580 V1.1.1 [7] indicates that the maximum allowed application layer latency is 100 ms and that an emergency brake is only triggered if a movement authority message is not received for a period of 2.5 s. CBTC systems would trigger an emergency brake due to interference from VLP only if the interference causes no movement authority message to be received during this period, which would seldom happen if the interference duration is short (e.g. lower than 1 to 2 seconds).

7.1 STATISTICAL STUDY A

This study (see results in section 7.1.3) determines the probability of a 2 seconds window for a VLP interfering with a single CBTC link in a static scenario (e.g. a train standing still at a random position along the track), where: CBTC operates in degraded mode, CBTC signal is at minimum level, VLP is at MCL (from either TU or AP depending on the scenario) and VLP is operating on lower channel.

For reference, assuming interference probabilities in any 2 s windows are independent from one another:

- a 10^{-7} probability for such 2 seconds window leads to an event every six months;
- a 10^{-9} probability for such 2 seconds window leads to an event every 63 years;
- a $3.9 \cdot 10^{-9}$ probability for such 2 seconds window leads to an event every 16 years;
- a $3.1 \cdot 10^{-9}$ probability for such 2 seconds window leads to an event every 20 years.

7.1.1 List of variables, probability and typical duration

The probabilistic elements considered in the technical studies include:

- the CBTC is operating in degraded mode, i.e. either a TU or an AP is not functioning;
- the CBTC signal level is at its minimum;
- the VLP is operating on the lower channel;
- the VLP is transmitting at maximum e.i.r.p.;
- the VLP packet is colliding with the CBTC packet (full or partial synchronisation).

The probability of each variable, as well as the typical duration of an event, are provided in Table 40.

Table 40: Probability of variables and corresponding typical duration

Variable	Probability	Duration
CBTC train functioning in degraded mode (one of the 2 TUs not functioning)	0.035% (Note 1)	14 hours (Note 2)
CBTC Access Point functioning in degraded mode	0.028% (Note 3)	14 hours (Note 3)
CBTC signal at minimum level	1%	0.5-1.5 s (Note 4)
VLP onboard located at MCL to TU	Significant	Minutes
VLP on platform located at MCL to TU	Significant	Minutes
VLP located at MCL to AP	Less than 1% (Note 5)	0.2-0.06 s (Note 6)
VLP operating on the lower channel	16% (Note 7)	Up to several minutes
VLP transmitting at maximum e.i.r.p.	0.69% (section 3.2.4)	Up to several minutes
VLP packet colliding with CBTC packet at TU	0.24% (Note 8)	Less than 20 ms
VLP packet colliding with CBTC packet at AP	1.2% (Note 9)	Less than 20 ms

Variable	Probability	Duration
Note 1: Assuming MTBF of 40000 h and MTTR of 14 h = 14/40000= 0.035% Note 2: Assuming MTTR of 14 h, corresponding to the time the train will continue to operate in degraded mode before entering the workshop and being repaired. Note 3: Assuming MTBF of 50000 h and MTTR of 14 h = 14/50000=0.028%, the same remark as in Note 2 applies as well. Note 4: Based on inter-AP distance of 400 m, the 1% worst location should not represent more than 4 m (8 m if one AP is defect). This worst-case location is clearly smaller than the typical length of a train and is therefore irrelevant when both TUs are functioning. When the CBTC train is functioning in degraded mode with one TU down, the duration of such event depends on the speed of the train. At 20 km/h, the train travels at 5.5 m/s and takes 1.4 s to clear the zone of minimum signal. At 60 km/h, the train travels at 16.6 m/s and takes 0.5 s to clear the zone of minimum signal. Note 5: In order to have a VLP onboard the train to interfere an AP, it must be located exactly behind the front window of a driverless train with non-insulated front window and for the train to be located exactly at the MCL location to the AP. Note 6: Based on an inter-AP distance of 400 m, the MCL between a user on the train and the AP is reached on a 1 m wide position of the train. The duration of such event is less than 0.2 s for a train travelling at 20 km/h and less than 0.06s for a train travelling at 60km/h. Note 7: Assuming equal distribution of 80 MHz VLP devices in the 6 channels available in the 5945-6425 MHz band. Note 8: Assuming a VLP activity factor of 2% and a CBTC TU activity factor (reception) of 6-12%. Note 9: Assuming a VLP activity factor of 2% and a CBTC AP activity factor of 6-60%.		

7.1.2 Event probability derivation

7.1.2.1 Variable cross-correlation

None of the variables seem to be correlated with each other. As a result, the probability of an event combining several of these variables can simply be estimated as the multiplication of the probability of each variable.

7.1.2.2 Probability of scenario vs degradation of performance

Assuming that interference for more than 2 s should be avoided, it is important to differentiate between variables whose duration is typically in the order of seconds and those whose duration is less or much less than 2 s.

For a variable with long duration, it can be considered that the situation occurs during 2 s or does not occur. This determines an overall probability of the scenario.

For a variable with short duration (much less than 2 s), any interference would not directly result in emergency brake, but may result in a degradation of the CBTC transmission. This may lead to CBTC packet retransmission and potentially additional latency at the application layer. Whether such effects trigger an emergency brake cannot be determined through consideration of single link interference exceedance. Testing the impact of VLP on the overall CBTC system would be required to precisely determine the impact of such interference, taking into account retransmission capacities, redundancy configurations, etc.

7.1.2.3 Probability of event and interference exceedance

The studies in this Report consider specific values for each variable and derive whether a specific threshold is exceeded. Multiplying the probability of each variable provides the probability of the event considered during the derivation.

Should the derivation conclude on a slight exceedance of the interference criterion (e.g. less than 2 dB), the probability of interference can be approximated by multiplying the probability of each variable. Should the interference criterion only be slightly exceeded, it means that interference only occurs when making some parameters more extreme, i.e. less likely. While other assumptions would also lead to exceeding the interference criterion, such assumptions would also be much less likely and therefore not relevant compared with the precise situation studied.

On the other hand, should the derivation conclude on significant exceedance of the interference criterion, the probability of such event becomes less relevant. Significant exceedance of the interference criterion indicates that some parameters may be relaxed and still lead to the interference criterion being exceeded. In such case, some specific value with much higher overall probability may also lead to interference and it the probability assessment of the derivation is inconclusive.

7.1.3 Probability of each scenario

- **Section 4.1.1**

  The scenario does not lead to significant desensitisation and therefore does not require a probability assessment.
- **Section 4.1.2**

  The interference criterion is exceeded with too much margin to enable a significant probability analysis of the scenario.
- **Section 4.1.3**

  For the RER train, the interference criterion is not exceeded. For the metros, the interference criterion is exceeded with too much margin to enable a significant probability analysis of the scenario.
- **Section 4.1.4**

  The scenario would only occur when:
  - the CBTC AP is functioning in degraded mode (0.028%);
  - the CBTC signal is at minimum level (1%);
  - the VLP is operating on the lower channel (16%);
  - the VLP is transmitting at maximum e.i.r.p. (0.69%);

  resulting in a combined probability of $3.1 \cdot 10^{-9}$ where a single CBTC link in a static scenario is assumed (e.g. a train standing still at a random position along the track).
- **Section 4.2.1**

  The scenario would only occur when:
  - the CBTC AP is functioning in degraded mode (0.028%);
  - the CBTC signal is at minimum level (1%);
  - the VLP is operating on the lower channel (16%);
  - the VLP is transmitting at maximum e.i.r.p. (0.69%);

  resulting in a combined probability of $3.1 \cdot 10^{-9}$where a single CBTC link in a static scenario is assumed (e.g. a train standing still at a random position along the track).
- **Section 4.2.2**

  The interference criterion is exceeded with too much margin to enable a significant probability analysis of the scenario.
- **Section 4.2.3**

  The interference criterion is exceeded with too much margin to enable a significant probability analysis of the scenario.
- **Section 4.2.4**

  The interference criterion is exceeded with too much margin to enable a significant probability analysis of the scenario.
- **Section 5.1.2**

  While the SINR falls slightly below the 4 dB threshold, the scenario would only occur when:
  - the CBTC train is functioning in degraded mode (0.035%);
  - the CBTC signal is at minimum level (1%);
  - the VLP is operating on the lower channel (16%);
  - the VLP is transmitting at maximum e.i.r.p. (0.69%);

  resulting in a combined probability of $3.9 \cdot 10^{-9}$ where a single CBTC link in a static scenario is assumed (e.g. a train standing still at a random position along the track).

  Additionally, the activity factor for both CBTC TU and VLP suggests that less than 1% of the VLP packets should collide with CBTC packet. The scenario studied considers 100% collision and is therefore worst-case.
- **Section 5.2.1**

The scenario does not lead to insufficient SINR and therefore does not require a probability assessment.

- **Section 5.2.2**

  The scenario does not lead to insufficient SINR and therefore does not require a probability assessment.
- **Section 5.2.3**

  The interference criterion is exceeded with too much margin to enable a significant probability analysis of the scenario.
- **Section 5.2.4**

  The scenario would only occur when:
  - the CBTC AP is functioning in degraded mode (0.028%);
  - the CBTC signal is at minimum level (1%);
  - the VLP is operating on the lower channel (16%);
  - the VLP is transmitting at maximum e.i.r.p. (0.69%),;

  resulting in a combined probability of $3.1 \cdot 10^{-9}$. where a single CBTC link in a static scenario is assumed (e.g. a train standing still at a random position along the track).
- **Section 6.1.1**

  The interference threshold is not exceeded and therefore the scenario does not require a probability assessment.
- **Section 6.1.2**

  The interference threshold is not exceeded and therefore the scenario does not require a probability assessment.
- **Section 6.1.3**

  While the interference criterion is slightly exceeded for MP89, the scenario would only occur when:
  - the CBTC train is functioning in degraded mode (0.035%);
  - the CBTC signal is at minimum level (1%);
  - the VLP is operating on the lower channel (16%);
  - the VLP is transmitting at maximum e.i.r.p. (0.69%);

  resulting in a combined probability of $3.9 \cdot 10^{-9}$ where a single CBTC link in a static scenario is assumed (e.g. a train standing still at a random position along the track).

  Additionally, the activity factor for both CBTC TU and VLP suggests that less than 1% of the VLP packets should collide with CBTC packet. The scenario studied considers 100% collision and is therefore worst-case.
- **Section 6.1.4**

  The interference threshold is not exceeded and therefore the scenario does not require a probability assessment.
- **Section 6.2.1**

  The interference threshold is not exceeded and therefore the scenario does not require a probability assessment.
- **Section 6.2.2**

  The interference criterion is exceeded with too much margin to enable a significant probability analysis of the scenario.
- **Section 6.2.3**

  The interference criterion is exceeded with too much margin to enable a significant probability analysis of the scenario.
- **Section 6.2.4**

  The interference criterion is exceeded with too much margin to enable a significant probability analysis of the scenario.

7.2 STATISTICAL STUDY B (SCENARIO 2: VLP ON PLATFORM INTERFERING A CBTC TU)

The purpose of this section is to derive the number of occurrences of interference to a CBTC single link over a year that could originate from VLP present on platforms for one representative line. Interference is defined as a 1% packet loss of QPSK ¾. This study also characterises in which range of duration these interferences fall. The impact of interference is further assessed by considering the redundancies in the CBTC system if they are available (nominal mode) or not available (degraded mode), with an indication of corresponding volumetry for a year.

For the purpose of the probability study in this section, a -32 dB protection ratio is considered with VLP out-of-band emissions of -37 dBm/MHz when the CBTC single link is using a channel at 5930 MHz (50% of the cases). For a CBTC channel at 5920 MHz (50% of the cases), the protection ratio is -37 dB. Those are based on measurements for 40 MHz WAS/RLAN channel with occupancy factor of 2%, and QPSK ¾ in Annex 5.

The variations with respect to RLAN channel bandwidth are not considered. Annex 5 also measured the protection ratio of one CBTC receiver operating at 5930 MHz vs VLP with out-of-band emissions of -37 dBm/MHz, for WAS/RLAN bandwidth of 20, 40 and 80 MHz. The measured protection ratios for QPSK ¾ were -34, -28 and -35 dB for respectively 20, 40 and 80 MHz (however, it should be noted that the 80 MHz triggered some bandwidth limitations of the vector signal generator). 160 MHz could not be measured.

7.2.1 Introduction

A statistical study was performed to complement the worst case MCL single link analysis by considering the scenario of a VLP on a platform interfering a train unit (TU):

a) some variations in parameters that improve the worst-case assumptions;
b) the redundancy which is built into CBTC systems to ensure high reliability.

The statistical simulation counted how often and how long interference cases could happen, from a VLP on a platform in an urban rail line, and what could be the practical consequence on the CBTC radio system. As a reference, CBTC systems contractual requirements for the radio system impose a few minutes of unavailability per year (e.g. 5 minutes, or 99.999% reliability).

The simulation considered 400000 train entrance in stations per year, representative of the central part of a high traffic urban rail line with 6 high-capacity stations and a peak throughput of 22 trains per hour each way. The simulation is performed at a CBTC target minimum signal level of -84 dBm at TU receiver RF port and uses QPSK ¾ modulation.

The simulation assumed significant VLP usage, resulting into one VLP always present in the vulnerable zone on the platform (20 m long). It considered some CBTC antenna diversity, VLP body loss, VLP occupancy factor, variations of C/I_{adj} threshold depending on VLP OOB emission and CBTC channel.

The interference criterion is the same as for the measurements and theoretical studies, i.e. resulting in 1% packet loss or more, under the above assumptions.

The methodology and detailed results are described in section A7.2.

7.2.2 Simulation results-single link

The simulation provided the following results:

Table 41: Simulation for OOB emission -45 dBm/MHz and -37 dBm/MHz

	VLP OOB emission -45 dBm/MHz	VLP OOB emission -37dBm/MHz
Interference occurrences per year	10000	170000
% of train entrance	2.5%	42.5%
Interference duration		
Lasting more than 1 s	0	90000
Lasting more than 2 s	0	30000
Interference intensity		
Budget margin < -3 dB	0	80000
Budget margin < -6 dB	0	20000
Budget margin < -9 dB	0	10000
Budget margin < -12 dB	0	0

A sensitivity analysis indicated that results should not be taken at exact face value. In fact, the computation showed sensitivity to the choice of parameters while the overall picture is robust to the assumptions when examining the differences between the VLP OOB emission limits of -45 dBm/MHz and -37 dBm/MHz.

Sensitivity analysis showed that if the CBTC minimum target signal level over the platform was -77 dBm, the - 37 dBm/MHz option would be equivalent to -45 dBm/MHz with a CBTC minimum signal level of -84 dBm (see Figure 7).

Minimum RF level			-84 dBm	-87 dBm	-77 dBm
			OOBE	OOBE	OOBE
			-37 dBm/MHz	-37 dBm/MHz	-37 dBm/MHz
Interference occurrences					
	per year		170 000	250 000	10 000
	%		42,5%	62,5%	2,5%
Lasting more than 1s			90 000	190 000	-
Lasting more than 2 s			30 000	120 000	-
Interference intensity					
Cases with budget <					
	-3	dB	80 000	170 000	-
	-6	dB	20 000	80 000	-
	-9	dB	10 000	20 000	-
	-12	dB	-	10 000	-

Figure 7: Sensitivity analysis versus the minimum CBTC signal level

7.2.3 System aspects considering the OOB emission limit of -45 dBm/MHz

With the VLP OOB emission limit of -45 dBm/MHz, there could be cases of single link interference (2.5% of train entrances or 6 per day per station), lasting less of a second. They could impact a CBTC weak link (<-81 dBm). Taking into account CBTC system design and redundancy, most would not impact the radio link of the TU carrying the useful signal and the other ones (typically 6 per year) could be managed by CBTC redundancies without a loss in systems reliability.

7.2.4 System aspects considering the OOB emission limit of -37 dBm/MHz

Based on single link analysis in 7.2.2, with the VLP OOB emission limit of -37 dBm/MHz, there could be 170000 single link interference or more per year (more than 43% of train entrances), with 90000 lasting more than 1 s and 30000 lasting more than 2 s. The system impact is mitigated by CBTC radio redundancies, to an extent that depends on nominal and degraded modes as described below.

7.2.4.1 Nominal mode

In nominal mode (see Figure 1), in most cases the interference would impact the weaker radio link in the TU (performing association), while the CBTC transmission is carried over the stronger link on the other frequency. In the other cases the system will be able to cope by relying on the other TU.

7.2.4.2 Degraded mode (AP failure)

Failure of an access point (AP) covering one of the stations would happen typically two days per year, when more than 100 interference events could impact the CBTC useful link of the TU, requiring to rely on the other TU.

7.2.4.3 Double failure (AP and TU)

In this very rare event of a train with a failed TU entering a station with a failed AP, the CBTC is relying on a single link when passing the station. If this train makes 5 such passages in the day until repair, statistically 2 or 3 might be interfered, and there could be instances of partial or total loss of CBTC communication in those critical periods.

7.2.5 Conclusions for VLP on platform interfering a Train Unit

Under the studied assumptions, OOB emission limit of -37 dBm/MHz would increase the probability of single link interference[9] (from 2.5% to 43%), and their duration compared with a reference case set to -45 dBm/MHz. It is expected some would affect the useful link of a TU, therefore the CBTC system would be affected, although still able to cope in most cases. The system would become more exposed in case of double failures, and in those very rare but critical events, there could be instances of partial or total loss of CBTC communication.

As shown in Annex A7.6, in case a Transmit Power Control (TPC) mechanism would be applied, it is expected that for nomadic VLP usage, most or all VLP would transmit with a small back off, with a non-linear reduction in OOB emission. This would result in much lower OOB emission, ensuring similar coexistence situation as with the OOB emission limit of -45 dBm/MHz.

Sensitivity analysis showed that if the CBTC minimum target signal level over the platform was -77 dBm, the -37 dBm/MHz option would be equivalent to -45 dBm/MHz with a CBTC minimum signal level of -84 dBm.

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[9] An interference event is considered to occur at a given time instant when the C/Iadj experienced at the CBTC receiver is below the protection threshold

7.3 STATISTICAL STUDY C (SCENARIO 3: VLP ONBOARD INTERFERING A CBTC TU)

This section is a summary of the study presented in detail in ANNEX 8:. The purpose of this subsection is to assess how often interference cases lasting more than 1 second could occur for the scenario of a VLP inside a metro without driver's cabin impacting a single TU. A simulation run consists in considering the C/I_{adj} experienced by a single TU over a period of 24 hours.

The outcome corresponds to the number of interference cases faced within a given 24 hours period that are sustained for a duration of 1 second, i.e. shorter interference events are not counted.

An interference event is considered to occur at a given time instant when the C/I_{adj} experienced at the CBTC receiver is below the following thresholds:

For VLP with OOB emission at -37 dBm/MHz:

- -33 dB, for the channel centred at 5920 MHz;
- -28 dB, for the channel centred at 5930 MHz;
- no interference if the VLP channel is above 6105 MHz.

For VLP with OOB emission at -45 dBm/MHz:

- -38 dB, for the channel centred at 5920 MHz;
- -35 dB, for the channel centred at 5930 MHz;
- no interference if the VLP channel is above 6105 MHz.

These thresholds correspond to 1% packet loss of QPSK ¾ and WAS/RLAN channel of 40 MHz. Annex 5 also measured the protection ratio of one CBTC receiver operating at 5930 MHz vs VLP with out-of-band emissions of -37 dBm/MHz, for WAS/RLAN bandwidth of 20, 40 and 80 MHz (however, it should be noted that the 80 MHz triggered some bandwidth limitations of the vector signal generator). The measured protection ratios were -34, -28 and -35 dB for respectively 20, 40 and 80 MHz. The study does not address the case of VLP devices operating on 20 MHz channel bandwidth or BPSK modulation.

The simulations are repeated 60 times, labelled day 1 to 60, and the above interference counts are plotted for every "day".

Because each simulation represents 24 hours and the duration of degraded mode operation (when a TU is out of order) is in the range of 24 hours per month and per metro line, the results below can also be interpreted as the number of occurrences per month where the risk of service outage materialises.

The following three simulations are performed:

- nominal situations for both OOB VLP emission levels: -45 dBm/MHz and -37 dBm/MHz;
- simulation for VLP OOB emission level of -37 dBm/MHz and all VLP devices implementing TPC;
- simulation for VLP OOB emission level of -37 dBm/MHz and all VLP devices implementing both TPC and upper channel prioritisation.

Detailed hypothesis and additional simulations are also given in , investigating the effects of a specific WAS/RLAN VLP traffic pattern (with channel load of 2%), and the impact of a different antenna pattern and body loss distribution.

7.3.1 Results

7.3.1.1 Results when VLP channel prioritisation is not applied and not all WAS/RLAN devices implement TPC

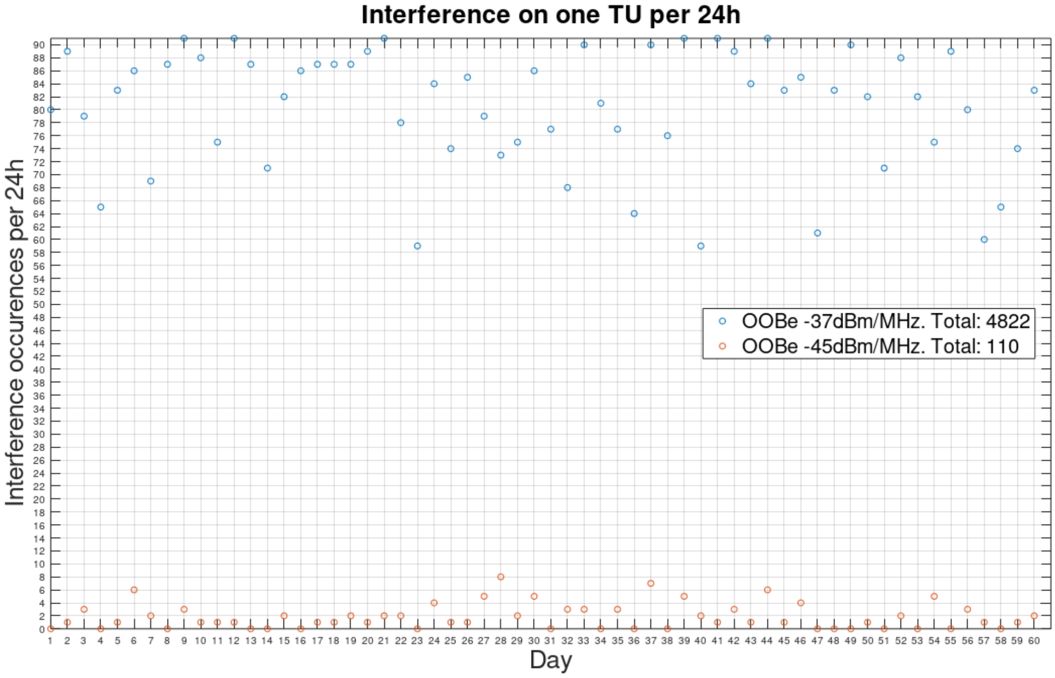

Figure 8: No VLP channel prioritisation and not all VLP WAS/RLAN devices implementing TPC, metro MP14

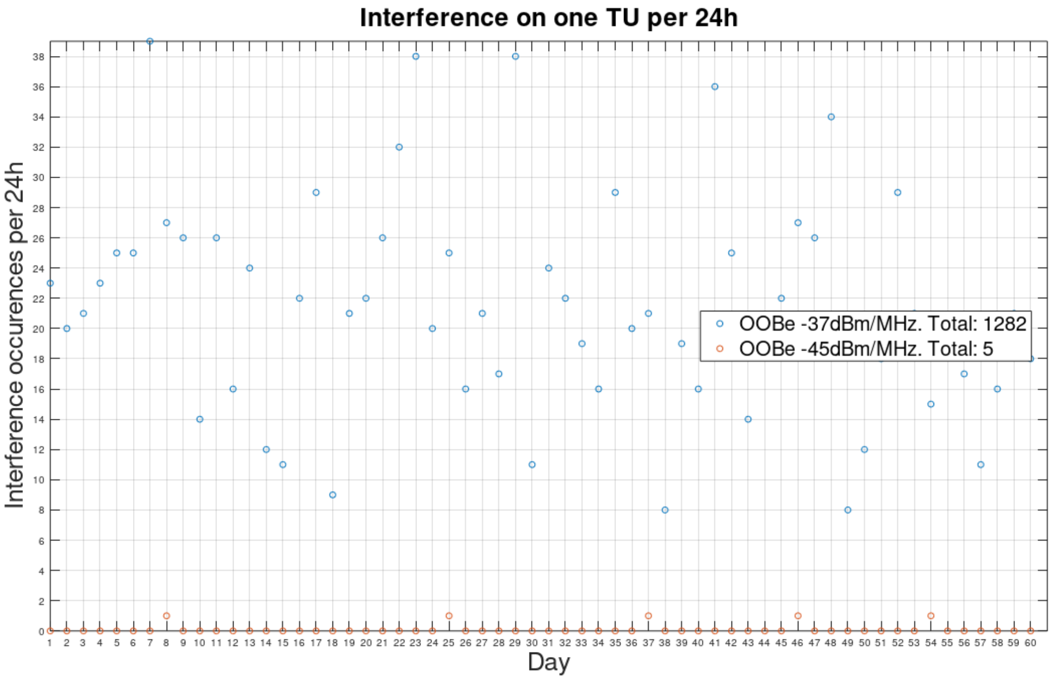

Figure 9: No VLP channel prioritisation and not all VLP WAS/RLAN devices implementing TPC, metro MP05

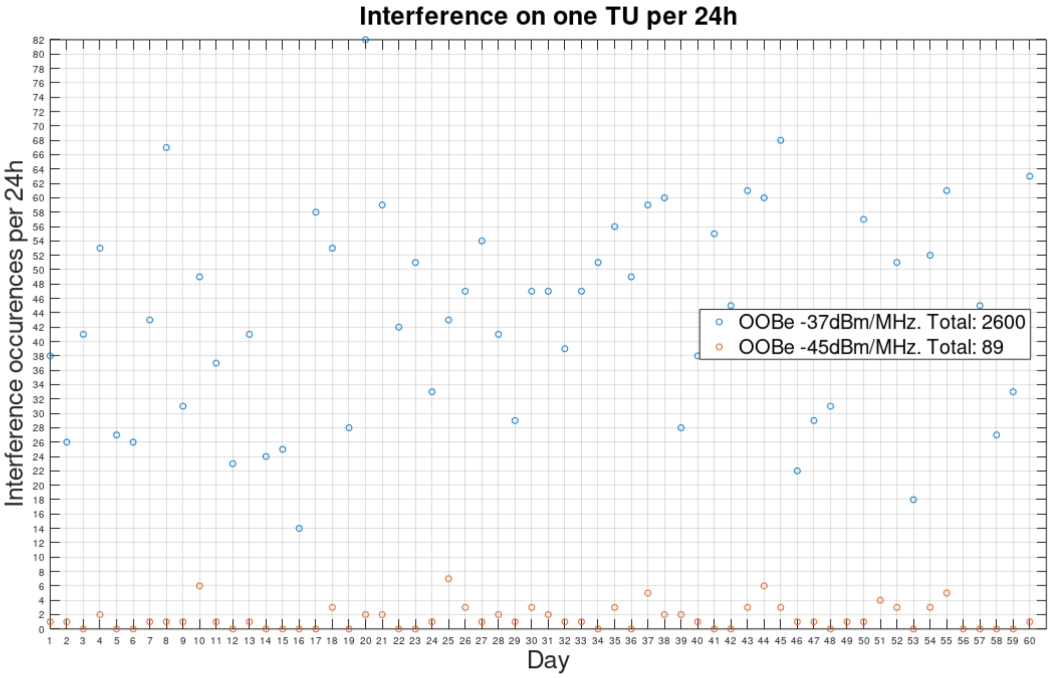

Figure 10: No VLP channel prioritisation and not all VLP WAS/RLAN devices implementing TPC, metro MP89

7.3.1.2 Results when VLP channel prioritisation is not applied and all WAS/RLAN devices implement TPC

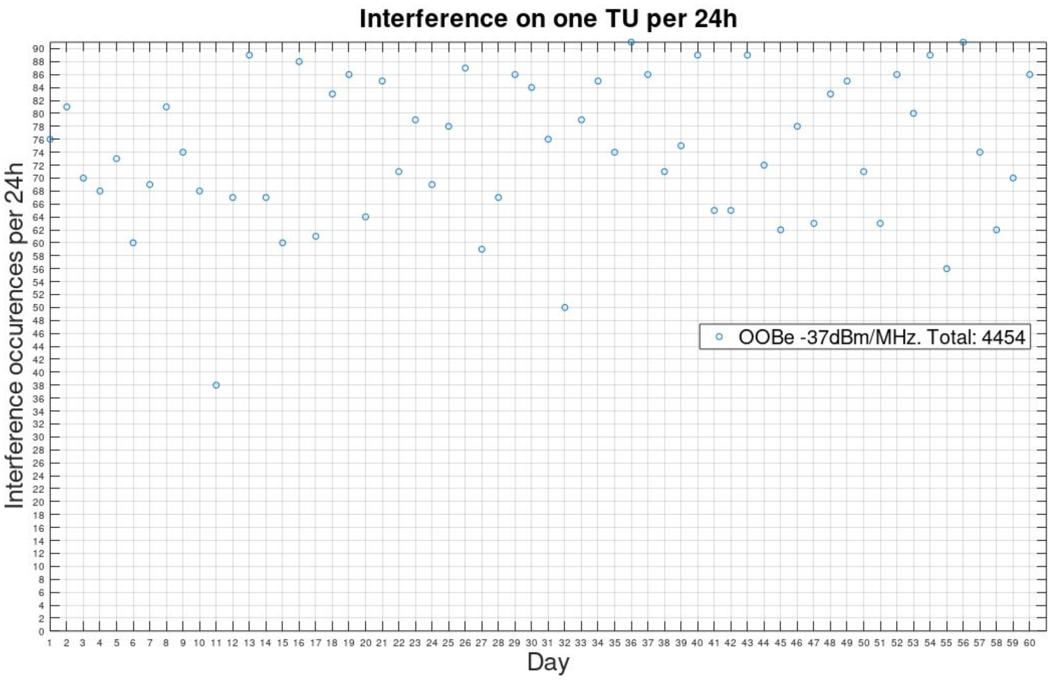

Figure 11: No VLP channel prioritisation, all VLP WAS/RLAN devices implementing TPC, metro MP14

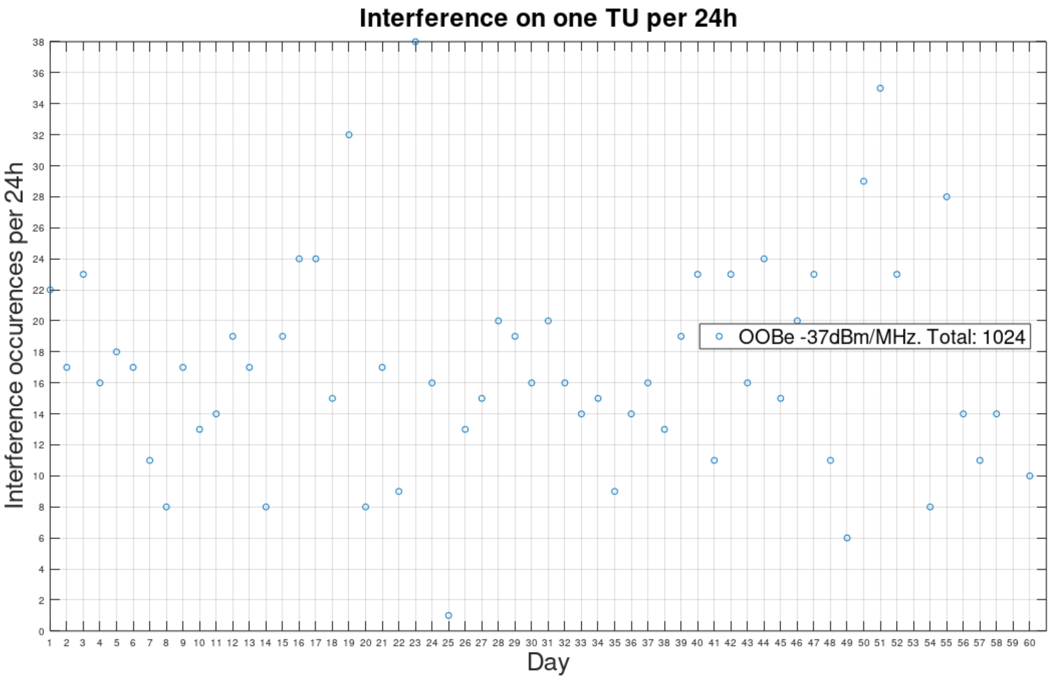

Figure 12: No VLP channel prioritisation, all VLP WAS/RLAN devices implementing TPC, metro MP05

