CEPT

CEPT ECC Electronic Communications Committee

ECC Report 296

National synchronization regulatory framework options in 3400-3800 MHz: a toolbox for coexistence of MFCNs in synchronised, unsynchronised and semi-synchronised operation in 3400-3800 MHz

Approved 8 March 2019

0 EXECUTIVE SUMMARY

The purpose of this Report is to support Administrations in setting up the synchronisation frameworks at national level for the introduction of 5G-NR in the 3400-3800 MHz band in a multi-operator environment leveraging on the synchronised, unsynchronised and semi-synchronised modes.

This Report extends the contents in previous ECC Report 216 [1] and in ECC Report 281 [2] to account for the following new aspects:

- 5G-NR new frame structures bring new compatibility and performance aspects to be considered in the case of synchronised operation between 5G-NR and LTE-TDD, which make it desirable to also consider unsynchronised operation;
- The adoption of Active Antenna System (AAS) technology to MFCN base stations brings new challenges for unsynchronised operation (in terms of cost-effectiveness and spectrum efficiency of the LRTC's implementation), which makes it desirable to consider synchronised operation;
- Semi-synchronised operation is a new mode of operation that was not studied previously (LRTCs defined were conservative and aligned with unsynchronised operation in ECC Decision (11)06 (October 2018) [3].

Section 2 provides a general introduction about synchronised, semi-synchronised and unsynchronised operation including definitions, benefits and challenges.

Section 3 assesses the performance impacts (in terms of spectrum efficiency, UL/DL throughput and latency) for a few selected 5G-NR frame structures. The analysis also addresses options for the “LTE compatible” 5G-NR frame structures, suitable for the cross-technology synchronised operation between a 5G-NR and LTE-TDD networks.

Section 4 assesses the applicability of different mechanisms to manage the cross-link interference deriving from simultaneous UL/DL transmissions in case of unsynchronised and semi-synchronised operation when the ECC “baseline” out of block power limit (defined for the synchronised operating mode in ECC Decision (11)06 (October 2018)) is applied. This section analyses the impact of geographic separation between Macro-cellular networks as well as the impact associated with the adoption of alternative topologies (Micro BSs and Indoor BSs networks).

Leveraging on the analysis and studies performed in the previous sections, Section 5 proposes a “toolbox” with options to support Administrations and operators in identifying the most appropriate synchronisation regulatory framework at national level. The key elements from the “toolbox” are summarised hereafter.

Synchronised operation avoids any BS-BS and MS-MS interference therefore allowing coexistence between adjacent networks without the need for guard bands or additional filters. This operating mode simplifies network deployment because no additional interference mitigation is required. However, in order to implement this, within each deployment area/region, all MFCN licensees operating in the same band[1] should use:

- A common phase clock reference (e.g. UTC), with proper accuracy/performance constraints that depend on the underlining technology, and permanent monitoring and agreed remedies in case of accuracy loss. Those aspects and challenges are detailed in ECC Report 216;
- A compatible frame structure to avoid simultaneous UL/DL transmission, which determines a specific DL/UL transmission ratio and frame length. The chosen frame structure will contribute to the network performance (e.g. latency, spectral efficiency, throughput and coverage[2]). The feasibility and performance impacts of synchronised operation between different radio technologies have to be assessed on a case-by-case basis depending on the specific technologies. As assessed in this Report,

[1] Not limited to the licensees with adjacent blocks.

[2] For example: the size of the guard periods between DL and UL transmissions will have an impact on maximum cell radius. Increasing the number of UL transmissions has an impact on the UL coverage performance.

the synchronised operation of 5G-NR and LTE-TDD may imply a cost in terms of user plane latency and performance, especially with regards to 5G URLLC latency targets. Agreements on synchronised operation between operators will be simplified when the same type of services are targeted with the associated desired user plane latency and performance targets.

Unsynchronised operation does not require the adoption of a compatible frame structure among licensees. Licensees select the most appropriate frame structure independently and can adapt the frame structure to service and end user requirements, which may change depending on the location and on time. However, in a multi-operator scenario, the flexibility in operators' frame structure selection leads to a number of interference scenarios that need to be assessed and managed.

The cross-link interference deriving from simultaneous UL/DL transmissions could be managed with the adoption of the ECC restricted baseline out of block power limit which, based on currently available technology, would imply operator-specific filters and inter-operator guard bands. It is assumed that it will be challenging to implement operator-specific filters cost effectively in case of AAS BS, and that significant guard bands would be needed in such case (i.e. in case of implementation of the ECC restrictive out of block power limits). Therefore, this Report emphasizes on the need to implement a framework that would not require the implementation of the ECC restrictive out of block power limits, and provides an analysis on whether and under which conditions the unsynchronised operation can be used when base stations implement the ECC baseline out of block power limits. Here follows a concise summary of the outcomes:

- **Unsynchronised Macro-cellular networks:** Based on currently available filtering technology, guard bands and operator specific filters are necessary to enable unsynchronised operation between operators. Alternatively, geographic separation distances could be necessary but a specific recommendation or single set of trigger values cannot be provided due to the dependency on various factors. The studies show minimum distances required between unsynchronised Macro-cellular networks could be up to 60 km when operating co-channel and up to 14 km when operating in the adjacent channel without guard bands[3].
- **Unsynchronised Micro BS networks and Macro-cellular networks:** the studies show that, in general, adjacent channel unsynchronised operation of Macro-cellular networks and Micro BS networks might not be feasible in the same area. Separation distances have not been assessed in this Report. If there is no Macro-cellular network, adjacent channel unsynchronised operation between two Micro BS networks might be feasible with careful planning avoiding line of sight.
- **Unsynchronised Indoor BS networks and Macro-cellular networks:** under specific assumptions, adjacent channel unsynchronised operation should be possible with careful installation[4] of the indoor BSs. Such planning seems to be feasible in case of industrial – type of use case (e.g. smart factory indoor coverage). In the case of co-channel operation of Macro BSs and indoor BSs, the lack of out of block filtering on the Macro BS and on the indoor BS transmitters' sides will need to be considered.

Semi-synchronised operation corresponds to the case where part of the frame is consistent with synchronised operation as described above, while the remaining portion of the frame is consistent with unsynchronised operation as described above.

This leads to a limited degree of frame structure flexibility at the expense of some additional interference that can be controlled to some extent (for example, this operating mode could be implemented to avoid simultaneous UL/DL transmissions for control channels). All MFCN licensees operating in the same band and same coverage area/region should use:

- A common phase clock reference, as for synchronised operation;
- Partial frame alignment: the agreement shall define a default frame structure as for synchronised operation (for which UL/DL directions are defined across the whole frame) and at the same time the part of the frame where each operator is allowed to reverse the default transmission direction (flexible part). If

[3] These studies have assumed a "fully unsynchronised", also called "anti-synchronised" situation between the cellular networks (see Section 4).

[4] For example, "careful installation" would include measures like ceiling-mounted installation, placement of indoor BS away from windows, additional shielding around buildings in the worst case. Such measures may be more appropriate for professional installations which seem less suitable for consumer-type of scenario (without further mitigation schemes implemented in the indoor BS).

no changes are applied to the default frame structure, the semi-synchronised operation is identical to the synchronous case;

- The terms and conditions under which the ECC baseline out of block power limit can be applied to the semi-synchronised operation. These terms and conditions could be agreed between all operators, or they could be facilitated by the regulator. Some semi-synchronised scenarios might not require regulatory intervention.

With respect to semi-synchronised operation with the ECC baseline out of block power limit, it is useful to distinguish DL to UL and UL to DL modifications compared to the reference frame:

- **"DL to UL modifications"**: the default DL transmission direction in the flexible part is modified into UL
- From BS-BS interference perspective, the network that modifies the default DL into UL will not interfere with the other network(s) but it will receive additional interference from the other network(s);
- In most circumstances, MS-MS interference will be negligible because terminals typically transmit intermittently and many will be mobile so any interference would be transient. It is expected that some 5G use cases will imply the deployment of MSs that are in fixed positions and close to each other[5] which would result in permanent MS-MS interference[6]. No specific studies were performed on MS-MS interference, therefore, in case of MSs that are in fixed positions and close to each other, no conclusion can be derived. In any case, MS RF requirements are handled by SDOs and associated harmonised standards.

- **"UL to DL modifications"**: the default UL transmission direction in the flexible part is modified into DL
- From BS-BS interference perspective, the network that modifies the default UL transmission direction into DL will interfere the other network while it will not receive additional interference from the other network;
- Coexistence is facilitated if semi-synchronised operation is applied to Micro and indoor BS but it could be technically challenging for indoor BS to be semi-synchronised with outdoor networks; and
- Coexistence could be more challenging if semi-synchronised operation is applied to Macro BS before efficient interference cancellation algorithms have been developed and implemented. At the date of publication of this Report, 3GPP is studying such algorithms.

As a consequence, and considering that:

- With reference to the unsynchronised operation, it is assumed that the implementation of the ECC restricted baseline limit would imply operator-specific filters, which are challenging to implement cost effectively in the case of AAS BS with currently available technology. In addition, the implementation of the ECC restricted baseline limit would also require significant inter-operator guard bands, which are highly undesirable. Without operator-specific filters, it may not be possible to rely on guard bands alone to enable unsynchronised operation between Macro cells, and significant separation distances are likely to be required (up to 60 km when co-channel and up to 14 km when operating in the adjacent channel). Based on currently available AAS BS technology, it is therefore assumed that equipment will only implement filters designed to comply with the ECC baseline out of block power limit;
- Synchronised operation requires operators to agree on a compatible frame structure (which determines a specific DL/UL transmission ratio) and frame length, which contribute to the network performance (e.g. latency, spectral efficiency, throughput and coverage). Compatible frame structure may also introduce new operational constraints and additional costs: for instance, inter-operator synchronisation may lead to a less flexible DL/UL ratio selection, resulting in suboptimal spectrum utilisation for an individual operator (see ECC Report 216, section 3.3). Agreements on synchronised operation between operators will be simplified when operators adopt the same technology (e.g. 5G-NR) and target the same type of services with the associated desired user plane latency and performance targets;
- Synchronised operation and semi-synchronised operation both require a multilateral agreement between all MFCN licensees in the same band and coverage area / region (not limited to the licensees with adjacent blocks). Such agreement could be facilitated by the regulator (e.g. for reasons described in ECC Report 216 section 3.3).

---

[5] E.g. crowded stadiums, trains, buses, (home) CPEs in fixed wireless access (FWA) systems.

[6] The MS-MS interference will occur for MSs close to each other while communicating with different BSs / networks.

A **general framework** could be defined at the national level by Administrations wishing to do so specifying:

- The technical parameters for synchronised operation , and for semi-synchronised operation if appropriate (including reference clock and reference frame structure);
- The scope of synchronised, semi-synchronised and unsynchronised operation in terms of geographical areas and type of cells: E.g. in the case of AAS BSs, the general framework could specify that unsynchronised operation could only be implemented in those cases where additional isolation is available (e.g. separation distances would still allow the use of the ECC baseline out of block limit); in the case of semi-synchronised operation the general framework could specify in which scenarios DL slots may / may not be unilaterally converted to uplink slots, depending on national circumstances;
- Mechanisms to ensure the periodic review of the agreed conditions.

TABLE OF CONTENTS

LIST OF ABBREVIATIONS

Abbreviation	Explanation
3GPP	3rd Generation Partnership Project
AAS	Active Antenna System
ACI	Adjacent Channel Interference
ACIR	Adjacent Channel Interference Ratio
ACK	Acknowledgment
ACLR	Adjacent Channel Leakage Ratio
ACS	Adjacent Channel Selectivity
ARQ	Automatic Repeat reQuest
BEM	Block Edge Mask
BS	Base Station
CA	Carrier Aggregation
CEPT	European Conference of Postal and Telecommunications Administrations
CQI	Channel Quality Indicator
CSI	Channel State Information
DL	Downlink
DwPTS	Downlink Pilot Time Slot
EC	European Commission
ECC	Electronic Communications Committee
e.i.r.p.	Equivalent Isotropically Radiated Power
FDD	Frequency Division Duplex
GP	Guard Period
GSM	Global System for Mobile Communications
HARQ	Hybrid Automatic Repeat reQuest
IMT	International Mobile Telecommunications
ISD	Inter-Site Distance
LoS	Line of Sight
LRTC	Least Restrictive Technical Conditions
LTE	Long Term Evolution
eMBB	Enhanced Mobile Broadband
MIMO	Multiple Input Multiple Output
MFCN	Mobile/Fixed Communications Network
MS	Mobile Station

Abbreviation	Explanation
MU	Multi User
NLoS	Non Line of Sight
NR	New Radio
OFDM	Orthogonal Frequency Division Multiplexing
OOB	Out of Band
PRTC	Primary Reference Time Clock
RAN	Radio Access Network
RF	Radio Frequency
RTT	Round Trip Time
SCS	Sub Carrier Spacing
SEM	Spectrum Emission Mask
SLA	Service Level Agreement
SLAV	Side Lobe Attenuation
SR	Scheduling Request
SUL	Supplemental UpLink
TAI	International Atomic Time
TDD	Time Division Duplex
TRP	Total Radiated Power
TSG	Technical Specification Group
UL	Uplink
UMa	Urban Macro-cellular
UMi	Urban Micro-cellular
UMTS	Universal Mobile Telecommunications System
UPT	User Perceived Throughput
UpPTS	Uplink Pilot Time Slot
URLLC	Ultra Reliable Low Latency Communications
UTC	Coordinated Universal Time
WCDMA	Wideband Code Division Multiple Access

1 INTRODUCTION

The 3400-3800 MHz band has already been harmonised for MFCN in CEPT and is recognised to be the 5G primary band in Europe. The 3400-3800 MHz band has more contiguous spectrum than lower frequency bands and can allow wide channels which are necessary to make the 3400-3800 MHz band effective for 5G deployments. Compared to lower frequency bands and taking into account its expected introduction in most countries in the world this primary 5G band offers a combination of higher bandwidth and higher capacity as well as a good potential to become a future worldwide band for 5G.Many national Administrations within CEPT plan to enable initial 5G deployments in the 3400-3800 MHz band. At the date of publication of this Report, several European countries have awarded frequencies in at least a portion of the 3400-3800 MHz band since 2015 (e.g. Czech Republic, Finland, Hungary, Ireland, Italy, Latvia, Norway, Poland, Romania, Slovakia, Spain and the UK[7]). Other Administrations (e.g. Austria, Cyprus, France, Germany, Sweden, Switzerland, Portugal and the UK[8]) are planning to conduct similar auctions. Information on the synchronisation aspects during latest 3400-3800 MHz spectrum award procedures is provided in ANNEX 1.

While preparing the assignment procedures, Administrations may find ways to ensure the definition of the most appropriate synchronisation framework accounting for the local circumstances and local market demand.

The aim of this Report is to support the setup of the most suitable synchronisation framework at national level. This Report relies on the previously published ECC Report 216 (August 14) [1], ECC Report 281 (July '18) [2] and ECC Decision (11)06 (October 2018) [3].

- ECC Report 216 [1] provides band-neutral practical guidance for synchronisation of TDD networks. The Report addresses specific BS-BS and MS-MS interference scenarios in case of unsynchronised operation and provides background about synchronised operation, definitions, technical aspects for clock and phase / time, cross-technology frame alignment between WiMAX / LTE-TDD, and options for Administrations for designing a general framework at the national level for synchronised operation in a multi-operator context;
- ECC Report 281 (July '18) [2] and ECC Decision (11)06 (October 2018) [3] define the Least Restrictive Technical Conditions (LRTCs) applicable to 5G MFCN using non-AAS and AAS based station systems in the 3400-3800 MHz band. Such LRTCs extend the LRTCs defined in ECC Report 203 [5] (which was based on IMT-Advanced / 4G). The LRTCs include the baseline out of block power limit and the transitional regions power limits to be used in case of synchronised operation as well as the restricted baseline out of block power limit to be used in case of unsynchronised and semi-synchronised operation;
- Synchronisation and coordination of TDD MFCN networks across national borders is addressed by ECC Recommendation (15)01 [4].

This Report extends the contents in ECC Report 216 and in ECC Report 281 to account for the following new aspects:

- 5G-NR new frame structures bring new compatibility and performance issues in case of synchronised operation between 5G-NR and LTE-TDD, which make it desirable to consider unsynchronised operation;
- The adoption of Active Antenna System (AAS) technology to MFCN base stations brings new challenges for unsynchronised operation (in terms of cost-effectiveness of the LRTCs implementation), which makes it desirable to consider synchronised operation;
- Semi-synchronised operation is a new mode of operation that was not studied previously (LRTCs defined were conservative and aligned with unsynchronised operation in the aforementioned ECC Decision).

This Report provides:

- An analysis for the specific circumstances under which the unsynchronised operation could be allowed when the ECC baseline out of block power limit is applied instead of the ECC restricted baseline out of

[7] 3410-3480 MHz and 3500-3580 MHz.

[8] 3600-3800 MHz.

block power limit (see ECC Decision (11)06 Table 3 and Table 4 [3]) when adopting specific interference mitigation techniques or geographical isolation between networks;

- An analysis of the specific circumstances under which semi-synchronised operation could be allowed when the ECC baseline out of block power limit is applied, providing some degree of flexibility in the selection of UL/DL transmission direction at the cost of increased cross-link interference;
- An analysis of the performance impact of cross-technology synchronised operation between LTE-TDD and 5G-NR;
- A general toolbox to help Administrations define a regulatory framework for synchronised, semi-synchronised and unsynchronised operation for TDD networks at the national level.

2 SYNCHRONISATION MODES FOR TDD NETWORKS COEXISTENCE

Starting from the definitions provided in ECC Report 281 [2] for the synchronised, unsynchronised and semi-synchronised operation, this section highlights benefits and challenges associated with each mode and provides an overview on the interference mechanisms that characterise each operating mode.

Different interference scenarios may occur when two TDD networks are deployed in blocks within the same band (including the co-channel case and the adjacent channel case). Cross link interference will occur when simultaneous transmissions in uplink (UL) and downlink (DL) directions take place in different TDD networks (i.e. one BS (or MS) belonging to one network transmits while another BS (or MS) belonging to the other network receives (this will be referred to as "simultaneous UL/DL transmissions" throughout this Report).

As explained in the following Sections, simultaneous UL/DL transmissions do not take place in case of synchronised operation while such kind of transmissions take place in case of unsynchronised and semi-synchronised operation.

Figure 1 illustrates the interference scenarios in case of simultaneous UL/DL transmissions: the green arrows represent the desired links, while the potential interference is represented by the yellow arrows. BS-MS interference happens in all cases (FDD and TDD, whether synchronised or not) and is handled as part of the standards. MS-MS and BS-BS interference in unsynchronised and semi-synchronised TDD networks are within the scope of this Report.

