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Next Generation Communication System;  
Radio performance simulations and  
evaluations in rail environment;  
Part 1: Long Term Evolution (LTE)**

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# Foreword

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

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

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

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

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# Modal verbs terminology

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

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# Executive summary

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

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

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

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

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

---

## Introduction

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

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

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# 1 Scope

The present document:

- Defines the simulation parameters relevant to rail environment relating to 3GPP LTE radio performance. This includes in particular operating frequency bands, bandwidths, deployment scenario (inter-site distance), and antenna characteristics, transmit powers and channel models, along with relevant metrics to be evaluated.
- Collects and analyse the simulation results of an LTE system in the rail environment operating in the 900 MHz frequency band (UIC and E-UIC bands).
- Identifies limitations of an LTE system in the rail environment.

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## 2 References

### 2.1 Normative references

Normative references are not applicable in the present document.

### 2.2 Informative references

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

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

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

- [i.1] ETSI TS 145 005 (V14.4.0) (04-2018): "Digital cellular telecommunications system (Phase 2+) (GSM); GSM/EDGE Radio transmission and reception (3GPP TS 45.005 version 14.4.0 Release 14)".
- [i.2] ETSI TS 136 104 (V14.7.0) (04-2018): "LTE; Evolved Universal Terrestrial Radio Access (E-UTRA); Base Station (BS) radio transmission and reception (3GPP TS 36.104 version 14.7.0 Release 14)".
- [i.3] ETSI TS 136 101 (V14.7.0) (04-2018): "LTE; Evolved Universal Terrestrial Radio Access (E-UTRA); User Equipment (UE) radio transmission and reception (3GPP TS 36.101 version 14.7.0 Release 14)".
- [i.4] Recommendation ITU-R M.2135-1 (12-2009): "Guidelines for evaluation of radio interface technologies for IMT advanced".
- [i.5] IST-4-027756 Winner II D1.1.2 V1.2 Winner II Part I: "Channel Models", European Commission, Deliverable IST-WINNER D.
- [i.6] Ikuno, J. Colom, Martin Wrulich, and Markus Rupp.: "Performance and modelling of LTE H-ARQ." Proc. International ITG Workshop on Smart Antennas (WSA 2009), Berlin, Germany, 2009.
- [i.7] ETSI TS 136 211 (V14.6.0) (04-2018): "LTE; Evolved Universal Terrestrial Radio Access (E-UTRA); Physical channels and modulation (3GPP TS 36.211 version 14.6.0 Release 14)".
- [i.8] Recommendation ITU-R M.1225 (1997): "Guidelines for evaluation of radio transmission technologies for IMT-2000".

- [i.9] European Integrated Railway Radio Enhanced Network System Requirements Specification, UIC CODE 951, GSM-R Operators Group, December 2015.
- [i.10] ETSI TR 145 050 (V15.0.0) (07-2018): "Digital cellular telecommunications system (Phase 2+) (GSM); GSM/EDGE Background for Radio Frequency (RF) requirements (3GPP TR 45.050 version 15.0.0 Release 15)".
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- [i.12] Loïc Brunel, Hervé Bonneville, Akl Charaf and Émilie Masson: "System-Level Evaluation of Next-Generation Radio Communication System for Train Operation Services", Proceedings of 7<sup>th</sup> Transport Research Arena TRA 2018, April 16-19, 2018.

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## 3 Definition of terms, symbols and abbreviations

### 3.1 Terms

Void.

### 3.2 Symbols

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

$\lambda$  wave length

### 3.3 Abbreviations

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

ACS	Adjacent Channel Selectivity
AMC	Adaptive Modulation and Coding
AWGN	Additive White Gaussian Noise
BS	Base Station
BTS	Base Transceiver Station
BW	Bandwidth
CDF	Cumulative Distribution Function
CDL	Clustered Delay Line
COST	Cooperation of Scientific and Technical
CP	Cyclic Prefix
DL	Down Link
EIRENE	European Integrated Railway radio Enhanced Network
eNB	evolved Node B
ETU	Extended Typical Urban model
E-UTRA	Evolved UMTS Terrestrial Radio Access
FDD	Frequency Division Duplex
FEC	Forward Error Correction
FRMCS	Future Rail Mobile Communications System
FSTD	Frequency Switched Transmit Diversity
GSM	Global System for Mobile communications
GSM-R	Global System for Mobile communication for Railway application
HARQ	Hybrid Automatic Repeat-Request
HO	Hand Over
HST	High Speed Train
IMT	International Mobile Telecommunications



IP	Internet Protocol
ISD	Inter Site Distance
ISI	Inter-Symbol Interference
ITU-R	Internail Telecommunication Union - Radiocommunication sector
LOS	Line Of Sight
LTE	Long Term Evolution
MAC	Media Access Control
MCS	Modulation and Coding Scheme
MIMO	Multiple Input, Multiple Output
MISO	Multiple Input, Single Output
MOS	Mean Opinion Score
MRS	Mobile Relay Station
NLOS	Non Line Of Sight
OFDM	Orthogonal Frequency Division Multiplexing
PBCH	Physical Broadcast Channel
PDCCH	Physical Downlink Control Channel
PDCP	Packet Data Convergence Protocol
PDP	Power Delay Profile
PER	Packet Error Rate
PHY	PHYSical layer
PUCCH	Physical Uplink Control Channel
QAM	Quadrature Amplitude Modulation
QCI	QoS Class Identifier
RB	Resource Block
REC	Railways Emergency Call
RF	Radio Frequency
RLC	Radio Link Control
RT	Rail Telecommunications
SFBC	Space-Frequency Block Coding
SGW	Serving Gateway
SIMO	Single Input, Multiple Output
SINR	Signal to Interference-plus-Noise Ratio
SISO	Single Input, Single Output
SNR	Signal to Noise Ratio
SRS	System Requirement Specification
TC	Technical Committee
TCP	Transmission Control Protocol
TDD	Time Duplex Division
UDP	User Datagram Protocol
UE	User Equipment
UIC	Union Internationale des Chemins de fer
UL	Up Link
UMTS	Universal Mobile Telecommunications System
USB	Universal Serial Bus

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## 4 Assumptions and parameters for simulations and evaluations

### 4.1 Introduction

In the scope of the present document, the following points are addressed:

- Simulations take into account railway specifics
- Simulations are flexible in order to simulate different system configurations, parameter settings and scenarios
- Consideration of different carrier band-widths (at least 1,4 MHz, 3 MHz and 5 MHz)

- Consideration of TDD and FDD duplex modes
- Consideration of different subscriber and train densities and distributions
- Consideration of FRMCS system parameters (e.g. Cyclic Prefix)
- Different power classes of FRMCS equipment
- Different antenna radiation patterns and tilts
- SISO, SIMO, MISO und MIMO
- Different installation heights of antennas
- Different distances and densities of fixed transmitter equipment (eNB)
- Different specified and appropriate coding and modulation schemes
- Different 3GPP Releases (e.g. LTE:  $\geq 13$ ) to take into account new features, e.g. performance improvements for high speed

## 4.2 Simulation tools

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

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

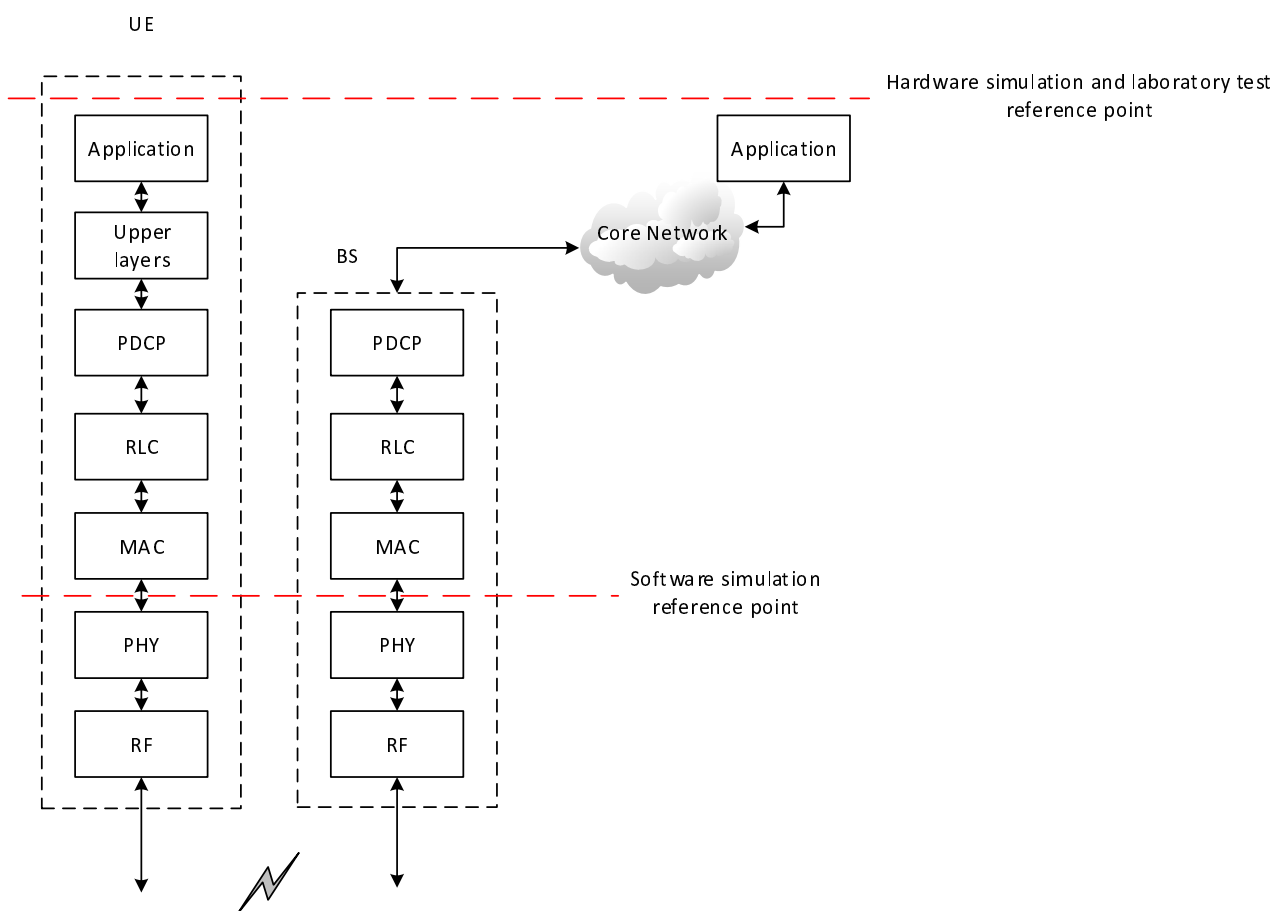


Figure 1: Reference point for the software simulations

## 4.3 Scenarios

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

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

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

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

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

## 4.4 Bandwidth and transmit power

### 4.4.1 Bandwidths

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

- 1) Scenario 1 considers GSM-R in UIC band as per today, with the addition of a 1,4 MHz LTE carrier in the upper part of E-UIC band. This scenario corresponds to a migration phase, with co-existence of both GSM-R and LTE systems.
- 2) Scenario 2 is an extension of scenario 1 with an LTE carrier extended to 3 MHz in the E-UIC band.
- 3) Scenario 3 assumes a deployment with no GSM-R and one LTE 5 MHz carrier in UIC band, overlapping the E-UIC band.

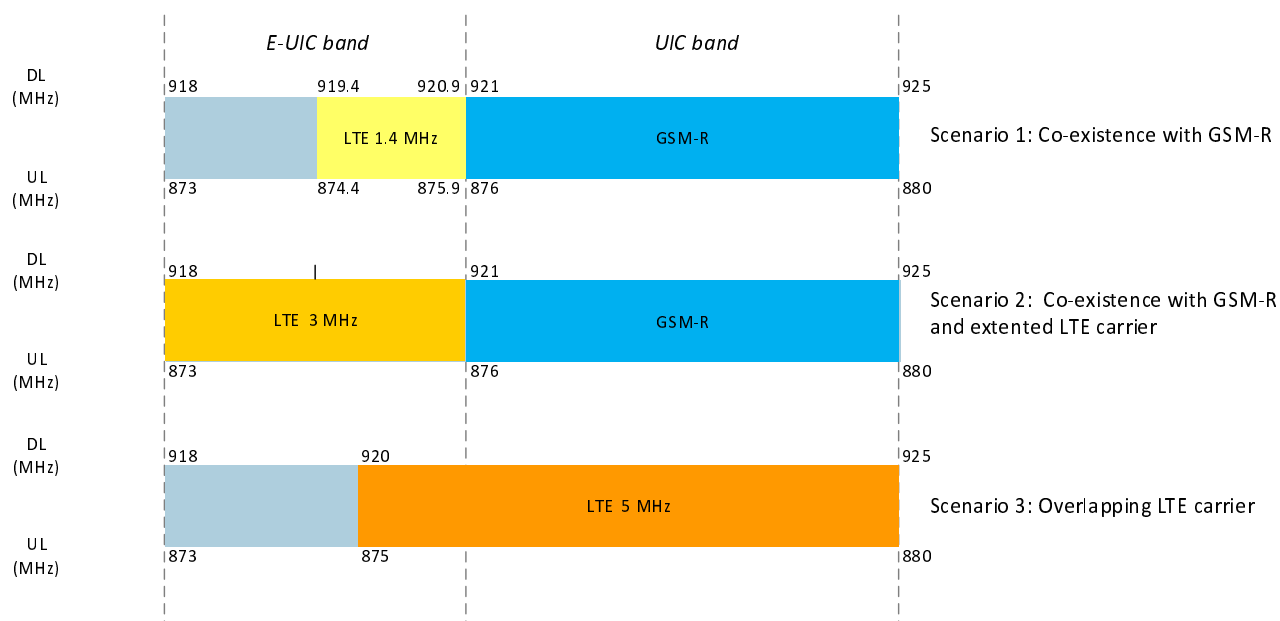


Figure 2: Carriers and bandwidths in the deployment scenarios considered

## 4.4.2 Transmit powers

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

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

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

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

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

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

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

## 4.5 Antenna diagrams

### 4.5.1 Antenna diagrams at the base station

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

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

**Table 2: Summary of base station antenna patterns**

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

### 4.5.2 Antenna diagrams at the UE

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

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

## 4.6 Radio propagation aspects

### 4.6.1 Radio propagation model

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

Four families of standards have been considered:

- 1) Okumura-Hata, Cost 207-GSM, COST 231 models and GSM specified models (see ETSI TR 145 050 [i.10])
- 2) ITU-R 1997 for IMT 2000 (see Recommendation ITU-R M.1225 [i.8]) and LTE specified scenarios (see ETSI TS 136 104 [i.2] and ETSI TS 136 101 [i.3])
- 3) ITU-R for IMT advanced (see Recommendation ITU-R M.2135-1 [i.4])
- 4) Winner II (see [i.5])

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

Most relevant parameters in rail environment are then:

- Frequency range
- Delays in Cluster Delay Line models
- Geometry, most of models are considering 1,5 m for handheld User Equipment
- Inter Site Distances (ISD)
- LOS scenarios are using Ricean factor with high domination of the direct path

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

**Table 3: Summary of model characteristics**

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

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

**Table 4: Main characteristics of Railway context**

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

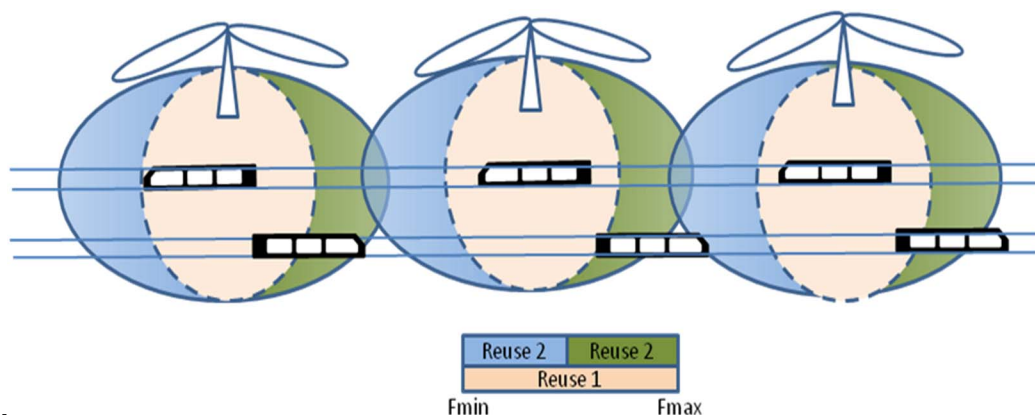
The Ricean factor taken here corresponds to worst case scenario. In actual deployments, higher values could be encountered, leading to more favourable channel conditions.

## 4.6.2 Conclusion

Okumura-Hata models and COST 207-GSM COST 231 family (see ETSI TR 145 050 [i.10]) are taken as the basis.

## 4.7 Frequency reuse scheme

In LTE radio, the frequency band is split in Resource Blocks (RB) which can be allocated individually to UEs by the base station scheduler for each frame. All LTE cells may operate on the same frequency band; however, to mitigate interference from neighbouring LTE cells, one technique is to coordinate RB allocations among cells. One possible coordination scheme is fractional frequency reuse, which consists for example in allocating different RBs among two neighbouring cells to cell edge UEs, while still allocating all the RBs (at a reduced power) for cell centre UEs (see Figure 3). This can be seen as a frequency reuse factor 1 for cell centre UEs, and a frequency reuse factor > 1 (equal to 2 in Figure 3 example) for cell edge UEs. Hence, not all RBs are allocated to cell edge UEs, but this is compensated by a better SINR for those blocks.



**Figure 3: Example of fractional frequency reuse for rail deployment**

Results should indicate which kind of Fractional Frequency Reuse techniques is used.

## 4.8 Summary

Table 5 sums up all the parameters.

**Table 5: Summary of evaluation parameters**

Environment/scenario	Rural/Urban
Railway shape and LOS/NLOS propagation	Rural: Straight: LOS Curves: NLOS (2 separate sets of results) Hilly: NLOS only Urban: NLOS only
Carrier Frequency (DL/UL) (MHz)	875,2/920,2 (for 1,4 MHz bandwidth) 874,5/919,5 (for 3 MHz bandwidth) 877,5/922,5 (for 5 MHz bandwidth)
Bandwidth (MHz)	1,4 (mandatory) 3 (optional) 5 (optional)
Inter-site distance (ISD) (km)	Rural: 8 Urban: 2 and 4
BS antenna height (m)	18 (urban) - 30 or 40 (rural)
Train antenna height (m)	4,5 or 4
Tower to track distance (m)	15
Neighbour cells load	<b>Rural:</b> 4 trains (2 in each direction) <b>High speed:</b> 2 trains (1 in each direction) <b>Urban:</b> - 6 trains (3 in each direction) - 4 trains (2 in each direction) See note 1
Train speeds (km/h)	<b>Urban:</b> 80 <b>Rural:</b> 350 <b>Hilly:</b> 160
DL max power (dBm)	In UIC-band: 46 before feeder (output of the BTS) 3 dB feeder loss In E-UIC band (see clause 4.4.2) 46 (output of the BTS) 3 dB feeder loss
UL max Power (dBm)	23 26 31 See note 2
UL Power Control	For instance: Open loop full compensation to be mentioned along with the results
Channel Estimation	For instance: Real channel estimation Time interpolation - to be mentioned along with the results
Link Channel Model Tap delay lines  Clustered delay lines	Based on ETSI TS 145 005 [i.1] Urban area 6 taps Rural area 6 taps Hilly terrain 12 taps <i>Channels for different antennas are not correlated.</i>  ETSI TS 145 005 [i.1] channel models are Tapped Delay Line models. Other Models (Recommendation ITU-R M.2135-1 [i.4]) provide additional small scale parameters (Angles of arrival/departure (AoA/AoD) of the rays). To take into account some small scales parameters, ETSI TS 145 005 [i.1] channel models can be combined with the AoA/AoD provided in ITU-R models. Since the number of taps in ETSI TS 145 005 [i.1] models (6 taps/12 taps) is generally different from ITU-R models, AoA/AoD from ITU-R models corresponding to the strongest first 6/12 taps are considered for this hybrid channel model

Environment/scenario	Rural/Urban
Path Loss Model (propagation model)	<b>Urban:</b> Okumura-Hata (LOS/NLOS effect is only taken into account in link channel model through Rice coefficient distribution for the first tap) <b>Rural:</b> Hata sub-urban (LOS/NLOS effect is only taken into account in link channel model through Rice coefficient distribution for the first tap) <b>Hilly:</b> Hata sub-urban See details in annex E
Shadowing standard deviation (dB)	<b>Urban:</b> Okumura-Hata 8 dB (NLOS only) <b>Rural:</b> Hata sub-urban 6 dB in LOS, 8 dB in NLOS <b>Hilly:</b> 8 dB (NLOS only) See details in annex E
Noise (dBm)	-121,4 See note 3
Cyclic prefix	<b>Rural:</b> Extended prefix <b>Urban:</b> Normal prefix <b>Hilly:</b> Extended prefix
Fractional frequency reuse technique	To be mentioned along with the results
Antenna pattern eNB/Antenna gain	See clause 4.5.1 See note 4
eNB antenna downtilt (°)	To be mentioned along with the results
Antenna pattern UE/antenna gain	One antenna: Omnidirectional/0 dBi - Vertical polarization Two antennas: Vertical polarization, > 10 $\lambda$ separation See note 5
Transmission modes	To be mentioned along with the results
NOTE 1: The aggregate data traffic per cell is 100 %.	
NOTE 2: It is considered that the UE antenna gain compensates the feeder loss.	
NOTE 3: Corresponds to thermal noise in a Resource Block of 180 kHz.	
NOTE 4: In rural environment with straight line railway shape, the 30° HP antenna is assumed.	
NOTE 5: See clause 4.5.2.	

## 4.9 Outcomes of the simulations

Output metrics need to include at least throughputs for DL and UL under the following conditions:

- Peak Data Rate
- Average
- 5 %-tile cell edge. This metric corresponds to the worst case of radio propagation conditions at the worst position in the cell (maximum throughput experienced by the 5 % of trains with worst throughput)

NOTE: This 5 %-tile cell edge (or *Worst Cell Edge*) differs from coverage specification as defined in EIRENE SRS ([i.9]), in which the specified GSM-R radio coverage probability is 95 % in each location intervals of 100 m.

Worst cell edge is 5 %-tile on every location starting from the hand over point, and therefore the associated data throughput corresponds to a much more severe criteria than the one used in EIRENE specification [i.9].

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## 5 Simulation results

### 5.1 Results set 1

#### 5.1.1 Description

The simulator used for this result set is a software chain tool using a Monte-Carlo statistical approach. It simulates a complete LTE PHY layer, i.e. it operates at '*Software simulation reference point*' as defined in Figure 1.



The simulator considers multiple cells in a linear deployment along the track and encompasses link-level simulation as well as system-level simulation.

Link level simulations allow to compute the bit error rate and packet/block error rate (PER) of the radio transmission scheme, including detailed simulation of modulation and coding, MIMO scheme, channel estimation, small-scale fading effects and AWGN. However, link level simulation does not include any effect of large-scale fading, i.e. distance-dependent path-loss and shadowing, which impacts the (experienced) Signal-to-Noise Ratio (SNR) as well as the inter-cell interference level.

System level simulations are required in order to quantify the impact of inter-cell interference on the system throughput at cell level.

The simulation tool comprises then (see also [i.12]):

### Step 1: Link level simulation

- 1) Computation of the  $PER_i$  vs. Signal-to-Interference-plus-Noise Ratio (SINR) for  $N$  different transmission schemes (characterized by a specific modulation, coding rate, and MIMO scheme) that results in link level throughputs  $T_i, i=1, \dots, N$  (assuming AWGN interference).
- 2) For each transmission scheme  $i$  and each SINR value, computation of the resulting throughput  $T_{res,i}(SINR)$  taking into account PER as:

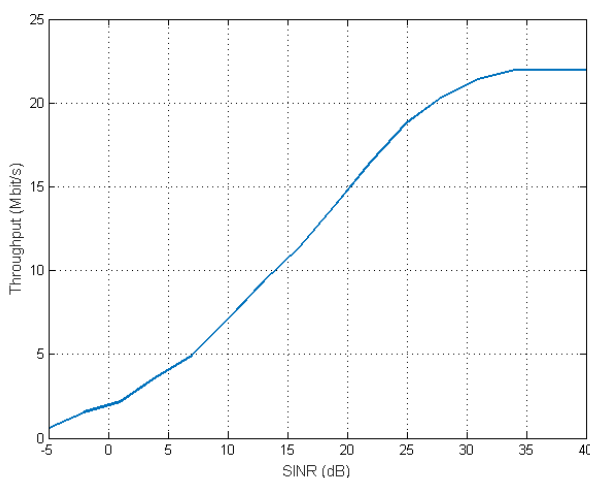
$$T_{res,i} = T_i \times (1 - PER_i(SINR))$$

- 3) For each SINR, storage in a look-up table of the maximum resulting throughput as shown in Figure 4 among all transmission schemes (modulation, coding rate, MIMO) as a result of ideal link adaptation to large-scale channel properties:

$$T_{\max}(SINR) = \arg \max_i (T_{res,i}(SINR))$$

### Step 2: System level simulation

- 1) For many drops of User Equipments (UEs) and many large-scale channel realizations (including large-scale fading statistics), computation of the resulting SINR for each UE:
  - A drop is a realization of UE positions within the cells. These positions are randomly drawn under the constraints of the scenario of interest. For instance, the UE distribution depends on UE density.
- 2) From all the drops, computation of the Cumulative Density Function (CDF) of the throughput by using the obtained SINR values as inputs in the look-up table  $T_{\max}(SINR)$  obtained in the link-level evaluation step.



**Figure 4: Maximum resulting throughput example for a given transmission scheme and UE speed (link level simulation)**

Antenna patterns are taken into account together with antenna down-tilt in the system level step. Large-scale fading statistics follows a log-normal distribution.

In this railway environment, a straight railway line is assumed, with trains moving on both directions (see Figure 5). The Inter Site Distance (ISD) is set depending on the scenario, i.e. ISD is set to 8 km for rural and to 2 km for urban, as required in clause 4.8.

Each train embeds one UE and train positions are drawn following a uniform random distribution ensuring the train density requirement for each scenario, i.e. 1 train per cell in each direction in high velocity train scenario, 2 in rural scenario and 3 in urban scenario. These train positions form a train position set, each set corresponding to a UE drop.

A worst-case interference level is assumed: all active cells are fully loaded in both UL and DL, i.e. transmission occurs over the whole bandwidth. DL interference experienced by the train in the serving cell depends on its position. UL interference in the serving cell depends on the position of the trains in neighbour cells.

In total, 1 600 train positions sets have been considered during simulations, with 400 channel models realizations per set.

From system-level simulations, the cell average spectral efficiency and the cell-edge throughput (e.g. the 5 %-tile throughput) are computed. For getting the 5 %-tile throughput, the throughput CDF at any position of a track is computed. This is different from the cell-edge throughput computed in 3GPP, which is the cell 5 %-tile throughput taken over the entire cell coverage. The resulting curve allows evaluating the 5 %-tile data throughput at the worst position of the train on the track.

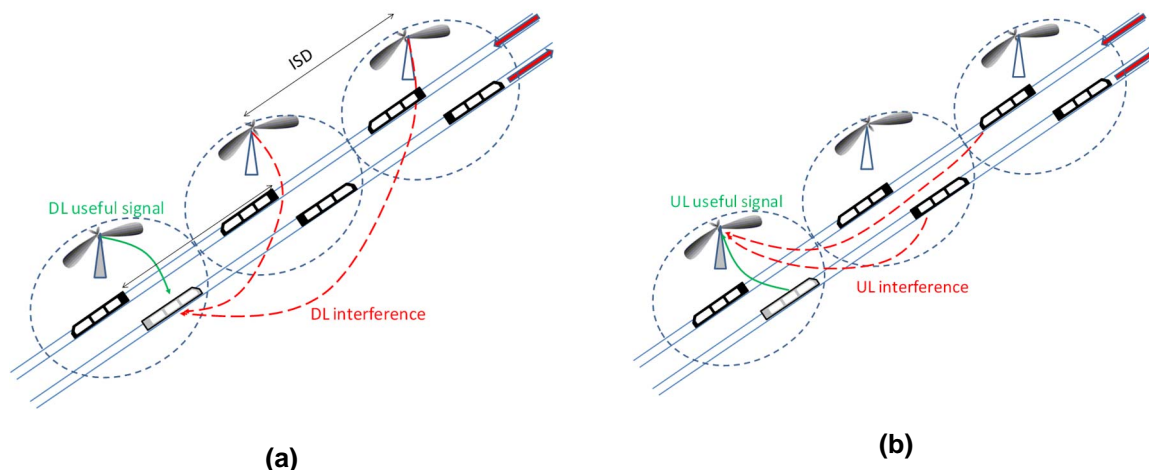


Figure 5: Railway line configuration and inter-cell interference (a: downlink; b: uplink)

### 5.1.2 Specific assumptions and parameters

A **first round** of simulations has been made with the following assumptions:

- The noise figures at eNB and UE have not been considered.
- Link channel model: As foreseen in clause 4.7, link level simulations combine Power Delay Profiles (PDP) taken from ETSI TS 145 005 [i.1] and geometrical aspects (angle of arrival and angle of departure of the rays) of Clustered Delay Lines (CDL) from Recommendation ITU-R M.2135-1 [i.4].
- Channel estimation includes a time-interpolation between consecutive subframes. It introduces a small processing delay (0,07 ms in downlink with 2 transmit antennas, 0,14 ms with 4 transmit antennas and 0,29 ms in uplink) but lowers Doppler effect.

- In DL, the MIMO schemes that have been chosen for the simulations are transmission schemes providing transmit diversity (see clause 6.3.4.3 of ETSI TS 136 211 [i.7]), as they are more robust to the high train velocity:
  - The transmit diversity scheme with two transmit antennas is the Alamouti Space Frequency Block Code (SFBC) applied on two adjacent sub-carriers (spatial diversity of  $2 N_R$  with  $N_R$  number of receive antennas).
  - The transmit diversity scheme with four transmit antennas is a combination of Alamouti SFBC and Frequency Switched Transmit Diversity (FSTD) on four adjacent sub-carriers (spatial diversity of  $4 N_R$ ).
- In UL, single-antenna transmission only is considered (SIMO) (diversity gain of  $N_R$ ).
- Transmit power in DL is 43 dBm taking into account a 3 dB feeder loss. This power is spread over all the antennas.
- Transmit power in UL is 23 dBm.
- Antenna tilt is 3 degrees downtilt, if not stated otherwise.
- Bandwidth is 1,4 MHz, centred at 875,2/920,2 MHz.
- Rice factor for rural model (high speed scenario) is 0,4475 dB. There is no line of sight component in the other models.
- Large scale shadowing standard deviation is 4 dB in Rural model, and 8 dB for Urban and Hilly models.
- It is considered that antennas at base station and on train are using vertical polarization.

A **second round** of simulations has then been made, with some differences in the assumptions. In the first round, the path loss computed to assess neighbouring cells interference for Rural and Hilly scenarios is computed with Okumura-Hata model, whatever the distance from the victim and the interference source. After analysis, this was considered too pessimistic, since the probability of LOS component for far away interference source becomes low. For the second round of simulations, a breakpoint distance of 8 km has been introduced. For source-victim distance below this breaking point, Okumura-Hata model is kept. However, for distance above the breaking point, a stronger attenuation (Hata model) is assumed for interfering signals. As a consequence, the serving cell in Rural and Hilly scenarios is subject to lower interference levels compared with previous results.

In order to better align with result set §3 assumptions, the following two parameters have been modified:

- Train antenna height: 4 m
- BS antenna height: 40 m

In this second round:

- Transmit powers in UL are 23, 26 and 31 dBm.
- At the base station, one TRX (Transmitter/receiver) is assumed per antenna, and the feeder loss (distribution cable) of 3 dB is assumed per antenna connector. Hence, the maximum transmit power is 43 dBm at each antenna connector. For a DL 2x2 transmission mode, the total power transmitted is 46 dBm (2 x 43 dBm), and 49 dBm for 4x2 transmission mode (4 x 43 dBm). In the first round, the transmitted power was assumed to be spread among the antennas, with one feeder loss for all the antennas, i.e. total transmit power was 43 dBm in all transmission modes.
- A noise figure at receiver of 3 dB at the base station and of 5 dB at the UE is introduced (was not considered in the first round).
- The noise power is applied only to the resource blocks actually used. Bandwidths are 1,4 MHz, 3 MHz and 5 MHz.
- Large scale shadowing standard deviation is 6 dB in Rural model, and 8 dB for Urban and Hilly models (in line with Table 5).

Other assumptions are kept unchanged.

The following points are clarifications that apply to first and second rounds of simulations:

- Only co-channel interference is taken into account. This co-channel interference is added as noise over the wanted signal. Hence, for frequency reuse 2 and 3 schemes, the interference is considered in the sub-bands only.
- The total transmit power is used independently of the frequency reuse scheme.. This turns into a higher transmit power density in frequency reuse 2 and 3 compared to frequency reuse 1.
- The antenna polarization mismatch between base station and UE due to the usage of cross-polarized antennas at the base station has not been taken into account.
- The shadowing is correlated over a distance of 100 m.

### Frequency reuse scheme

The simulations do not implement a fractional frequency reuse algorithm. Separate results are provided for different frequency reuse factors (hard frequency reuse), leading to a strong decrease of offered throughput in cell centres for frequency reuse > 1.

However, with a fractional frequency reuse algorithm, the throughput results with frequency reuse 2 or 3 will be the ones cell edge UEs could experience, while frequency reuse 1 results should be considered for cell centre UEs.

## 5.1.3 Results

### 5.1.3.1 Introduction

Simulations have been made for the different scenarios foreseen in clause 4 and considering frequency reuse factors of 1, 2 and 3.

The different scenarios simulated are described in Table 6.

**Table 6: Scenarios summary**

Scenario name	Model and speed	ISD (km)	Neighbour cell load (trains)
Urban	Urban (NLOS, 80 km/h)	2	6
High Density	Urban (NLOS, 80 km/h)	4	4
Hilly	Hilly (NLOS, 160 km/h)	8	2
High speed	Rural (LOS, 350 km)	8	2

A summary of the throughput performance is provided in the clauses below. In the summary tables:

- **Cell Centre** column corresponds to the maximum throughput available at the cell centre. It is the maximum data throughput that can be expected in a cell for the scenario considered and corresponds to the *Peak Data Rate* defined in clause 4.9;
- **Median cell edge** corresponds to the 50 %-tile value at the worst position in the cell; and
- **Worst cell edge** to the 5 %-tile value at the worst position in the cell (see clause 4.9).

UL and DL throughput values correspond to the total throughputs available in the cell, to be shared among the different trains that are served by the base station.

For the second round of results, metrics have been modified to average the effect of shadowing around each position, by averaging the 50 %-tile and the 5 %-tile values over a sliding window of 100 m. The reasoning is to mitigate the impact on throughput metric of deep fading events, since the train is moving and will not in reality encounter these events during a time long enough to actually impact the transmission of a packet.

Hence, for second round of results, the output metrics are the following:

- **Cell Centre** metric is kept unchanged;

- **Smth. 100 m median cell edge** (Smoothed 100 m median cell edge) corresponds to the 50 %-tile value at the worst position in the cell computed over a position sliding window of 100 m; and
- **Smth. 100 m worst cell edge** (Smoothed 100 m worst cell edge) corresponds to the 5 %-tile value at the worst position in the cell computed over a position sliding window of 100 m.

### 5.1.3.2 Results at 1,4 MHz - First round

#### High speed scenario

**Table 7: Set §1 - First Round - High speed scenario**

Speed (km/h)	DL	Reuse factor	Throughput (Mbit/s)			Speed (km/h)	UL	Reuse factor	Throughput (Mbit/s)		
			Cell centre	Median cell edge	Worst cell edge				Cell centre	Median cell edge	Worst cell edge
350	2x2	1	3,50	0,30	0	350	1x2	1	3,60	0,25	0
350	4x2	1	3,50	0,40	0	350	1x4	1	3,60	0,40	0
350	2x2	2	1,75	1,00	0,45	350	1x2	2	1,80	0,75	0,30
350	4x2	2	1,75	1,20	0,45	350	1x4	2	1,80	1,0	0,50
350	2x2	3	1,20	1,20	0,50	350	1x2	3	1,20	0,70	0,40
350	4x2	3	1,20	1,10	0,60	350	1x4	3	1,20	0,80	0,60

#### Urban scenario

**Table 8: Set §1 - First Round - Urban scenario**

Speed (km/h)	DL	Reuse factor	Throughput (Mbit/s)			Speed (km/h)	UL	Reuse factor	Throughput (Mbit/s)		
			Cell centre	Median cell edge	Worst cell edge				Cell centre	Median cell edge	Worst cell edge
80	2x2	1	4,20	0,40	0	80	1x2	1	4,40	0	0
80	4x2	1	4,00	0,40	0	80	1x4	1	4,40	0	0
80	2x2	2	2,20	1,12	0,10	80	1x2	2	2,20	0,30	0
80	4x2	2	2,00	1,25	0,10	80	1x4	2	2,20	0,55	0
80	2x2	3	1,40	1,25	0,30	80	1x2	3	1,45	0,45	0
80	4x2	3	1,30	1,15	0,30	80	1x4	3	1,45	0,75	0,05

#### High density scenario

**Table 9: Set §1 - First Round - High density scenario**

Speed (km/h)	DL	Reuse factor	Throughput (Mbit/s)			Speed (km/h)	UL	Reuse factor	Throughput (Mbit/s)		
			Cell centre	Median cell edge	Worst cell edge				Cell centre	Median cell edge	Worst cell edge
80	2x2	1	4,20	0,30	0	80	1x2	1	4,30	0	0
80	4x2	1	4,00	0,40	0	80	1x4	1	4,30	0	0
80	2x2	2	2,10	1,25	0,10	80	1x2	2	2,20	0,30	0
80	4x2	2	2,00	1,25	0,15	80	1x4	2	2,20	0,50	0
80	2x2	3	1,40	1,25	0,4	80	1x2	3	1,45	0,45	0
80	4x2	3	1,30	1,12	0,30	80	1x4	3	1,5	0,75	0,1

## Hilly scenario

Table 10: Set §1 - First Round - Hilly scenario

Speed (km/h)	DL	Reuse factor	Throughput (Mbit/s)			Speed (km/h)	UL	Reuse factor	Throughput (Mbit/s)		
			Cell centre	Median cell edge	Worst cell edge				Cell centre	Median cell edge	Worst cell edge
160	2x2	1	2,10	0,25	0	160	1x2	1	3,60	0,25	0
160	4x2	1	2,40	0,35	0	160	1x4	1	3,60	0,50	0
160	2x2	2	1,00	0,90	0,15	160	1x2	2	1,80	0,75	0,15
160	4x2	2	1,20	1,10	0,13	160	1x4	2	1,80	1,13	0,25
160	2x2	3	0,70	0,70	0,25	160	1x2	3	1,20	0,40	0,20
160	4x2	3	0,85	0,80	0,30	160	1x4	3	1,20	1,0	0,3

The figures in the summary tables are picked up from (throughput vs. distance to base station) curves. An example of such a curve is provided in Figure 6; the full set can be found in annex B.

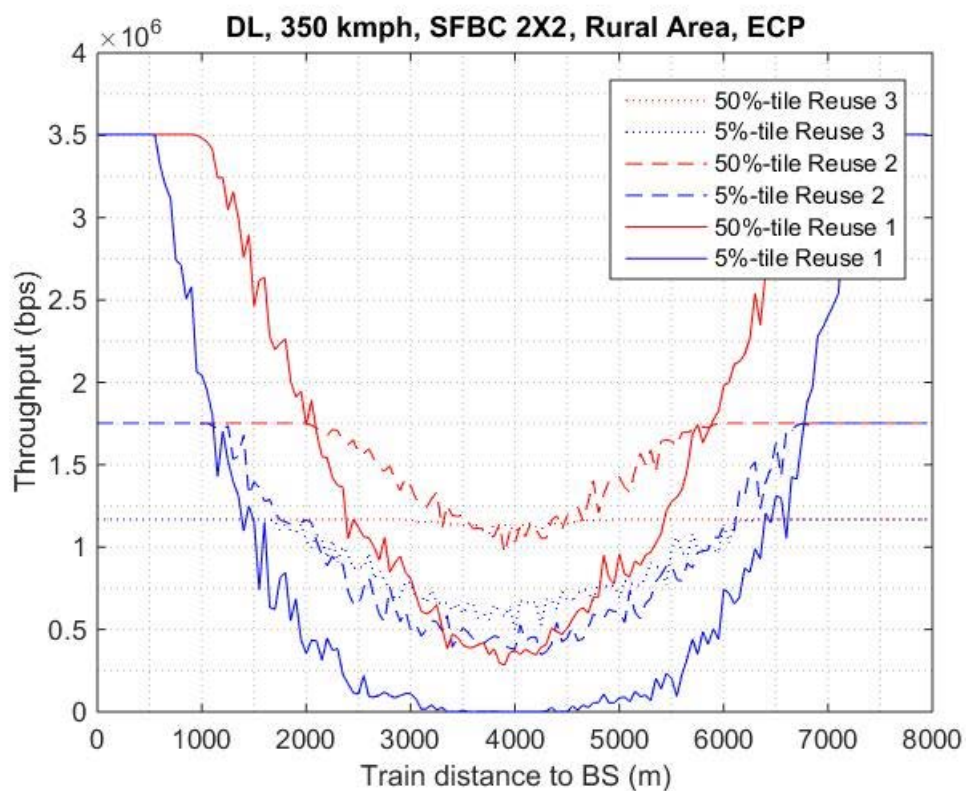


Figure 6: Example of throughput vs distance to base station (first round)

## 5.1.3.3 Results at 1,4 MHz - Second round

## High speed scenario

Table 11: Set §1 - Second Round - 1,4 MHz - High density scenario

Bandwidth (MHz)	Speed (km/h)	Reuse factor	DL	Throughput (Mbit/s)		
				Cell centre	Smth. 100 m median cell edge	Smth. 100 m worst cell edge
1,4	350	1	2x2	4,12	1,24	0,11
		1	4x2	3,86	1,25	0,12
		2	2x2	2,06	2,05	1,06
		2	4x2	1,93	1,87	1,00
		3	2x2	1,37	1,37	1,17
		3	4x2	1,29	1,29	1,08

Bandwidth (MHz)	Speed (km/h)	Tx Power (dBm)	Reuse factor	UL	Throughput (Mbit/s)		
					Cell centre	Smth. 100 m median cell edge	Smth. 100 m worst cell edge
1,4	350	23	1	1x2	3,81	0,28	0,00
			1	1x4	3,85	0,53	0,00
			2	1x2	1,90	1,49	0,84
			2	1x4	1,92	1,85	1,19
			3	1x2	1,27	1,15	0,78
			3	1x4	1,28	1,28	1,06
1,4	350	26	1	1x2	3,81	0,20	0,00
			1	1x4	3,85	0,38	0,00
			2	1x2	1,90	1,48	0,81
			2	1x4	1,92	1,84	1,15
			3	1x2	1,27	1,17	0,81
			3	1x4	1,28	1,28	1,10
1,4	350	31	1	1x2	3,81	0,09	0,00
			1	1x4	3,85	0,20	0,00
			2	1x2	1,90	1,39	0,71
			2	1x4	1,92	1,75	1,07
			3	1x2	1,27	1,17	0,80
			3	1x4	1,28	1,28	1,09

## Urban scenario

Table 12: Set §1 - Second Round - 1,4 MHz - Urban scenario

Bandwidth (MHz)	Speed (km/h)	Reuse factor	DL	Throughput (Mbit/s)		
				Cell centre	Smth. 100 m median cell edge	Smth. 100 m worst cell edge
1,4	80	1	2x2	3,19	0,42	0,00
		1	4x2	3,16	0,46	0,00
		2	2x2	1,59	1,28	0,23
		2	4x2	1,58	1,26	0,24
		3	2x2	1,06	0,98	0,47
		3	4x2	1,05	0,93	0,49

Bandwidth (MHz)	Speed (km/h)	Tx Power (dBm)	Reuse factor	UL	Throughput (Mbit/s)		
					Cell centre	Smth. 100 m median cell edge	Smth. 100 m worst cell edge
1,4	80	23	1	1x2	4,62	0,81	0,00
			1	1x4	4,65	1,49	0,01
			2	1x2	2,31	1,41	0,37
			2	1x4	2,33	2,12	0,64
			3	1x2	1,54	1,44	0,52
			3	1x4	1,55	1,55	0,86
1,4	80	26	1	1x2	4,62	0,71	0,00
			1	1x4	4,65	1,24	0,00
			2	1x2	2,31	1,30	0,30
			2	1x4	2,33	1,93	0,54
			3	1x2	1,54	1,36	0,47
			3	1x4	1,55	1,55	0,80
1,4	80	31	1	1x2	4,62	0,44	0,00
			1	1x4	4,65	0,83	0,00
			2	1x2	2,31	1,09	0,20
			2	1x4	2,33	1,65	0,39
			3	1x2	1,54	1,21	0,38
			3	1x4	1,55	1,55	0,65

## High density scenario

Table 13: Set §1 - Second Round - 1,4 MHz - High density scenario

Bandwidth (MHz)	Speed (km/h)	Reuse factor	DL	Throughput (Mbit/s)		
				Cell centre	Smth. 100 m median cell edge	Smth. 100 m worst cell edge
1,4	80	1	2x2	3,19	0,00	0,00
		1	4x2	3,16	0,00	0,00
		2	2x2	1,59	0,59	0,00
		2	4x2	1,58	0,59	0,00
		3	2x2	1,06	0,80	0,11
		3	4x2	1,05	0,78	0,12

Bandwidth (MHz)	Speed (km/h)	Tx Power (dBm)	Reuse factor	UL	Throughput (Mbit/s)		
					Cell centre	Smth. 100 m median cell edge	Smth. 100 m worst cell edge
1,4	80	23	1	1x2	4,62	0,10	0,00
			1	1x4	4,65	0,26	0,00
			2	1x2	2,31	0,53	0,03
			2	1x4	2,33	0,88	0,07
			3	1x2	1,54	0,56	0,11
			3	1x4	1,55	0,91	0,23
1,4	80	26	1	1x2	4,62	0,07	0,00
			1	1x4	4,65	0,17	0,00
			2	1x2	2,31	0,48	0,01
			2	1x4	2,33	0,81	0,05
			3	1x2	1,54	0,55	0,10
			3	1x4	1,55	0,90	0,21
1,4	80	31	1	1x2	4,62	0,01	0,00
			1	1x4	4,65	0,07	0,00
			2	1x2	2,31	0,38	0,00
			2	1x4	2,33	0,67	0,02
			3	1x2	1,54	0,52	0,07
			3	1x4	1,55	0,85	0,16



## Hilly scenario

Table 14: Set §1 - Second Round - 1,4 MHz - Hilly scenario

Bandwidth (MHz)	Speed (km/h)	Reuse factor	DL	Throughput (Mbit/s)		
				Cell centre	Smth. 100 m median cell edge	Smth. 100 m worst cell edge
1,4	160	1	2x2	2,36	0,00	0,00
		1	4x2	2,23	0,00	0,00
		2	2x2	1,18	0,71	0,04
		2	4x2	1,12	0,70	0,03
		3	2x2	0,79	0,70	0,19
		3	4x2	0,74	0,69	0,19