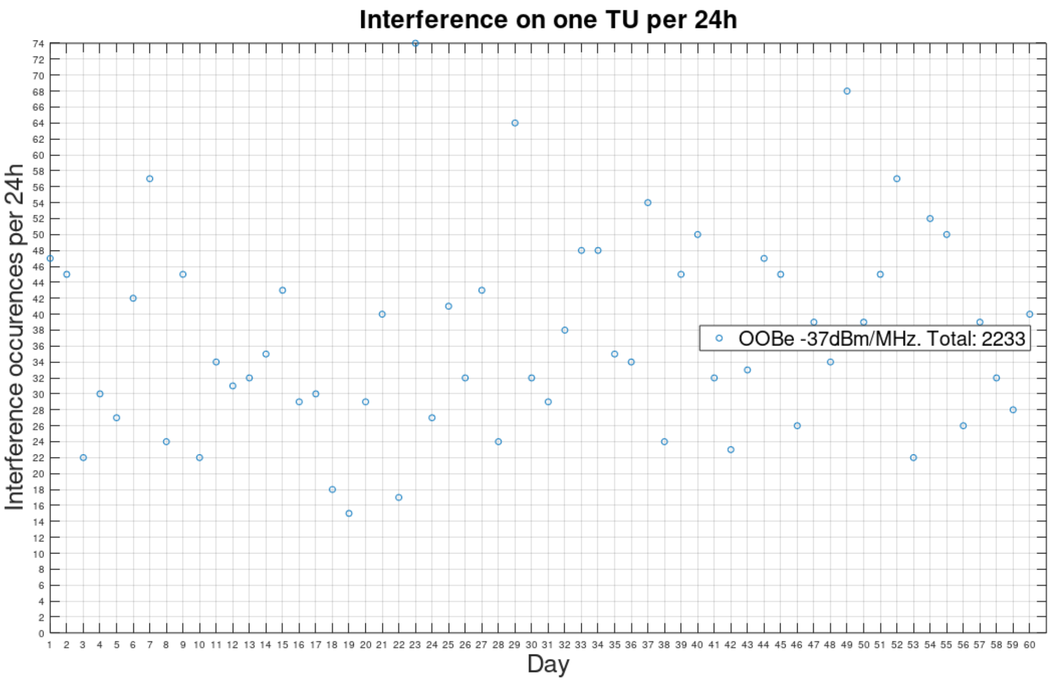

Figure 13: No VLP channel prioritisation, all VLP WAS/RLAN devices implementing TPC, metro MP89

7.3.1.3 Results when VLP channel prioritisation is applied and all WAS/RLAN devices implement TPC.

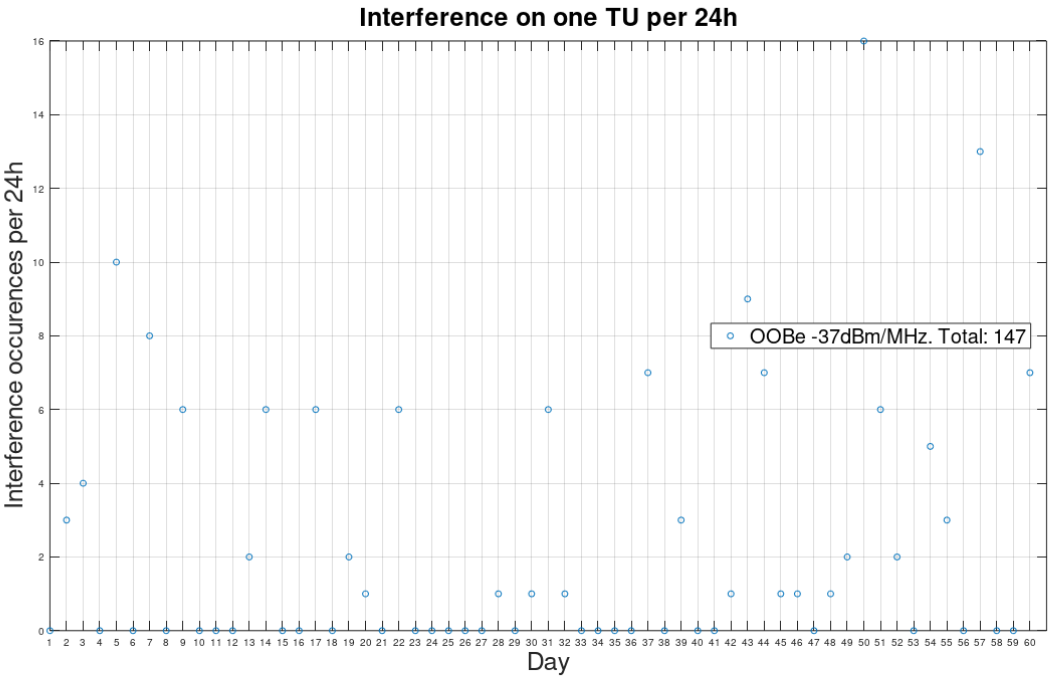

Figure 14: VLP channel prioritisation, all VLP WAS/RLAN devices implementing TPC, metro MP14

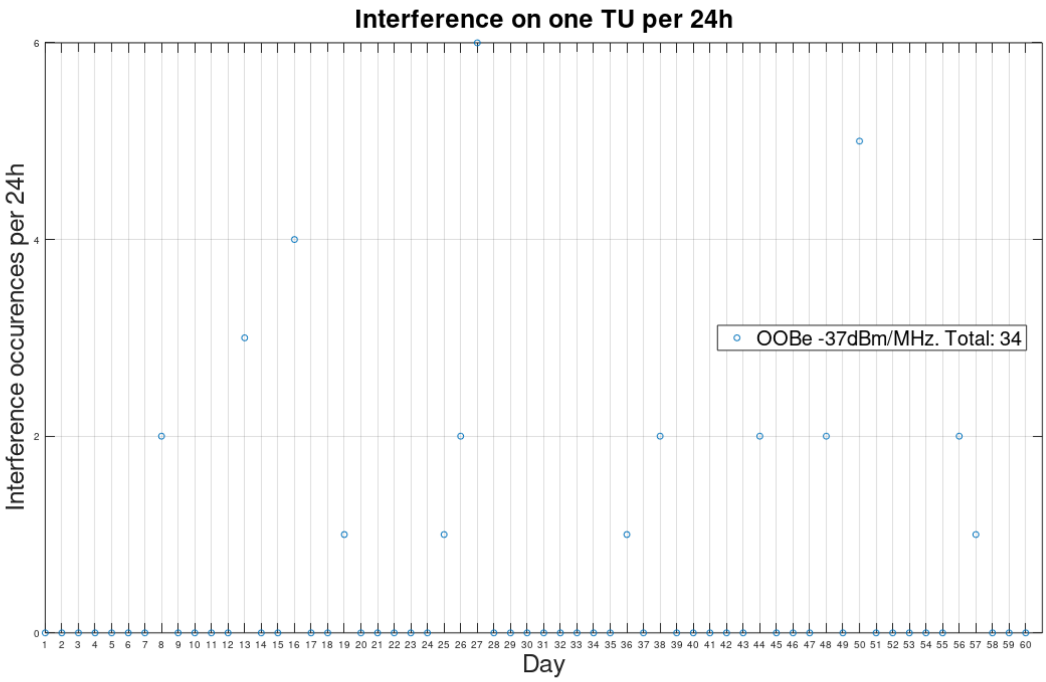

Figure 15: VLP channel prioritisation and all VLP WAS/RLAN devices implementing TPC, metro MP05

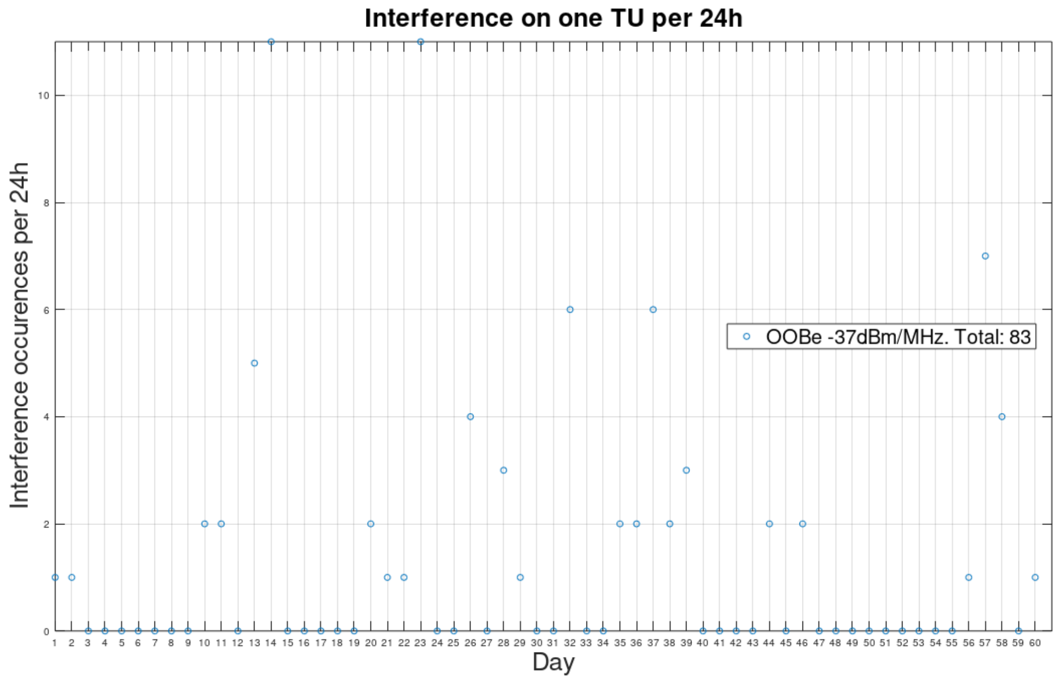

Figure 16: VLP channel prioritisation and all VLP WAS/RLAN devices implementing TPC, metro MP89

7.3.2 Conclusion for VLP onboard interfering a Train Unit

The study shows that the likelihood of interference events lasting more than 1 s from VLP to CBTC would be increased if the OOB emissions are relaxed from -45 dBm/MHz to -37 dBm/MHz from 110, 5 and 89 interference cases per 60 days to 4822, 1282 and 2600 cases, for respectively MP14, MP05 and MP89 metros.

However, when implementing transmit power control and channel prioritisation above 6105 MHz on all VLP devices, together with OOB emissions relaxed to -37 dBm/MHz for the channels below 6105 MHz, the likelihood of interference events is not changed significantly compared to OOB emissions of -45 dBm/MHz.

Therefore, the combination of these two techniques appears to mitigate effectively the likelihood of interference events lasting more than 1s, in case OOB emissions are relaxed. It should be noted that an emergency brake is automatically triggered if a train is not able to receive and successfully demodulate the movement authority message for a period of typically 2.5 s. The study does not assess the probability of WAS/RLAN and CBTC packets colliding within the 1 s time windows.

8 MITIGATION TECHNIQUES

In this section, some mitigation techniques on both VLP WAS/RLAN and CBTC are considered, in order to minimise as much as possible, the risk of interference.

8.1 MITIGATION TECHNIQUES ON VLP WAS/RLAN

Two mitigation techniques are here considered for a WAS/RLAN VLP communicating with another VLP:

- prioritise upper channels in the 6 GHz band;
- implement transmit power control (TPC).

These two features have been made mandatory for VLP devices by the FCC[10] in the USA from 2024 along with an OOB emission level of -27 dBm/MHz to protect road ITS below 5925 MHz directly adjacent to WAS/RLAN above 5925 MHz, i.e. no 10 MHz guard band is applied as in CEPT.

Studies in section 7.2 and section 7.3 show that when applying to VLP devices both transmit power control and giving priority to channels above 6105 MHz, together with VLP OOB emissions relaxed to -37 dBm/MHz, the risk of interference lasting more than 1 s would not change significantly compared to the current situation with an out-of-band limit of -45 dBm/MHz with no mitigation measures.

8.1.1 Priority to the upper channels

When accessing spectrum, the channel selection procedure by a VLP device could give priority to channels above 6105 MHz (instead of a random selection) in order to minimise the risk of interference.

Noting that domestic use cases would not be present in trains, it seems unlikely that a large number of WAS/RLAN channels would be heavily loaded in an urban rail environment. Hence such priority mechanism is understood to be without prejudice for the VLP communication.

As a consequence, a VLP would select lower channels below 6105 MHz only if the spectrum access mechanism has failed with the upper channels. When using channels below 6105 MHz, the channel selection would be reassessed approximately every 100 seconds, for example, in order that VLP initiating communication at home would reassess the channel availability by the time it reaches the urban rail.

It would then become unlikely that the VLP would select the lowest channels in an urban rail environment.

8.1.2 Power control

Expected use cases predominantly require limited coverage ranges. In such configuration, the implementation of Transmit Power Control (TPC) would make unlikely that a VLP device operates at full power. As a consequence, it is expected that TPC will have at least a similar effect on VLP OOB emissions, which would thus be generally below the maximum e.i.r.p. allowed below 5935 MHz.

8.2 MITIGATION TECHNIQUES ON CBTC

Given the results of the studies, CBTC deployments should benefit from the application of the mitigation techniques described above, which are expected to be effective to reduce the risk of interference in most cases. In specific cases where the VLP mitigation techniques would not be sufficient, CBTC systems may consider additional mitigation techniques on a case-by-case basis, such as:

- deploy additional APs
- higher minimum signal levels (e.g. -77 dBm (for wayside) or -76 dBm (for trains)). Depending on the line, this may be needed on a local basis only;

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[10] see https://docs.fcc.gov/public/attachments/FCC-23-86A1.pdf, Appendix A page 100

- allow CBTC stations to transmit at higher power than currently allowed, e.g. up to 26 dBm/MHz e.i.r.p. to allow a total e.i.r.p. of 33 dBm/5MHz (while avoiding any possible impact on FSS satellite receivers).

Studies also highlighted several aspects of CBTC design that have an impact on the overall risk of interference:

- CBTC receiver robustness, meaning that CBTC receivers should be robust against WAS/RLAN wanted emissions in the adjacent band;
- radio isolation between passenger compartment and CBTC train antenna system;
- position of the CBTC AP when in close proximity to the passenger platforms;
- CBTC signal level;
- additional features, such as antenna diversity and/or modulation selected, which could provide additional protection against interference.

The feasibility of retrofitting existing trains or modifying existing train models to enhance the radio isolation between passenger compartment and CBTC train antenna system was not studied (including time for specification, certification, and implementation, taking into account possible service disruptions resulting from operational constraints).

For new lines, the CBTC radio design and the train antenna system should take account of WAS/RLAN VLP OOB emissions and potential related mitigation techniques on WAS/RLAN VLP.

9 CONCLUSIONS

ECC Report 302 [1] and CEPT Report 75 [3] studied the coexistence between Wireless Access Systems including Radio Local Area Networks (WAS/RLAN) operating above 5945 MHz and Communication Based Train Control (CBTC) operating below 5935 MHz. ECC Decision (20)01 [5] harmonises the use of WAS/RLAN in the 5945-6425 MHz band, including Very Low Power (VLP) portable use, with maximum mean[11] 25 mW e.i.r.p., that may operate both indoor and outdoor. VLP WAS/RLAN devices are in the scope of this Report.

ECC Decision (20)01 [5] as published in November 2020 mentioned that "It should be noted that the -45 dBm/MHz OOB limit below 5935 MHz for VLP would allow VLP initial market to take up. CEPT also agreed that this OOB limit should be valid in time only until 31 December 2024 and be re-examined with regard to an opportunity to relax it based on the real IEEE and DSSS Urban Rail interference situation. In absence of the justified evidence, a value of -37 dBm/MHz, for the OOB limit below 5935 MHz, will be adopted from 1 January 2025." ECC Decision is expected to be amended in due course.

This Report gathers findings of laboratory and field measurement campaigns as well as additional studies with the aim of re-examining the OOB emission limit below 5935 MHz for VLP WAS/RLAN devices operating in the 6 GHz band. The measurement campaigns were conducted thanks to the help of the French administration ANFR, the German administration BNetzA, the JRC, and CBTC and WAS/RLAN industry stakeholders.

These measurement campaigns provided new technical elements relevant for interference to a single CBTC link. The studies in the Report first analyse single link interference scenarios. Then based on these analyses, the Report provides probabilistic assessments of the overall risk of interference to the CBTC system. No measurement was performed on the overall resilience of the system to interference.

This Report considered the following four scenarios:

- Scenario 1: impact of a VLP WAS/RLAN operated on a platform to CBTC Access Point (AP);
- Scenario 2: impact of a VLP WAS/RLAN operated on a platform to CBTC Train Unit (TU);
- Scenario 3: impact of a VLP WAS/RLAN operated onboard a train to CBTC TU;
- Scenario 4: impact of a VLP WAS/RLAN operated onboard a train to CBTC AP.

Studies conducted in this Report include:

- Coupling loss approach: VLP OOB emissions potential impact on CBTC through an I/N analysis;
- Coupling loss approach: VLP OOB emissions potential impact on CBTC through an SINR analysis;
- Coupling loss approach: VLP in-band and OOB emissions potential impact on CBTC through a protection ratio analysis;
- Statistical assessments of the overall risk of interference to the CBTC system.

From these studies, it was observed that the critical scenario for the studied RER train is Scenario 2 (VLP on platform vs CBTC TU), while the critical scenario for the studied metro types[12] (labelled as MP14, MP89, and MP05) is Scenario 3 (VLP onboard vs CBTC TU).

9.1 RESULTS OF COUPLING LOSS STUDIES

Some studies demonstrated that VLP with OOB emission levels at both -37 dBm/MHz and -45 dBm/MHz can lead, for some scenarios, to degradation of performance of a single CBTC radio link. The risk of interference is shown to be increased by relaxing the OOB emissions from -45 dBm/MHz to -37 dBm/MHz.

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[11] The "mean e.i.r.p." refers to the e.i.r.p. during the transmission burst, which corresponds to the highest power, if power control is implemented.

[12] For the definition of RER trains and metro trains refer to section 2.4.2

Some other studies demonstrated that with both OOB emission levels there is no degradation of performance of a single CBTC radio link, except for one studied metro type (MP14), lacking a margin of less than 1 dB due to its lower measured coupling loss[13].

The different results mainly come from the variation in the assumptions used for the noise floor, the minimum CBTC signal level, the modulation and the body loss. It was also observed that the coupling loss between the passenger cabin and the CBTC TU can vary significantly between trains. Therefore, the variation in the coupling loss has a significant impact on the coexistence between VLP WAS/RLAN and CBTC.

9.2 RESULTS OF STATISTICAL STUDIES

Noting that an emergency brake is automatically triggered if a train is not able to receive and successfully demodulate the movement authority message for a period of typically 2.5 s, statistical studies were conducted.

A first statistical analysis further analysed the MP14 case and showed that the likelihood of interference is low.

A second statistical analysis on the impact from a VLP WAS/RLAN on platform to a CBTC TU showed that the risk of single link interference is increased from 2.5% to 43% of trains entering a platform when relaxing OOB emissions from -45 dBm/MHz to -37 dBm/MHz, and could be mitigated by transmit power control. It is expected some interference would affect the useful link of a TU, therefore the CBTC system would be affected, although still able to cope in most cases (nominal mode). The system would become more exposed in case of double failures, and in those very rare but critical events, there could be instances of partial or total loss of CBTC communication. A sensitivity analysis showed that with a minimum CBTC signal level of -77 dBm/MHz over the platforms there is no interference with the OOB emissions of -37 dBm/MHz.

A third statistical analysis on the impact from a VLP WAS/RLAN onboard to a CBTC TU showed that the number of interference events per 24 hours (lasting more than 1 second) is low for OOB emissions at -45 dBm/MHz, but substantially increased with OOB emissions relaxed to -37 dBm/MHz (70-fold increase). The study also showed that VLP with OOB emissions at -37 dBm/MHz are unlikely to produce harmful interference to CBTC under the following conditions:

- A VLP would select lower channels below 6105 MHz only if the spectrum access mechanism has failed with the upper channels. When channels below 6105 MHz are used, the channel selection would be reassessed approximately every 100 seconds, for example;
- Transmit Power Control (TPC) would be able to reduce the total power from VLP maximum transmit power P_{max} down to at least P_{max} – 6 dB.

Some possible mitigation techniques on both VLP WAS/RLAN and CBTC and their possible implications are described in section 8.

It has to be noted that the one CBTC receiver with 10 MHz bandwidth measured (ANNEX 5:) responds heterogeneously to changes of OOB emission levels and WAS/RLAN bandwidths. The laboratory measurements did not highlight a CBTC receiver selectivity issue. The measurements of characteristics of this receiver were conducted specifically for the purpose of this study and are not meant to be used or referenced outside the scope of this Report.

[13] Metro MP14 exhibits a 44.2 dB coupling loss while metros MP89 and MP05 exhibit 50.1 dB and 54.2 dB, respectively

ANNEX 1: COEXISTENCE SCENARIOS

A1.1 VLP WAS/RLAN TO CBTC AP

A1.1.1 Scenario 1: VLP WAS/RLAN device operated on a platform to CBTC AP

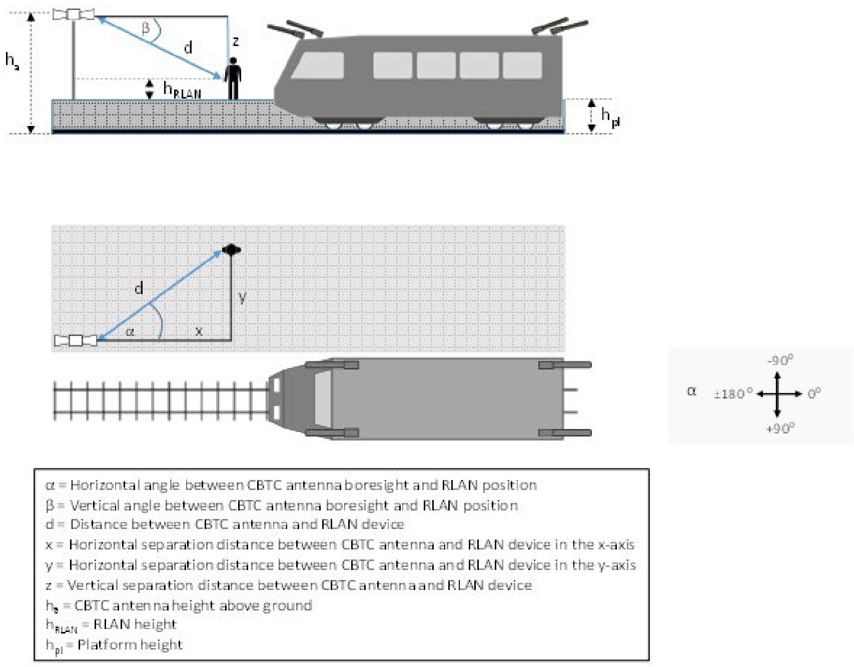

Figure 17: Scenario 1: VLP WAS/RLAN operated on a platform to CBTC AP

A1.1.2 Scenario 4: VLP WAS/RLAN device operated onboard a train to CBTC AP

A person operates a VLP WAS/RLAN device inside a moving train and it is interfering to a CBTC AP. This scenario is based on the layout of the automated metro.

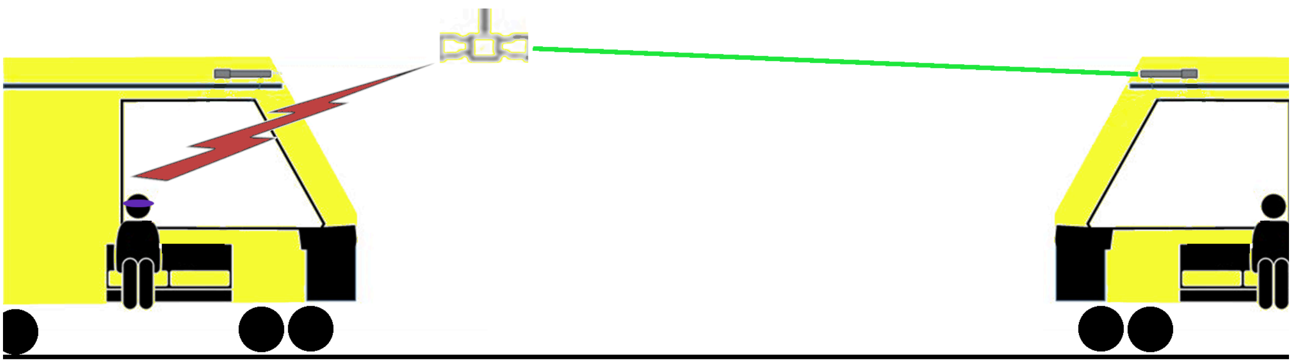

Figure 18: Scenario 4: VLP onboard WAS/RLAN to CBTC AP

A1.2 VLP WAS/RLAN TO CBTC TU

A1.2.1 Scenario 2: VLP WAS/RLAN device operated on a platform to CBTC TU

A user waiting for the train on the platform is operating a portable VLP WAS/RLAN device.

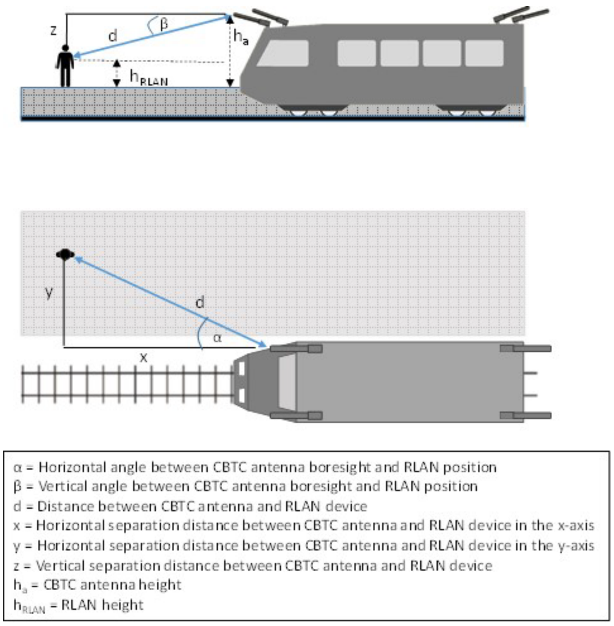

Figure 19: Scenario 2: VLP WAS/RLAN operated on a platform to CBTC TU

A1.2.2 Scenario 3: VLP WAS/RLAN device operated onboard a train to CBTC TU

A person operates a VLP WAS/RLAN device inside a moving train.

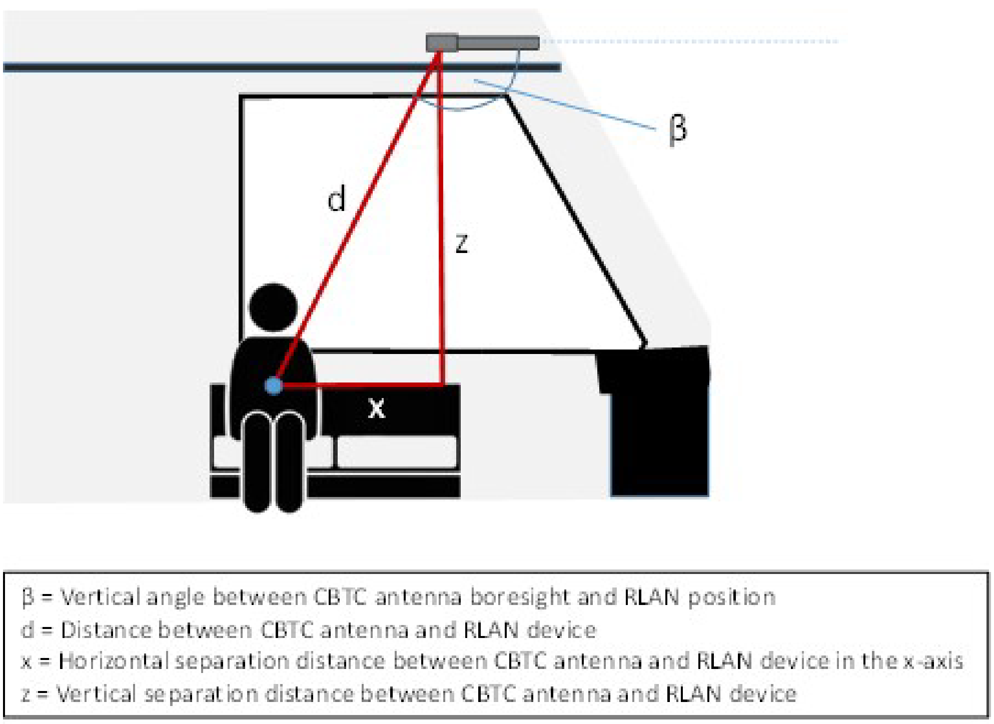

Figure 20: Scenario 3: VLP WAS/RLAN onboard a train to CBTC TU

This scenario is based on the layout of the automated Paris metro train shown in Figure 21.

Figure 21: Automated train for Paris metro Line 1

ANNEX 2: SUMMARY OF THE REPORT OF THE GAGNY MEASUREMENT CAMPAIGN

A2.1 PRESENTATION

During the measurement campaign in the CBTC test base of Gagny (France) on 12 December 2022, a team of radio experts gathered experimental results on the practical Minimum Coupling Loss (MCL) in the interfering link between a VLP and a CBTC receiver in one realistic CBTC environment.

A2.2 DESCRIPTION OF THE TEST ENVIRONMENT

The Gagny test base is a dedicated outdoor urban rail line in the Paris suburb approximately 2 km long, equipped with 5 CBTC access points and one next generation train with 2 CBTC train units.

Test line and escabelle/stepladder

NG Train

Access point

Figure 22: Elements of the Gagny test base

A2.3 MEASUREMENT PROCEDURE

While the potential interference would in reality be from a VLP transmitter into a CBTC receiver, for practical reasons the measurements of the coupling loss were made on the reciprocal link (from CBTC to VLP). The validity of the reciprocity hypothesis was verified in one test setting by one measurement.

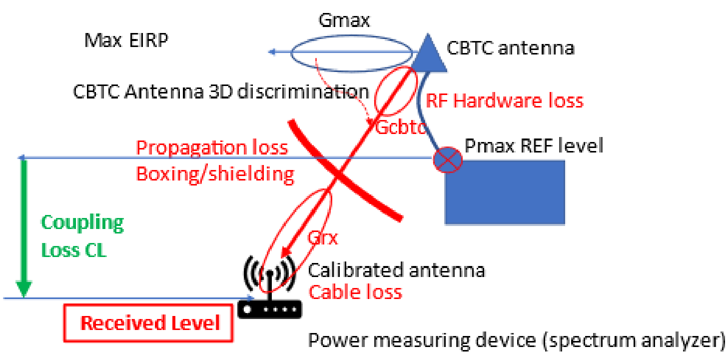

Figure 23: Measurement setup and coupling loss definition

An antenna on a tripod simulated the VLP. The CBTC transceiver was either a CBTC train unit in the front of the train or a CBTC access point.

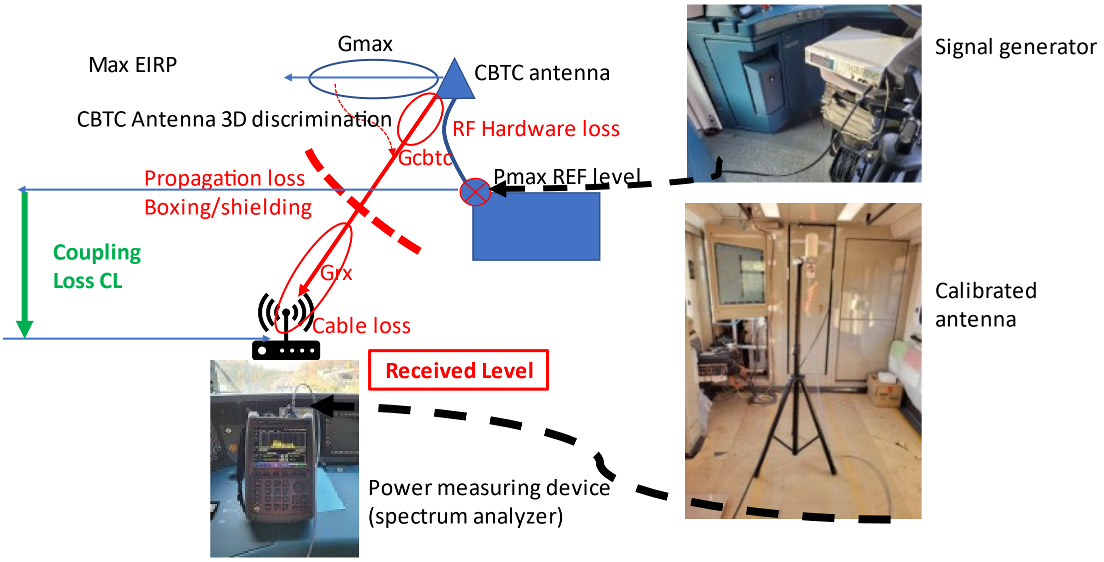

Figure 24: Measurement chain

The measurement chain was made of:

- a signal generator connected to the CBTC antenna (in a train unit or an access point). The signal generator was set at a pre-determined power level and was connected through a cable with known loss to the CBTC antenna feeder departure point from the CBTC transceiver;
- a receiving antenna close to omni and of known gain: the receiving antenna was placed on a tripod at various height thereby simulating a VLP carried by a passenger (including additional height in outdoor cases to simulate that the passenger would be on a platform above ground level);
- the receiving antenna was connected to a spectrum analyser by a cable also of known loss;
- all measurements were made in static conditions both for train and VLP;

The coupling loss between the CBTC transceiver and the receiving spectrum analyser was determined by subtracting the measured received power to the power injected at CBTC antenna system input.