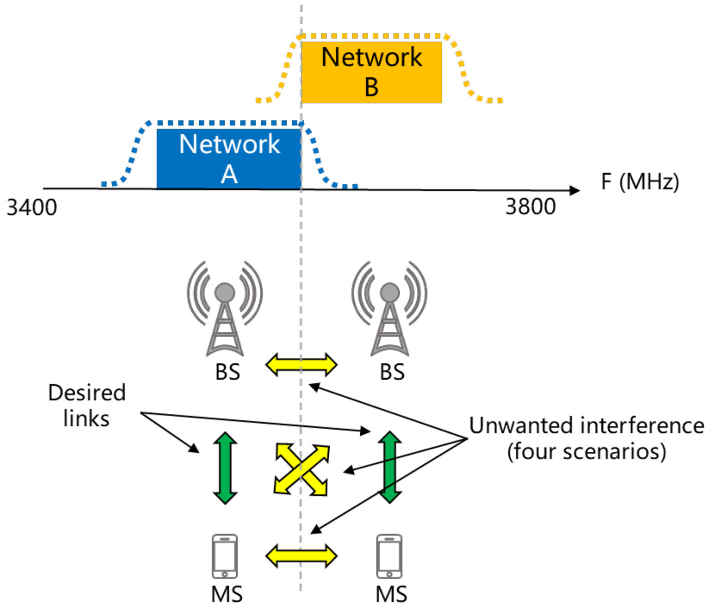


Figure 1: Interference scenarios in case of simultaneous UL/DL transmissions in MFCN TDD networks

2.1 SYNCHRONISED OPERATION

2.1.1 Definition

The word “synchronisation” is used in many different contexts with different meanings. For example, BS-MS synchronisation within the same network, frequency and phase synchronisation at the carrier level for demodulation purposes, frequency synchronisation for FDD networks such as GSM, etc. This Report will only focus on phase / time synchronisation at the frame level between TDD networks for interference mitigation purposes.

ECC Report 281 provides the following definition: "synchronised operation in the context of this Report means operation of TDD in several different networks, where no simultaneous UL/DL transmissions occur, i.e. at any given moment in time either all networks transmit in DL or all networks transmit in UL. This requires non-simultaneous UL/DL transmissions for all TDD networks involved as well as synchronising the beginning of the frame across all networks".

In order to deploy synchronised TDD mobile networks in a multi-operator context, operators need to reach agreement on:

- A common phase clock reference (e.g. UTC - Coordinated Universal Time) and accuracy / performance constraints that depend on the underlining technology (e.g. +/- 1.5 μs for LTE-TDD and 5G-NR), either using their own equipment to provide the clock, or sharing the same phase / time clock infrastructure;
- Permanent monitoring of the agreed clock source. When losing the primary reference time clock (PRTC) equipment may continue operation for a period of time ("holdover period") that has to be agreed and which depends on the quality of the local oscillator in the BS and on the wireless network accuracy requirement. If the PRTC is lost for a duration longer than the holdover period, the system shall no longer be considered in synchronised operation and may start interfering other channels, and therefore proper action shall be taken (e.g. the BS shall be shut down until the PRTC is recovered);
- A frame structure (including TDD DL/UL ratio and frame length) in order to avoid simultaneous UL/DL transmissions (guard periods may be different, as illustrated in Figure 3). The assessments in ANNEX 3 (summarised in Section 3) provide information on the implications associated with some specific but representative frame structures in terms of throughput performance, spectrum efficiency and latency.

The following figure illustrates the frequency, phase and time synchronisation concepts, which are described in [1].

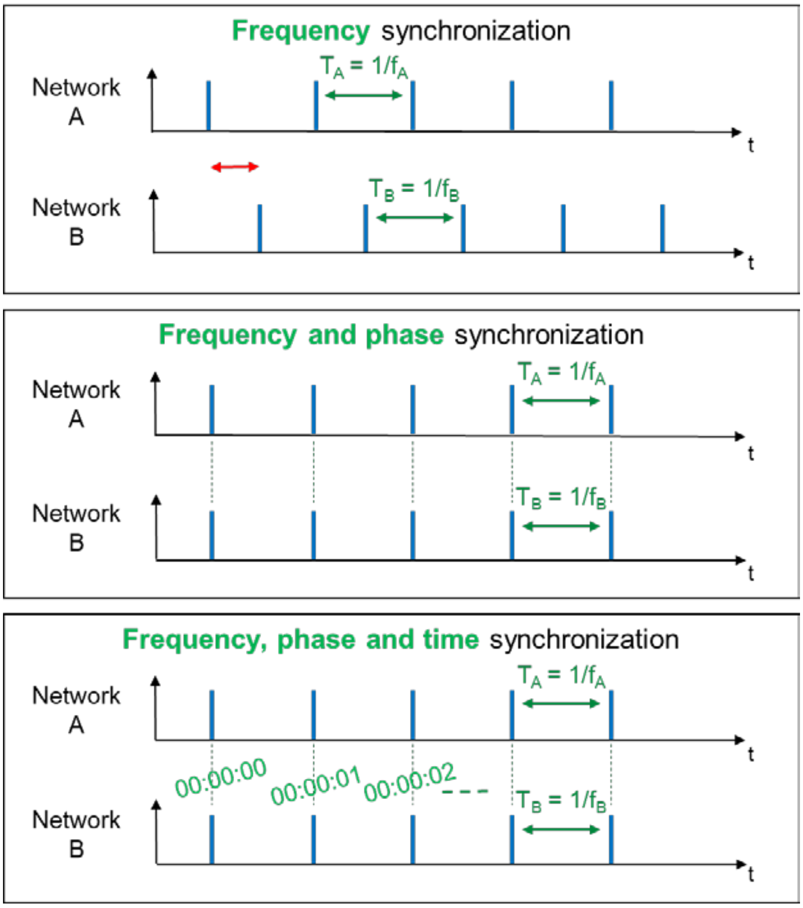


Figure 2: Frequency, phase and time synchronisation concepts

The following table provides the synchronisation requirements for MFCN technologies including 5G-NR in terms of frequency and phase accuracy.

Table 1: Frequency and phase synchronisation requirements for different MFCN technologies

Technology	Parameter	
	Frequency accuracy relatively to the reference oscillator	Phase accuracy relatively to the reference clock
GSM, UMTS, WCDMA, LTE-FDD	50 ppb	N/A
LTE-TDD	50 ppb	±1.5 µs (for cell radius ≤ 3 km)
	50 ppb	±5 µs (for cell radius > 3 km)
5G-NR	50 ppb	±1.5 µs

The following figure provides examples for simultaneous and non-simultaneous UL/DL transmissions in TDD networks.

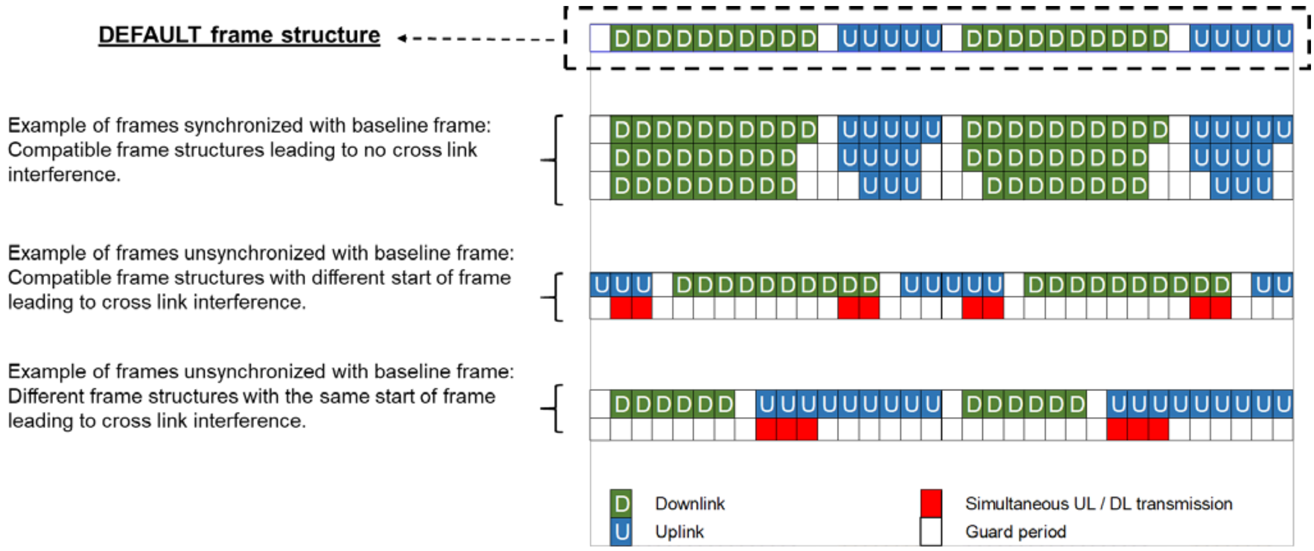


Figure 3: Examples of simultaneous UL/DL transmissions in TDD networks

In TDD networks, the maximum cell radius depends on the guard period between DL and UL transmissions: the examples above show how operators may implement guard periods of different durations (enabling different coverage radii) while maintaining compatible frame structures (i.e. while avoiding simultaneous UL/DL transmissions.

2.1.2 Benefits and challenges of synchronised operation

The ECC has defined the baseline and transition region out of block power limits for synchronised operation of MFCN BSs (see ECC Decision (11)06 (October 2018) Table 3 [3]). The ECC baseline accounts for the fact that BS-BS and MS-MS interference scenarios do not take place in case of synchronised operation. ECC baseline regulatory limit does not introduce additional constraints compared to the spectrum emission mask as defined by the standards.

The purpose of synchronised operation is to prevent BS-BS and MS-MS interference scenarios. Synchronised operation avoids performance degradation due to such interference without requiring additional mitigation techniques such as additional filtering (that may be challenging to implement in AAS BSs and MSs as will be described in section 2.2.2), inter-operator guard bands, geographical separation between BSs, etc.

Synchronised operation therefore simplifies operators' network deployments since less coordination for BS radio planning is required among synchronised operators.

However, the requirements associated with synchronised operation as described in the previous Section also lead to some challenges:

- Setup of the clock reference: operators have to agree on a common reference clock and common accuracy / performance. The +/- 1.5 µs accuracy might be challenging to achieve in some cases. Operators might consider deciding to share the clock infrastructure. Operators will in any case need to setup such accurate clock solutions within their own networks regardless on the possible need to synchronise their network with other networks;
- Clock quality monitoring and enforcement: since any imperfection in synchronisation affects other users in the band, operators must constantly monitor their reference clock quality (depending on the performance of the BS local oscillator) and take proper action (e.g. equipment shutdown if the reference clock is lost for more than an agreed amount of time). Operators (and/or Administrations) should therefore be able to test and enforce whether the clock quality is met;
- Compatible frame structure across operators: the frame structure determines a specific DL/UL transmission ratio and frame length, which contribute to the network performance (e.g. latency, spectral efficiency, throughput and coverage[9]). Therefore, the selection of a compatible[10] frame structure will provide the same contribution to the performance of all operators involved, with similar impacts on the services to end users.

  The compatible frame structures can be renewed over time, subject to the agreement. There are already precedents for this[11]. Some new mechanisms might be specified to review and periodically (involving regulators if needed) or dynamically adjust such parameters (this option is currently considered as challenging). For example, the agreement on a common DL/UL ratio could be based on a compromise taking all operators' performance requirements into account.

  The agreement between a small number of operators, potentially using the same technology, is easier to achieve than an agreement between multiple operators, potentially using different technologies and potentially targeting different services.

  It is to be noted that the adaptability of DL/UL ratios in time and according to different geographic locations may or may not be a market requirement in a given market.

  Depending on the regulatory framework in place, the possible regulator choice for a "preferred frame structure" could lead to problems in terms of compliance with the technology neutrality principle if the chosen format would not be supported by some candidate TDD technology for the band.

In case of existing unsynchronised networks with locally / regionally assigned spectrum, the unsynchronised operation of the 5G network would result in interference with the local / regional networks while the synchronised operation of the 5G network with the local / regional networks would lead to interference within the national network. In this case, it might be desirable to consider the synchronised operation also for the existing local / regional networks.

All issues above apply in all cases of TDD coexistence, including in 5G-NR / 5G-NR and LTE-TDD / 5G-NR coexistence cases. In case of LTE-TDD / 5G-NR synchronised operation, 5G-NR may be negatively impacted in terms of latency performance of 5G; section 3.3 and ANNEX 3 provide detailed assessments on these matters.

---

[9] For example: the size of the guard periods between DL / UL transmissions will have an impact on maximum cell radius. Increasing the number of UL transmissions has an impact on the UL coverage performance.

[10] As described in ECC Report 216 section2.1, 8 the frame structures do not need to be exactly identical provided that the last transmitter stops before the first receiver starts, taking into account the propagation delay (e.g. in LOS non co-sited cases).

[11] Two of the Italian operators (Tiscali and Linkem) that acquired spectrum usage rights from the 3400-3600 MHz assignment procedure in 2007 have agreed on common synchronisation and non-simultaneous UL/DL transmissions by agreeing on a common frame structure. The following format was chosen to facilitate coexistence between LTE-TDD and the existing WiMAX system: LTE configuration #2 with Special sub-frame structure #5 3:9:2 - "WiMAX compatible". At a latter stage, the two operators eventually agreed to change to a new common format after WiMAX migration to LTE-TDD. With the progressive refarming of WiMAX technology towards LTE-TDD, operators started their migration towards a different frame structure which is the one that is now more commonly adopted: LTE configuration #2 with Special sub-frame structure #7 10:2:2.

2.2 UNSYNCHRONISED OPERATION

2.2.1 Definition

The “unsynchronised operation” terminology refers to the general case where neither time synchronisation between operators’ MFCNs nor inter-operator frame alignment is implemented (of course, this does not prevent an operator to use the synchronised operation within its own network to avoid co-channel interferences). More precisely, ECC Report 281 has provided the following definition “the unsynchronised operation in the context of this Report means operation of TDD in several different networks, where at any given moment in time at least one network transmits in DL while at least one network transmits in UL. This might happen if the TDD networks either do not align all UL and DL transmissions or do not synchronise at the beginning of the frame".

The ECC has defined the restricted baseline out of block power limit for unsynchronised and semi-synchronised operation of MFCN BSs (see ECC Decision (11)06 (October 2018) Table 4 [3]).

2.2.2 Benefits and challenges of unsynchronised operation

The benefit of unsynchronised operation is in the fact that it does not require the adoption of a compatible frame structure among operators. Operators can select the most appropriate frame independently and can adapt the frame structure to service and end user requirements in space and time domains. This allows more flexibility in the execution of operators’ business models.

However, in a multi-operator scenario, the flexibility in operators’ frame structure selection leads to a number of interference scenarios that need to be assessed and managed.

As illustrated in Figure 4, BS-BS interference is a result of two separate and independent phenomena.

Spectral leakage from the interfering BS transmitter side:

This is where a BS radiates unwanted emissions into adjacent channels, thereby effectively increasing the noise-plus-interference floor at a victim BS and resulting in desensitisation. The extent of spectral leakage of the interfering BS is defined by its adjacent channel leakage ratio (ACLR) and unwanted emission specifications.

BS-BS interference due to spectral leakage can be mitigated by restricting the unwanted emissions of unsynchronised BSs through the specification of regulatory block edge masks (BEMs). An example is the restricted baseline out of block power limit defined in the ECC Decision (11)06 (October 2018)[3]: the regulatory upper limit of -43 dBm/5MHz on the out-of-block TRP of unsynchronised AAS BSs in the 3400-3800 MHz band applicable at the frequency boundary (block edge) with another operator. The ECC restricted baseline out of block power limit is significantly more restrictive than the ECC baseline limits for synchronised BSs, and compliance with it would require the installation of costly operator-specific transmitter filters in non-AAS systems. It is even more challenging to achieve in AAS systems where additional internal filters would be required.

Therefore, based on currently available filtering technology for AAS, unsynchronised operation could be implemented only in those cases where additional isolation (e.g. separation distances) or specific network configurations (e.g. indoor low power BSs) would still allow the use of the ECC baseline out of block limit as defined in ECC Decision (11)06 (October 2018) Table 3[12]. The identification of such specific cases is addressed in Section 4, which highlights deployment challenges.

[12] With reference to the restricted baseline limits defined for AAS base stations, ECC Report 281 [2] states: ”For unsynchronised and semi-synchronised operations, if no geographic or indoor/outdoor separation is available, the restricted baseline limit must be respected. However, agreements at national level (including bilateral agreements among any pair of adjacent MNOs) may be concluded to allow the definition of a different BEM. ”With this respect, ECC Report 281 refers to the possibility to account the information provided in this toolbox Report.

Blocking of the victim BS receiver:

This is where the victim BS's receiver is unable to decode a weak wanted signal when simultaneously being exposed to a relatively high received carrier power radiated by an interfering BS operating in another channel. The impact would be a desensitisation of the victim BS or, in an extreme case, the complete overload of the victim BS's RF front-end. The extent of susceptibility of a victim BS receiver is defined by its adjacent channel selectivity (ACS) and blocking specifications.

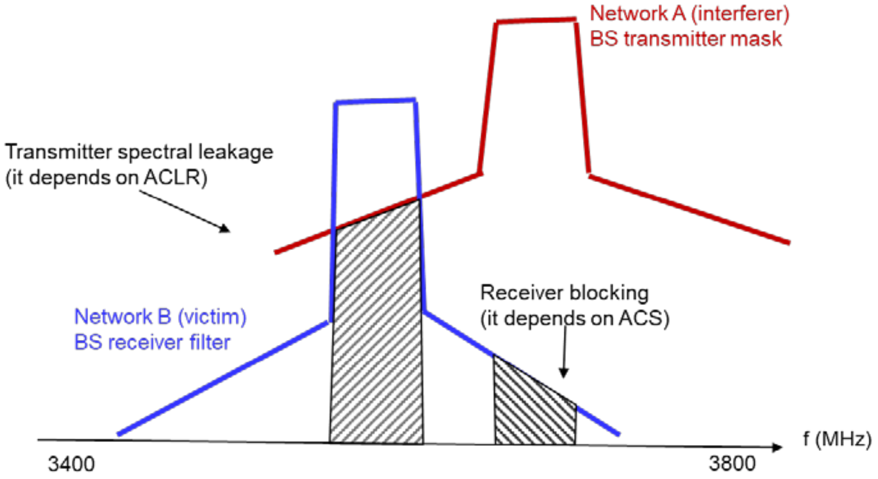


Figure 4: BS-BS interference mechanisms in case of simultaneous UL/DL transmissions

It should be noted that the application of stringent regulatory limits on the interfering BS wanted emissions alone may not be sufficient to mitigate BS-BS interference with the currently available equipment. This is because the in-band blocking phenomenon can only be avoided through installation of additional operator-specific RF receiver filters at the victim BSs receiver to suppress the received adjacent channel carriers. As such, a regulatory framework for unsynchronised BSs should take into account for the level of the victim BS receiver selectivity. For the same reason, implementing a guard band within a TDD band does not solve all interference cases if equipment does not implement operator specific hardware filters in their RF front-end to protect from in-band blocking. These RF filters would have to be operator specific, which would not be implementable from an economical or mechanical point-of-view. In addition this approach is totally not applicable on MS side to solve MS to MS interference

Unsynchronised operation therefore requires all of the operators in a band in the same geographical area / region to comply with the ECC restricted baseline out of block limit over the frequency blocks of other operators. Furthermore the addition of inter-operator guard band and operator-specific RF filters on both BSs transmit and receive sides is required to avoid blocking.