Bandwidth (MHz)	Speed (km/h)	Tx Power (dBm)	Reuse factor	UL	Throughput (Mbit/s)		
					Cell centre	Smth. 100 m median cell edge	Smth. 100 m worst cell edge
1,4	160	23	1	1x2	3,87	0,00	0,00
			1	1x4	3,87	0,00	0,00
			2	1x2	1,93	0,42	0,02
			2	1x4	1,93	0,69	0,06
			3	1x2	1,29	0,44	0,08
			3	1x4	1,29	0,72	0,18
1,4	160	26	1	1x2	3,87	0,00	0,00
			1	1x4	3,87	0,00	0,00
			2	1x2	1,93	0,40	0,02
			2	1x4	1,93	0,66	0,05
			3	1x2	1,29	0,44	0,09
			3	1x4	1,29	0,73	0,19
1,4	160	31	1	1x2	3,87	0,00	0,00
			1	1x4	3,87	0,00	0,00
			2	1x2	1,93	0,32	0,01
			2	1x4	1,93	0,56	0,03
			3	1x2	1,29	0,43	0,08
			3	1x4	1,29	0,71	0,16

## 5.1.3.4 Results at 3 MHz

## High speed scenario

Table 15: Set §1 - Second Round - 3 MHz - High speed scenario

Bandwidth (MHz)	Speed (km/h)	Reuse factor	DL	Throughput (Mbit/s)		
				Cell centre	Smth. 100 m median cell edge	Smth. 100 m worst cell edge
3,0	350	1	2x2	10,31	3,10	0,28
		1	4x2	9,64	3,11	0,29
		2	2x2	5,15	5,12	2,65
		2	4x2	4,82	4,68	2,51
		3	2x2	3,44	3,44	2,93
		3	4x2	3,21	3,21	2,71

Bandwidth (MHz)	Speed (km/h)	Tx Power (dBm)	Reuse factor	UL	Throughput (Mbit/s)		
					Cell centre	Smth. 100 m median cell edge	Smth. 100 m worst cell edge
3,0	350	23	1	1x2	9,55	0,72	0,00
			1	1x4	9,61	1,35	0,00
			2	1x2	4,77	3,31	1,86
			2	1x4	4,81	4,23	2,71
			3	1x2	3,18	2,58	1,68
			3	1x4	3,20	3,17	2,28
3,0	350	26	1	1x2	9,55	0,47	0,00
			1	1x4	9,61	0,94	0,00
			2	1x2	4,77	3,37	1,93
			2	1x4	4,81	4,28	2,74
			3	1x2	3,18	2,67	1,82
			3	1x4	3,20	3,20	2,48
3,0	350	31	1	1x2	9,55	0,20	0,00
			1	1x4	9,61	0,48	0,00
			2	1x2	4,77	3,29	1,73
			2	1x4	4,81	4,22	2,64
			3	1x2	3,18	2,74	1,91
			3	1x4	3,20	3,20	2,62

Urban scenario

Table 16: Set §1 - Second Round - 3 MHz - Urban scenario

Bandwidth (MHz)	Speed (km/h)	Reuse factor	DL	Throughput (Mbit/s)		
				Cell centre	Smth. 100 m median cell edge	Smth. 100 m worst cell edge
3,0	80	1	2x2	7,96	1,06	0,00
		1	4x2	7,89	1,14	0,00
		2	2x2	3,98	3,20	0,57
		2	4x2	3,95	3,14	0,60
		3	2x2	2,65	2,45	1,17
		3	4x2	2,63	2,32	1,23

Bandwidth (MHz)	Speed (km/h)	Tx Power (dBm)	Reuse factor	UL	Throughput (Mbit/s)		
					Cell centre	Smth. 100 m median cell edge	Smth. 100 m worst cell edge
3,0	80	23	1	1x2	11,58	2,07	0,00
			1	1x4	11,65	3,79	0,01
			2	1x2	5,79	3,51	0,95
			2	1x4	5,83	5,23	1,61
			3	1x2	3,86	3,54	1,34
			3	1x4	3,88	3,88	2,16
3,0	80	26	1	1x2	11,58	1,85	0,00
			1	1x4	11,65	3,15	0,00
			2	1x2	5,79	3,26	0,74
			2	1x4	5,83	4,80	1,36
			3	1x2	3,86	3,39	1,23
			3	1x4	3,88	3,88	2,03
3,0	80	31	1	1x2	11,58	1,13	0,00
			1	1x4	11,65	2,19	0,00
			2	1x2	5,79	2,77	0,52
			2	1x4	5,83	4,14	1,03
			3	1x2	3,86	2,96	1,01
			3	1x4	3,88	3,88	1,63

## High density scenario

Table 17: Set §1 - Second Round - 3 MHz - High density scenario

Bandwidth (MHz)	Speed (km/h)	Reuse factor	DL	Throughput (Mbit/s)		
				Cell centre	Smth. 100 m median cell edge	Smth. 100 m worst cell edge
3,0	80	1	2x2	7,96	0,00	0,00
		1	4x2	7,89	0,00	0,00
		2	2x2	3,98	1,48	0,00
		2	4x2	3,95	1,46	0,00
		3	2x2	2,65	1,99	0,27
		3	4x2	2,63	1,96	0,29

Bandwidth (MHz)	Speed (km/h)	Tx Power (dBm)	Reuse factor	UL	Throughput (Mbit/s)		
					Cell centre	Smth. 100 m median cell edge	Smth. 100 m worst cell edge
3,0	80	23	1	1x2	11,58	0,24	0,00
			1	1x4	11,65	0,63	0,00
			2	1x2	5,79	1,13	0,05
			2	1x4	5,83	1,98	0,16
			3	1x2	3,86	1,22	0,19
			3	1x4	3,88	2,01	0,42
3,0	80	26	1	1x2	11,58	0,15	0,00
			1	1x4	11,65	0,44	0,00
			2	1x2	5,79	1,05	0,02
			2	1x4	5,83	1,92	0,12
			3	1x2	3,86	1,27	0,20
			3	1x4	3,88	2,08	0,42
3,0	80	31	1	1x2	11,58	0,02	0,00
			1	1x4	11,65	0,17	0,00
			2	1x2	5,79	0,96	0,00
			2	1x4	5,83	1,62	0,04
			3	1x2	3,86	1,23	0,16
			3	1x4	3,88	2,03	0,40

## Hilly scenario

Table 18: Set §1 - Second Round - 3 MHz - Hilly scenario

Bandwidth (MHz)	Speed (km/h)	Reuse factor	DL	Throughput (Mbit/s)		
				Cell centre	Smth. 100 m median cell edge	Smth. 100 m worst cell edge
3,0	160	1	2x2	5,90	0,00	0,00
		1	4x2	5,58	0,00	0,00
		2	2x2	2,95	1,77	0,10
		2	4x2	2,79	1,74	0,08
		3	2x2	1,97	1,75	0,47
		3	4x2	1,86	1,73	0,47

Bandwidth (MHz)	Speed (km/h)	Tx Power (dBm)	Reuse factor	UL	Throughput (Mbit/s)		
					Cell centre	Smth. 100 m median cell edge	Smth. 100 m worst cell edge
3,0	160	23	1	1x2	9,66	0,00	0,00
			1	1x4	9,71	0,00	0,00
			2	1x2	4,83	0,90	0,01
			2	1x4	4,86	1,56	0,11
			3	1x2	3,22	0,93	0,13
			3	1x4	3,24	1,52	0,31
3,0	160	26	1	1x2	9,66	0,00	0,00
			1	1x4	9,71	0,00	0,00
			2	1x2	4,83	0,90	0,01
			2	1x4	4,86	1,56	0,10
			3	1x2	3,22	1,02	0,17
			3	1x4	3,24	1,67	0,37
3,0	160	31	1	1x2	9,66	0,00	0,00
			1	1x4	9,71	0,00	0,00
			2	1x2	4,83	0,82	0,00
			2	1x4	4,86	1,41	0,04
			3	1x2	3,22	1,06	0,17
			3	1x4	3,24	1,71	0,37

### 5.1.3.5 Results at 5 MHz

#### High speed scenario

Table 19: Set §1 - Second Round - 5 MHz - High speed scenario

Bandwidth (MHz)	Speed (km/h)	Reuse factor	DL	Throughput (Mbit/s)		
				Cell centre	Smth. 100 m median cell edge	Smth. 100 m worst cell edge
5,0	350	1	2x2	17,18	5,17	0,46
		1	4x2	16,07	5,19	0,48
		2	2x2	8,59	8,53	4,40
		2	4x2	8,04	7,79	4,17
		3	2x2	5,73	5,73	4,87
		3	4x2	5,36	5,36	4,50

Bandwidth (MHz)	Speed (km/h)	Tx Power (dBm)	Reuse factor	UL	Throughput (Mbit/s)		
					Cell centre	Smth. 100 m median cell edge	Smth. 100 m worst cell edge
5,0	350	23	1	1x2	15,89	1,17	0,00
			1	1x4	16,03	2,29	0,00
			2	1x2	7,95	4,88	2,64
			2	1x4	8,02	6,65	4,17
			3	1x2	5,30	3,84	2,39
			3	1x4	5,34	4,83	3,39
5,0	350	26	1	1x2	15,89	0,77	0,00
			1	1x4	16,03	1,51	0,00
			2	1x2	7,95	5,08	2,83
			2	1x4	8,02	6,87	4,39
			3	1x2	5,30	4,09	2,75
			3	1x4	5,34	5,15	3,77
5,0	350	31	1	1x2	15,89	0,36	0,00
			1	1x4	16,03	0,78	0,00
			2	1x2	7,95	5,14	2,76
			2	1x4	8,02	6,90	4,35
			3	1x2	5,30	4,31	3,04
			3	1x4	5,34	5,32	4,10

## Urban scenario

Table 20: Set §1 - Second Round - 5 MHz - Urban scenario

Bandwidth (MHz)	Speed (km/h)	Reuse factor	DL	Throughput (Mbit/s)		
				Cell centre	Smth. 100 m median cell edge	Smth. 100 m worst cell edge
5,0	80	1	2x2	13,27	1,77	0,00
		1	4x2	13,16	1,90	0,00
		2	2x2	6,64	5,34	0,95
		2	4x2	6,58	5,24	1,01
		3	2x2	4,42	4,08	1,94
		3	4x2	4,39	3,86	2,05

Bandwidth (MHz)	Speed (km/h)	Tx Power (dBm)	Reuse factor	UL	Throughput (Mbit/s)		
					Cell centre	Smth. 100 m median cell edge	Smth. 100 m worst cell edge
5,0	80	23	1	1x2	19,24	3,44	0,00
			1	1x4	19,37	6,16	0,03
			2	1x2	9,62	5,71	1,54
			2	1x4	9,68	8,51	2,64
			3	1x2	6,41	5,60	2,14
			3	1x4	6,46	6,46	3,55
5,0	80	26	1	1x2	19,24	3,02	0,00
			1	1x4	19,37	5,22	0,00
			2	1x2	9,62	5,35	1,22
			2	1x4	9,68	7,89	2,26
			3	1x2	6,41	5,46	1,96
			3	1x4	6,46	6,46	3,32
5,0	80	31	1	1x2	19,24	1,87	0,00
			1	1x4	19,37	3,50	0,00
			2	1x2	9,62	4,49	0,87
			2	1x4	9,68	6,77	1,69
			3	1x2	6,41	4,76	1,63
			3	1x4	6,46	6,43	2,69

## High density scenario

Table 21: Set §1 - Second Round - 5 MHz - High density scenario

Bandwidth (MHz)	Speed (km/h)	Reuse factor	DL	Throughput (Mbit/s)		
				Cell centre	Smth. 100 m median cell edge	Smth. 100 m worst cell edge
5,0	80	1	2x2	13,27	0,00	0,00
		1	4x2	13,16	0,00	0,00
		2	2x2	6,64	2,46	0,01
		2	4x2	6,58	2,44	0,00
		3	2x2	4,42	3,32	0,46
		3	4x2	4,39	3,26	0,48

Bandwidth (MHz)	Speed (km/h)	Tx Power (dBm)	Reuse factor	UL	Throughput (Mbit/s)		
					Cell centre	Smth. 100 m median cell edge	Smth. 100 m worst cell edge
5,0	80	23	1	1x2	19,24	0,36	0,00
			1	1x4	19,37	0,87	0,00
			2	1x2	9,62	1,64	0,04
			2	1x4	9,68	2,86	0,18
			3	1x2	6,41	1,66	0,21
			3	1x4	6,46	2,75	0,59
5,0	80	26	1	1x2	19,24	0,22	0,00
			1	1x4	19,37	0,63	0,00
			2	1x2	9,62	1,63	0,03
			2	1x4	9,68	2,84	0,14
			3	1x2	6,41	1,77	0,26
			3	1x4	6,46	2,99	0,65
5,0	80	31	1	1x2	19,24	0,04	0,00
			1	1x4	19,37	0,23	0,00
			2	1x2	9,62	1,47	0,01
			2	1x4	9,68	2,57	0,06
			3	1x2	6,41	1,80	0,24
			3	1x4	6,46	3,07	0,64

## Hilly scenario

Table 22: Set §1 - Second Round - 5 MHz - Hilly scenario

Bandwidth (MHz)	Speed (km/h)	Reuse factor	DL	Throughput (Mbit/s)		
				Cell centre	Smth. 100 m median cell edge	Smth. 100 m worst cell edge
5,0	160	1	2x2	9,84	0,00	0,00
		1	4x2	9,29	0,00	0,00
		2	2x2	4,92	2,95	0,16
		2	4x2	4,65	2,90	0,13
		3	2x2	3,28	2,90	0,78
		3	4x2	3,10	2,87	0,79

Bandwidth (MHz)	Speed (km/h)	Tx Power (dBm)	Reuse factor	UL	Throughput (Mbit/s)		
					Cell centre	Smth. 100 m median cell edge	Smth. 100 m worst cell edge
5,0	160	23	1	1x2	16,07	0,00	0,00
			1	1x4	16,18	0,00	0,00
			2	1x2	8,04	1,24	0,02
			2	1x4	8,09	2,15	0,08
			3	1x2	5,36	1,21	0,13
			3	1x4	5,39	2,00	0,35
5,0	160	26	1	1x2	16,07	0,00	0,00
			1	1x4	16,18	0,00	0,00
			2	1x2	8,04	1,30	0,03
			2	1x4	8,09	2,24	0,11
			3	1x2	5,36	1,36	0,19
			3	1x4	5,39	2,18	0,50
5,0	160	31	1	1x2	16,07	0,00	0,00
			1	1x4	16,18	0,00	0,00
			2	1x2	8,04	1,24	0,01
			2	1x4	8,09	2,14	0,05
			3	1x2	5,36	1,51	0,24
			3	1x4	5,39	2,49	0,55

A few examples of curves where figures are picked up from are provided in Figure 7. The full set can be found in annex B.

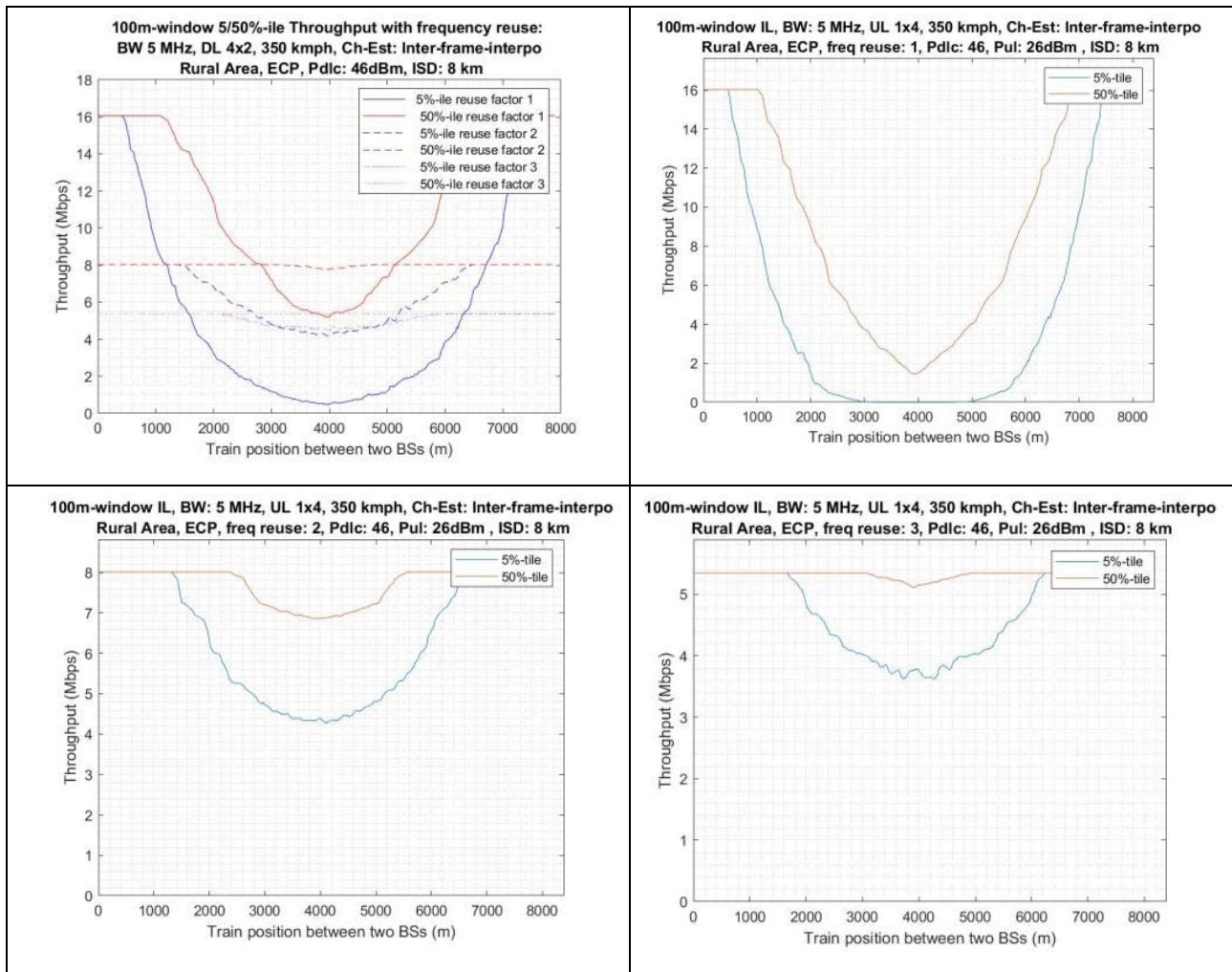


Figure 7: Example of throughput vs distance to base station (second round)

## 5.1.4 Notes and remarks

### 5.1.4.1 Notes and remarks on first round of results

#### Interference from neighbouring cells

Interference from neighbouring cells explains the low performance obtained for *worst cell edge* metric. Indeed, neighbouring cells are assumed to have a 100 % cell load, which is a pessimistic assumption. The impact on Urban scenario throughput performance is particularly visible, due to a smaller cell size compared to other scenarios. Antenna tilt and interference mitigation techniques should greatly improve the results.

#### Antenna tilt

An antenna down tilt of 3 degrees has been taken for all scenarios. However, in Urban scenarios, an antenna tilt of 5 degrees may provide better throughput at cell edge for frequency reuse 2 and 3 patterns, as shown in Table 23.



**Table 23: UL Throughput for Urban scenario with an antenna tilt of 5° and 1,4 MHz bandwidth**

Speed (km/h)	UL	Reuse factor	Throughput (Mbit/s)		
			Cell centre	Median cell edge	Worst cell edge
80	1x2	2	2,20	0,70	0,05
80	1x4	2	2,20	1,13	0,10
80	1x2	3	1,40	0,80	0,15
80	1x4	3	1,40	1,25	0,25

### Shadowing

The large scale shadowing is simulated with a log-normal distribution having a standard deviation of 4 dB in Rural model, and 8 dB for Urban and Hilly models. In the 5 %-tile curves, this may correspond to shadowing values that can reach 8 dB (Rural) and 16 dB (Urban and Hilly).

### Doppler impact

Under the assumptions of the present document, Doppler has not a big impact on throughput performances compared to other factors as interferences, neither in UL nor in DL. This is due to the relative low frequency band, the effect of directive antennas, and the inclusion in the channel estimation at receiver side of a time-interpolation between consecutive subframes.

### Uplink vs. downlink performances

It can be noticed that uplink and downlink throughputs are almost the same for rural and urban deployments. For hilly, the uplink throughput is even much higher than the downlink throughput.

Indeed, interferences in DL are in average higher than interferences in UL, due to less transmit power in UL compared to DL and due to the varying position on the interfering trains.

Moreover, UL MIMO scheme strongly relies on receive diversity: Having 4 antennas in reception (e.g. UL in 1x4) provides a SNR gain of 3 dB compared to having 2 antennas in reception (all DL schemes). In addition, Reference Signals (pilot patterns) have higher density in UL than in DL, leading to have an UL channel estimation more robust for high MCS.

For hilly, the channel is characterized by a very high frequency selectivity (the max delay spread is 20  $\mu$ s, which is higher than the length of the extended cyclic prefix with a coherence bandwidth of 50 KHz). UL channel estimation is more robust than in DL in these conditions: In UL, the 64 QAM can be used at cell centre, which is no longer the case for the DL of hilly terrain channel.

## 5.1.4.2 Notes and remarks on second round of results

### Impact of throughput smoothing over distance

Median cell edge and worst cell edge throughput values are computed over a position sliding window of 100 m, to limit the impact of deep shadowing on throughput metric. However, since in the simulations the shadowing is correlated over the train position, the difference between *Smth. 100 m* metrics and not smoothed metrics is limited, as shown in Table 24 for high speed scenario.

**Table 24: Comparison between Smoothed 100 m and non-smoothed throughput metrics**

Bandwidth (MHz)	Speed (km/h)	Reuse factor	DL	Throughput (Mbit/s)				
				Cell centre	Smth. 100 m median cell edge	Smth. 100 m worst cell edge	Median cell edge	Worst cell edge
5,0	350	1	2x2	17,18	5,17	0,46	5,23	0,34
		1	4x2	16,07	5,19	0,48	5,27	0,34
		2	2x2	8,59	8,53	4,40	8,57	4,47
		2	4x2	8,04	7,79	4,17	7,90	4,21
		3	2x2	5,73	5,73	4,87	5,73	4,90
		3	4x2	5,36	5,36	4,50	5,36	4,55

Bandwidth (MHz)	Speed (km/h)	Tx Power (dBm)	Reuse factor	UL	Throughput (Mbit/s)				
					Cell centre	Smth. 100 m median cell edge	Smth. 100 m worst cell edge	Median cell edge	Worst cell edge
5,0	350	23	1	1x2	15,89	1,17	0,00	1,15	0,00
			1	1x4	16,03	2,29	0,00	2,24	0,00
			2	1x2	7,95	4,88	2,64	4,90	2,58
			2	1x4	8,02	6,65	4,17	6,68	4,02
			3	1x2	5,30	3,84	2,39	3,85	2,33
			3	1x4	5,34	4,83	3,39	4,84	3,34
5,0	350	26	1	1x2	15,89	0,77	0,00	0,76	0,00
			1	1x4	16,03	1,51	0,00	1,50	0,00
			2	1x2	7,95	5,08	2,83	5,13	2,64
			2	1x4	8,02	6,87	4,39	6,89	4,18
			3	1x2	5,30	4,09	2,75	4,07	2,73
			3	1x4	5,34	5,15	3,77	5,13	3,73
5,0	350	31	1	1x2	15,89	0,36	0,00	0,35	0,00
			1	1x4	16,03	0,78	0,00	0,75	0,00
			2	1x2	7,95	5,14	2,76	5,13	2,68
			2	1x4	8,02	6,90	4,35	6,89	4,28
			3	1x2	5,30	4,31	3,04	4,28	2,98
			3	1x4	5,34	5,32	4,10	5,30	4,05

### UL Tx power

The benefit of increasing the UL Tx power is limited, and may even lead to a decrease in throughput at cell edge. Indeed, the best throughput results for *worst cell edge* throughput are obtained for an UL Tx power of 23 or 26 dBm except for Hilly scenario at 5 MHz. Peak values are not affected by the added power since at cell centre, the system operates already at its maximum achievable capacity.

Under the assumptions taken in the present document, limiting the interference level from adjacent cells is always necessary. A frequency reuse 3 scheme provides the better results for *worst cell edge* metric, except for some UL cases where a frequency reuse 2 could be enough. Regarding the *median cell edge* metric, best results are obtained for a frequency reuse 2 schemes in most of the cases, the reuse 3 schemes providing better results in high density scenario.

### 3 MHz bandwidth

In High speed scenario, the peak throughput can reach almost 10 MBit/s in DL and in UL (frequency reuse 1) at cell centre, and almost 3 MBit/s in DL and UL could be expected as minimum guaranteed bit rate at cell edge.

For Urban scenario, peak DL throughput could reach 8 Mbit/s, and 1,2 Mbit/s can be obtained as DL minimum guaranteed throughput. In UL, up to 11 MBit/s could be expected at cell centre, and around 2 Mbit/s for minimum guaranteed value (frequency reuse 3, 1x4, 23 dBm Tx power).

High density scenario experiences more interferences, leading to lower minimum guaranteed throughputs: They drop down to 0,3 Mbit/s in DL (frequency reuse 3) and 0,5 in UL (frequency reuse 3, 1x4, 26 dBm).

Hilly shows the worst radio conditions. Throughput performance could be up to 6 MBit/s in peak DL, for 0,5 Mbit/s minimum guaranteed value. In UL, peak values could reach almost 10 Mbit/s, but minimum guaranteed value drop to 0,4 MBit/s.

### 5 MHz bandwidth

Results for 5 MHz bandwidth are rather proportional to the bandwidth compared to results obtained at 3 MHz.

In High speed scenario, peak DL throughput is around 17 Mbit/s, while minimum guaranteed value is about 5 Mbit/s (frequency reuse 3). In UL, results are quite equivalent, with 16 Mbit/s for peak value, and around 4,5 MBit/s as minimum guaranteed throughput (frequency reuse 2, 1x4, 26 dBm Tx power).

In Urban scenario, peak DL falls to 13 MBit/s, and minimum guaranteed throughput to 2 MBit/s (frequency reuse 3). In UL, peak throughput is at 19 MBit/s and minimum guaranteed value around 3,5 MBit/s (frequency reuse 3, 1x4, 23 dBm Tx power).

For High density scenario, peak throughputs are similar to urban case, but minimum guaranteed throughputs are lower, 0,5 Mbit/s in DL (frequency reuse 3) and 0,65 Mbit/s in UL (frequency reuse 3, 1x4, 36 dBm).

For Hilly scenario, peak DL is below 10 MBit/s and peak UL at 16 MBit/s, while minimum guaranteed values are 0,8 MBit/s in DL (frequency reuse 3) and 0,55 MBit/s in UL (frequency reuse 3, 1x4, 31 dBm Tx power).

## 5.2 Results set 2

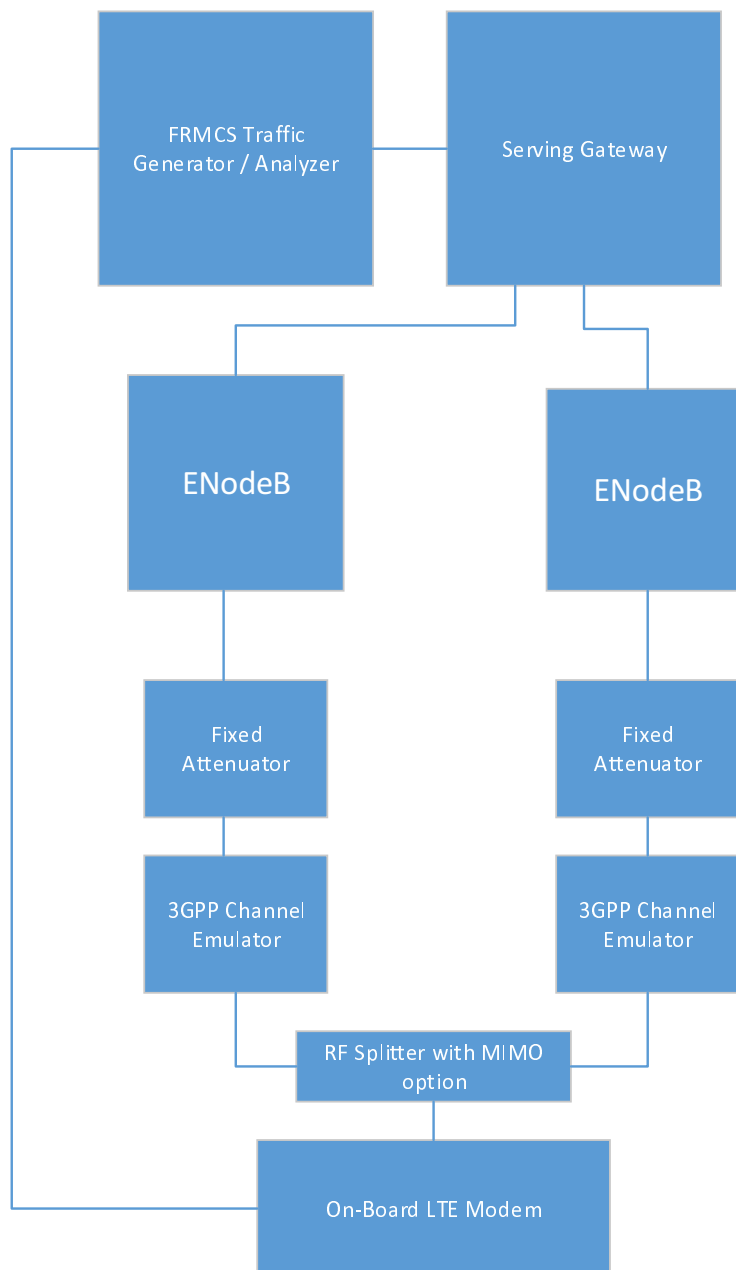
### 5.2.1 Description

#### 5.2.1.1 Lab setup high level description

A system level simulation is proposed based on an RF lab with eNodeBs in band 8 or band 20. Advantage of RF lab based approach is that all cell topology methods (i.e. CoMP, MIMO) can be implemented as part of the simulation. It operates at '*Hardware simulation and laboratory test reference point*' as defined in Figure 1.

Lab setup includes (see Figure 8):

- 2 eNodeBs in a band neighbouring the E-GSM-R band (band 8 or band 20)
- Fixed attenuators RF cable wired to the output of each eNodeB
- 3GPP Channel Fading Simulator wired to the fixed attenuators to insert the fading
- On-board LTE modem RF cable wired to the 3GPP Channel Fading Simulator
- Traffic Generator/Analyser port connected to IP port of the On-board LTE modem
- Service Gateway connected to each eNodeB via IP connection
- Traffic Generator/Analyser port connected to IP port of Serving Gateway



**Figure 8: Architectural diagram of the Lab Simulation Setup**

### 5.2.1.2 Lab setup: 3GPP RF Channel Emulator

Fading Profiles Available: Constant, Rayleigh, Rice, Nakagami, Lognormal, Suzuki, Pure Doppler, flat, rounded, Gaussian, Jakes, Butterworth, user-defined profiles, models from 3rd party simulation tools and ray-tracing applications.

Channel Configuration Topologies: Single or multiple independent or fully synchronized MIMO, MISO, SIMO, SISO, CoMP and relaying transmission schemes.

Run-time fading engine Amplitude, delay, Doppler and environment separately controlled for each fading channel.

Emulation of 2D and 3D beamforming channels, single and multi-user scenarios.

Emulation of high speed train scenarios, measured with channel sounder or defined with channel modelling tools.

Geometric channel modelling tool for user-defined Multi-link MIMO, beamforming and smart antenna testing; includes dynamic spatial, defined antenna patterns.

### 5.2.1.3 Lab setup: FRMCS Traffic Generator and Analyzer

Multi-FRMCS Application emulation provides end-to-end measurements from ingress/egress of SGW to the ingress/egress of the UE per application or bearer. Data emulation supports voice, video, and data traffic generation. Dedicated radio bearers are established from the test system and the service type is appropriately mapped to the correct bearer. By fully-loading the lab environment with enough traffic to cause congestion and resource contention of the RF interface it is possible to determine the maximum throughput per bearer, per UE and per channel.

By setting traffic generator to configure layer 7 (L7) activities it is possible to emulate FRMCS application activities according to specific QCI and DSCPs. The traffic analyser then measures QCI performance for each of the L7 activities.

KPIs for FRMCS applications include:

- Loss packets
- Max and average jitter
- Average latency
- Mean Opinion Score (MOS)
- Throughput

#### QoS Validation

It is possible using this setup to measure the performance of the network while varying input loads, such as traffic rates and types, and subscriber classes. In this way one can vary specific FRMCS activities and measure the QoS impact on the others. One of the railway's important tests is the verification of latency thresholds that ensure delay-sensitive train control and REC traffic gets priority over best-effort data traffic. The railway can use the traffic generator equipment to emulate a constant level of data traffic (number of subscribers and data rate), while increasing the level of emulated train control or REC traffic.

### 5.2.2 Specific assumptions and parameters

No specific parameters and assumptions have been considered. See clause 4.7.

### 5.2.3 Results

No results available from this set.

### 5.2.4 Notes and remarks

No results available from this set.

## 5.3 Results set 3

### 5.3.1 Description

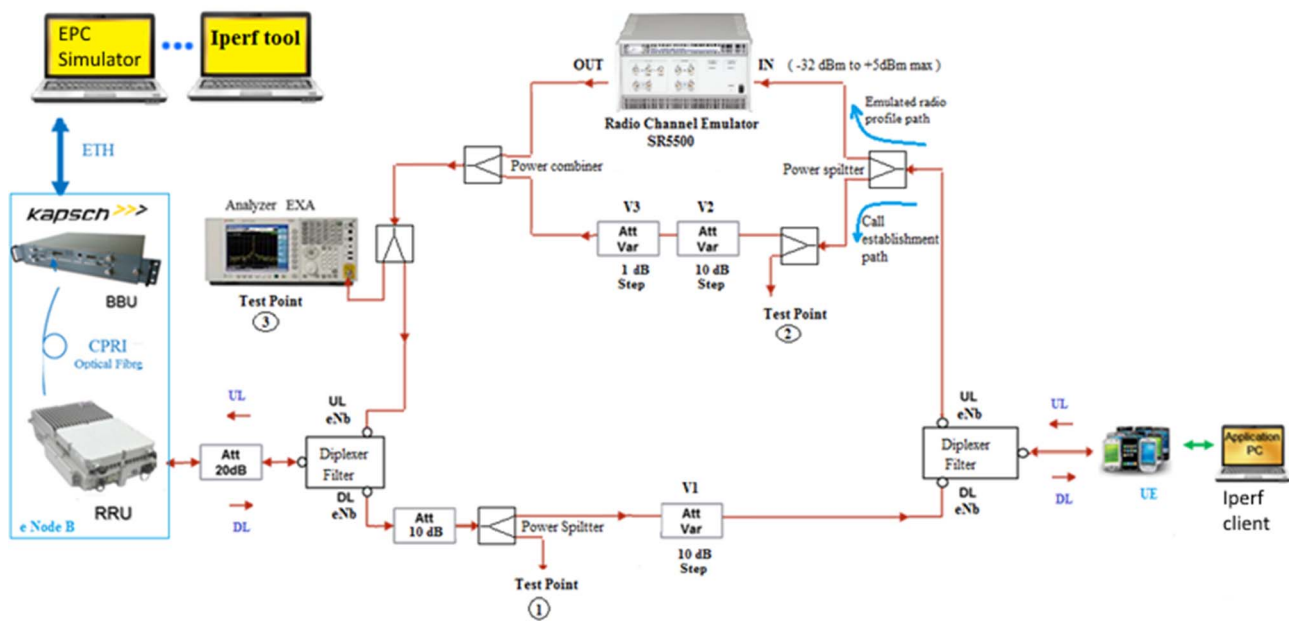
The primary objective of the study for this result set is to assess the uplink throughput performance of an LTE based radio setup when used in a Railways environment.

For that purpose, measurements have been carried out under conditions as close as possible to "real life" railways situation.

An evolved radio test bench, including a wireless channel emulator, has been customized to reflect the most critical railways and high-speed propagation conditions.

Extra features have been implemented to manually select the Modulation Coding Scheme (MCS) and measure throughput for each of them.

The test set-up is represented in Figure 9.



**Figure 9: Measurement setup schematic**

Data throughput evaluation (UDP throughput using 1 024 bytes packet size.) was assessed with widely-used Iperf network performance measurement and tuning tool (see <https://iperf.fr/>). Every throughput value provided in clause 5.3.3 is the average of at least one hundred fluctuating values over a period of time of at least 100 s. Iperf is delivering 1 throughput value per second. Reported results are about effective payload.

Multipath are simulated with a Spirent Radio Channel Emulator SR 5500. This device is able to add white Gaussian noise to generate desired SNR level.

## 5.3.2 Specific assumptions and parameters

### 5.3.2.1 Common assumptions

Parameters for these experiments have been selected as close as possible to recommendations. Exceptions or complementary information are listed below:

- Mobile handset is a category 3 USB dongle:
  - Maximum constellation is 16 QAM.
- Network loading is 1 user.
- Normal Cyclic Prefix.
- Configuration under test is 1x1, however an extrapolation is performed to evaluate 1x2 (receive diversity at eNB level).
- Down Link path is not experiencing multi-path effects.
- Multipath scenario is derived from ETSI TS 145 005 [i.1]

A simplified link budget has been made to evaluate worst case SNR (at Hand Over point: HO) and extract minimum guaranteed data throughput along the track. SNR are given for two antenna gain (17 dBi and 21 dBi) and extrapolation are given to evaluate performance with 2 way Rx diversity at Base Station level.

### 5.3.2.2 Hilly channel model

- Hilly terrain profile is used; however, profile is restricted to 6 taps.
- Considered Doppler shift is higher than the one resulting from the speed, it is incorporating some double effect part (Shift is doubled), applied shifts are:
  - 360 km/h: 600 Hz (named HT600)
  - 500 km/h: 834 Hz (named HT834)
- Speeds are: 360 km/h and 500 km/h for 3 MHz LTE Channel BW, and 360 km/h for LTE 1,4 MHz Ch BW.

The simplified link budget computation for the hilly channel is given in Table 25.

**Table 25: Simplified link budget at HO point for Hilly channel model**

UL link budget (1x1)			
Train parameters	UE Tx power (dBm)	23	
	Coupling loss (dB)	2	
	Antenna gain (dB)	2	
	EIRP (dBm)	23	
	Height (m)	4	
Base station	Antenna gain (dB)	17	21
	Height (m)	40	
	Coupling loss (dB)	3	
	eNB NF (dB)	3	
Path loss (BS 40 m, MS 4m)	Distance (km)	4	
	Path loss (dB)	129	
	Standard deviation (dB)	8	
	Margin for 95% (dB)	13,2	
	Guaranteed (dB)	142,2	
	UL Rx lev (dBm)	-105,2	-101,2
LTE 1,4 MHz	Thermal noise (dBm)	-113,7	
	Noise floor (dBm)	-110,7	
	SNR (dB)	5,5	9,5
	Rx Div min gain (dB)	3,0	
	SNR with Rx Div (dB)	8,5	12,5
LTE 3 MHz	Thermal noise (dBm)	-110,0	
	Noise floor (dBm)	-107,0	
	SNR (dB)	1,8	5,8
	Rx Div min gain (dB)	3,0	
	SNR with Rx Div (dB)	4,8	8,8

### 5.3.2.3 Rural channel model

Two channel profiles have been defined considering UL path for a train moving at 360 km/h toward the antenna mast and away from the antenna mast.

It is assumed that the UE is using the stronger direct path (LOS) to synchronize.

Since direct path is frequency shifted due to the doppler effect, then the UE emission will also experience a frequency shift by the same amount.

- 1) *Train is moving toward the antenna mast:* RA295 Hz (fading doppler) + 310 Hz of fixed frequency shift:
  - +310 Hz is the maximum doppler shift experienced in DL considering a centre frequency of 930 MHz, a train speed of 360 km/h and an angle of arrival of 0° (realistic when the train is far from the BTS site).

- 295 Hz is the fading doppler in UL considering a centre frequency of 885 MHz and a train speed of 360km/h.
- Shortest path is defined with an angle of arrival of 0°, a Rician factor of 6,9 dB and a RICE doppler spectrum.

**In details:** 310 Hz frequency shift is assuming an angle of arrival of 0° of the DL direct path element (= LOS @ 930 MHz). To be coherent, in UL (885 MHz), the same angle of arrival 0° is taken that leads to a 295 HZ LOS doppler frequency shift. The other 295 Hz fading doppler, stands for the UL channel fluctuating rate, and set the classical doppler spectrum limits. The rician factor set the power ratio between the direct path (LOS) energy and scattering energy (modelled as a classical doppler spectrum).

2) *Train is moving away from the antenna mast:* RA295Hz (fading doppler) - 310Hz of fixed frequency shift:

- -310 Hz is the maximum negative doppler shift experienced in DL considering a centre frequency of 930 MHz, a train speed of 360 km/H and an angle of arrival of 180° (realistic when the train is far from the BTS site).
- 295 Hz is the fading doppler in UL considering a centre frequency of 885 MHz and a train speed of 360 km/H.
- Shortest path is defined with an angle of arrival of 180°, a Rician factor of 6,9 dB and a RICE doppler spectrum.

It is important to note that the two profiles are giving equivalent results.

The simplified link budget computation for the Rural channel is given in Table 26.

**Table 26: Simplified link budget at HO point for Rural channel model for 1,4 and 3 MHz**

UL budget link (1x1) - Std Dev = 6 dB + Diversity sensitivity gain extrapolation BS antenna height = 40 m							
Train parameters	UE Tx power (dBm)	23		26		31	
	Coupling loss (dB)	2		2		2	
	Antenna gain (dB)	2		2		2	
	EIRP (dBm)	23		26		31	
	Height (m)	4		4		4	
Base station	Antenna gain (dBi)	17	21	17	21	17	21
	Height (m)	40		40		40	
	Coupling loss (dB)	3		3		3	
	eNB NF (dB)	3		3		3	
Path loss	Distance (km)	4		4		4	
	Rural area path loss (dB)	129		129		129	
	Standard deviation (dB)	6		6		6	
	Margin for 95% (dB)	10		10		10	
	Guaranteed (dB)	139		139		139	
	UL Rx lev (dBm)	-102	-98	-99	-95	-94	-90
LTE 1,4 MHz	Thermal noise (dBm)	-113,7		-113,7		-113,7	
	Noise floor (dBm)	-110,7		-110,7		-110,7	
	SNR (dB)	8,7	12,7	11,7	15,7	16,7	20,7
	SNR with Rx Div gain (dB)	11,7	15,7	14,7	18,7	19,7	23,7
LTE 3 MHz	Thermal noise (dBm)	-110,0		-110,0		-110,0	
	Noise floor (dBm)	-107,0		-107,0		-107,0	
	SNR (dB)	5,0	9,0	8,0	12,0	13,0	17,0
	SNR with Rx Div gain (dB)	8,0	12,0	11,0	15,0	16,0	20,0

NOTE: For 30 m antenna height, SNR values are by 2 dB below the values computed for 40 m antenna height.

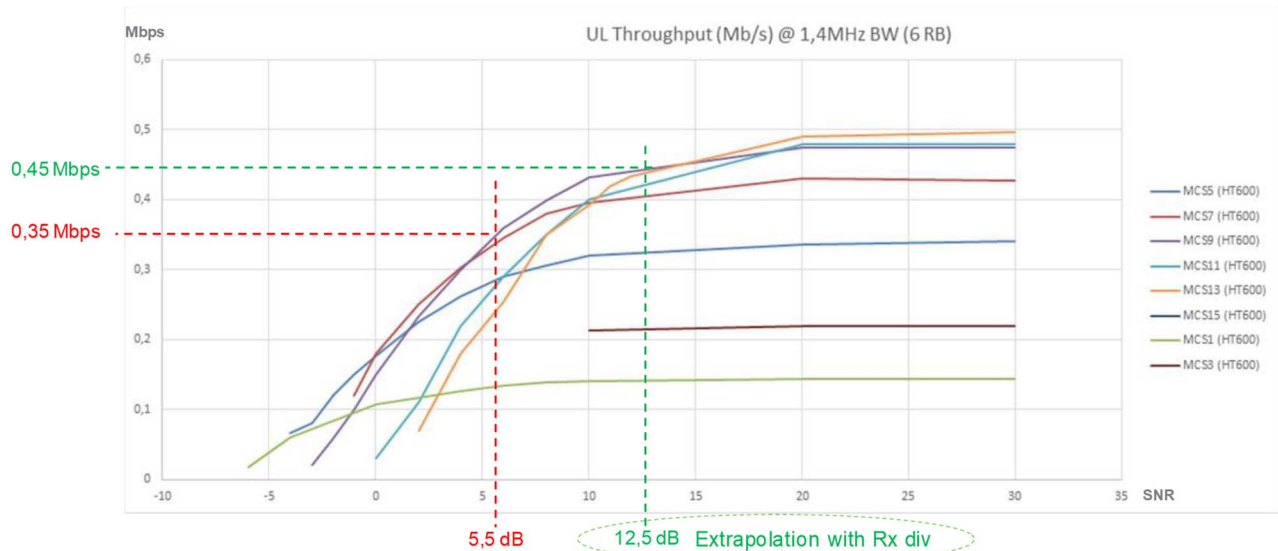
Similarly, a rural channel profile for 500 km/h has been designed by extrapolation, with fading Doppler at 410 Hz and an additional fixed frequency shift of 431 Hz.



### 5.3.3 Results

#### 5.3.3.1 Hilly channel model

In this clause, only LTE 1,4 MHz channel BW with 360 km/h is considered, other results are available in annex C. Results are reported and SNR conditions at HO point are superimposed to derive corresponding data rate.



**Figure 10: Measurement results for 1,4 MHz channel BW at 360 km/h and Hilly channel model**

The measurements are made on a per MCS (Modulation Coding Scheme) basis. On real conditions, an adaptive feature (AMC: Adaptive Modulation Coding) will be used to get access to the envelope of all results.

The minimum data throughput is obtained with 17 dBi antenna and without Rx diversity. This corresponds to 5,5 dB SNR and offers 0,35 Mbps data throughput.

Using 21 dBi antenna and with Rx diversity 3 dB minimum gain, SNR reaches 12,5 dB which corresponds to 0,45 Mbps.

Similar curves for 3 MHz with 360 km/h and 500 km/h are given in annex C.

Results are summarized in Table 27.

**Table 27: Guaranteed data throughput at HO point for Hilly channel model**

Data throughput (Mbps)		17 dBi ant gain		21 dBi ant gain	
		Rx diversity		Rx diversity	
LTE Ch BW	Speed (km/h)	Without	With	Without	With
3	360	0,61	0,81	0,9	1,05
3	500	0,42	0,55	0,6	0,68
1,4	360	0,35	0,43	0,4	0,45

It is believed that actual results in the field would be better and this is explained in clause 5.3.4.