It was then adjusted for the gain of the measurement antenna system by adding the receiving antenna gain minus the cable loss to obtain the minimum coupling loss MCL that would apply between a CBTC transceiver and a VLP with omni gain (assuming no body loss).

A2.4 MEASUREMENT CAMPAIGN DESCRIPTION

After setup of the rail and CBTC environment, the team validated the measurement chain in one outdoor scenario by comparing the received level with the expected level according to a theoretical link budget under Free Space Loss propagation. The team concluded that the measurement chain was operational and reliable.

The team then measured the level of signal received from a CBTC transmitter (AP or TU) in an area or volume close to where the minimal coupling is expected to occur for 4 different test settings described below. The team looked for the hot spot where the level was highest and also gathered information on how the coupling varies locally around the hot spot.

The measurement settings therefore reproduce the radio coupling between respectively:

- setting 1: a VLP on a platform and a CBTC front train unit (the antenna is close to the top above the front windshield)

Figure 25: Setting 1

- setting 2: a VLP on the closest passenger deck and a CBTC front train unit.

Figure 26: Setting 2

- setting 3: a VLP onboard the driver's cabin and a CBTC front train unit, noting this situation is not representative of a passenger use case for the urban rail configuration under test (RER).

Figure 27: Setting 3

- setting 4: a VLP on a platform and a CBTC access point nearby (antenna over the mast around which the operators are gathered).

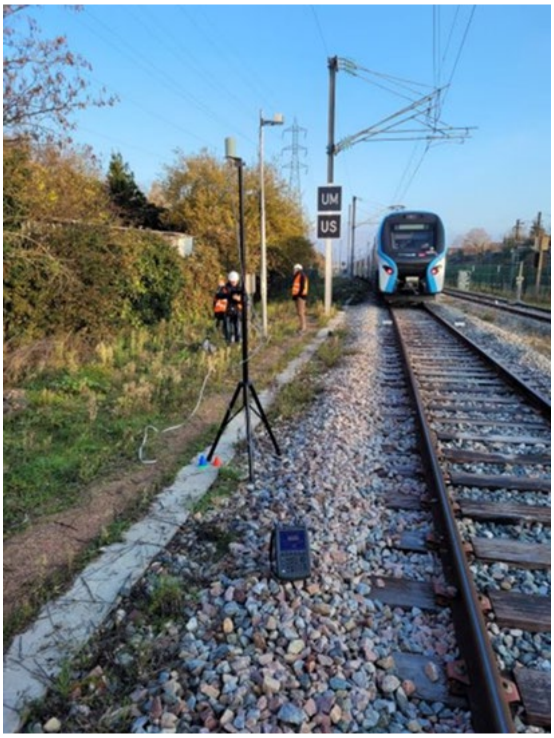

Figure 28: Setting 4

A2.5 CONCLUSIONS

In the test environment, the MCL between a VLP on a platform and a CBTC TU may be close to 56.3 dB with a measurement uncertainty of $\pm$2 dB. This MCL seems in accordance with theory.

In the test environment, the MCL between a VLP passenger onboard a RER train and a CBTC TU may be close to 92 dB. with a measurement uncertainty of $\pm$5 dB. The minimum coupling loss is much higher than the previous case.

In the RER urban rail environment, the MCL between a VLP in a RER driver’s cabin and a CBTC TU may be close to 71.3 dB. with a measurement uncertainty of $\pm$5 dB. The found MCL is higher than the one with a VLP on a platform, and also higher than what would be expected based on a simple modelling with front to back ratio, small ceiling loss and small distance.

The team could not identify with confidence the hot spot and the associated MCL between a passenger in a station and an AP, but in hindsight it is likely to be further away than 10 m from the AP. Further theoretical work and/or test is needed for the practical MCL between a VLP on a platform and an Access Point, exploring a more distant range than previous studies, typically 10 to 20 m instead of 10 m away from the AP, and possibly distinguishing between outdoor and indoor stations.

A2.6 REMARKS

The results are samples in one specific urban rail environment (i.e. outdoor RER train).

The measurement uncertainty which is quoted is the expanded uncertainty (confidence interval of 95%) of the measuring system (spectrum analyser, cable and antenna) under the measurement conditions (including channel variations): it is assessed to be $\pm$2 dB in outdoor case and $\pm$5 dB in onboard cases with non-uniform field.

If relevant, body loss applying to VLP emissions would have to be added to the measured MCL.

ANNEX 3: THEORETICAL CALCULATION OF THE MCL BETWEEN A VLP ON A PLATFORM AND A CBTC ACCESS POINT

The use case is the following: a passenger on the platform holding a VLP is interfering with the CBTC receiver of an access point which can be located either on the platform (diagram in the left) or nearby, either in front of the platform or over the tracks (picture on the right).

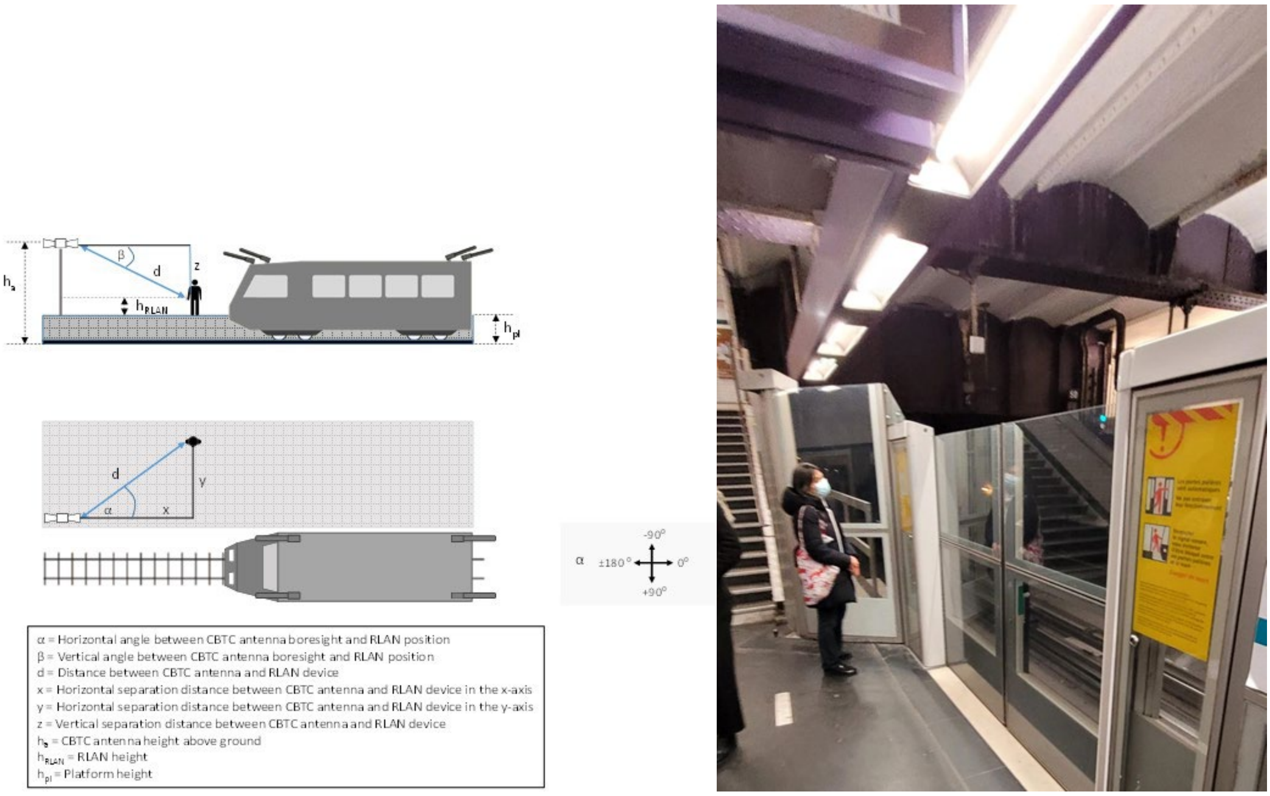

Figure 29: Use case

Because of the very narrow beam of the AP (typically 18x18 degrees), the MCL will not be located very close to the AP, but more likely further than 10 m away: at shorter distance the interferer is outside the AP main lobe, at least in one dimension.

The MCL is to be expected to be found at 15 m and around 66 dB (65.8 dB in the outdoor case and 66.8 dB in the indoor case).

The calculations to simulate the MCL in the VLP versus AP cases are shown in Figure 30 and Figure 31:

- one consistent with outdoor configurations such as Gagny's where the AP is away from the tracks and towards the platform and therefore the VLP can be in the main horizontal lobe; the vertical separation is 2.5 m.
- one consistent with indoor configurations where the AP is hanging from the vault over the tracks. In such a case, there is an offset between the AP main horizontal lobe and the platform: a 2 m horizontal offset and a vertical separation of 2 m. This would correspond to a passenger withdrawn from 1 m of platform edge and an AP 1 m away from platform edge above the tracks.

Both calculations assume an AP hardware loss of 9 dB (feeder and coupler) consistent with previous theoretical studies and ECC Report 302 [1].

COMPANION REPORT	SIMULATION COUPLING WITH ACCESS POINT - OUTDOOR CASE										
	PRESET PARAMETERS										
	CALCULATED										
	Name	Value								unit	Source/calc
GEOMETRY	VLP versus AP										
In the rail axis	X	9	10	12	14	15	16	17	20	m	
Offset from AP vertical plane	Y	0	0	0	0	0	0	0	0	m	
Height separation	Z	2,5	2,5	2,5	2,5	2,5	2,5	2,5	2,5	m	
DISTANCE	D	9,3	10,3	12,3	14,2	15,2	16,2	17,2	20,2	m	SQR(X2+Y2+Z2)
AZIMUTH (TX -> RX)	TETAaz	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	degrees	Arctan(Y/X)
ELEVATION (TX-> RX)	TETAel	15,5	14,0	11,8	10,1	9,5	8,9	8,4	7,1	degrees	Arctan(Z/X)
RADIO											
Frequency	F	5920	5920	5920	5920	5920	5920	5920	5920	MHz	
Feeder and other loss	HW Loss	9,0	9,0	9,0	9,0	9,0	9,0	9,0	9,0	dB	TR 103 580
Boxing loss (antenna casing)	Box loss	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	dB	TR 103 580
Gain	Gmax	18,0	18,0	18,0	18,0	18,0	18,0	18,0	18,0	dBi	TR 103 580
3dB Beamwidth Horizontal	TETAh	18	18	18	18	18	18	18	18	degrees	Data sheet
3dB Beamwidth Vertical	TETAv	18	18	18	18	18	18	18	18	degrees	Data sheet
RX ANTENNA Gain	Gr	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	dBi	Data Sheet
TX Horizontal discrimination	Dih	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	dB	12*(TETAaz/TETAh)2
TX Vertical Discrimination	Div	8,9	7,3	5,1	3,8	3,3	2,9	2,6	1,9	dB	12*(TETAel/TETAv)2
Free Space Loss	FSL	67,3	68,1	69,6	70,9	71,5	72,0	72,5	73,9	dB	32,4+20*log10(F/km)+20log10(D/MHz)
EXPECTED COUPLING LOSS	CL	67,2	66,4	65,7	65,7	65,8	66,0	66,1	66,8	dB	HW loss+ Box loss + Dih+Div-Gmax +FSL

Figure 30: Calculation - outdoor case

COMPANION REPORT	SIMULATION COUPLING WITH ACCESS POINT - INDOOR CASE										
	PRESET PARAMETERS										
	CALCULATED										
	Name	Value								unit	Source/calc
GEOMETRY	VLP versus AP										
In the rail axis	X	9	10	12	14	15	16	17	20	m	
Offset from AP vertical plane	Y	2	2	2	2	2	2	2	2	m	
Height separation	Z	2	2	2	2	2	2	2	2	m	
DISTANCE	D	9,4	10,4	12,3	14,3	15,3	16,2	17,2	20,2	m	SQR(X2+Y2+Z2)
AZIMUTH (TX -> RX)	TETAaz	12,5	11,3	9,5	8,1	7,6	7,1	6,7	5,7	degrees	Arctan(Y/X)
ELEVATION (TX-> RX)	TETAel	12,5	11,3	9,5	8,1	7,6	7,1	6,7	5,7	degrees	Arctan(Z/X)
RADIO											
Frequency	F	5920	5920	5920	5920	5920	5920	5920	5920	MHz	
Feeder and other loss	HW Loss	9,0	9,0	9,0	9,0	9,0	9,0	9,0	9,0	dB	TR 103 580
Boxing loss (antenna casing)	Box loss	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	dB	TR 103 580
Gain	Gmax	18,0	18,0	18,0	18,0	18,0	18,0	18,0	18,0	dBi	TR 103 580
3dB Beamwidth Horizontal	TETAh	18	18	18	18	18	18	18	18	degrees	Data sheet
3dB Beamwidth Vertical	TETAv	18	18	18	18	18	18	18	18	degrees	Data sheet
RX ANTENNA Gain	Gr	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	dBi	Data Sheet
TX Horizontal discrimination	Dih	5,8	4,7	3,3	2,5	2,1	1,9	1,7	1,2	dB	12*(TETAaz/TETAh)2
TX Vertical Discrimination	Div	5,8	4,7	3,3	2,5	2,1	1,9	1,7	1,2	dB	12*(TETAel/TETAv)2
Free Space Loss	FSL	67,3	68,2	69,7	70,9	71,5	72,1	72,6	74,0	dB	32,4+20*log10(F/km)+20log10(D/MHz)
EXPECTED COUPLING LOSS	CL	70,0	68,7	67,3	66,8	66,8	66,8	66,9	67,4	dB	HW loss+ Box loss + Dih+Div-Gmax +FSL

Figure 31: Calculation - indoor case

ANNEX 4: COUPLING LOSS MEASUREMENTS FOR THE DENSE URBAN ENVIRONMENT

A4.1 CONTEXT

The measurement campaign aimed at identifying the minimum coupling loss (MCL) values for different interfering scenarios. The measurements took place on two RATP sites on Paris metro lines 1 and 4 on the 23rd and 24th May 2023 respectively.

Paris metro line 1 uses MP05 trains, while metro line 4 uses simultaneously MP89, MP05 and MP14 trains. At the time when the measurement was conducted, the MP14 trains were being rolled-out.

A4.2 MEASUREMENT SETUP

A Keysight N9961B analyser has been used for the measurements. The device was provided and setup by ANFR. The analyser was connected to a Cobham Ultra Wide Band Omni Antenna (OA2-0.3-10.0V/1505)[14]. provided by the European Commission's Joint Research Centre.

The losses of the connector and cable (4 dB) are accounted for in the measurement results, i.e. the coupling losses given in the table is referenced at the antenna connector.

In order to compute the coupling losses between the antenna port of the CBTC receiver and the measurement antenna[15], the gain and antenna pattern of the measurement antenna have been measured by the European Commission's Joint Research Centre in the European Microwave Signature Laboratory (EMSL) and removed from the direct measurement data by post processing the outcome of the analyser, assuming that the signal comes mainly from a single direction.

The analyser was configured as a power meter by using a 0 span mode with a bandwidth of 5 MHz in order to overlap the CBTC channel used by the train. The centre frequency of this channel was checked with a spectrum measurement.

Because the power varies with the transmitted bits, multiple sweeps have been recorded at all measurement points so that the maximum received power measured is likely to correspond to a time instant when the mean conducted power delivered by the CBTC transmitter was close to its maximum. This is used as a reference Tx power to compute the coupling loss. Peak power received during synchronisation signals (3 dB increase compared to useful bits) is compensated for.

The expanded uncertainty (confidence interval of 95%) of the measuring system (spectrum analyser, cable and antenna) is evaluated at 5 dB.

It is also worth noting that the cable used on the 23rd May experienced during that day in a kind of "on-off" behaviour. In addition, it is likely that some measurements performed during the first day were taken when the train was idle, leading to possibly confuse the power received by neighbouring trains with power from the targeted train. The measurements on that day may therefore be considered as a higher bound of the MCL. The cable was replaced on the 24th May and it was ensured the train would not turn idle.

A4.3 MEASUREMENT LAYOUT

A4.3.1 Scenario 1: impact of an outdoor VLP WAS/RLAN operated on a platform to CBTC AP

This scenario was repeated five times during the first day.

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[14] https://www.european-antennas.co.uk/media/1638/ds1505-060510.pdf

[15] So that when using these results to compute the interfering power at the antenna port of the CBTC receiver, the e.i.r.p. of the interfering signal could be used.

The first four measurements targeted the same AP. The fifth measurement targeted a different AP.

During the first measurement, a train was also present on the platform, and the signal coming the train exceeded the signal from the AP. Consequently, assessing the losses from the AP required to identify the shape of the "burst" coming from the AP only.

Table 42: VLP WAS/RLAN on platform versus AP receiver. Dense Urban

Comment	Coupling Loss (dB)
Platform. 50 cm from platform screen door. Measuring AP at about 10 m. Possible cable issue. The received power from the train was likely exceeding the power received from the AP.	< 66.8 probably from the train < 74.6 from visual inspection of a single sweep
Platform. 50 cm from platform screen door. Measuring AP at 12 m. Possible cable issue.	< 81.2
Platform. 50 cm from platform screen door. Measuring AP at 14.4 m. Possible cable issue.	< 82.7
Platform. 50 cm from platform screen door. Measuring AP at 17 m. Possible cable issue.	< 83.3
Platform. At the end of the platform with train stopped and AP at 10 m. Possible cable issue.	< 81.2
The symbol < is used to recall that the measurement was performed with a possibly lossy cable.	

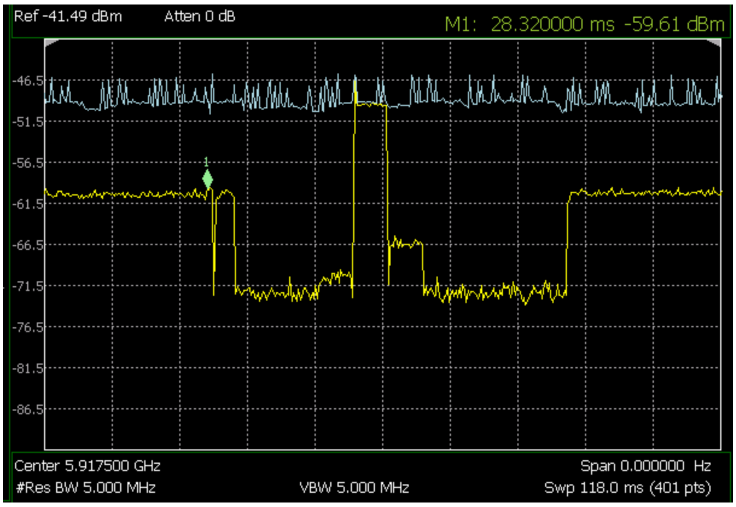

Figure 32: Single sweep visual analysis. The large bursts correspond to the signal from the AP

A4.3.2 Scenario 2: impact of an outdoor VLP WAS/RLAN operated on a platform to CBTC TU

This measurement could not be completed during the measurement campaign.

A4.3.3 Scenario 3: impact of a VLP WAS/RLAN operated onboard a train to CBTC TU

This scenario was repeated for three types of trains. For each train, a grid of points has been used to assess the coupling losses from different locations from where passengers could be standing. The grid layout is illustrated in Figure 34 and Figure 35. Different heights were also used to encompass devices held in various ways.

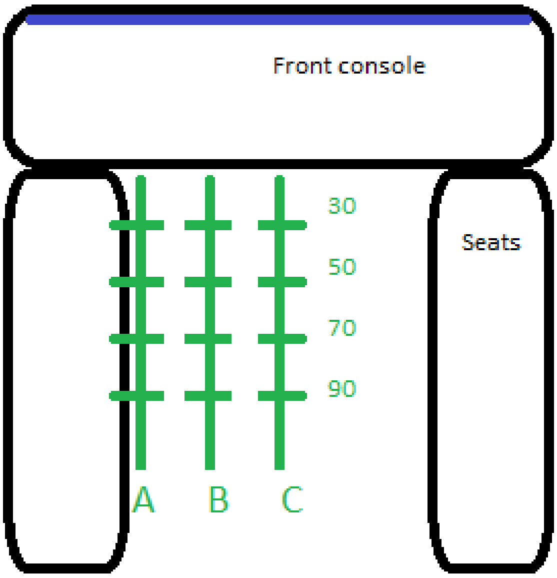

Figure 33: Measurement grid layout

The CBTC antenna is at the vertical of the console above the false roof on the left.

Figure 34: Measurement grid and antenna

The results are presented in Table 43 where the first 30 rows (out of 90), are sorted by increasing value of coupling losses.

Table 43: Onboard VLP WAS/RLAN versus train receiver - Measurements on grids

Train	Point	Height (cm)	Angle from vertical min (°)	Angle from vertical max (°)	Gain min (dB)	Gain max (dB)	Delta gain (max-min)	Gain median (dB)	Coupling Loss (dB) with correction of the measurement antenna gain	Coupling loss (dB) w/o correction of the measurement antenna gain
MP89	A30	115	18.1	30.1	-26.0	-10.0	16.0	-13.3	41.2	54.5
MP89	B30	115	21.4	36.3	-22.8	-7.2	15.6	-11.4	45.7	57.1
MP14	C50	137	60.3	68.8	-0.9	0.4	1.3	-0.4	47.2	47.6
MP14	B30	172	74.6	83.4	0.1	1.9	1.8	1.0	47.8	46.8
MP89	B30	137	27.3	45.8	-12.4	-1.6	10.8	-7.8	48.1	55.9
MP14	B30	137	52.9	64.1	-1.0	-0.1	0.9	-0.5	48.3	48.8
MP05	A30	115	15.2	30.9	-26.0	-7.8	18.2	-12.6	48.4	61.0
MP89	A30	137	23.2	39.1	-15.9	-6.0	9.9	-10.7	48.5	59.2
MP14	C30	172	75.7	83.8	0.1	1.9	1.8	1.0	48.8	47.8
MP05	B30	115	19.2	38.4	-26.0	-6.0	20.0	-11.4	48.9	60.3
MP05	A50	115	26.1	39.1	-12.4	-6.0	6.4	-10.1	49.0	59.1
MP14	A50	137	58.6	67.4	-1.0	0.1	1.1	-0.6	49.5	50.1
MP89	A30	172	40.6	65.9	-4.7	0.6	5.2	-0.5	49.6	50.1
MP14	C30	137	54.9	65.4	-1.0	-0.1	0.9	-0.5	49.6	50.1
MP89	A50	115	28.5	39.4	-11.9	-6.0	5.9	-9.5	49.6	59.1
MP14	B50	172	77.8	84.5	-0.3	1.9	2.2	0.7	49.6	48.9
MP14	C70	137	64.5	71.5	-0.8	0.7	1.5	0.0	49.7	49.7
MP14	A70	137	63.4	70.6	-0.9	0.7	1.6	-0.2	50.2	50.4
MP14	A50	172	77.5	84.3	-0.3	1.9	2.2	0.7	50.5	49.8
MP14	C90	172	81.6	86.0	-0.3	1.5	1.8	0.5	50.5	50.0
MP05	A50	137	32.7	48.7	-11.1	0.5	11.6	-4.7	51.0	55.7
MP05	A30	137	19.7	40.0	-26.0	-6.0	20.0	-11.4	51.1	62.5
MP14	B50	115	45.1	56.0	-1.6	0.6	2.2	-0.2	51.2	51.4
MP14	A30	137	51.8	63.1	-1.0	0.2	1.2	-0.4	51.3	51.7
MP89	B50	115	30.3	43.1	-11.9	-3.2	8.8	-7.1	51.5	58.6

Train	Point	Height (cm)	Angle from vertical min (°)	Angle from vertical max (°)	Gain min (dB)	Gain max (dB)	Delta gain (max-min)	Gain median (dB)	Coupling Loss (dB) with correction of the measurement antenna gain	Coupling loss (dB) w/o correction of the measurement antenna gain
MP89	B50	137	37.6	52.7	-7.0	0.6	7.6	-1.6	51.6	53.2
MP14	C50	172	78.3	84.7	-0.3	1.9	2.2	0.7	51.8	51.1
MP14	C90	137	67.8	73.6	-0.6	1.4	1.9	0.4	51.8	51.4
MP05	B30	137	24.6	48.0	-13.2	-0.3	12.9	-7.8	51.9	59.7
MP14	B50	137	59.2	68.0	-1.0	0.4	1.4	-0.5	52.0	52.5
MP89	A50	172	55.0	72.5	-1.0	1.4	2.4	-0.2	52.5	52.7
MP14	A30	115	37.3	49.6	-7.0	0.5	7.5	-3.2	52.8	56.0
MP14	B70	137	63.8	71.0	-0.9	0.7	1.6	-0.2	52.8	53.0
MP89	A90	115	44.4	55.4	-1.6	0.6	2.2	-0.2	53.1	53.3
MP14	B30	115	38.4	50.9	-6.2	0.6	6.8	-1.6	53.2	54.8
MP89	B90	172	69.2	80.3	-0.2	1.9	2.1	0.7	53.4	52.7
MP05	B50	137	35.1	53.5	-8.5	0.6	9.1	-1.9	53.5	55.4
MP05	A30	162	32.0	61.5	-11.1	0.6	11.7	-0.7	53.6	54.3
MP05	C90	137	53.3	65.0	-1.0	-0.1	0.9	-0.5	53.7	54.2
MP14	B90	137	67.3	73.3	-0.6	1.4	1.9	0.4	53.9	53.5
MP89	B50	172	57.0	74.5	-1.0	1.6	2.6	-0.2	53.9	54.1
MP89	A50	137	35.5	49.0	-8.5	0.5	9.1	-3.6	54.2	57.8
MP05	B70	137	44.2	58.6	-1.6	0.6	2.2	-0.3	54.4	54.7
MP14	A90	172	81.3	85.8	-0.3	1.5	1.8	0.5	54.4	53.9
MP05	A70	137	42.9	55.7	-3.3	0.6	3.9	-0.4	54.5	54.9
MP14	A90	137	67.1	73.0	-0.6	1.4	1.9	0.4	54.5	54.1
MP89	B30	172	45.9	70.5	-1.6	0.7	2.4	-0.3	54.5	54.8
MP89	A90	137	52.1	63.8	-1.0	-0.1	0.9	-0.5	54.7	55.2
MP05	A70	162	58.4	72.8	-1.0	1.4	2.4	-0.2	54.8	55.0
MP14	A90	115	54.7	62.9	-1.0	-0.1	0.9	-0.5	55.0	55.5
MP89	B90	137	52.8	64.8	-1.0	-0.1	0.9	-0.5	55.1	55.6
MP89	C30	137	35.5	52.7	-8.5	0.6	9.1	-1.9	55.2	57.1
MP14	C70	172	80.2	85.4	-0.3	1.5	1.8	0.5	55.4	54.9

Train	Point	Height (cm)	Angle from vertical min (°)	Angle from vertical max (°)	Gain min (dB)	Gain max (dB)	Delta gain (max-min)	Gain median (dB)	Coupling Loss (dB) with correction of the measurement antenna gain	Coupling loss (dB) w/o correction of the measurement antenna gain
MP05	B30	162	38.7	67.7	-6.2	0.6	6.8	-0.5	55.6	56.1
MP89	C50	137	42.5	57.0	-3.3	0.6	3.9	-0.4	55.9	56.3
MP05	B50	115	28.2	44.0	-11.9	-3.2	8.8	-7.8	55.9	63.7
MP14	B90	172	81.4	85.9	-0.3	1.5	1.8	0.5	55.9	55.4
MP89	C70	172	66.5	78.7	-0.6	1.8	2.4	0.6	56.0	55.4
MP14	A50	115	44.4	55.1	-1.6	0.6	2.2	-0.2	56.1	56.3
MP05	C30	162	49.7	72.3	-1.0	1.4	2.4	-0.2	56.6	56.8
MP05	B90	137	51.3	62.9	-1.0	0.2	1.2	-0.4	56.7	57.1
MP14	A70	172	79.7	85.2	-0.3	1.9	2.2	0.7	56.9	56.2
MP05	B70	162	59.5	74.5	-1.0	1.6	2.6	-0.2	57.0	57.2
MP14	B90	115	55.0	63.3	-1.0	-0.1	0.9	-0.5	57.0	57.5
MP05	C70	137	47.5	61.8	-1.0	0.6	1.6	-0.2	57.1	57.3
MP05	A50	162	48.4	68.2	-1.0	0.6	1.6	-0.3	57.2	57.5
MP14	A30	172	74.1	83.1	0.1	1.9	1.8	1.0	57.2	56.2
MP05	B50	162	50.9	71.4	-1.0	0.7	1.8	-0.3	57.3	57.6
MP05	C70	162	62.3	76.3	-0.9	1.7	2.6	0.3	57.7	57.4
MP05	B90	115	43.5	54.4	-3.3	0.6	3.9	-0.4	57.9	58.3
MP89	B70	172	64.3	77.4	-0.8	1.7	2.5	0.4	58.0	57.6
MP89	C90	137	54.6	66.3	-1.0	0.1	1.1	-0.5	58.4	58.9
MP89	C30	172	55.0	74.5	-1.0	1.6	2.6	-0.2	58.6	58.8
MP89	A90	172	68.7	79.9	-0.2	1.8	2.0	0.7	58.9	58.2
MP05	C90	162	66.9	78.0	-0.6	1.8	2.4	0.6	59.5	58.9
MP89	C70	137	49.0	61.2	-1.0	0.6	1.6	-0.3	59.7	60.0
MP89	A70	137	45.0	56.3	-1.6	0.6	2.2	-0.3	60.0	60.3
MP05	A90	162	64.8	75.9	-0.8	1.6	2.4	0.3	60.1	59.8
MP05	C30	137	34.0	54.9	-11.1	0.6	11.7	-1.9	60.1	62.0
MP89	C90	172	70.4	80.9	-0.1	1.9	2.0	0.8	60.4	59.6
MP89	A70	172	63.4	76.4	-0.9	1.7	2.6	0.3	60.5	60.2

Train	Point	Height (cm)	Angle from vertical min (°)	Angle from vertical max (°)	Gain min (dB)	Gain max (dB)	Delta gain (max-min)	Gain median (dB)	Coupling Loss (dB) with correction of the measurement antenna gain	Coupling loss (dB) w/o correction of the measurement antenna gain
MP05	A90	137	50.5	61.1	-1.0	0.2	1.2	-0.4	60.5	60.9
MP05	B90	162	65.4	76.9	-0.8	1.7	2.5	0.4	61.2	60.8
MP05	C50	162	56.4	74.3	-1.0	1.6	2.6	-0.2	61.2	61.4
MP05	A90	115	42.7	52.3	-3.3	0.6	3.9	-0.4	61.6	62.0
MP14	B70	172	79.9	85.3	-0.3	1.9	2.2	0.7	61.7	61.0
MP89	B90	115	45.1	56.7	-1.6	0.6	2.2	-0.3	62.0	62.3
MP89	C50	172	61.3	76.7	-0.9	1.7	2.6	0.1	63.2	63.1
MP05	C50	137	40.7	58.3	-4.7	0.6	5.2	-0.5	65.0	65.5
MP89	B70	137	46.1	58.4	-0.8	0.6	1.4	-0.2	65.2	65.4

For every train, the front compartment was also "scanned" by moving the receiving antenna (at a height of 137 cm). The results are given in Table 44.

Figure 35: Scanning the MP14 train

Table 44: Onboard VLP WAS/RLAN versus train receiver - Scanning.

Train	Coupling Loss (dB)
MP14	44.2
MP89	48.3
MP05	53.5

It is worth noting that the most recent trains (MP14) exhibit the lowest coupling losses, which is probably due to the use of composite material.