- In case of non-AAS BSs, it is possible to deploy external custom filters specifically designed for each operator spectrum;
- In case of AAS BSs, as illustrated below the BS RF and antenna units are integrated without an accessible interface between the RF unit and the antennas. The regulatory requirements would therefore need to be met by product design and any filters would need to be internal, integrated by the vendor during the manufacturing process.

At the time of the publication of this Report, AAS systems can neither achieve cost-effectively the restricted ECC baseline out of block limit defined for unsynchronised (and for semi-synchronised) operation on the transmitter side, nor implement the required operator-specific filters to protect from blocking on the receiver side, both in adjacent and non-adjacent channels in the same band.

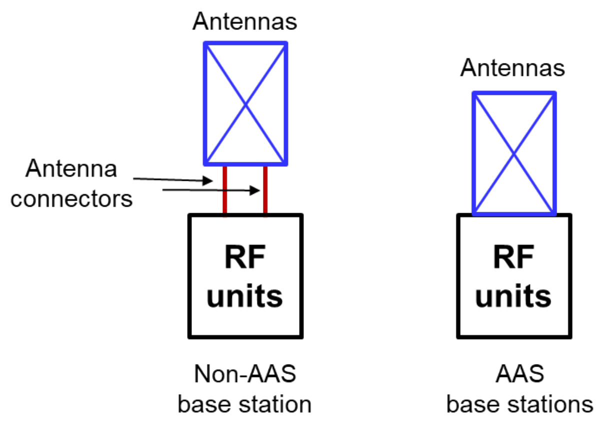


Figure 5: AAS and non-AAS base stations architecture

It is therefore expected that, based on currently available technology, AAS systems will have generic band filters aligned with SDOs RF requirements (and with the ECC baseline and transitional regions out of block limits). The introduction of guard bands alone would not be sufficient to allow unsynchronised operation; meeting the ECC restricted baseline limit would also require operator-specific filters for AAS BSs which are not currently seen as cost-effective. Based on the above, unsynchronised operation with AAS BS would require additional mitigation techniques, which are assessed in section 4.

Unsynchronised operation also leads to MS-MS interference as a result of both spectral leakages from the interfering MS and blocking of the victim MS. Out of band emissions and adjacent channel requirements for MS are defined in the relevant harmonised standards for synchronised operation rather than for unsynchronised operation.

ECC identifies the BS-BS interference scenario as the most critical and, for the interference resulting from transmitter spectrum leakage, regulates it accordingly. Blocking is taken into account in 3GPP standards in the case of synchronised operation. This is justified by the fact that MS activity is more intermittent than BSs', and by the fact that statistical factors mitigate the criticality of the MS-MS interference mechanism since devices are typically mobile.

MS-MS interference in the 2.6 GHz band was studied in ECC Report 131 [6], and. ECC concluded that MS-MS interference was handled through standardisation. Therefore, ECC did not adopt BEMs for terminals.

The situation in the 3400-3800 MHz band is more favourable due to the higher propagation losses, which further limit MS-MS interference.

2.3 SEMI-SYNCHRONISED OPERATION

2.3.1 Definition

ECC Report 281 provides the following definition: "the semi-synchronised operation corresponds to the case where part of the frame is consistent with synchronised operation as described above, while the remaining portion of the frame is consistent with unsynchronised operation as described above. This requires the adoption of a frame structure for all TDD networks involved, including slots where the UL/DL direction is not specified, as well as synchronising the beginning of the frame across all networks".

A very generic description of semi-synchronised operation is depicted in Figure 6 where Operator A and Operator B operate in adjacent channels. The operators can designate portions of the frame to have synchronised fixed duplex direction, i.e. they are always DL or always UL. For the remainder of the slots, the operators may choose semi-static but different, or time-varying duplex directions.

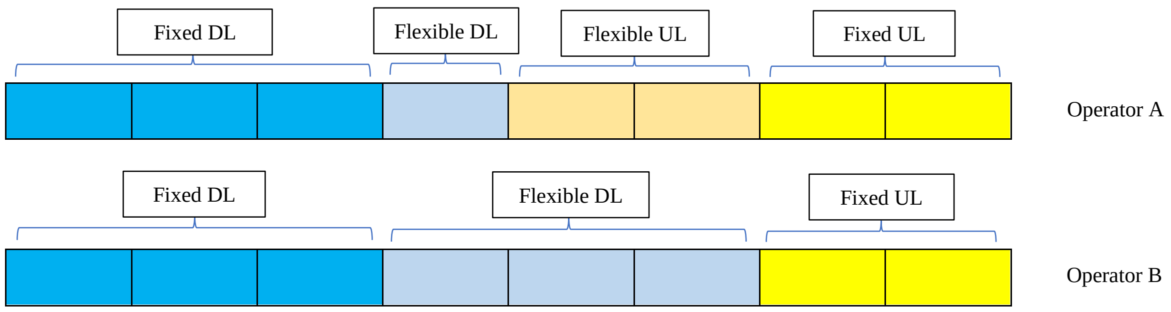


Figure 6: Example of semi-synchronised operation

Semi-synchronised operation is therefore a mode of operation similar to synchronised operation, with the exception that the frame structure alignment is relaxed to allow some controlled degree of flexibility at the expense of some additional interference that can be controlled to some extent. Taking into account the challenges to implement unsynchronised operation with the ECC restricted baseline out of block power limit as it was described in the previous Section, semi-synchronised operation aims to find a balance between more flexibility (compared to synchronised operation) and some acceptable data-loss. The part of the frame with flexible UL/DL transmissions may suffer from BS-BS and MS-MS interference with respect to both leakage and blocking interference mechanisms as described in section 2.2.2, therefore the conditions where semi-synchronised operation will be considered acceptable with regard to the data-loss have to be carefully discussed and agreed at the national level.

In a specific implementation of semi-synchronised operation, the control plane can be protected by ensuring that the control signals never belong to the flexible part of the frame. This is different from the case of unsynchronised operation where both control and data channels can be interfered leading to potentially larger loss (e.g. inability to decode the whole frame resulting in large throughput degradation).

Semi-synchronised operation between TDD networks requires the following agreements between operators:

- Time synchronisation – as in the case of synchronised operation;
- Partial frame alignment: the agreement shall define a default frame structure for synchronised operation (for which UL/DL directions are defined across the whole frame) and at the same time the part of the frame where each operator is allowed to reverse the default transmission direction.

Semi-synchronised operation can also be applied in case of coexistence between different technologies operating in adjacent frequency blocks if the operators involved agree on a frame structure, which could contain some flexible portions of the frame. A different degree of flexibility in the assignment of UL/ DL transmission directions to the different portion of the frame (e.g. in granularity, dynamic vs. static) and in the ability to protect control channels can be achieved by different features.

2.3.2 Benefits and challenges of semi-synchronised operation

Semi-synchronised operation allows for some degree of frame structure flexibility when compared with synchronised operation.

Just like synchronised operation, semi-synchronised operation requires operators to find an agreement with all other concerned operators in the band and in the same area if they want to deploy without any other additional coexistence mitigation. An agreement between two operators, potentially using the same technology, is easier to achieve than an agreement between multiple operators, potentially using different technologies and potentially targeting different services.

Semi-synchronised operation introduces an upper limit to the BS-BS and MS-MS interference when compared with unsynchronised operation.

Operators may trade-off between frame flexibility and risk of interference. In some circumstances, semi-synchronised operation of BSs meeting the ECC baseline out of block limits (defined for the synchronised operation) will be possible in the same geographical areas without guard bands and operator-specific filters with an increase in lost packets that operators may consider acceptable[13]. The applicability of the ECC baseline out of block limit is investigated in section 4.5.

Should operators agree to allow semi-synchronised operation based on the ECC baseline out of block power limit (waiving the requirement for ECC restricted baseline), then the part of the frame with flexible UL/DL transmissions may suffer from BS-BS and MS-MS interference with respect to both leakage and blocking interference mechanisms as described in section 2.2.2.

- There are some 5G use cases that imply the deployment of MSs that are in fixed positions and close to each other (e.g. crowded stadiums, trains, busses, (home) CPEs in fixed wireless access (FWA) systems, fixed machinery/robots in factories). In such scenarios, the MS-MS interference might not be negligible anymore: no studies were performed with this respect.

In order to support semi-synchronised operation, BSs may have to implement interference mitigation techniques. For example, in a scenario where a portion of the DL periods can be used for UL:

- Using zero forcing to create a null in the direction of the interference coming from the neighbour network operating in the adjacent band although it is currently unclear to what extent such techniques will be effective and additional implementation costs that still need be determined;
- Limiting the UL transmission to part of the occupied bandwidth far from the edge of the operator block and using a robust modulation and coding scheme although the extent to which this would reduce spectral efficiency still needs to be determined.

In terms of market availability, some features needed to support some semi-synchronised operation scenarios are optional in 3GPP specifications. The latest updates on the status and future plans in 3GPP (Rel. 15 and Rel. 16) on the unsynchronised and semi-synchronised operating modes are available in ANNEX 9.

2.4 OPERATING MODES SUMMARY

The following table provides a summary for the options associated with the synchronised, unsynchronised and semi-synchronised operating modes.

Table 2: Options associated with the synchronised, unsynchronised and semi-synchronised operating modes

Options	Synchronised	Semi-synchronised	Unsynchronised
Common clock across networks	Mandatory (with proper SLA) ▪ A common phase clock reference (e.g. UTC) and accuracy/performance constraints (e.g. +/- 1.5 μs), either using their own equipment to provide the clock, or sharing the same phase / time clock infrastructure. ▪ Operators shall monitor their clock source and shutdown their equipment if they lose the reference clock for duration longer than the holdover period of their equipment (which depends on the quality of the local oscillator in the BS).		Not needed.

[13] With reference to the restricted baseline limits defined for AAS base stations, ECC Report 281 [2] states "For unsynchronised and semi-synchronised operations, if no geographic or indoor/outdoor separation is available, the restricted baseline limit must be respected. However, agreements at national level (including bilateral agreements among any pair of adjacent MNOs) may be concluded to allow the definition of a different BEM". With this respect, ECC Report 281 refers to the possibility to account the information provided in this toolbox Report.

<table>
<tr><th>Options</th><th>Synchronised</th><th>Semi-synchronised</th><th>Unsynchronised</th></tr>
<tr><td>Compatible frame structure across networks</td><td>A compatible frame structure (including TDD DL/UL ratio and frame length) in order to avoid simultaneous UL/DL transmissions.</td><td>Same as for synchronised operation with the additional possibility for operators to agree on the parts of the frame when flexible UL/DL transmissions can occur.</td><td>Not needed, full flexibility.</td></tr>
<tr><td rowspan="2">Out of block power limits: need for filters, guard bands …</td><td rowspan="2">The baseline out of block power limit as defined in ECC Decision (11)06 (October 2018) Table 3 [3] applies.

No additional filtering required on top of 3GPP RF specifications (e.g. AAS BS may be provided with generic band filters in their RF frontend). No need for any guard bands or additional isolation.</td><td colspan="2">The ECC restricted baseline limit (as defined in ECC Decision (11)06 (October 2018) Table 4 [3]) applies by default. In this case:
▪ The interfering BS transmitter side requires custom filters and guard band;
▪ The victim BS receiver side also requires custom filters to avoid blocking.

Both requirements are difficult to be cost effectively implemented in AAS BSs with currently available technology.

However, as described below, this Report indicates those cases where the ECC baseline limit could be applied to the semi-synchronised mode and those cases where the ECC baseline limit can be applied to the unsynchronised operation mode.</td></tr>
<tr><td>The ECC baseline out of block power limit is expected to be applicable to the semi-synchronised operation in a wider range of circumstances compared to the case of unsynchronised operation. Coexistence between operators can be managed by agreeing which portions of the frame may be used for flexibly for UL/DL transmissions.

Operators may find the most appropriate balance between improved frame structure flexibility and throughput degradation caused by cross-link interference.

Coexistence studies (see section 4.5 and ANNEX 8) assessed the impacts in case of Macro BS and Micro BS deployments.</td><td>However, at national level, operators, in specific scenarios (e.g. power restrictions, geographic isolation) that are in the scope of this Report - section 4 and in the associated Annexes), may mutually agree to apply the baseline out of block power limit (as defined in ECC Decision (11)06 (October 2018) Table 3) to unsynchronised operation under specific circumstances.</td></tr>
</table>

With reference to the synchronised and semi-synchronised operation which require a common clock synchronisation and the initial agreement among operators on compatible frame structure:

- ANNEX 2 provides an overview on the mainstream technical options to implement network synchronisation.
- Section 3 and the associated ANNEX 3 provide performance assessments (in terms of UL/DL throughput spectral efficiency and latency) associated with different 5G-NR frame structures;
- Section 5 provides more information on the operator agreements required at national level to enable the synchronised operation mode;

3 PERFORMANCE IMPACTS FROM FRAME STRUCTURE SELECTION

One of the main scenarios for the rollout of 5G will be based on the 5G-NR air interface and on Macro BSs implementing AAS technology in a multi-operator environment. The unsynchronised operation in such scenario would pose additional challenges compared to the existing TDD uses in the 3500 MHz or 2600 MHz which:

- Were mostly based on Macro non-AAS BSs (see section 2.2.2), where unsynchronised operation with guard band and custom filters was feasible cost-effectively;
- Were often involving one operator per geographic region with limited inter-operator synchronisation issues;
- Were mostly based either on WiMAX or LTE-TDD.

Inter-technology synchronised operation between WiMAX and LTE-TDD has been achieved in a number of cases by adopting the “WiMAX compatible” LTE-TDD frame structure[14] without significant performance loss for LTE-TDD (see ECC Report 216 section 2.3.2). However, synchronised operation between WiMAX / LTE-TDD and 5G-NR may imply a cost in terms of performance with regards to 5G latency targets especially.

This Section focusses on the implications associated with the selection of a compatible frame structure in a 5G-NR multi-operator context. There may also be a need to ensure coexistence with LTE-TDD base stations for some Administrations. This section summarises the results from two performance assessments (see the full studies in ANNEX 3) between three possible examples of 5G-NR frames (“DDDSU”, “DSDU” and “DDDDDDDSUU”[15]). Other 5G-NR frame structures can be considered for selection, although the performance has not been assessed in this Report, such as: "DDSU", "DDSUU", "DDDSUUDDDD[16]" or combinations like "DDDSUDDSUU".

3.1 GENERAL INFORMATION ABOUT 5G-NR FRAME STRUCTURE

Compared to LTE-TDD, 5G-NR allows significantly more flexibility in the frame structure with the ability to configure uplink / downlink / mixed transmission at the symbol level. This is necessary for some solutions to fulfil IMT-2020 compliance on URLLC latency.

This section provides a brief description for the 5G-NR frame structures while sections A3.1 and A3.2 include more details on LTE-TDD and 5G-NR frame structures respectively.

5G-NR downlink and uplink transmissions are organised into frames with 10ms duration, each consisting of ten sub-frames of 1ms duration. The number of consecutive OFDM symbols per sub-frame is given by:

$$N_{\text{symb}}^{\text{subframe},\mu} = N_{\text{symb}}^{\text{slot}} N_{\text{slot}}^{\text{subframe},\mu}$$

Each frame is divided into two equally-sized half-frames of five sub-frames each with half-frame 0 consisting of sub-frames 0 – 4 and half-frame 1 consisting of sub-frames 5 – 9. The UL or DL transmissions are configured within each slot. With reference to the transmission directions, OFDM symbols in a slot can be classified as 'downlink' (denoted 'D'), 'flexible' (denoted 'X'), or 'uplink' (denoted 'U') see ANNEX 3.

3.2 PERFORMANCE IMPACTS OF 5G-NR FRAME STRUCTURES

The frame structure selection has an impact on several aspects of network performance, including:

---

[14] LTE frame structure #2 with Special Sub-frame structure #5 3:9:2.

[15] 5G-NR frame structure compatible with LTE frame structure.

[16] 5G-NR frame structure compatible with LTE frame structure.

- DL/UL traffic ratio;
- Spectrum utilisation efficiency;
- Round-trip time (RTT) latency[17];
- Coverage (DL synch. coverage and UL coverage).
- As described below, there are links between the aspects that are listed above. The selection of a certain frame structure will improve performance in some aspects whilst reducing it in others. The selection of a certain frame structure therefore aims at reaching the most appropriate performance trade-off for the specific operator's needs and targets in terms of services to the end users.

The frame structure determines a specific DL/UL ratio: the frame structure selection shall therefore carefully account for the expected traffic patterns. The DL/UL ratio typically relates to the traffic generated by the services proposed by the operator and therefore can be linked to the business model of the operator.

The more frequent the DL/UL and UL/DL switching, the lower the RTT is. A short latency improves the channel estimation quality (CQI feedback) using TDD channel reciprocity properties and also enables fast HARQ retransmissions. More frequent switching therefore has a positive impact on spectrum efficiency in high mobility conditions. On the other hand, considering that guard periods (GP) are required at each DL/UL switch, more frequent switching increases the GP overhead that can have a negative impact on spectrum efficiency.

The frame structure impacts coverage performance. The guard period (GP) between downlink and uplink must be large enough to compensate the propagation delay for large cells (and for coexistence with other cells in line of sight). If a TDD cell can interfere with another cell up to 60km away in co-channel, then this means that the GP may need to be larger than 200µs.

As illustrated in Figure 7, different frame structures correspond to different trade-offs relatively to key performance aspects. Operators in different markets will assess the behaviour of the key network characteristics associated with the different frame structure options in order to decide the most appropriate frame structure for their own networks and when discussing the options for a compatible frame structure with other operators. Operators owning other MFCN frequency bands (e.g. 700, 800, 900, 1800 MHz or mmWave) will have the possibility to use jointly such frequencies with the 3400-3800 MHz band through the Carrier Aggregation or Supplemental Uplink schemes (CA/SUL). Such combined use will provide additional ways to meet the target network characteristics. The terminals supporting the CA/SUL schemes will require to support another band in addition to the C-band.

Carrier Aggregation (CA) is a technique that aggregates various component bands into an overall wider bandwidth. Supplementary UpLink (SUL) makes it possible to use another frequency carrier for NR UL transmission instead of NR's dedicated UL carrier in a switchable manner. SUL is similar to CA, however, unlike CA concept, simultaneous data transmissions are not possible in SUL carrier and NR UL carrier it is linked to. Additionally, there is no possibility for precise estimation by the UE of the coupling loss needed for the open loop power control.