#### 5.3.3.2 Rural channel model

This clause provides results with a rural channel model and 3 MHz bandwidth, for train speeds up to 500 km/h. Results are reported and SNR conditions at HO point are superimposed to derive corresponding data rate.

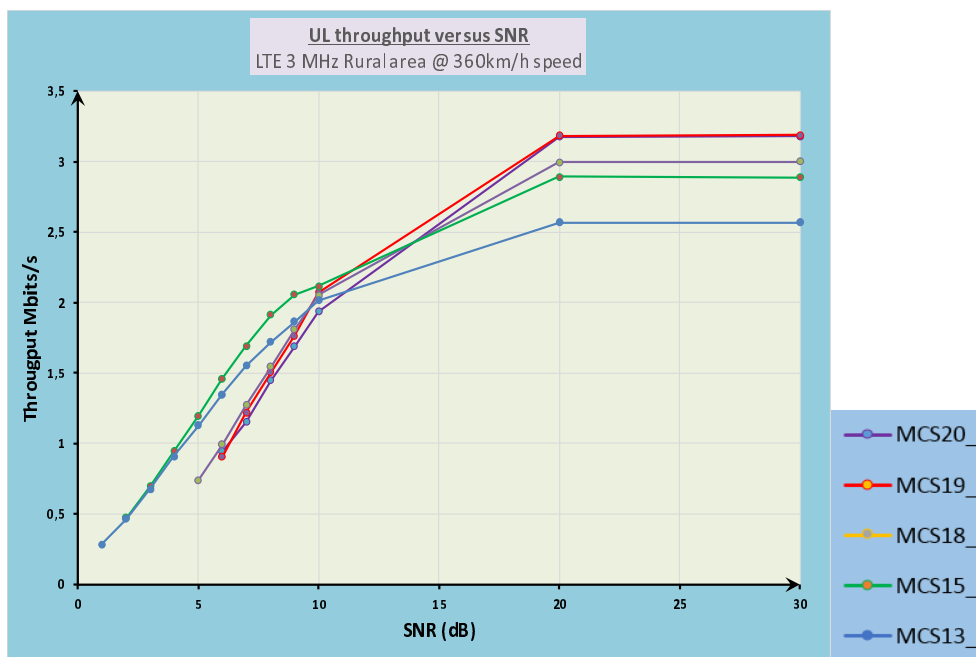


Figure 11: Measurement results for 3 MHz channel BW at 360 km/h and Rural channel model

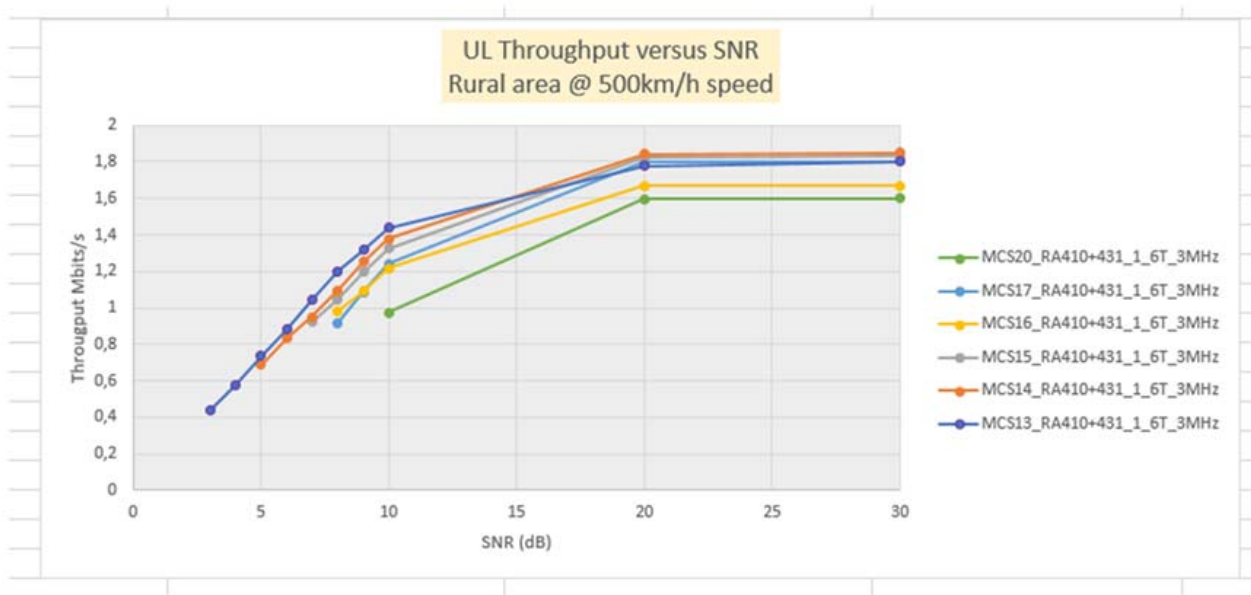


Figure 12: Measurement results for 3 MHz channel BW at 500 km/h and Rural channel model

Table 28: Guaranteed data throughput at HO point for Rural channel model

UL LTE 3 MHz Throughput with Rx diversity sensitivity gain (2 antennas)								
UE Tx power (dBm)		23		26		31		
Antenna gain (dBi)		17	21	17	21	17	21	
Height 40 m	SNR with Rx Div gain (dB)	8,0	12,0	11,0	15,0	16,0	20,0	
	Throughput (Mbps)	1,9	2,2	2,1	2,6	2,7	3,2	
Height 30 m	SNR with Rx Div gain (dB)	6,0	10,0	9,0	13,0	14,0	18,0	
	Throughput (Mbps)	1,45	2,1	2,2	2,4	2,5	2,9	
Note		LTE 3 MHz throughputs for 10 dB < SNR < 20 dB are interpolated						

In case of rural environment and considering a 3 MHz LTE carrier, a minimum guaranteed UL throughput of 1,45 Mbits/s can be expected, to be shared by all UEs in the cell. A maximum UL throughput of 3,2 Mbits/s at the speed of 360 km/h.

For a 5 MHz bandwidth channel, data has been extrapolated with the following methodology:

- BW difference impact on SNR:
  - UE Tx power is constant, thus SNR in 5 MHz channel is to be corrected for RF occupied bandwidth
  - 3 MHz → 15 RB, 5 MHz → 25 RB
  - SNR is lower by:  $10 \times \log_{10}(25/15) = 2,22$  dB
- BW impact on capacity:
  - Data throughput multiplied by:  $25/15 = 1,66$

This leads to the following link budget and data throughput for 5 MHz of bandwidth:

**Table 29: Link budget and data throughput at HO point for Rural channel model for 5 MHz**

UL LTE 5 MHz Throughput with Rx diversity sensitivity gain (2 antennas) extrapolated from LTE 3 MHz UL with Rx diversity sensitivity gain						
UE Tx power (dBm)	23		26		31	
Antenna gain (dBi)	17	21	17	21	17	21
SNR with Rx Div gain (dB)	8,0	12,0	11,0	15,0	16,0	20,0
LTE 3 MHz Throughput (Mbps)	1,9	2,2	2,1	2,6	2,7	3,2
LTE 5 MHz Corrected SNR (dB)	5,8	9,8	8,8	12,8	13,8	17,8
Corrected Throughput in 3 MHz (Mbps)	1,4	2,1	2	3,15	2,5	3
LTE 5 MHz Throughput (Mbps)	2,3	3,5	3,3	5,3	4,2	5,0

LTE 3 MHz throughputs for  $10 \text{ dB} < \text{SNR} < 20 \text{ dB}$  are interpolated.

### 5.3.4 Notes and remarks

The actual performance in the field could be better than the results of these experiments:

- Hilly Terrain is simulated with 6 taps. However, during experiments it has been noticed that a richer environment has a positive impact on data throughput. ETSI TS 145 005 [i.1] offers the possibility of Hilly Terrain with 12 taps. Using this set-up gave higher data throughput.
- Rx diversity. Actual diversity in the field offers 3 dB gain at minimum gain. However, practical gain is higher since Rx diversity offers better processing possibilities for the signal.
- Extended CP could also be a key contributor to enhance data throughput. Latest echo for Hilly Terrain from ETSI TS 145 005 [i.1] Hilly Terrain profile is 20  $\mu\text{s}$  later than main signal. Normal CP used in this experiment offers protection against ISI up to 4,6  $\mu\text{s}$ , and extended CP offers protection up to 16  $\mu\text{s}$ . It is expected that this could be beneficial for data throughput.
- Actual Doppler shift range could be lower in real life.
- MCS delivering best data throughput depends on propagation scenario. This is illustrated with the graph: "Maximum data rate per MCS vs. conditions (3 MHz)"(Figure C.4).

## 6 Results evaluation

### 6.1 Analysis

#### 6.1.1 General

Table 30 summarizes the assumption differences between the evaluation sets §1 and §3 that seem to have the highest impact on throughput results.

**Table 30: Assumption differences between the evaluation sets**

Result Set §1	Results Set §3	Remarks
Link simulation: channel and TX/Rx are simulated	Actual transmission devices, channel emulation	
System simulation including deployment impact, in particular including interference from neighbouring cells	One cell only. Interferences from neighbours not included in link budget	Interference is a strong limiting factor
Frequency-domain channel estimation: Wiener	Non Available	
Time-domain channel estimation: Time interpolation between pilots among and between sub-frames at receiver	Probably no interpolation	
Doppler model follows the spatial channel model (AoD/AoA)	Random Doppler shift ([i.1])	
Commercial antenna diagram (KATHREIN)	Fixed antenna gain	The antenna diagram may have an impact on Doppler action
Gross throughput: Overhead of pilot signals and cyclic prefix included	Net payload throughput: All the protocol stack overhead is included	An estimation of protocol stack overhead is necessary to conclude
No HARQ	HARQ included (up to 4 retransmissions)	HARQ brings a gain in terms of PER, with a cost on delay and transmission resources
Extended CP	Normal CP	

The two sets are not operating at the same level: Result Set §1 operates at *Software simulation reference point* while Result Set §3 operates at *Hardware simulation and laboratory test reference point*, see clause 4.2).

In the following, the term *gross throughput* is used to refer to throughput corresponding to *Software simulation reference point* and *net throughput* the values obtained at *Hardware simulation and laboratory test reference point*.

#### 6.1.2 Overheads analysis

##### 6.1.2.1 General

To better compare the Result Sets, it is necessary to understand and assess the difference lying below the *gross throughput* and the *net throughput* evaluations.

This clause assumes a static UE (i.e. train).

##### 6.1.2.2 IP stack, PDCP and RLC overheads

IP stack overhead corresponds to the overhead of the IP/UDP used by the application Iperf in result set §3.

The PDCP may compress the IP header. Compression depends on the type of packet (IP/UDP, IP TCP, etc.), and compressor is a state machine, i.e. the compression ratio depends of the time and of the transport conditions. Considering one UE and a constant session, which is the scenario in the simulation/evaluation picture, PDCP could be expected to remove 20 bytes of IP header, and 8 bytes of the UDP header and replace them by 2 bytes.

MAC will add something like 4 bytes of overhead.

Then, even without header compression, considering maximum packet length of 1 500 octets, the overhead corresponds to something like 2 %, which is negligible (2,5 % with 1 024 octets packet length).

### 6.1.2.3 Physical layer overheads

Result Set §1 takes into account cyclic prefix and pilots overhead. But the PHY layer introduces additional overheads, related to control signalling such as PDCCH, and PBCH channels.

This overhead is different on UL and DL and depends on channel bandwidth, being more important with a small number of PRBs. This overhead is typically between 15 % and 30 %.

### 6.1.2.4 Link-level comparison

In order to get an upper absolute limit value, the computation of the maximum theoretical throughput is provided below, assuming no HARQ, but with pilots overhead and normal CP. The formula is provided for MCS20 (Modulation and Coding scheme) at 1,4 MHz, which corresponds to the highest MCS used in Result Set §3:

$$12 \text{ sub-Carriers} \times 6 \text{ RBs} \times 12 \text{ Symbols} \times 4 \text{ bits (16 QAM)} \times 0,74 \text{ FEC Rate} / 10^{-3} \text{ (sub-frame duration)} = 2,56 \text{ Mbps}$$

To be able to compare more easily the different results, a set of (throughput vs. SNR) curves at link level step coming from simulation chain of Result Set §1 is shown in Figure 14, to be compared with curves coming from Result set §3 (Figure 13).

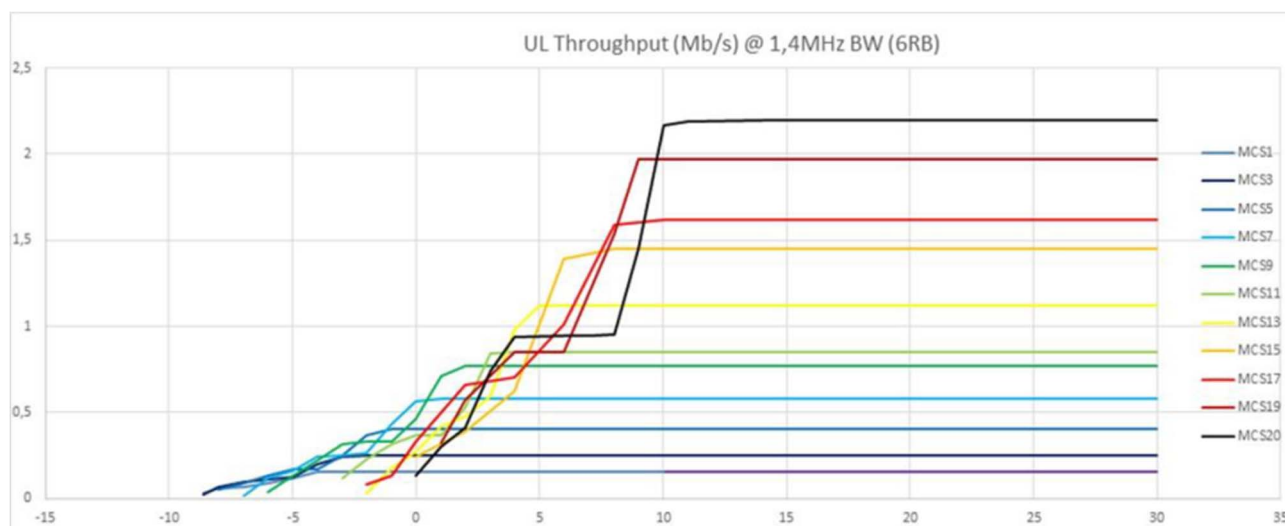
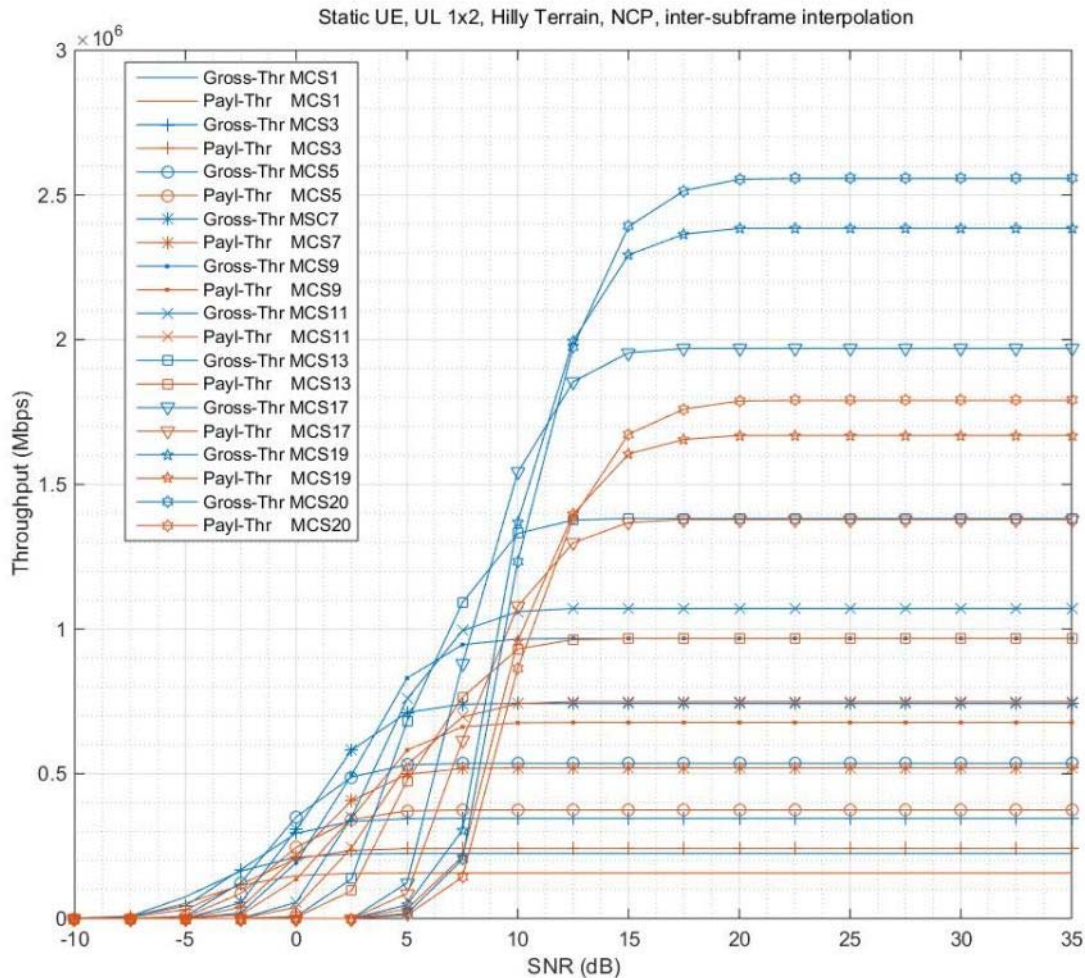


Figure 13: Net UL throughput for a static UE in case of Result Set §3 (1,4 MHz bandwidth)



**Figure 14: UL throughput for a static UE in case of Result Set §1 (link simulation) (1,4 MHz bandwidth)**

For MCS 20, Result Set §3 gives a maximum throughput of 2,2 Mbit/s of net throughput. Result Set §1 gives 2,55 Mbit/s of gross throughput.

The difference between the 2 values is about 14 %, although the overhead for UL considering a 1,4 MHz bandwidth is likely to be more around 30 %. Moreover, the two sets of curves are shifted in SNR of about 10 dB: For this MCS 20, the maximum throughput is reached for a SNR of 10 dB in Result Set §3, and for a SNR around 20 dB for Result Set §1.

Hence, overhead cannot explain alone this difference.. There may be other factors impacting the results:

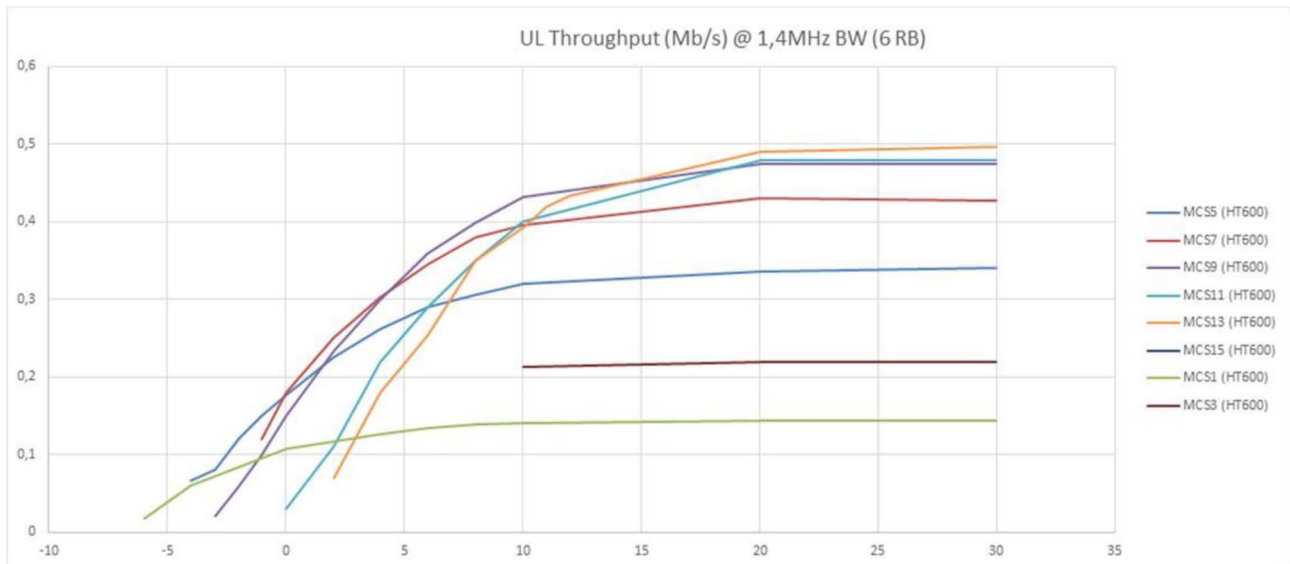
- i) Result Set §1 assumes 2 antennas in reception, although only 1 is considered for Result Set §1. This could explain a +3 dB difference in favour of Set §1.
- ii) A second factor is the HARQ which may provide between 7 to 10 dB gain [i.6] to Result Set §3.

Hence, gross throughput in UL has to be corrected by around 30 %, due to different overheads, but a gain of 7 to 10 dB could be expected with HARQ.

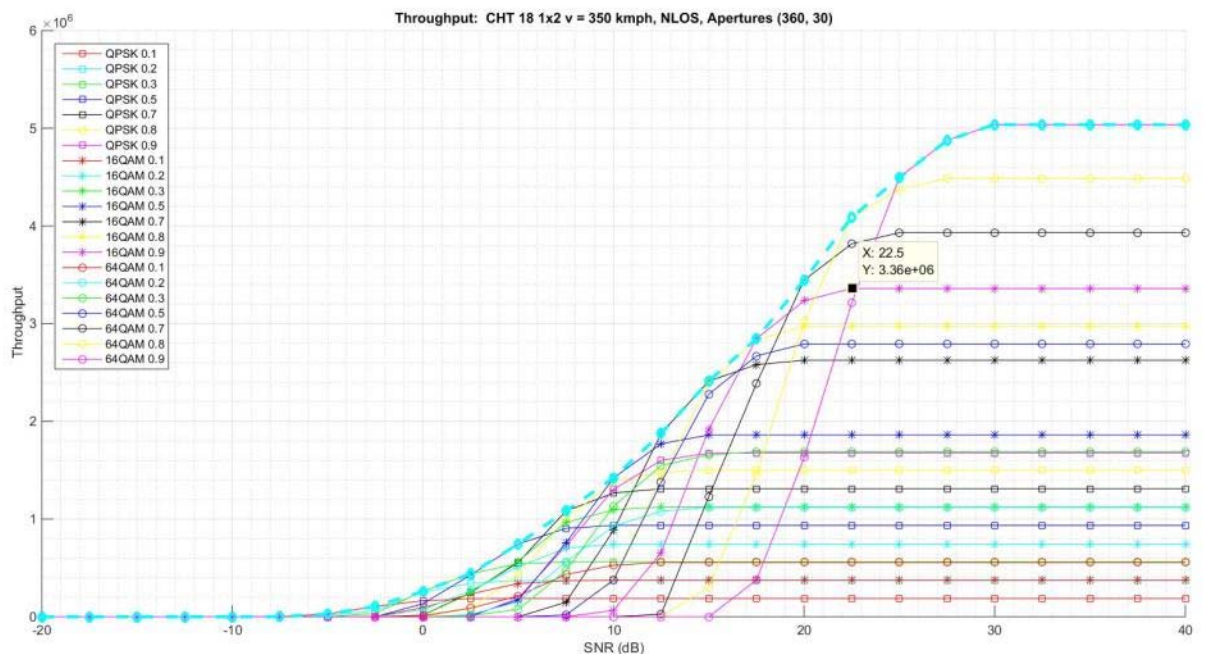
### 6.1.3 Train speed impact

This clause analyses the difference in Results Set §1 and Result Set §2 considering high train velocity. Figure 15 shows UL throughput for a UE at 350 km/h as provided by Result Set §3, while the UL throughput for a UE at 350 km/h at link simulation set up is provided in Figure 16.





**Figure 15: Net UL throughput for a UE at 350 km/h for Result Set §3 (1,4 MHz bandwidth)**



**Figure 16: UL throughput for a UE at 350 km/h for Result Set §1 (link simulation only) (1,4 MHz bandwidth)**

MCS 13 in Result Set §3, corresponding to 16QAM code rate 0,4, provides a max net throughput of 0,5 Mbit/s. A similar MCS in Result Set §1 indicates a gross throughput around 1,8 Mbit/s.

The difference may come from the following factors:

- Diversity gain due to the 2 Rx antenna assumed in Result Sets §1, while only 1 is present in Result Set §3
- Antenna diagram that filters the Doppler on paths arriving at high angles in Result Set §1
- Channel estimation time interpolation in Result Set §1

The impact of different factors has been evaluated with a link-level simulation for one MCS corresponding to MCS 20 (16 QAM code rate 0,7) of Result Set §3, as depicted in Figure 17. Blue curves provide the gross throughput, while a 30 % overhead is assumed in the red curves. Curves labelled "AoA/D 2pi" (Angle of Arrival/Departure) corresponds to a Doppler which is spread among 360 degrees, and curves labelled "CDL" corresponds to Doppler effect following a Cluster Delay Line model.

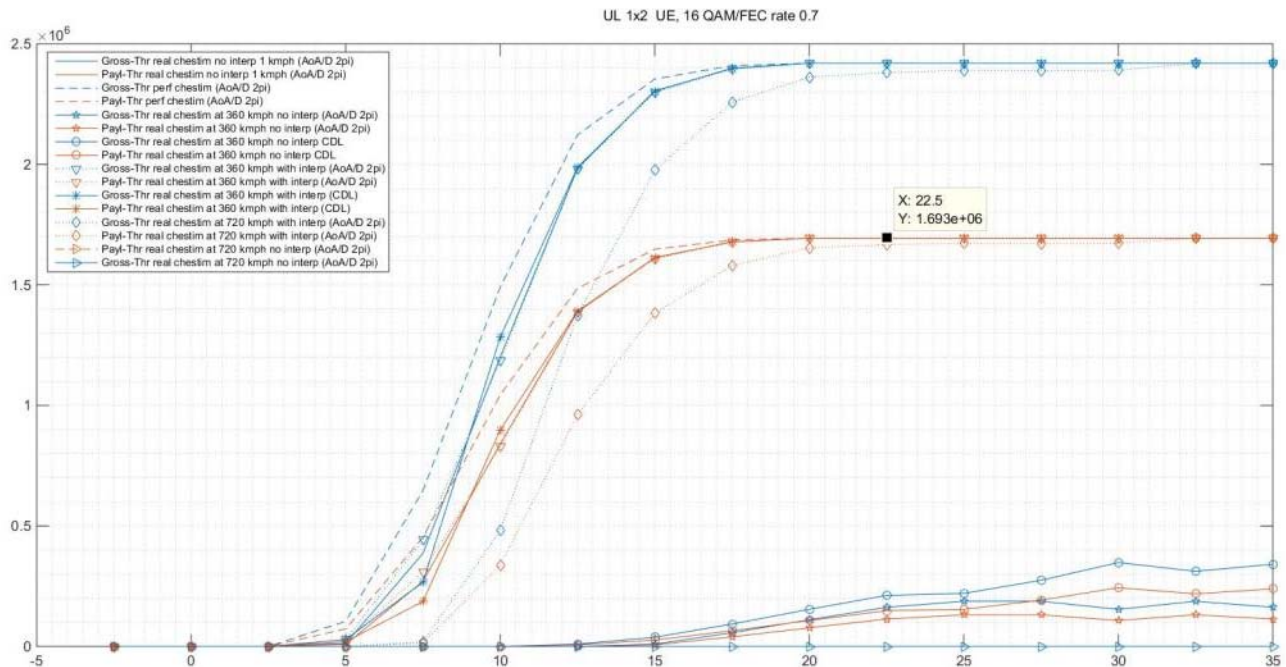


Figure 17: Impact of Doppler model and channel estimation time interpolation on throughput

The following can be observed:

- Channel estimation time interpolation has the main impact to fight against the Doppler.
- The effect of antenna filtering is noticeable, but of second order compared to channel estimation interpolation. With channel interpolation, the impact is clear in the intermediate SNR values (between 5 and 15 dB). With no interpolation and antenna diagram filtering, the maximum gross throughput is around 0,4 Mbit/s, to be compared to 0,2 Mbit/s with a random Doppler shift assumed.

The two last results are in the same order than Result Set §3, which shows 0,45 Mbit/s net max throughput, with an MCS 16 QAM code rate 0,4 (MCS 13) (which is more robust than MCS 20), and HARQ function on.

#### 6.1.4 Neighbouring cells interference impact

Result Set §1 takes into account interference from neighbouring cells, and results shows that it is an important factor of the system performance that depends on neighbouring cell loads. Interference coordination has to be performed, for example with fractional frequency reuse techniques that could be implemented in an LTE system.

#### 6.1.5 HARQ impact estimation

Along with the second round of simulation of Result Set §1, the impact of HARQ has been estimated at the hand-over point by artificially pushing up the SINR by a fixed value of 6 dB. The actual effect of a true HARQ algorithm is more complex than just raising the SINR, but this approach provides an overview of what could be expected when HARQ is taken into account. Table 31 provides the result for UL in high speed scenario for metrics *Smth. 100 m median cell edge* and *Smth. 100 m worst cell edge*. The impact is not big enough for the frequency reuse 1 scheme to provide a meaningful guaranteed throughput at cell edge - the interference level is too high; however, the improvement is significant as soon as some interference mitigation is in place.



Table 31: Set §1 - Second Round - HARQ impact estimation

1,4 MHz - High speed scenario - HARQ estimation

Bandwidth (MHz)	Speed (km/h)	Tx Power (dBm)	Reuse factor	UL	Throughput (Mbit/s)				
					No HARQ			HARQ impact estimation	
					Cell centre	Smth. 100 m median cell edge	Smth. 100 m worst cell edge	Smth. 100 m median cell edge	Smth. 100 m worst cell edge
1,4	350	26	1	1x2	3,81	0,20	0,00	0,68	0,02
			1	1x4	3,85	0,38	0,00	1,16	0,05
			2	1x2	1,90	1,48	0,81	1,86	1,24
			2	1x4	1,92	1,84	1,15	1,92	1,66
			3	1x2	1,27	1,17	0,81	1,27	1,12
			3	1x4	1,28	1,28	1,10	1,28	1,28

3 MHz - High speed scenario - HARQ estimation

Bandwidth (MHz)	Speed (km/h)	Tx Power (dBm)	Reuse factor	UL	Throughput (Mbit/s)				
					No HARQ			HARQ impact estimation	
					Cell centre	Smth. 100 m median cell edge	Smth. 100 m worst cell edge	Smth. 100 m median cell edge	Smth. 100 m worst cell edge
3,0	350	26	1	1x2	9,55	0,47	0,00	1,74	0,05
			1	1x4	9,61	0,94	0,00	2,94	0,14
			2	1x2	4,77	3,37	1,93	4,42	2,92
			2	1x4	4,81	4,28	2,74	4,81	4,01
			3	1x2	3,18	2,67	1,82	3,18	2,59
			3	1x4	3,20	3,20	2,48	3,20	3,17

5 MHz - High speed scenario - HARQ estimation

Bandwidth (MHz)	Speed (km/h)	Tx Power (dBm)	Reuse factor	UL	Throughput (Mbit/s)				
					No HARQ			HARQ impact estimation	
					Cell centre	Smth. 100 m median cell edge	Smth. 100 m worst cell edge	Smth. 100 m median cell edge	Smth. 100 m worst cell edge
5,0	350	26	1	1x2	15,89	0,77	0,00	3,01	0,07
			1	1x4	16,03	1,51	0,00	4,86	0,23
			2	1x2	7,95	5,08	2,83	6,91	4,63
			2	1x4	8,02	6,87	4,39	8,02	6,25
			3	1x2	5,30	4,09	2,75	5,14	3,95
			3	1x4	5,34	5,15	3,77	5,34	4,97

3 MHz - Hilly scenario - HARQ estimation

Bandwidth (MHz)	Speed (km/h)	Tx Power (dBm)	Reuse factor	UL	Throughput (Mbit/s)				
					No HARQ			HARQ impact estimation	
					Cell centre	Smth. 100 m median cell edge	Smth. 100 m worst cell edge	Smth. 100 m median cell edge	Smth. 100 m worst cell edge
3,0	160	26	1	1x2	9,66	0,00	0,00	0,00	0,00
			1	1x4	9,71	0,00	0,00	0,02	0,00
			2	1x2	4,83	0,90	0,01	1,74	0,29
			2	1x4	4,86	1,56	0,10	2,80	0,61
			3	1x2	3,22	1,02	0,17	1,77	0,57
			3	1x4	3,24	1,67	0,37	2,54	0,99

1,4 MHz - Hilly scenario - HARQ estimation

					Throughput (Mbit/s)				
Bandwidth (MHz)	Speed (km/h)	Tx Power (dBm)	Reuse factor	UL	No HARQ			HARQ impact estimation	
					Cell centre	Smth. 100 m median cell edge	Smth. 100 m worst cell edge	Smth. 100 m median cell edge	Smth. 100 m worst cell edge
1,4	160	26	1	1x2	3,87	0,00	0,00	0,01	0,00
			1	1x4	3,87	0,00	0,00	0,02	0,00
			2	1x2	1,93	0,40	0,02	0,77	0,12
			2	1x4	1,93	0,66	0,05	1,19	0,26
			3	1x2	1,29	0,44	0,09	0,78	0,25
			3	1x4	1,29	0,73	0,19	1,13	0,43

### 6.1.6 Results comparison and *net throughputs* at hand-over point

This clause compares some Results set §1 and Results set §3 throughputs, taken into account different correction factors discussed in previous clauses, so as to better align the different assumptions.

For Result set §1, a *gross throughput* value is picked up as *Smth. 100 m worst cell edge* metric with no HARQ providing the best result for a given scenario. This is considered as the low range value. The high range is computed from *Smth. 100 m worst cell edge* with HARQ impact estimation. Then, *gross throughput values* are converted into *net throughput* values by taking into account an overhead of 30 % for 1,4 MHz bandwidth and 15 % for 3 and 5 MHz bandwidths.

Result set §3 provides *net throughput* values directly. Value ranges come from different antenna gains assumptions and different UL Tx powers in the link budget estimation.

Table 32 provides a summary of the estimation of the guaranteed net throughput at cell edge in uplink direction as estimated by Results sets §1 and §3.

**Table 32: Comparison between Results Sets §1 and §3 of UL net guaranteed throughput at hand-over point**

Scenario	Net guaranteed throughput at HO point (MBit/s)	
	Result set §1	Result set §3
UL Hilly 1,4 MHz	0,1 - 0,3	0,3 - 0,5
UL Hilly 3 MHz	0,3 - 0,8	0,6 - 1,0
UL Rural 3 MHz	2,3 - 3,3	1,5 - 3,2
UL Rural 5 MHz	3,7 - 5,3	2,3 - 5,0

To be reminded that:

- For Results set §3:
  - Set does not take into account interferences from neighbouring cells
  - Set does not implement Doppler mitigation techniques
  - Results at 5 MHz are interpolated from results at 3 MHz
- For Results set §1:
  - Throughput is computed at PHY level. *Net throughput* is extrapolated
  - HARQ is not included in the simulations, its impact is roughly estimated

Guaranteed net throughputs at HO point are further estimated for all the scenarios from Result set§1 with the same method:

- **Low range** corresponds to **Smth. 100 m worst cell edge** metric with no HARQ.
- **High range** is computed from **Smth. 100 m worst cell edge** with HARQ impact estimation.
- **Net throughputs** are computed from **gross throughputs** by assuming a 30 % overhead for 1,4 MHz bandwidth and a 15 % overhead for 5 MHz bandwidth.

Results are provided in Table 33.

**Table 33: Net guaranteed throughput at hand-over point for the different scenarios (from Result Set §1)**

Bandwidth (MHz)	Scenario	Direction	Gross guaranteed throughput at HO point (Mbit/s) -		Net guaranteed throughput at HO point (Mbit/s)	
			Low range	High range	Low range	High range
1,4	High speed (350 km/h)	UL	1,2	1,7	0,8	1,2
		DL	1,2	1,5	0,8	1,1
	Urban (80 km/h)	UL	0,9	1,3	0,6	0,9
		DL	0,5	0,8	0,4	0,6
	High density (80 km/h)	UL	0,2	0,5	0,1	0,4
		DL	0,1	0,4	0,1	0,3
	Hilly (160 km/h)	UL	0,2	0,4	0,1	0,3
		DL	0,2	0,4	0,1	0,3
5,0	High speed (350 km/h)	UL	4,4	6,2	3,7	5,3
		DL	4,9	7,0	4,2	6,0
	Urban (80 km/h)	UL	3,6	5,1	3,1	4,3
		DL	2,0	3,4	1,7	2,9
	High density (80 km/h)	UL	0,6	1,8	0,5	1,5
		DL	0,5	1,5	0,4	1,3
	Hilly (160 km/h)	UL	0,6	1,5	0,5	1,3
		DL	0,8	1,7	0,7	1,4

## 6.2 Identified system limitations

The study with 3 MHz and 5 MHz of bandwidth is finalized without limitations identified at this time.

## 7 Conclusion

The assumptions considered in the present document have been chosen to be stringent in order to test the system at its limits. In particular, a radio channel with a higher Rice factor (LOS component), which would lead to increased performance, could be encountered in the field.

Result set 3 includes a full LTE stack and provides net throughput values, but interferences from neighbours are not taken into account.

Result set 1 shows that interference can be a limiting factor if cells are operated in a frequency reuse 1 scheme and are fully loaded. However, LTE system has some flexibility in radio resource assignment and several interference mitigation techniques could be implemented, for example fractional frequency reuse. Therefore, and considering that 50 % load instead of 100 % load in all neighbouring cells is a more realistic assumption, it could be expected to have a minimum throughput at cell edge corresponding to results provided for frequency reuse 2 or 3 schemes.

Considering the two sets of results, a throughput in UL and DL in the range 0,3 - 0,4 Mbit/s could be expected in a hilly environment as minimum guaranteed bit rate at handover point in a railway deployment, with a 1,4 MHz spectrum bandwidth in the 900 MHz band. This throughput is to be shared by trains served by the cell. Thanks to resource re-use techniques, this throughput could be made available at the same time on both sides of each site which could result in an increase of the total capacity available. With 5 MHz of bandwidth, this minimum guaranteed throughput could reach 1,3 Mbit/s in UL and 1,4 Mbit/s in DL.

In rural radio environment at high speed (360 km/h), a minimum guaranteed bit rate around 1 Mbit/s could be expected at handover point in UL or in DL with a 1,4 MHz spectrum bandwidth in the 900 MHz band. With 5 MHz of spectrum bandwidth, a minimum guaranteed bit rate in the range 3,5 - 6,0 Mbit/s could be expected.

## Annex A:

# Theoretical peak throughput for LTE

Table A.1 provides the peak data rates at physical layer that are theoretically achievable by an LTE radio operating on a 1,4 MHz bandwidth, considering no packet loss (PER = 0), 64 QAM modulation, normal cyclic prefix and the following transmission schemes:

- The 2x2 MIMO transmission scheme is the Alamouti Space Frequency Block Code (SFBC) applied on two adjacent sub-carriers.
- The 4x2 MIMO transmission scheme is a combination of Alamouti SFBC and Frequency Switched Transmit Diversity (FSTD) on four adjacent sub-carriers.

Those transmission schemes have been selected among all schemes proposed by LTE standard for their high transmit diversity properties, which make them more robust to the high train velocity.

**Table A.1: Some maximum theoretical throughputs for LTE physical layer operating in a 1,4 MHz bandwidth**

Max. theoretical throughput (Mbps)	DL		UL
	2x2 (SFBC)	4x2 (FSTD)	SIMO
Without control signalling overhead	4,92	4,67	4,67
With control signalling overhead (2 OFDM symbols for PDCCH in DL, 2 PRBs for PUCCH in UL)	4,75	4,61	3,46

In DL, 4x2 transmission scheme has a peak throughput lower than 2x2 due to the increased pilot overhead (9,52 % for 2x2 against 14,29 % in 4x2), but is expected to be more resistant under bad radio conditions.