Two additional refinements of this scenario have been assessed emulating respectively a passenger standing at the front or seated at the second row of seats with an equipment at the head height. These are illustrated in Figure 36 and Figure 37. The results are given in Table 45.

Figure 36: Standing at the front. MP05 train

Figure 37: Seated at the front. MP05 train

Table 45: Onboard VLP WAS/RLAN versus train receiver - Specific scenarios (standing and seated)

Train	Coupling Loss (dB)	Comment
MP05	< 59.2	Front cabin. Holding the antenna at ears height. Standing at the front. Possible cable issue.
MP05	< 63.3	Front cabin. Holding the antenna at ears height. Seated on the second seat. Possible cable issue.
The symbol < is used to recall that the measurement was performed with a possibly lossy cable.		

Another refined scenario has been investigated. where the passenger is holding a device while leaning against the console. This is illustrated by Figure 39. The results are given in Table 46.

Figure 38: Leaning against the console. MP14 train

Table 46: Onboard VLP WAS/RLAN versus train receiver - Specific scenarios (leaning)

Train	Coupling Loss (dB)	Comment
MP14	50.3	Leaning against the console while holding the antenna
Note: Beware receiving antenna attenuation may be significant at this location.		

A4.3.4 Scenario 4: impact of a VLP WAS/RLAN operated onboard a train to CBTC AP

The scenario was assessed on both days, hence two access point locations could be measured from two different trains. Results are given in Table 47.

Table 47: Onboard VLP WAS/RLAN versus AP receiver

Train	Coupling Loss (dB)	Comment
MP14	45.6 dB. But CL may be attributed to the train.	One way
MP14	49.1 dB. But CL may be attributed to the train. 59 dB. By visual inspection of individual sweeps.	Return. By visual inspection, a CL lower than 62 dB can be attributed to the AP. The AP antenna configuration in the depot has two splitters. For a typical antenna configuration, the losses may be around 59 dB.
MP05	< 62.0	Possible cable issue
The symbol < is used to recall that the measurement was performed with a possibly lossy cable.		

ANNEX 5: LABORATORY MEASUREMENT OF ONE CBTC RECEIVER IN THE PRESENCE OF INTERFERENCE IN ADJACENT FREQUENCIES

A5.1 MEASUREMENT SETUP

The aim of this measurement campaign is to determine the carrier-to-interference ratio (C/I_{adj}), also called protection ratio, between a WAS/RLAN system as an interferer and a CBTC system as a victim. The CBTC system that is also using WAS/RLAN technology for RF transmission and reception operates in the frequency range 5915-5935 MHz and the WAS/RLAN system works in the frequency band above 5945 MHz.

For the CBTC system a bandwidth of 10 MHz has been chosen and for the WAS/RLAN system the bandwidths of 20, 40 and 80 MHz have been chosen. Figure 39 shows the various frequency and signal combinations used in the laboratory measurements.

The measurements were performed between 21 and 27 February 2023 at the test laboratory of the BNetzA in Munich, Germany.

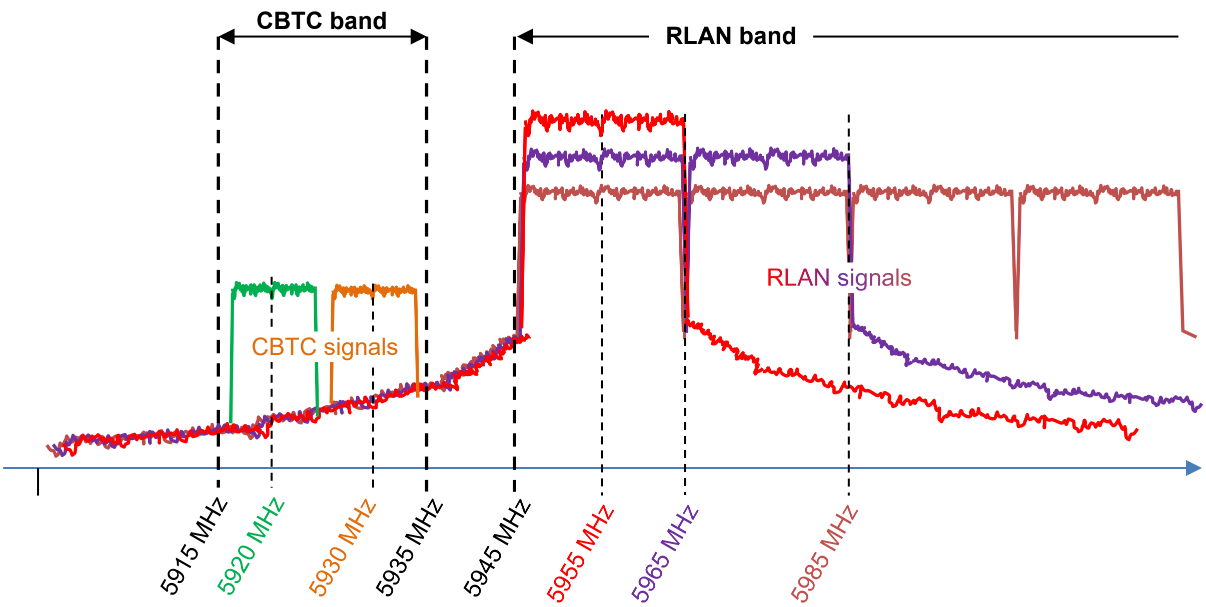

Figure 39: Frequency arrangement

A5.2 MEASURED CBTC RECEIVER

The Tx/Rx was a WAS/RLAN-based CBTC onboard unit (OBU) provided by a CBTC system manufacturer for the measurements as the device under test (DUT). It was controlled via LAN from a laptop using terminal software. Through this software it was possible to set the desired RF parameters such as Tx/Rx frequency, bandwidth and transmission speed/data rate.

A5.3 WANTED CBTC SIGNALS

The wanted signal was generated by a CBTC rack operating as the access point. This device is hereafter called “server” as it provides the data for the DUT. It was designed with the same technology as the DUT.

The following RF parameters for the wanted signal were defined and used for the C/I_{adj} measurements:

- Centre frequencies: 5920 and 5930 MHz;
- Bandwidth: 10 MHz;
- Signal level: 10 and 30 dB above measured system sensitivity.

The low level is on one hand sufficiently high above the sensitivity of the DUT to exclude receiver noise as being the dominant interfering factor. On the other hand, it is low enough to ensure that the DUT receiver is still in a linear state (not overdriven) so that the unwanted emissions of the interfering WAS/RLAN signal may be the dominant interfering factor.

The high level is used to determine a possible transition to an overload or saturation state of the DUT receiver where the existence of a strong signal outside the wanted channel is the dominant interfering factor.

To explain certain anomalies that appeared during the measurements, it was necessary to perform some measurements with additional levels ranging from 3 dB to 40 dB above system sensitivity.

For all measurements, a stream of 300 UDP packets/s with a length of 200 bytes was generated by the server.

In actual implementations, data over the CBTC system can be divided into mandatory (or safety-relevant) data to control the train, and additional (optional) data required by the customer. The technology allows to transmit data with different speeds and FEC. Safety-relevant data is transmitted with more robust subcarrier modulation and more error correction as optional data. It was agreed to limit the measurements to the two modulation/FEC combinations, which are realistic for the transmission of safety-relevant data as shown in Table 48. Note that due to the equal packet length and number of packets per second, the two RF data rates result in different pulse/pause ratios of the wanted signals.

Table 48: RF parameters of the wanted CBTC signals

Speed (Note 1)	Subcarrier modulation	FEC	Burst length	Pause length	Channel occupancy
3 Mbit/s	BPSK	1/2	750 µs	3.23 ms	23%
9 Mbit/s	QPSK	3/4	280 µs	3.14 ms	9%
Note 1: "Speed" refers to the nominal gross data rate during bursts only (not the average data rate).					

All eight combinations of the above-mentioned RF parameters (2 frequencies, 2 signal levels and 2 data rates) were measured.

All levels in this Report are RMS levels measured during the burst only (“AV-burst levels”), and in the whole respective signal bandwidth (CBTC: 10 MHz, WAS/RLAN: 20, 40 or 80 MHz respectively). No bandwidth correction must therefore be applied when using the results for compatibility studies.

Figure 40 and Figure 41 show the spectrum and timings of the wanted signals.

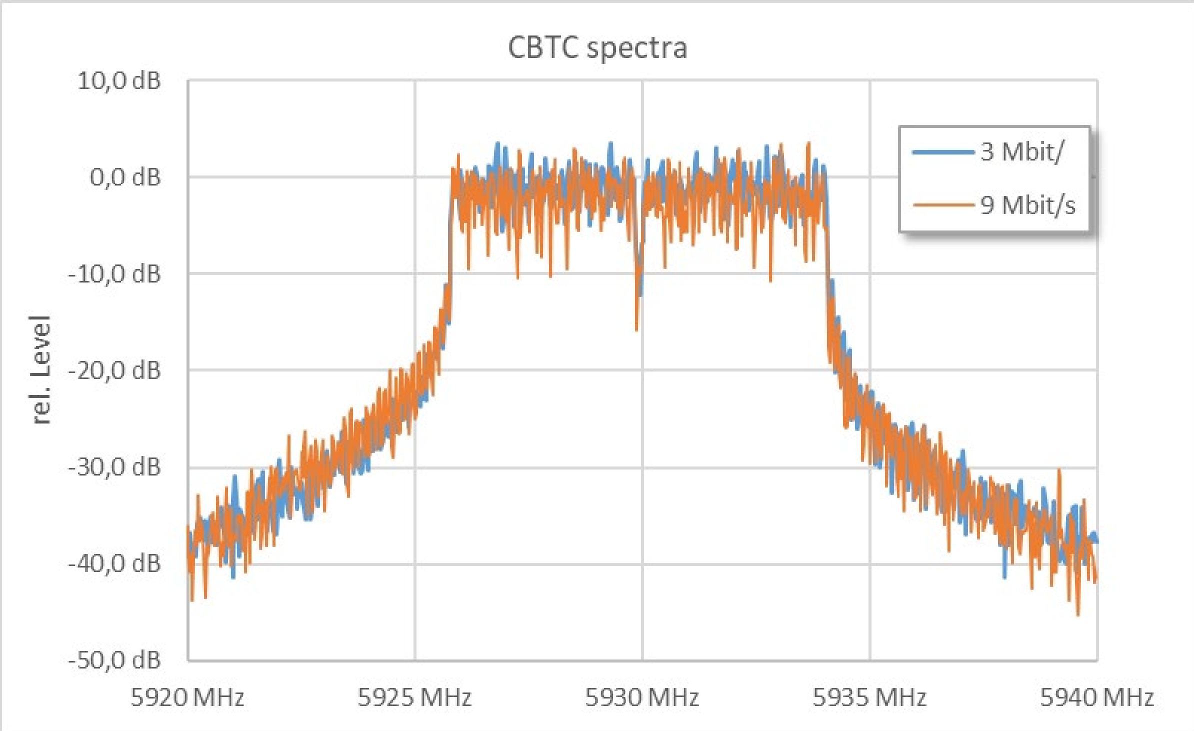

Figure 40: Spectra of the wanted CBTC signals (example on 5930 MHz)

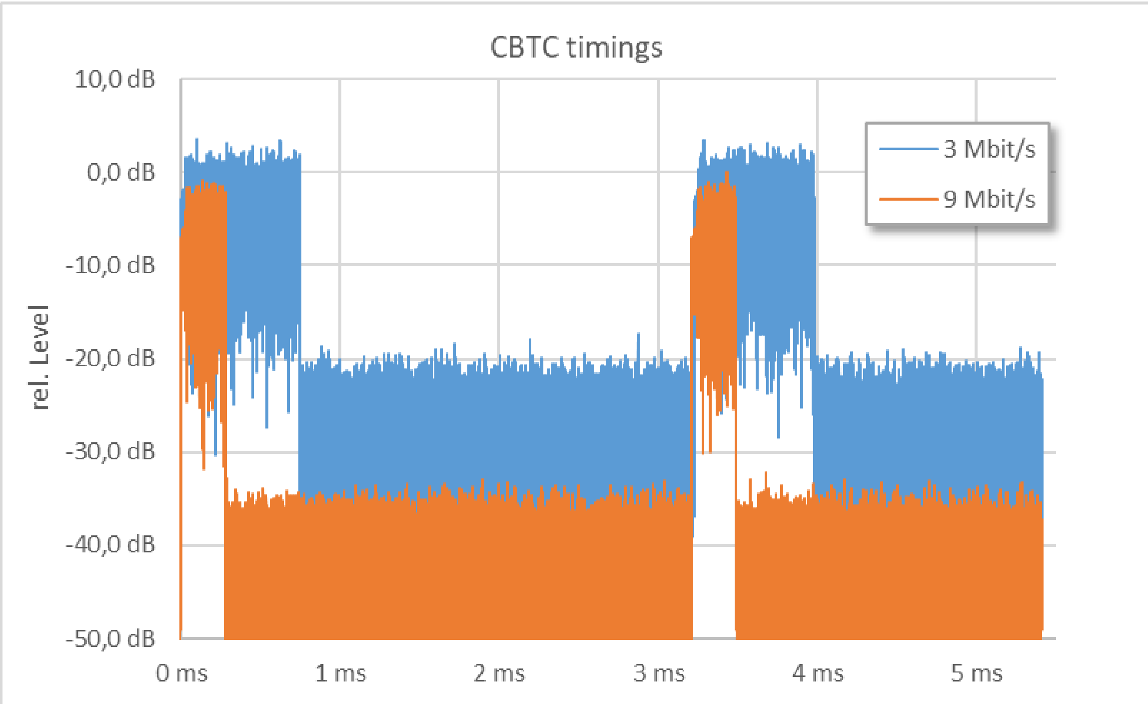

Figure 41: Timings of the wanted CBTC signals

A5.4 INTERFERING WAS/RLAN SIGNALS

The WAS/ RLAN signals used as interferers were originally taken from a consumer access point operating in the 5 GHz range, performing a TCP/IP download of a large file. The complex data signals (I/Q) were recorded with a real time spectrum analyser (Tektronix RSA6114). Digital processing then takes place in order to achieve the special out-of-band (OOB) levels in the CBTC band. The resulting I/Q files were then loaded into a vector signal generator (R&S SMBV100), modulated on the desired frequency and repeatedly played out. This setup provides stable and reproducible WAS/RLAN signals on the desired frequency with adjustable level.

As shown in Figure 39, the centre frequencies of the WAS/RLAN signals were always set in a way that the lower spectrum edge is close to 5945 MHz. This corresponds to the lowest usable WAS/RLAN channel in the 6 GHz band and always provides the same frequency spacing (“guard band”) between WAS/RLAN and CBTC signal, independent of the WAS/RLAN bandwidth.

ECC Decision (20)01 [5] distinguishes between low power indoor (LPI) and very low power devices (VLP), each having a different maximum radiated power (e.i.r.p.) limit for unwanted signal levels below 5935 MHz to protect CBTC, which are defined as absolute power densities per MHz. Furthermore, from 1st January 2025 on, the ECC Decision foresees that the allowed unwanted emission level for VLPs is less restrictive if there is no justified evidence for interference gained until then.

To assess pure overload or saturation effects, an additional WAS/RLAN signal of 20 MHz was created where the OOB emissions are suppressed as much as possible (> 65 dB rel.).

Figure 43 to Figure 45 show the lower spectrum part of the WAS/RLAN signals used for the measurements, in comparison with the OOB limits from ECC Decision (20)01. The OOB levels have been designed to closely match, but not exceed, those limits. The relative limit lines result from the difference between maximum on-channel power and absolute OOB power, after bandwidth correction. The WAS/RLAN interfering OOB signals shown in the below graphs, were an output created by the signal generator (R&S SMBV100).

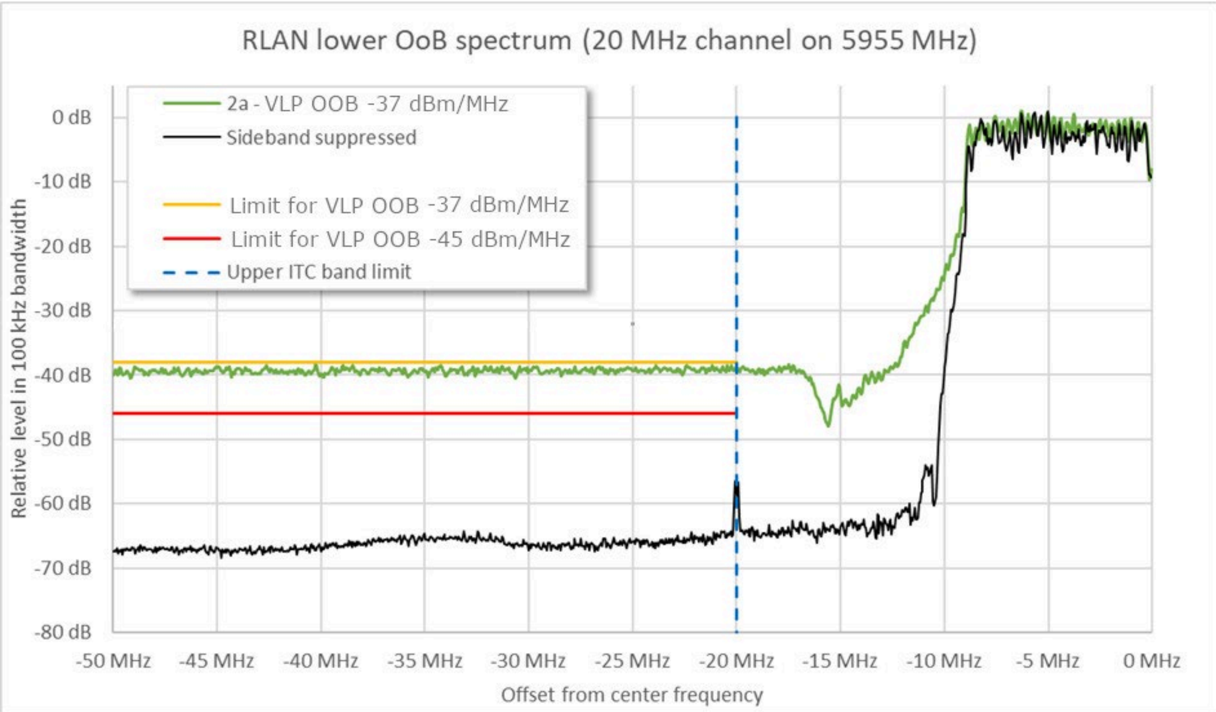

Figure 42: Lower OOB spectrum of the interfering WAS/RLAN signals with 20 MHz bandwidth

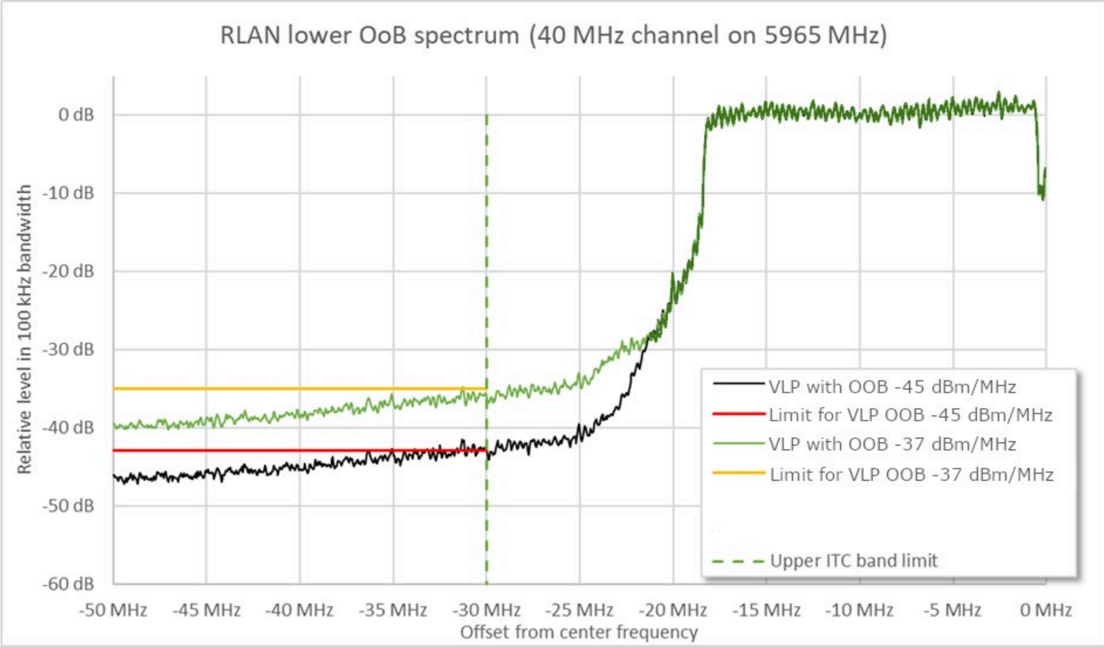

Figure 43: Lower OOB spectrum of the interfering WAS/RLAN signals with 40 MHz bandwidth

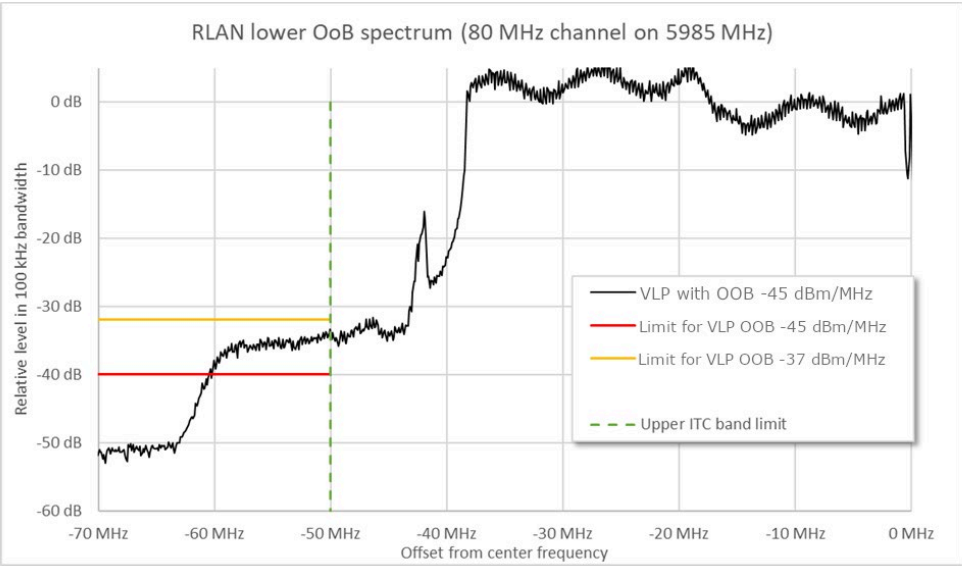

Figure 44: Lower OOB spectrum of the interfering WAS/RLAN signals with 80 MHz bandwidth

Due to bandwidth limitations of the vector signal generator, the 80 MHz WAS/RLAN signal could only be measured against a CBTC signal on 5930 MHz, because the OOB emissions on 5920 MHz could not be generated to match the mask.

The measurements aimed to determine the dependencies of the C/I_{adj} from the following parameters of the interfering WAS/RLAN signal:

- Threshold where the receiver shows overload or saturation effects;
- Dependency on the WAS/RLAN bandwidth;
- Dependency on the OOB level of the WAS/RLAN signal;
- Dependency on the channel occupancy of the WAS/RLAN signal;
- Dependency on the burst duration of the WAS/RLAN signal.

To isolate the dependencies as much as possible, only the parameter under investigation was altered while all other parameters of the WAS/RLAN signal were kept constant. For practical reasons, it was not possible to measure all possible combinations of the above parameters. It was therefore agreed to measure these dependencies with selected WAS/RLAN signals where the other parameters, except the one to be measured, are fixed. The interfering WAS/RLAN signals used for the measurements are defined in Table 49 to Table 53.

Table 49: RF parameters of the WAS/RLAN signals to determine the dependency on wanted level

#	Centre frequency	Bandwidth	OOB level at 5935 MHz	Wanted level above sensitivity	Channel occupancy	Burst/Pause duration
1	5955 MHz	20 MHz	As low as possible	3 dB, 10 dB, 20 dB, 30 dB and 40 dB	96%	1 ms/50 µs

Table 50: RF parameters of the WAS/RLAN signals to determine the dependency on WAS/RLAN bandwidth

#	Centre frequency	Bandwidth	OOB level at 5935 MHz	Wanted level above sensitivity	Channel occupancy	Burst/Pause duration
2a	5955 MHz	20 MHz	-37 dBm/MHz	10 dB, 30 dB	96%	1 ms/50 µs
2b	5965 MHz	40 MHz	-37 dBm/MHz	10 dB, 30 dB	96%	1 ms/50 µs
2c	5985 MHz	80 MHz	-37 dBm/MHz	10 dB, 30 dB	96%	1 ms/50 µs

Table 51: RF parameters of the WAS/RLAN signals to determine the dependency on OOB level

#	Centre frequency	Bandwidth	OOB level at 5935 MHz	Wanted level above sensitivity	Channel occupancy	Burst/Pause duration
3a	5965 MHz	40 MHz	-45 dBm/MHz	10 dB, 30 dB	96%	1 ms/50 µs
3b	5965 MHz	40 MHz	-37 dBm/MHz	10 dB, 30 dB	96%	1 ms/50 µs

Table 52: RF parameters of the WAS/RLAN signals to determine the dependency on channel occupancy

#	Centre frequency	Bandwidth	OOB level at 5935 MHz	Wanted level above sensitivity	Channel occupancy	Burst/Pause duration
4a	5965 MHz	40 MHz	-37 dBm/MHz	10 dB, 30 dB	96%	1 ms/50 µs
4b	5965 MHz	40 MHz	-37 dBm/MHz	10 dB, 30 dB	50%	500 µs/500 µs
4c	5965 MHz	40 MHz	-37 dBm/MHz	10 dB, 30 dB	10%	50 µs/500 µs
4d	5965 MHz	40 MHz	-37 dBm/MHz	10 dB, 30 dB	2%	50 µs/2.5 ms
4e	5965 MHz	40 MHz	-37 dBm/MHz	10 dB, 30 dB	1%	50 µs/5 ms

Table 53: RF parameters of the WAS/RLAN signals to determine the dependency on burst timing

#	Centre frequency	Bandwidth	OOB level at 5935 MHz	Wanted level above sensitivity	Channel occupancy	Burst/Pause duration
5a	5965 MHz	40 MHz	-37 dBm/MHz	10 dB, 30 dB	50%	50 µs/50 µs
5b	5965 MHz	40 MHz	-37 dBm/MHz	10 dB, 30 dB	50%	500 µs/500 µs
5c	5965 MHz	40 MHz	-37 dBm/MHz	10 dB, 30 dB	50%	2 ms/2 ms

Signal 1 has very low OOB emissions, so that overload or saturation of the DUT receiver may be assumed as the dominant effect. The 20 MHz bandwidth ensures the highest possible power density of an interfering signal close to the wanted channel, which challenges the selectivity of the DUT receiver.

The signals 3a and 3b represent the maximum allowed VLP WAS/RLAN OOB levels mentioned in the ECC Decision (20)01 [5]. The bandwidth of 40 MHz was selected because preliminary measurements done by the JRC showed that the frequency range of the unwanted emissions reaches further down, compared to signals with 20 MHz bandwidth. Therefore, the 40 MHz signals may have a higher interference potential when the OOB emissions inside the CBTC channel are the dominant interfering effect.

Regarding the channel occupancy, the signal with 96% represent a situation where the user performs a download of a larger file or buffers a video of high quality. It is to be noted that the channel occupancy is not linked to the duty cycle or “RF activity factor” used in ECC Report 302. For instance, if a 20 minute video stream would require a 1% DC[16], it may be downloaded:

- At once at the beginning of the video, during a 12 s period, during which the channel occupancy would be close to 100%, or
- Evenly during the course of the video, with lower channel occupancy, or
- Using any “caching” strategy selected by the application.

The burst and pause durations for signals 5a – c were determined by the given channel occupancies and the assumption that 50 µs is the shortest possible burst and pause length of the WAS/RLAN systems.

The unwanted emissions in the OOB domain are only present during the bursts. During the pauses, the signal as well as the OOB emissions are completely switched off. This can be seen in the Figure 46 which shows a spectrogram of a 10 ms sequence from one of the 40 MHz WAS/RLAN signals. The level is shown in different colours (temperature scale). This also represents the real behaviour of WAS/RLAN devices.

[16] The actual figure would vary depending on the link throughput (i.e. experienced channel conditions), WAS/RLAN performance, and actual size of the video. 1% DC could correspond to e.g. a video of 2.4 Gb and channel capacity of about 200 MBit/s.

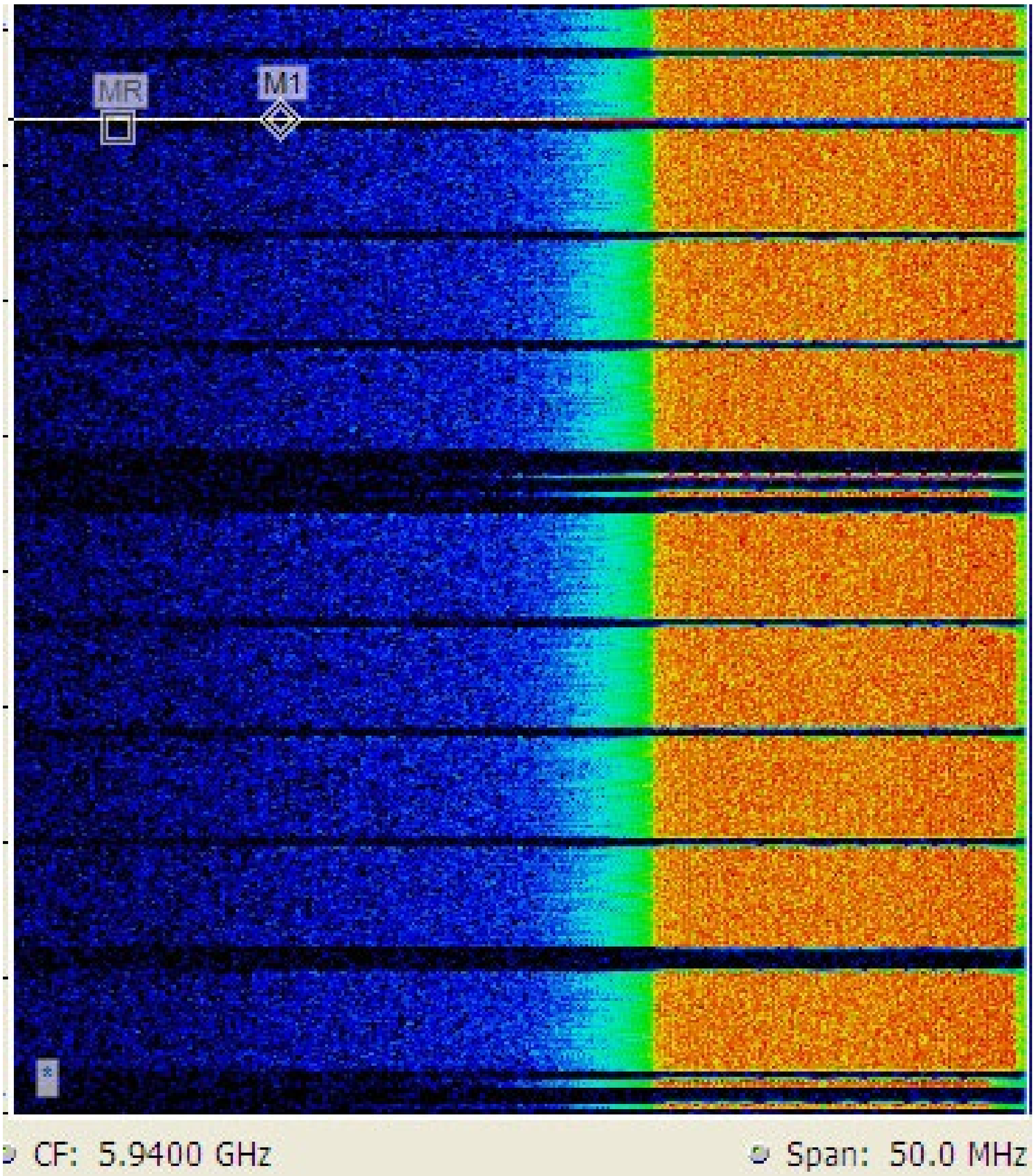

Figure 45: Spectrogram of a 40 MHz WAS/RLAN signal with 97% channel occupancy

A5.5 FAILURE CRITERION

In accordance with the agreed measurement concept, the failure or performance criterion was defined to be an average packet error rate exceeding 1%. This was evaluated during a transmission of 300 UDP packets per second with a length of 200 bytes each.