17 As defined in Section A3.1.7.

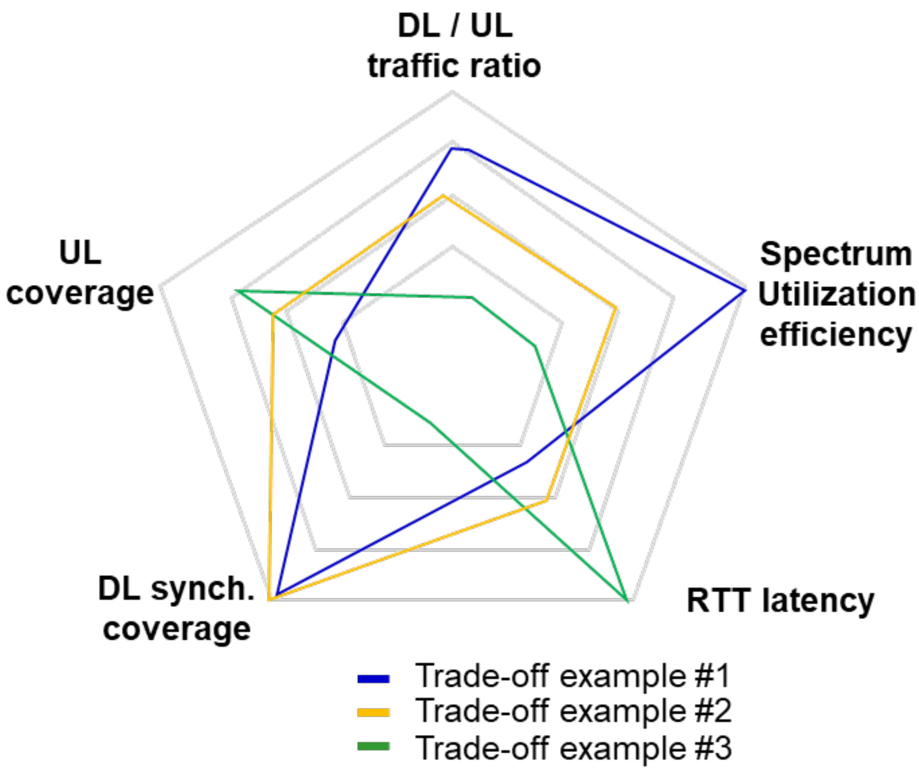


Figure 7: Factors for frame structure selection[18]

All of those effects have been studied in order to quantify them, and the detailed studies are in ANNEX 3.

3.3 COMPATIBILITY OF 5G-NR FRAME WITH LTE-TDD FRAME STRUCTURE

With reference to the synchronised operation of 5G-NR BSs and LTE-TDD BSs, noting that every LTE-TDD frame configuration has at least one compatible 5G-NR equivalent configuration, the 5G-NR TDD pattern should be based on the following sequence of DL, UL and special slots: "DDDSUUDDDD". Two example variants[19] may be considered:

- Variant 1: LTE-TDD and 5G-NR have an aligned frame start, e.g. "DDDSUUDDDD";
- Variant 2: non-zero frame start offset between LTE-TDD and 5G-NR, e.g. “DDDDDDDSUU”.

These variants, with 30 kHz subcarrier spacing (SCS) can be aligned to LTE-TDD “DSUDD” frame structure with 15 kHz SCS (LTE-TDD frame configuration #2).

It is to be noted that there should also be a compatible structure for the symbols within the LTE-TDD "S" sub-frame. For the studies considered in this Report, the “DDDDDDDSUU” frame configuration is used to represent the performance that 5G-NR would have in case of synchronised operation with a neighbour LTE-TDD network in the same band and in the same area using LTE-TDD frame configuration #2. Note that similar results apply in case the non-shifted variant, i.e. "DDDSUUDDDD", is used.

[18] The examples in this figure do not refer to the frame structures that are addressed in the studies from this Report.

[19] Applicable in case of LTE-TDD configuration #2 frame.

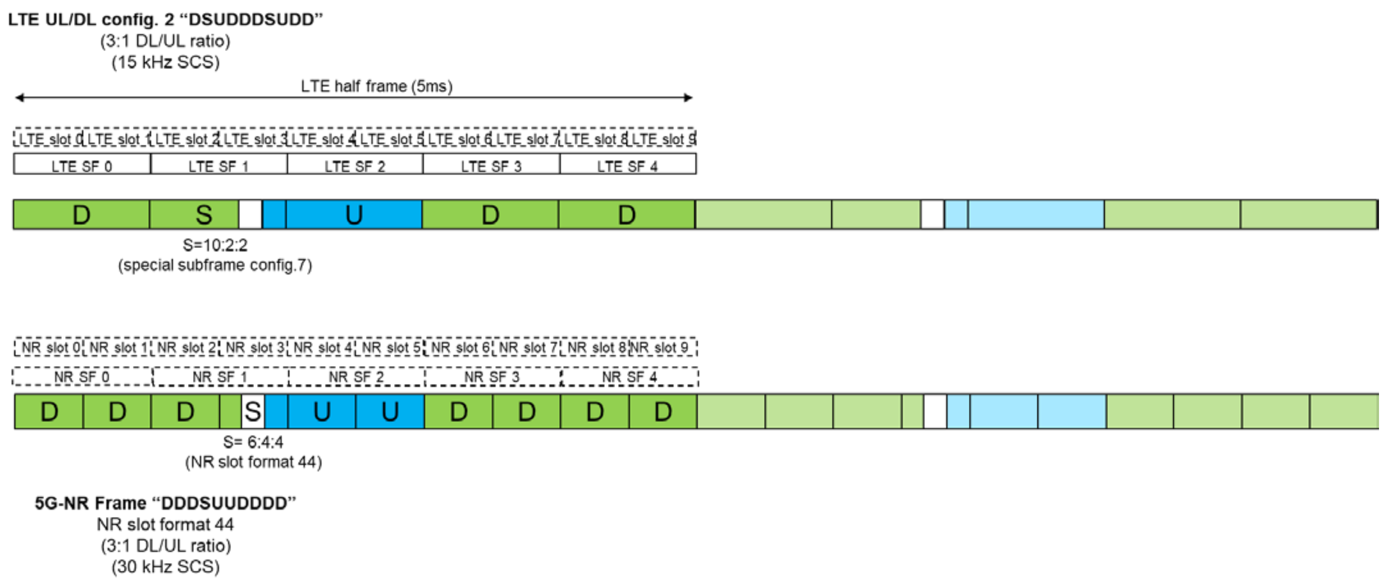


Figure 8: Variant 1 - Synchronised operation of 5G-NR ("DDDSUUDDDD" frame) and LTE-TDD ("DSUDD" frame)

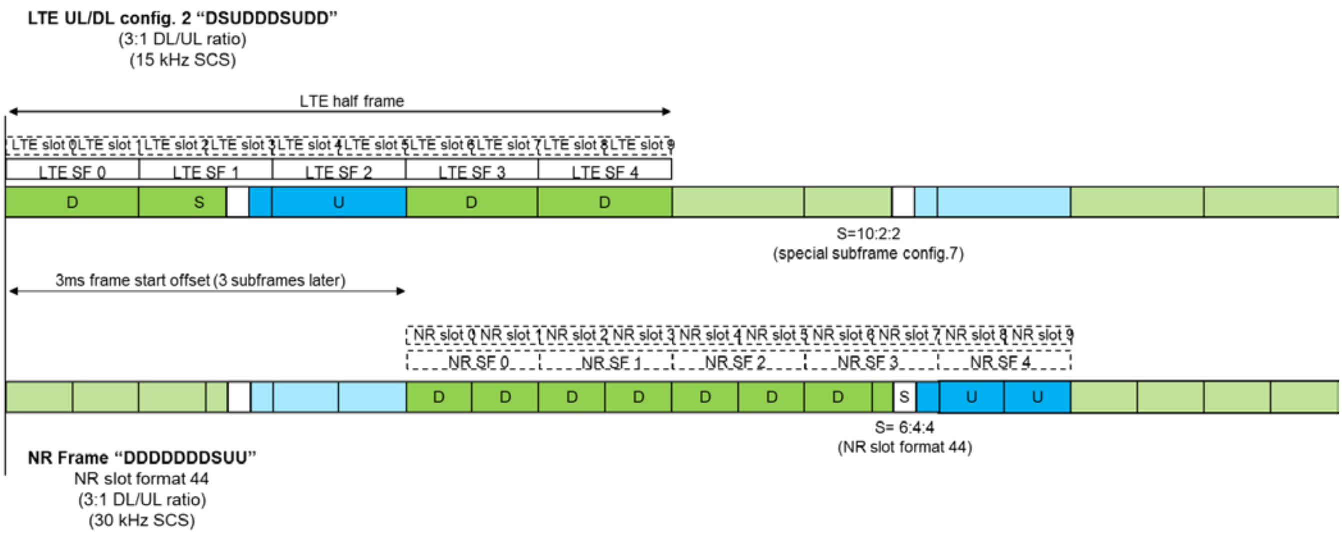


Figure 9: Variant 2 - Synchronised operation of 5G-NR ("DDDDDDDSUU" frame) and LTE-TDD ("DSUDD" frame)

The performance assessment of 5G-NR in case of adoption of the "LTE-TDD compatible" frame structure is provided in the following sections where the results from studies # 1 and # 2 are provided.

3.3.1 Summary from Study #1 (grant-based UL transmissions)

Study #1 provides an assessment in terms of latency and capacity performance for two frame structures provided, namely DSDU and LTE-TDD compatible frame structure.

The analysis carried out in this study assumes grant-based UL transmissions.

Detailed assumptions and a full set of simulation results are presented in Appendix A.3.3.1; in the following a summary of latency and capacity comparison between the two analysed frame structure is reported.

Latency assessment

A summary of the latency analysis results is reported in Table 3.

Table 3: Simulation analysis – latency

Parameter	DSDU	LTE-TDD compatible frame structure[20]
# required HARQ processes	4	8
DL HARQ RTT	2-3 ms	5 ms
UL HARQ RTT	2 ms	5 ms
UL scheduling delay	1-2 ms	4.5-9.5 ms

It can be observed that when 5G-NR has a frame structure aligned with LTE-TDD (configuration #2 as in this specific example), considering scheduling and MS / network processing latency, this frame structure will lead to L1 latency > 4 ms. As already mentioned, the IMT-2020 eMBB latency requirement is 4 ms and URLLC latency requirement is 1 ms. Therefore, 5G-NR deployments in 3400-3800 MHz using the LTE-TDD frame structure would not be able to meet some of the IMT-2020 requirements, including the deployment of innovative services such as URLLC, unless spectrum in other bands can also be used.

With the assumptions provided in Appendix 3.3.1, the DSDU configuration shows significant benefits over the LTE-TDD compatible 5G-NR frame structure with respect to HARQ RTT and UL scheduling delay, as reported in Table 3. The simulations result in more than twice the time (5 ms) that is needed to complete one HARQ round trip as compared to DSDU (2-3 ms).

Table 3 also shows the improved scheduling delay (1-2 ms) over the time required in the case of LTE-TDD synchronisation (4.5-9.5 ms). This is achieved by more frequent transmit opportunities for UL Scheduling Requests (SR) and UL data, and is suitable to multiplex low latency services with existing eMBB traffic.

Capacity assessment

The increased flexibility of the DSDU frame structure also has a direct impact on the overall capacity of the network. The more frequent UL opportunities can allow a higher spectral efficiency due to the fast channel feedback. The UL symbols allows MS to send sounding reference signals (SRS) and channel quality information (CQI) every 1 ms, allowing the BS to have an up-to-date estimate of the channel conditions. A more accurate channel estimation allows for a more efficient usage of beamforming and better rate control through more accurate modulation and coding scheme (MCS) selection.

The result is improved cell capacity, as shown for a heavily loaded scenario in in Figure 10. The figure has been obtained considering an outdoor user with different moving speeds running a full buffer DL traffic pattern. More frequent opportunities to transmit SRS leads to better spectral efficiency over the PDSCH symbols in a fast fading channel. Faster sounding allows better tracking of channel fluctuations, thus allowing improved demodulation performance. Figure 10 compares the simulated spectral efficiency at 5 ms and 1 ms SRS transmission opportunities. The median and 5%-tile spectral efficiency are shown in Figure 10. It can clearly be seen that the fast switching of DSDU achieves a better spectral efficiency across all speeds as compared to LTE-TDD compatible 5G-NR frame structure. While the median gain is 30 to 40%, the gain at the lower percentile (e.g. cell edge conditions) rises to 70%.

[20] The DDDDDDDSUU frame structure was used in the simulations.

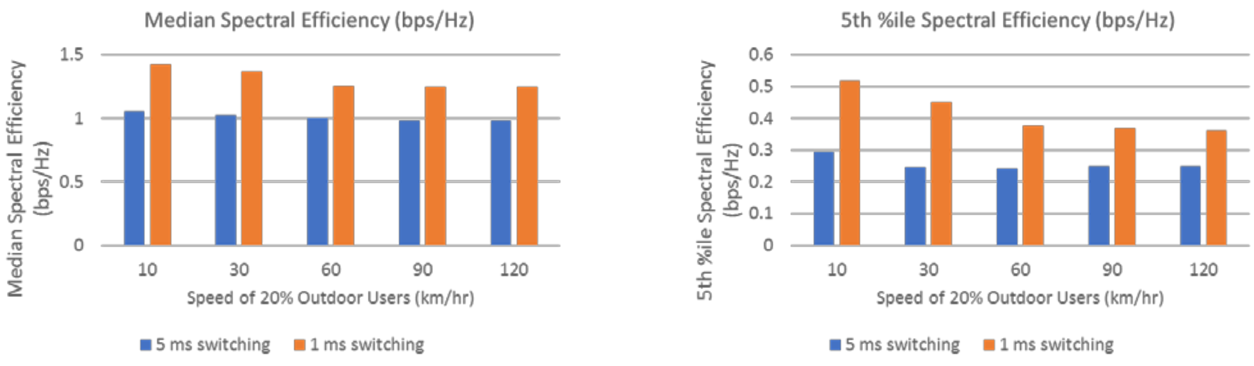


Figure 10: Spectral efficiency gains vs. speed

To simulate the effect of the slot structure on user perceived throughput in a realistic scenario, a bursty traffic pattern (bursty FTP model 3, 0.5 MB file size, variable file arrival time) was simulated. The results are shown in Figure 11. The shorter DL/UL switching periodicity of DSDU creates more transmission opportunities. The improved spectral efficiency enables the use of larger transport blocks. With these advantages, the gain of the median throughput can be as high as 50% (593 Mbps for DSDU vs. 394 Mbps for LTE-TDD compatible 5G-NR frame structure). Even in cell edge conditions, a 23% gain can still be achieved.

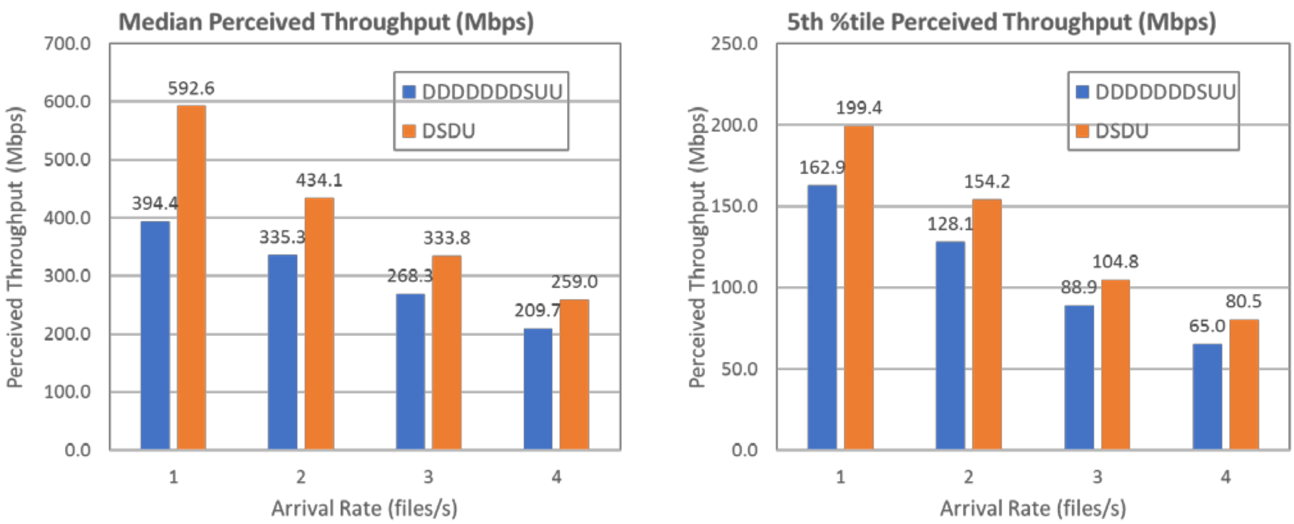


Figure 11: Bursty traffic – perceived throughput vs. file arrival rate

3.3.2 Summary from Study #2

Study #2 provides an assessment in terms of latency and capacity performance for the three frame structures shown in Figure 12.

Among the three frames that are addressed in this study, the DDDDDDDSUU frame structure is the only one to be LTE-TDD compatible.

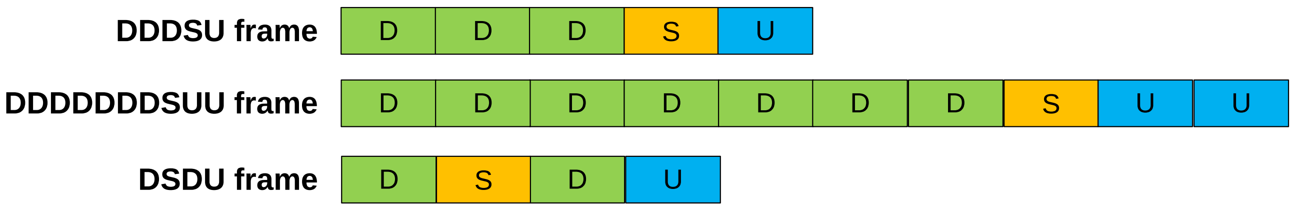


Figure 12: 5G-NR frame structures for evaluation – slot level

The analysis carried out in this study assumes grant-free UL transmissions for the latency assessment and grant-based UL transmissions for the assessment of UL and DL capacity and spectral efficiency.

The more complete set of results and detailed assumptions for this study are available in section A3.3.2.The round-trip time (RTT) for the frame structures is presented in Table 4. Due to the shorter DL/UL switching period, the DSDU frame structure has a lower RTT than the other frame structures considered.

The RTT associated with DDDSU and LTE-TDD compatible 5G-NR frame structures can be reduced by using lower frequencies (e.g. 700 MHz, 800 MHz, 900 MHz, 1800 MHz) in combination with the 3400-3800 MHz band (e.g. through Carrier Aggregation (CA) or Supplemental Uplink (SUL) schemes). The resulting RTT will meet the most stringent latency requirement for URLLC and eMBB simultaneously. It is to be noted, that licensees for the 3400-3800 MHz frequencies do not necessarily have access to lower frequency bands and so may not be able to take advantage of CA or SUL to enable URLLC.