## Annex B: Throughput curves for simulation results set 1

### B.1 First round of simulations

High speed scenario

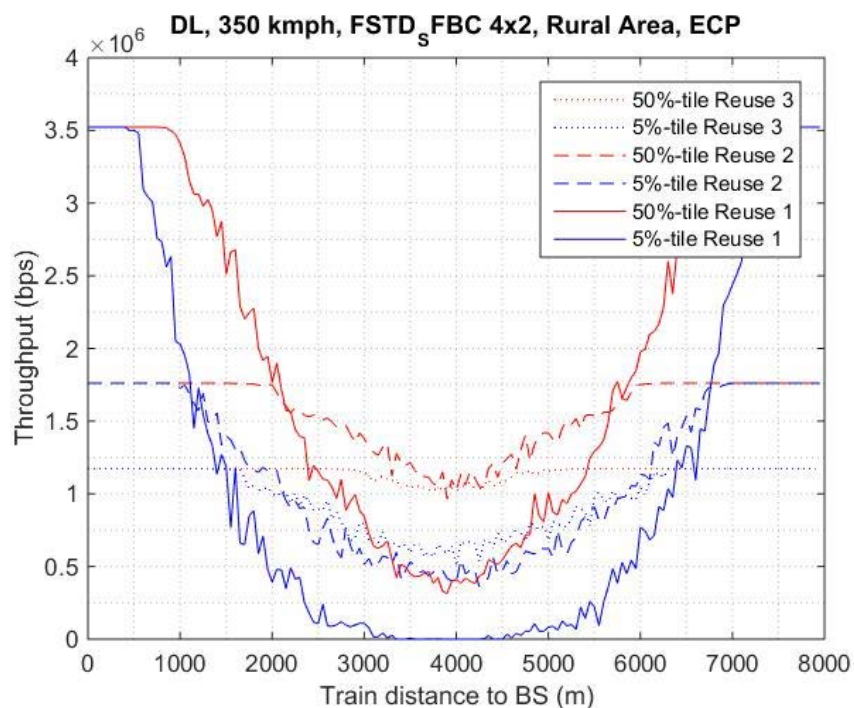


Figure B.1

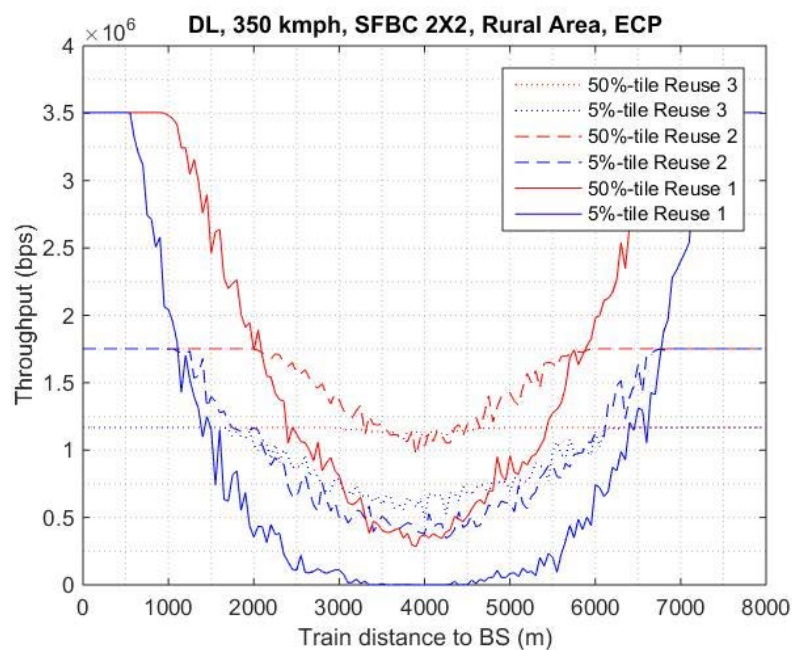


Figure B.2

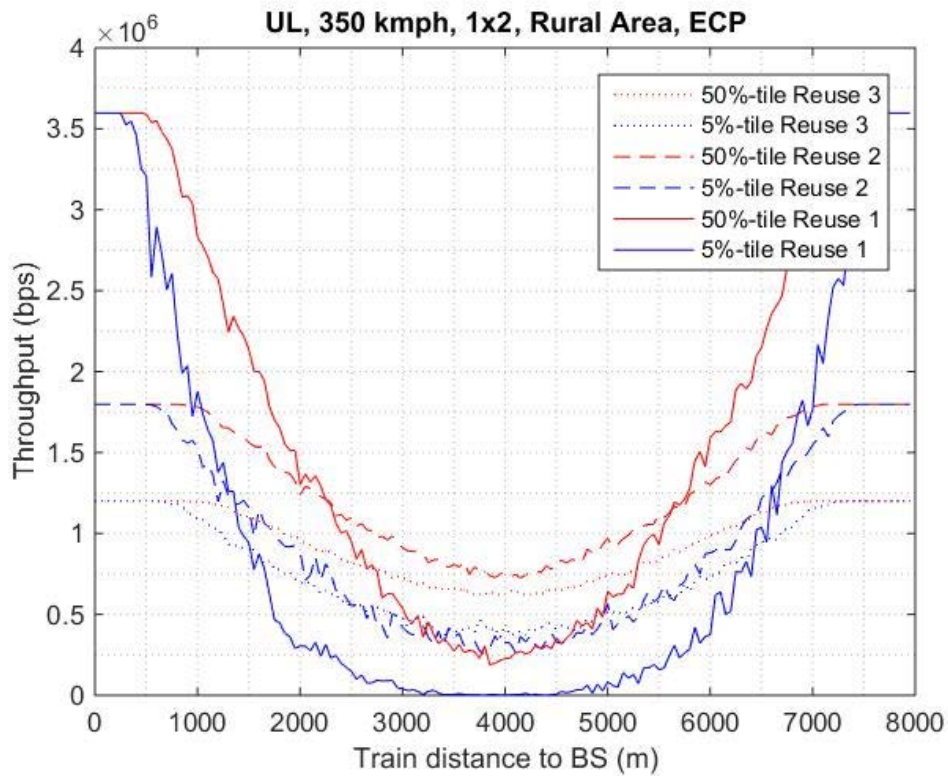


Figure B.3

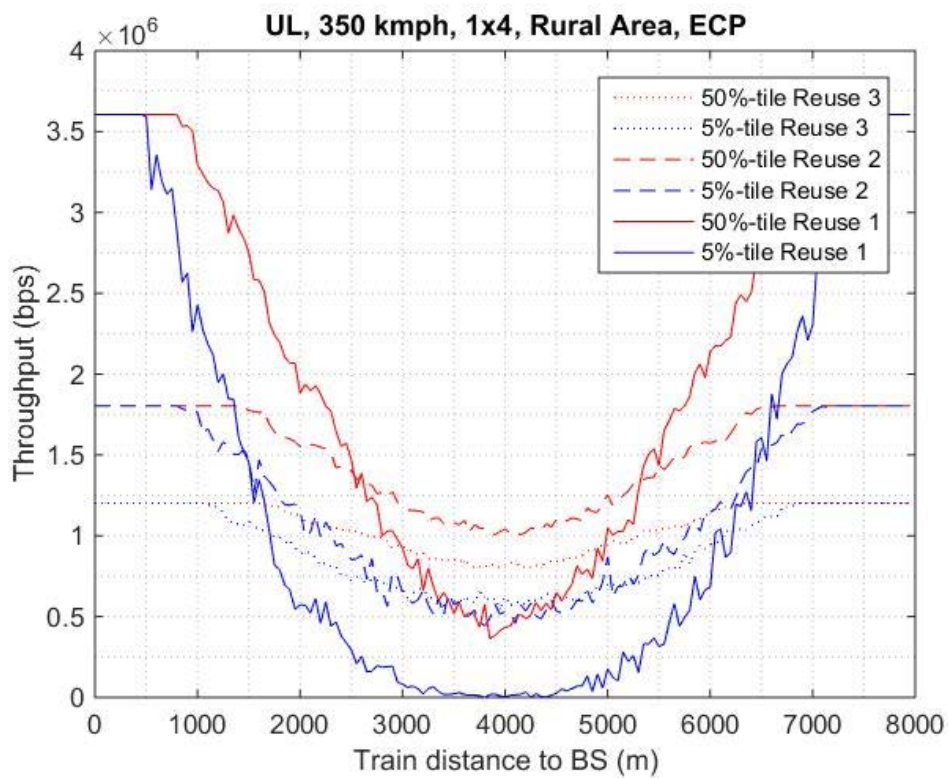


Figure B.4



## Urban scenario

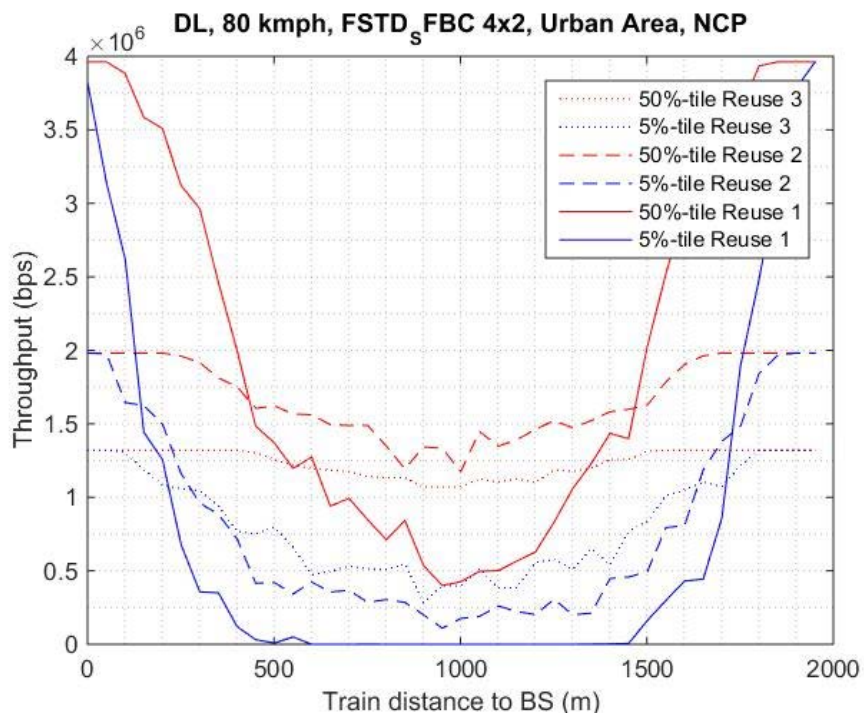


Figure B.5



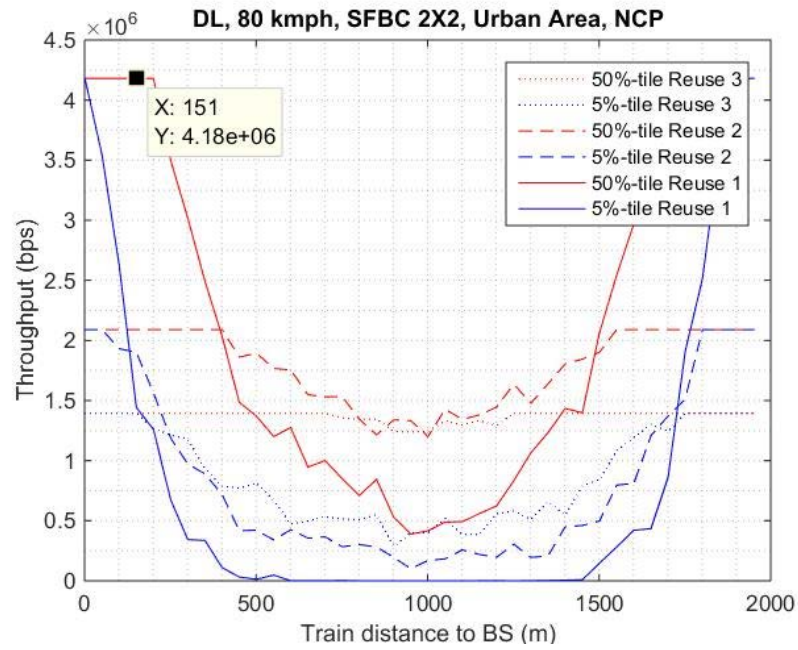


Figure B.6

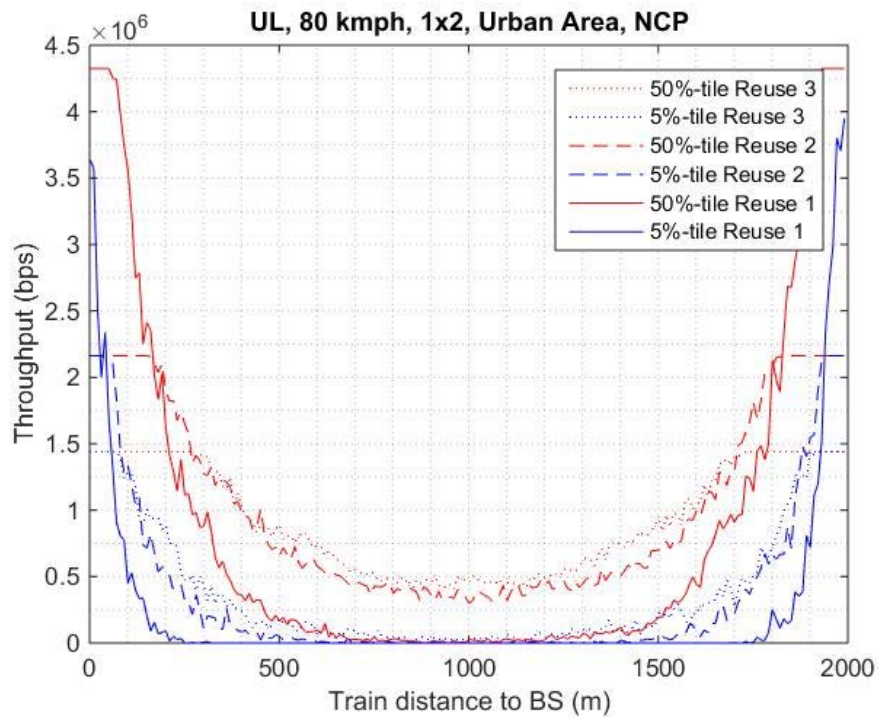


Figure B.7

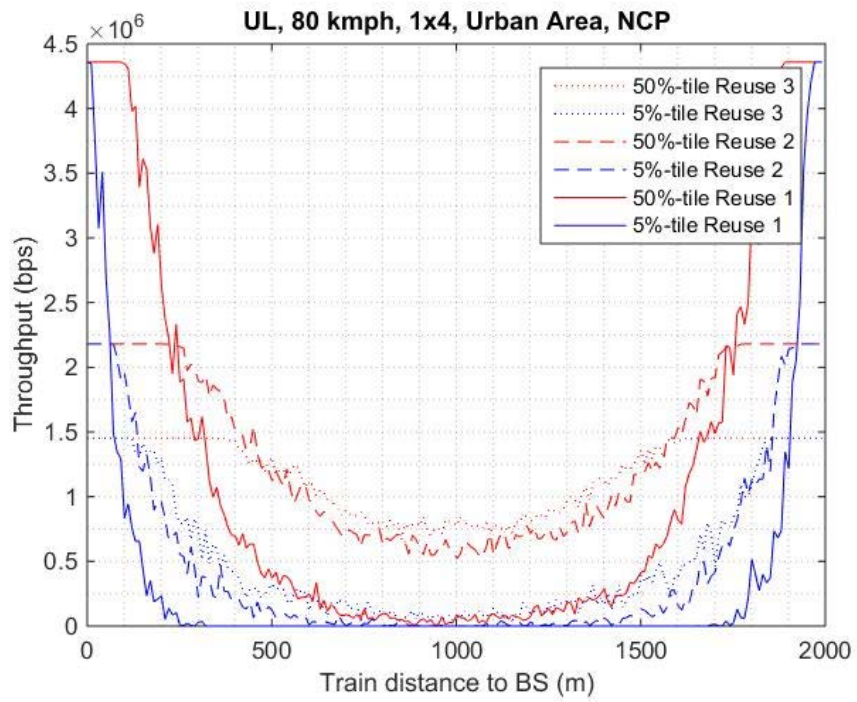


Figure B.8

## High density scenario

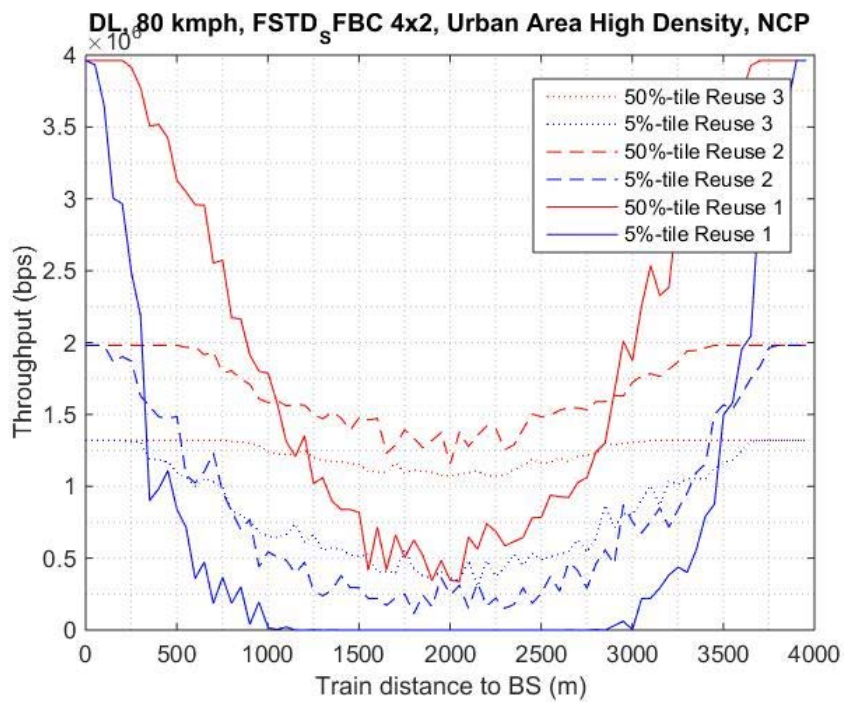


Figure B.9

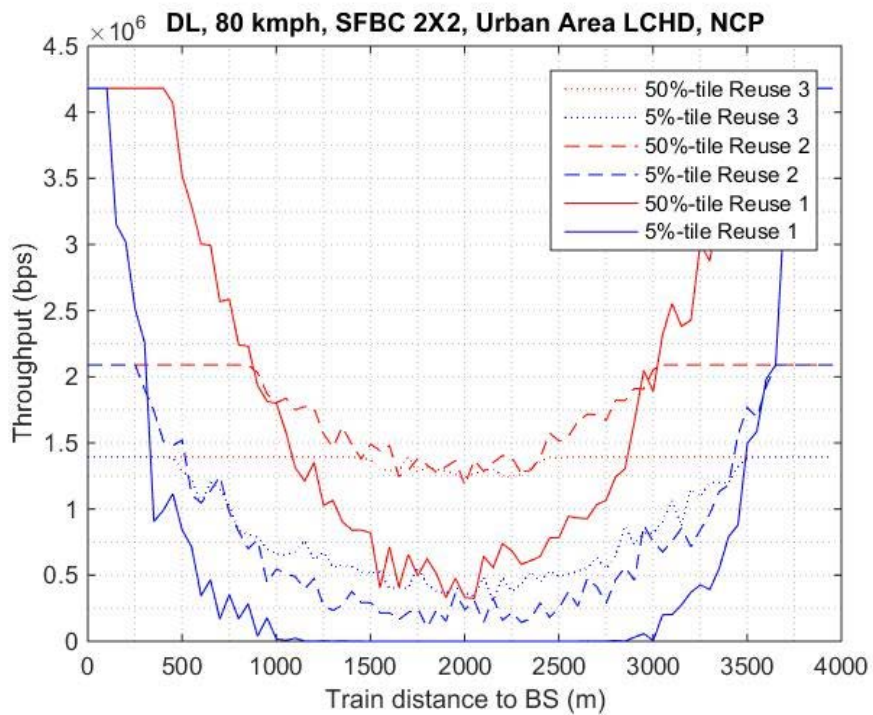


Figure B.10

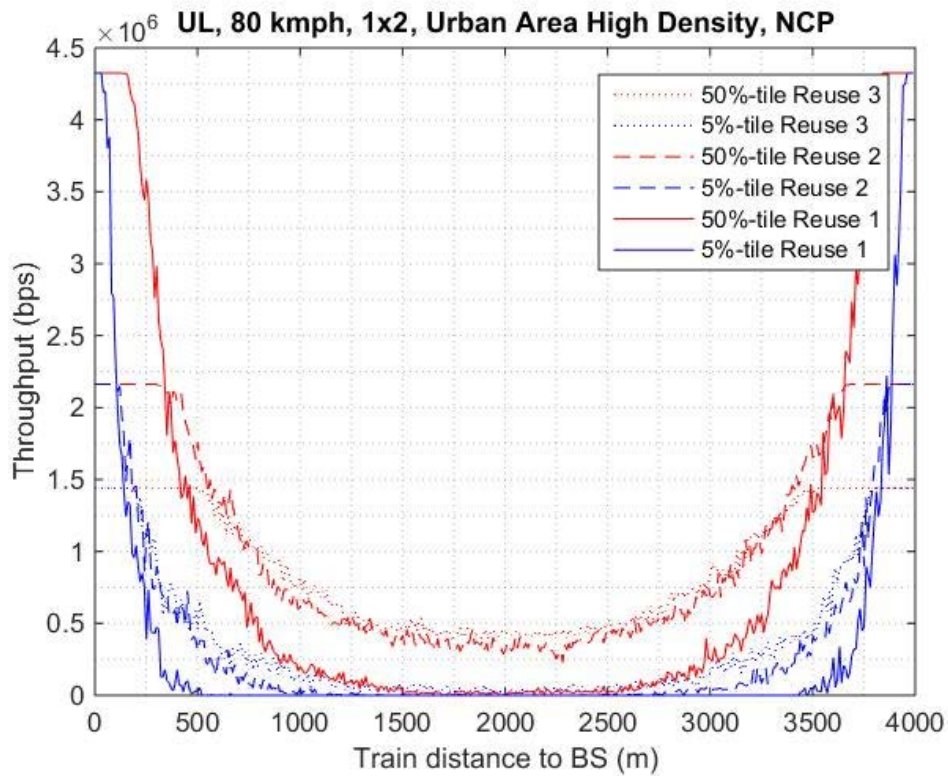


Figure B.11

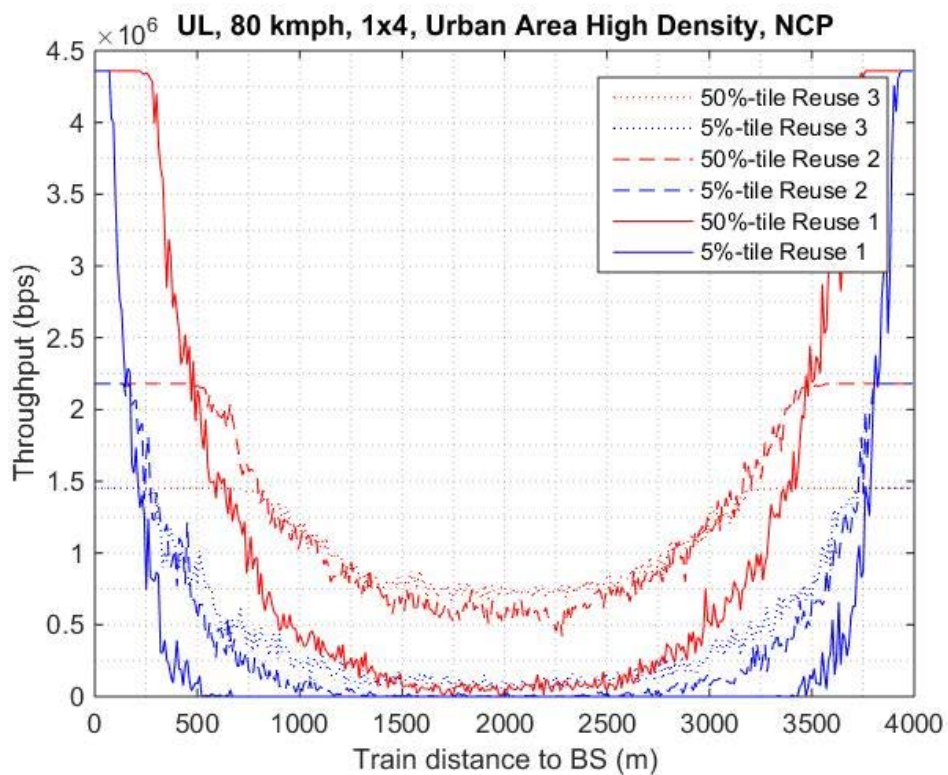


Figure B.12



## Hilly scenario

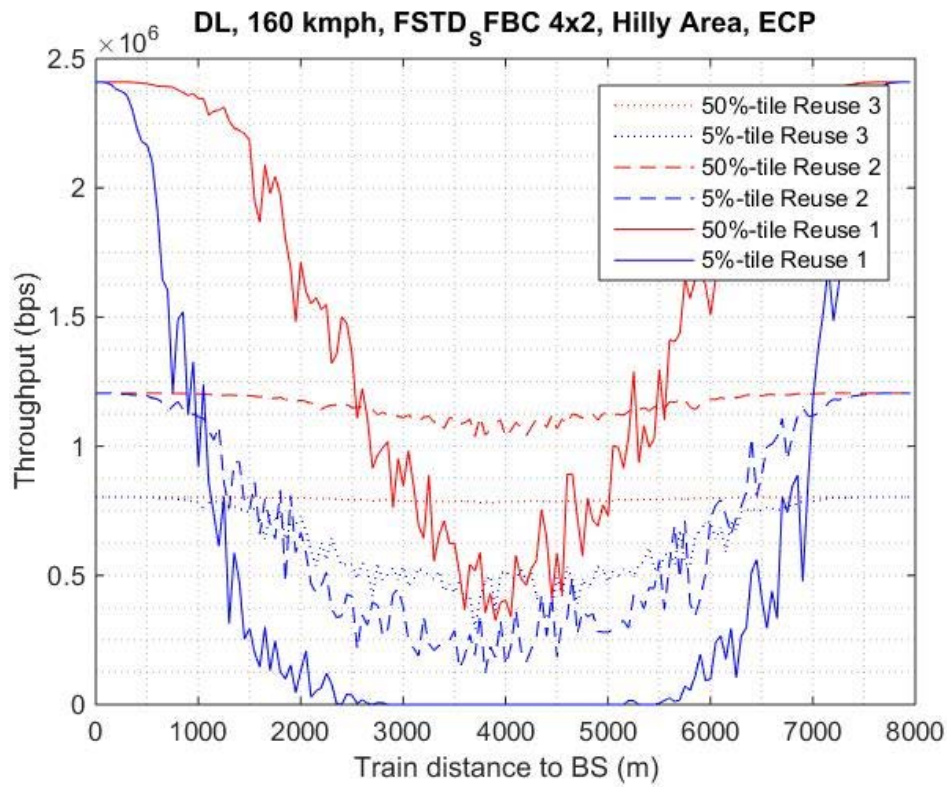


Figure B.13

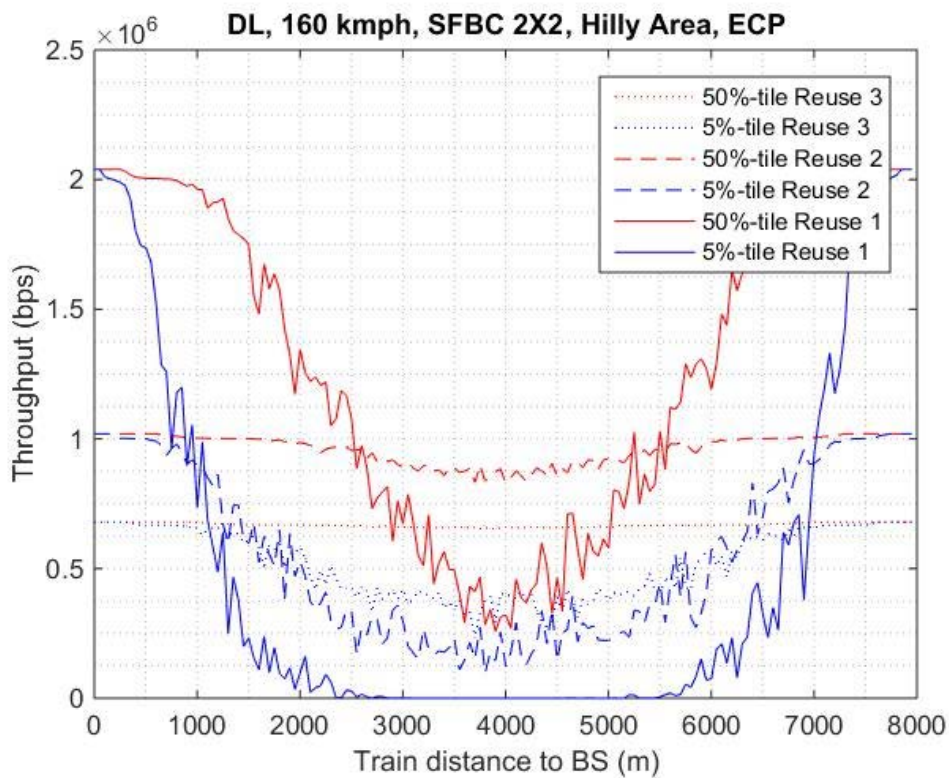


Figure B.14

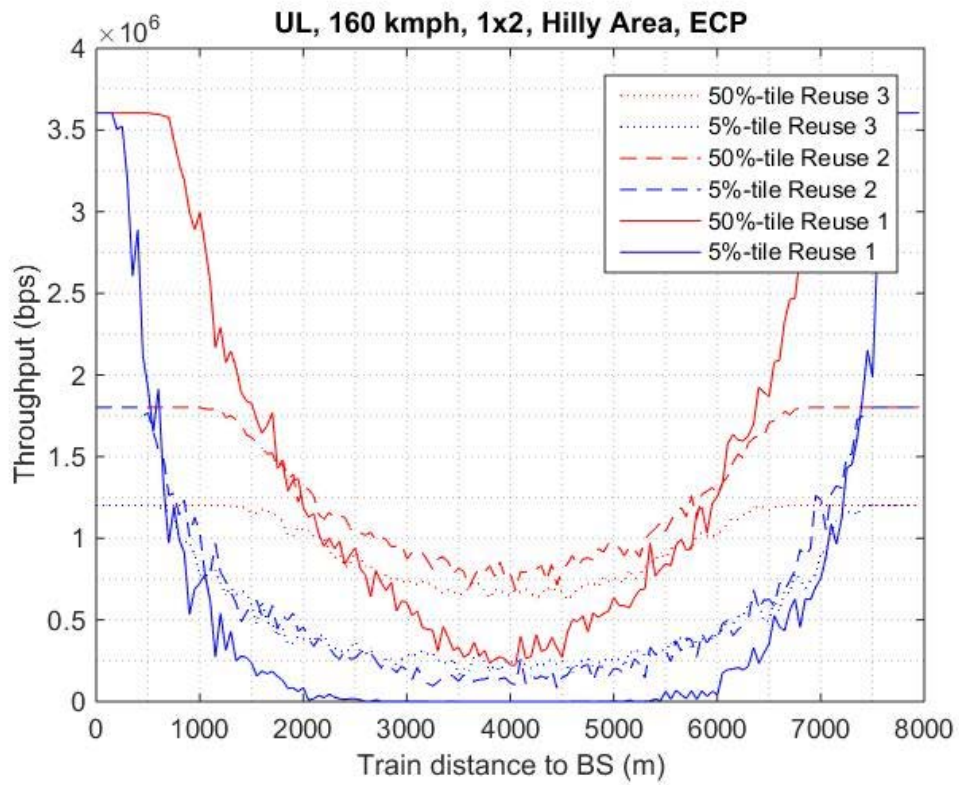


Figure B.15

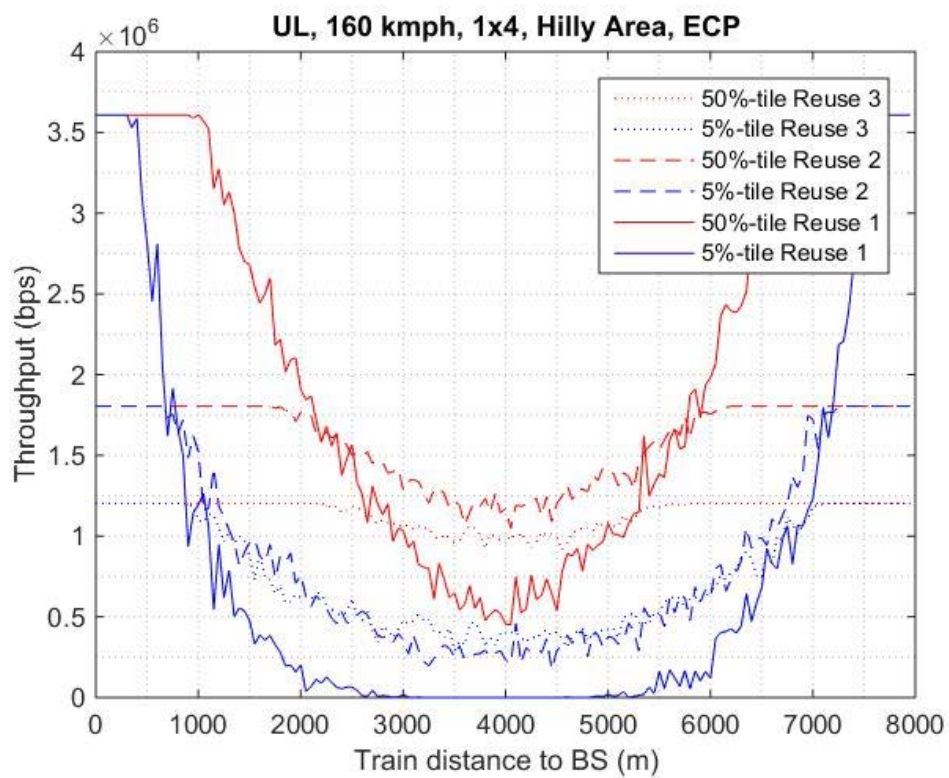


Figure B.16

Urban scenario with antenna tilt of 5°

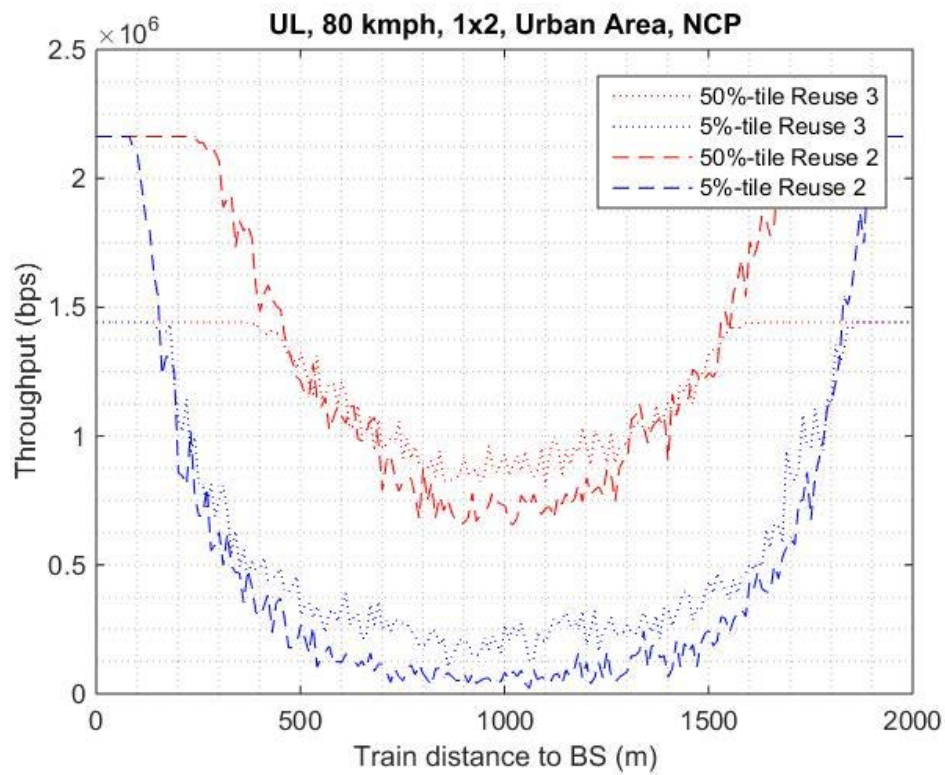


Figure B.17

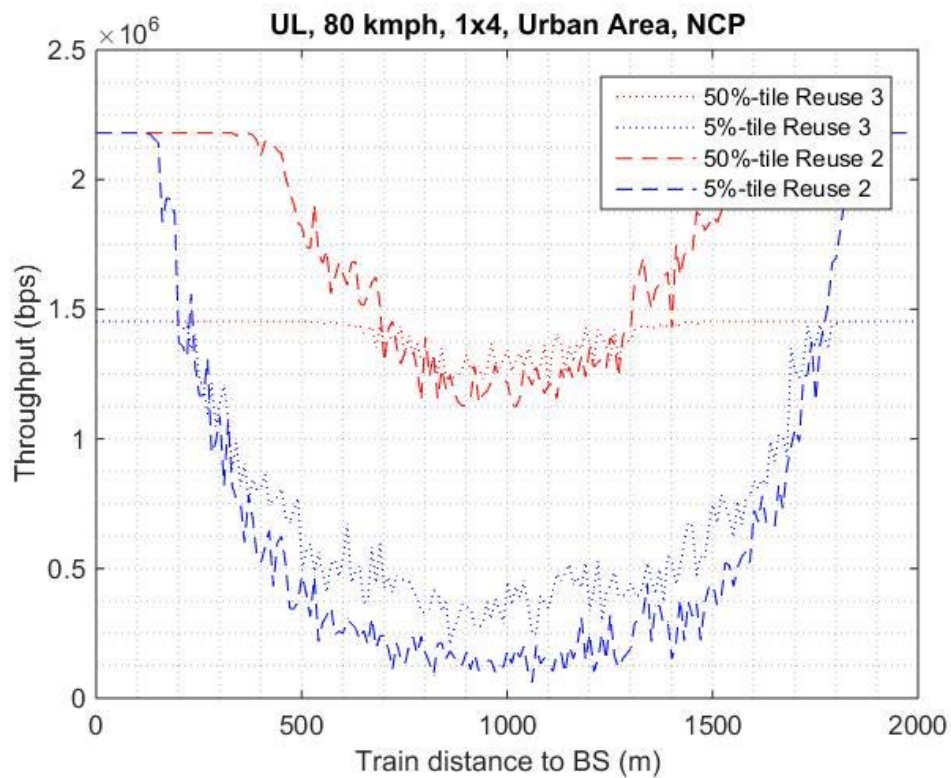


Figure B.18



## B.2 Second round of simulations

### Results at 1,4 MHz

#### High speed scenario

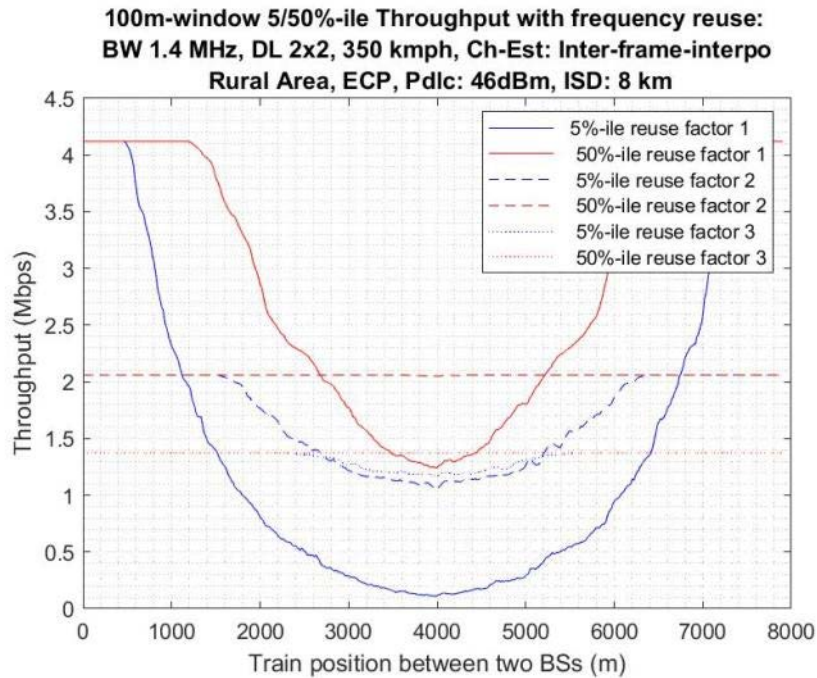


Figure B.19

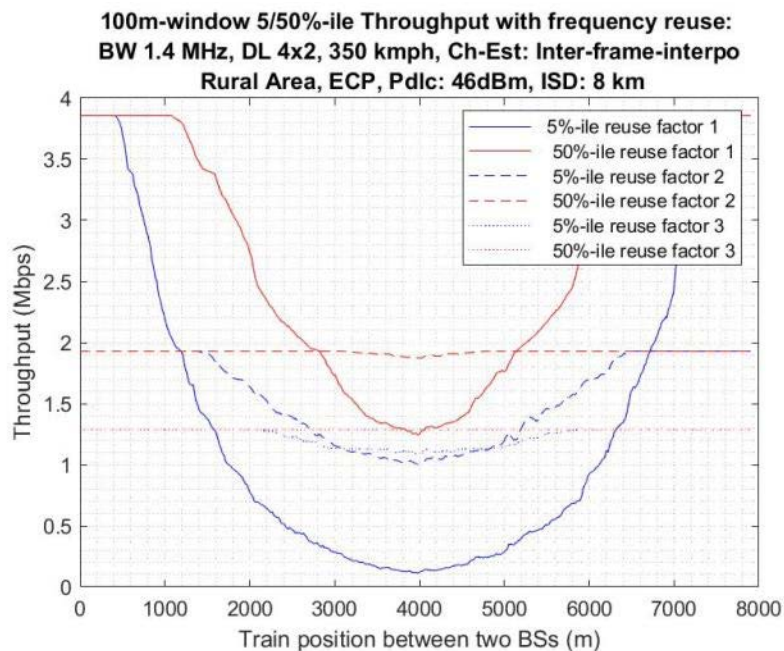


Figure B.20



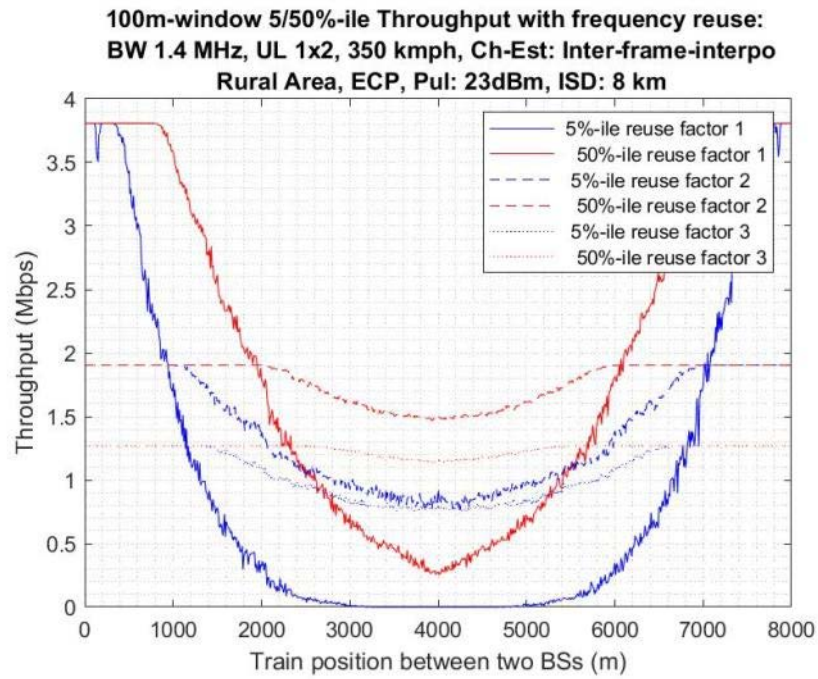


Figure B.21

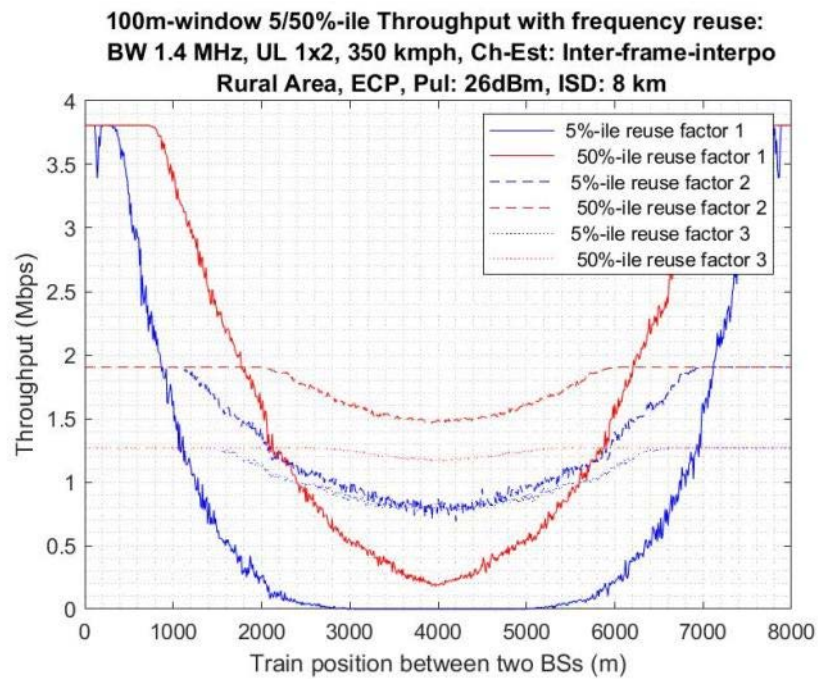


Figure B.22

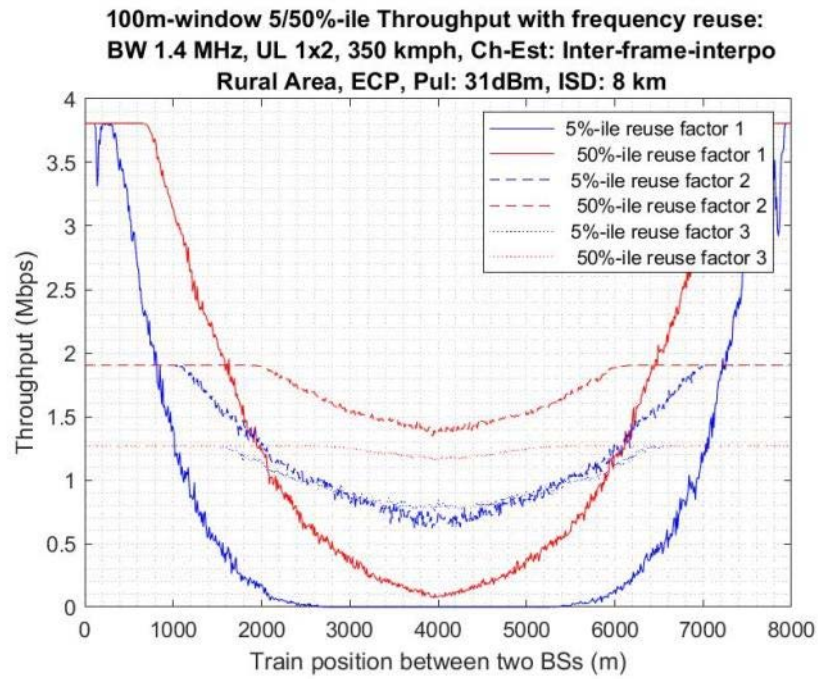


Figure B.23

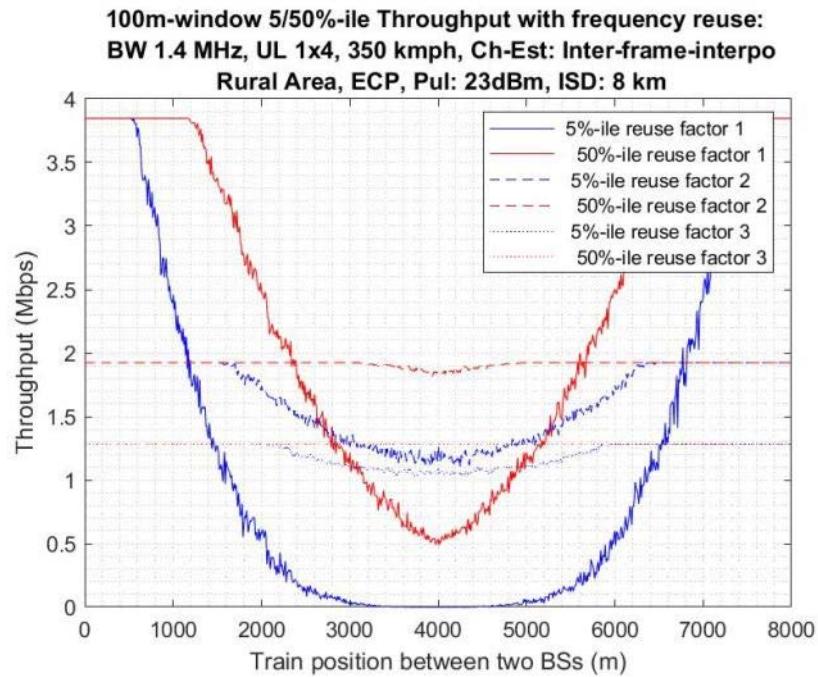


Figure B.24

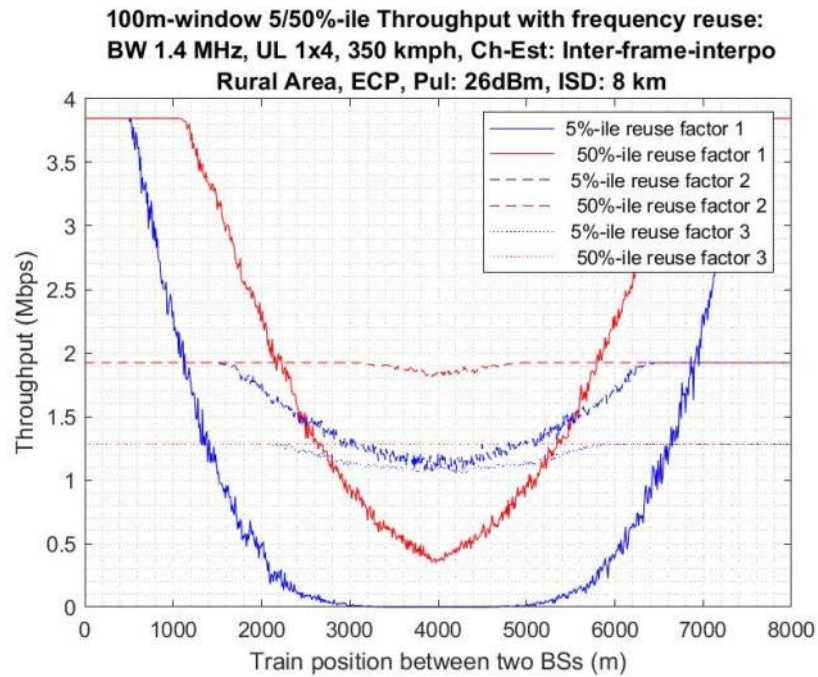


Figure B.25

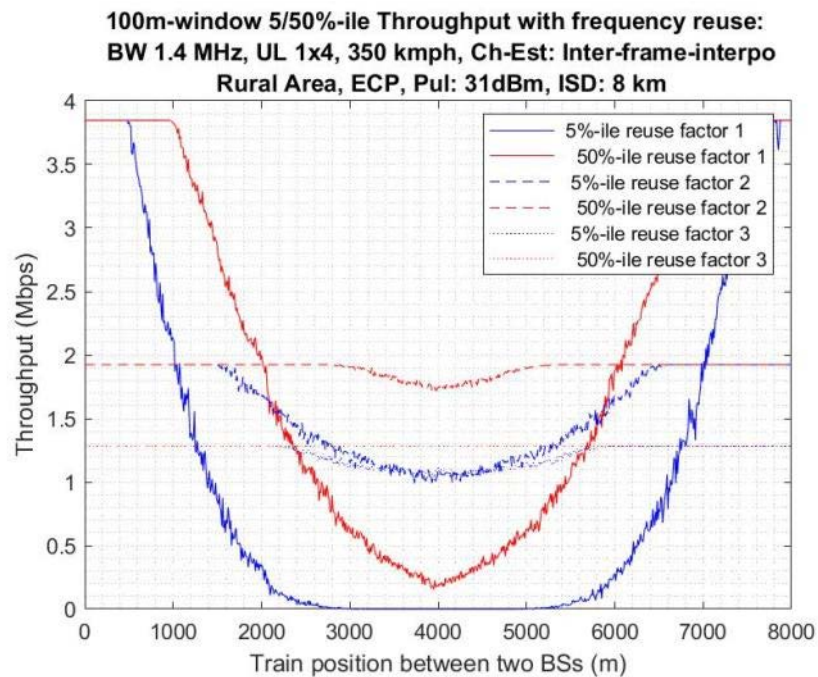


Figure B.26



## Hilly scenario

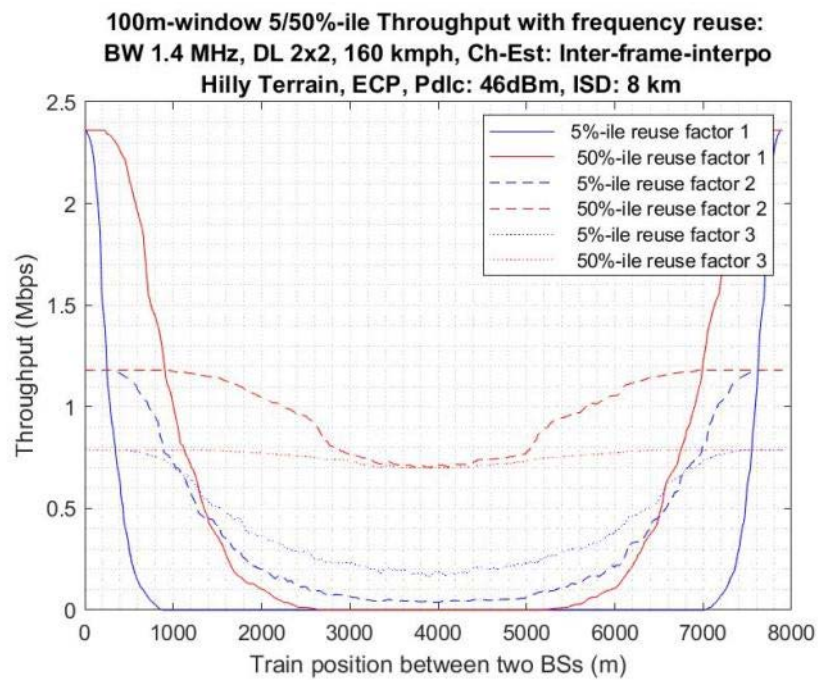


Figure B.27

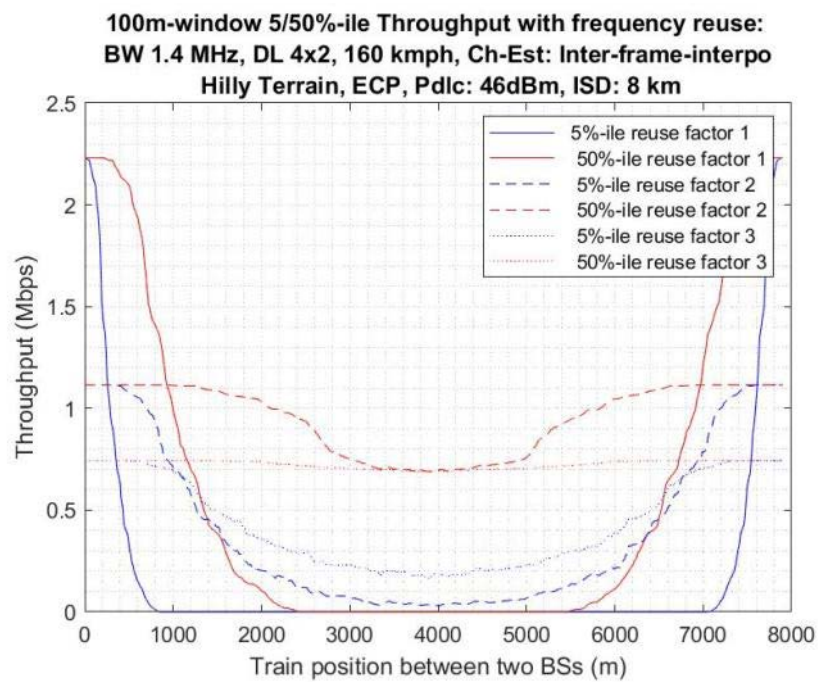


Figure B.28

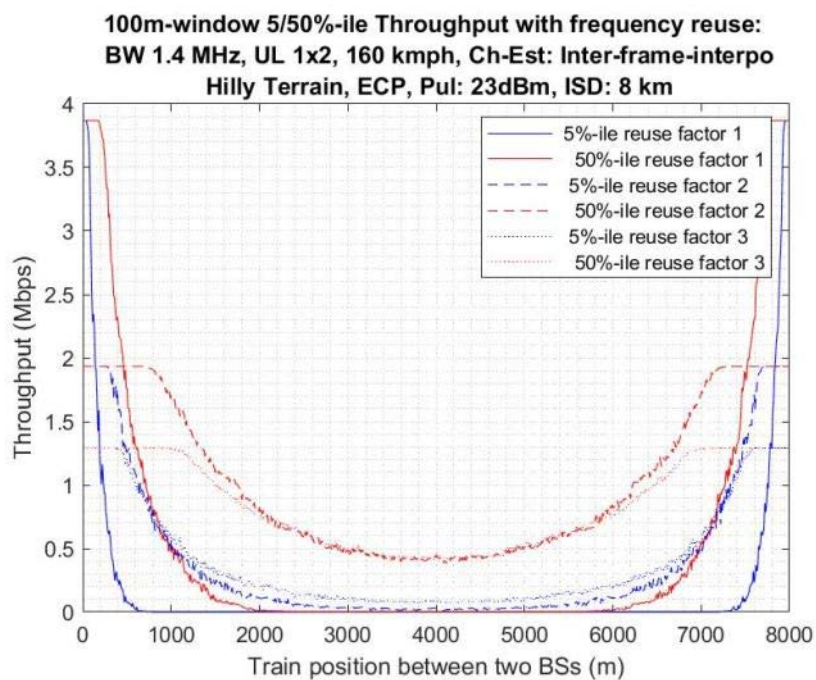


Figure B.29

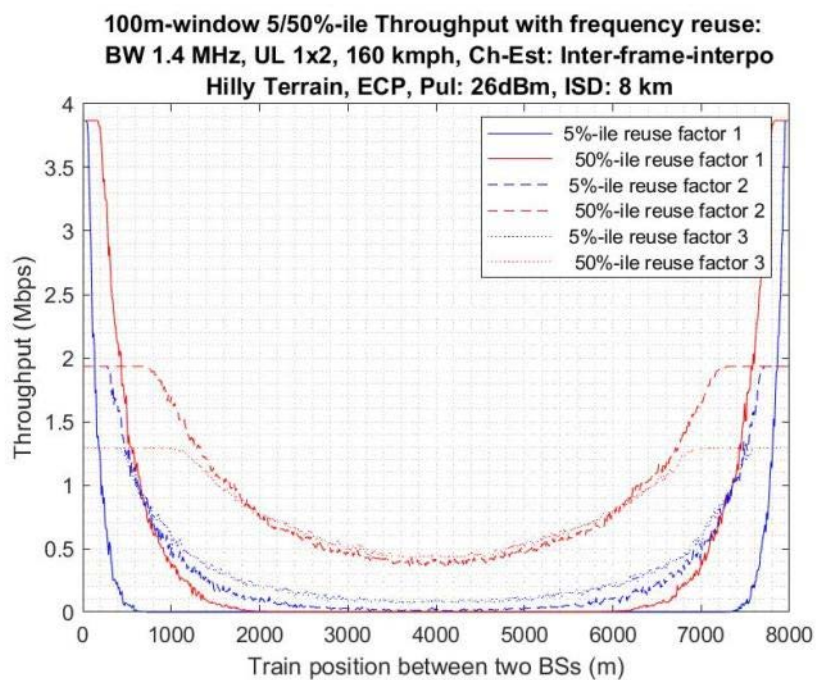


Figure B.30

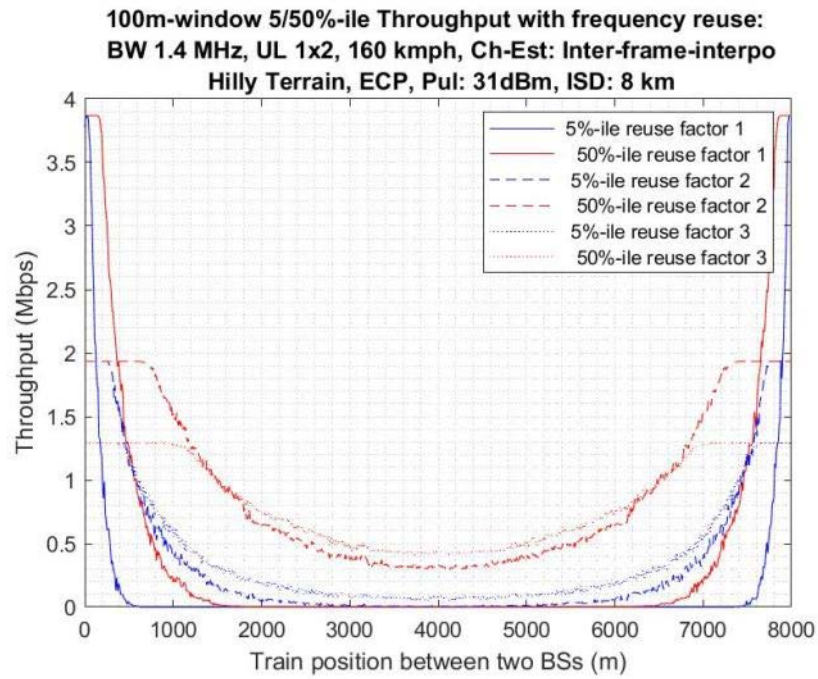


Figure B.31

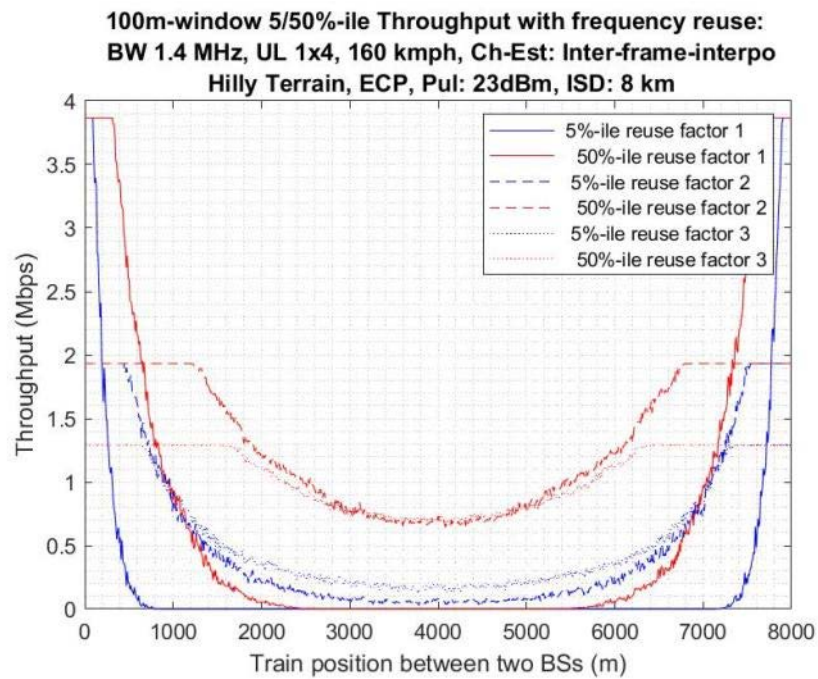


Figure B.32



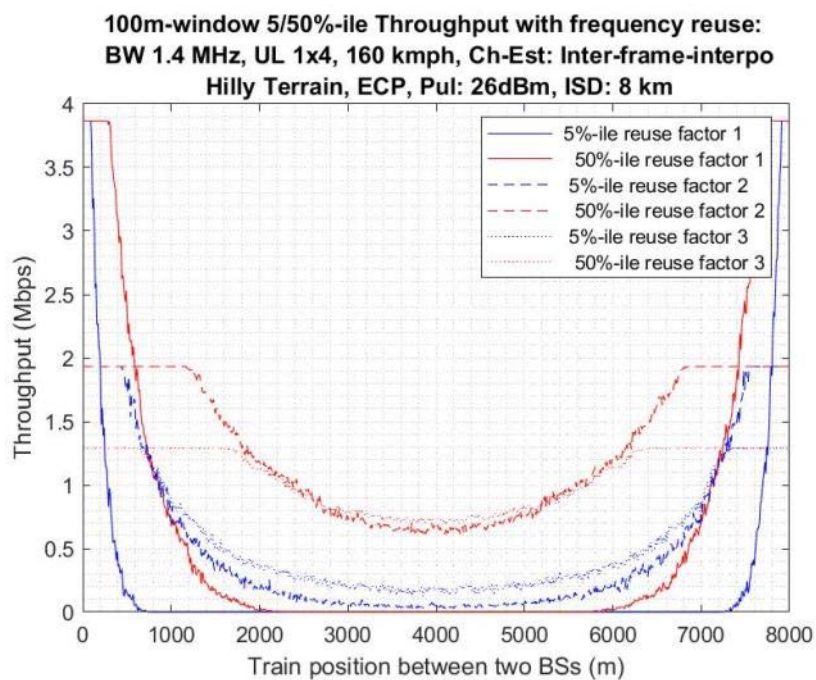


Figure B.33

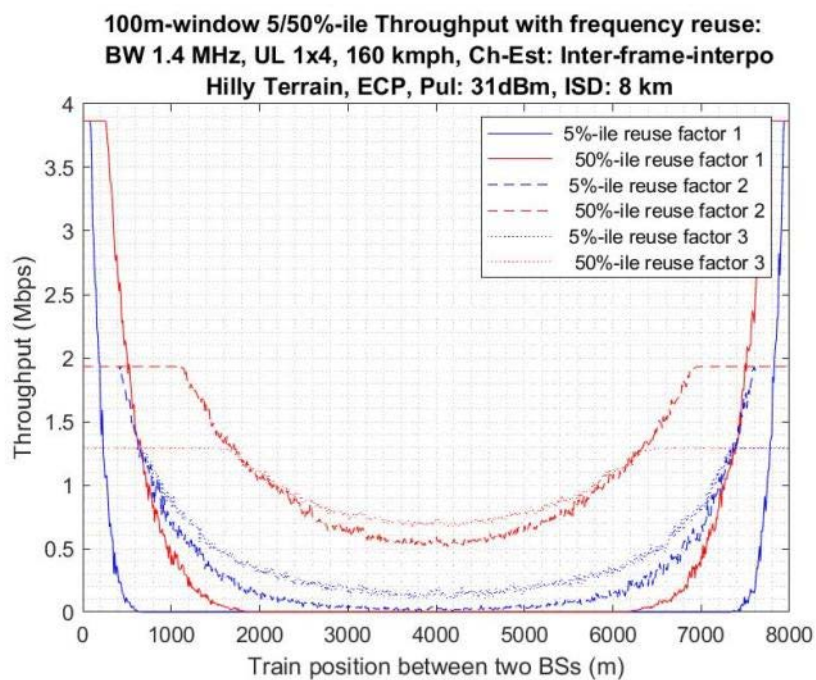


Figure B.34

## Urban scenario

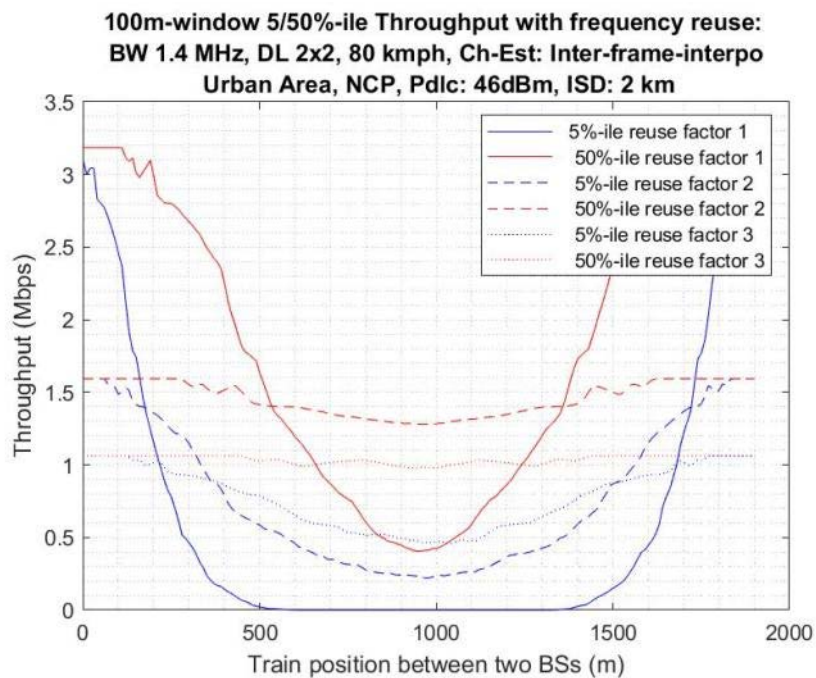


Figure B.35

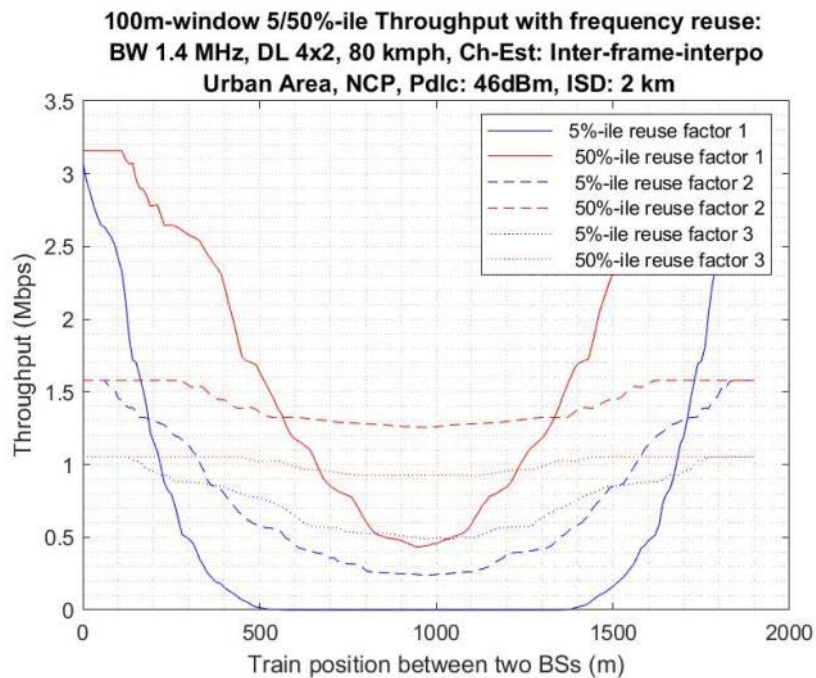


Figure B.36



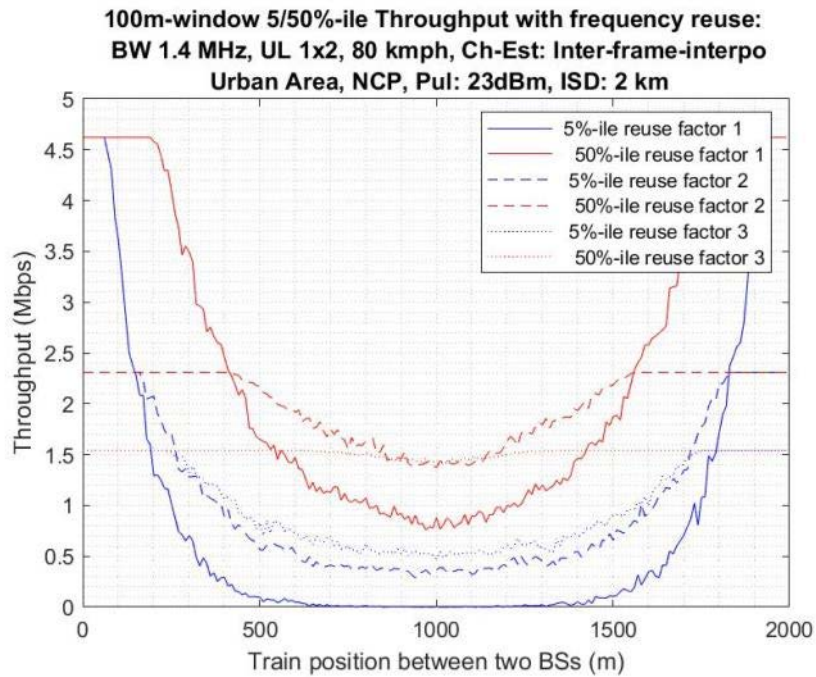


Figure B.37

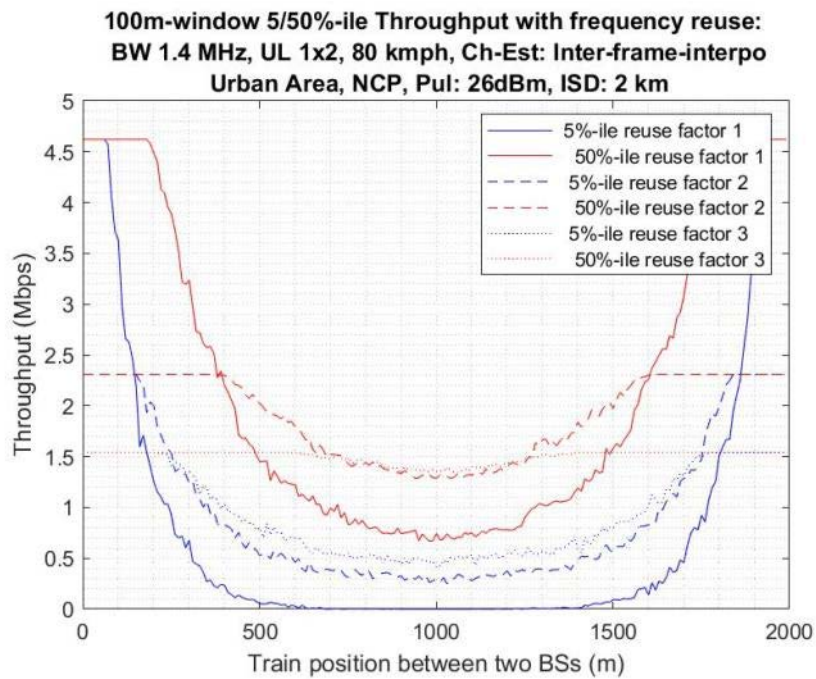


Figure B.38

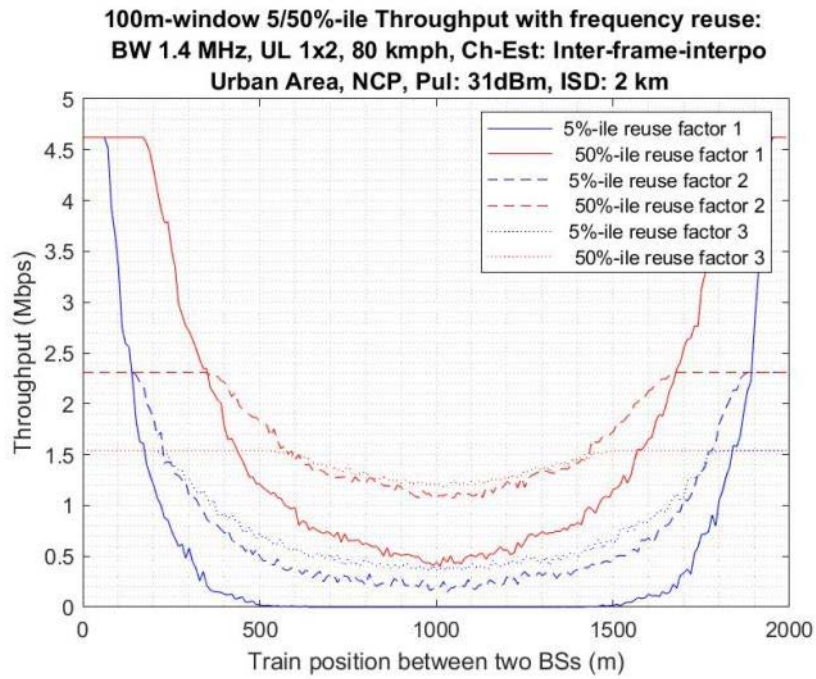


Figure B.39

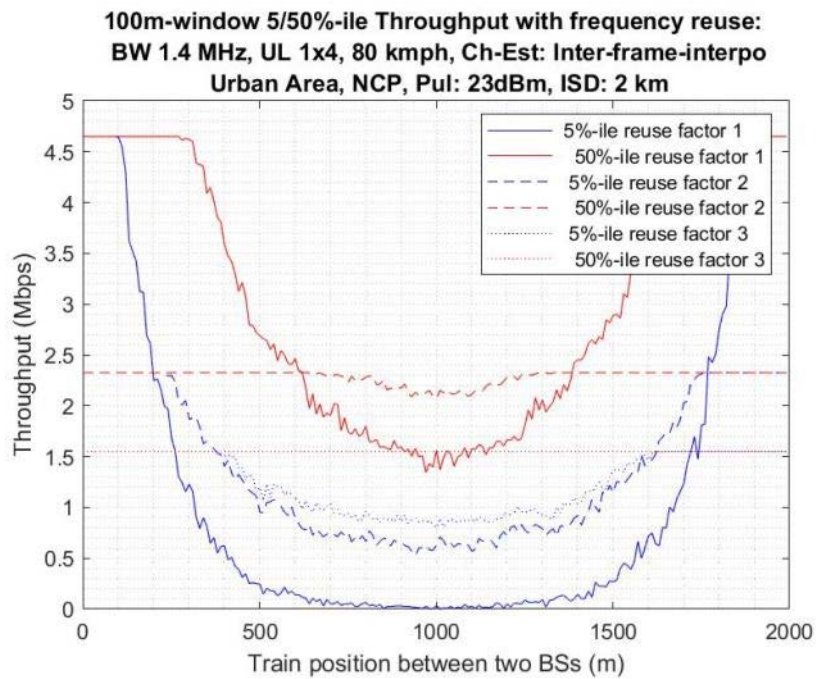


Figure B.40

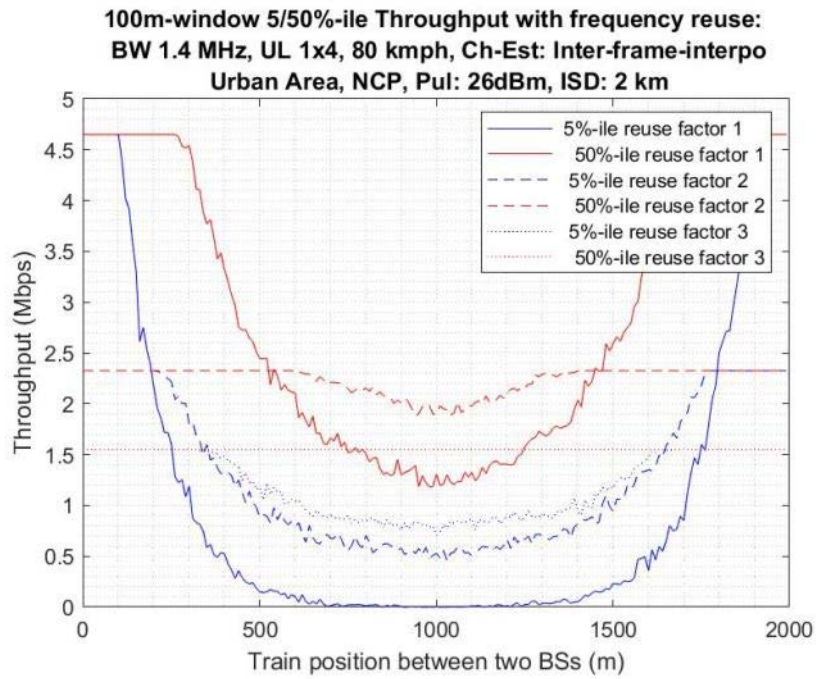


Figure B.41

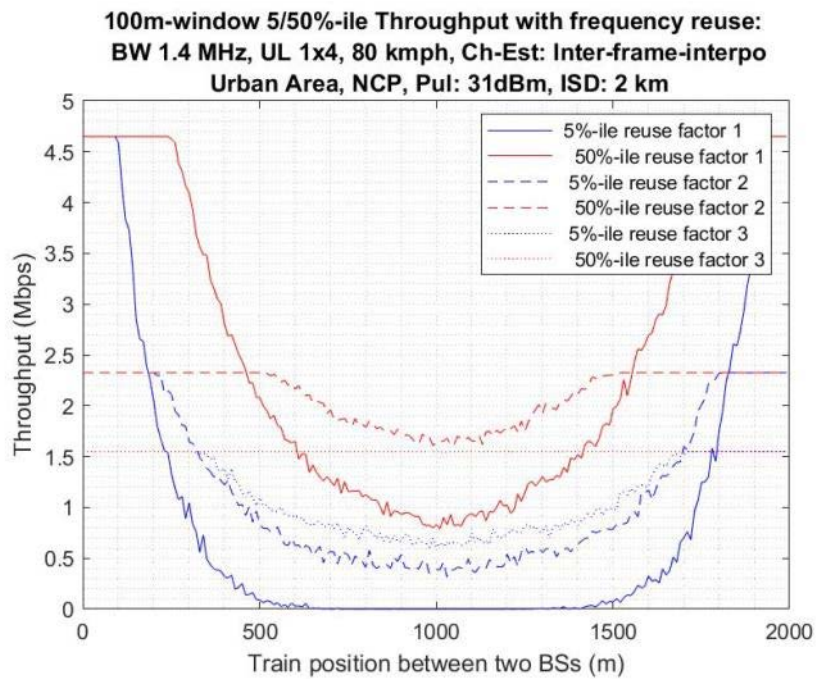


Figure B.42



## High density scenario

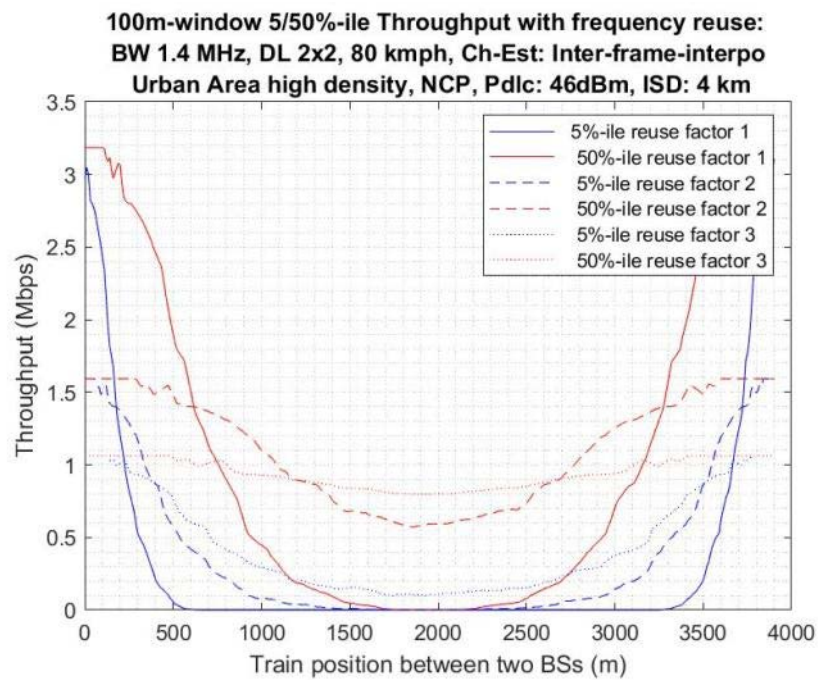


Figure B.43

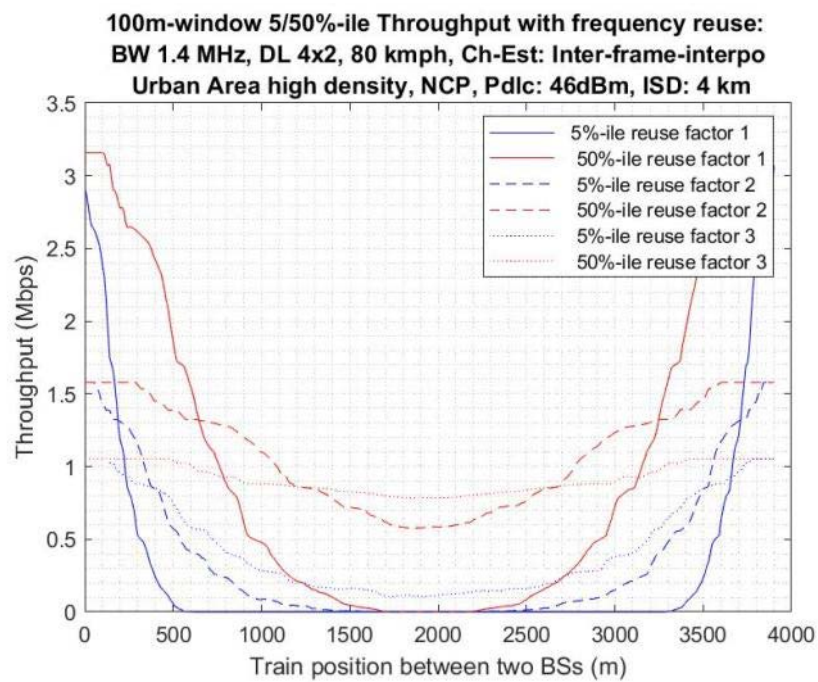


Figure B.44

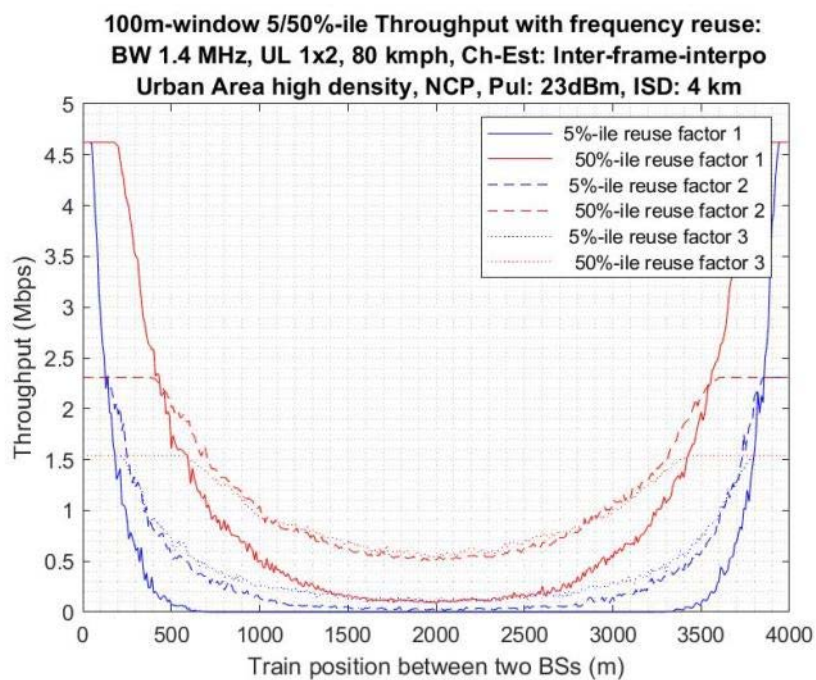


Figure B.45

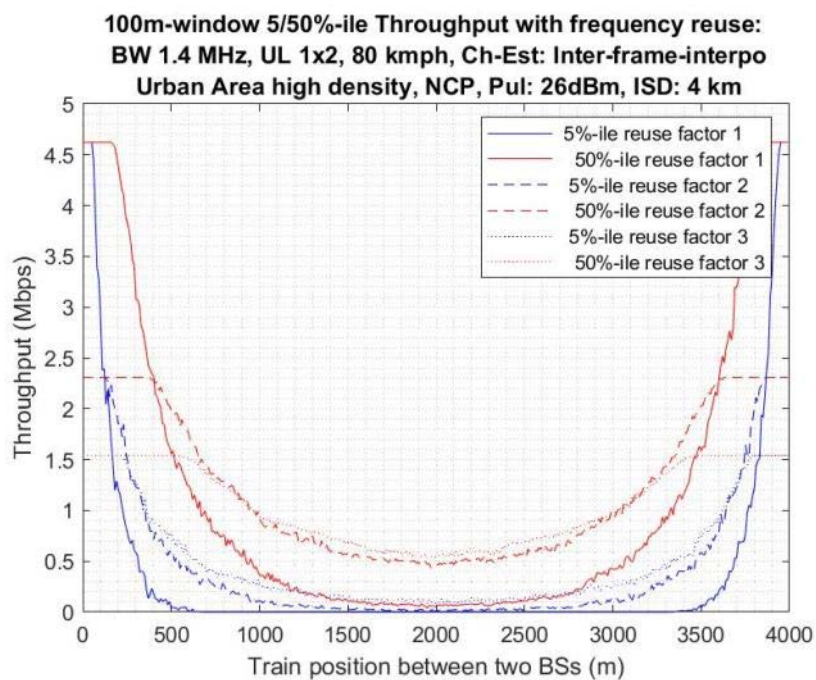


Figure B.46

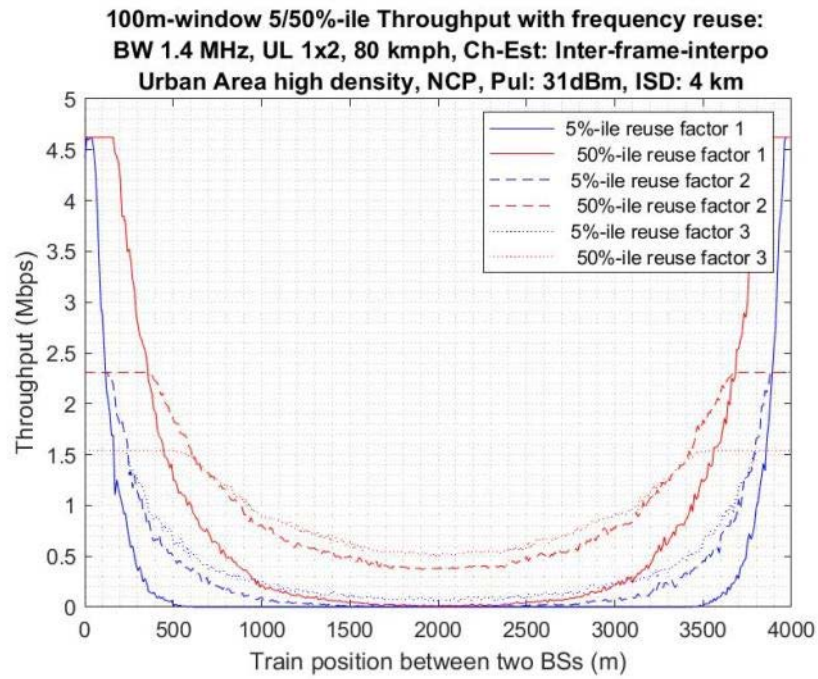


Figure B.47

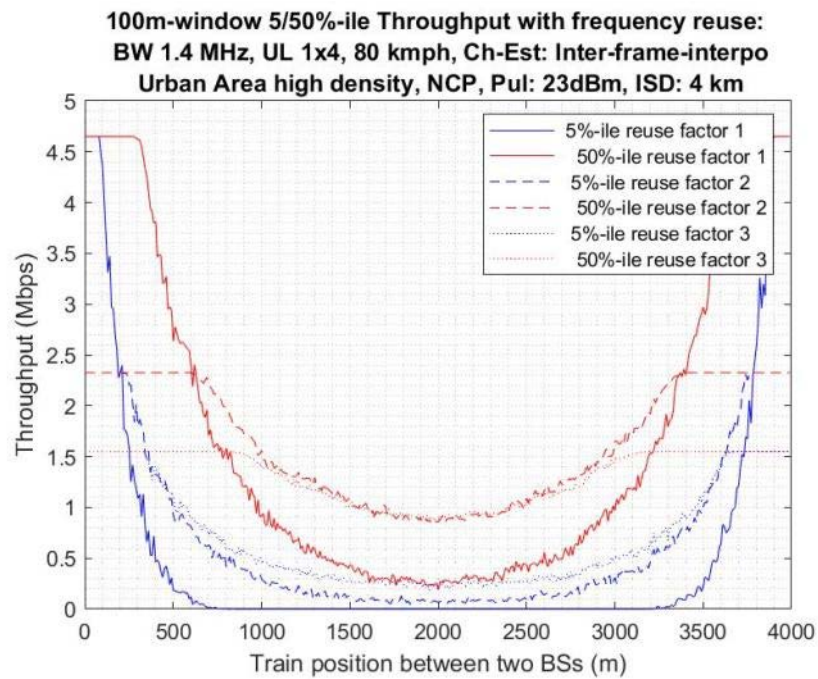


Figure B.48



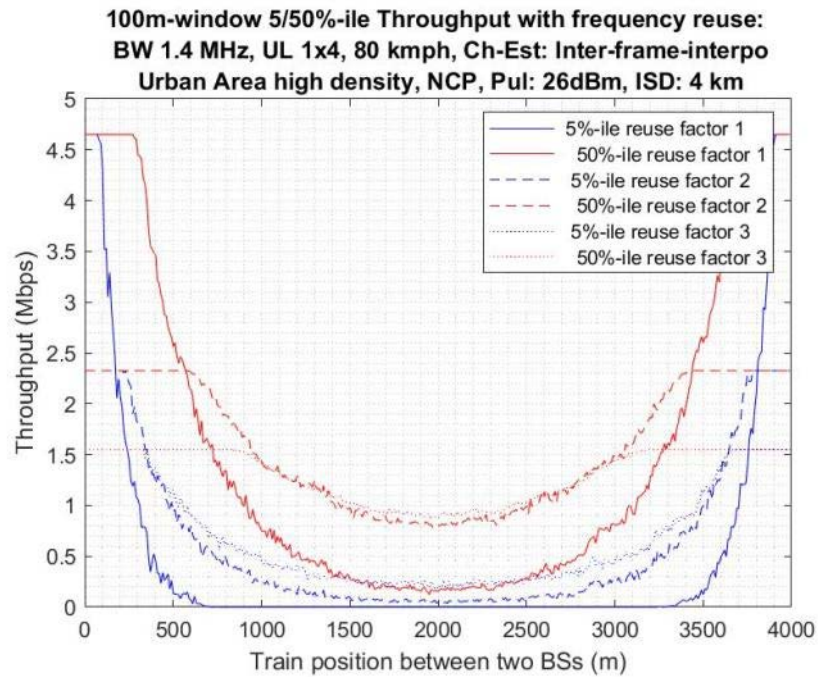


Figure B.49

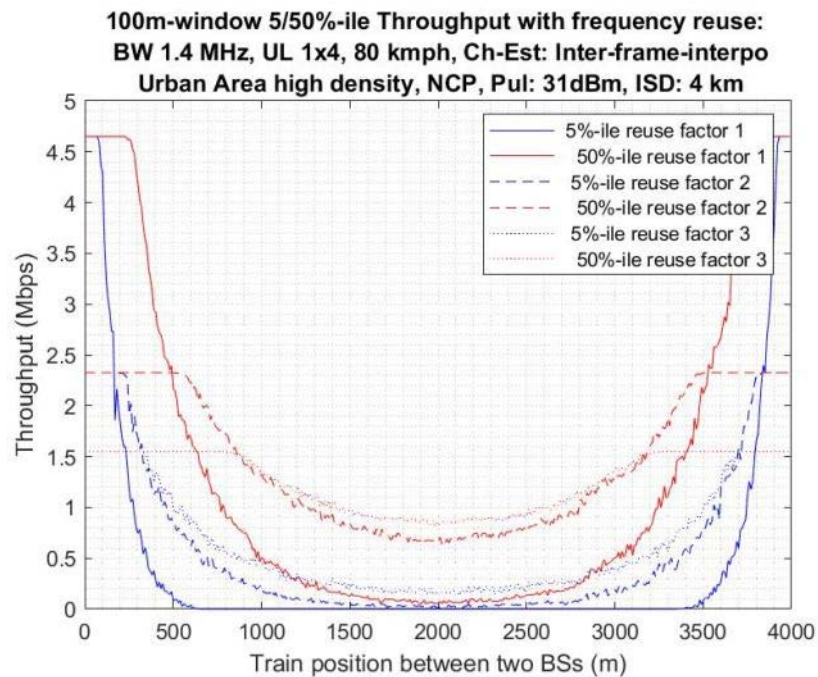


Figure B.50

## Results at 3 MHz

## High speed scenario

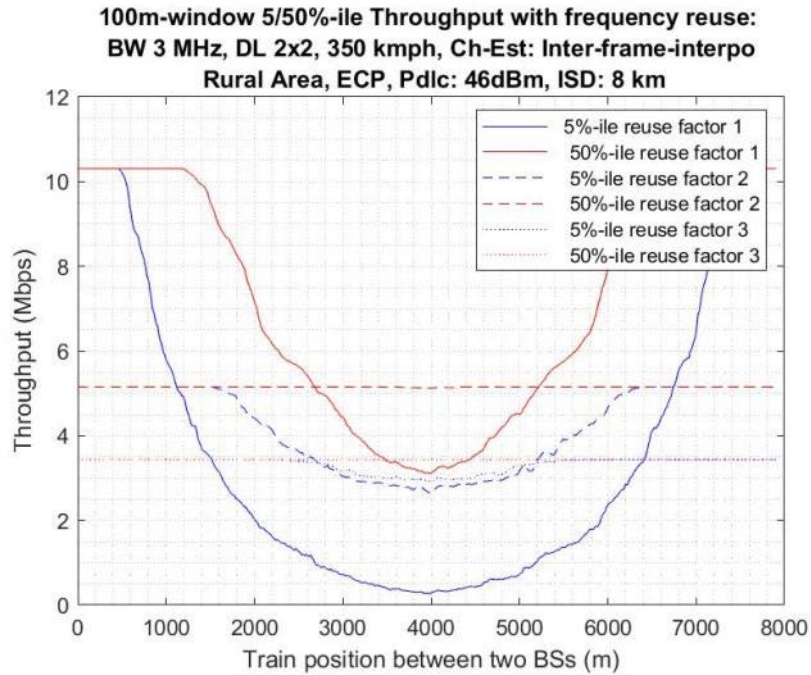


Figure B.51

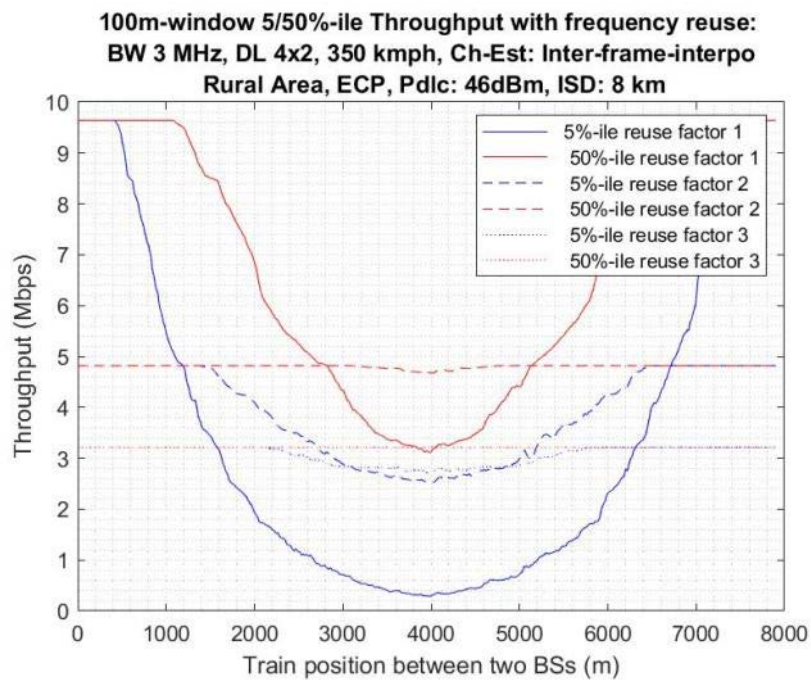


Figure B.52



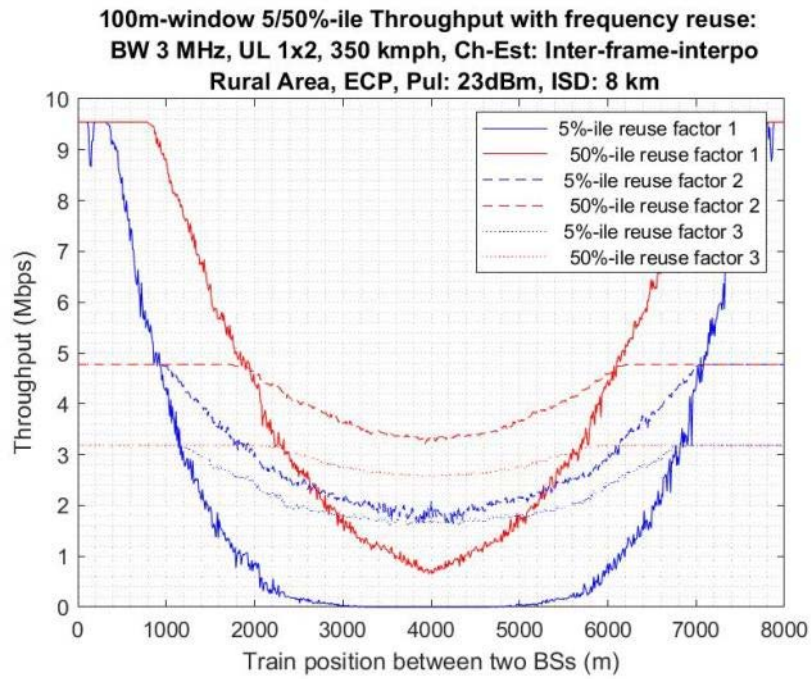


Figure B.53

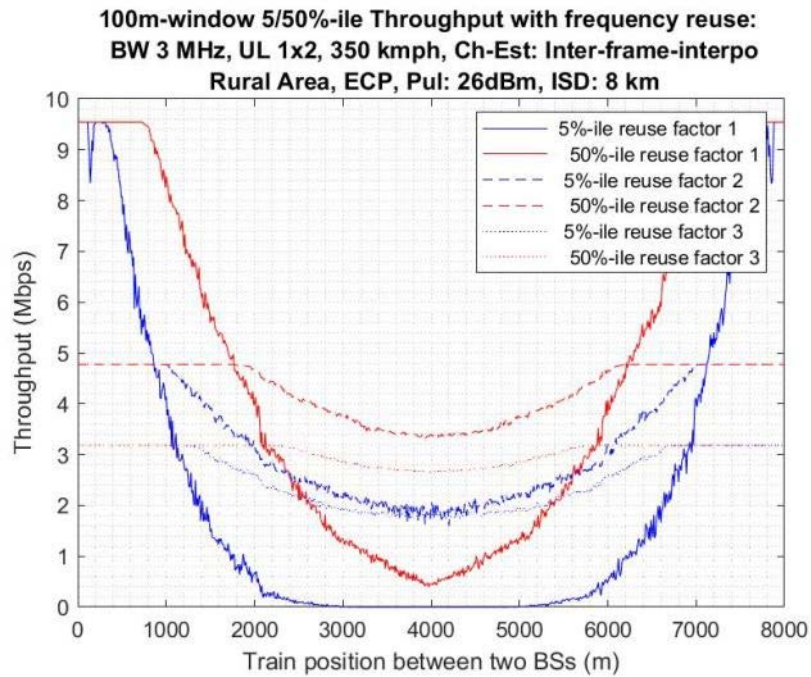


Figure B.54

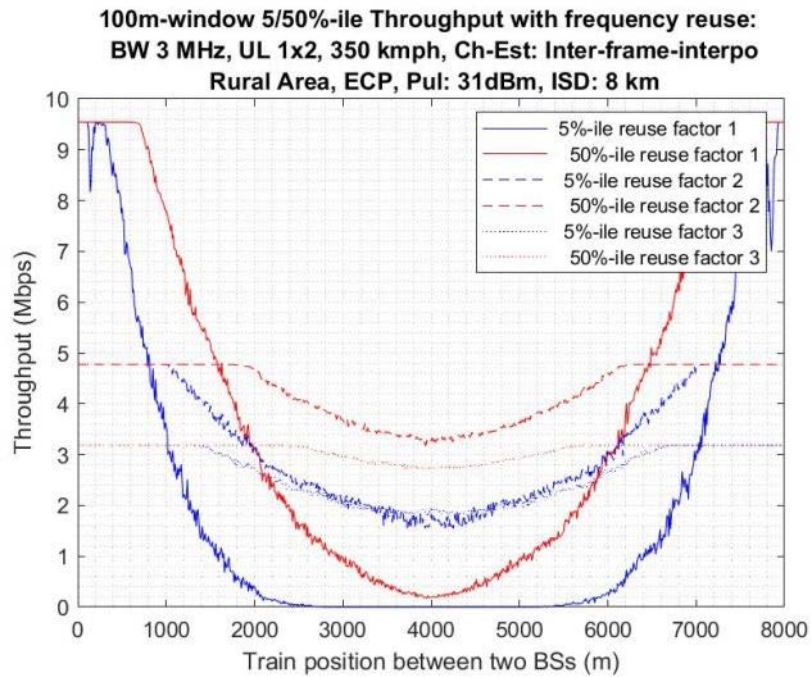


Figure B.55

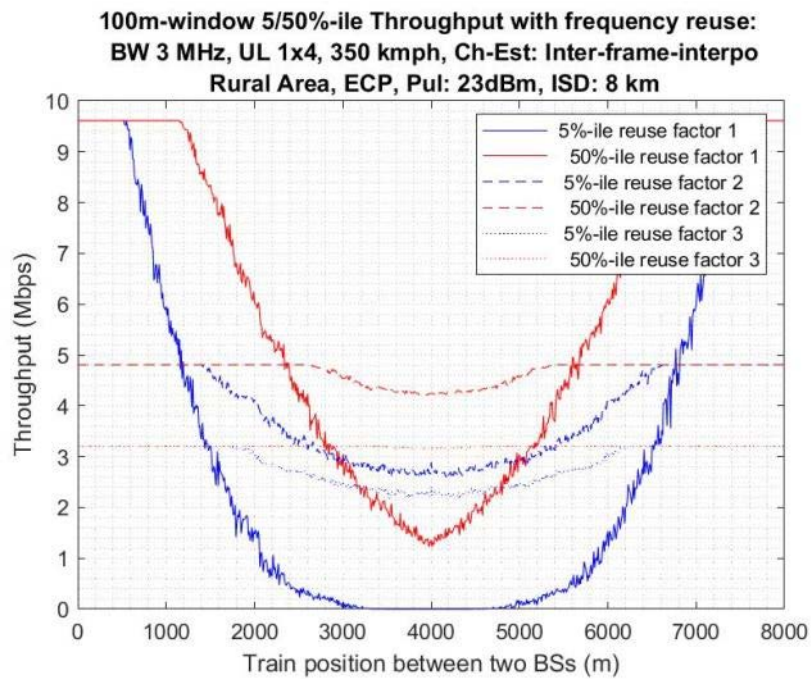


Figure B.56

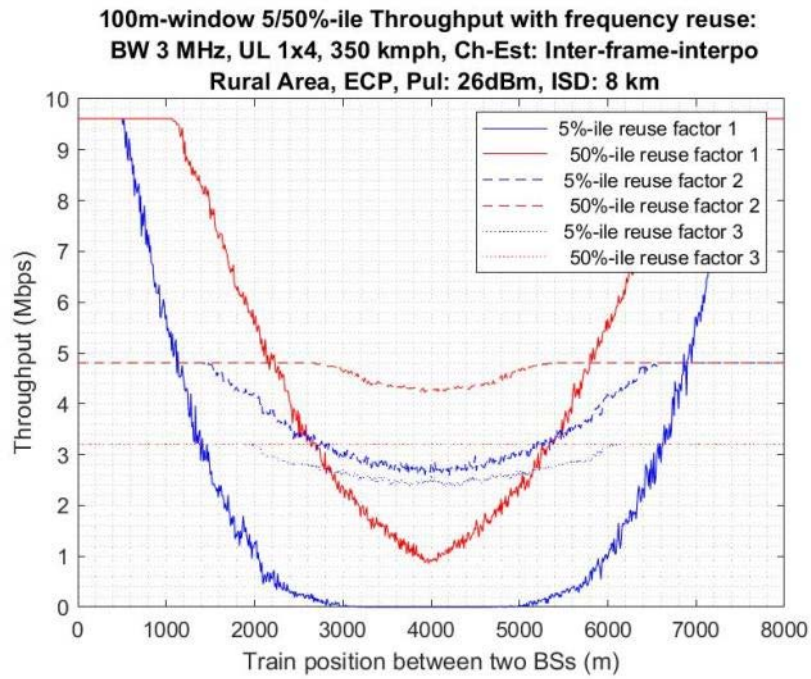


Figure B.57

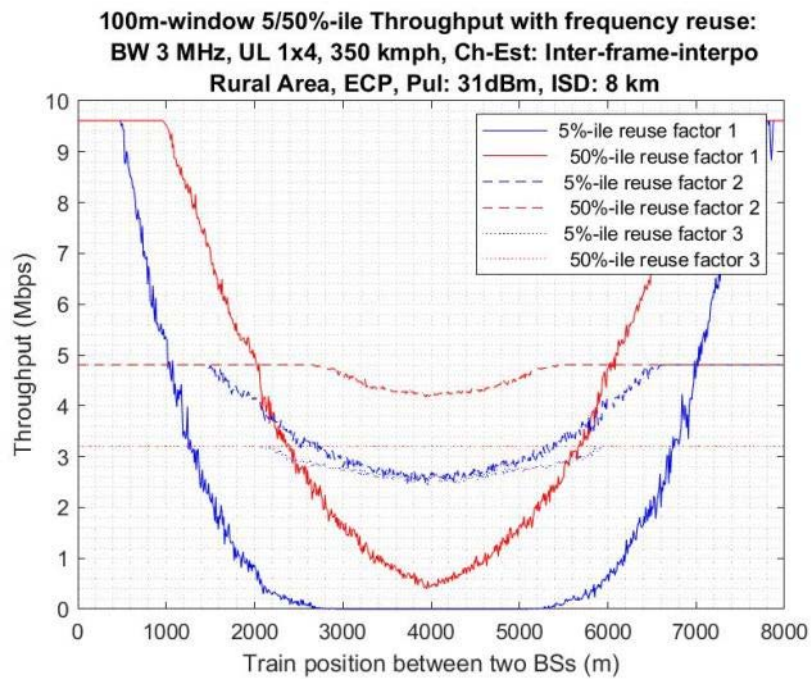


Figure B.58



## Hilly scenario

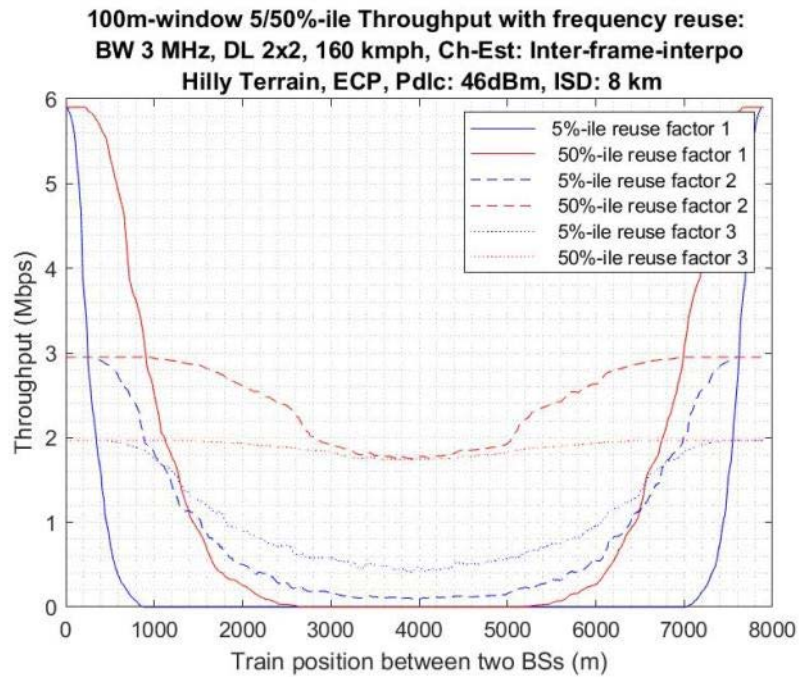


Figure B.59

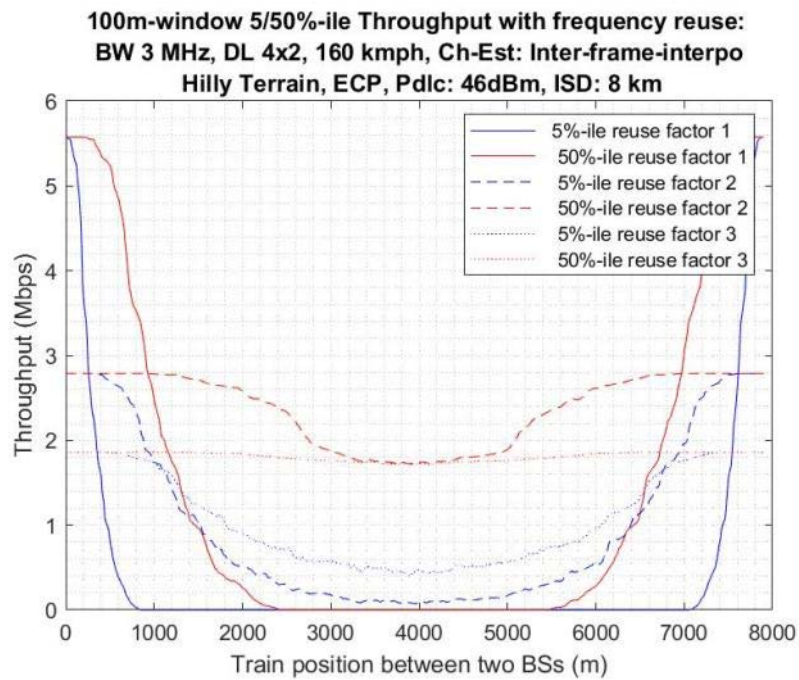


Figure B.60

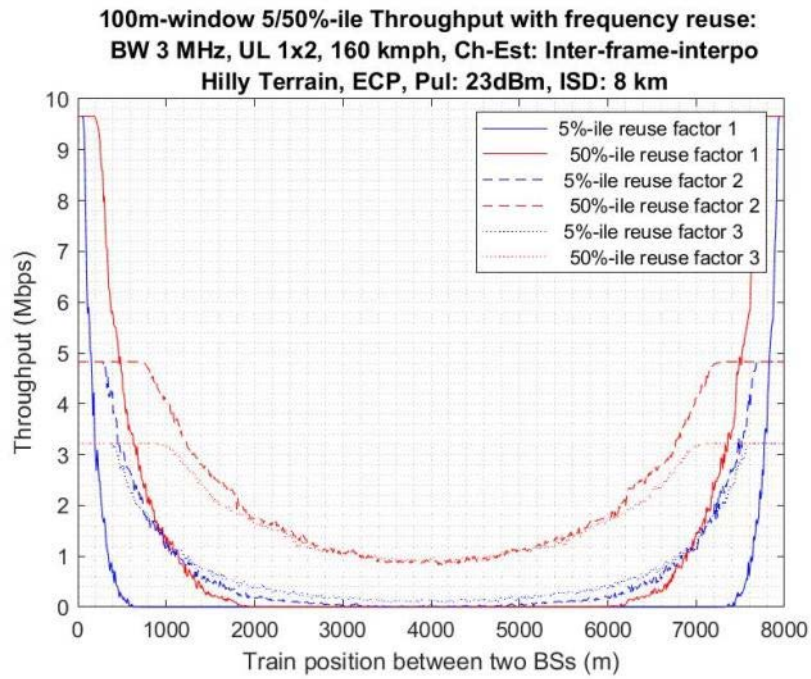


Figure B.61

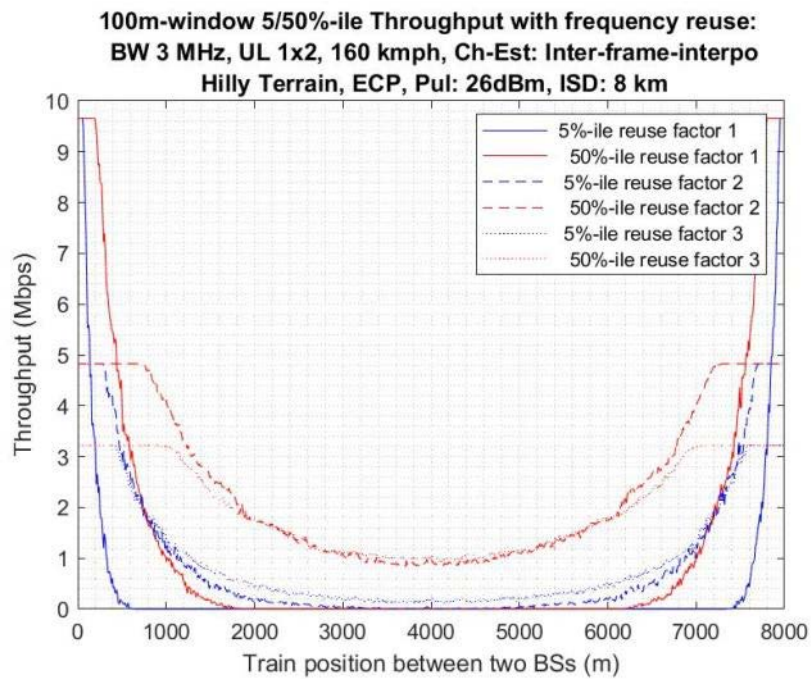


Figure B.62

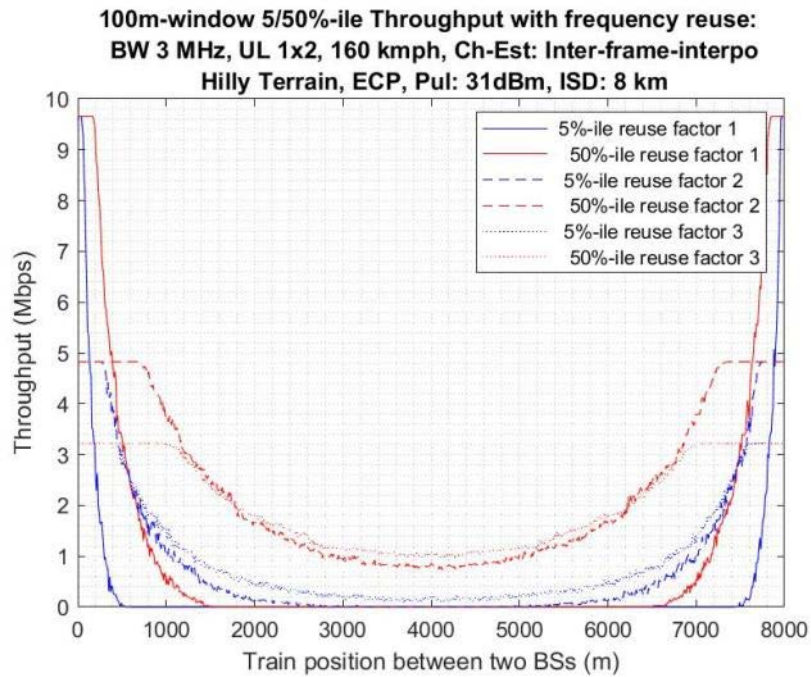


Figure B.63

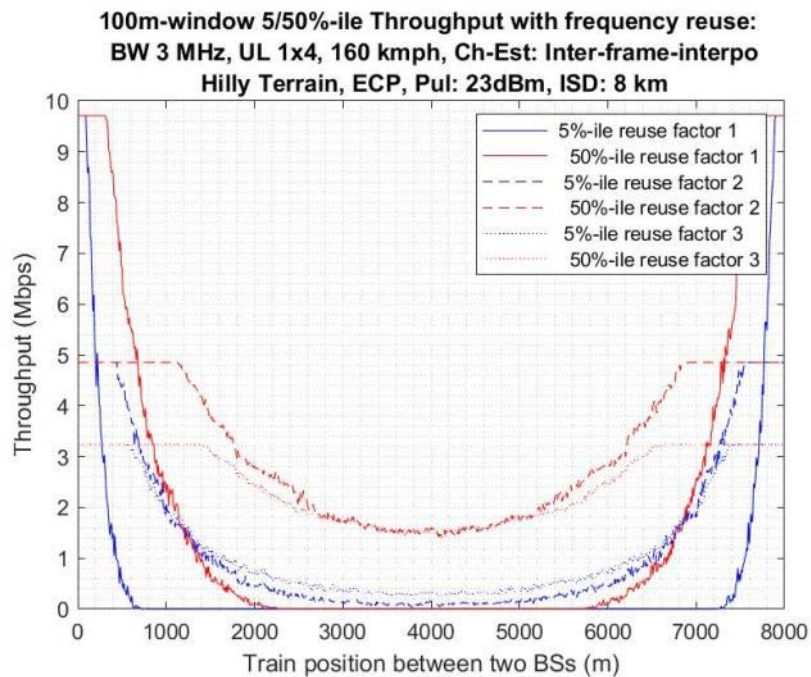


Figure B.64



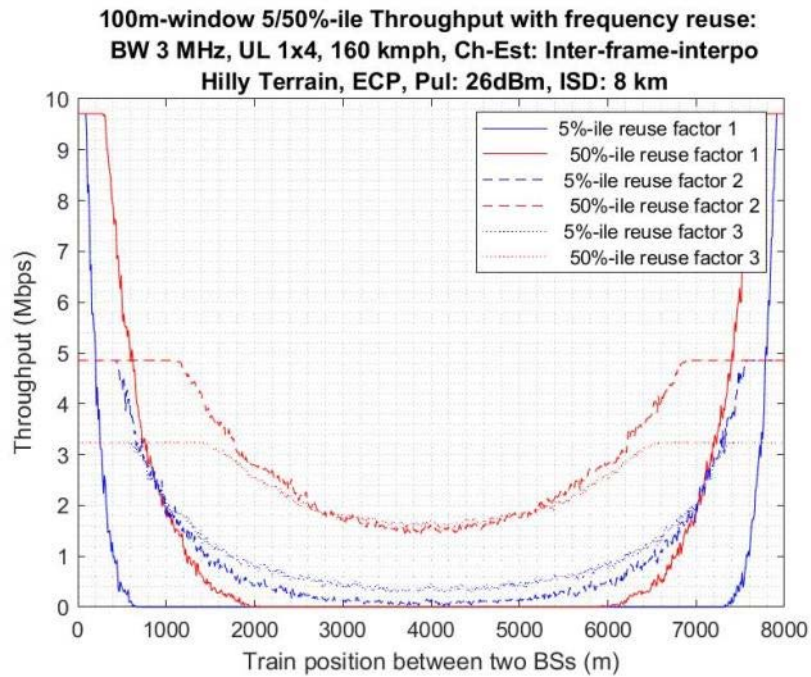


Figure B.65

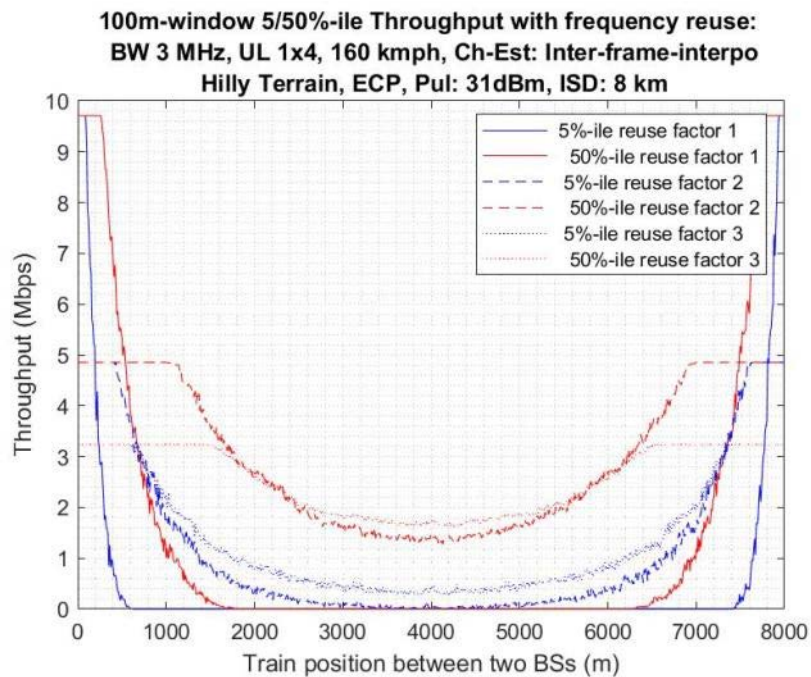


Figure B.66



## Urban scenario

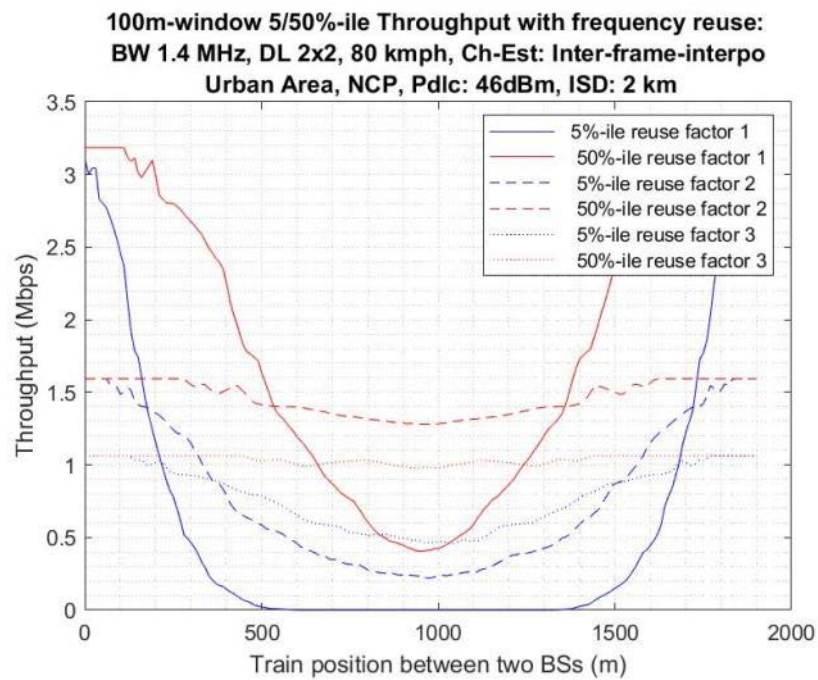


Figure B.67

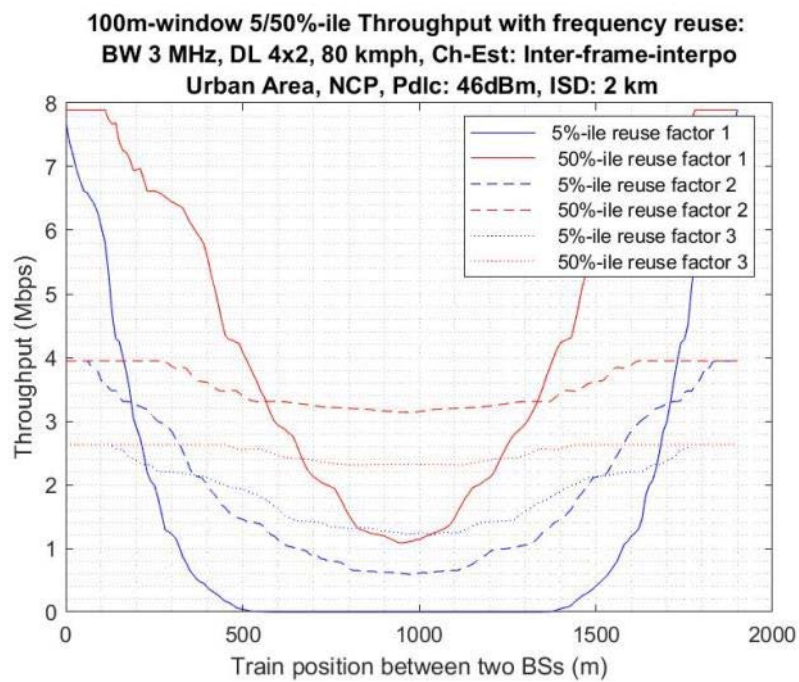


Figure B.68

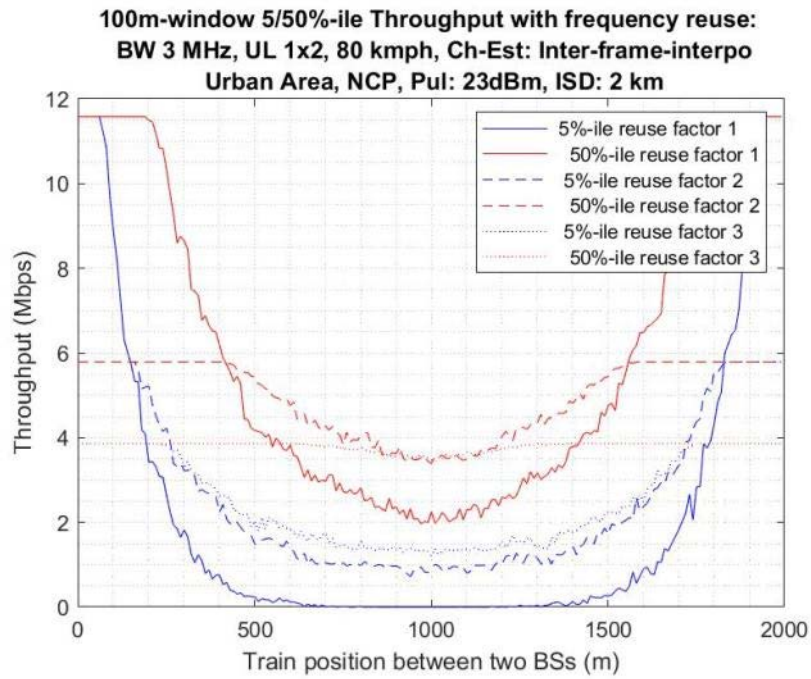


Figure B.69

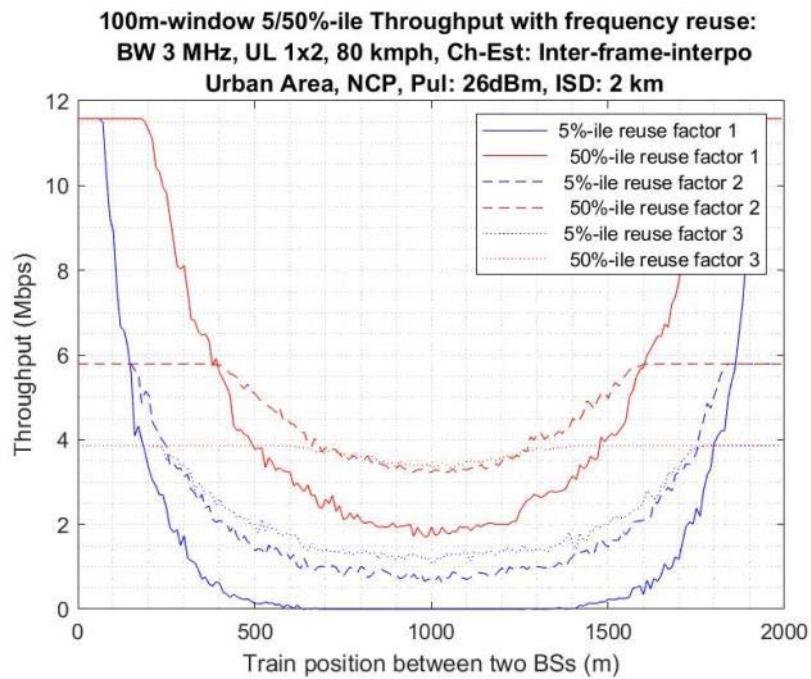


Figure B.70

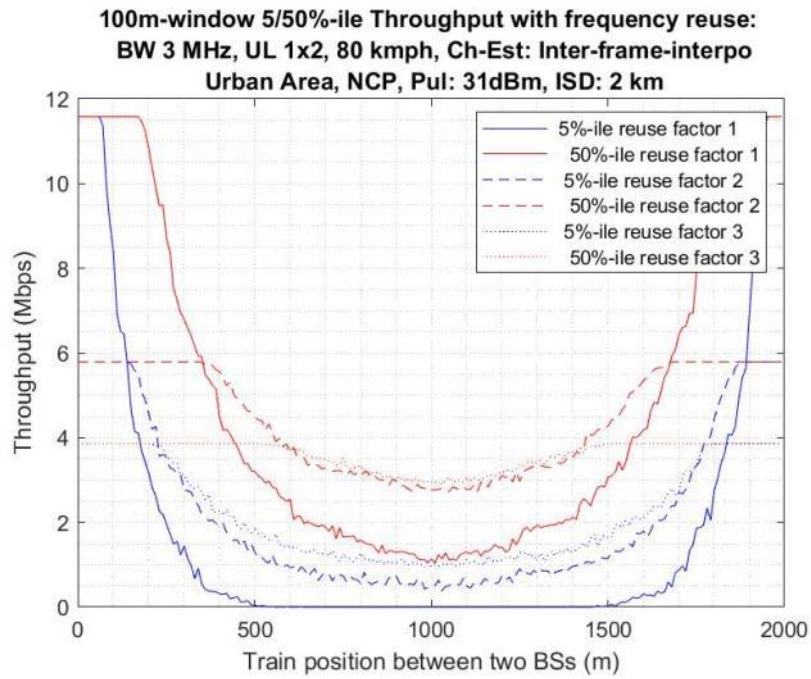