A5.6 MEASUREMENT SETUP

Since the measurements were based on UDP packet transmission, it was sufficient to establish a one-way connection from the “server” to the DUT (“downlink”). A return uplink path was not necessary. This allowed a simplified setup compared to the originally planned measurement concept. The final setup used for the measurements is shown in Figure 46.

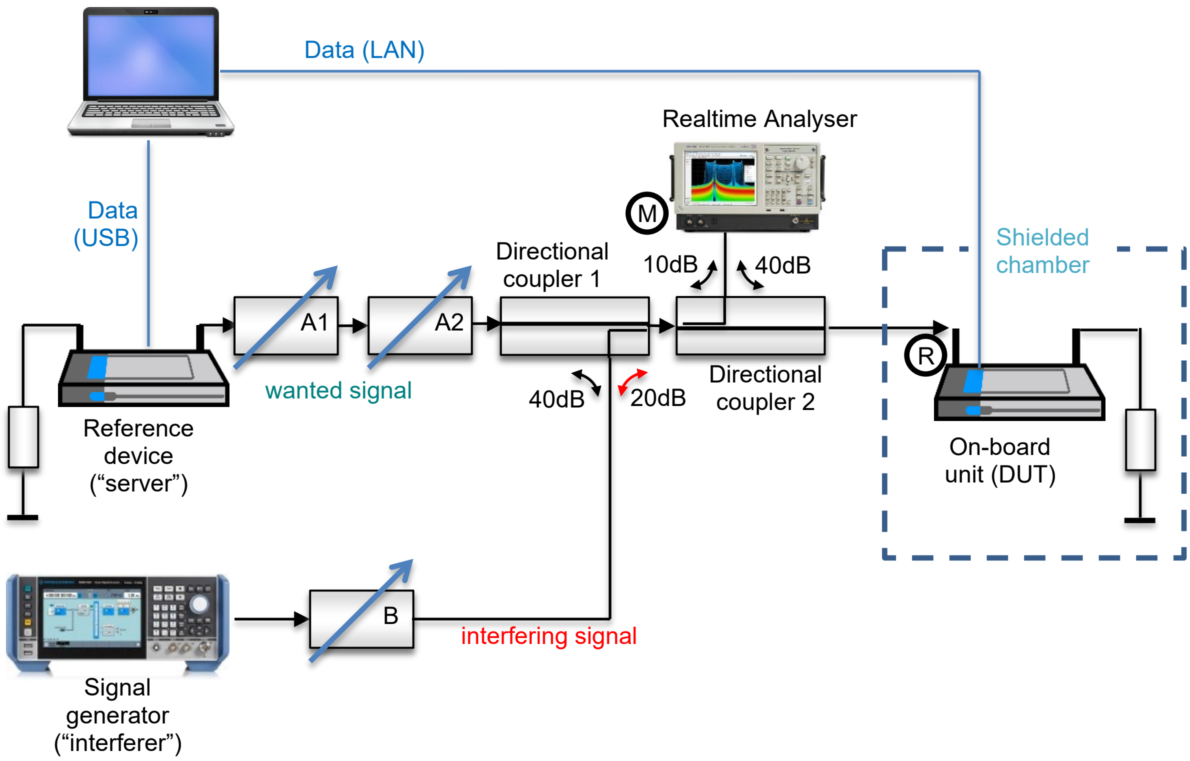

Figure 46: Measurement setup

All signal levels are given as AV-burst levels at the receiver input (point "R"), over the whole signal bandwidth. Wanted and interfering signals were measured at point "M". The attenuation difference between points "M" and "R" was measured in advance and happened to be 0 dB by coincidence (the RF cable between directional coupler 2 and "R" had an attenuation of 10 dB). The real time analyser allows measurement of the channel power during bursts by manual selection of the actual measurement time. Figure 47 shows such an average burst level measurement on the example of interfering signal 5b (40 MHz bandwidth, 500 µs burst and 500 µs pause time).

The right window shows the total level in 40 MHz vs time. The signal is captured for 1.2 ms. The blue bar indicates the position and length of the selected measurement time of 500 µs. The left window shows the channel power measurement during the selected time only. The resulting AV-burst value is marked with a red circle (40.54 dBm).

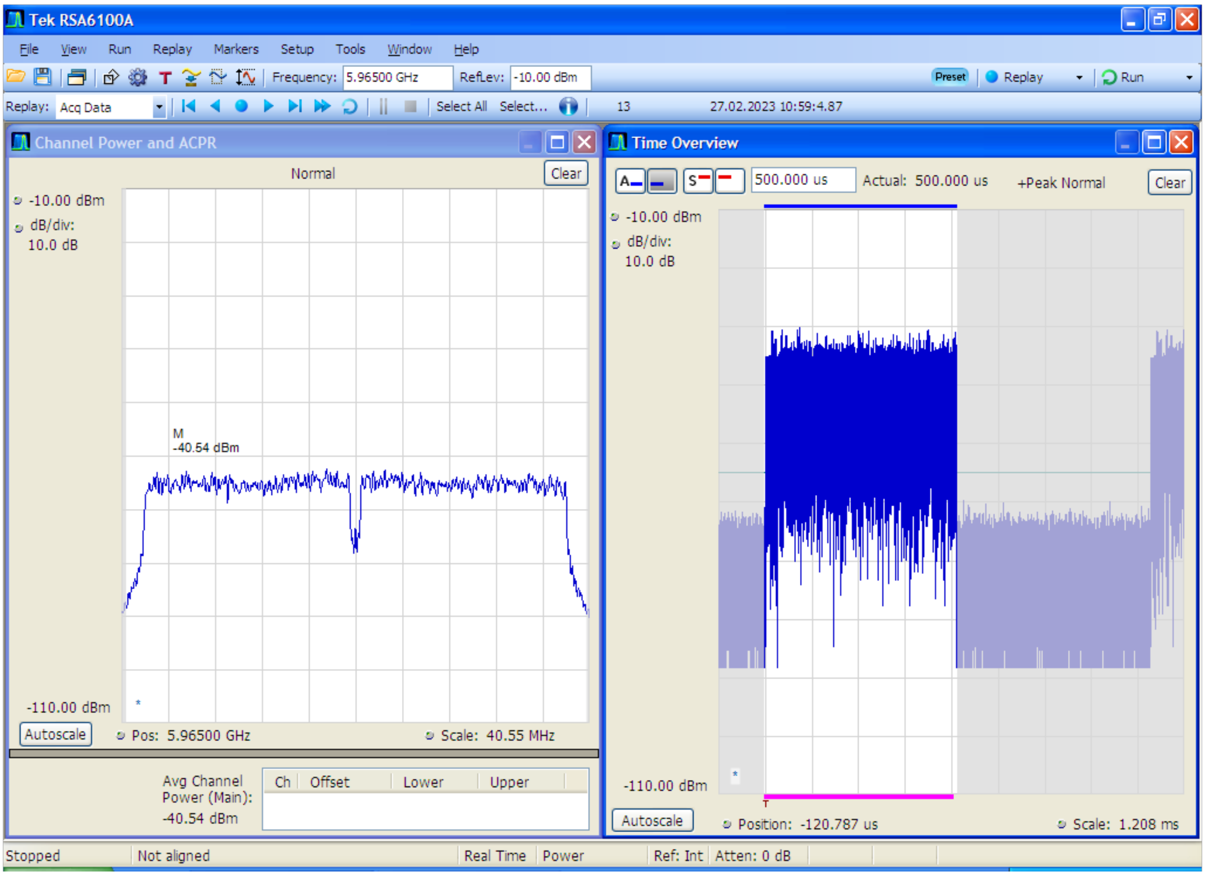

Figure 47: Average burst level measurement on the example of interfering signal 5b

A5.7 SENSITIVITY MEASUREMENT

The sensitivity of the DUT was measured using the same failure criterion as for the C/I_{adj} measurements (packet error rate of 1%). With the interferer switched off, the wanted signal level was decreased in steps of 1 dB using attenuators A1 and A2 until the packet error rate just exceeded 1%. The recorded sensitivity level is 1 dB above this value. This is the lowest receive level where the packet error rate remains below 1%.

Table 54 shows the result for both frequencies and data rates.

Table 54: Sensitivity of the DUT

Centre frequency	Data rate / mod. / FEC	Min. wanted receive level
5920 MHz	3Mbit/s / BPSK / ½	-94 dBm
5920 MHz	9 Mbit/s / QPSK / ¾	-91 dBm
5930 MHz	3Mbit/s / BPSK / ½	-94 dBm
5930 MHz	9 Mbit/s / QPSK / ¾	-91 dBm

As a result, the wanted signal level was adjusted to -84 dBm and -64 dBm for C/I_{adj} measurements at 3 Mbit/s, and -81 dBm and -61 dBm for measurements at 9 Mbit/s. This corresponds to wanted levels 10 and 30 dB above sensitivity.

A5.8 C/I$_{ADJ}$ MEASUREMENTS

A5.8.1 General procedure

The general measurement procedure to determine the C/I$_{adj}$ was as follows:

1. A wanted signal connection between reference device and DUT was established on the desired frequency (5920 or 5930 MHz). Using the attenuators A1 and A2, the wanted level was adjusted at 10 or 30 dB above the sensitivity determined in section A5.7.

2. A stream of numbered UDP packets was sent from the server to the DUT. The packet error rate was monitored through software on the laptop.

3. Then, the interfering WAS/RLAN signal level was gradually increased until the packet error rate exceeded 1%. This interfering level was recorded. The difference between wanted and interfering level is the C/I$_{adj}$.

The following sections contain graphic presentations of the measurement results for each investigated parameter of the interfering WAS/RLAN signal. Because the results for the two CBTC frequencies and the two data rates may not be directly linked, they are shown in different graphs. Therefore, the dependency of each parameter results is four graphs, with the exception of overload/saturation effects which were measured only at one frequency and with one WAS/RLAN signal.

A5.8.2 Overload/saturation effects

To measure possible overload or saturation effects, interfering signal 1 (see Table 48) was used. Since this signal has suppressed OOB emissions, it could be expected that only the presence of a strong interfering signal outside the wanted channel causes interference. This may be either because of limited receiver selectivity, or overload effects.

Table 55: Parameters for overload/saturation measurements

Parameter	Value
Tx signal	UDP packets
Frequency	5930 MHz
Bandwidth	10 MHz
Packet length	200 bytes
Speed	3 Mbit/s
Interfering signal	1
Interfering frequency	5955 MHz
Bandwidth	20 MHz
OOB level	none/as low as possible
Ch. Occupancy	96%
Burst/pause	1 ms / 50 µs
Failure criterion	Packet error rate > 1%

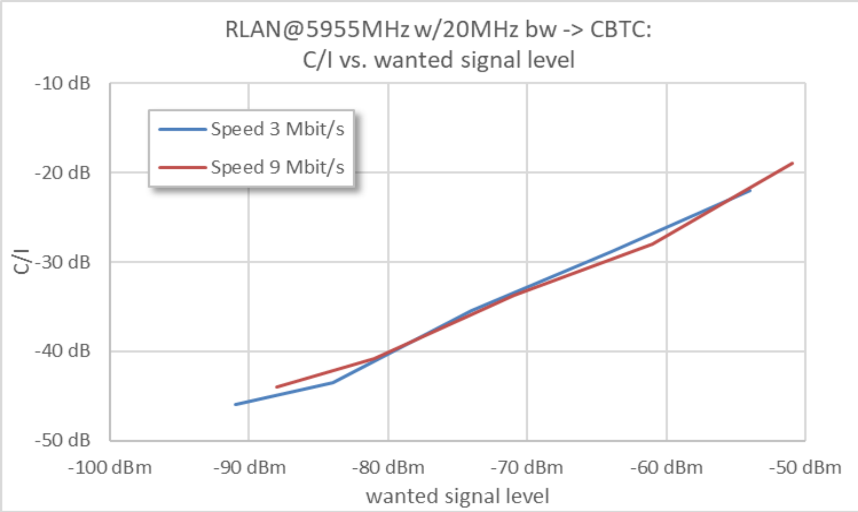

Figure 48: C/I_{adj} dependency on wanted signal level - WAS/RLAN at 5955 MHz 20 MHz bandwidth

Observations:

- The C/I_{adj} varies over the whole range of wanted signal levels, even from as low as 3 dB above sensitivity to 10 dB above sensitivity. This may indicate that some sort of automatic gain control (AGC) is implemented, as it is unlikely that the receiver is already overloaded at these low levels. Insufficient selectivity is obviously not the dominating factor here;
- The C/I_{adj} values for the selected WAS/RLAN signal are independent of the CBTC data rate;
- The laboratory measurement does not highlight a CBTC receiver selectivity issue.

A5.8.3 C/I_{adj} dependency on the WAS/RLAN bandwidth

These measurements have been conducted with WAS/RLAN signals 2a, 2b and 2c (see Table 49 for details). Due to the limited OOB bandwidth of the vector signal generator, the 80 MHz WAS/RLAN signal could not be measured against a CBTC signal on 5920 MHz.

Table 56: Parameters of the C/I_{adj} measurements at different WAS/RLAN bandwidths

Parameter	Value
Tx signal	UDP packets
Frequency	5920 MHz
Bandwidth	10 MHz
Packet length	200 bytes
Speed	3 MBit/s
Interfering signal	2
Interfering frequency	(variable)
Bandwidth	(variable)
OOB level	-37 dBm/MHz
Ch. Occupancy	96%
Burst/pause	1 ms / 50 µs

Parameter	Value
Failure criterion	Packet error rate > 1%

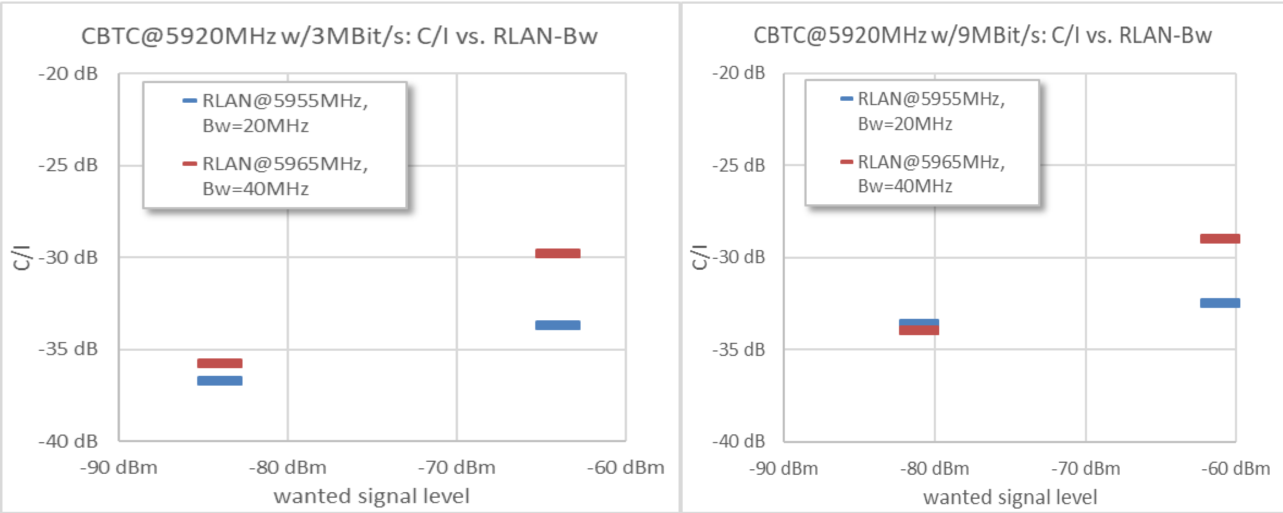

Figure 49: C/I$_{adj}$ for WAS/RLAN with different bandwidths against CBTC on 5920 MHz

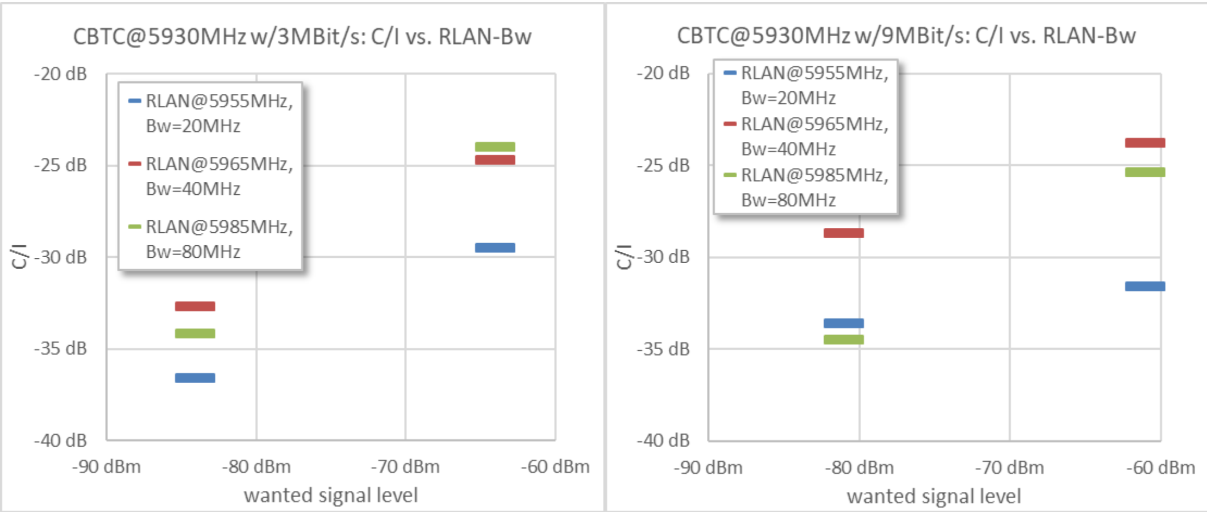

Figure 50: C/I$_{adj}$ for WAS/RLAN with different bandwidths against CBTC on 5930 MHz

Observations:

- The 20 MHz wide WAS/RLAN signal requires the lowest C/I$_{adj}$. However, this may be due to the fact that the OOB emissions especially of the used 40 and 80 MHz WAS/RLAN signals could not perfectly be matched to the limit lines;
- With very view exceptions, the C/I$_{adj}$ required for 40 MHz wide WAS/RLAN is the highest. Even 80 MHz wide WAS/RLAN have less interference potential;
- The difference of the C/I$_{adj}$ at 3 Mbit/s and 9 Mbit/s is mostly less than 5 dB.

A5.8.4 C/I$_{adj}$ dependency on the OOB level

These measurements have been conducted with RLAN signals 3a and 3b (see Table 50 for details).

Table 57: Parameters of the C/I$_{adj}$ measurements at different WAS/RLAN OOB levels

Parameter	Value
Tx signal	UDP packets
Frequency	5920 MHz
Bandwidth	10 MHz
Packet length	200 bytes
Speed	3 MBit/s
Interfering signal	3
Interfering frequency	(variable)
Bandwidth	40 MHz
OOB level	(variable)
Ch. Occupancy	96%
Burst/pause	1 ms / 50 µs
Failure criterion	Packet error rate > 1%

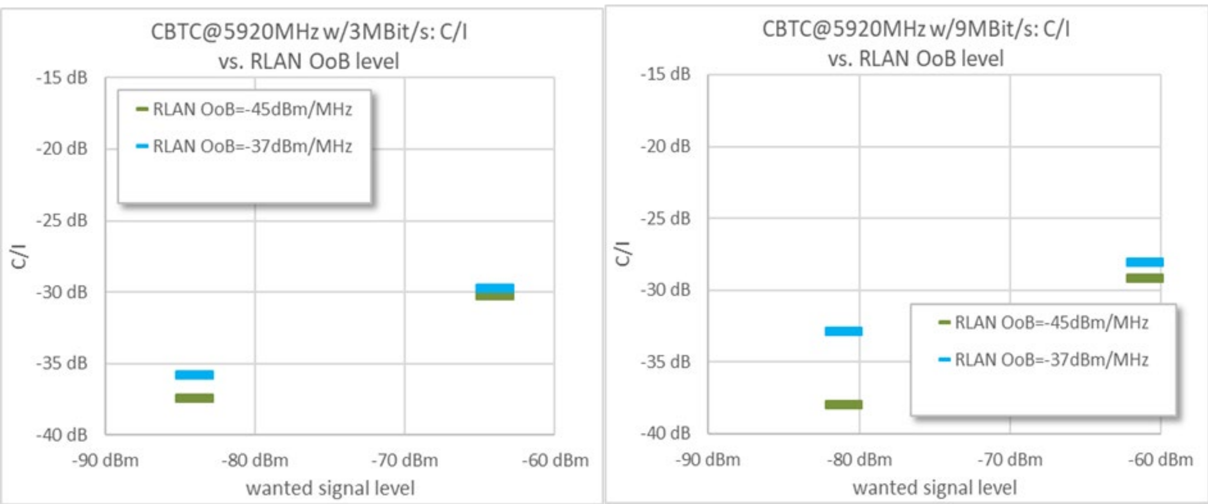

Figure 51: C/I$_{adj}$ for WAS/RLAN with different OOB levels against CBTC on 5920 MHz

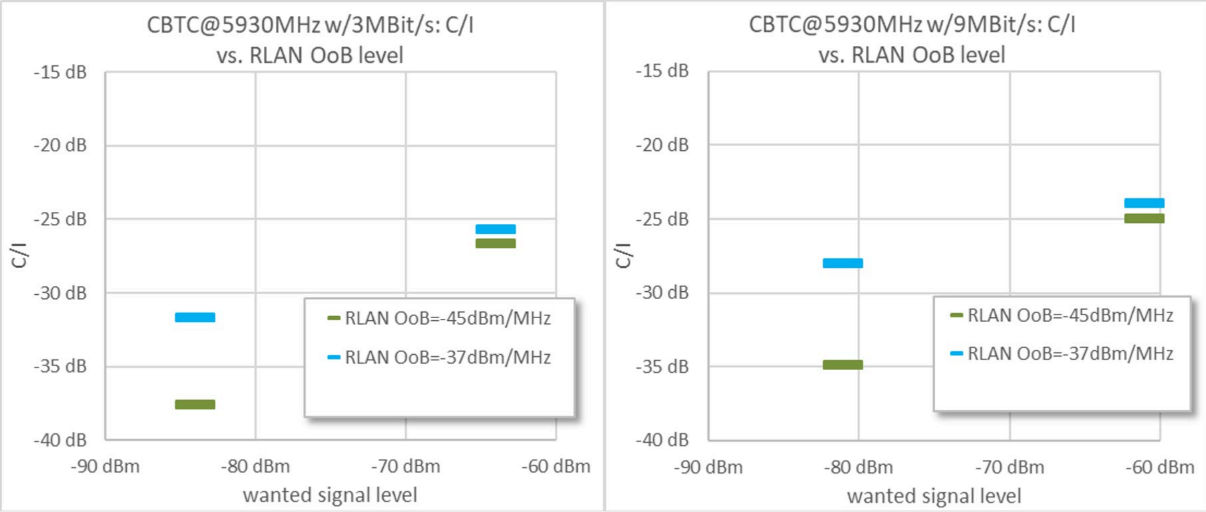

Figure 52: C/I_{adj} for WAS/RLAN with different OOB levels against CBTC on 5930 MHz

Observations:

- The dependency of the required C/I_{adj} on the OOB level is clearly visible, especially at the lower wanted signal level. This behaviour is expectable;
- The difference in C/I_{adj} between LPI WAS/RLAN and current VLP is up to 13 dB;
- The less stringent OOB levels for VLP WAS/RLAN from 2025 on causes an increase of required C/I_{adj} of 6 to 7 dB.
- The measurements do not indicate a CBTC receiver selectivity issue.

A5.8.5 C/I_{adj} dependency on the WAS/RLAN channel occupancy

These measurements have been conducted with WAS/RLAN signals 4a to 4e with channel occupancies ranging from 1% to 96% (see Table 51 for details).

Table 58: Parameters of the C/I_{adj} measurements at different WAS/RLAN channel occupancies

Parameter	Value
Tx signal	UDP packets
Frequency	5920 MHz
Bandwidth	10 MHz
Packet length	200 bytes
Speed	3 MBit/s
Interfering signal	4
Interfering frequency	5965 MHz
Bandwidth	40 MHz
OOB level	-37 dBm/MHz
Ch. Occupancy	(variable)
Burst/pause	(variable)
Failure criterion	Packet error rate > 1%

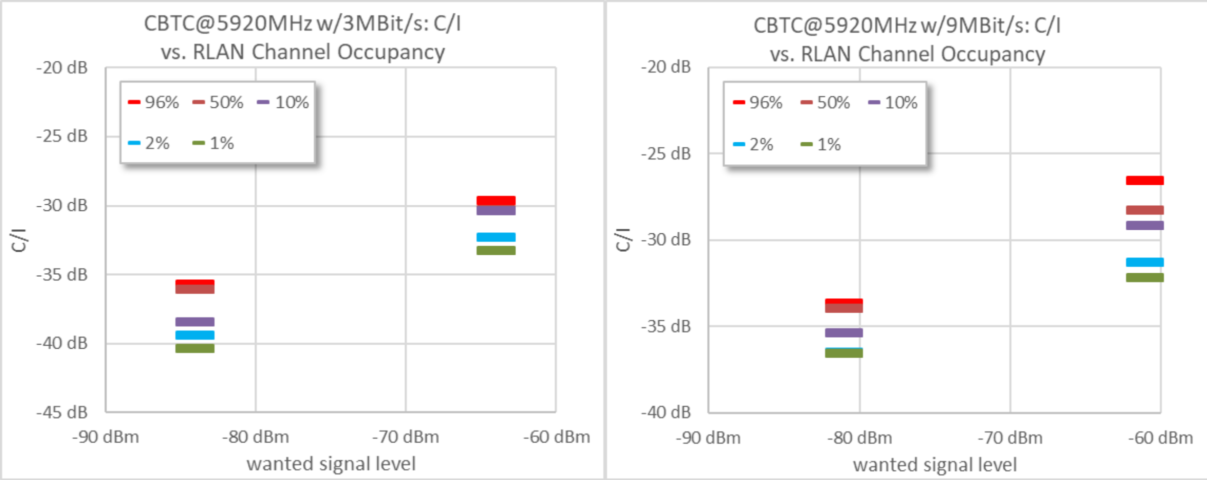

Figure 53: C/I_{adj} for WAS/RLAN with different channel occupancies against CBTC on 5920 MHz

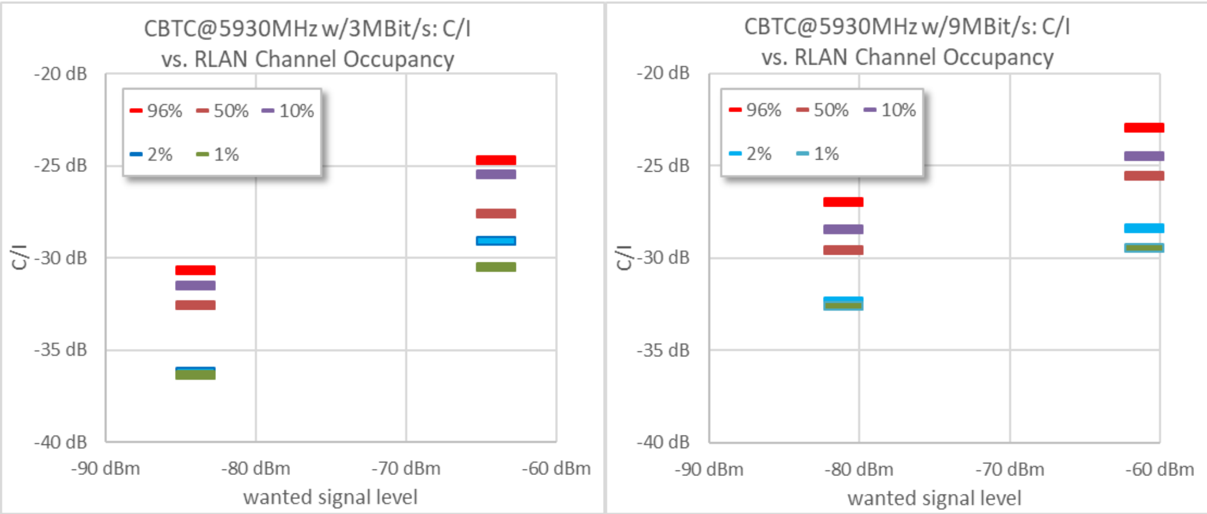

Figure 54: C/I_{adj} for WAS/RLAN with different channel occupancies against CBTC on 5930 MHz

Observations:

- WAS/RLAN signals with 96% channel occupancy require the highest C/I_{adj}, which was generally an expected result.
- On 5930 MHz, the C/I_{adj} for 10% was slightly higher than that for 50%. The reason for this effect could not be explained.
- The difference in C/I_{adj} between WAS/RLAN with 1% and 96% is only between 3 and 6 dB.

A5.8.6 C/I_{adj} dependency on the WAS/RLAN burst length

These measurements have been conducted with WAS/RLAN signals 5a to 5c with an equal channel occupancy of 50%, but burst/pause lengths ranging from 50 µs to 2 ms (see Table 52 for details).

Table 59: Parameters of the C/I_{adj} measurements at different WAS/RLAN burst length

Parameter	Value	
DUT	TU9108	
Tx signal	UDP packets	
Frequency	5920 MHz	5930 MHz
Bandwidth	10 MHz	
Packet length	200 bytes	
Speed	3 MBit/s	9 MBit/s
Interfering signal	5	
Interfering frequency	5965 MHz	
Bandwidth	40 MHz	
OOB level	-37 dBm/MHz	
Ch. Occupancy	50%	
Burst/pause	(variable)	
Failure criterion	Packet error rate > 1%	

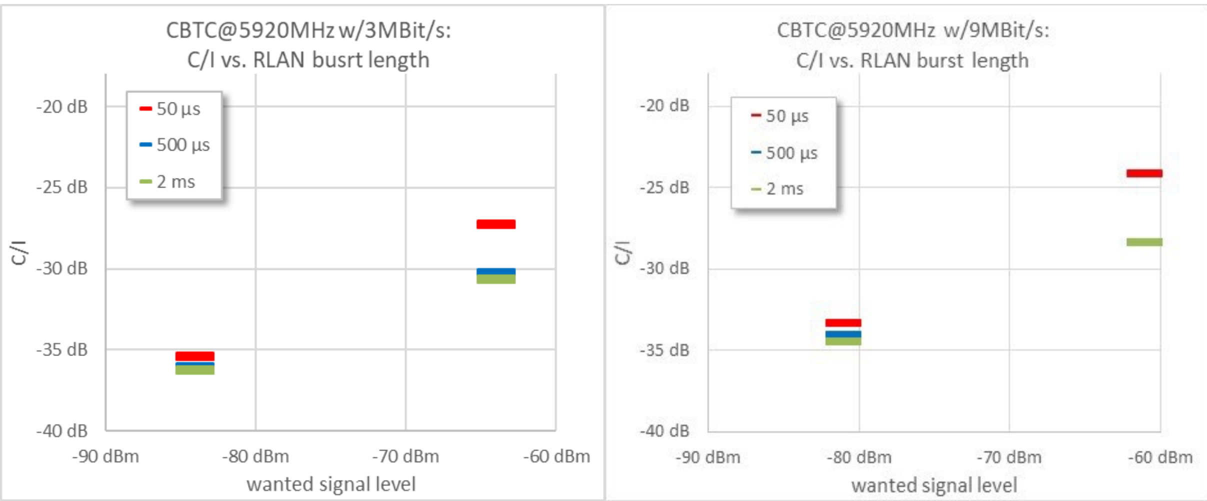

Figure 55: C/I_{adj} for WAS/RLAN with different burst length against CBTC on 5920 MHz

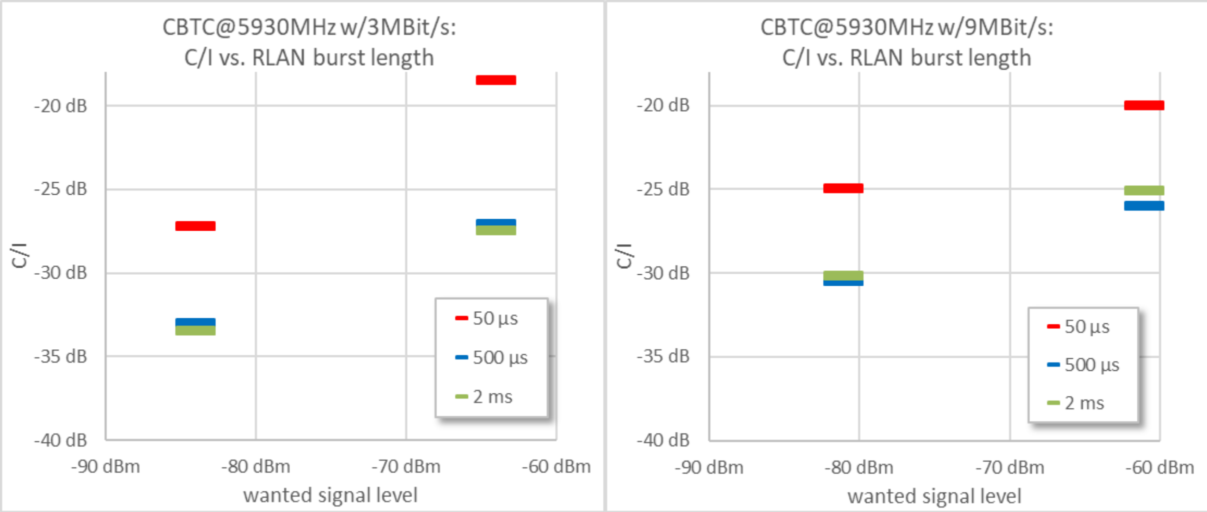

Figure 56: C/I_{adj} for WAS/RLAN with different burst length against CBTC on 5930 MHz

Observations:

- For WAS/RLAN with longer burst lengths down to at least 500 µs, the C/I_{adj} is independent of the burst length;
- One exception is the burst length of 50 µs, to which the CBTC receiver reacts extremely sensible;
- To find possible reasons for the unusually high required C/I_{adj} for WAS/RLAN signals with 50 µs burst length (signal 5a), an additional measurement series was performed where the packet error rate was recorded vs. the C/I_{adj}. For comparison, this measurement was also made with signal 5b having 500 µs burst length, where the receiver showed "normal" behaviour.