In this evaluation, it was assumed that one MS always uses either the SUL for all its UL transmissions, or always uses the 3400-3800 MHz UL for all its UL transmissions, based on measured RSRP. NR specifications allow configuring the MS to use both uplinks in a TDM manner, which provides more flexibility in the operation than simulated here. Taking this into account, the simulation results presented here should be interpreted as a "best case" scenario., as the impact of the signalling required to assign the lower band UL to CA/SUL operation has not been taken into account. Accounting for partial resource availability for NR users in the SUL band (or in the uplink portion of the band in case of CA) would reduce the improvement in latency to some extent.

The latency assessment results in Table 4[21] account for the “grant-free” UL transmissions feature (also known as “configured grant”) which is an optional feature for 5G-NR in 3GPP. The “grant-free” UL is beneficial for low latency since it avoids the need to first transmit a scheduling request on UL followed by a scheduling grant on DL before UL data transmission can take place. It is to be noted that decisions to mandate features for Rel-15 5G-NR MSs were made in consideration of eMBB services, which are first services that are likely to be delivered using early 5G. Most of the features relating to low latency and/or reliability are optional. This includes not only the “grant-free” feature, but also other features such as the mini-slots (frequency control monitoring and short transmission durations), MS processing capability #2 (necessary for the "self-contained" slot operation), dynamic signalling of slot format (see Table 16), etc.

Simulations results with grant-free based UL transmission are valuable in deriving the lowest possible user plane latency performance.

It is also worth noticing that a comparison between Carrier Aggregation (CA) and SUL has not been analysed in this report. When CA and SUL are applied to FDD lower frequency bands, at least the same latency improvement presented for the SUL case can be achieved in case of Carrier Aggregation.

Both CA and SUL have their own merits and drawbacks, which are not addressed in this Report. Carrier Aggregation (CA) is a technique that aggregates various component bands into an overall wider bandwidth. Supplementary Up Link (SUL) makes it possible to use another frequency carrier for NR UL transmission instead of NR's dedicated UL carrier in a switchable manner. SUL is similar to CA, however, one of the main differences between CA and SUL is the possibility to use the DL carrier in the Carrier Aggregation case. Therefore with CA there is an increase in both DL and UL throughput compared to SUL scenario. In addition,

[21] In case of grant-based transmission, the latency is expected to be higher.

the DL carrier can be used e.g. for DL measurements, power control calculation, mobility management DL CA requires the UE to have one additional receiver for the downlink.

Table 4: DL and UL latency evaluation results for 5G-NR frame structures (SCS = 30 kHz)

DL/UL	Non-slot based scheduling	RTT (ms) for 5G-NR frame structure (GP: 2 OFDM symbols)				
		DDDSU	DDDDDDDSUU	DSDU	DDDSU+SUL	DDDDDDDSUU+SUL
DL	2 OFDM symbols	1.77	3.02	1.12	0.78	0.82
UL	2 OFDM symbols	1.71	2.95	1.05	0.82	0.86

3.3.2.1 DL capacity assessment (grant-based UL transmissions)

Grant-based UL transmissions are assumed for this assessment, therefore the latency results presented in Table 4 (which assume grant-free UL transmissions) do not apply here.

Spectral efficiency with different MS moving speeds and the user-perceived throughput (UPT) with different arrival rates are evaluated.

It is observed that the DSDU frame structure performance benefits from fast CSI measurement and feedback, however the frequent DL/UL switching brings about the extra GP overhead.

Figure 13 provides the cell average and cell-edge spectrum efficiency under 10 km/h moving speed can achieve 15% and 23% gain for DDDDDDSUU vs. DSDU, due to the lower overhead.

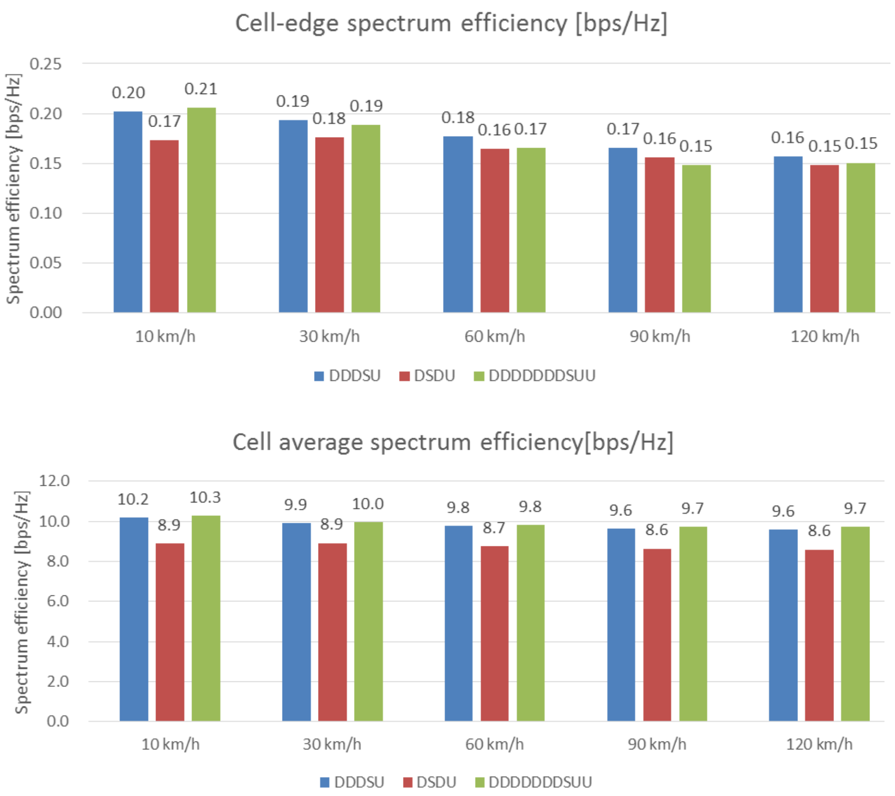


Figure 13: DL spectrum efficiency with different speeds

Figure 14 shows the balance between overhead and feedback delay, DDDSU frame structure has the best performance in most cases and the gain compared to DSDU can be achieved by more than 10%.

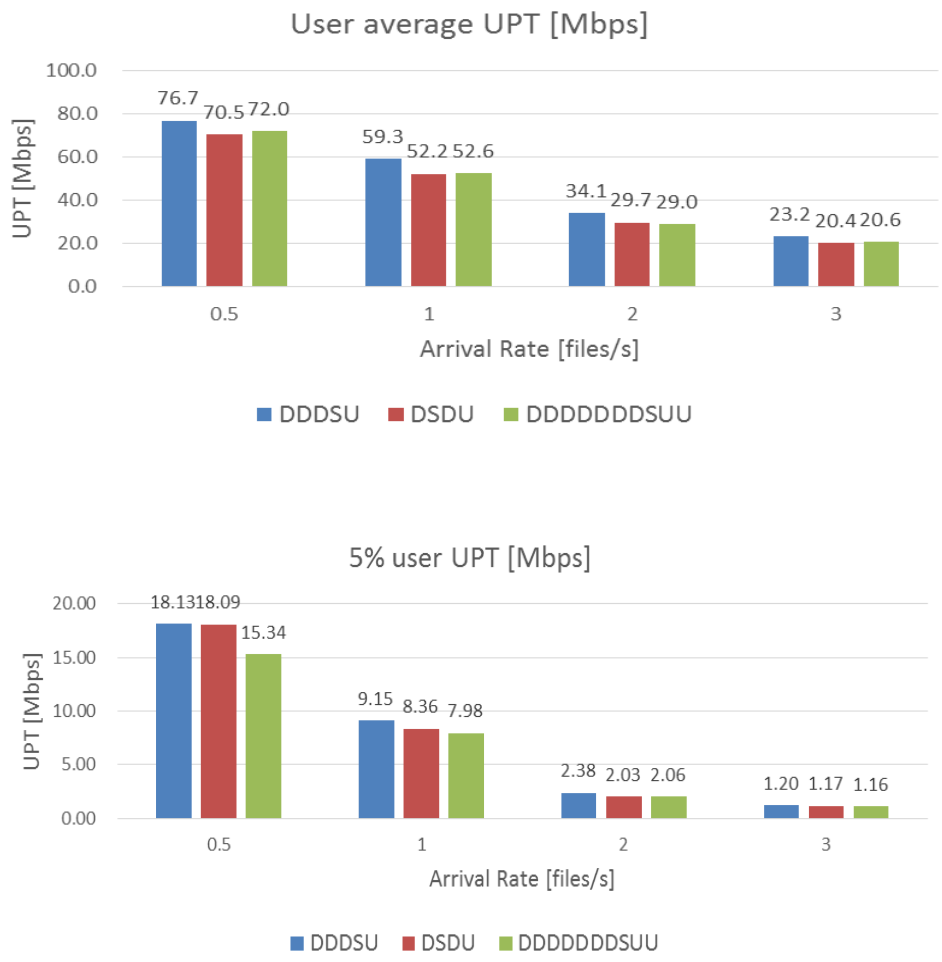


Figure 14: DL user-perceived throughput (UPT) with different file arrival rates

3.3.2.2 UL capacity assessment (grant-based UL transmissions)

According to the study performed:

- DDDSU frame structure with the good balance of overhead and delay has better performance in most cases under different traffic loads. Compared to DSDU, the gain of user average UPT can achieve to 17%;
- If using SUL band, up to 5-times gain can be reached for 5% user throughput since such users benefit from the lower path loss and the sufficient bandwidth in the SUL band.

4 INTERFERENCE MITIGATION FOR UNSYNCHRONISED OPERATION WITH ECC BASELINE OUT OF BLOCK POWER LIMIT

As it was mentioned in section 2.2, the ECC has defined the restricted baseline out of block power limit for unsynchronised and semi-synchronised operation of MFCN BSs (see ECC Decision (11)06 (October 2018) Table 4 [3]. However, the ECC Decision allows CEPT Administrations to define a "relaxed alternative “restricted baseline limit” applying to specific implementation cases to ensure a more efficient usage of spectrum […] depending on national circumstances.").

The practical interference criteria adopted to derive the ECC restricted baseline limit is 5%[22] degradation in the mean UL throughput of the victim MFCN due to ACLR of interfering BS, with the understanding that interference is not dominated by the adjacent channel selectivity (ACS) of the victim BS. The limits were derived from a study (see ANNEX 3 in ECC Report 281) which considered the interfering and victim MFCNs consisting of Macro BSs in a hexagonal grid (19 sites with three cells each) with an inter-site distance (ISD) of 500 metres. The study considered a shift of the victim MFCN with respect to the interfering MFCN by 70 metres (representing a conservative, not worst case, scenario) and by 288 metres (the best-case scenario). The restricted baseline limit was then derived considering the 70 metres shift. Coexistence in case of uncoordinated collocated sites (e.g. two base stations installed in different corners on the same rooftop and possibly pointing at each other) would correspond to the worst-case scenario.

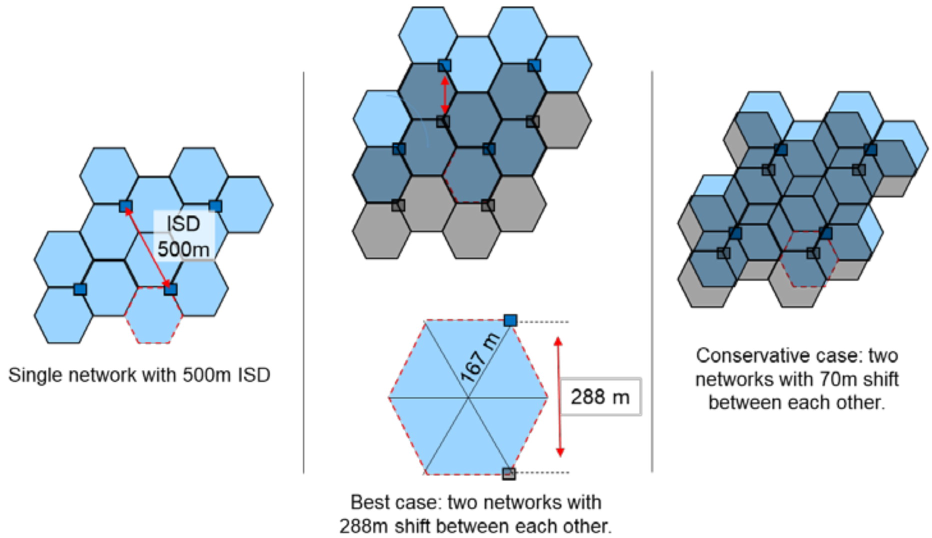


Figure 15: Best case and conservative network shifts

The study has assumed the required ACLR to be nominally equal to the required ACIR, with the understanding that interference is not dominated by the adjacent channel selectivity (ACS) of the victim base station. Therefore the study does not account for the blocking effect due to BS-BS interference.

The study does not assess the MS-MS interference while it is expected that some 5G use cases will imply the deployment of MSs that are in fixed positions and close to each other (e.g. crowded stadiums, trains, busses, (home) CPEs in fixed wireless access (FWA) systems, and fixed machinery/robots in factories). In such scenarios, the MS-MS interference might not be negligible anymore.

It is worth noting that ECC restricted baseline out of block power limit defined in ECC Report 281 was derived assuming the specific case of two adjacent operators with misaligned duplex directions for the whole frame duration which in this Report is referred to as "fully-synchronised". The probability for this specific case

[22] The studies have adopted the performance criteria of 5% maximum average UL throughput loss. It is worth noting that, for URLLC use cases, 5% loss may not be acceptable while the target throughput loss level could be closer to 0%.

to happen is low[23] and, therefore, "fully-unsynchronised" is a theoretical worst-case assumption purely for study purposes.

The implementation challenges, based on currently available technology, associated with the ECC restricted baseline out of block limit have been described in section 2.2.2.

Interference due to unsynchronised operation can be partly mitigated by adopting the following solutions individually or in combination:

- Adoption of a guard band and operator-specific filtering between the adjacent spectrum assignments associated with the interfering network and the victim network;
- Geographic separation between the interfering network and the victim network;
- Alternative network topologies to macro-cellular networks:
- Micro BS networks;
- Indoor BS networks;
- Semi-synchronised operation.

The following sections assess to what extent each of these interference mitigations can improve coexistence between operators. The main results from coexistence studies are introduced while leaving the full set of studies to the Annexes of this Report.

It is worth noting that the performance criteria in the coexistence studies is maximum 5% throughput loss[24]. For URLLC use cases 5% loss is not acceptable. For these use cases the relevant throughput loss level should be closer to 0%.

4.1 GUARD BAND REQUIREMENT FOR UNSYNCHRONISED OPERATION

For non-AAS BSs, according to ECC Report 203 a 5 MHz guard band and operator-specific filtering are necessary for coexistence between TDD and FDD networks in the 3400-3800 MHz band and it is expected that a similar guard band and external filtering would be required for unsynchronised non-AAS TDD networks.

There was no technical analysis on the size of guard band and internal operator-specific filters required for AAS to meet the ECC restrictive baseline out of block power limit.

With AAS operation, operator-specific RF filters implementation would be very challenging, and the implementation of a guard band, which would also reduce the spectral efficiency in the band, would not provide any benefit in practice.

For AAS BSs, ECC Report 281 states that, using current filtering technology, about 20 MHz guard band and internal filters would be required for AAS to meet the ECC additional baseline out of band power limit to protect radars below 3400MHz. A similar size of guard band and similar operator-specific internal filters may be required for AAS to meet the ECC restrictive baseline out of block power limit.

4.2 GEOGRAPHIC SEPARATION OF NETWORKS

This section investigates the coexistence between unsynchronised macro-cellular networks operating in 3400-3800 MHz band.

---

[23] For example, in case of a completely random situation, in which the two adjacent operators are fully uncoordinated and select a random direction, the probability of Tx/Rx overlapping in adjacent channels is a function of the average DL/UL ratio. For instance, an average 1:1 DL/UL ratio (i.e. equal DL and UL probability), at a given point in time the probability for the UL slots to be interfered will be 25%, and the probability for the DL slots to be interfered will be 25%. Nevertheless as slots would not be aligned in case of unsynchronised use, a given slot of Operator A may overlap in time with two slots of Operator B, so that the number of interfered slots might be higher.

[24] The same throughput loss was assumed to derive the ECC baseline limit in ECC Decision (11) 06 (October 2018).

The objective is to derive the minimum isolation, expressed in terms of separation distance, required between two unsynchronised networks when all deployed BSs meet the baseline out of block power limits as defined in ECC Decision (11)06 (October 2018) Table 3 [3].

4.2.1 Proposed methodologies

This section discusses and proposes the methodology when coordinating two unsynchronised TDD macro-cellular networks at national level.

There are two possible approaches to deal with coexistence between two unsynchronised TDD networks within a country:

- Method #1: define the minimum required separation distance between the two unsynchronised networks;
- Method #2: define the electric field strength trigger value at the nearest victim BS.

Either of these two approaches can be applied.

With reference to the BS technology options, three possible cases can be considered:

- Non-AAS Network A to non-AAS Network B, which could represent two LTE-TDD FWA networks;
- AAS Network A to non-AAS Network B, which could represent one 5G-NR network and another LTE-TDD FWA network;
- AAS Network A to AAS Network B, which could represent two 5G-NR networks.

The separation distance can be derived based on different protection thresholds:

- 5% network cluster mean UL throughput loss;
- I/N=-6 dB at the nearest victim BS.

4.2.1.1 Method #1: Separation distance calculation

As illustrated in Figure 16 and Figure 17, the separation distance is defined between the two nearest BSs in network A and network B.

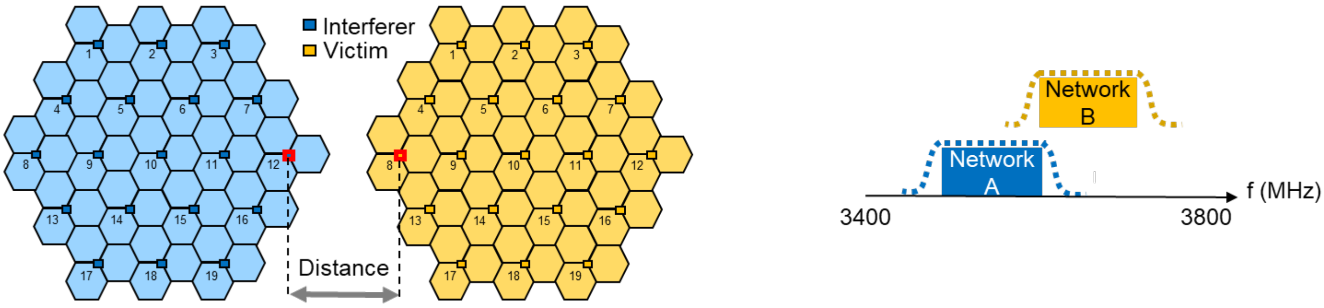


Figure 16: Separation distance between Networks A and B – adjacent channel

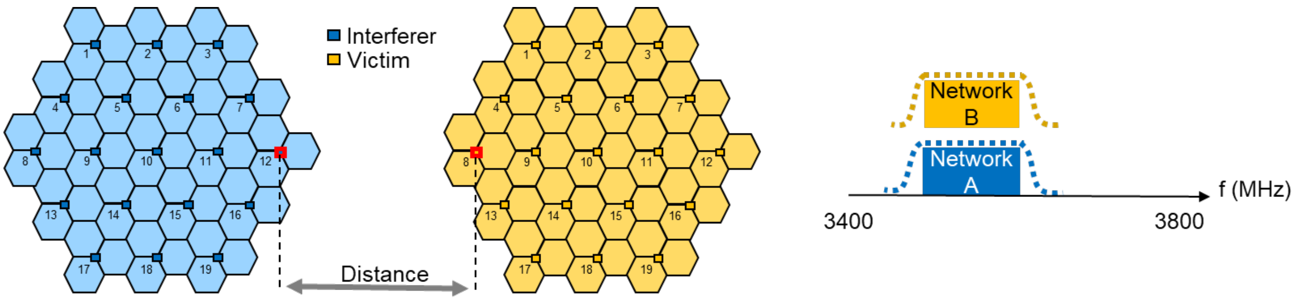


Figure 17: Separation distance between Networks A and B – co-channel

If networks A and B are both non-AAS, then the separation distance can be calculated using the protection ratio of I/N=-6 dB or determined by simulation based on the agreed mean UL throughput loss (e.g. 5% network cluster mean UL throughput loss) between the two concerned mobile operators.