Figure B.71

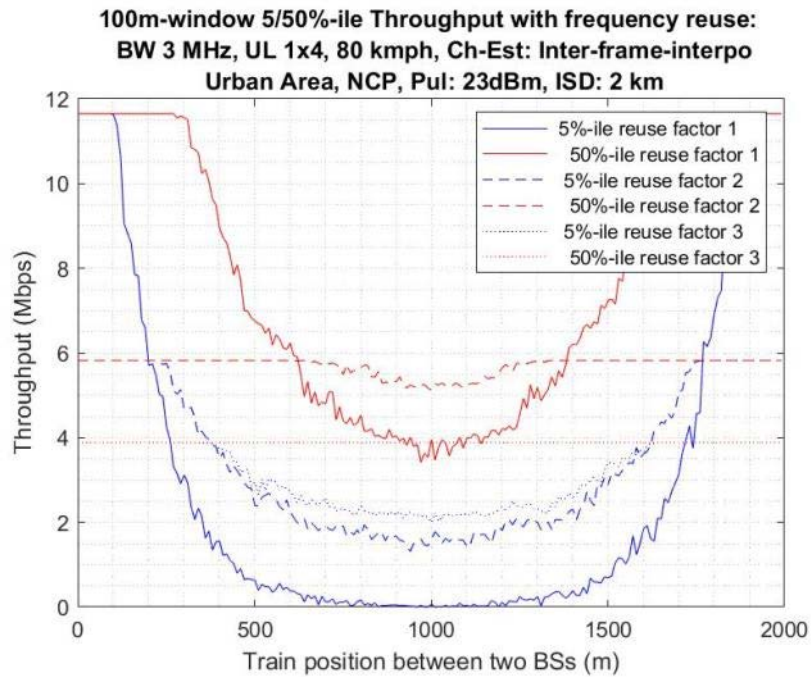


Figure B.72

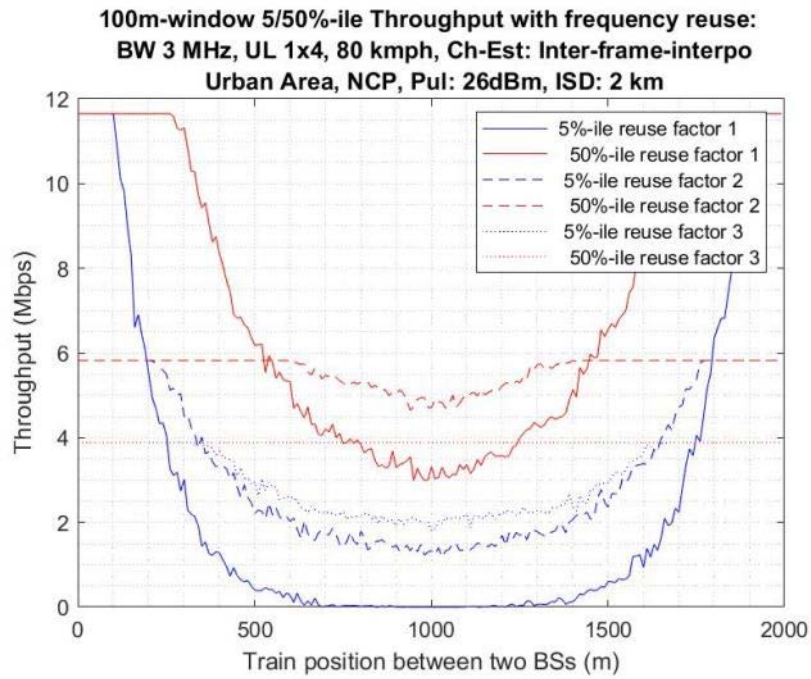


Figure B.73

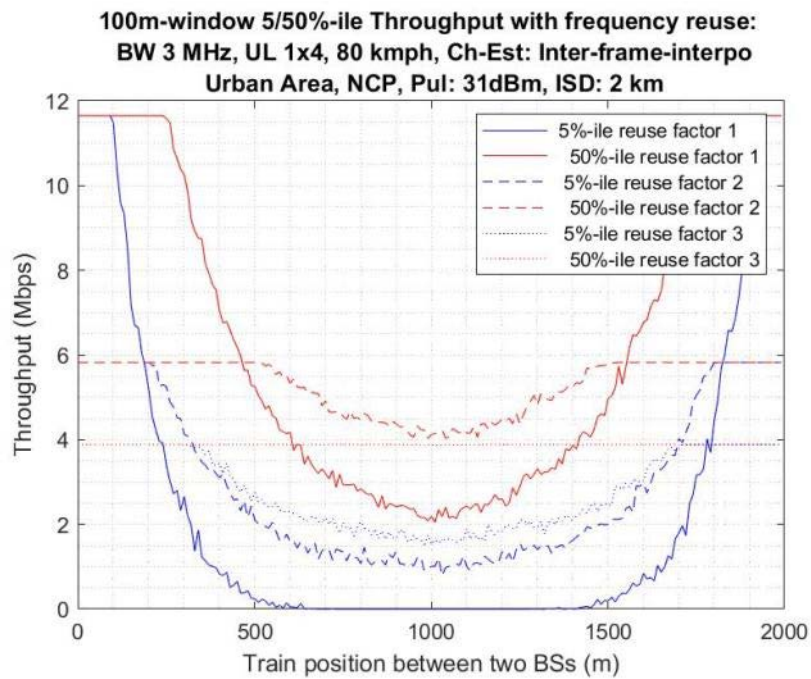


Figure B.74



High density scenario

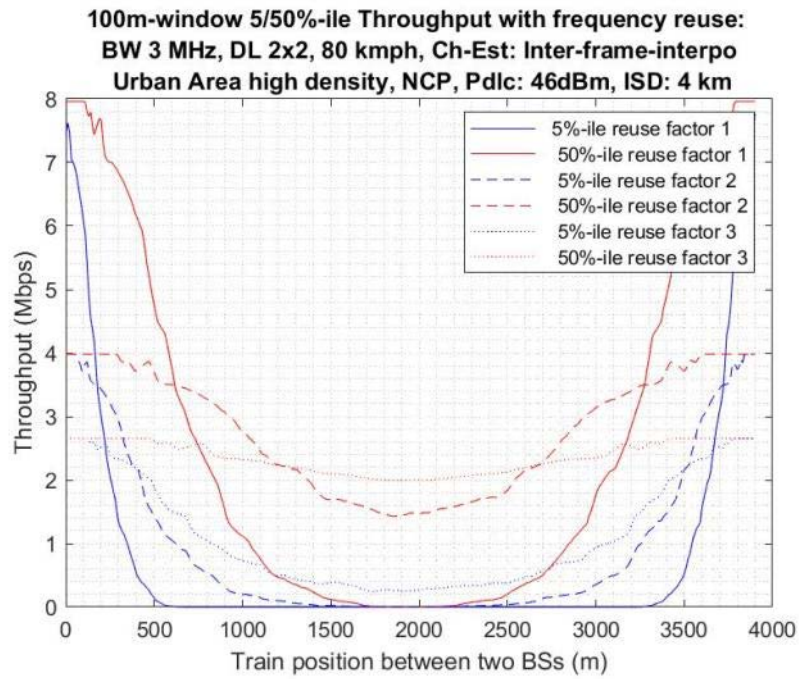


Figure B.75

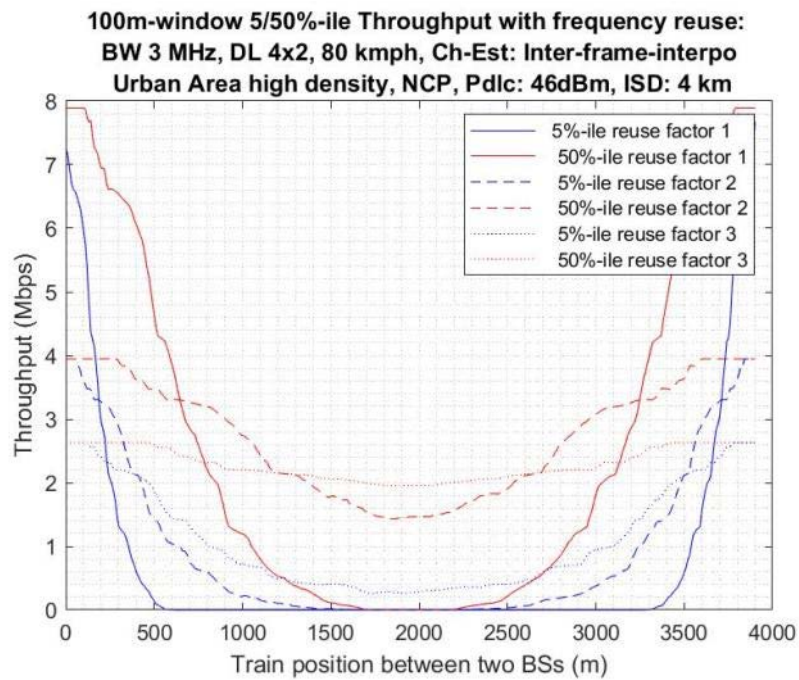


Figure B.76

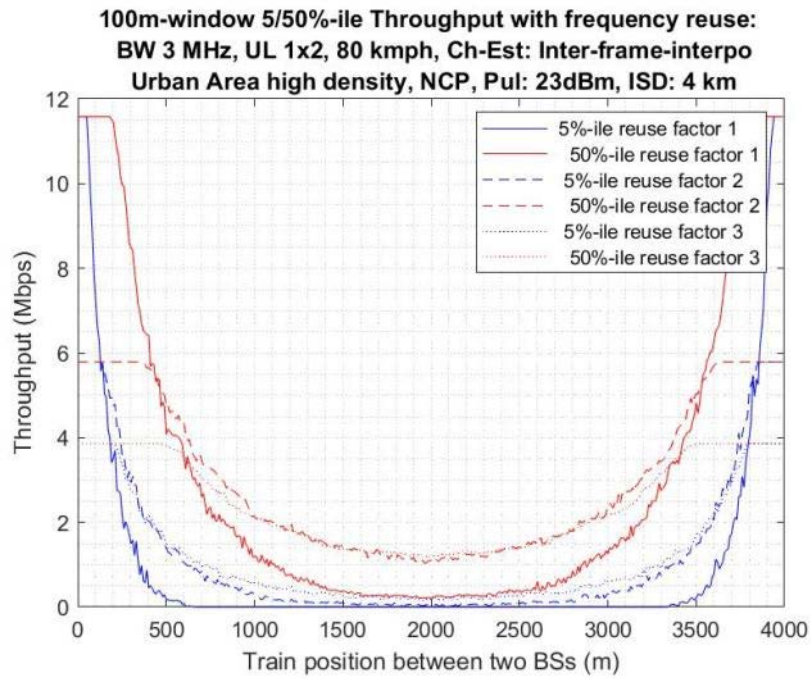


Figure B.77

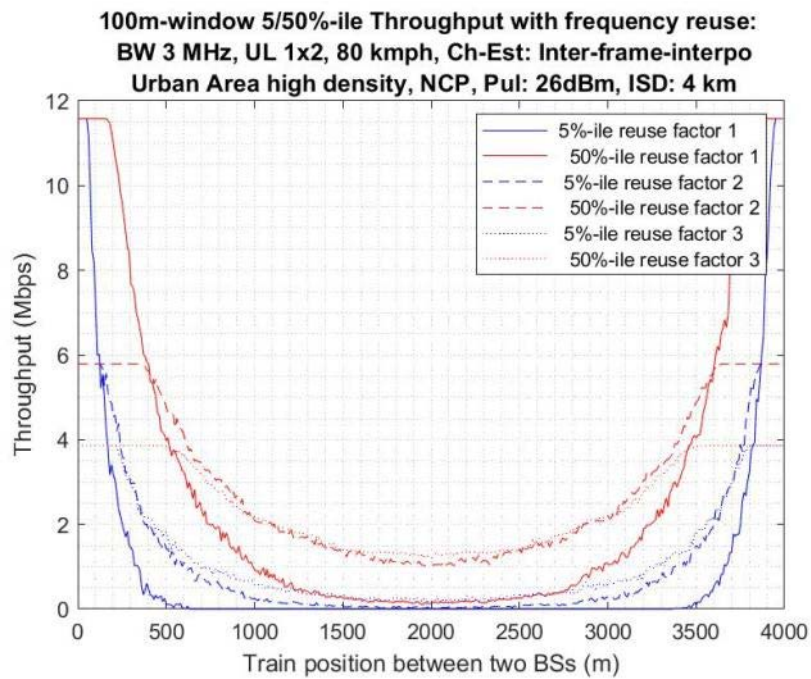


Figure B.78

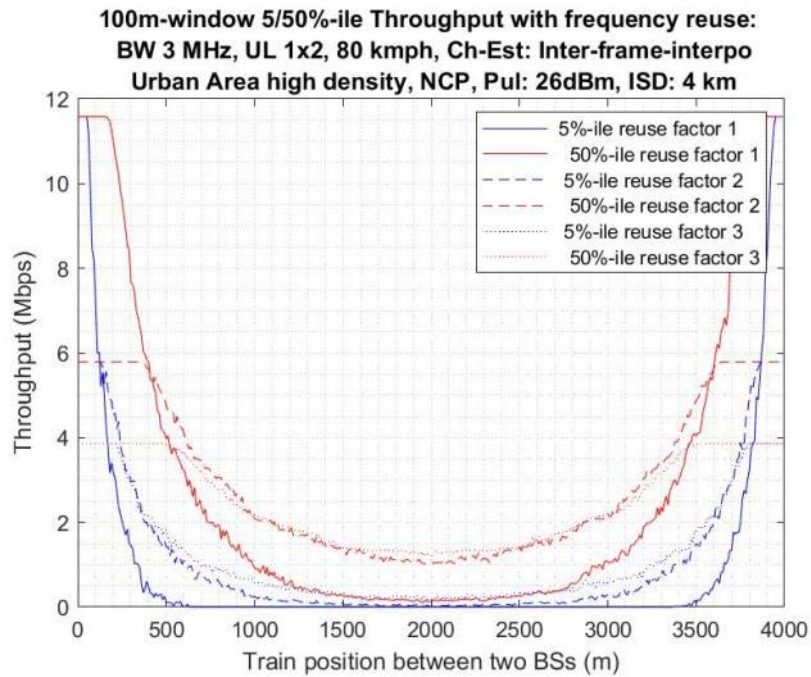


Figure B.79

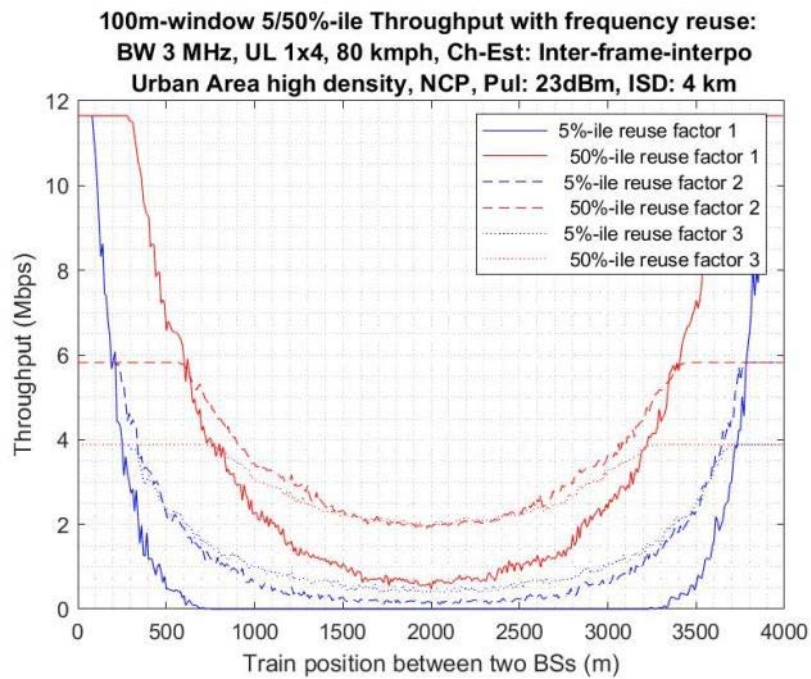


Figure B.80



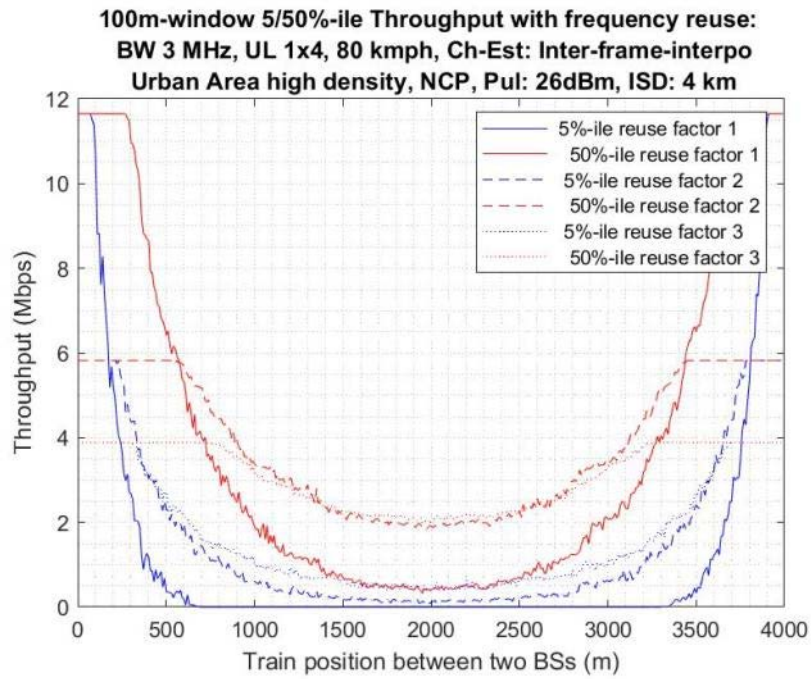


Figure B.81

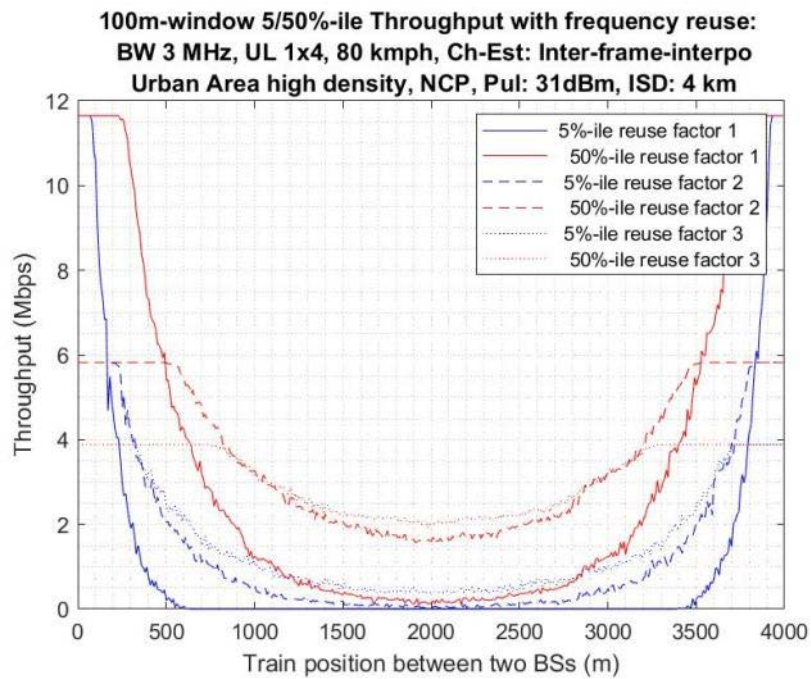


Figure B.82

Results at 5 MHz

High speed scenario

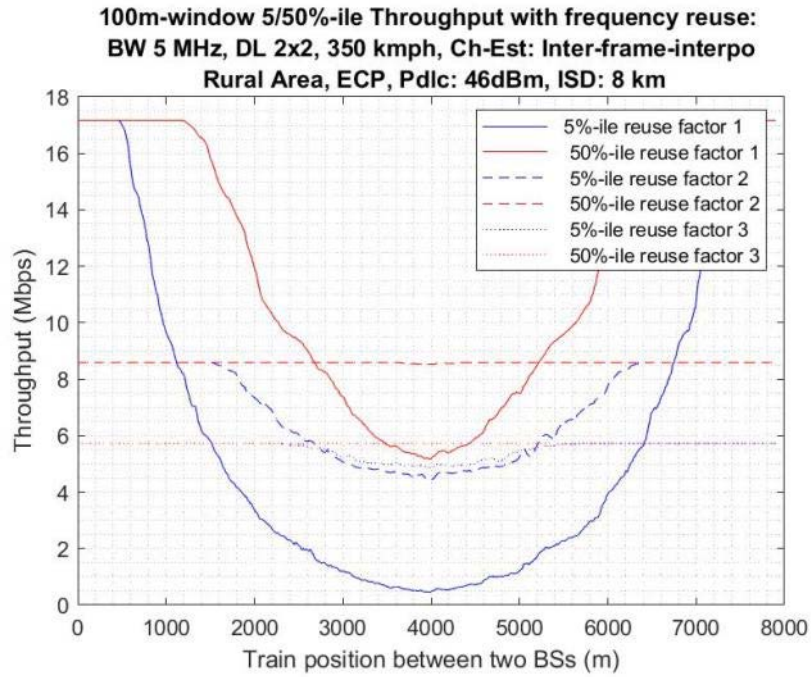


Figure B.83

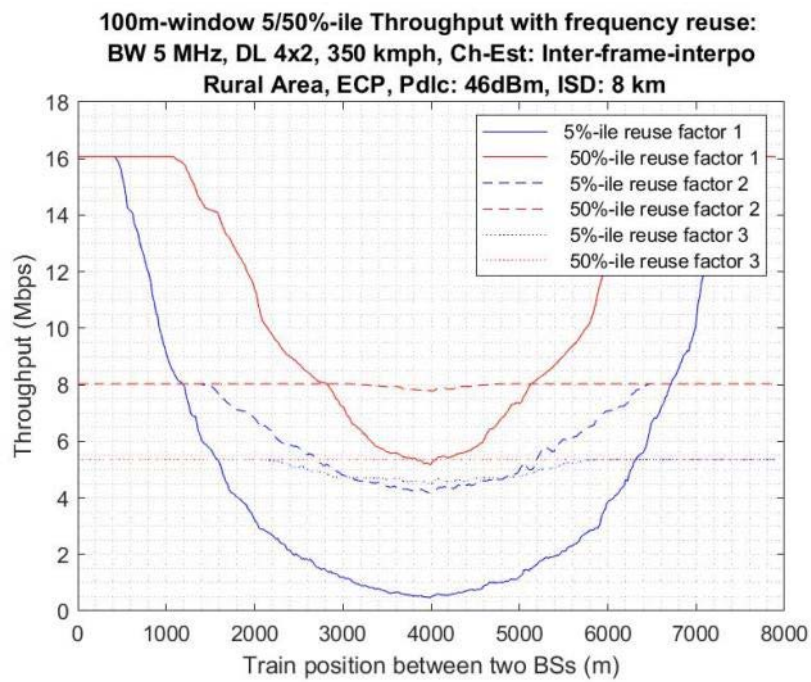


Figure B.84

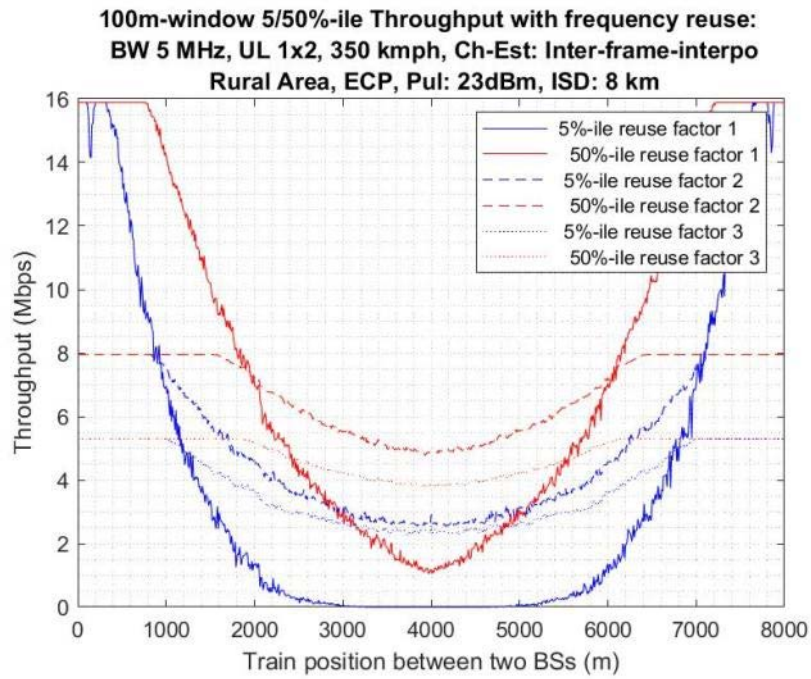


Figure B.85

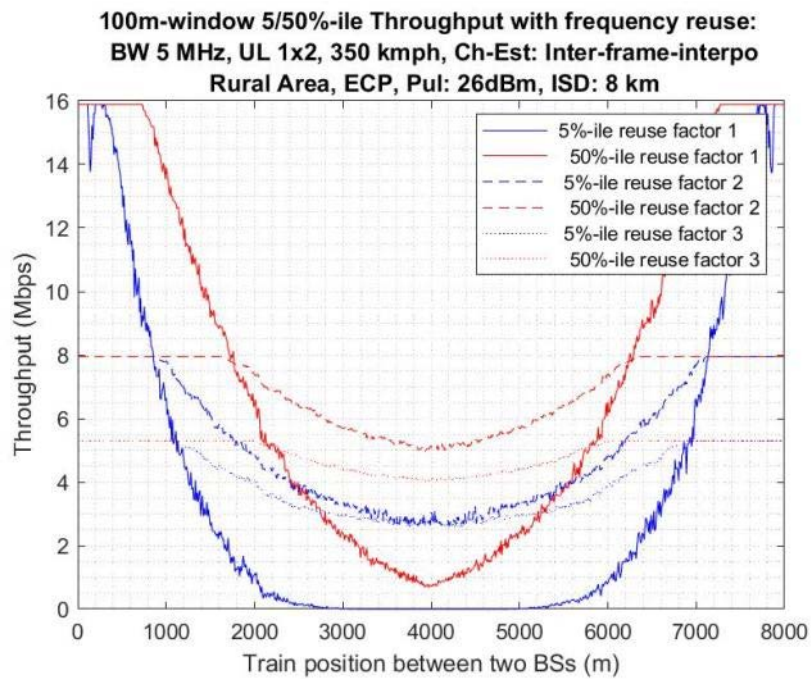


Figure B.86



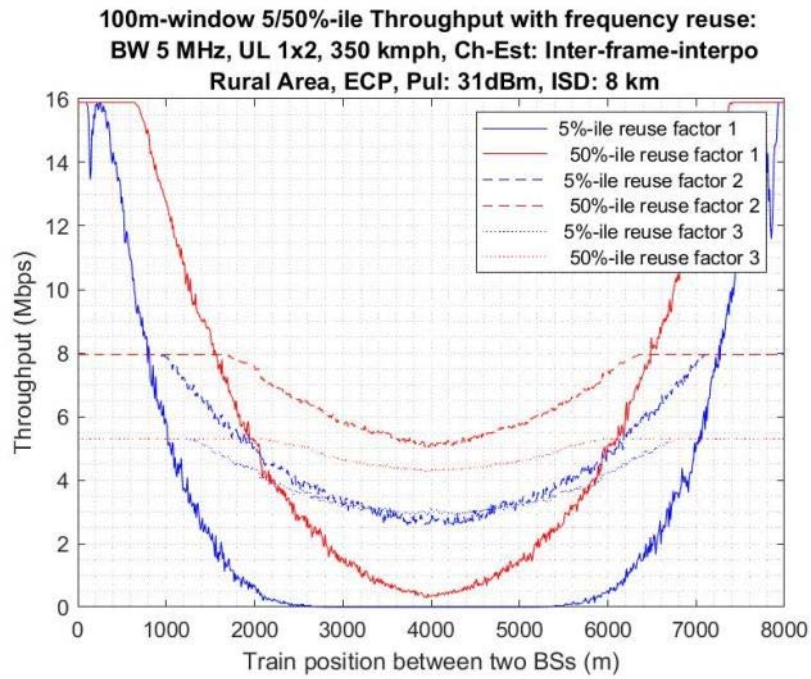


Figure B.87

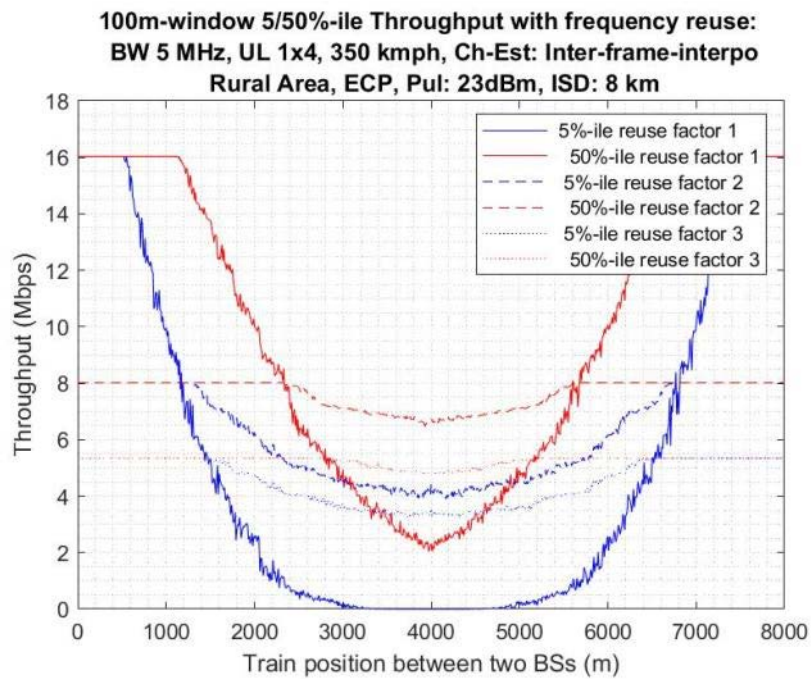


Figure B.88

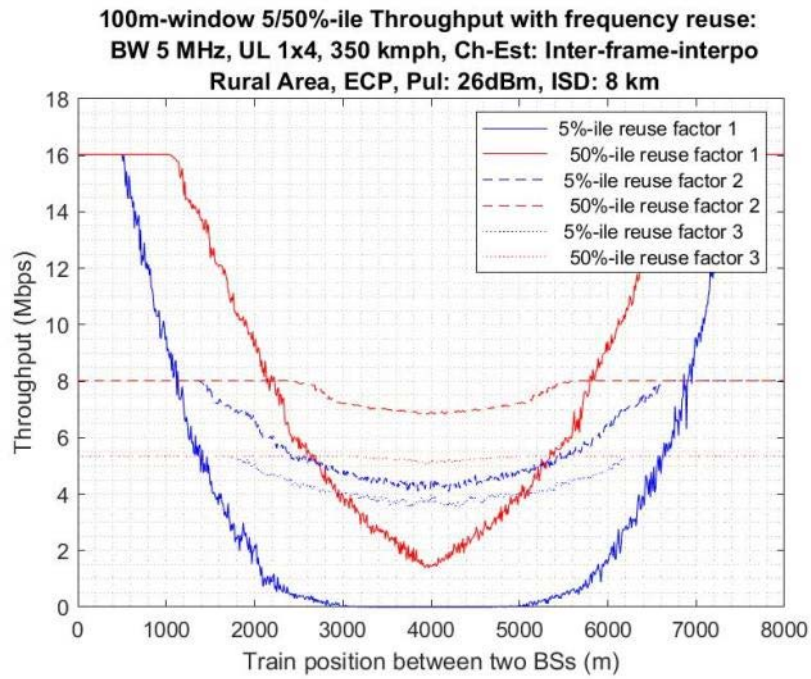


Figure B.89

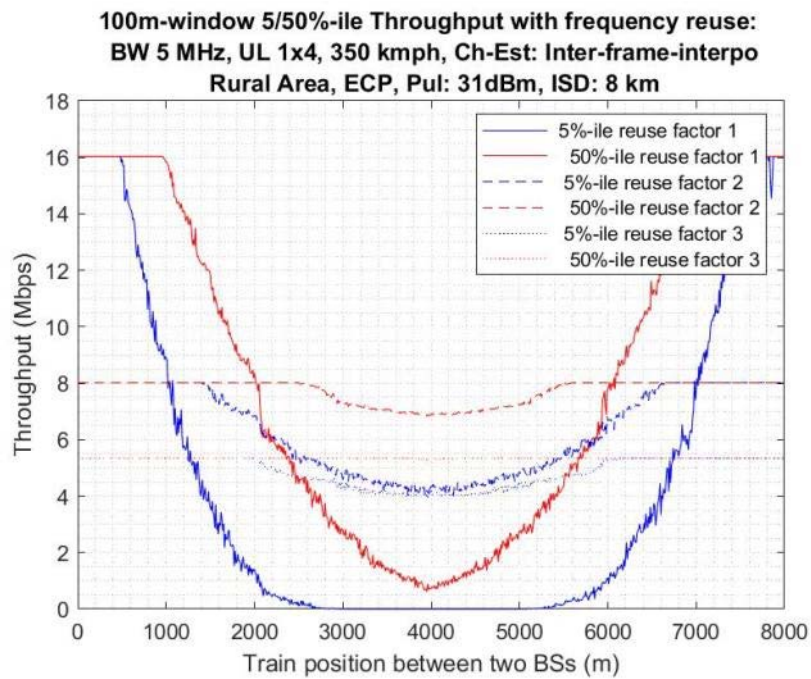


Figure B.90

Hilly scenario

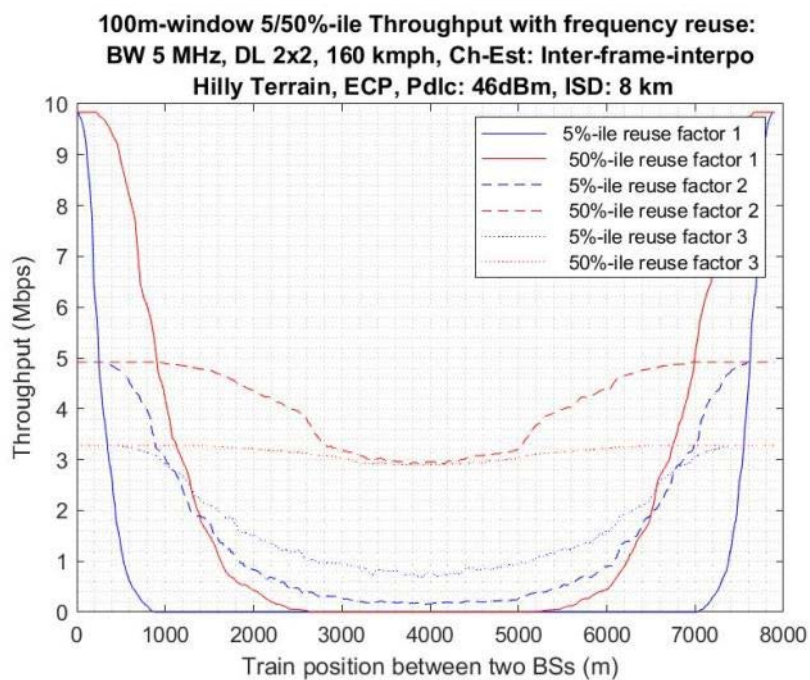


Figure B.91

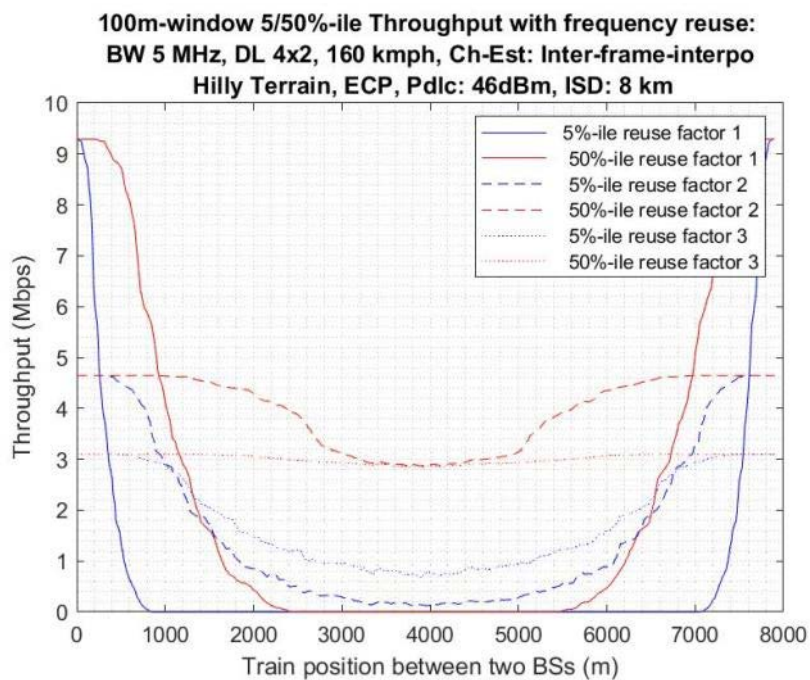


Figure B.92



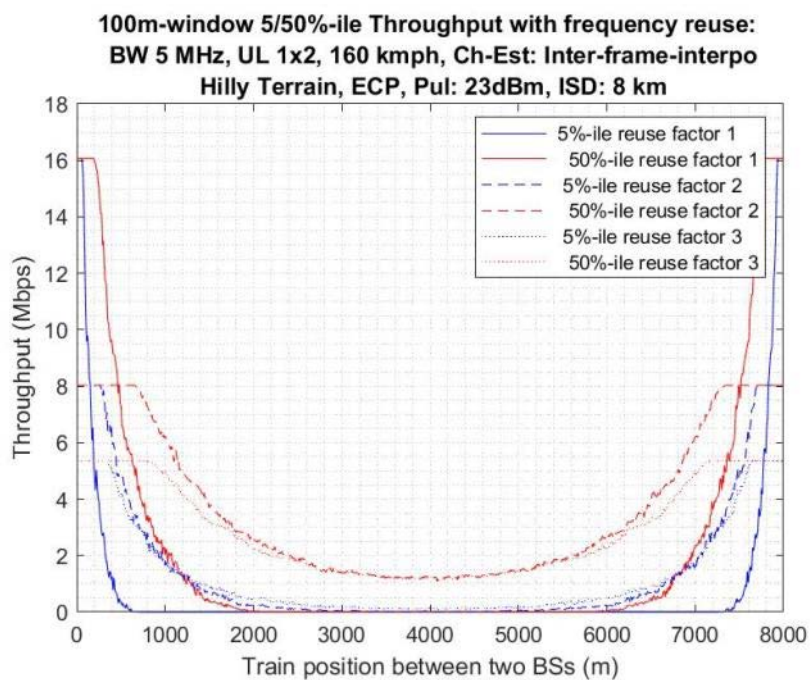


Figure B.93

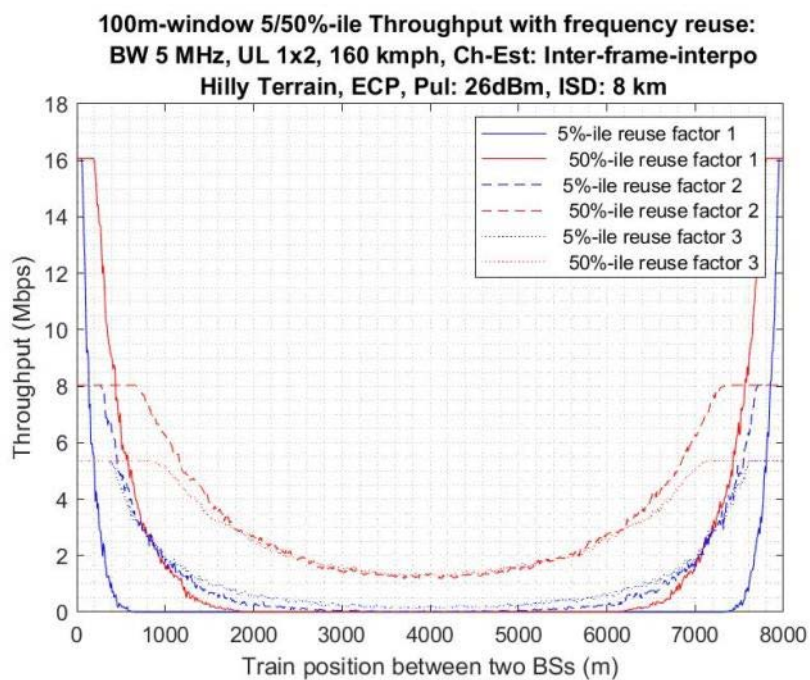


Figure B.94

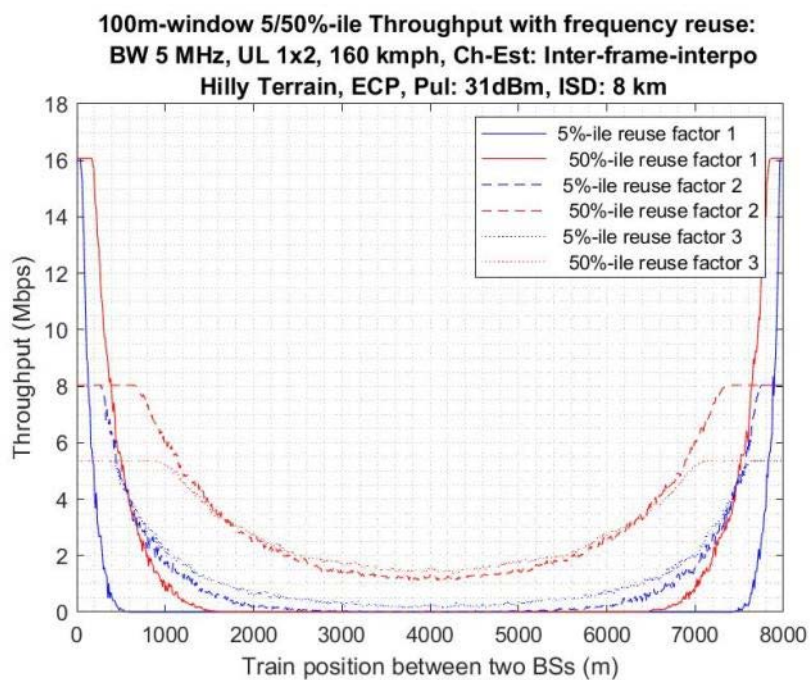


Figure B.95

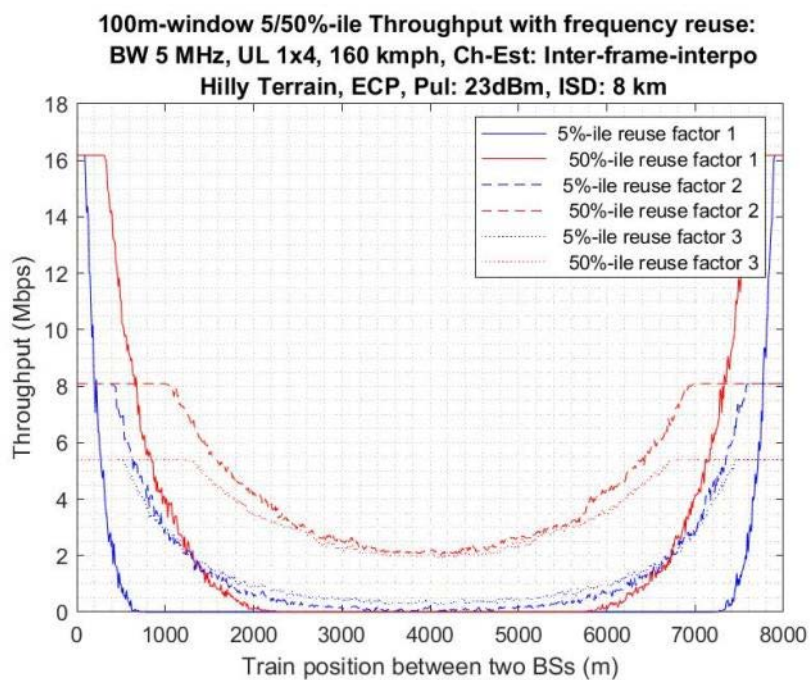


Figure B.96

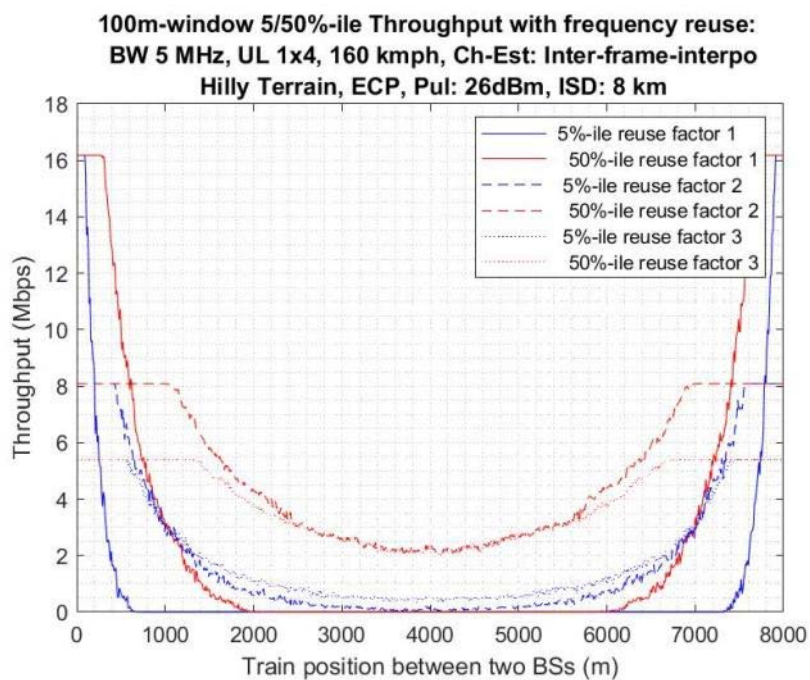


Figure B.97

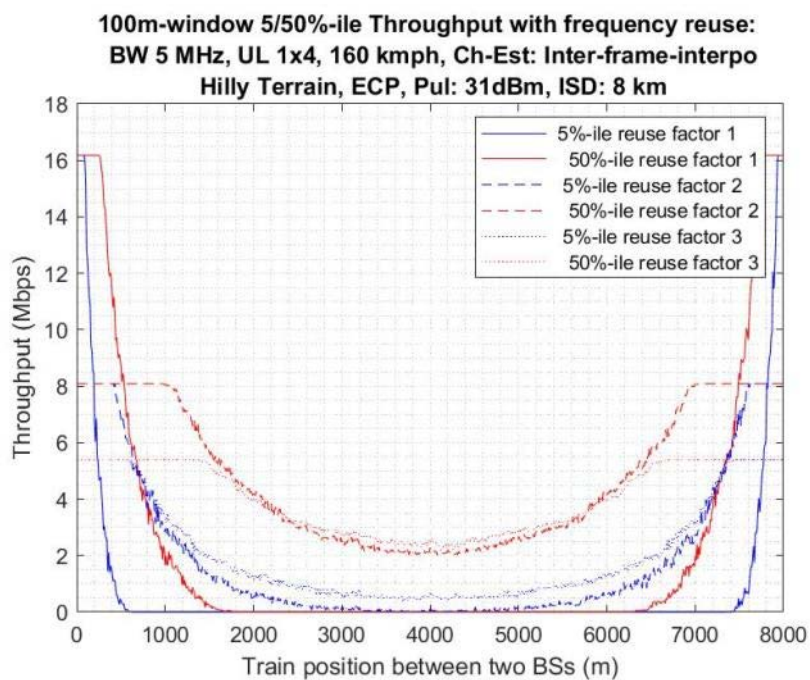


Figure B.98



Urban scenario

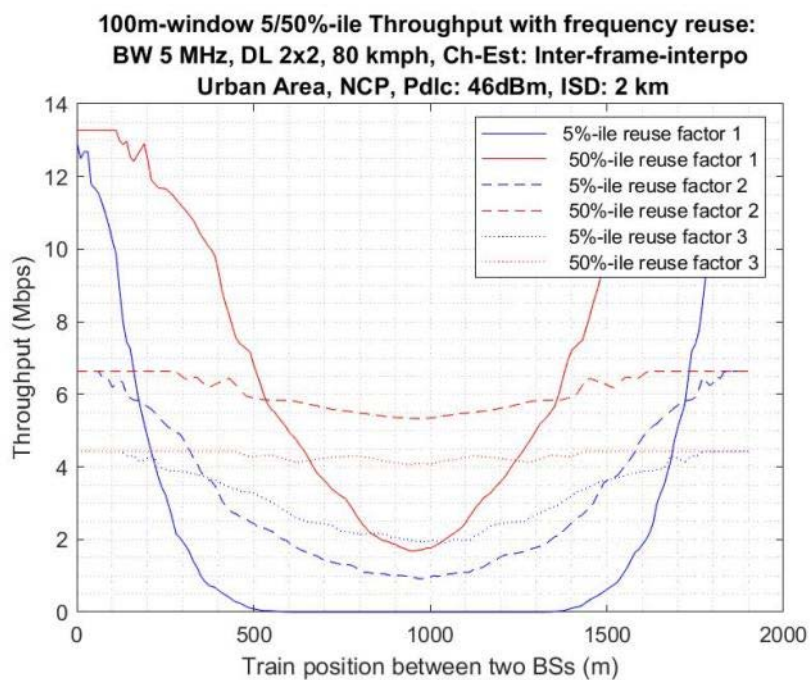


Figure B.99

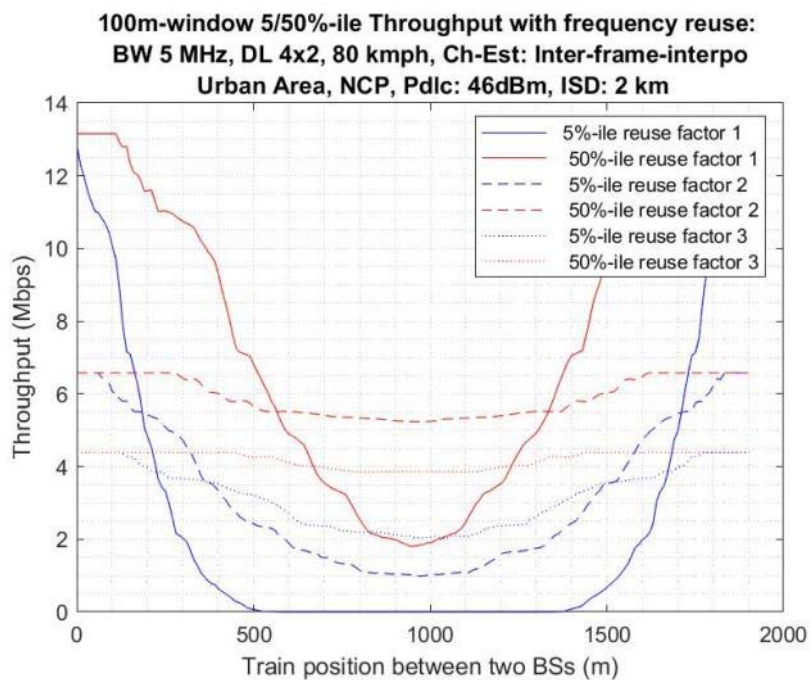


Figure B.100

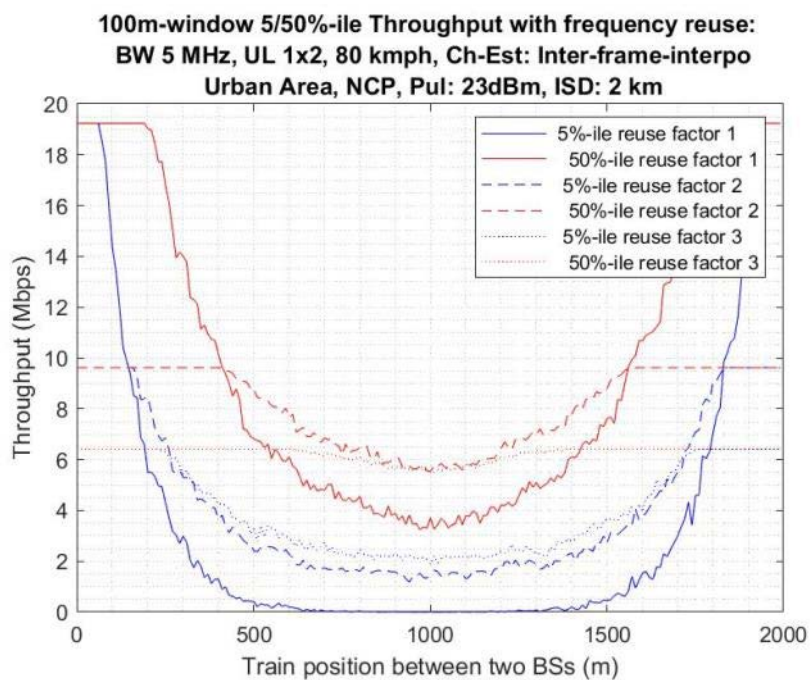


Figure B.101

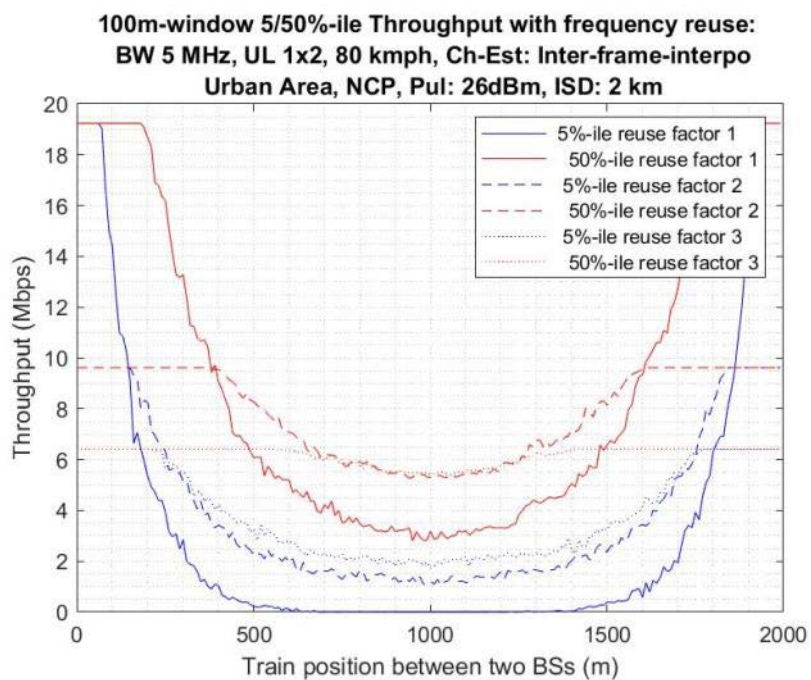


Figure B.102



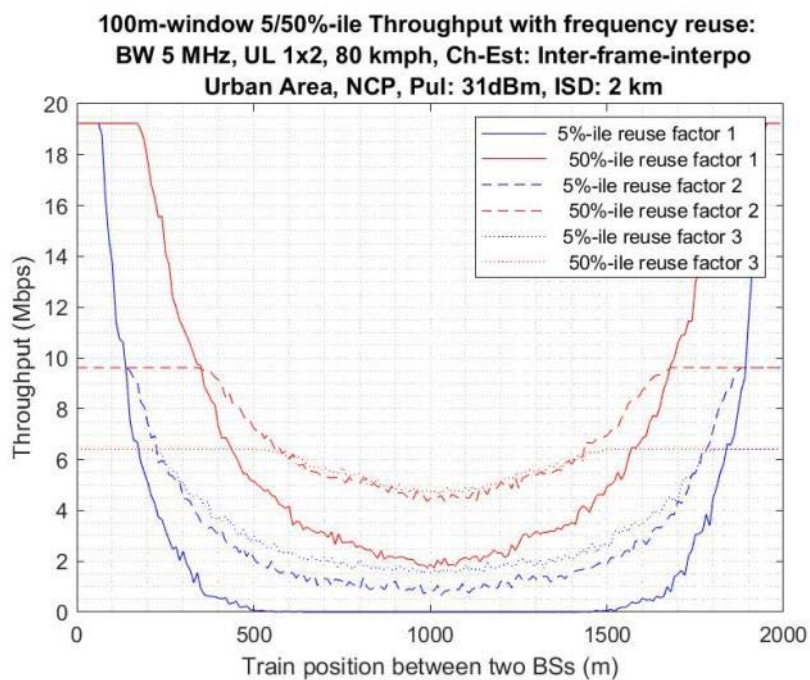


Figure B.103

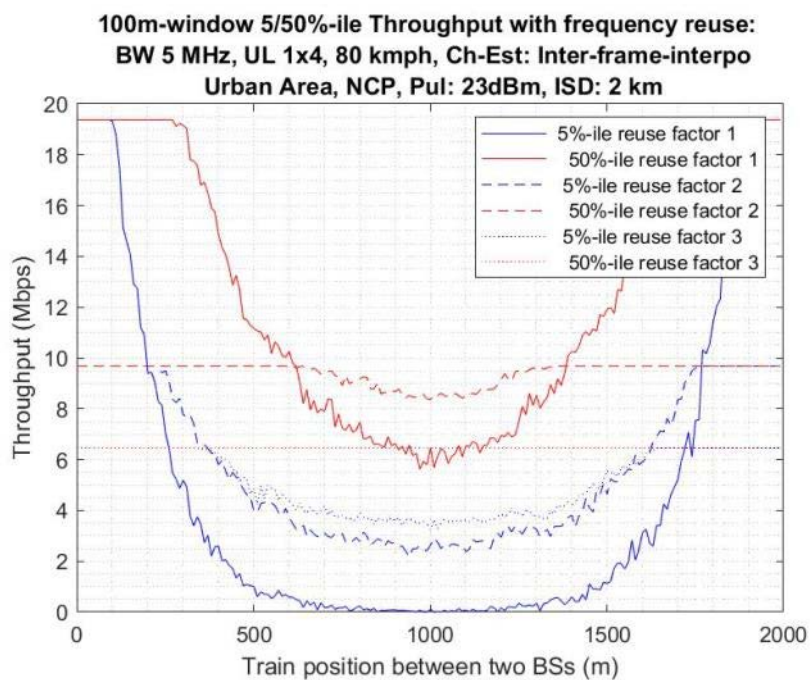


Figure B.104

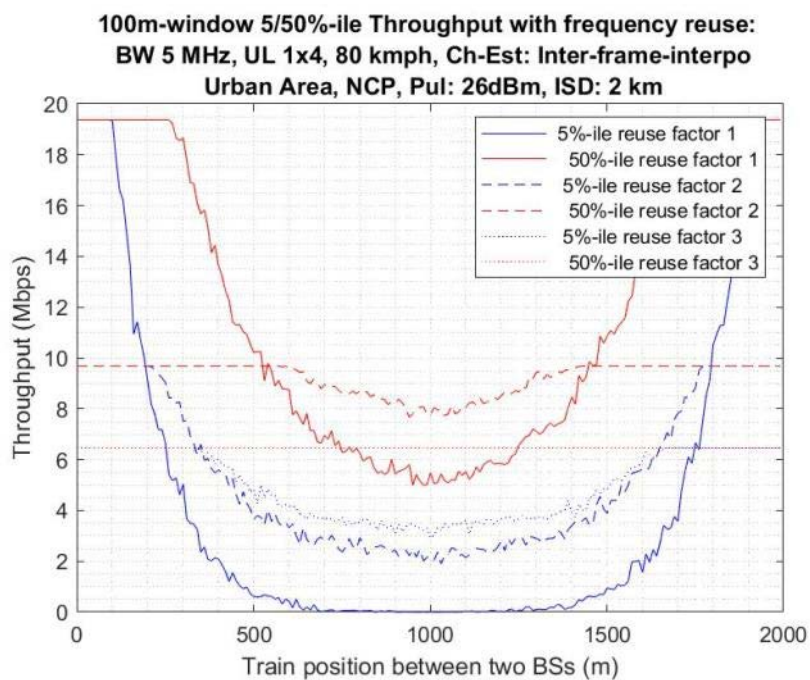


Figure B.105

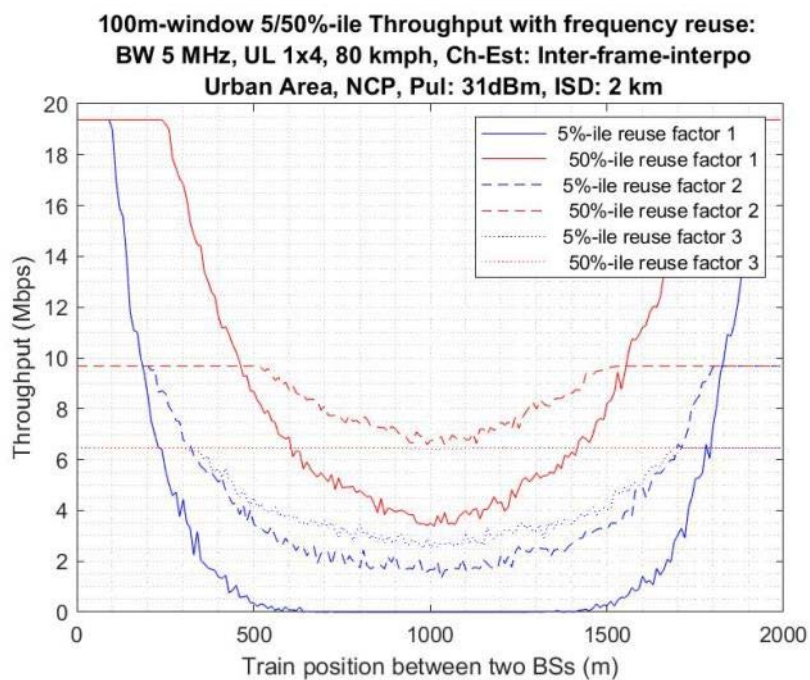


Figure B.106

High density scenario

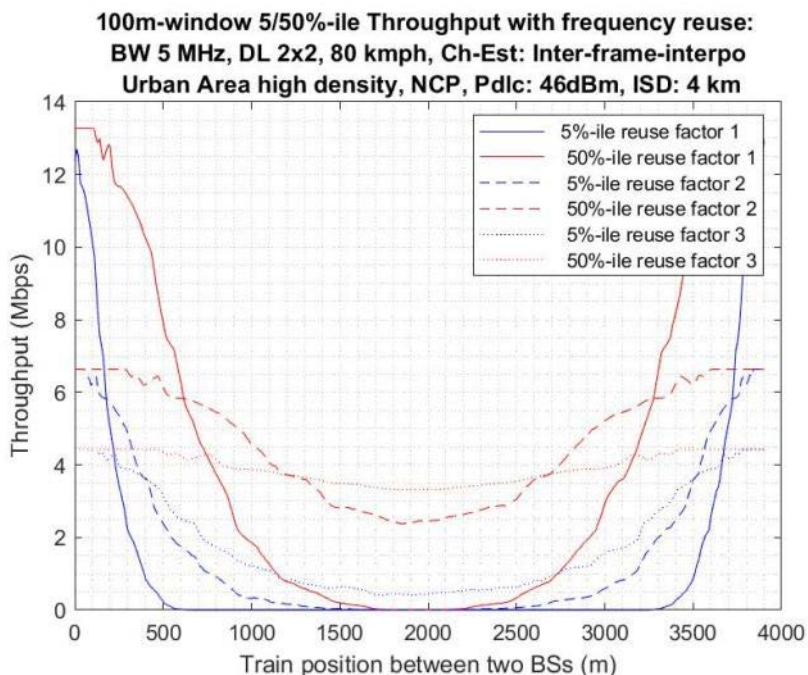


Figure B.107

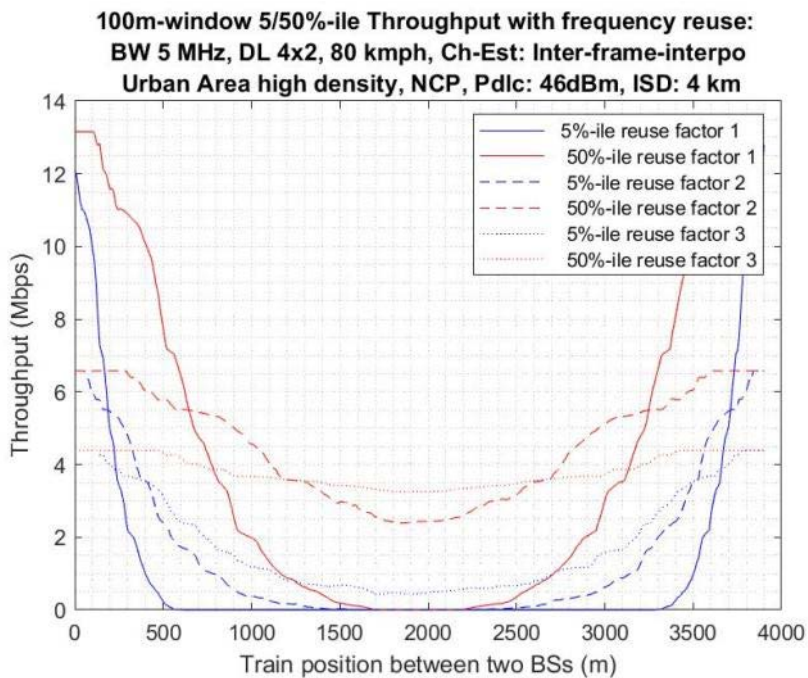


Figure B.108



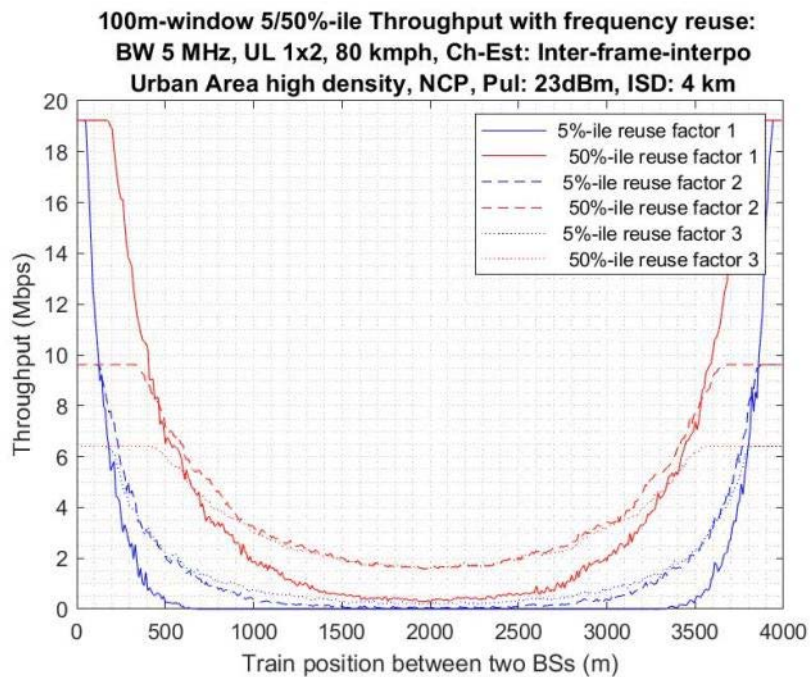


Figure B.109

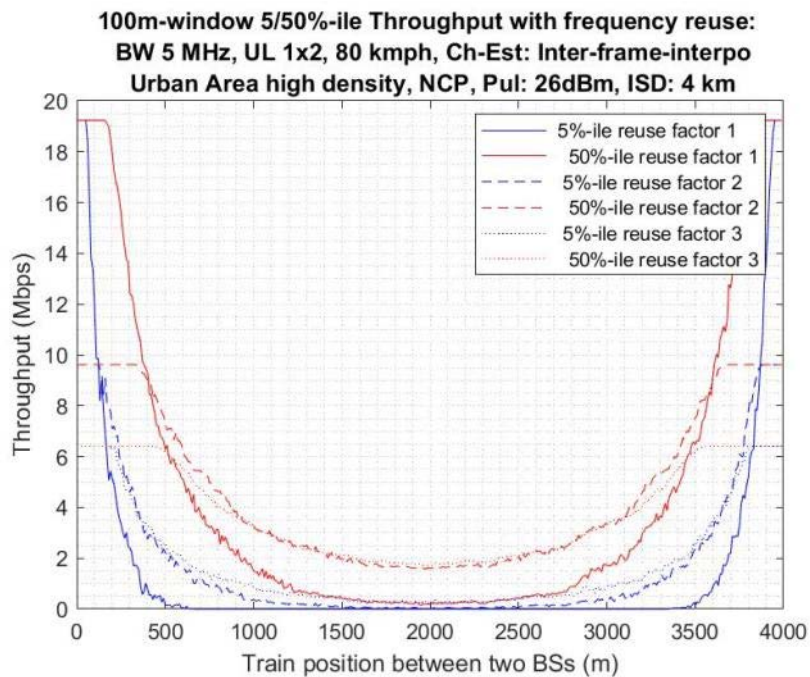


Figure B.110

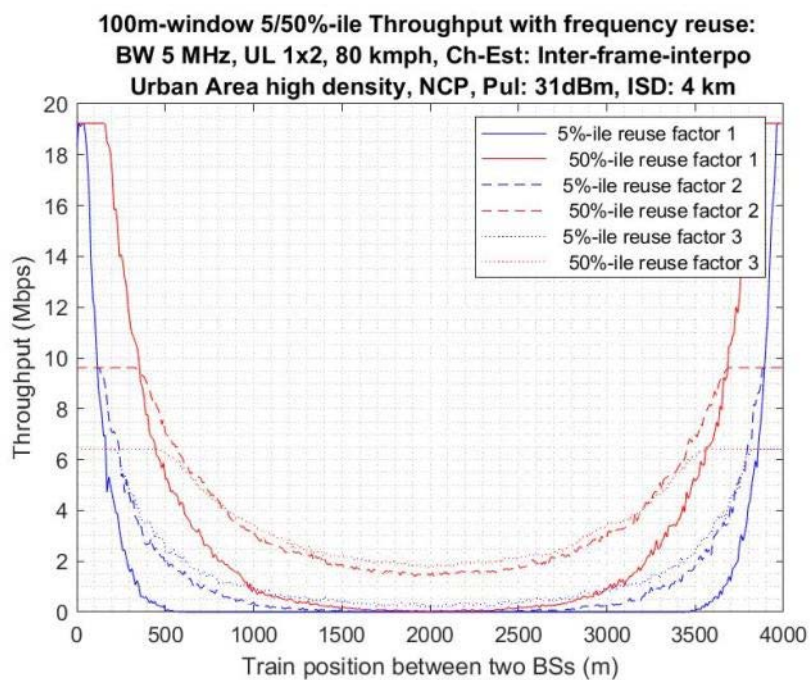


Figure B.111

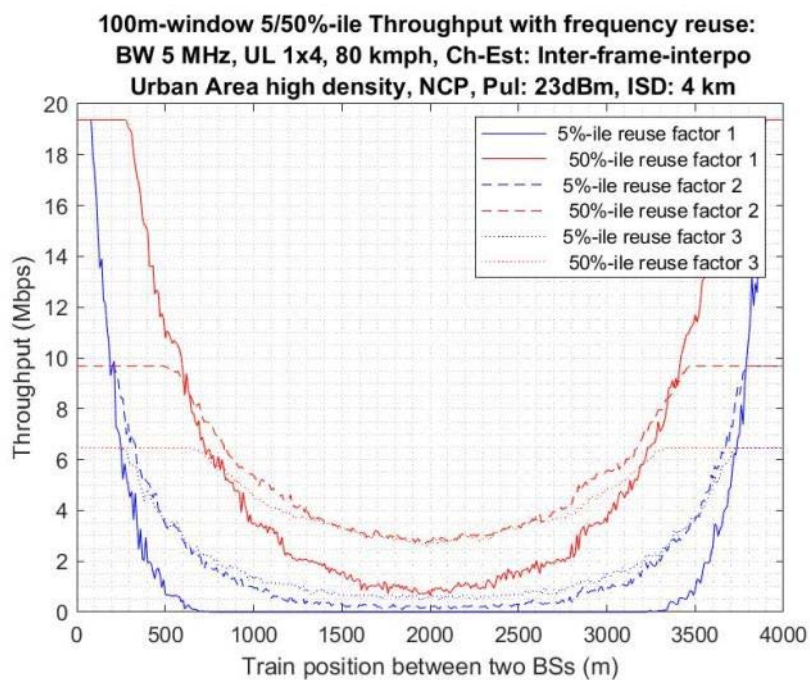


Figure B.112



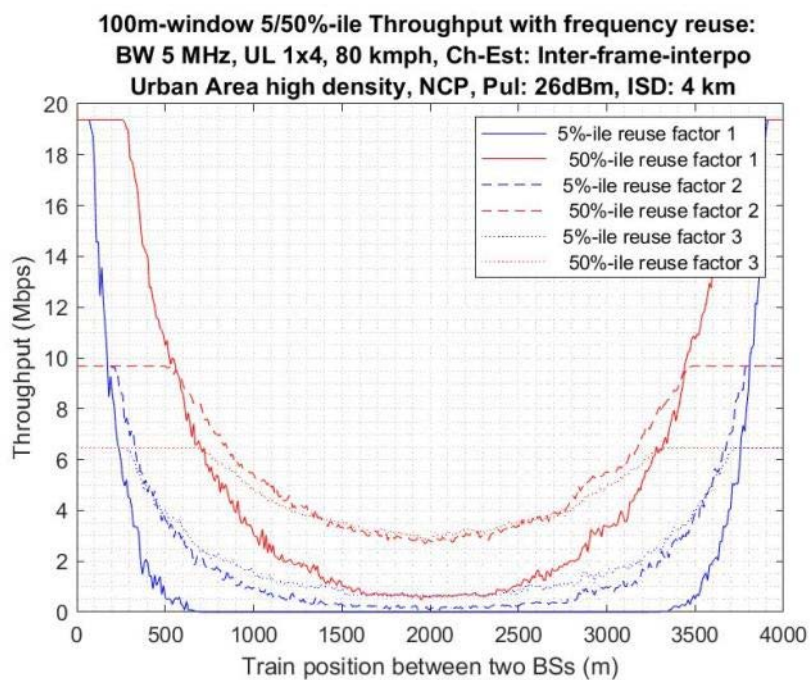


Figure B.113

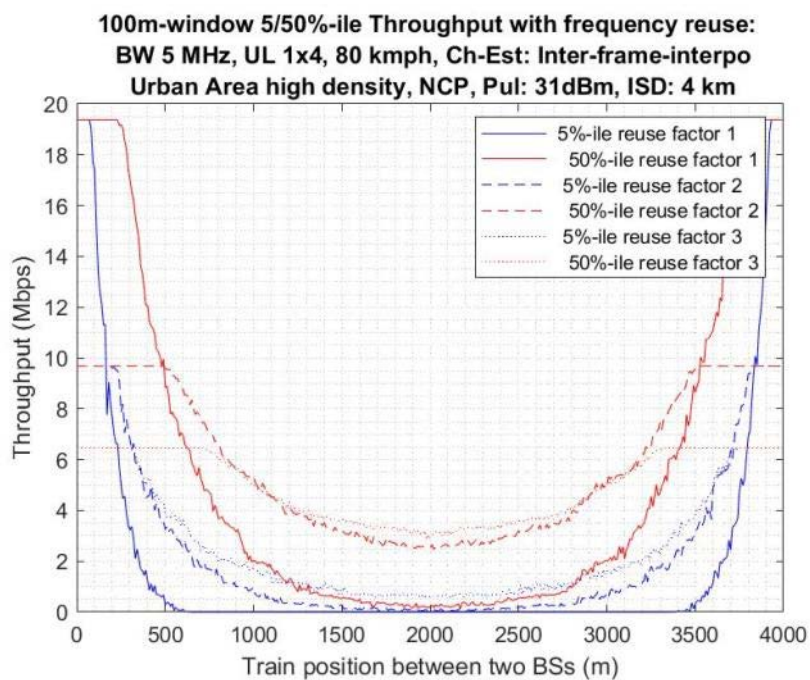


Figure B.114

# Annex C: Data Throughput Measurements for results set 3

The following curves show UL throughput measurements obtained with the test bed described in clause 5.3.1, with UDP traffic using 1 024 bytes packet size.

**LTE Channel Bandwidth = 3 MHz, Speed = 360 km/d Hilly Terrain with 6 taps**

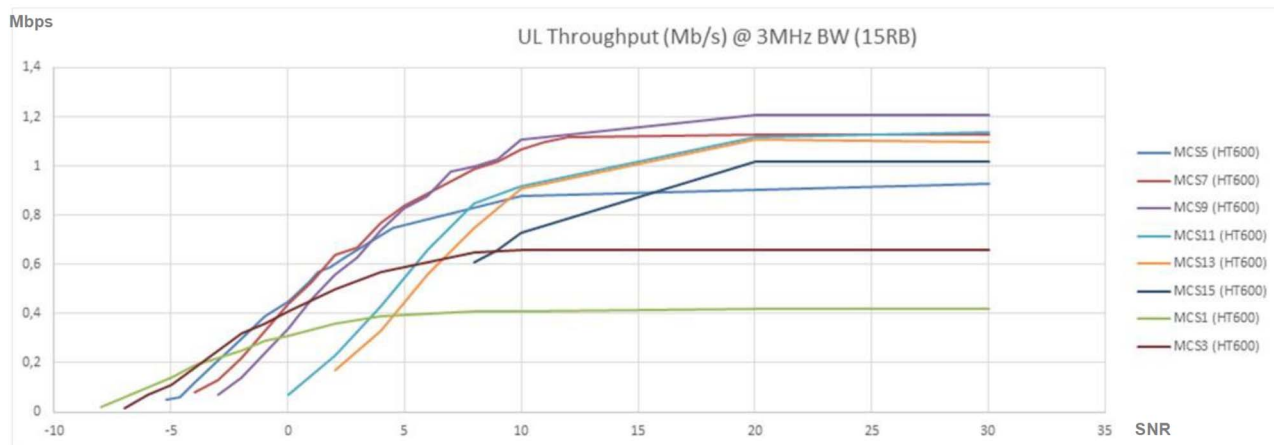


Figure C.1

**LTE Channel Bandwidth = 3 MHz, Speed = 500 km/d Hilly Terrain with 6 taps**

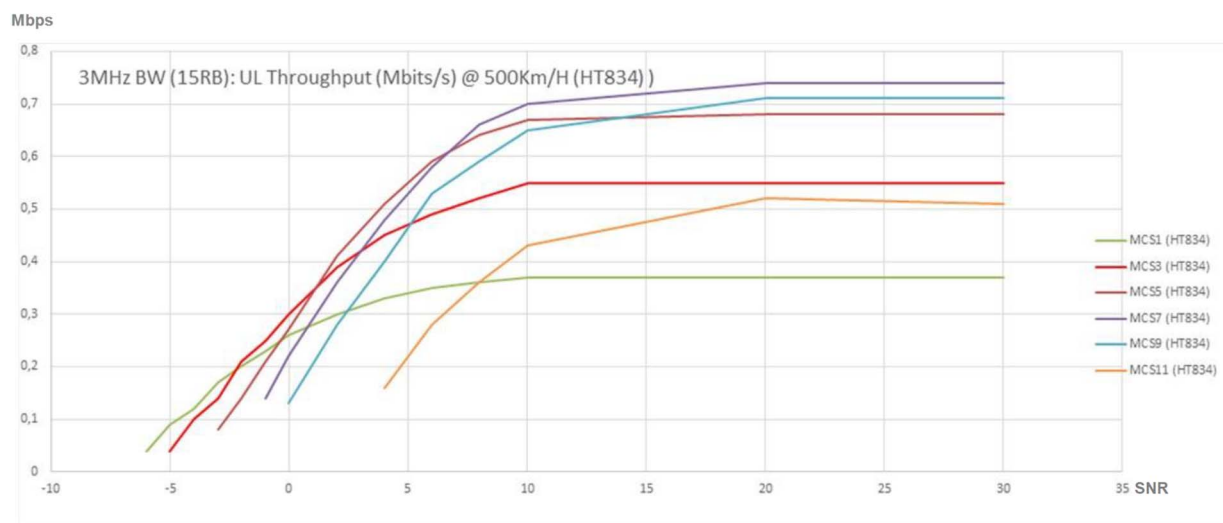


Figure C.2

LTE Channel Bandwidth = 1,4 MHz, Speed = 360 km/h Hilly Terrain with 6 taps

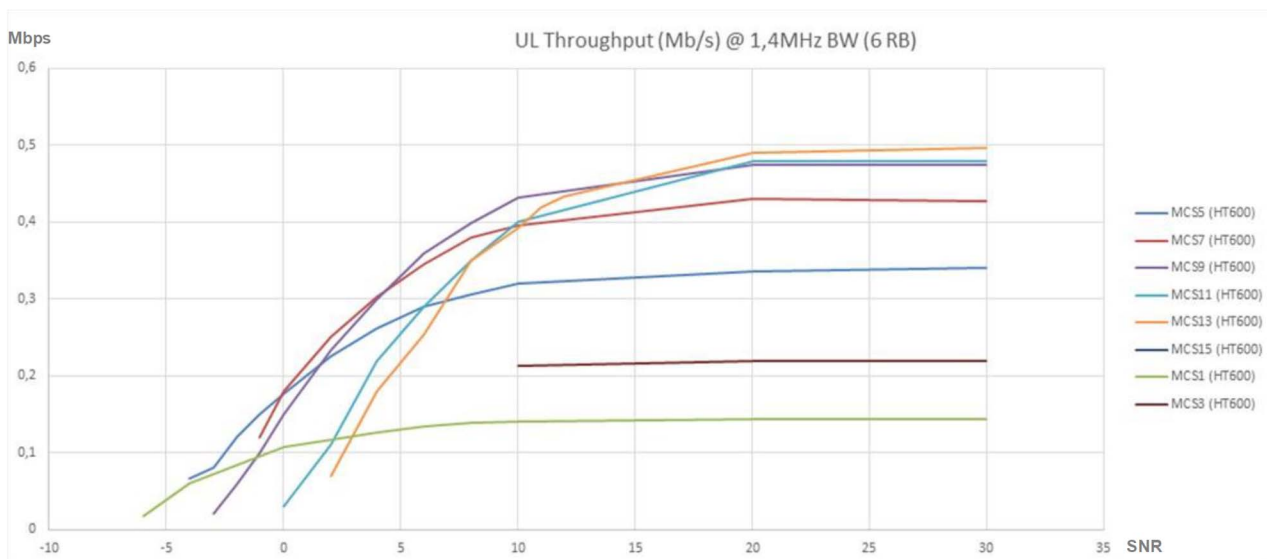


Figure C.3

Maximum data rate per MCS vs conditions (3 MHz)

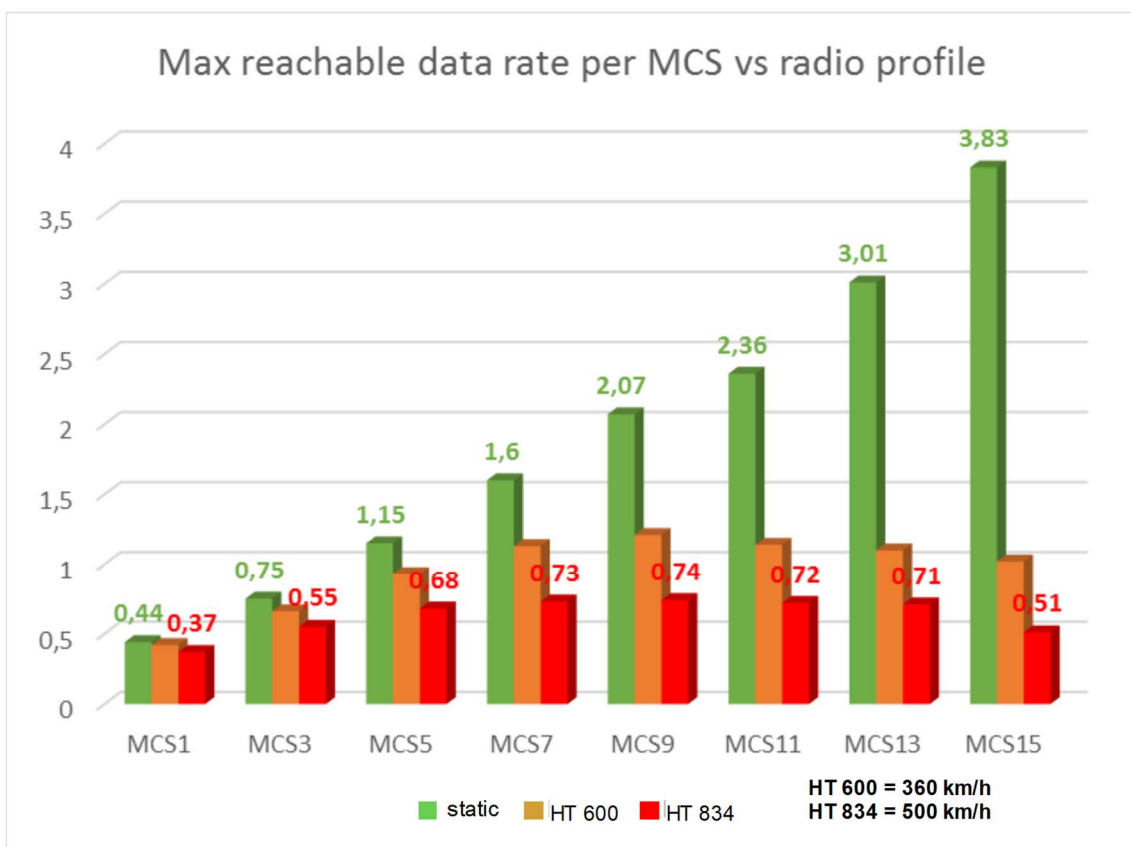


Figure C.4

## Annex D: Antenna diagrams

Antenna diagram 1

Gain (dB)	Horizontal aperture (°)	Vertical aperture (°)
20,5	30	8,5

Angle (°)	Attenuation (dB)	
	Horizontal	Vertical
0	0,00	0,00
1	0,02	0,18
2	0,06	0,71
3	0,13	1,61
4	0,23	2,92
5	0,35	4,67
6	0,50	6,97
7	0,67	9,99
8	0,87	14,07
9	1,10	20,09
10	1,35	28,71
11	1,63	24,72
12	1,94	20,96
13	2,28	19,66
14	2,64	19,85
15	3,04	21,32
16	3,47	24,29
17	3,94	28,98
18	4,45	29,38
19	5,01	24,68
20	5,62	21,56
21	6,29	19,86
22	7,02	19,20
23	7,81	19,42
24	8,67	20,50
25	9,60	22,54
26	10,61	25,71
27	11,70	29,83
28	12,89	31,65
29	14,22	29,83
30	15,71	28,58
31	17,43	28,86
32	19,50	30,69
33	22,00	33,28

Angle (°)	Attenuation (dB)	
	Horizontal	Vertical
34	25,02	32,18
35	28,06	28,39
36	28,67	25,48
37	26,40	23,63
38	23,87	22,58
39	21,82	22,16
40	20,23	22,27
41	18,98	22,86
42	17,95	23,91
43	17,09	25,47
44	16,36	27,64
45	15,75	30,53
46	15,21	33,85
47	14,76	35,28
48	14,39	33,44
49	14,08	31,29
50	13,84	29,93
51	13,65	29,34
52	13,52	29,44
53	13,42	30,19
54	13,35	31,63
55	13,32	33,93
56	13,31	37,62
57	13,32	44,70
58	13,36	54,87
59	13,41	41,09
60	13,49	36,15
61	13,59	33,23
62	13,71	31,24
63	13,84	29,81
64	13,98	28,77