Table 60: Parameters for the packet error rate measurement

Parameter	Value	
Tx signal	UDP packets	
Frequency	5930 MHz	
Bandwidth	10 MHz	
Packet length	200 bytes	
Packet rate	300 pck/s	
Data rate / speed	3 MBit/s	
Interfering signals	5b	5a
Bandwidth	40 MHz	40 MHz
OOB level	-37 dBm/MHz	-37 dBm/MHz
Burst/Pause	500 µs/500 µs	50 µs/50 µs
Channel occupancy	50%	50%
Wanted level	-84 dBm	-64 dBm

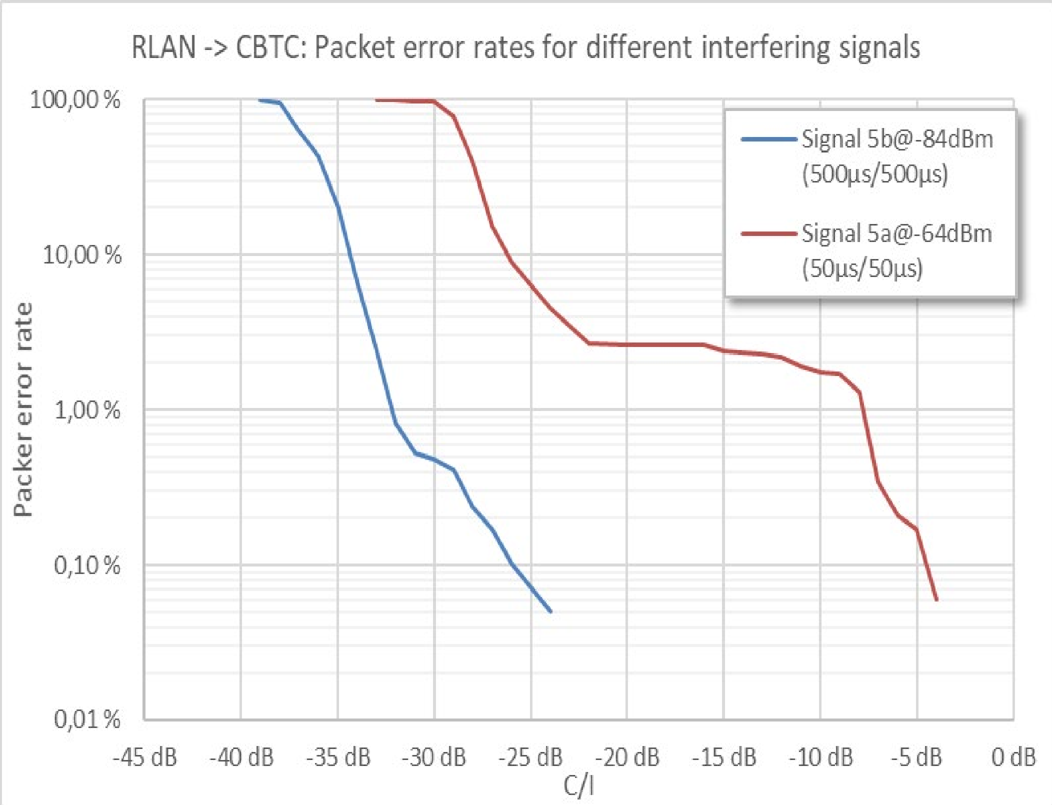

Figure 57: Packet error rates vs. C/I_{adj} for different WAS/RLAN burst lengths

Observations:

- The increase of packet error rate with increasing C/I_{adj} for WAS/RLAN signals with 500 µs burst length is as expected.
- The packet error rate for WAS/RLAN signals with 50 µs burst length remains around 2% for a wide C/I_{adj} range from -8 dB to -23 dB. This is not normal behaviour. The cause lies in the internals of the receiver and cannot be explained by these measurements. However, it is the reason for the unexpectedly high C/I_{adj} values for signal 5a in Figure 55 and Figure 56.

A5.9 SUMMARY

Table 61: TABLE OF MEASURED PROTECTION RATIOS (C/I_{ADJ})

Frequency MHz	Modulation (Note 1)	Sensitivity dBm (Note 2)	C dBm (Note 3)	C/I_{adj} min dB (Note 4)	C/I_{adj} max dB (Note 5)	References
5920	BPSK ½	-94	-84	-37	-36	A5.8.3 C/I_{adj} dependency on the WAS/RLAN bandwidth (20 MHz, 40 MHz)
5920	QPSK ¾	-91	-81	-34	-34	A5.8.3 C/I_{adj} dependency on the WAS/RLAN bandwidth (20 MHz, 40 MHz)
5930	BPSK ½	-94	-84	-37	-33	A5.8.3

Frequency MHz	Modulation (Note 1)	Sensitivity dBm (Note 2)	C dBm (Note 3)	C/I_{adj} min dB (Note 4)	C/I_{adj} max dB (Note 5)	References
						C/I_{adj} dependency on the WAS/RLAN bandwidth (20 MHz, 40 MHz)
5930	QPSK ¾	-91	-81	-34	-29	A5.8.3 C/I_{adj} dependency on the WAS/RLAN bandwidth (20 MHz, 40 MHz)
5920	BPSK ½	-94	-84	-38	-36	A5.8.4 C/I_{adj} dependency on the OOB level (-37 dBm/MHz,-45 dBm/MHz)
5920	QPSK ¾	-91	-81	-38	-33	A5.8.4 C/I_{adj} dependency on the OOB level (-37 dBm/MHz, -45 dBm/MHz)
5930	BPSK ½	-94	-84	-38	-32	A5.8.4 C/I_{adj} dependency on the OOB level (-37 dBm/MHz, -45 dBm/MHz)
5930	QPSK ¾	-91	-81	-35	-28	A5.8.4 C/I_{adj} dependency on the OOB level (-37 dBm/MHz, -45 dBm/MHz)
5920	BPSK ½	-94	-84	-40	-36	A5.8.5 C/I_{adj} dependency on the WAS/RLAN channel occupancy (1% to 96%)
5920	QPSK ¾	-91	-81	-37	-34	A5.8.5 C/I_{adj} dependency on the WAS/RLAN channel occupancy (1% to 96%)
5930	BPSK ½	-94	-84	-36	-31	A5.8.5 C/I_{adj} dependency on the WAS/RLAN channel occupancy (1% to 96%)
5930	QPSK ¾	-91	-81	-33	-27	A5.8.5 C/I_{adj} dependency on the WAS/RLAN channel occupancy (1% to 96%)
5920	BPSK ½	-94	-84	-35	-36	A5.8.6 C/I_{adj} dependency on the WAS/RLAN burst length (burst/pause: 50 µs to 2 ms)
5920	QPSK ¾	-91	-81	-35	-33	A5.8.6

Frequency MHz	Modulation (Note 1)	Sensitivity dBm (Note 2)	C dBm (Note 3)	C/I_{adj} min dB (Note 4)	C/I_{adj} max dB (Note 5)	References
						C/I_{adj} dependency on the WAS/RLAN burst length (burst/pause: 50 µs to 2 ms)
5930	BPSK ½	-94	-84	-34	-27	A5.8.6 C/I_{adj} dependency on the WAS/RLAN burst length (burst/pause: 50 µs to 2 ms)
5930	QPSK ¾	-91	-81	-30	-25	A5.8.6 C/I_{adj} dependency on the WAS/RLAN burst length (burst/pause: 50 µs to 2 ms)
Note 1: The data rate for BPSK ½ is 3 Mbit/s and for QPSK ¾ is 9 Mbit/s Note 2: The sensitivity has been measured for a bandwidth of B=10 MHz Note 3: For the measurement, a CBTC wanted signal C of 10 dB above sensitivity at receiver input was assumed Note 4: Minimum values of the protection ratios (C/I_{adj}) Note 5: Maximum values of the protection ratios (C/I_{adj})						

ANNEX 6: DETERMINATION OF BODY LOSS

The material in this annex was developed to obtain an average body loss value for generic 6 GHz WAS/RLAN devices. The measurements were not performed to respond specifically to the VLP vs CBTC use cases and therefore do not always perfectly match the corresponding scenario. VLP are portable devices and train stations are not areas where people would typically sit to work with their VLP device on a table or away from them. It is also anticipated that smartphone, smart glasses, headphones and other wearables devices would be predominant in the metro environment, and those devices have not been measured. Nevertheless, the material below provides a reference for determining an average body loss.

The Annex presents measurements of radiation patterns of form factor laptop/tablet devices in free space mode and impact on the radiated patterns due to proximity to human body and associated losses. A representative Body Loss is determined by comparing radiated patterns in free space and in proximity to a human body. The Body Loss derived below can be considered a worst case, as VLP devices are expected to be in closer proximity to the human body than tablets and laptops.

A6.1 INTRODUCTION AND METHODOLOGY

Radiated pattern and changes due to proximity to human body and clutters depend on different parameters including antenna placement, mechanical design and the type of laptop. Antenna gain and variation in radiation pattern depend on and increase with the electrical size of the antenna and frequency range of operation. In case of form factor devices such as laptops, electrical size of the antenna could be as large as the laptop. Over The Air (OTA) characteristic of laptops/tablets also depends on the use cases including the placement and positioning of the device on the lap or on the table.

Laptops with different antenna placements are considered here. Tablet mode vs laptop mode in a convertible device is measured as well.

A6.1.1 Laptop devices platforms and antenna placements

Three types of antenna placement in laptops are considered here:

a) Platform 1 (laptop): Under wrist pad inside the keyboard on the two sides of touch pad;
b) Platform 2 (laptop): Bottom of screen at the hinges;
c) Platform 3 (laptop/tablet convertible): On top of LCD display.

Figure 58 shows different platforms with antenna placements highlighted in light blue. Three platforms are using Intel® Wi-Fi 6E AX210, Intel® Wi-Fi 6E AX210 and Intel® Wi-Fi 6E AX211.

Figure 58: a) Platform 1 b) Platform 2 c) Platform 3

A6.1.2 Over the Air measurement system

The OTA measurement system used here is a full anechoic chamber with distributed-axes measurement system. Measurements, including Free Space measurements, are far-field and use a measurement step of 15°x15° (300 points).

The measurement samples distribution is scaled with a 15 deg grid for uniform sampling. Specific measurements conducted are spherical e.i.r.p. samples, max e.i.r.p.and conducted power. Subsequently, spherical gain samples and CDF of gain samples are calculated and plotted.

Figure 60 illustrates device placement and positioning in anechoic chamber for free space, human with device on a desk and human with device on lap.

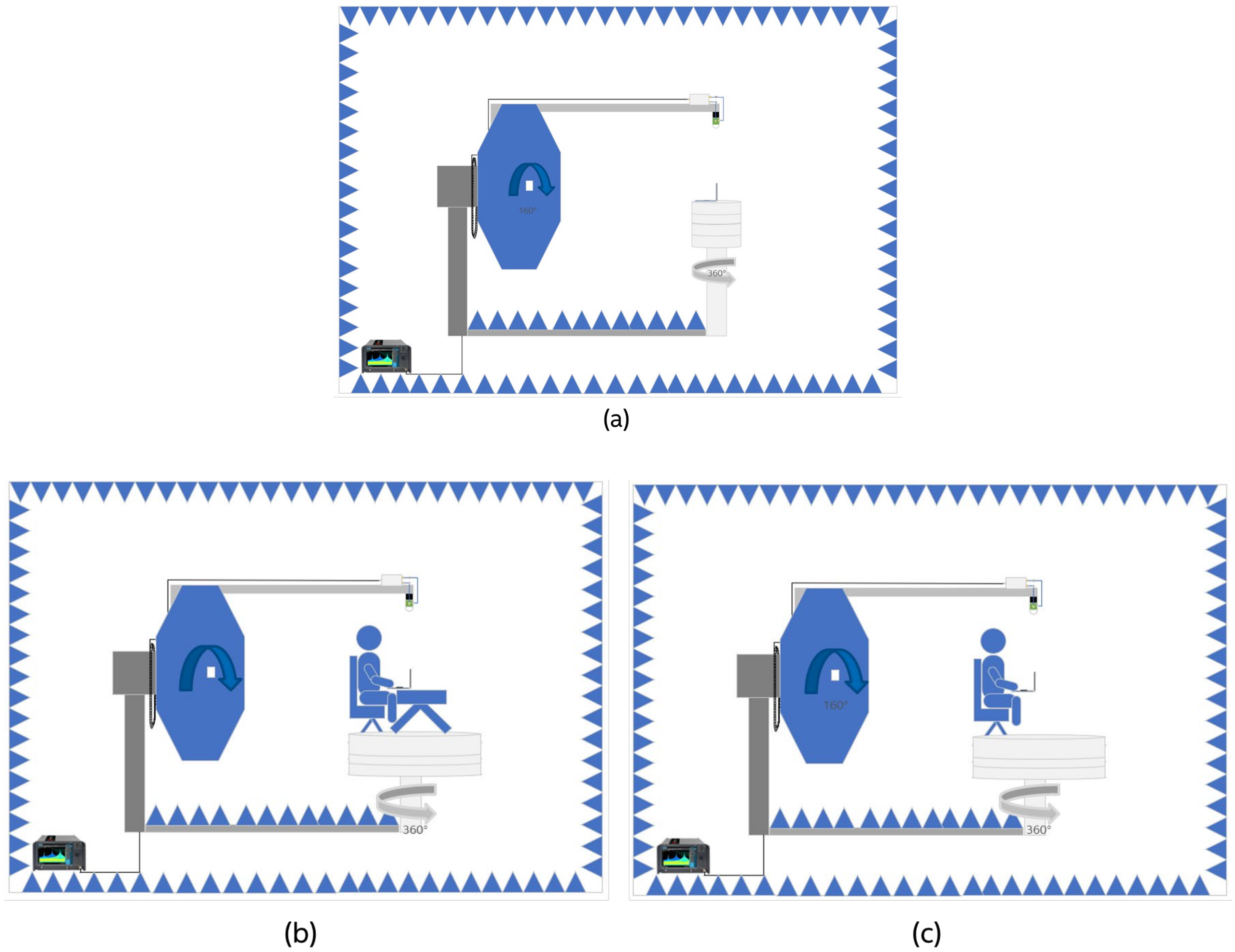

Figure 59: a) Free Space b) Human and Desk c) Human and Lap

A6.1.3 Test methodology, use case setups and device positioning

For each platform, a number of scenarios are identified to cover various channels and use cases. Different measurement cases are listed next. All use cases in all platforms are measure at three frequencies with channel bandwidth of 160 MHz and transmit power of ~14 dBm peak e.i.r.p.

1. Channel 1 (Low), 6025 MHz (Ch 15)
2. Channel 2 (Mid), 6505 MHz (Ch 111)
3. Channel 3 (High), 6985 MHz (Ch 207)

Use cases for Platform 1:

a) Free Space
b) Body human lap (Normal BMI type)
   - Hands on the keyboard
   - Hands off the keyboard

c) Body human (Normal BMI type) and wood desk
   - Hands on the keyboard
   - Hands off the keyboard

d) Body Human (Normal BMI type) and metal desk
   - Hands off the keyboard

Use cases for Platform 2:

a) Free space
b) Body human lap (Normal BMI type), Hands “on” the keyboard position
c) Body human (Normal BMI type) and wood desk, Hands “on” the keyboard position

Use cases for Platform 3:

a) Free space Laptop mode
b) Body human (laptop mode) and wooden desk
c) Body human lap (tablet mode)
   - Hands on left and right side of the screen
d) Body human (tablet mode) and wooden desk
   - 45 deg inclination hands on left and right side of the screen

Figure 60 and Figure 61 are showing the use-cases and device positioning for the three platforms.

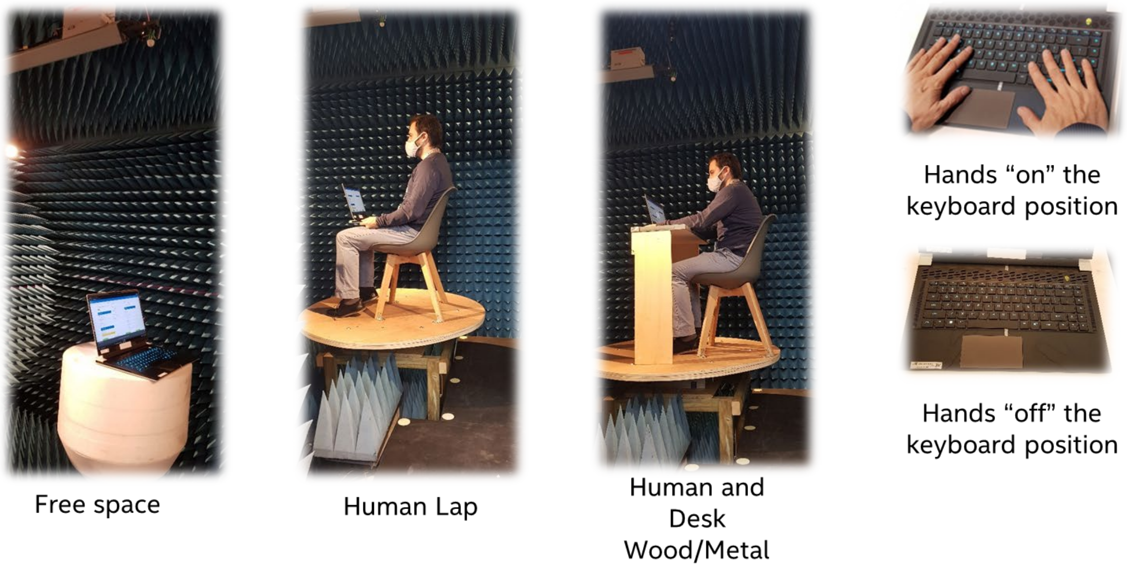

Figure 60: Use-cases and Device Positioning for Laptop Platforms 1 and 2

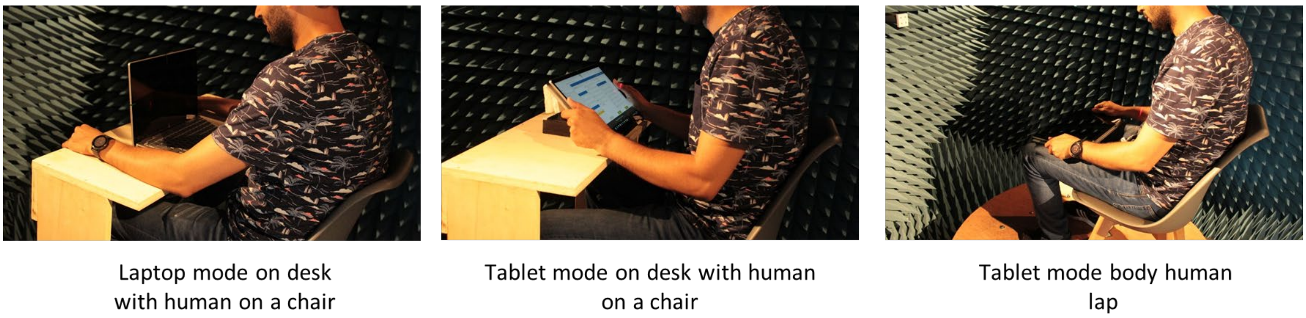

Figure 61: Use-cases and Device Positioning for Convertible Laptop Platforms 3

A6.2 RESULTS

A6.2.1 Measurement results

For each platform and specific frequency, the CDF of 3D measured gain samples are plotted for free space and different use cases.

Figure 62, Figure 63 and Figure 64 are showing sample CDF of 3D measured gain for Platform 1, 2 and 3 at Mid Channel 6505 MHz.

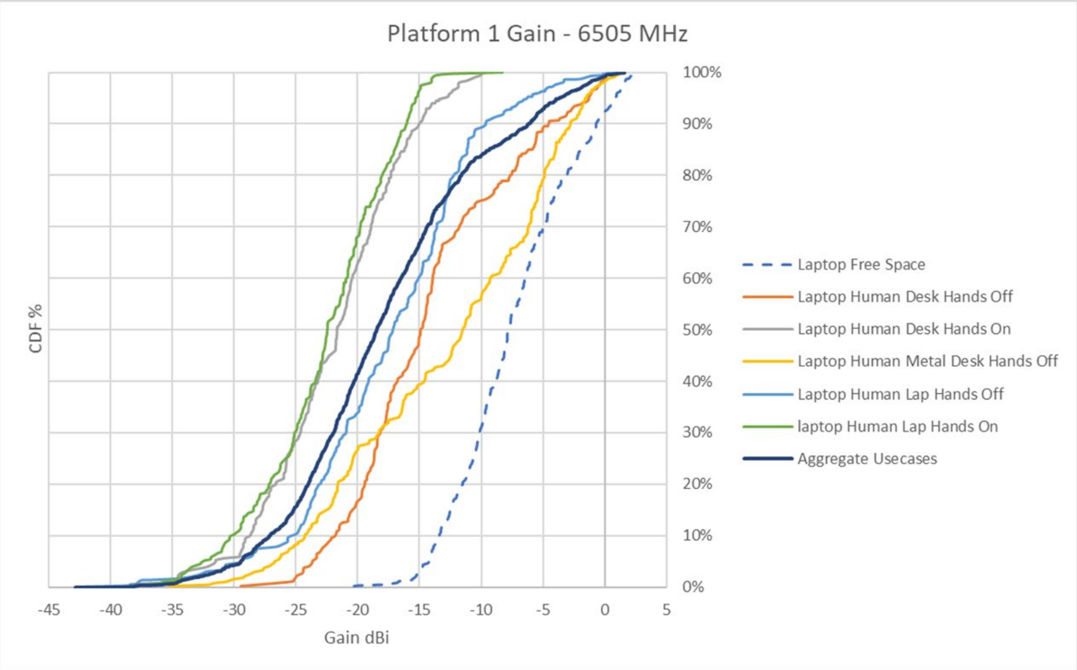

Figure 62: CDF of 3D Gain Samples for Platform 1 at 6505 MHz (Channel 111)

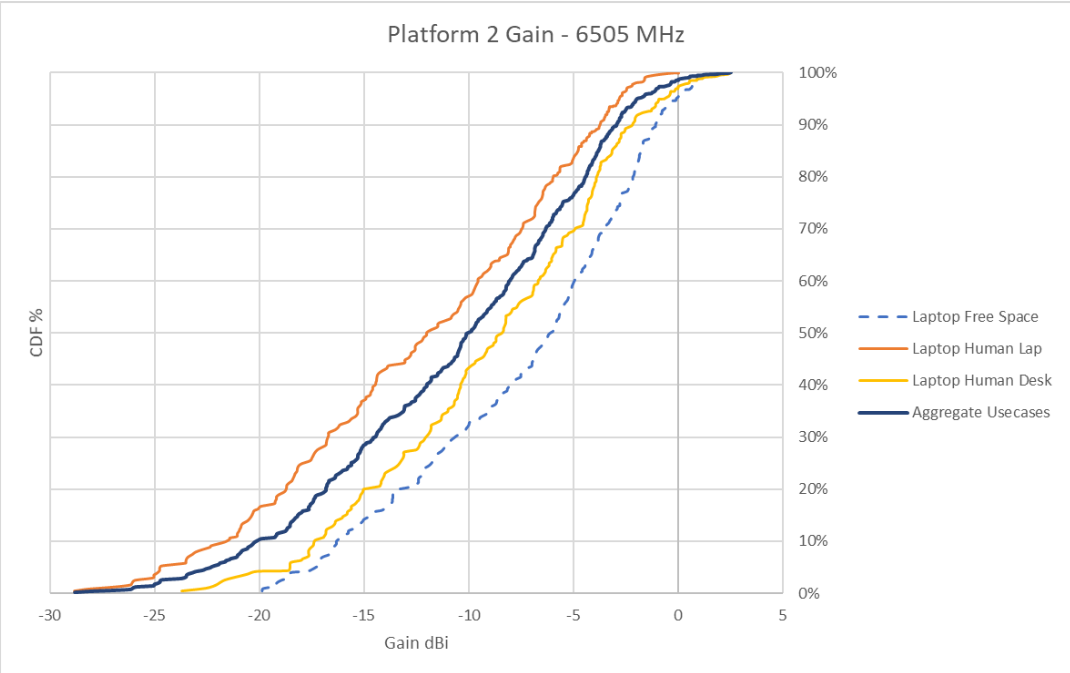

Figure 63: CDF of 3D Gain Samples for Platform 2 at 6505 MHz (Channel 111)

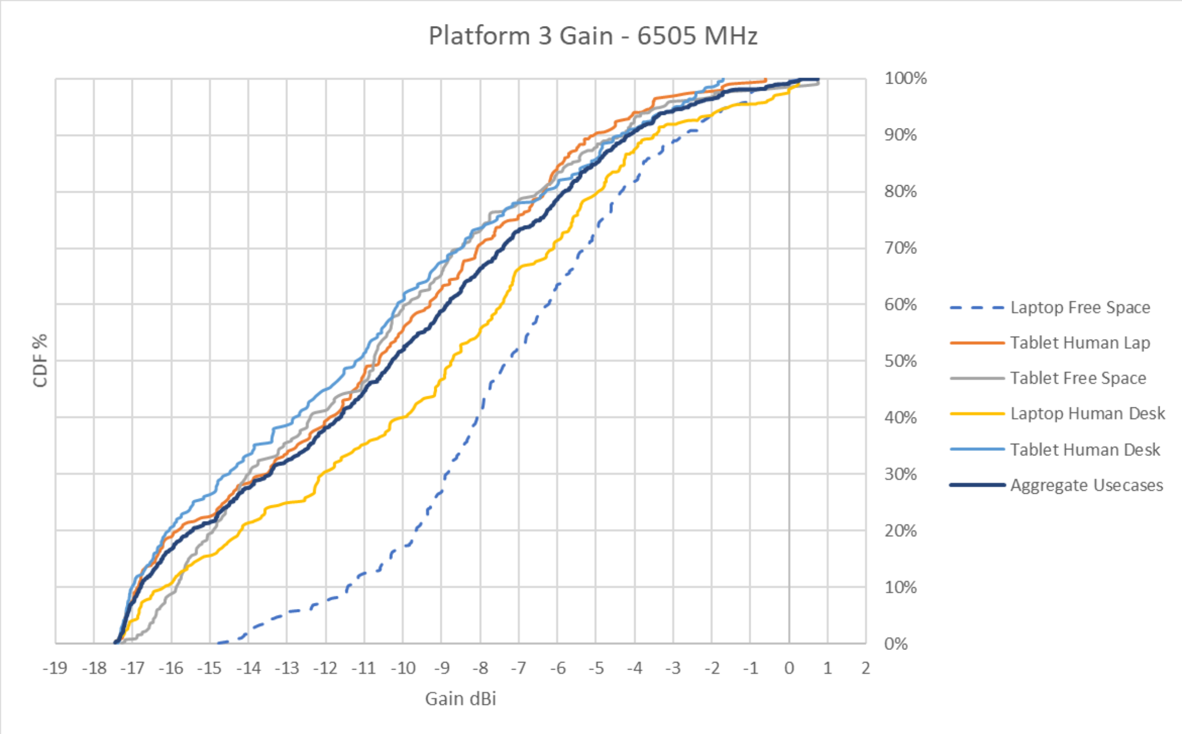

Figure 64: CDF of 3D Gain Samples for Platform 3 at 6505 MHz (Channel 111)

Table 62 provides a summary of the Means and Standard Deviations from CDF of measured gains for Free Space and relevant use cases for three platforms in Low, Mid and High frequencies. Free Space gains are deducted from total gains from use cases to have an estimate for the so-called loss due to proximity to human and desk.

Table 62: Statistical summary of radiated pattern for Free Space and various use cases

Reference	Free Space Gain (Radiated Pattern)		Total Gain (=Free Space + Proximity/Body)		Proximity/Body Loss
	Mean	Standard Deviation	Mean	Standard Deviation	Δ Mean
Platform 1 Low	-6.92	5.22	-16.08	8.87	-9.16
Platform 1 Mid	-7.22	4.89	-16.77	8.57	-9.55
Platform 1 High	-6.80	4.45	-16.40	8.54	-9.60
Platform 2 Low	-4.76	4.85	-8.54	7.24	-3.78
Platform 2 Mid	-5.65	5.60	-9.24	6.76	-3.59
Platform 2 High	-6.50	5.98	-10.00	6.76	-3.50
Platform 3 Low	-7.07	3.49	-11.03	5.26	-3.96
Platform 3 Mid	-6.75	3.56	-9.92	5.05	-3.17
Platform 3 High	-7.38	2.95	-10.21	4.05	-2.83
Cross-platform Means	-6.56		-12.02		-5.46

Across antenna placement, platforms and frequency variations, the mean of Free Space gain distribution is at -6.56 dB and the mean of aggregate total gain distribution of use cases is at -12.02 dB. The delta between the two numbers is considered as an estimate for the mean of proximity/body loss associated with the change in radiated pattern relative to Free Space. This value is estimated at -5.46 dB.

The loss associated with body proximity is maximum in Platform 1 with antenna placement under wrist pad and minimum in Platform 3 with antenna on top of LCD screen. As expected, proximity to lap and hands introduce considerable losses.

A6.3 CONCLUSION

This annex provides a summary of Intel's OTA radiated RF power measurement on laptops/tablets devices at 6 GHz band at power levels targeted for VLP. The measurements were conducted on three platforms with different placement for antenna subsystem. Measurements were done when devices are positioned in Free Space mode and in different use cases with human body presence and at mid, low and high frequency channels of 160 MHz wide.

Across antenna placement, platforms and frequency variations, the mean of Free Space gain distribution is at -6.56 dB and the mean of aggregate total gain distribution of use cases is at -12.02 dB. The delta between the two numbers, considered as an estimate for the mean of proximity/loss associated with the change in radiated pattern relative to Free Space, is estimated at -5.46 dB.

Results of the measurements are used to characterize the radiation pattern of the devices in Free Space mode and changes in radiation patterns due to proximity to human body or so-called proximity/body loss.

ANNEX 7: METHODOLOGY AND DETAILED RESULTS FOR STATISTICAL STUDY B

A7.1 INTRODUCTION, METHODOLOGY AND LIMITATIONS

A7.1.1 Introduction

The purpose of this study is to complement the worst case minimum coupling loss (MCL) single link analysis by considering for the scenario of a VLP WAS/RLAN on a platform interfering a train unit (TU):

a) the variations in parameters that exist around the worst-case assumptions;
b) the redundancy which is built into CBTC systems to ensure high reliability.

The statistical simulation counts when and how often interference cases could happen in an urban rail line, and what could be the practical consequence on the CBTC radio system. As a reference, CBTC systems contractual requirements for the radio system impose a few minutes of unavailability per year (e.g. 5 minutes, or 99.999% reliability). Therefore, even one single case per year of harmful interference which would result in a traffic incident would materially impact the CBTC reliability.

A7.1.2 Methodology

The simulated situation includes one VLP WAS/RLAN on a platform interfering a CBTC TU of an urban train (RER) entering the station. The VLP is located where the CBTC wanted signal of a single link is the most vulnerable, in a representative station setting.

Starting from worst-case situation (with a negative margin) then random or dynamic variations of geometry or VLP characteristics is modelled, which can offset the negative margin. it is then possible to assess the number, intensity and duration of single link interference there could be each year, for the whole CBTC line, depending on VLP parameters.