If either network A or B or both adopt AAS BSs, then the separation distance has to be determined by simulations based on the agreed mean UL throughput loss (e.g. 5% network cluster mean UL throughput loss) between the two concerned mobile operators.

4.2.1.2 Method #2: Trigger Values calculation

An alternative approach is to define a trigger value (dBµV/m/5MHz) at the nearest BS receiving antenna or at 3m height above the ground, as shown in Figure 18.

When the trigger value is defined at 3m height above ground, a BS antenna height conversion factor should be used, the determination of antenna height conversion factor is discussed in ANNEX 5 section A5.2.7.

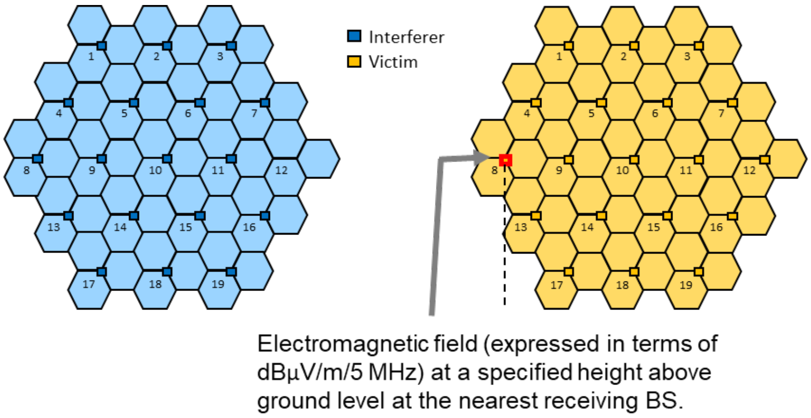


Figure 18: Electromagnetic field trigger value between Networks A and B

Calculation of trigger values

The relation between field strength E (dBµV/m) and power level P_R (dBm) can be expressed as[25]:

$$E = PR + 20 * \log_{10}(F) + 77.2 \qquad (1)$$

$$PR = PTX + G1 - PL \qquad (2)$$

Where:

- F (MHz): frequency;
- PR (dBm): received power level at the receiving BS antenna (before antenna);
- PTX (dB): transmit power before antenna;
- G1 (dB): interfering BS antenna gain including feeder loss in the direction of the receiving antenna;
- PL (dB): path loss at the distance D.

---

[25] The formula is derived from the following relationship (after some units conversions):

$$P_r(W) = \frac{E^2 \cdot c^2 \cdot G_R}{480 \cdot \pi^2 \cdot f^2} \quad \textit{where c is the light speed, f in Hz}$$

It should be pointed out that the trigger value determination for the case AAS BSs is much more complicated due to the dynamic behaviour of the AAS antenna pattern.

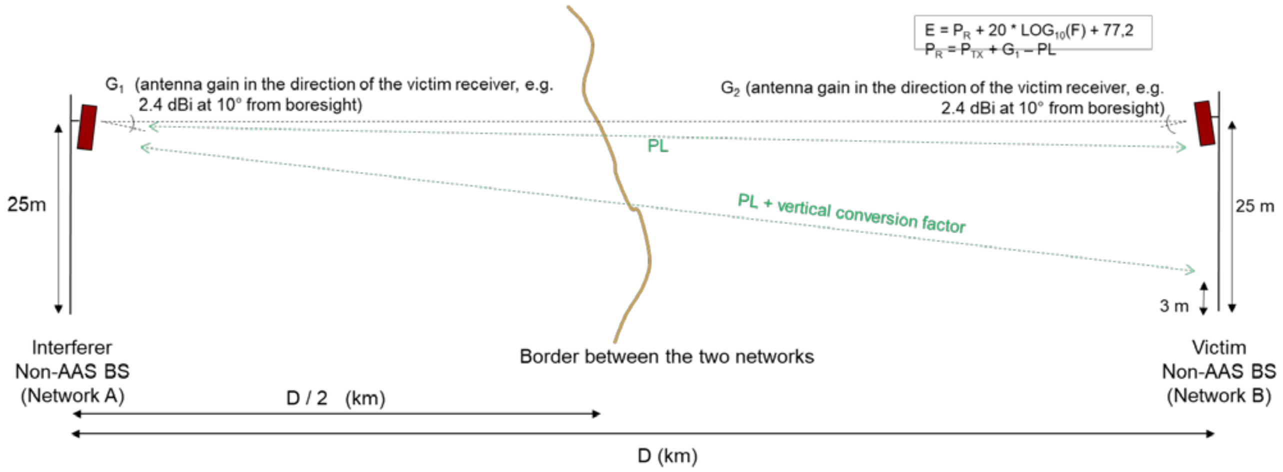


Figure 19: Relationship between the interferer transmitter power and the electric field strength at the victim receiver

4.2.2 Summary of the studies

Two studies described in ANNEX 5 have presented the simulation results in terms of separation distance between two unsynchronised macro-cellular networks. The simulation results are summarised in Table 5 .

Table 5: Summary of the simulation results of separation distance between two macro-cellular networks

Scenario		Study # 3 (5% avg. throughput loss, ITU-R P.452 [21] 20% time)	Study # 4 (5% avg. throughput loss,ITU-R P.452 [21] 50% time)
Co-channel	AAS-AAS	60 km	50 km
	Non-AAS – Non-AAS		50 km
Adjacent Channel	AAS-AAS	10.5 km	14 km
	Non-AAS – Non-AAS		15 km

The results from the two studies based on 5% network mean UL throughput loss show that:

1 For the co-channel case, the required separation distance is in the order of 50 to 60 km;

2 For the adjacent channel case, the required separation distance is in the order of 10 to 15 km.

For the non-AAS to non-AAS co-channel case, the calculated separation distance based on I/N=-6 dB for non-AAS to non-AAS case is 44 km.

It is to be noted that Study #4 was based on the SEAMCAT software which at the time of publication of this Report was using a beta version for the module associated with the AAS system. Future improvements to this specific SEAMCAT module might lead to different results.

4.2.3 Conclusions from studies

The analysis and the simulations that were carried out in this Section lead to the following conclusions:

- The two methodologies are described in this Section, either based on the separation distance or on the electric field trigger value, can be applied;
- Specific separation distance values can be defined at national level based on the specific circumstances. This is because the required separation distance and electric field trigger values calculation depend on many factors:
  - Cellular network technology and topology (LTE-TDD or 5G-NR, non-AAS or AAS, BS antenna height, environment, cell range);
  - Propagation environment and propagation model used in relation with this environment;
  - Frequencies and overlap of the blocks, e.g. full overlap for co-channel case, or partial overlap (e.g. in some cases of coexistence between operators in adjacent areas), or adjacent channel);
  - Protection ratio, e.g. I/N, or nearest cell throughput loss at x%, or network mean throughput loss at y%, etc.

4.3 COEXISTENCE BETWEEN UNSYNCHRONISED MICRO BS AND MACRO BS DEPLOYMENTS

4.3.1 Coexistence between unsynchronised Micro BSs and Macro BSs – Study #5

In Annex A1.1.1, the interference between Micro and Macro BSs is studied. For the macro-cellular network the BSs have an output power (TRP) of 51 dBm and 500 m ISD while the BS in the Micro BS network has an output power (TRP) of 40 dBm and an ISD of 166 m. The impact on both types of BSs is studied. The distance between aggressor and victim BS varies, but for the closest pair the distance is 30 m.

The propagation between BSs is modelled using the Urban Macro-cellular (UMa) model, and this model has a random component. Performance of one specific realisation of the BS-BS propagation is studied. This is the best way to model the situation in practical deployments since the BS-BS propagation will not vary over time. According to the study, in order to limit the throughput loss to maximum 5% the required ACIR between the networks has to be around 60 dB to protect the Micro BS network and 45 dB to protect the Macro-cellular network for typical deployments. For the most sensitive pair of BS, the ones with 30m separation, the ACIR has to be between 50 dB and 70 dB to protect the Micro BS network and between 45 dB and 60 dB to protect the macro-cellular network.

Considering that the ECC baseline gives an ACIR of slightly less than 45 dB, it can be concluded that there are a few cases, i.e. deployment scenarios, where standard equipment will result in less than 5% throughput loss, but in the majority of cases the losses are larger. In these scenarios, synchronisation will be an effective interference mitigation technique.

4.3.2 Coexistence between unsynchronised Micro BSs and Macro BSs – Study #6

This Section provides the main conclusions from the study in A6.2, which considers the impact of BS-BS interference between MFCNs with simultaneous UL/DL transmission in terms of the resulting degradation in the mean UL throughput of the victim MFCN. The MFCNs consist of Macro BSs and Micro BSs.

The study addresses two scenarios according to the specific class of base stations, namely:

- Macro-cellular network (hexagonal grid of outdoor stations) is operating as the interferer and the Micro BS network (hexagonal grid of outdoor stations) is interfered;
- Micro BS network (hexagonal grid of outdoor stations) is operating as the interferer and the Macro BS (placed outdoors) is interfered;
- Interference from one Micro BS to another Micro BS (both base stations are placed outdoors).

4.3.2.1 Network topologies and main assumptions

The two interfering deployments operate in the same geographic area on adjacent frequency channels.

All Micro and Macro BSs are assumed to be AAS base stations forming a beam towards a MS (MSs are assumed to be uniformly distributed within a cell).

The Macro BSs have 25 m high antennas and comprise three sectors per site; the Micro BSs are placed 6 m above ground, comprising one sector per site with random boresight.

Base stations are assumed to be "fully-unsynchronised".

See Section A6.2.3 for the full list of assumptions and parameters.

a) Macro BSs network as interferer; Micro BSs network as victim

Figure 20 provides the topology used for the coexistence studies in case of a macro-cellular network (hexagonal grid placed outdoors) operating as the interferer towards a Micro BS network (hexagonal grid placed outdoors).

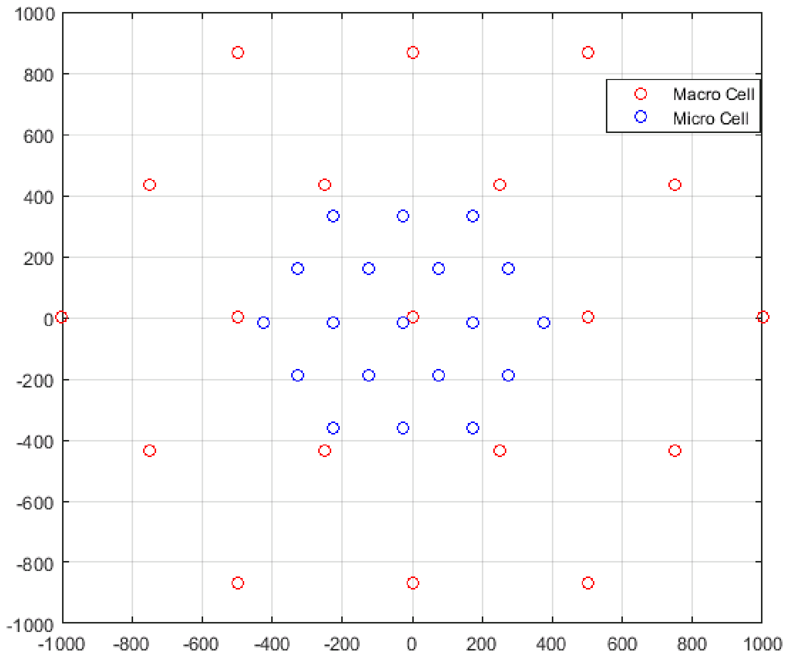


Figure 20: Topology for the Macro BS to Micro BS interference scenario

b) Micro BSs network as interferer; Macro BSs network as victim

Figure 21 provides the topology used to support coexistence studies in case of Micro BS network (hexagonal grid placed outdoors) operating as the interferer towards the Macro-cellular network (hexagonal grid placed outdoors). In line with ECC Report 203 [5][26], the simulations address one Macro BS, which is completely surrounded by the Micro BS network grid.

[26] ECC Report 203 page 26: “One important thing to note here is that the results contained in Table 17 are for one reference cell in the Macro-cellular network, which is overlapped completely by the Micro BS network (Manhattan) grid (see Figure 19).”

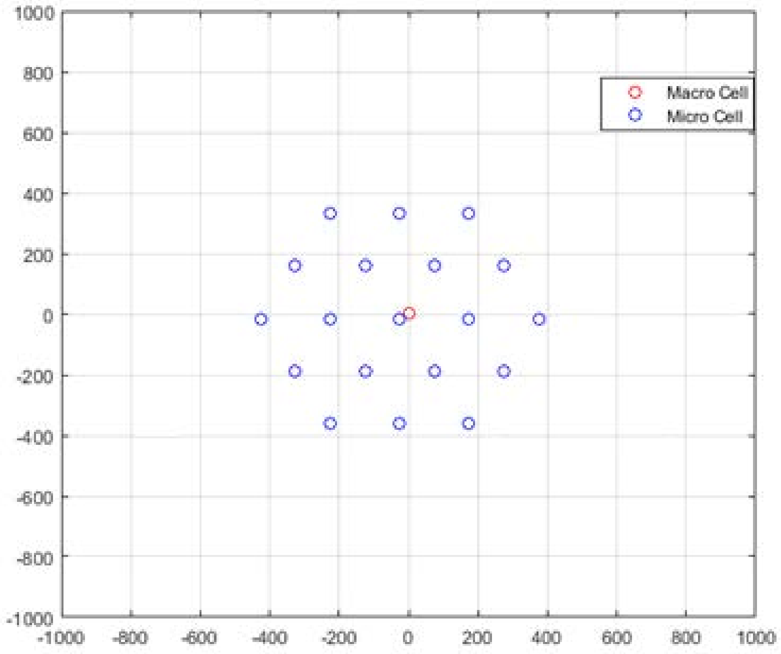


Figure 21: Topology for the Micro BS to Macro BS interference scenario

c) Micro BSs to Micro BSs

The two approaches which have been used to assess the interference from AAS Micro BSs to AAS Micro BSs are described below.

Approach 1: in this analysis the separation distance between the Micro BSs is an input parameter, the Urban Micro-cellular (UMi) path loss model determines the associated Line-of-Sight (LoS) probability.

The following two settings have been considered:

- Case 1a: 30m separation distance between the two Micro BSs leading to 80% LoS probability based on the UMi path loss model (the smaller the distance, the greater the probability the two Micro BSs will be along the same street).

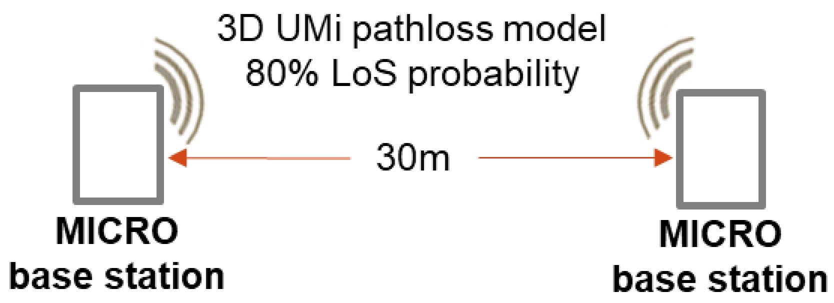


Figure 22: Micro BS to Micro BS interference scenario topology - Case 1a:
30m separation distance leading to 80% LoS probability based on UMi path loss model

- Case 1b: 100m separation distance between the two Micro BSs leading to 25% LoS probability based on the UMi path loss model (the larger the distance, the greater the probability the two Micro BSs will be located in different streets).

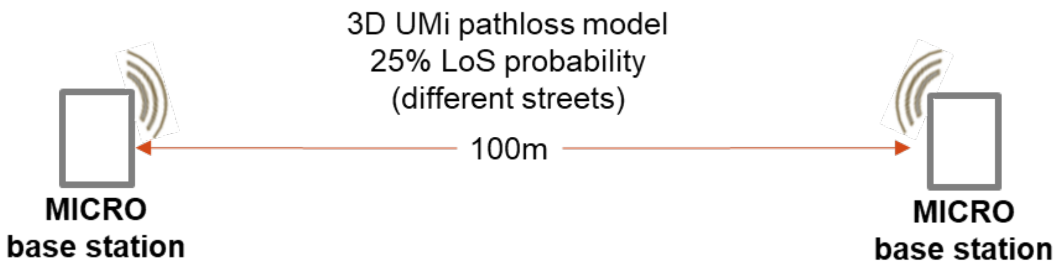


Figure 23: Micro BS to Micro BS interference scenario topology - Case 1b: 100m separation distance leading to 25% LoS probability based on UMi path loss model

Approach 2: in this analysis, the separation distance between the Micro BSs is an input parameter as well as the LoS probability.

This approach accounts for the fact that it is difficult to carry out meaningful simulations to assess the interference between two Micro BS networks in the same urban area since the interference scenario will be strongly impacted by the LoS/NLoS conditions, which radically change depending on where the Micro BS are installed with respect to each other in built-up areas.

The study therefore considers two specific set of cases for the deployments of the interfering and victim base stations:

- Cases 2a, 2b and 2c: two Micro BSs located in different streets at 30m, 50m and 75m separation distance with 0% LoS probability.