65	14,14	28,04
66	14,32	27,54
67	14,51	27,23
68	14,71	27,07
69	14,93	27,04
70	15,17	27,11
71	15,41	27,28
72	15,66	27,56

Angle (°)	Attenuation (dB)	
	Horizontal	Vertical
73	15,93	27,95
74	16,19	28,43
75	16,46	28,99
76	16,74	29,57
77	17,02	30,11
78	17,31	30,55
79	17,60	30,85
80	17,90	31,04
81	18,21	31,16
82	18,52	31,27
83	18,83	31,42
84	19,14	31,64
85	19,44	31,94
86	19,75	32,30
87	20,06	32,71
88	20,37	33,16
89	20,68	33,64
90	20,99	34,14
91	21,31	34,66
92	21,64	35,14
93	21,96	35,55
94	22,29	35,88
95	22,63	36,16
96	22,96	36,50
97	23,29	37,03
98	23,62	37,90
99	23,94	39,27
100	24,25	41,27
101	24,55	43,83
102	24,84	45,94
103	25,12	45,82
104	25,39	44,50
105	25,66	43,70
106	25,93	43,81
107	26,18	44,61
108	26,44	45,20
109	26,69	44,40
110	26,93	42,65
111	27,18	41,08

Angle (°)	Attenuation (dB)	
	Horizontal	Vertical
112	27,41	40,07
113	27,62	39,61
114	27,82	39,55
115	27,99	39,67
116	28,13	39,71
117	28,23	39,45
118	28,33	38,82
119	28,41	37,91
120	28,50	36,93
121	28,59	36,07
122	28,72	35,47
123	28,86	35,19
124	29,00	35,25
125	29,12	35,60
126	29,23	36,12
127	29,29	36,64
128	29,33	37,00
129	29,36	37,14
130	29,41	37,11
131	29,50	37,01
132	29,63	36,90
133	29,82	36,80
134	30,06	36,80
135	30,33	36,97
136	30,60	37,39
137	30,87	38,05
138	31,14	38,79
139	31,40	39,16
140	31,67	38,74
141	31,99	37,64
142	32,39	36,40
143	32,85	35,40
144	33,39	34,79
145	33,98	34,64
146	34,59	34,96
147	35,16	35,78
148	35,68	37,03
149	36,13	38,53
150	36,50	39,91
151	36,79	40,82
152	37,02	41,44
153	37,21	42,30
154	37,29	43,65

Angle (°)	Attenuation (dB)	
	Horizontal	Vertical
155	37,25	44,69
156	37,08	43,97
157	36,79	42,25
158	36,40	40,97
159	35,97	40,42
160	35,51	40,23
161	35,07	39,65
162	34,65	38,45
163	34,28	37,21
164	33,96	36,56
165	33,69	36,78
166	33,47	38,09
167	33,31	40,75
168	33,19	45,28
169	33,10	51,94
170	33,03	54,18
171	32,98	53,77
172	32,95	52,67
173	32,94	45,92
174	32,98	40,70
175	33,07	37,39
176	33,23	35,42
177	33,44	34,46
178	33,70	34,36
179	34,01	35,06
180	34,37	36,55
181	34,69	38,89
182	34,99	42,00
183	35,26	44,68
184	35,51	44,51
185	35,77	42,92
186	36,07	41,89
187	36,42	41,66
188	36,83	42,03
189	37,29	42,62
190	37,82	42,97
191	38,38	42,72
192	38,94	41,75
193	39,49	40,32
194	40,03	38,82
195	40,49	37,64
196	40,89	37,01
197	41,21	37,02

Angle (°)	Attenuation (dB)	
	Horizontal	Vertical
198	41,46	37,68
199	41,63	38,78
200	41,75	39,62
201	41,82	39,26
202	41,81	37,84
203	41,69	36,27
204	41,45	35,01
205	41,10	34,18
206	40,62	33,83
207	40,08	34,01
208	39,56	34,78
209	39,12	36,18
210	38,74	37,94
211	38,42	38,99
212	38,21	38,26
213	38,02	36,75
214	37,82	35,65
215	37,57	35,28
216	37,30	35,72
217	37,01	37,03
218	36,70	39,37
219	36,43	43,20
220	36,24	49,56
221	36,13	52,60
222	36,07	46,94
223	36,09	43,92
224	36,14	42,66
225	36,20	42,58
226	36,19	43,58
227	36,16	45,92
228	36,10	50,69
229	36,00	63,80
230	35,89	52,12
231	35,80	45,70
232	35,75	42,16
233	35,70	39,85
234	35,64	38,25
235	35,56	37,16
236	35,45	36,49
237	35,27	36,21
238	35,04	36,32
239	34,80	36,88
240	34,55	37,93



Angle (°)	Attenuation (dB)	
	Horizontal	Vertical
241	34,30	39,62
242	34,05	42,15
243	33,82	45,75
244	33,57	48,75
245	33,28	46,31
246	32,93	42,68
247	32,55	40,03
248	32,12	38,15
249	31,64	36,75
250	31,16	35,64
251	30,68	34,73
252	30,23	33,95
253	29,79	33,29
254	29,39	32,72
255	29,00	32,24
256	28,61	31,85
257	28,21	31,55
258	27,80	31,32
259	27,37	31,13
260	26,93	30,95
261	26,47	30,74
262	26,02	30,46
263	25,58	30,12
264	25,14	29,73
265	24,72	29,32
266	24,31	28,92
267	23,91	28,55
268	23,50	28,21
269	23,10	27,88
270	22,69	27,53
271	22,27	27,12
272	21,85	26,65
273	21,44	26,10
274	21,03	25,50
275	20,64	24,88
276	20,25	24,28
277	19,86	23,70
278	19,49	23,17
279	19,11	22,67
280	18,73	22,18
281	18,36	21,69
282	17,99	21,17
283	17,63	20,64

Angle (°)	Attenuation (dB)	
	Horizontal	Vertical
284	17,27	20,11
285	16,94	19,60
286	16,61	19,13
287	16,30	18,75
288	16,00	18,45
289	15,71	18,26
290	15,43	18,18
291	15,16	18,20
292	14,90	18,31
293	14,65	18,53
294	14,42	18,84
295	14,21	19,26
296	14,01	19,81
297	13,84	20,52
298	13,68	21,46
299	13,54	22,69
300	13,41	24,33
301	13,31	26,55
302	13,23	29,66
303	13,18	34,20
304	13,16	39,46
305	13,17	36,84
306	13,21	32,77
307	13,29	30,38
308	13,40	29,14
309	13,55	28,77
310	13,74	29,20
311	13,98	30,56
312	14,28	33,27
313	14,64	38,04
314	15,07	38,24
315	15,59	31,93
316	16,21	27,63
317	16,95	24,76
318	17,82	22,82
319	18,85	21,56
320	20,07	20,88
321	21,50	20,71
322	23,07	21,07
323	24,41	22,00
324	24,74	23,60