Finally, the likely CBTC system behaviour is assessed, based on the CBTC redundancy design.

A7.1.3 Limitations

This analysis is only indicative because:

- The simulation relies on the measurements, data in the public domain, and best estimate for remaining parameters. The result describes one experience case in one specific setting. The simulation using other equipment in other CBTC setting may give different results.
- simplifications are needed on the parameters which vary dynamically during the interference case, as the full distribution of possible values cannot be reproduced.

The reasoning and order of magnitude of results are intended as informative for the administrations.

A7.2 DESCRIPTION

A7.2.1 Trial scenario

The CBTC system considered is the one controlling a RER line:

- Urban train (double train 230 m long, capacity 3000 passengers) with majority of underground tracks;
- 6 high-capacity stations on the central section of the line;
- CBTC based on IEEE802.11 technology, 5 MHz channels, 2 frequencies, QPSK ¾;
- Access points work on 1 frequency each, alternating in frequencies along the line;
- 2 TU per train (front and rear), each equipped with 2 radios, each configured to one of the two frequencies;
- Antenna diversity (on each TU, one radio is connected to the left antenna, and one is connected to the right antenna);

- In nominal mode, at any given time, both TU receive control information. On each TU, one frequency carries the CBTC useful information while the other is associating and communicating with access points in anticipation of a frequency hand-over;
- Track coverage planned for a minimum received level at receiver input of -84 dBm per frequency.

The trial scenario of VLP on a platform interfering a Train TU is as follows:

- For an interference to occur, the VLP must be in an area where the CBTC wanted signal is weak (static condition), and be physically close to the TU of the entering train (dynamic condition);
- Coverage for one CBTC link is marginal in one vulnerable zone of a platform (i.e. at the minimum received level) (A7.2.2);
- In the vulnerable zone, there is one and only one VLP transmitting on a WAS/RLAN channel adjacent to CBTC and close to the tracks (A7.2.3);
- An urban train enters the station, and the beam of the TU sweeps the area around the VLP (A7.2.4).

Figure 65 shows the trial scenario in a schematic way, not at scale (the access point is far away from the vulnerable zone).

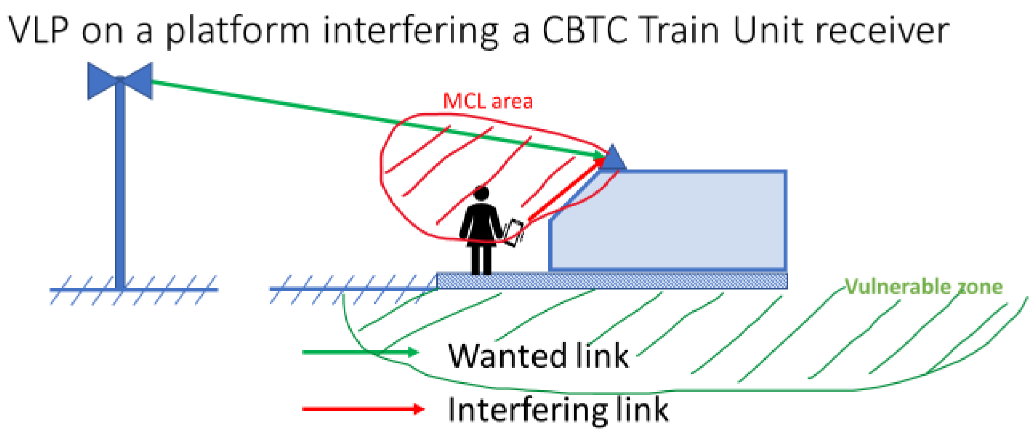

Figure 65: Trial scenario VLP on platform versus TU

This individual trial is then repeated for each train passage on each station over a long period (one year) to build a case representative of the line operation (A7.2.5).

A7.2.2 Vulnerable zone

For a single link (same frequency), the CBTC signal is the weakest in between 2 non-consecutive APs (as frequencies alternate with APs).

There is in each station one and only one vulnerable zone of approximately 20 m long located on the platform for an entering train and the front TU.

Figure 66 shows where the vulnerable zone[17] might be for f1 for a typical station design where one access point (AP2 with f2) is close to the platform. It is assumed a train is entering from right to left. Red dots represent the access points and the blue circle depicts the vulnerable zone, not at scale.

[17] Exact location for a given frequency depends on local RF planning, on the direction where the train is moving and whether the TU is in front or rear position, also considering the front-to-back ratio of the TU. This gives in practice up to 4 vulnerable zones per frequency. Because of the long platform length with respect to intersite distance, we expect there would be one, and only one vulnerable zone over a platform for an entering train and the front TU, for one train direction. To simplify, we neglect the risk of VLP interference to the departing train and the rear TU, assuming descending passengers are evacuating the platform and passengers waiting for the next train are withdrawn from the front row compared to those waiting just before the entrance of the train.

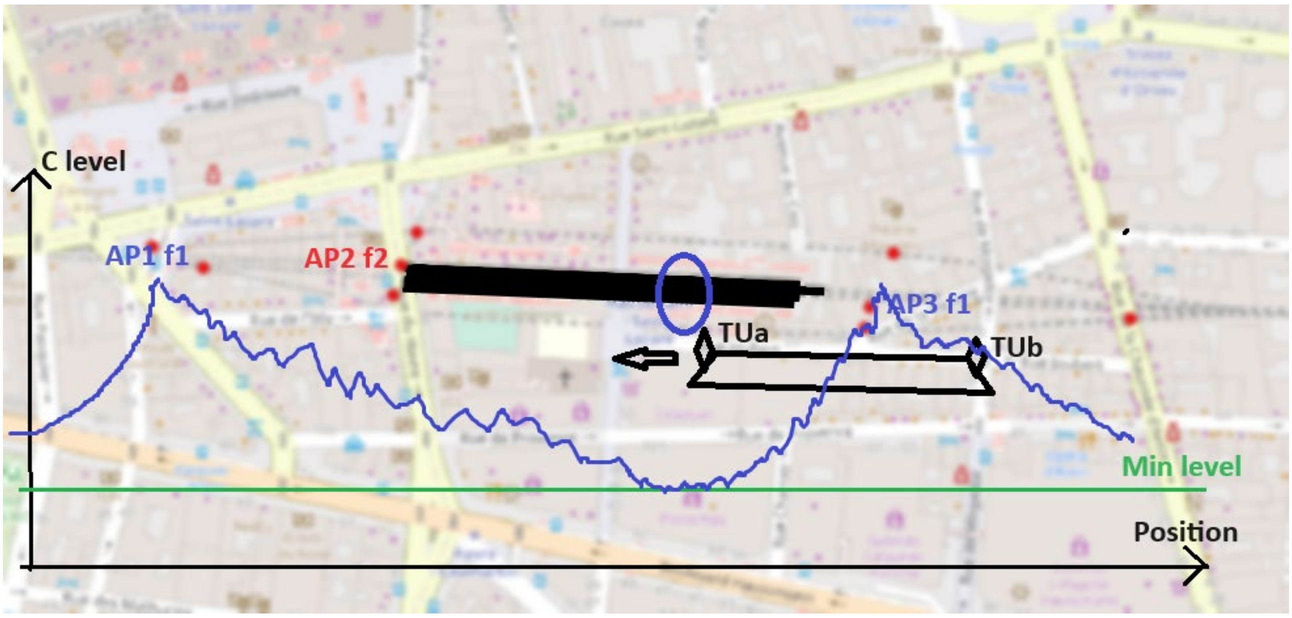

Figure 66: Vulnerable zone for the reception of F1 over a platform

A7.2.3 VLP transmitting close to the tracks in the vulnerable zone

Figure 67 shows passengers in the front row, in a situation to interfere.

Figure 67: Passengers in the front row

Assuming passengers spread evenly 1 m apart linearly, about 20 passengers close to the tracks are obtained, in the front row of the 20 m long vulnerable zone.

This corresponds to at least 200 people in the station. If there are more, other passengers will gather behind the front row (at peak hour, a train may have 3000 passengers, assuming a churn of 1/3 there could be more than 1000 passengers on the platform).

The number of active VLP will depend on the future VLP usage. Assuming a strong VLP active usage in the 6 GHz band by 1/3 of the passengers[18], 6 passengers with active VLP are in the vulnerable zone.

Assuming 1/6[19] of active VLP use the channels closest to CBTC frequencies, the case of one VLP in a situation to interfere is realistic in case of very intensive usage.

A7.2.4 MCL area

A7.2.4.1 Definition

As it can be understood from Figure 67, interference can occur only when the train is close enough to the VLP from the coupling loss stand point.

In practice the train defines a moving MCL area ahead of the TU and there can be interference when this area sweeps over where the VLP is standing.

Or alternatively it can be considered there is a static MCL area around the VLP and interference happens when the TU crosses that area.

The MCL 3 dB area is defined as the area in a static configuration where the coupling loss between a VLP and a TU is within 3 dB of the MCL.

A7.2.4.2 MCL area for the closest TU antenna to the platform

Theoretical calculations suggest that the MCL 3 dB area is approximately 5 m long in the front row (7 m at 1.4 m from the tracks, 4 m at 2 m from the tracks) (see A7.8.1.1).

For a train entering the station at 5m/s it means that the MCL 3 dB area is swept in about 1 second.

A 6 dB area can also be considered. With the same speed assumption, the MCL 6 dB area is about 10 m long (see A7.8.1.2) and is swept in about 2 seconds.

Importantly, based on the length of those zones and the speed an idea is obtained of the length of an interference: any trial with an interference margin worse than -3 dB (respectively -6 dB) would extend beyond the MCL 3 dB area and last longer than 1 (respectively 2) seconds.

A7.2.4.3 Antenna diversity: MCL and MCL 3 dB area for the antenna further away from the platform

In RER trains, there are 2 antennas per TU, each connected to one radio (frequency). The MCL from the platform to the antenna further away was not measured, it can be estimated by theoretical calculation to be 4.4 dB higher than the MCL measured for the closest antenna. In this configuration pertaining to one of the two CBTC channels (considered randomly), MCL equals 60.7 dB.

The shape of the MCL 3 dB area is distorted: compared to the one for the other antenna, it will be ahead of the TU by a couple of metres and longer along the platform (10 m instead of 5 m) (see A7.8.1.3). Therefore, there will be less interference likelihood if the CBTC channel is received on that antenna (MCL is higher) but they would last longer for the same train speed (2 s instead of 1 s).

A7.2.5 Case description for a year

[18] Current usage of nomadic WiFi AP in urban rail platform is unknown but expected to be much lower, typically a few AP visible on a platform, with activity unknown. A usage of 1/3 of passengers would be comparable to a very successful application, such as Bluetooth connection to ear buds.

[19] Approximation based on one 80 MHz channel out of 6. The proportion of 20, 40 MHz, 80 MHz and 160 MHz channels in nomadic conditions is not known.

The following is considered:

- 6 high-capacity stations, focusing on the central part of the line where dimensioning elements such as passenger throughput are highest;
- 22 trains/hour (each way) at peak hour;
- a day to peak hour factor of x 5 (i.e. the train throughput of one full day would be the equivalent of 5 peak hours);
- 52 weeks *6 days per year (assuming week-end is equivalent to one day);
- in total, 220 trials per day per high traffic station, or 400000 trials per year per line.

A7.3 CASE STUDY WITH THE VLP OOB EMISSION LIMIT OF -45 DBM/MHZ

A7.3.1 Worst case C/I$_{adj}$ budget

C= -84 dBm, VLP I = 14 dBm, OOB emission = -45 dBm/MHz, MCL = 56.3 dB.

C/I$_{adj}$ threshold for QPSK channel at 5930 MHz is -35 dB[20] for 1% packet loss.

C/I$_{adj}$= -84 - (14-56.3) = -41.7 dB

Therefore, the worst-case budget is missing 6.7 dB.

A7.3.2 Improvement factors

CBTC antenna diversity is considered, which increases the MCL by 4.4 dB in 50% of the cases.

The following distribution for VLP antenna gain/body loss is considered. This is taken from the measurement for a tablet held by a human, corrected to reflect the half space in front of the passenger.

Table 63: Distribution for VLP combined antenna gain/body loss effect

Percentage of occurrence	Body loss + antenna pattern loss
10%	0 dB
10%	3.5 dB
20%	5 dB
20%	6.5 dB
20%	8 dB
20%	9.5 dB

The C/I$_{adj}$ threshold is decreased for the CBTC channel at 5920 MHz: 3 dB measured improvement for OOB emission at -45 dBm/MHz. This improvement applies to 50% of the trials.

Finally, an improvement for the VLP activity factor is considered. No measurement was performed with OOB emission at -45 dBm/MHz and 2% occupancy, therefore, measurements at -37 dBm/MHz are assumed as applicable and 4 dB gain is used to simulate a 2% occupancy.

[20] This threshold was measured in a 10 MHz channel at -81 dBm. It is therefore assumed it would apply to a 5 MHz channel at -84 dBm.

Note: the measurements made with a 40 MHz VLP channel are used. For those the most complete and consistent set of measurements is available. All VLP are assumed as transmitting at full power (for discussion on the impact of back off, see section A7.6).

A7.3.3 Simulation results-single link

The simulation starts from the worst-case interference margin and applies a series of corrections depending in a probabilistic way on the CBTC channel, CBTC antenna, VLP body loss and VLP occupancy factor. Provision is made for an additional random factor (e.g. VLP back-off; or masking, tested, but negligible in this context). This allows to compute the number and probability of interference in a given year, get a histogram of their intensity (compared to the threshold) and identify those which exceed a given duration.

Interference is defined as loss of 1% of packets or more, consistent with C/I measurements.

The results of the simulation detailed in A7.8.2 is summarised in Table 65:

Table 64: Simulation for OOB emission -45 dBm/MHz

	VLP OOB emission -45 dBm/MHz
Interference occurrences	
Per year	10000
% of train entrance	2.5%
Interference duration	
Lasting more than 1 s	0
Lasting more than 2 s	0
Interference intensity	
Budget margin < -3 dB	0
Budget margin < -6 dB	0
Budget margin < -9 dB	0
Budget margin < -12 dB	0

It shows that potentially 2.5% of trials will encounter an interference of any duration. In all of those, the interference budget is negative, with less than 3 dB missing to reach the C/I_{adj} threshold.

No trial was found with an interference lasting 1 s or more.

A7.3.4 System aspects

A7.3.4.1 Nominal mode

For the limited number of cases where there is interference on the single link, being in the vulnerable zone the link is close to the minimum level of -84 dBm. From CBTC conception this is a situation where the CBTC control information would normally be carried over the other frequency of the TU where the CBTC signal is higher. This is understandable from Figure 68 where TUa would likely receive the useful signal from AP2 (red signal).

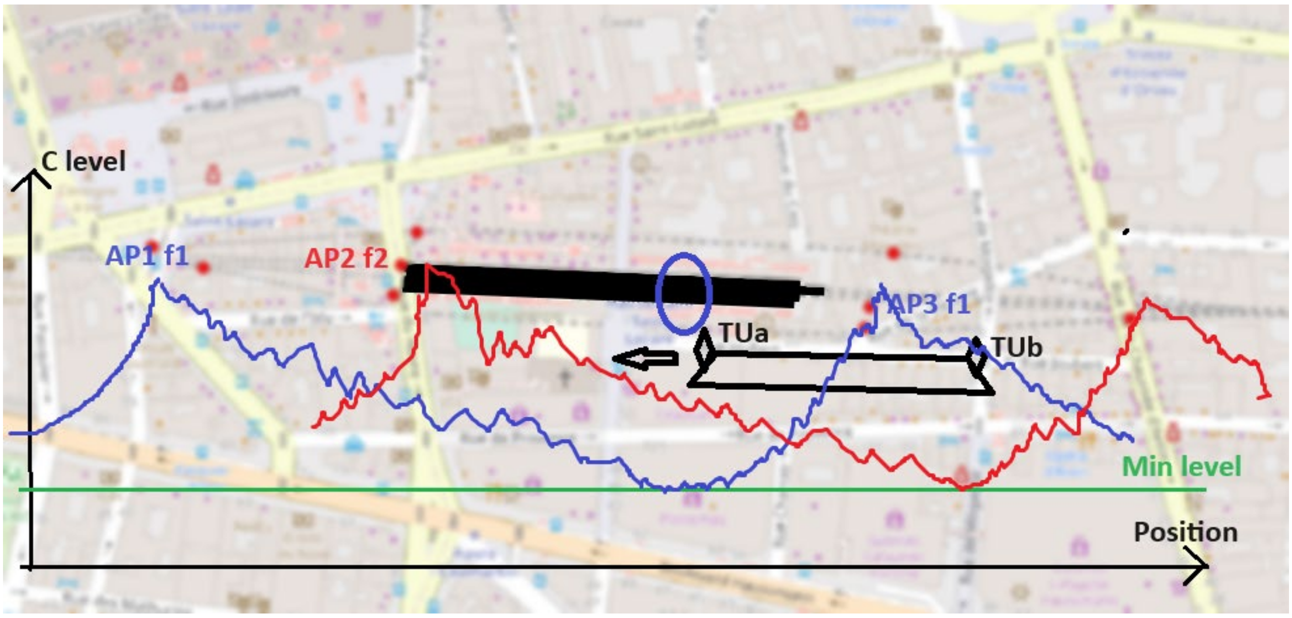

Figure 68: Configuration in nominal mode

Therefore, the interference is in practice most often impacting the weaker link, which is busy keeping association with the access point, in anticipation of a later hand-over.

As a conclusion, the TU transmission is not impacted in nominal mode.

A7.3.4.2 Degraded mode (one AP out of order)

In a degraded mode, where the access point carrying the other frequency is out of order, the link which normally would be stronger is no longer available. If there are 6 stations, with AP MTBF of 6 years (50000h), this would happen typically once a year, and in a single station, for each direction. This would last until repair, assumed to be 12 to 24 hours later. In this case it is assumed there are 2 such “bad” days per year[21], each impacting one direction of one station (most likely not the same). This is depicted in Figure 69.

[21] There are many more days per year when one AP is down in the line (which may consist of 100 APs). But here the focus is only on the AP which ensures the main coverage of the platforms.

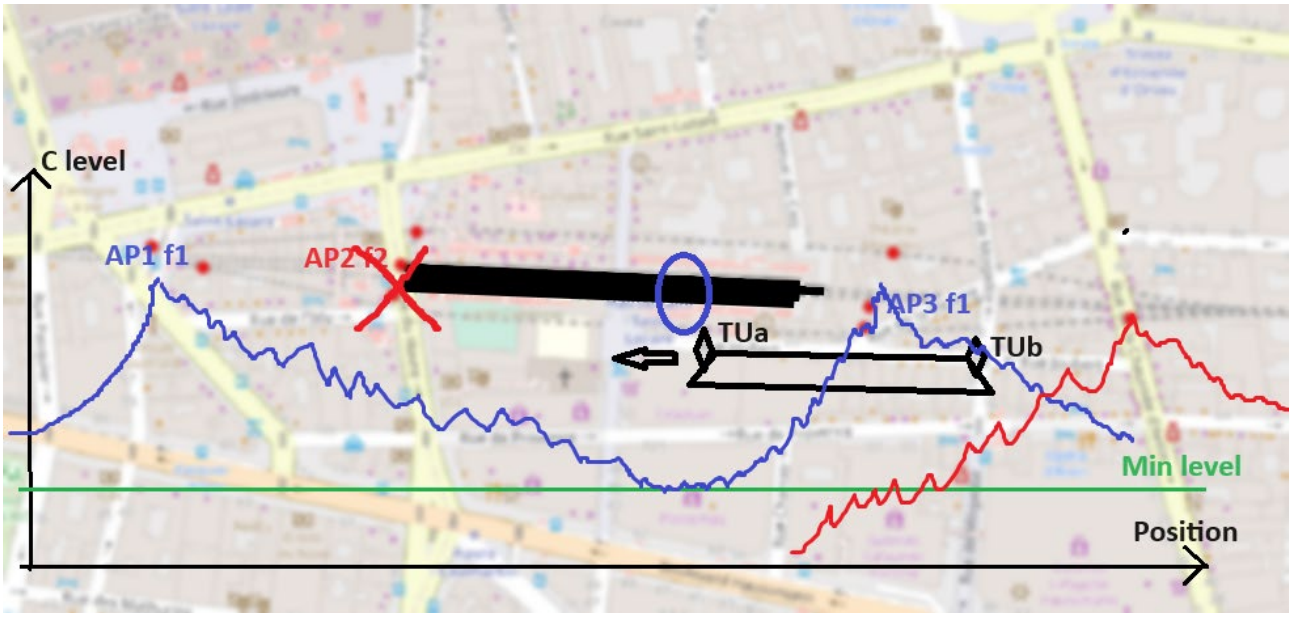

Figure 69: Configuration in degraded mode (AP2 out of order)

In such a case, the weak link which is interfered is carrying the useful information for that TU, until connection can be re-established on the other frequency. The interference will actually impact useful information. The train will need to rely on the TU on the other end of the train for control.

Considering 2.5% of trials with single link interference, which in degraded mode apply to the 110 trials in the station per direction where the nearby AP is down for one day, and because there are 2 “bad” days (reflecting both directions) there are 6 cases per year of interference requiring a switch to the other TU.

The logical switch to the other TU would normally ensure proper transmission of the CBTC control information.

A7.3.4.3 Double failure

The exception is a double failure situation, where simultaneously one AP and one TU fail in vicinity of a station, as depicted in Figure 70.

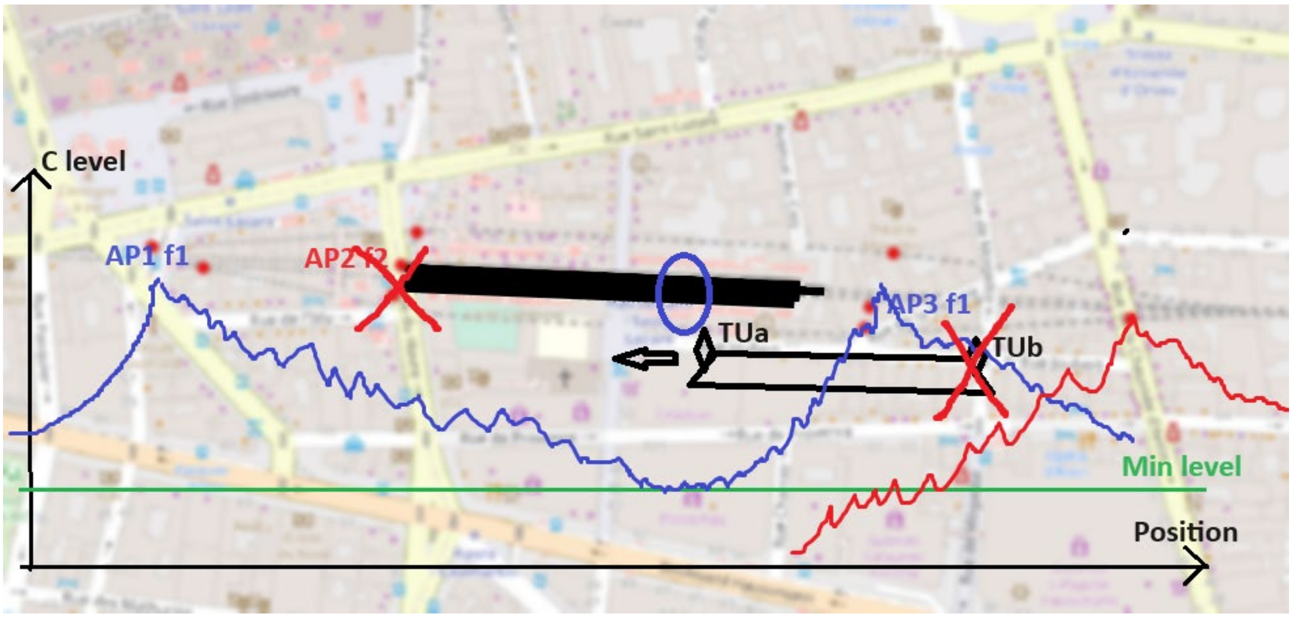

Figure 70: Configuration in double failure (AP2 and TUb are out of order)

This is a very rare case, because AP failure in any of the 6 stations is only twice a year. And TU failure is something rare also. So combined occurrence of TU and AP failed in a station is very uncommon, say a probability of 7% to 13% that it happens in a given year [22]. Then the train with faulty TU would make a series of passages that day until repair but each with a risk of interference of 2.5%.

In such case, the interfered link would most likely still be able to carry the CBTC signal, with a degraded packet loss rate, because the link is at 3 dB or less from the C/I_{adj} threshold for 1% packet loss.

A7.3.5 Conclusions for the OOB emission limit of -45 dBm/MHz

Assuming there is VLP body loss and a low VLP activity factor, the current limit of OOB emission of -45 dBm/MHz is sufficient to ensure coexistence for the case of VLP on a platform interfering a train TU.

There could be cases of single link interference (6 per day per station), lasting less of a second. Most would not impact the useful signal and the other ones could be managed by CBTC redundancies without a loss in systems reliability.

A7.4 CASE STUDY WITH THE VLP OOB EMISSION LIMIT OF -37 DBM/MHZ

A7.4.1 Worst case C/I_{adj} budget

C= -84 dBm, VLP I = 14 dBm, OOB emission = -37 dBm/MHz, MCL = 56.3 dB.

C/I_{adj} threshold for QPSK channel at 5930 MHz is -28 dB.

C/I_{adj}= -84 - (14-56.3) = -41.7 dB

Therefore, the worst-case budget is missing 13.7 dB, situation is 7 dB worse than in the case of OOB emission limit of -45 dBm/MHz.

A7.4.2 Improvement factors

The same improvement factors as previously are considered:

- CBTC antenna diversity which increases the MCL by 4.4 dB in 50% of the cases;
- Same distribution for VLP antenna gain/body loss;
- C/I_{adj} threshold is decreased for the CBTC channel at 5920 MHz: 5 dB measured improvement for OOB emission at -37 dBm/MHz. This improvement applies to 50% of the trials;
- Improvement for the VLP activity factor of 4 dB corresponding to the measured difference between C/I_{adj} at 96% and 2% occupancy for a -37 dBm/MHz OOB emission CBTC channel;
- The net effect of the improvements in the previous 2 bullets is that a -32 dB protection ratio is considered with VLP out-of-band emissions of -37 dBm/MHz when the CBTC single link is using a channel at 5930 MHz (50% of the cases). For a CBTC channel at 5920 MHz (50% of the cases), the protection ratio is – 37 dB. Those values match the measurements for 40 MHz WAS/RLAN channel with occupancy factor of 2%, and QPSK ¾ in Annex 5 (see Figure 53 and Figure 54, CBTC signal 9 MBit/s at -81 dBm).

A7.4.3 Simulation results-single link

The simulation detailed in A7.8.3 gives the following results:

[22] Assuming one TU failure in the train populations once or twice a month, probability that it happens during one of the 2 bad days in a year is 2 x 12/365 or 2 x 24/365 = 7% to 13%

Table 65: Simulation results

	VLP OOB emission -45 dBm/MHz	VLP OOB emission -37dBm/MHz
Interference occurrences		
Per year	10000	170000
% of train entrance	2.5%	42.5%
Interference duration		
Lasting more than 1 s	0	90000
Lasting more than 2 s	0	30000
Interference intensity		
Budget margin < -3 dB	0	80000
Budget margin < -6 dB	0	20000
Budget margin < -9 dB	0	10000
Budget margin < -12 dB	0	0

This shows that potentially 43% of trials will encounter an interference of any duration in the vulnerable zone. The main reason is that the C/I_{adj} threshold to maintain a packet loss of 1% or more is increased by 7 dB when the OOB emission limit are relaxed.

22% of trials will encounter an interference of 1 second or more, out of which one third (7.5% of all trials, or one train passage out of 13) will last more than 2 s.

The simulation is made considering one VLP in a 20 m long vulnerable zone where the CBTC level is minimal (<= -84 dBm). Because some of the trials happen with a very negative interference budget, there would be interference even with a stronger CBTC signal, happening in front of VLP outside the vulnerable zone. This will lead to a larger number of interferences for the same train passage.

For instance, assuming that there is a 20 m long zone outside of the vulnerable zone where the CBTC level is 3 dB higher than the minimum, i.e. -81 dBm, in this second zone there will be statistically another VLP in a position to interfere. Interference will be less intense and shorter, but 80000 additional interferences can be expected, and 30000 of those would last more than 1 s.

From that it can be concluded:

- If the minimum level on the station is -84 dBm, the number of interference at -37 dBm/MHz OOB emission is likely to be higher than in Table 65;
- Even if the minimum CBTC level is higher due to the radio planning of a specific station (e.g. -81 dBm), the number of interference case remains high (e.g. more than 80000);
- Moreover, the simulation shows that for 10000 or 2.5% of the trials, the link budget is missing more than -9 dB to meet the threshold. It means that VLP interference may impact a CBTC signal of -84 +9 =-75 dBm (this would happen for a VLP outside the vulnerable zone).

A7.4.4 System aspects

Around one half of train passages in a station (more than 43%) are now exposed to single link interference.

A7.4.4.1 Nominal mode

In most cases, the interference will impact the weaker radio link in the TU, while the useful signal is carried over the other frequency.

However, there is a non-negligible proportion of trials (2.5% or 10000 trials per year) when the interference margin is more than 9 dB below the threshold. In such case, the interference can affect a link at non minimum RF level (e.g. -75 dBm), which even in nominal mode may be carrying the useful CBTC information, thereby triggering a switch to the other TU.

Compared to the case at -45 dBm where this was happening only in degraded mode and therefore 6 times per year, the loss of one TU will happen more often (an unknown proportion of 10000). In such case the CBTC radio system is impacted, although still able to cope in most cases by relying on the other TU.

A7.4.4.2 Degraded mode

In A7.3.4.2, the degraded mode could represent 220 train entrance per year. With a risk of 43% or more interference, about 100 interferences could impact the CBTC useful link of the TU (compared to 6).

A7.4.4.3 Double failure

In this very rare case, the CBTC is relying on a single link for one train passing the station. If this train makes 5 such passages in the day until repair, 2 or 3 will be interfered, and there could be instances of partial or total loss of CBTC communication.

A7.5 SENSITIVITY ANALYSIS

The base case for the simulation is a CBTC system in QPSK ¾ with minimum RF level of -84 dBm, interfered by a VLP operating a 40 MHz channel with an occupancy factor of 2% (proxy for the activity factor 2%) with a combined body loss + antenna gain variation as per the measurements of a tablet on human lap (corrected for the front half space).

The following alternative parameters/variables have been assessed, for VLP OOB emission of -37 dBm/MHz.

- VLP Body loss: truncated gaussian distribution with a mean of 4 dB and a min of 0 and a max of 8 dB; proximity/body loss distribution determined for aggregate PC and tablets; instead of the base assumption (distribution for combined antenna and body loss for a tablet on human lap in the front half space);
- VLP Occupancy factor of 10% or 96% instead of base assumption 2%;
- Minimum CBTC level: -87 dBm and -77 dBm; instead of base assumption -84 dBm;
- CBTC Modulation: 16 QAM at -84 dBm, assuming a 2 dB increase in C/I_{adj} threshold; BPSK modulation at -87 dBm; instead of base which is QPSK at -84 dBm.

It is also compared the variation between -45 dBm/MHz VLP OOB emission versus -37 dBm/MHz in an alternative base case, where the VLP channel occupancy factor is set at 96% (instead of 2%) and 80% of VLP transmit with a back-off with respect to the maximum e.i.r.p. (instead of 100% VLP at full power).

Detailed results are shown in section A7.8.4.

In conclusion the sensitivity analysis confirms that results should not be taken at exact face value but that the computation shows sensitivity to the choice of parameters while the overall picture is robust to the assumptions.

A7.6 INFLUENCE OF BACK-OFF – MITIGATION WITH TPC

A factor which can facilitate coexistence is that the VLP is not necessarily transmitting at full power (back-off).

Maximum OOB emission is generated when the VLP amplifier is close to saturation. It is expected that a back-off is applied to a VLP that would otherwise reach the regulatory OOB emission limits. This would result in a non-linear reduction in OOB emission. One measurement suggests that a 2 dB back-off would result in OOB emission being reduced by 7 dB. This means that in practice the OOB emission would be reduced from - 37 dBm/MHz to OOB emission of -45 dBm/MHz, or less.

Because in nomadic usage VLP would in practice communicate at very close distance, existence of a back-off seems likely if there is a transmit power control mechanism (TPC). If all VLP are equipped with TPC, the TPC would ensure that each VLP transmits with the right amount of power, and it is assumed to simplify that in a nomadic use case, this would always lead to a back-off of 2 dB.