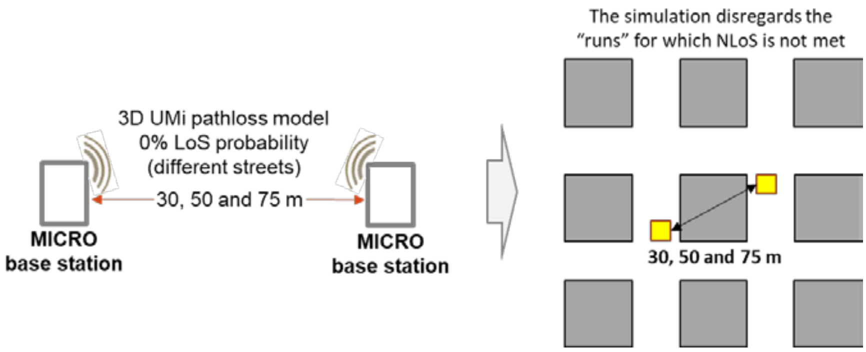


Figure 24: Micro BS to Micro BS interference scenario topology. Case 2a, 2b and 2c: 30, 50, 70 m separation distance and 0% LoS probability (different streets)

Case 2d: two Micro BSs located along the same street (100% LoS probability) at 100 m separation distance.

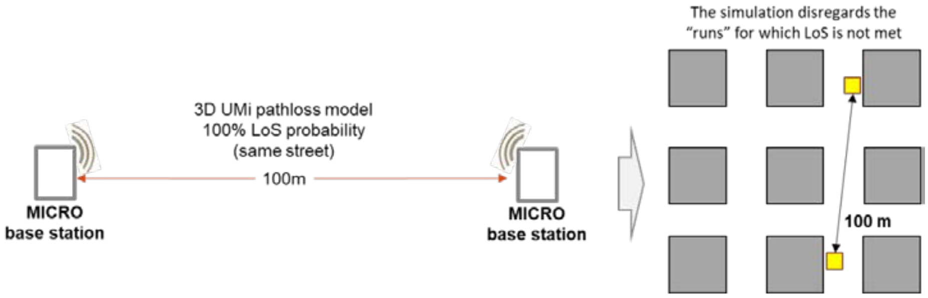


Figure 25: Micro BS to Micro BS interference scenario topology. Case 2d: 100 m separation distance and 100% LoS probability (same street)

4.3.2.2 Simulations results and conclusions

This section presents the simulations results expressed in terms of degradation of the mean uplink throughput of the victim MFCN due to base station to base station interference from the interfering MFCN, presented as a function of ACIR. In general terms, as expected, the impact of interference on network performance diminishes with increasing values of ACIR.

Note that the required ACLR is assumed to be nominally equal to the required ACIR, with the understanding that interference is not dominated by the adjacent channel selectivity (ACS) of the victim base station. Therefore the study did not take into account the BS blocking effects on the victim BS receiver.

Note that both victim BS and interferer base stations are assumed to operate with 60 MHz channel bandwidth.

It is important to highlight that the study did not account for MS-MS interference.

Interference from AAS macro-cellular network into AAS Micro BS network:

With reference to the topology proposed in Figure 20, an ACIR greater than 68dB is required to ensure a mean uplink throughput degradation smaller than 5%.

Interference from AAS Micro BS network into AAS Macro BS network:

With reference to the topology proposed in Figure 21, an ACIR greater than 55dB is required to ensure mean uplink throughput degradation smaller than 5%.

Interference between two AAS Micro BSs:

With reference to the topology proposed in Figure 22 (Case 1a: 30m separation distance leading to 80% LoS probability based on UMi path loss model), an ACIR greater than 63dB is required to ensure a mean uplink throughput degradation smaller than 5%.

With reference to the topology proposed in Figure 23 (Case 1b: 100m separation distance leading to 25% LoS probability based on UMi path loss model), an ACIR greater than 54dB is required to ensure a mean uplink throughput degradation smaller than 5%.

With reference to the topology proposed in Figure 24 (Case 2a, 2b and 2c: 30, 50, 70 m separation distance and 0% LoS probability (different streets), shows how an ACIR greater than 49dB is required to ensure a mean uplink throughput degradation smaller than 5% for 30m separation distance. If the separation distance is 50 m, 45 dB ACIR is required to ensure mean uplink throughput degradation smaller than 5%.

With reference to the topology proposed in Figure 25 (Case 2d: 100m separation distance and 100% LoS probability (same street). An ACIR greater than 70 dB is required to ensure a mean uplink throughput degradation smaller than 5%.

4.4 COEXISTENCE BETWEEN UNSYNCHRONISED INDOOR BSS AND MACRO BS - STUDY #7

In ANNEX 7, the impact on an indoor system from a macro-cellular network is studied. The indoor BS network is located in a 50x120m large building, which is located 70m from the Macro BS. For the macro-cellular network the BS have an output power (TRP) of 51 dBm and 500m ISD while the indoor BS is ceiling mounted with an output power (TRP) of 24 dBm.

The propagation between BS is modelled using the UMa model and this model has a random component. We study performance of one specific realisation of the BS-BS propagation. This is the best way to model the situation in practical deployments since the BS-BS propagation will not vary over time.

Based on the study, in order to limit the mean UL throughput degradation for the indoor network to maximum 5% the ACIR (adjacent channel interference ratio) between the networks has to be in the range 25 dB to 65 dB, depending on the actual channel realisation between the Macro BS and indoor BS.

The ECC baseline gives an ACIR of slightly less than 45 dB. From this it can be concluded that in some cases standard equipment will result in less than 5% throughput loss and in other cases the losses are larger. This indicates that, for this type of scenario, unsynchronised operation may be possible for carefully installed indoor BS, but synchronisation may be required for BS installed in shallow indoor locations...

While the 5% mean UL throughput degradation applies to the eMBB use case, it is worth noting that the UL mean throughput closer to 0%. According to the results above, the URLLC use cases will require an additional isolation somewhere in the order of 20-25 dB compared to the 5% loss results. Such additional isolation could be obtained with accurate indoor BS planning and, for example, with adoption of proper shielding of the building.

4.5 STUDY ON SEMI-SYNCHRONISATION FOR MICROCELL AND MACRO-CELL CASES - STUDY #8

The benefits and challenges associated with semi-synchronised operation have been discussed in section 2.3. In the following sub-sections, adjacent channel simulation results are presented. These results are based on the study available in ANNEX 8.

Table 6: Study on semi-synchronisation for Micro-cell and Macro-cell cases – summary of results

Scenario	Macro-cellular network to Macro-cellular network				Micro BS network to Micro BS network			
Minimum distance among networks	288 m				96 m			
BS-BS propagation model	Free space path loss				3GPP TR 38.901 – Umi			
Semi-synchronisation percentage	10% unsynch.	20% unsynch.	50% unsynch.	100% (fully unsynch.)	10% unsynch.	20% unsynch.	50% unsynch.	100% (fully unsynch.)
ACIR needed for 5% mean UL throughput degradation	54 dB	62 dB	70 dB	75 dB	N/A	40 dB	47 dB	54 dB

As shown in Figure 15, the 288 m network shift assumption between macro-cellular networks represents the best case. Similarly, the 96 m network shift assumption between micro-cellular networks represents the best case between the two analysed assumptions[27].

Differently from the approach followed in ANNEX 8, the recommended approach is to use the separation distance and the line-of-sight probability as input parameter during the coexistence studies for the macro-cellular network and the Micro BSs network cases. This approach accounts for the fact that it is difficult to carry out meaningful simulations to assess the interference between two Micro BS networks in the same

27 According the studies' assumptions reported in Table 33:
-Network shift (Macro BS ↔ Macro BS case): Baseline: 70 m
Additional for reference: 288 m
- Min. separation distance between Macro BS and Micro BS: 30 m

urban area since the interference scenario will be strongly impacted by the LoS/NLoS conditions which radically change depending on where the Micro BS are installed with respect to each other in built-up areas.

Coexistence between the macro-cellular network and the Micro BS network was not assessed by this study.

It is worth noting that the study assumes that operators do not always decide to modify UL symbols / slots into DL symbols / slots in the flexible part of the frame. This reflects a real deployment scenario where:

- The two operators adopt the same default frame structure;
- When the default frame structure is not modified (in its flexible portion), the network is actually operating in synchronised mode;
- An operator might decide to modify the agreed default frame structure in some specific locations (hot spots) and at specific point in time (specific event or busy hour, for instance). In this particular case, only the base stations in these areas and at these times will be subject to cross-link interference[28].

Taking this into account the results presented in this section represent a worst-case scenario in terms of throughput degradation resulting from the semi-synchronised case.

"DL to UL modifications": the default DL transmission direction in the flexible part is modified into UL

In this case, from BS-BS interference perspective, the network that modifies the default DL transmission direction into UL will not interfere with the other network while it will receive additional interference from the other network during the period of the modified transmission direction.

In most circumstances, MS-MS interference will be negligible because terminals typically transmit intermittently and many will be mobile so any interference would be transient

"UL to DL modifications": the default UL transmission direction in the flexible part is modified into DL

In this case, from BS-BS interference perspective, the network that modifies the default UL transmission direction into DL will interfere with the other network while it will not receive additional interference from the other network.

Under the specific assumptions and methodology used in this study, it can be concluded:

- For macro-cellular network to macro-cellular network results show that the throughput degradation is ~9% when operators are unsynchronised (UL to DL modification) for 10% of the frame (i.e. the flexible part). The modelling considered that the interfering operator always changes the transmission direction during the flexible part of the frame, this represents worst-case assumptions. This means that the throughput degradation will likely be lower in a realistic scenario where the interfering operator will not always modify the transmission direction of the flexible portion of the frame. 288 m BS - BS separation distance is assumed;
- From Micro BS to Micro BS interference perspective, it is possible to use the ECC baseline out of block power limit for synchronised operation as specified if the operators have simultaneous UL/DL transmissions for at most 20% of the frame(based on acceptable Loss 5% and ACIR 45 dB); for a BS - BS separation distance at 96 m; No conclusion can be derived for the Macro-cellular network to Micro BS network case since this scenario was not studied. In the case of Micro BS network to Macro-cellular network, due to the lower power of the interfering BS it is expected that interference from the Macro base station will dominate the coexistence analysis.-.

[28] For example: assuming a configuration in which the flexible "X" slots represent 20% of the entire frame and are used for DL, the actual percentage of time with cross DL to UL interference will be lower. Even assuming that the operator will use his flexible part in DL for 50% of the time and for all gNBs, the actual percentage of slots affected by cross interference will be 10% if and only if the other operator always switches the UL in the same 50% of time. It follows that the actual cross-link interference will be even lower than 10%. On top of this, not all the gNBs in the network will need to change the baseline configuration and as a consequence the cumulative interference will be strongly reduced

Based on the above, since UL to DL flexibility creates additional BS-BS interference to the neighbour operator, the specific cases in which the semi-synchronised operation (for UL to DL flexibility) could be allowed require agreement at national level.

4.6 SUMMARY OF ALL STUDIES PERFORMED

The following tables collect the results from the studies performed.

Table 7: Coexistence between unsynchronised/semi-synchronised macro-cellular network and macro-cellular network – summary of results

	Interference scenario				Required ACIR (dB) needed for 5% mean UL t-put degradation	
					Study #8	ECC Report 281 Annex 3
MACRO BS → MACRO BS	70 m shift	Adjacent channel	AAS to non-AAS	Unsynch.	N/A	83
			AAS to AAS	Unsynch.	N/A	77
				Semi-synch.	N/A	N/A
	288 m shift (best case) (*)		AAS to non-AAS	Unsynch.	N/A	79
			AAS to AAS	Unsynch.	75	74
				50% unsynch.	70	N/A
				20% unsynch	63	N/A
				10% unsynch.	55	N/A
	Interference scenario				Geographic separation distance (km) needed for 5% mean UL t-put degradation	
					Study #3	Study #4
	3GPP SEM (45 dB ACIR)	Adjacent channel	AAS to AAS	Unsynch.	10.5 km	N/A
			AAS to non-AAS	Unsynch.	14 km	N/A
			non-AAS to non-AAS	Unsynch.	N/A	31 km (5% t-put loss) 12 km (50% t-put loss)
		Co-channel	AAS to AAS AAS to non-AAS	Unsynch.	60 km	N/A
			non-AAS to non-AAS	Unsynch.	N/A	58 km (5% t-put loss) 49 km (50% t-put loss)

(*) Best case. Agreed assumption for the network shift (Macro BS ↔ Macro BS case): baseline: 70m, additional for reference: 288 m (see Table 33)

Table 8: Coexistence between unsynchronised/semi synchronised macro-cellular network and Micro BS network – summary of results

<table>
<tr><th colspan="5" rowspan="2">Interference scenario</th><th colspan="3">Required ACIR (dB)
needed for 5% mean UL t-put degradation</th></tr>
<tr><th>Study #5</th><th>Study #8</th><th>Study #6</th></tr>
<tr><td rowspan="6">MACRO BS → MICRO BS</td><td rowspan="6">30 m separation</td><td rowspan="4">Adjacent channel</td><td rowspan="2">AAS to AAS</td><td>Unsynch.</td><td>63 (58 to 65)
Micro BS in the middle:
50 - 70 (worst case)</td><td>N/A</td><td>68</td></tr>
<tr><td>Semi-synch.</td><td>N/A</td><td>N/A</td><td>N/A</td></tr>
<tr><td>AAS to non-AAS</td><td>Unsynch. & Semi-synch.</td><td>N/A</td><td>N/A</td><td>N/A</td></tr>
<tr style="display:none"></tr>
<tr><td rowspan="2">co-channel</td><td>AAS to AAS</td><td>Unsynch. & Semi-synch.</td><td>N/A</td><td>N/A</td><td>N/A</td></tr>
<tr><td>AAS to non-AAS</td><td>Unsynch. & Semi-synch.</td><td>N/A</td><td>N/A</td><td>N/A</td></tr>
<tr><td rowspan="4">MICRO BS → MACRO BS</td><td rowspan="4">30 m separation</td><td rowspan="2">Adjacent channel</td><td>AAS to AAS</td><td>Unsynch.</td><td>43 (40 - 50)
Macro BS in the middle:
43 - 50 (worst case)</td><td>N/A</td><td>55</td></tr>
<tr><td>AAS to non-AAS</td><td>Unsynch. & Semi-synch.</td><td>N/A</td><td>N/A</td><td>N/A</td></tr>
<tr><td rowspan="2">co-channel</td><td>AAS to AAS</td><td>Unsynch. & Semi-synch.</td><td>N/A</td><td>N/A</td><td>N/A</td></tr>
<tr><td>AAS to non-AAS</td><td>Unsynch. & Semi-synch.</td><td>N/A</td><td>N/A</td><td>N/A</td></tr>
<tr><td rowspan="4">MICRO BS → MICRO BS</td><td rowspan="3">96 m separation (**), (***)</td><td rowspan="3">Adjacent channel</td><td rowspan="3">AAS to AAS</td><td>Unsynch.</td><td>N/A</td><td>54</td><td>N/A</td></tr>
<tr><td>50% unsynch.</td><td>N/A</td><td>47</td><td>N/A</td></tr>
<tr><td>20% unsynch.</td><td>N/A</td><td>40</td><td>N/A</td></tr>
<tr><td>Case 1a 30 m separation, 80% LoS prob. (***)</td><td>Adjacent channel</td><td>AAS to AAS</td><td>Unsynch.</td><td>N/A</td><td>N/A</td><td>63</td></tr>
</table>

	Case 1b 100 m separation, 25% LoS prob. (***)	Adjacent channel	AAS to AAS	Unsynch.	N/A	N/A	54
	Case 2a, 2b, 2c 30, 50, 70 m separation, 0% LoS prob.	Adjacent channel	AAS to AAS	Unsynch.	N/A	N/A	49 (30m) 45 (50m) <40 (70m)
				Semi-synch.	N/A	N/A	N/A
			AAS to non-AAS	Unsynch. & Semi-synch.	N/A	N/A	N/A
		co-channel.	AAS to AAS & AAS to non-AAS	Unsynch. & Semi-synch.	N/A	N/A	N/A
	Case 2d 100 m separation, 100% LoS prob.	Adjacent channel	AAS to AAS	Unsynch.	N/A	N/A	70
				Semi-synch.	N/A	N/A	N/A
			AAS to non-AAS	Unsynch. & Semi-synch.	N/A	N/A	N/A
		co-channel	AAS to AAS & AAS to non-AAS	Unsynch. & Semi-synch.	N/A	N/A	N/A

(**) Best case. Agreed assumption for the min. separation distance between Macro BS and Micro BS: 30m (see Table 33).

(***) Differently for this study, it was agreed to use the separation distance and the line-of-sight probability as input parameter during the coexistence studies between the Macro-cellular network and the Micro BSs network. This approach accounts for the fact that it is difficult to carry out meaningful simulations to assess the interference between two Micro BS networks in the same urban area since the interference scenario will be strongly impacted by the LoS/NLoS conditions which radically change as the Micro BSs change their locations with respect to buildings.

Table 9: Coexistence between unsynchronised macro-cellular network and indoor BS network – summary of results

Interference scenario					Required ACIR (dB) needed for 5% mean UL t-put degradation
					Study #7
MACRO BS → INDOOR BS	70m separation btw. MACRO BS and building wall CEILING MOUNT	Adjacent channel.	AAS to AAS	Unsynch	Building short side facing BS: 43 (34 to 57) Building long side facing BS: 53 (23 to 63)
				Semi-synch	NA
			AAS to non AAS	Unsynch & Semi-synch	NA
		Co-channel.	AAS to AAS & AAS to non-AAS	Unsynch & Semi-synch	NA
INDOOR BS → MACRO BS		Adjacent channel.	AAS to AAS	Unsynch (qualitative) (****)	"not simulated. However we can observe that the indoor BS has lower output power, which means that we should see lower impact from the indoor. On the other hand if there are several buildings with indoor systems deployed there is a need to consider the effect of the aggregate interference."
				Semi-synch	NA
			non-AAS to AAS	Unsynch & Semi-synch	NA
		Co-channel.	AAS to AAS & non-AAS to AAS	Unsynch & Semi-synch	NA
INDOOR BS ↔ INDOOR BS		Adjacent channel. & co -ch.	AAS to AAS & AAS to non-AAS	Unsynch & Semi-synch	NA

(****) Qualitative assessment was performed for this scenario.

5 TOOLBOX: OPTIONS FOR ADMINISTRATIONS TO SUPPORT THE DESIGN OF SYNCHRONISATION FRAMEWORKS AT NATIONAL LEVEL

5.1 KEY ASPECTS TO BE CONSIDERED WHEN SETTING UP THE SYNCHRONISATION FRAMEWORK AT NATIONAL LEVEL

Synchronisation and semi-synchronisation are effective for avoiding (in the case of synchronised) or minimising (in the case of semi-synchronised) cross-link interference between operators. Additional interference mitigation techniques may be required (including separation distances, alternative network topologies, etc.) if operators intend to use unsynchronised AAS BS. Synchronised operation is accompanied with some challenges related to the selection of common clock and frame structure. Such challenges are explained in more detail in Section 5.2.1.

At the time of this writing, new 5G AAS systems cannot cost-effectively implement the operator-specific filtering which would be required to meet the ECC restricted baseline out of block power limits and protect the receiver from blocking from adjacent and non-adjacent channels in the same band. Based on currently available AAS BS technology, it is assumed that equipment will only implement filters designed to comply with the ECC baseline out of band power limits[29].