325	23,53	26,11
326	21,49	29,88

Angle (°)	Attenuation (dB)	
	Horizontal	Vertical
327	19,34	34,05
328	17,39	32,37
329	15,68	28,71
330	14,18	26,42
331	12,86	25,22
332	11,68	24,66
333	10,62	24,22
334	9,65	23,32
335	8,75	21,83
336	7,92	20,17
337	7,15	18,79
338	6,43	17,90
339	5,76	17,61
340	5,15	18,02
341	4,58	19,27
342	4,06	21,67
343	3,58	25,81
344	3,14	30,26
345	2,74	26,59
346	2,36	22,83
347	2,02	21,14
348	1,70	21,28
349	1,41	23,52
350	1,15	26,23
351	0,92	20,27
352	0,72	14,32
353	0,54	10,12
354	0,39	7,03
355	0,26	4,68
356	0,16	2,91
357	0,09	1,60
358	0,03	0,70
359	0,01	0,17

## Antenna diagram 2

Gain (dB)	Horizontal aperture (°)	Vertical aperture (°)
18	65	7

Angle (°)	Attenuation (dB)	
	Horizontal	Vertical
0	0,00	0,00
1	0,01	0,11
2	0,03	0,65
3	0,05	1,62
4	0,08	3,07
5	0,11	5,06
6	0,16	7,70
7	0,20	11,20
8	0,26	15,97
9	0,32	22,93
10	0,39	30,72
11	0,46	27,23
12	0,54	25,52
13	0,63	26,17
14	0,72	28,30
15	0,82	30,81
16	0,93	32,21
17	1,04	33,26
18	1,16	36,50
19	1,28	50,77
20	1,41	37,04
21	1,55	29,94
22	1,69	26,41
23	1,84	24,53
24	1,99	23,77
25	2,15	23,90
26	2,32	24,79
27	2,49	26,22
28	2,66	27,42
29	2,84	27,21
30	3,03	25,80
31	3,22	24,35
32	3,42	23,42
33	3,62	23,15
34	3,83	23,61
35	4,04	24,91

Angle (°)	Attenuation (dB)	
	Horizontal	Vertical
36	4,26	27,37
37	4,48	31,82
38	4,71	41,04
39	4,94	36,20
40	5,18	29,97
41	5,42	26,89
42	5,66	25,24
43	5,92	24,48
44	6,17	24,37
45	6,43	24,80
46	6,69	25,75
47	6,96	27,30
48	7,23	29,69
49	7,51	33,58
50	7,79	41,09
51	8,07	40,56
52	8,36	33,05
53	8,64	29,12
54	8,94	26,80
55	9,23	25,45
56	9,53	24,82
57	9,83	24,80
58	10,13	25,30
59	10,44	26,24
60	10,75	27,43
61	11,05	28,49
62	11,37	28,93
63	11,68	28,67
64	11,99	28,17
65	12,30	27,88
66	12,61	28,03
67	12,92	28,73
68	13,23	30,08
69	13,54	32,22
70	13,85	35,42
71	14,16	39,80
72	14,47	42,13
73	14,78	38,87
74	15,09	35,76
75	15,40	33,74
76	15,70	32,52
77	16,01	31,88
78	16,31	31,70

Angle (°)	Attenuation (dB)	
	Horizontal	Vertical
79	16,62	31,92
80	16,92	32,51
81	17,22	33,43
82	17,53	34,66
83	17,82	36,16
84	18,13	37,94
85	18,43	39,94
86	18,74	42,13
87	19,05	44,41
88	19,37	46,64
89	19,69	48,58
90	20,00	49,91
91	20,33	50,59
92	20,66	50,97
93	20,99	51,13
94	21,33	50,27
95	21,67	47,87
96	22,02	44,88
97	22,37	42,14
98	22,73	39,85
99	23,09	38,02
100	23,47	36,62
101	23,85	35,65
102	24,23	35,09
103	24,62	34,94
104	25,02	35,15
105	25,43	35,66
106	25,84	36,36
107	26,27	37,15
108	26,70	37,93
109	27,14	38,59
110	27,58	39,00
111	28,04	39,01
112	28,50	38,73
113	28,97	38,51
114	29,45	38,73
115	29,94	39,72
116	30,44	41,92
117	30,94	46,14
118	31,46	52,67
119	31,98	47,93
120	32,51	43,10
121	33,05	40,73

Angle (°)	Attenuation (dB)	
	Horizontal	Vertical
122	33,60	39,87
123	34,16	40,21
124	34,73	41,63
125	35,30	43,91
126	35,88	45,44
127	36,47	44,12
128	37,06	42,03
129	37,66	40,76
130	38,26	40,46
131	38,86	40,91
132	39,47	41,50
133	40,08	41,19
134	40,69	39,79
135	41,31	38,26
136	41,92	37,28
137	42,55	37,09
138	43,19	37,85
139	43,85	39,82
140	44,55	43,77
141	45,27	52,41
142	46,09	50,00
143	46,98	43,21
144	48,00	40,22
145	49,18	39,01
146	50,62	39,05
147	52,47	40,24
148	54,91	42,78
149	58,51	47,45
150	65,46	56,50
151	75,75	52,14
152	61,12	46,68
153	55,72	44,30
154	52,28	43,49
155	49,73	43,83
156	47,69	45,16
157	45,99	47,52
158	44,52	50,88
159	43,24	55,04
160	42,10	59,93
161	41,08	71,69
162	40,16	61,44
163	39,32	52,80
164	38,55	48,12

Angle (°)	Attenuation (dB)	
	Horizontal	Vertical
165	37,85	45,12
166	37,21	43,04
167	36,63	41,43
168	36,09	39,98
169	35,60	38,55
170	35,14	37,21
171	34,74	36,02
172	34,37	35,06
173	34,04	34,34
174	33,74	33,80
175	33,48	33,40
176	33,25	33,08
177	33,06	32,83
178	32,89	32,63
179	32,76	32,50
180	32,66	32,67
181	32,59	33,11
182	32,55	33,92
183	32,54	35,26
184	32,57	37,35
185	32,62	40,50
186	32,71	44,84
187	32,83	46,66
188	32,98	43,72
189	33,16	41,58
190	33,38	41,00
191	33,64	41,89
192	33,93	44,27
193	34,26	47,53
194	34,64	47,71
195	35,06	45,30
196	35,52	44,10
197	36,04	44,68
198	36,61	46,99
199	37,25	48,69
200	37,95	45,65
201	38,73	42,45
202	39,61	40,79
203	40,58	40,54
204	41,69	41,65
205	42,95	44,30
206	44,41	48,42
207	46,13	49,81

Angle (°)	Attenuation (dB)	
	Horizontal	Vertical
208	48,22	46,65
209	50,81	44,51
210	54,04	43,86
211	57,37	44,43
212	57,37	46,13
213	54,23	49,09
214	51,28	53,95
215	48,96	63,25
216	47,12	61,64
217	45,66	54,87
218	44,42	51,23
219	43,39	48,50
220	42,48	46,11
221	41,69	44,08
222	40,98	42,54
223	40,34	41,56
224	39,75	41,19
225	39,21	41,43
226	38,71	42,28
227	38,23	43,76