Therefore, the analysis and conclusions in section A7.3 pertaining to OOB emission at -45 dBm/MHz would apply. TPC would ensure that despite relaxed OOB emission limits, the number of interference would not be increased in nomadic use case in urban rail context compared to OOB emission at -45 dBm/MHz. This would be sufficient to ensure coexistence for this use case.

A7.7 CONCLUSIONS FOR THE OOB EMISSION LIMIT OF -37 DBM/MHZ

Relaxation of the OOB emission limit would significantly increase the number of single link interference, and their duration. It can be expected that some would affect the useful link of a TU, therefore the CBTC system is affected, although still able to cope in most cases. The system becomes more exposed to double failures, or random elements such as masking, and there could be instances of partial or total loss of CBTC communication.

In case TPC would be applied, it is expected that most or all VLP would transmit with a small back off which would result in much lower OOB emission, ensuring similar coexistence situation as with the OOB emission limit of -45 dBm/MHz.

A7.8 DETAILED CALCULATIONS

A7.8.1 MCL area

A7.8.1.1 Estimation of the MCL 3 dB area

A theoretical calculation was made with a model representing the geometry of the TU with respect to the platform. Based on that model, a theoretical position of the MCL on the platform can be determined, and by calculating the coupling loss in a series of positions around that MCL position, an idea of the MCL 3 dB area can be determined.

Table 66: MCL 3 dB area

VLP position	X Ahead of train	3,5	1,2	8	2,7	6,8	3,5	6	m
	Y From tracks	1,4	1,4	1,4	2	2	2,2	2,2	m
	Z from platform	1,6	1,6	1,6	1,6	1,6	1,6	1,6	m
VARIATION wrt MCL		0,0	-3,2	-3,0	-3,0	-3,0	-3,0	-3,0	dB

It can be approximated by a rectangular plane of 5 x 0.7 m in the direction of the platform in the passenger safe area (i.e. withdrawn by 1.4 m from the tracks).

A7.8.1.2 Estimation of the MCL 6 dB area

Table 67: MCL 6 dB area

VLP position	X Ahead of train	3,5	0,8	13	1,6	12	6,5	10	m
	Y From tracks	1,4	1,4	1,4	2	2	3,5	3,2	m
	Z from platform	1,6	1,6	1,6	1,6	1,6	1,6	1,6	m
VARIATION wrt MCL		0,0	-6,1	-6,1	-6,3	-5,9	-6,1	-6,1	dB

The MCL 6 dB area can be approximated by a rectangle of 10 x 1.5 m.

A7.8.1.3 Estimation of the MCL 3 dB area and MCL 1.5 dB area in case of antenna diversity

Based on the model representing the geometry of the train, it can be estimated that the additional coupling loss for the antenna further away from the platform, which receives one of the two frequencies of the TU is 4.4 dB more than the one for which the measurements were made.

The MCL 3 dB area associated to that antenna is approximately 10 m long (2 s sweeping time).

Table 68: MCL 3 dB area - antenna diversity

VLP position	X Ahead of train	6	2,8	14	4,3	12,6	7	10
	Y From tracks	1,4	1,4	1,4	2	2	2,6	2,6
	Z from platform	1,6	1,6	1,6	1,6	1,6	1,6	1,6
VARIATION wrt MCL		-4,36	-2,9	-3,0	-2,9	-2,9	-2,9	-2,9

The MCL 1.5 dB area is approximately 5 m long (1 s sweeping time).

Table 69: MCL 1.5 dB area - antenna diversity

VLP position	X Ahead of train	6	3,5	10,5	4,2	9,8	5	9
	Y From tracks	1,4	1,4	1,4	1,6	1,6	1,8	1,8
	Z from platform	1,6	1,6	1,6	1,6	1,6	1,6	1,6
VARIATION wrt MCL		-4,36	-1,4	-1,4	-1,4	-1,4	-1,5	-1,4

Table 70: Simulation with the OOB emission limit of -45 dBm/MHz

Case OOBe = -45 dBm/MHz		
C level	-84	dBm/5 MHz
CBTC Mode	Nominal	
Cases trials	400 000	trials/year
MCL	56,3	dB
Min interf duration	0	s
Train speed	5	m/s
CL for interference	56,3	dB
VLP EIRP	14	dBm
C/I threshold	-35	dB
Interference margin	-6,7	dB

Channel 5920 MHz		
Gain	3	dB
Probability	50%	

Activity factor (2% occupancy)		
Gain	4	dB

Additional factor		
Gain	0	dB
Probability	0%	

BL distribution	Body Loss (dB)	Budget after BL Diversity	Occurrences	Budget after channel (dB)	Occurrences per year	Budget after activity factor (dB)	Occurrences per year	Budget after masking (dB)	Occurrences per year
10%	0	-6,7	20 000	-6,7	10 000	-2,7	10 000	-2,7	10 000
								-2,7	-
				-3,7	10 000	0,3	10 000	0,3	10 000
								0,3	-
10%	3,5	-3,2	20 000	-3,2	10 000	0,8	10 000	0,8	10 000
								0,8	-
				-0,2	10 000	3,8	10 000	3,8	10 000
								3,8	-
20%	5	-1,7	40 000	-1,7	20 000	2,3	20 000	2,3	20 000
								2,3	-
				1,3	20 000	5,3	20 000	5,3	20 000
								5,3	-
20%	6,5	-0,2	40 000	-0,2	20 000	3,8	20 000	3,8	20 000
								3,8	-
				2,8	20 000	6,8	20 000	6,8	20 000
								6,8	-
20%	8	1,3	40 000	1,3	20 000	5,3	20 000	5,3	20 000
								5,3	-
				4,3	20 000	8,3	20 000	8,3	20 000
								8,3	-
20%	9,5	2,8	40 000	2,8	20 000	6,8	20 000	6,8	20 000
								6,8	-
				5,8	20 000	9,8	20 000	9,8	20 000
								9,8	-
		Total	200 000		200 000		200 000		200 000

Trials with margin <0	10 000	3%	
Trials with margin <-3 dB	-	0%	will last more than 1 s
Trials with margin <-6dB	-	0%	will last more than 2 s
Trials with margin <-9 dB	-	0%	
Trials with margin <-12 dB	-	0%	

Antenna Diversity	
Gain in MCL(dB)	4,4
Probability	50%

BL distribution	Body Loss (dB)	Budget after BL and diversity	Occurrences	Budget after channel (dB)	Occurrences per year	Budget after activity factor (dB)	Occurrences per year	Budget after masking (dB)	Occurrences per year
10%	0	-2,3	20 000	-2,3	10 000	1,7	10 000	1,7	10 000
								1,7	-
				0,7	10 000	4,7	10 000	4,7	10 000
								4,7	-
10%	3,5	1,2	20 000	1,2	10 000	5,2	10 000	5,2	10 000
								5,2	-
				4,2	10 000	8,2	10 000	8,2	10 000
								8,2	-
20%	5	2,7	40 000	2,7	20 000	6,7	20 000	6,7	20 000
								6,7	-
				5,7	20 000	9,7	20 000	9,7	20 000
								9,7	-
20%	6,5	4,2	40 000	4,2	20 000	8,2	20 000	8,2	20 000
								8,2	-
				7,2	20 000	11,2	20 000	11,2	20 000
								11,2	-
20%	8	5,7	40 000	5,7	20 000	9,7	20 000	9,7	20 000
								9,7	-
				8,7	20 000	12,7	20 000	12,7	20 000
								12,7	-
20%	9,5	7,2	40 000	7,2	20 000	11,2	20 000	11,2	20 000
								11,2	-
				10,2	20 000	14,2	20 000	14,2	20 000
								14,2	-
		Total	200 000		200 000		200 000		200 000

Trials with margin <0	-	0%	
Trials with margin <-1,5	-	0%	will last more than 1 s
Trials with margin <-3 dB	-	0%	will last more than 2 s
Trials with margin <-6dB	-	0%	
Trials with margin <-9 dB	-	0%	
Trials with margin <-12 dB	-	0%	

Table 71: Simulation with the OOB emission limit of -37 dBm/MHz

Case OOBe = -37 dBm/MHz		
C level	-84	dBm/5 MHz
CBTC Mode	Nominal	
Cases trials	400 000	trials/year
MCL	56,3	dB
Min interf duration	0	s
Train speed	5	m/s
CL for interference	56,3	dB
VLP EIRP	14	dBm
C/I threshold	-28	dB
Interference margin	-13,7	dB

Channel 5920 MHz			Activity factor (2% occupancy)			Additional factor		
Gain	5	dB	Gain	4	dB	Gain	0	dB
Probability	50%					Probability	0%	

BL distribution	Body Loss (dB)	Budget after BL Diversity	Occurrences	Budget after channel (dB)	Occurrences per year	Budget after activity factor (dB)	Occurrences per year	Budget after masking (dB)	Occurrences per year
10%	0	-13,7	20 000	-13,7	10 000	-9,7	10 000	-9,7	10 000
								-9,7	-
				-8,7	10 000	-4,7	10 000	-4,7	10 000
								-4,7	-
10%	3,5	-10,2	20 000	-10,2	10 000	-6,2	10 000	-6,2	10 000
								-6,2	-
				-5,2	10 000	-1,2	10 000	-1,2	10 000
								-1,2	-
20%	5	-8,7	40 000	-8,7	20 000	-4,7	20 000	-4,7	20 000
								-4,7	-
				-3,7	20 000	0,3	20 000	0,3	20 000
								0,3	-
20%	6,5	-7,2	40 000	-7,2	20 000	-3,2	20 000	-3,2	20 000
								-3,2	-
				-2,2	20 000	1,8	20 000	1,8	20 000
								1,8	-
20%	8	-5,7	40 000	-5,7	20 000	-1,7	20 000	-1,7	20 000
								-1,7	-
				-0,7	20 000	3,3	20 000	3,3	20 000
								3,3	-
20%	9,5	-4,2	40 000	-4,2	20 000	-0,2	20 000	-0,2	20 000
								-0,2	-
				0,8	20 000	4,8	20 000	4,8	20 000
								4,8	-
		Total	200 000		200 000		200 000		200 000

Trials with margin <0	120 000	30%	
Trials with margin <-3 dB	70 000	18%	will last more than 1 s
Trials with margin <-6dB	20 000	5%	will last more than 2 s
Trials with margin <-9 dB	10 000	3%	
Trials with margin <-12 dB	-	0%	

Antenna Diversity	
Gain in MCL(dB)	4,4
Probability	50%

BL distribution	Body Loss (dB)	Budget after BL and diversity	Occurrences	Budget after channel (dB)	Occurrences per year	Budget after activity factor (dB)	Occurrences per year	Budget after masking (dB)	Occurrences per year
10%	0	-9,3	20 000	-9,3	10 000	-5,3	10 000	-5,3	10 000
								-5,3	-
				-4,3	10 000	-0,3	10 000	-0,3	10 000
								-0,3	-
10%	3,5	-5,8	20 000	-5,8	10 000	-1,8	10 000	-1,8	10 000
								-1,8	-
				-0,8	10 000	3,2	10 000	3,2	10 000
								3,2	-
20%	5	-4,3	40 000	-4,3	20 000	-0,3	20 000	-0,3	20 000
								-0,3	-
				0,7	20 000	4,7	20 000	4,7	20 000
								4,7	-
20%	6,5	-2,8	40 000	-2,8	20 000	1,2	20 000	1,2	20 000
								1,2	-
				2,2	20 000	6,2	20 000	6,2	20 000
								6,2	-
20%	8	-1,3	40 000	-1,3	20 000	2,7	20 000	2,7	20 000
								2,7	-
				3,7	20 000	7,7	20 000	7,7	20 000
								7,7	-
20%	9,5	0,2	40 000	0,2	20 000	4,2	20 000	4,2	20 000
								4,2	-
				5,2	20 000	9,2	20 000	9,2	20 000
								9,2	-
		Total	200 000		200 000		200 000		200 000

Trials with margin <0	50 000	13%	
Trials with margin <-1,5	20 000	5%	will last more than 1 s
Trials with margin <-3 dB	10 000	3%	will last more than 2 s
Trials with margin <-6dB	-	0%	
Trials with margin <-9 dB	-	0%	
Trials with margin <-12 dB	-	0%	

A7.8.2 SENSITIVITY

Simulations are made with OOB emission at -37 dBm/MHz using alternative parameters. The first column recalls the base assumption.

Table 72: Sensitivity to VLP Body loss distribution

BL distribution			Tablet on human lap	Gaussian mean 4 dB	PC laptop and tablet mix
			OOBE	OOBE	OOBE
			-37 dBm/MHz	-37 dBm/MHz	-37 dBm/MHz
Interference occurrences					
	per year		170 000	233 000	115 000
	%		42,5%	58,3%	28,8%
Lasting more than 1s			90 000	150 000	77 000
Lasting more than 2 s			30 000	83 000	39 000
Interference intensity					
Cases with budget <					
	-3	dB	80 000	133 000	40 000
	-6	dB	20 000	50 000	38 000
	-9	dB	10 000	16 000	1 000
	-12	dB	-	-	-

Table 73: Sensitivity to VLP channel occupancy factor

Occupancy factor			2%	10%	96%
			OOBE	OOBE	OOBE
			-37 dBm/MHz	-37 dBm/MHz	-37 dBm/MHz
Interference occurrences					
	per year		170 000	230 000	280 000
	%		42,5%	57,5%	70,0%
Lasting more than 1s			90 000	150 000	210 000
Lasting more than 2 s			30 000	70 000	120 000
Interference intensity					
Cases with budget <					
	-3	dB	80 000	120 000	190 000
	-6	dB	20 000	60 000	80 000
	-9	dB	10 000	10 000	30 000
	-12	dB	-	-	10 000

Table 74: Sensitivity to CBTC minimum RF level

Minimum RF level	-84 dBm	-87 dBm	-77 dBm
	OOBE	OOBE	OOBE
	-37 dBm/MHz	-37 dBm/MHz	-37 dBm/MHz
Interference occurrences			
per year	170 000	250 000	10 000
%	42,5%	62,5%	2,5%
Lasting more than 1s	90 000	190 000	-
Lasting more than 2 s	30 000	120 000	-
Interference intensity			
Cases with budget <			
-3 dB	80 000	170 000	-
-6 dB	20 000	80 000	-
-9 dB	10 000	20 000	-
-12 dB	-	10 000	-

Table 75: Sensitivity to CBTC modulation

Modulation	QPSK -84 dBm	16 QAM -84 dBm	BPSK -87 dBm
	OOBE	OOBE	OOBE
	-37 dBm/MHz	-37 dBm/MHz	-37 dBm/MHz
Interference occurrences			
per year	170 000	230 000	190 000
%	42,5%	57,5%	47,5%
Lasting more than 1s	90 000	150 000	120 000
Lasting more than 2 s	30 000	70 000	30 000
Interference intensity			
Cases with budget <			
-3 dB	80 000	120 000	80 000
-6 dB	20 000	60 000	20 000
-9 dB	10 000	10 000	10 000
-12 dB	-	-	-

A7.8.2.1 Alternative base case: VLP 96% occupancy; back-off in 80% of the cases

The variation between -45 dBm/MHz versus -37 dBm/MHz in the case where the VLP channel occupancy factor is set at 96% is compared and it is assumed that a large portion of VLP transmit with a back-off with respect to the maximum e.i.r.p.

- The back-off is assumed to have a non-linear effect on the out-of-band emissions, so that 1 dB, 3 dB and 6 dB of power reduction translates into an improvement of respectively 4 dB, 9 dB and 12 dB of the C/I_{adj};
- For simplicity in the case of -45 dBm/MHz OOB emission limit, in the simulation, it is assumed that transmission at full power happens 20% of the trials and in 80% of the trials there is an improvement of at least 4 dB in C/I_{adj} (at that level of OOB emission, neglecting higher level of back-off does not change the results);
- For the -37 dBm/MHz OOB emission limit, transmission is considered at full power in 20% of the trials and an improvement of 4 dB for 30% of trials, 9 dB for 40% of trials and 12 dB for 10% of trials.

Table 76: Alternative base case: VLP 96% occupancy; back-off in 80% of the cases

Alternative base				
			OOBE	OOBE
			-45dBm/MHz	-37 dBm/MHz
Interference occurrences				
	per year		26 000	120 000
	%		6,5%	30,0%
Lasting more than 1s			8 000	73 000
Lasting more than 2 s			2 000	33 000
Interference intensity				
Cases with budget <				
	-3	dB	6 000	66 000
	-6	dB	2 000	22 000
	-9	dB	-	9 000
	-12	dB	-	2 000

ANNEX 8: METHODOLOGY AND DETAILED RESULTS FOR STATISTICAL STUDY C

A8.1 HYPOTHESIS

This study investigates the interference generated by a VLP WAS/RLAN inside a driverless metro train, on a single train unit. Trains typically leverage two train units, one at each end of the train, unless facing degraded mode where a single TU would be then available due to the failure of the other one. For a metro line, such degraded modes typically occur 24 hours per month.

The study also considers there is always one VLP, but only one, located in the front of the train, at one of the 20 locations illustrated in Figure 71. The figure also shows the coupling losses for each of the three metros simulated, and corresponding to the losses from every location where measurements were performed to antenna port of the CBTC receivers (on green grid-points, the coupling loss are taken from measurements, on blue grid-points, 70 dB coupling loss is assumed). The VLP location is assumed to change randomly every 3 km (i.e. around 3 stations. The study does not assess the probability of WAS/RLAN and CBTC packets colliding within the 1 s time windows.

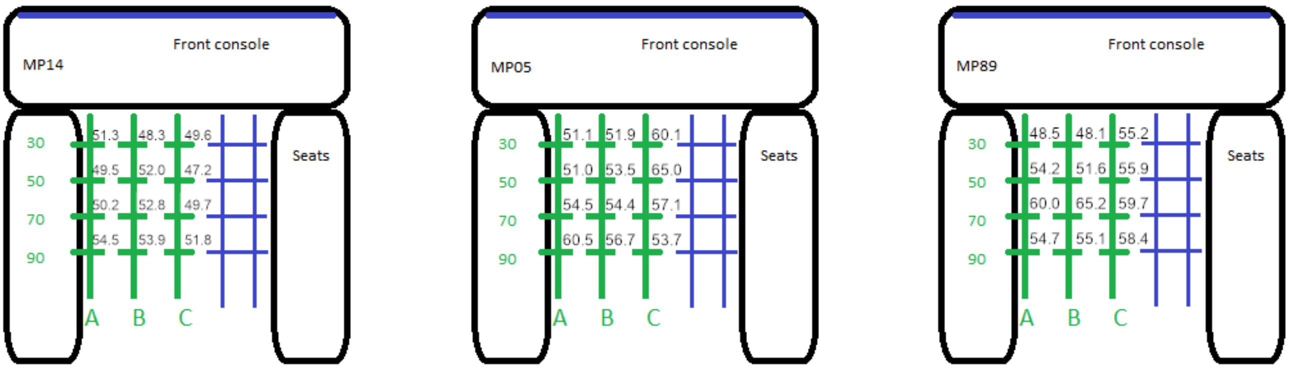

Figure 71: Locations and associated coupling loss values for all blue points the CL is assumed at 70 dB

The VLP channel is selected randomly as the VLP changes (i.e. every 3 km), with either equal probability (i.e. no channel prioritisation) or with prioritisation of the channels above 6105 MHz, as per the following probabilities.

Table 77: no channel prioritisation

Percentage of occurrence	VLP channel
33.3%	Channel below 6105 MHz
33.3%	Channel in 6105-6265 MHz
33.3%	Channel above 6265 MHz

Table 78: channel prioritisation above 6105 MHz

Percentage of occurrence	VLP channel
1% (Note 1)	Channel below 6105 MHz
49.5%	Channel in 6105-6265 MHz
49.5%	Channel above 6265 MHz
Note 1: This offload is believed to be achievable in the urban rail environment where home usage traffic is not present.	

The study considers that the wanted signal level experienced by the CBTC receiver is given by the measurements in Figure 72. It assumes train speed of 27 km/h. In the absence of measurements for the whole line, and given the fact that The course of the train is longer than the measurement (which extends over 5 km), this signal is therefore repeated to cover a 24 h course. The signal is picked from the strongest signal. Only when the power level difference on the two channels is less than 15 dB, and when the levels are higher than -80 dBm, the serving channel is chosen arbitrarily and remains the same for 50 m (unless the above two conditions are not satisfied).

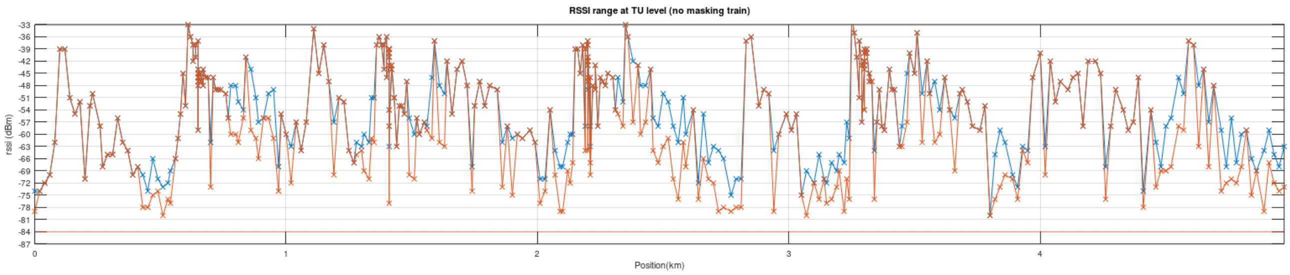

Figure 72: Wanted CBTC power level at TU receiver sampled in time domain

It must be pointed out that this study goes beyond the “single link analysis” by taking into account that there are two radios available on a TU (not actively serving at the same time) reproducing the behaviour of real systems.

A masking train is assumed to impair the wanted signal by 5 dB[23], with a probability of 1%. When this occurs, the study assumes that this impairment extends over a course of 2 km.

Body losses and antenna diagram losses are assumed to be as per the following probabilities, and change every 5 seconds.

Table 79: Body loss and antenna pattern attenuations

Percentage of occurrence	Body loss + antenna pattern loss
10%	0 dB
10%	3.5 dB
20%	5 dB
20%	6.5 dB
20%	8 dB
20%	9.5 dB

The power reduction of the out-of-band emissions of the VLP, taking into consideration some form of TPC algorithms, is assumed to be according to the following probabilities, and changes every 100 ms. The TPC is assumed to have a non-linear effect on the out-of-band emissions, so that 1 dB, 3 dB and 6 dB of power reduction translates into an improvement of respectively 4 dB, 9 dB and 12 dB of the C/I_{adj}.

[23] Masking penalty applicable to ‘’large’’ tunnels, consistently with the tunnel shape where the measurements in Figure 72 have been performed.

Table 80: Not all VLP WAS/RLAN devices implementing TPC

Percentage of occurrence	TPC OOB emission attenuation
20%	0 dB
30%	4 dB
40%	9 dB
10%	12 dB

Table 81: All VLP WAS/RLAN devices implementing TPC

Percentage of occurrence	TPC OOB emission attenuation
37.5% (Note 1)	4 dB
50%	9 dB
12.5%	12 dB
Note 1: This always effectively active TPC behaviour is believed to be achievable in the urban rail environment where the devices of the users are necessarily in very close vicinity.	

A8.2 THRESHOLDS

The C/I_{adj}[24] experienced by the CBTC receiver is derived every 100 ms over a period of 24 hours. It is then compared to the C/I_{adj} thresholds (i.e. the protection ratio) obtained through laboratory measurements.

For VLPs with OOB emission -37 dBm/MHz:
- -33 dB, for the channel centred on 5920 MHz;
- -28 dB, for the channel centred on 5930 MHz;
- No interference if the VLP channel is greater than 6105 MHz.

For VLPs with OOB emission -45 dBm/MHz:
- -38 dB, for the channel centred on 5920 MHz;
- -35 dB, for the channel centred on 5930 MHz;
- No interference if the VLP channel is greater than 6105 MHz.

The results are given as the number of interference cases faced within 24 hours periods and sustained for duration of 1 second, i.e. shorter interference events are not counted.

A8.3 SIMULATION ALGORITHM

In short, the simulator:
- Takes the wanted CBTC levels on both links from measurements;
- Selects the serving link, and hence the CBTC channel;
- Decides whether a masking train is present;
- Chooses where the VLP user is seating, i.e. the coupling loss;
- Selects the VLP channel;

24 "I_{adj}" is the power level in the RLAN channel, as per the definition of the C/I_{adj} used in the BNetzA measurements.

- Selects the body loss;
- Applies TPC.

Stochastic processes are generated for those random variables, with the time resolution of 100 ms, and the 1s or more interfered time windows are counted, based on the thresholds above.

A8.4 COMPLEMENTARY ANALYSIS

A8.4.1 Test with 2% WAS/RLAN channel load. No VLP channel prioritisation and not all VLP WAS/RLAN devices implementing TPC

This simulation plots the number of events that would have occurred if the CBTC and WAS/RLAN traffic were strictly the same as they were during the measurements performed by the BNetzA (see Annex 5) where the WAS/RLAN channel load was set to 2%. Note that this simulation is made to give an insight on the impact that a specific traffic pattern may have. It shows that the number of cases does not necessarily scale with the channel load: from 4822 cases at nearly full load, the number of cases is down to 687 cases, while 4822*0.02 = 96.

The impact of different traffic patterns, irrespective of the channel load, could range between 0 to 100% of the cases simulated at full load.

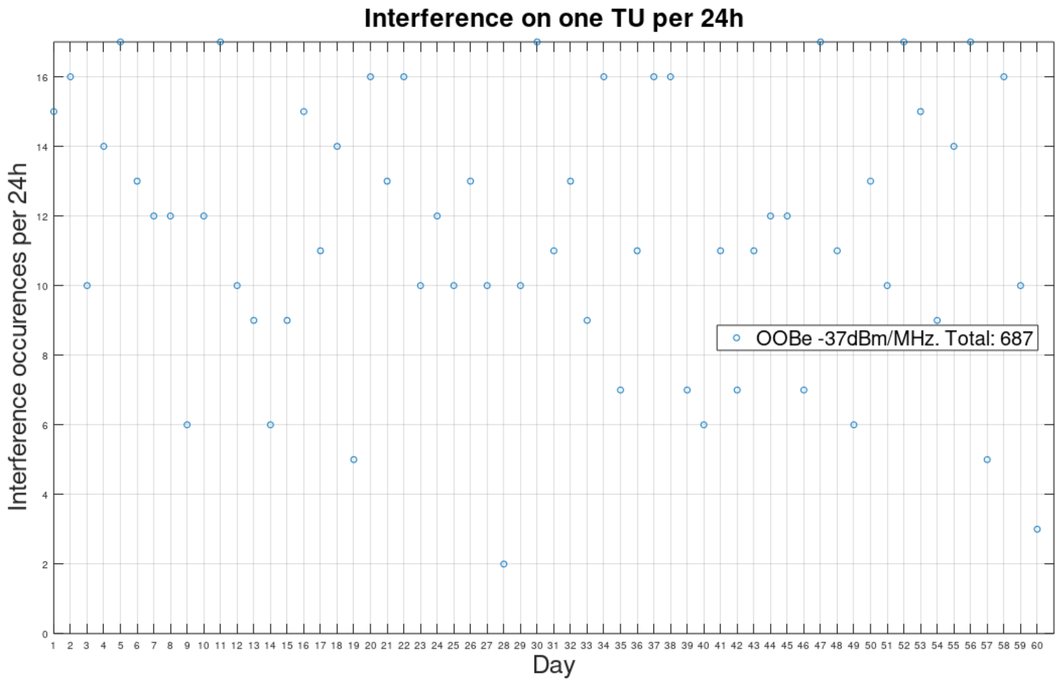

Figure 73: Channel load 2%. No VLP channel prioritisation and not all WAS/RLAN devices implementing TPC, train MP14

A8.4.2 Test with alternative body loss and antenna pattern. No VLP channel prioritisation and not all VLP WAS/RLAN devices implementing TPC

This simulation plots the number of events for an alternative body loss and antenna pattern assumption. The distribution is as follows:

Table 82: Body loss and antenna pattern alternative attenuations

Percentage of occurrence	Body loss + antenna pattern loss
0.7%	0 dB
37.53%	3 dB
61.77%	14 dB

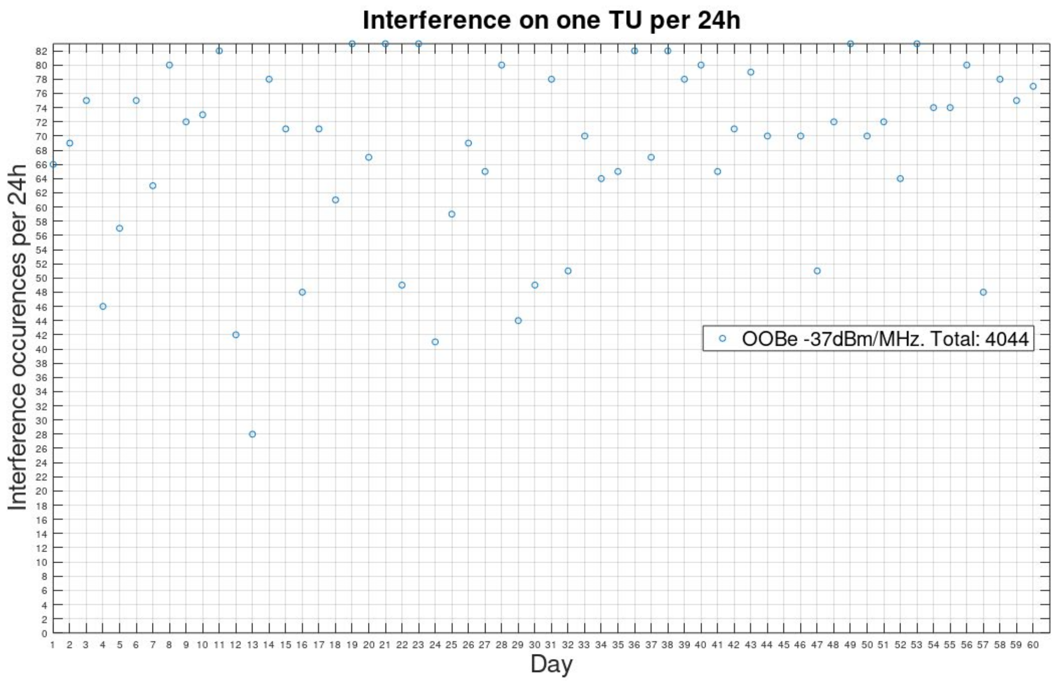

Figure 74: Alternative body loss. No VLP channel prioritisation and not all WAS/RLAN devices implementing TPC, train MP14

ANNEX 9: LIST OF REFERENCES

[1] ECC Report 302: "Sharing and compatibility studies related to Wireless Access Systems including Radio Local Area Networks (WAS/RLAN) in the frequency band 5925-6425 MHz", approved May 2019

[2] ECC Report 290: "Studies to examine the applicability of ECC Reports 101 and 228 for various Intelligent Transport Systems (ITS) technologies under EC Mandate (RSCOM 17-26Rev.3)", approved January 2019

[3] CEPT Report 75: "Report from CEPT to the European Commission in response to the Mandate “to study feasibility and identify harmonised technical conditions for Wireless Access Systems including Radio Local Area Networks in the 5925-6425 MHz band for the provision of wireless broadband services” - Report B: Harmonised technical parameters for WAS/RLANs operating on a coexistence basis with appropriate mitigation techniques and/or operational compatibility/coexistence conditions, operating on the basis of a general authorisation", approved November 2020

[4] Recommendation ITU-R P.1411: "Propagation data and prediction methods for the planning of short-range outdoor radiocommunication systems and radio local area networks in the frequency range 300 MHz to 100 GHz"

[5] ECC Decision (20)01: The harmonised use of the frequency band 5945-6425 MHz for Wireless Access Systems including Radio Local Area Networks (WAS/RLAN), approved November 2020

[6] ECC Decision (08)01: The harmonised use of Safety-Related Intelligent Transport Systems (ITS) in the 5875-5935 MHz frequency band, approved March 2008, latest updated November 2022

[7] ETSI TR 103 580 V1.1.1: “Urban Rail ITS and Road ITS applications in the 5,9 GHz band; Investigations for the shared use of spectrum”

[8] K. Guan et al., "Measurements and Analysis of Large-Scale Fading Characteristics in Curved Subway Tunnels at 920 MHz, 2400 MHz, and 5705 MHz," in IEEE Transactions on Intelligent Transportation Systems, vol. 16, no. 5, pp. 2393-2405, Oct. 2015, doi: 10.1109/TITS.2015.2404851

[9] Siemens, Trainguard MT: Optimal performance with the world’s leading automatic train control system for mass transit. Siemens AG 2015.

[10] ETSI TR 103 442 V1.2.1: "Railways Telecommunications (RT); Shared use of spectrum between Communication Based Train Control (CBTC) and ITS applications"