228	37,78	45,93
229	37,34	48,89
230	36,91	52,95
231	36,49	59,13
232	36,07	71,04
233	35,65	59,51
234	35,24	52,97
235	34,81	48,88
236	34,39	46,11
237	33,95	44,36
238	33,51	43,53
239	33,07	43,56
240	32,62	44,42
241	32,16	46,03
242	31,69	48,14
243	31,22	50,14
244	30,74	51,42
245	30,27	52,10
246	29,79	52,28
247	29,30	51,68
248	28,82	50,50
249	28,33	49,29
250	27,85	48,21

Angle (°)	Attenuation (dB)	
	Horizontal	Vertical
251	27,37	47,21
252	26,89	46,47
253	26,42	46,41
254	25,96	47,57
255	25,49	50,26
256	25,04	50,79
257	24,59	46,07
258	24,15	42,22
259	23,71	39,90
260	23,29	38,69
261	22,87	38,23
262	22,46	38,04
263	22,06	37,66
264	21,66	36,98
265	21,28	36,35
266	20,90	36,16
267	20,53	36,64
268	20,16	37,90
269	19,80	40,00
270	19,45	40,00
271	19,11	42,80
272	18,77	45,77
273	18,44	47,75
274	18,11	47,89
275	17,78	46,29
276	17,47	44,02
277	17,15	42,12
278	16,84	41,02
279	16,53	40,73
280	16,22	40,99
281	15,91	41,21
282	15,60	40,81
283	15,30	39,95
284	14,99	39,33
285	14,69	39,39
286	14,38	40,33
287	14,08	42,21
288	13,78	44,26
289	13,47	44,00
290	13,17	41,60
291	12,86	39,42
292	12,56	38,00
293	12,26	37,24

Angle (°)	Attenuation (dB)	
	Horizontal	Vertical
294	11,95	36,95
295	11,65	36,91
296	11,35	36,82
297	11,05	36,43
298	10,75	35,69
299	10,45	34,76
300	10,15	33,84
301	9,86	33,10
302	9,56	32,63
303	9,27	32,49
304	8,98	32,75
305	8,69	33,51
306	8,41	35,01
307	8,13	37,76
308	7,85	43,42
309	7,58	51,99
310	7,31	39,80
311	7,04	34,33
312	6,77	31,11
313	6,51	29,06
314	6,26	27,84
315	6,00	27,32
316	5,76	27,48
317	5,51	28,38
318	5,27	30,13
319	5,03	32,61
320	4,80	33,67
321	4,58	31,01
322	4,35	27,82
323	4,14	25,52
324	3,92	24,15
325	3,72	23,62
326	3,51	23,97
327	3,31	25,37
328	3,12	28,35
329	2,93	34,72
330	2,75	39,41
331	2,57	30,01
332	2,40	25,74
333	2,23	23,56
334	2,07	22,65
335	1,91	22,72
336	1,76	23,58

Angle (°)	Attenuation (dB)	
	Horizontal	Vertical
337	1,62	24,80
338	1,48	25,14
339	1,35	23,90
340	1,22	22,24
341	1,10	21,23
342	0,98	21,25
343	0,88	22,68
344	0,77	26,42
345	0,68	33,70
346	0,59	26,85
347	0,50	21,16
348	0,42	18,28
349	0,35	17,12
350	0,29	17,39
351	0,23	18,78
352	0,18	18,53
353	0,13	14,29
354	0,09	9,93
355	0,06	6,59
356	0,04	4,11
357	0,02	2,31
358	0,01	1,07
359	0,00	0,31

## Annex E: Propagation models

### The Hata model:

$$L_U = 69,55 + 26,16 \log_{10} f - 13,82 \log_{10} h_B - C_H + (44,9 - 6,55 \log_{10} h_B) \log_{10} d$$

For small or medium sized cities :

$$C_H = 0,8 + (1,1 \log_{10} f - 0,7) h_M - 1,56 \log_{10} f$$

For large cities:

$$C_H = 8,29 (\log_{10} (1.54 h_M))^2 - 1,1 \text{ if } 150 \leq f \leq 200$$

$$C_H = 3,29 (\log_{10} (11.75 h_M))^2 - 4,97 \text{ if } 200 \leq f \leq 15\,000$$

### The Okumura-Hata model:

$$L_U = 69,55 + 26,16 \log_{10} f - 13,82 \log_{10} h_B - a(h_M) + (44,9 - 6,55 \log_{10} h_B) \log_{10} d + C_H$$

In open and urban areas:

$$a(h_M) = (1,1 (\log_{10} f) - 0,7) h_M - (1,1 \log_{10} f) - 0,8$$

In urban areas :

$$C_H = 0$$

In rural areas :

$$C_H = -4,78 (\log_{10} f)^2 + 18,33 \log_{10} f - 40,98$$

where :

$L_U$ : path loss (dB)

$h_B$ : base station antenna (m)

$h_M$ : mobile station antenna height (m)

$f$ : carrier frequency (MHz)

$C_H$ : antenna height correction factor

$d$ : distance between the base and mobile stations (km).

**Table E.1: Application to scenarios of the present document**

Distance	Model	Scenario		
		Rural	Hilly	Urban/urban HD
Distance ≤ 8 km	Okumura-Hata Rural	X	X	
	Okumura-Hata Urban			X
Distance ≥ 8 km	Okumura-Hata Urban			X



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## Annex F: Change history

Date	Version	Information about changes
July 2017	0.0.1	Initial draft
December 2017	0.2.0	Integration of agreements from July meeting and October review, integration of drafting sessions of November 2017 and December 2017
January 2018	0.3.0	Integration of RT #68 decisions
March 2018	0.4.0	Integration of drafting session decisions: - LTE channel location - Results set 1 - Results set 3
March 2018	0.5.0	Added note and clarification on Worst Cell edge metric
April 2018	0.6.0	Added section on comparison results
June 2018	0.7.0	Interim conclusion with 1,4 MHz results
July 2018	0.9.2	Clarifications on Fractional Frequency Reuse
January 2019	1.2.1	Added results for 3 and 5 MHz bandwidth and added several UL Tx powers

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## History

<b>Document history</b>		
V1.1.1	August 2018	Publication as ETSI TR 103 554
V1.2.1	February 2019	Publication