If interference mitigation due to unsynchronised operation relies on separation distances, the minimum distances required will depend on network topology, terrain and clutter and will need to be discussed at the national level. The results from the coexistence studies summarised in Section 4 of this Report show that the separation distances required between unsynchronised Macro cells could be up to 60 km when co-channel and up to 14 km when operating in the adjacent channel.

Semi-synchronised operation is similar to synchronised operation, with the exception that simultaneous U /DL transmissions between networks can be allowed in some defined parts of the frame. This leads to a degree of flexibility at the expense of some additional interference that can be controlled to some extent. Compared to unsynchronised operation, semi-synchronised operation reduces the impact from BS-BS and MS-MS interference. Results from studies in Section 4.5 show that the ECC baseline out of block power limit can be applied to the semi-synchronised operation in specific circumstances. The interference impact on network performance associated with semi-synchronised operation is reduced when interference on the control channels is avoided (e.g. where possible, the flexible portions of the frame do not include control plane channels). As in the case of synchronised operation, semi-synchronised networks will need a common accurate phase / time synchronisation and an agreement on a compatible frame structure which identifies the portions of the frame where transmission direction is flexible.

5.2 ENABLING SYNCHRONISED, UNSYNCHRONISED AND SEMI-SYNCHRONISED OPERATION AT NATIONAL LEVEL BASED ON MULTILATERAL AGREEMENTS AMONG MFCN LICENSEES

5.2.1 Synchronised operation

Synchronised operation avoids any BS-BS and MS-MS interference therefore allowing coexistence between adjacent networks without the need for guard bands or additional filters. This operating mode therefore simplifies network deployment because no additional interference mitigation is required. Synchronised operation leads to the selection of a compatible frame structure, which determines a specific DL/UL transmission ratio and contributes to the network performance (e.g. latency, spectral efficiency, throughput and coverage).

---

[29] ECC baseline out of block power limit is defined in ECC Decision (11)06 (October 2018) Table 3 [3] with reference to the synchronised operation.

The out of block power limit associated with the synchronised operation mode was defined in ECC Decision (11)06 (October 2018) Table 3.

For synchronised operation the following issues should be agreed at national level with a general framework[30] involving all MFCN licensees in the band and in the same geographic area[31]. In some cases, Administrations may get involved in order to reach multilateral agreements in a fair and timely manner:

- A common phase clock reference (e.g. UTC) and accuracy/performance constraints that depend on the underlining technology (e.g. +/- 1.5 µs for LTE-TDD and 5G-NR), either using their own equipment to provide the clock, or sharing the same phase / time clock infrastructure. Permanent monitoring of the agreed clock source is needed. When losing the primary reference time clock (PRTC) equipment may continue operation for some time ("holdover period") that has to be agreed and which depends on the quality of the local oscillator in the BS and on the wireless network accuracy requirement. If the PRTC is lost for a period that is longer than the holdover period, the system shall no longer be considered in synchronised operation and may cause interference to other operators. Proper action shall therefore be taken (e.g. the BS shall be shut down until the PRTC is recovered);
- A compatible frame structure to avoid simultaneous UL/DL transmissions (guard periods between DL and UL transmissions may be different, as illustrated in Figure 3;Figure 3);
- The conditions when synchronisation must apply and/or may not be required (when additional isolation is available and in case of low power indoor BSs);
- Periodic review of the agreed conditions may be needed to account for possible market and technology developments (e.g. introducing new technologies, adjusting to new needs in the DL/UL ratio or latency, etc.).

Synchronised operation between 5G-NR and LTE-TDD/WiMAX systems could imply a cost in term of user plane latency and throughput performance; the summary from the detailed assessments in is provided in Section 3.3.2. Operators may have the option to reduce the user plane latency and RTT, under some circumstances, by using lower frequencies (e.g. 700, 800, 900, 1800 MHz) in combination with the 3400-3800 MHz band (e.g. through Carrier Aggregation or Supplemental Uplink schemes). Some licensees may not have access to additional spectrum in lower frequency bands with available capacity (e.g. verticals and some MNOs) and the user terminals supporting these functionalities may not be available in short term.

5.2.2 Unsynchronised operation based on the ECC baseline out of block power limit

Unsynchronised operation does not require the adoption of a compatible frame structure among licensees. Licensees can select the most appropriate frame structure independently and can adapt the frame structure to service and end user requirements, which may change depending on the location and on time.

However, in a multi-operator scenario, the flexibility in operators' frame structure selection leads to a number of interference scenarios that need to be assessed and managed.

The out of block power limit for unsynchronised and semi-synchronised operation is defined in ECC Decision (11)06 (October) Table 4, the "Restricted baseline". However, the ECC Decision allows CEPT Administrations to define a "relaxed alternative "restricted baseline limit" applying to specific implementation cases to ensure a more efficient usage of spectrum […] depending on national circumstances.") .

The simulations defined in this report assess the feasibility of unsynchronised operation when using the ECC baseline limit [32] and not the restricted baseline limit because of the practical difficulties in achieving the restricted baseline limit as discussed earlier . The assumptions in the studies are consistent with the

[30] As explained in section 2.2, operators' agreements must be multilateral, involving all operators sharing a band, because the blocking effect can happen within the whole band regardless of any frequency separation within that band and is not restricted to the adjacent channel.

[31] "Same geographic area" refers to an area within which two networks can be impacted by mutual interference in case of simultaneous UL/DL transmissions.

[32] ECC Decision (11)06 (October -2018) Table 3

definition and assumptions in ECC Report 281 [2], including the simultaneous UL/DL transmissions across the whole frame ("fully-unsynchronised" transmission scenario).

System level simulations do not account for the additional potential data loss that would result from interfered control channels (e.g. inability to decode the whole frame resulting in larger throughput degradation)[33]. Link-level simulations would be required for a more accurate analysis.

Unsynchronised operation could be allowed at national level in a limited number of specific cases where sufficient isolation between interferer and victim base stations exists. The associated parameters should be agreed at national level with multilateral[34] agreements among all MFCN licensees in the same geographic area35 in the band in a fair and timely manner. Such agreements could account for the following options.

5.2.2.1 Options for enabling the unsynchronised operation involving macro-cellular networks

A specific recommendation for the separation distance or a single set of trigger values between unsynchronised macro-cellular networks cannot be provided (due to the dependency on various factors[36]). Section 4.2.1 provides the methodology to support Administrations and MFCN licensees in deriving specific values for separation distances and/or trigger values at national level. MFCN licensees need those values to establish an agreement when their networks are not fully or semi-partially synchronised.

The results from the coexistence studies summarised in section 4 of this Report show that those distances could be up to 60 km when co-channel and up to 14 km when operating in the adjacent channel[37]. Those separation distances are based on the analysis detailed in ANNEX 6 for a flat terrain environment. Smaller distances may be achieved in a different environment and/or with proper mitigation techniques e.g. with some coordination on the azimuth/down tilt, etc.

In case of coordination within national borders, different coordination parameters may be defined (leading to different separation distances) compared to the case of international cross border coordination. While the specific coordination parameters will need to be agreed at national level, the international coordination approaches defined in Rec. ECC Recommendation (15)01 [4] may be used as a reference to deal with the case of two unsynchronised macro-cellular networks within a given country when the physical borderline is defined between two networks.

5.2.2.2 Options for the unsynchronised operation involving Micro BS networks in the same area:

The studies are summarised in section 4.3 and reported in ANNEX 6. Simulation results have shown that, in general, unsynchronised operation of Micro BSs in case of ECC baseline out of block power limit in the same geographic area might not be feasible.

---

[33] Simulations have mapped SINR to throughput, which allows accounting for interfered Physical Uplink Shared Channel (PUSCH).

When determining the average UL throughput loss, simulations have not accounted for interference on control channels such as the Physical Uplink Control Channel (PUCCH), which would have impacts on ACK/NACK transmissions (such mechanism cannot be covered by the SINR – throughput curve. Simulations, in fact, accounted for cell-to-cell interference).

[34] As explained in section 2.2, operators' agreements must be multilateral, involving all operators sharing a band, because the blocking effect can happen within the whole band regardless of any frequency separation within that band and is not restricted to the adjacent channel.

[35] "Same geographic area" refers to an area within which two networks can be impacted by mutual interference in case of simultaneous UL/DL transmissions.

[36] Network technologies and topologies (LTE / 5G-NR, non-AAS / AAS BS, BS antenna height), propagation environment and propagation model, frequency assignments, protection criteria (I/N or network throughput loss at x%, etc.….).

[37] It should be noted that ITU-R M.2374 [7] has performed a study between adjacent channel unsynchronised LTE systems in the 2.3 GHz band, with the conclusion that « without any additional RF improvement, one BS could influence unsynchronised BSs operating in adjacent spectrum block in an area with a radius of. 2.4 to 5.3 km depending on the propagation environment », which illustrates that input hypothesis such as the propagation model are of significant importance.

There could be very specific circumstances where two Micro BSs could coexist when using the ECC baseline out of block power limit. For example, when the adjacent channel Micro BSs are not in line of sight (i.e. 100% NLoS). These Micro BSs might still face coexistence issues with the macro-cellular network coverage layer above them because they are likely to be in LoS of Macrocells and Macrocells are higher power.

5.2.2.3 Options for the unsynchronised operation involving indoor BS:

Studies summarised in Section 4.4 and reported in ANNEX 7 investigated unsynchronised operation of indoor BS and Macro-cellular network in the same area. Simulation results have shown that (under specific assumptions, in the adjacent channel case) in order to limit the mean UL throughput degradation for the indoor BS network to maximum 5%, the ACIR (adjacent channel interference ratio) between the networks has to be in the range 25 to 65 dB, depending on the actual channel realisation between the Macro BS and indoor BS.

Based on the above, the unsynchronised operation of low power[38] indoor BSs standard equipment in some cases will lead to less than 5% mean UL throughput degradation and in other cases will lead to larger losses. This indicates that unsynchronised operation should be possible with careful installation[39] of the indoor BS. Synchronised operation of indoor BS may be difficult in practice because of the challenges involved in distributing the common clock signal to indoor BSs.

It is worth noting that the performance criteria in the coexistence studies are maximum 5% throughput loss. For URLLC use cases 5% loss is not acceptable. For these use cases the relevant throughput loss level should be closer to 0%. The studies' results show that a close to 0% throughput loss the URLLC use cases will require an additional isolation of around 20-25 dB. Such additional isolation could be obtained with accurate indoor BS planning and, for example, with adoption of proper shielding around the building.

The case where the macro-cellular network is the victim has not been simulated because the indoor cells will be lower power and so are expected to pose a lower risk of interference. However, if there are several buildings with indoor systems deployed, there could be a need to consider the effect of the aggregate interference.

In the case of co-channel operation of Macro BS and Indoor BS, the conclusions on coexistence between the two systems should account for lack of out of block filtering on the Macro BS and on the indoor BS transmitters' side.

Accounting for the above, agreements among MFCN licensees that operate macro-cellular networks and the Indoor BS in the same area and in the same band could include the conditions that identify the specific circumstances under which indoor BS networks could operate in unsynchronised mode.

5.2.3 Semi-synchronised operation based on the ECC baseline out of block power limit

Semi-synchronised operation is similar to synchronised operation, with the exception that simultaneous UL/DL transmissions between networks can be allowed in some defined parts of the frame. This leads to a degree of flexibility at the expense of some additional interference that can be controlled to some extent. Compared to unsynchronised operation, semi-synchronised operation reduces the impact on BS-BS and MS-MS interference. The results from studies in Section 4.5 show that in specific circumstances the ECC baseline (as defined in ECC Decision (11)06 (October 2018) Table 3), out of block power limit can be applied to the semi-synchronised operation.

---

[38] 24 dBm TRP was assumed in the study included in ANNEX 7 to this Report. 3GPP 38.104 [8] defines 24 dBm as the maximum TRP for the Local Area BS power class.

[39] For example “careful installation” would include measures like ceiling-mounted installation, placement of indoor BS away from windows, additional shielding around buildings in the worst case. Such measures may be more appropriate for professional installations which seem less suitable for consumer-type of scenario (without further mitigation schemes implemented in the indoor BS). Such measure seems to be feasible in case of industrial – type of use case (e.g. smart factory indoor coverage).

In order to deploy semi-synchronised operation of TDD mobile networks in a multi-network context (without guard bands or operator-specific custom filters), MFCN licensees need to reach agreement on:

- Time synchronisation, as for synchronised operation;
- Partial frame alignment: the agreement shall define a default frame structure for synchronised operation (for which UL/DL directions are defined across the whole frame) and the part of the frame where each operator is allowed to reverse the default transmission direction (flexible part);
- The conditions under which the ECC baseline out of block power limit can be applied to the semi-synchronised operation.

Options for the semi-synchronised operation of Macro BSs and Micro BSs:

The studies summarised in section 4.5 and reported in ANNEX 8 have led to the following results (under specific assumptions[40]):

- If no changes are applied to the default frame structure, the semi-synchronised operation is identical to the synchronous case;
- In case an operator selects the UL direction in the flexible part while the default frame structure adopts the DL direction (DL to UL modifications), the operator which follows the default (DL) frame transmission direction does not receive additional BS-BS interference compared the synchronous case;
- In case an operator selects the DL direction in the flexible part while the default frame structure adopts UL direction (UL to DL modifications), the operator which follows the default (UL) frame transmission direction receives additional BS-BS interference compared to the synchronous case.

<u>"DL to UL modifications": the default DL transmission direction in the flexible part is modified into UL:</u>

- In this case, from BS-BS interference perspective, the network that modifies the default DL transmission direction into UL will not interfere with the other network, while it will receive additional interference from the other network.
- In most circumstances, MS-MS interference will be negligible because terminals typically transmit intermittently and many will be mobile so any interference would be transient.
- It is expected that some 5G use cases will imply the deployment of MSs that are in fixed positions and close to each other (e.g. crowded stadiums, trains, busses, (home) CPEs in fixed wireless access (FWA) systems, and fixed machinery/robots in factories). In some of those specific scenarios, the MS-MS interference might not be negligible anymore: no specific studies were performed with this respect.
- A general framework could be defined at the national level specifying the scope of semi-synchronised operation in terms of geographical areas: defining whether and in which types of scenario downlink slots may be unilaterally converted to uplink slots should take into account situations when MS-MS interferences can be considered acceptable and when they cannot, assuming MS RF requirements are handled by SDOs and associated harmonised standards.

<u>"UL to DL modifications": the default UL transmission direction in the flexible part is modified into DL:</u>

- In this case, from BS-BS interference perspective, the network that modifies the default UL transmission direction into DL will interfere with the other network, while it will not receive additional interference from the other network.

A general framework could be defined at the national level specifying the scope of semi-synchronised operation in terms of geographical areas and type of cells: defining whether and in which types of scenario

---

[40] A) As shown in Figure 15, the 288 m network shift assumption between macro-cellular networks represents a best case assumption. Similarly, the 96m network shift assumption between micro-cellular networks represents a best case assumption.

B) Differently from the approach followed in this study, the recommended approach is to use the separation distance and the line-of-sight probability as input parameter during the coexistence studies between the macro-cellular network and the Micro BSs network. This approach accounts for the fact that it is difficult to carry out meaningful simulations to assess the interference between two Micro BS networks in the same urban area since the interference scenario will be strongly impacted by the LoS/NLoS conditions which radically change as the Micro BSs change their locations with respect to buildings.

C) Coexistence between the macro-cellular network and the Micro BS network was not assessed by this study.

uplink slots may be unilaterally converted to downlink or flexible slots. Such framework should take into account situations when BS-BS interferences can be considered acceptable and when they cannot.

It is worth noting that operators will not always decide to modify the default transmission direction from UL into DL (and from DL into UL) in the whole flexible part of the frame. In a typical scenario, an operator might decide to modify the agreed default frame structure in specific locations (e.g. hot spots) and at specific times (e.g. specific event or busy hour). In this particular case, only cells in areas where the transmission direction has been changed will be subject to cross-link interference.

Multi-stakeholder agreements will need to target the optimal balance between transmission direction flexibility and the additional interference (with associated throughput degradation). Such multi-stakeholder agreements should account for the following options which are based on the results from section 4.5, in case of UL to DL flexibility:

- Coexistence is facilitated if semi-synchronised operation is applied to Micro and indoor BS but it could be technically challenging for indoor BS to be semi-synchronised with outdoor networks;
- Coexistence could be more challenging if semi-synchronised operation is applied to Macro BS before efficient interference cancellation algorithms have been developed and implemented.

5.3 OPTIONS FOR AGREEMENTS

A general framework could be defined at the national level specifying:

- The technical parameters for synchronised and, for semi-synchronised operation if appropriate as described in previous Sections;
- The scope of synchronised, semi-synchronised and unsynchronised operation in terms of geographical areas and type of cells (e.g. whether indoor cells may operate in unsynchronised operation, and when semi-synchronised operation may be used);
- The definition of such framework before the spectrum awards would lead to greater market certainty.

Administrations may facilitate the process to ensure fair and timely agreements in cases where agreements could be more challenging, for example[41]:

- Different operators may prefer different frame structures based on the services they seek to provide. As a consequence, the negotiation to achieve common parameters (especially on the DL/UL ratio and performance targets) may become challenging;
- Multilateral agreements (involving all licensees in the band that may interfere with each other) are needed;
- Agreements on more complex synchronisation frameworks are more difficult to be achieved (e.g. regional/local licensing);
- Agreements may become more difficult in case of asymmetric or non-mutual interference scenarios (e.g. macro-cellular networks vs. Indoor BS networks, downlink-only configurations) - see also ECC Report 216 section 3.3 [1];
- Licensees operating networks in the band which do not implement AAS technology in their BSs might have less incentive in synchronised operation (due the possibility, in case of non-AAS BSs, to add external filters to meet the ECC restricted baseline out of block power limit).

Licensees may seek to periodically update (e.g. every few years) the characterising synchronisation framework. Such updates may be necessary to adapt to evolving technology and market requirements (e.g. latency and DL/UL ratio requirements and advances in semi-synchronised operation).

Administrations might consider consolidating similar systems together in specific portions of the 3400-3800 MHz band. Such measures will facilitate unsynchronised operation between 5G networks and existing MFCN networks by reducing the number of geographic and spectrum “boundaries” (see ECC Report 287 [9]).

[41] Such case have also been assessed in section §3.3 of ECC Report 216 [1].

In case of regional/local assignments, Administrations might consider defining stable borders and coexistence conditions at those borders. Such measures will facilitate unsynchronised operation between networks not in the same area e.g. based on approaches defined in ECC Recommendation (15)01 [4].

6 CONCLUSIONS

Starting from the definitions provided in ECC Report 281 [2] for the synchronised, unsynchronised and semi-synchronised operation, this Report supports Administrations, wishing to do so, in setting up a synchronisation framework at national level for the introduction of 5G-NR in the 3400-3800 MHz band in a multi-operator environment.

Benefits and challenges of the above mentioned three operating modes are briefly summarised as follows:

Synchronised operation avoids any BS-BS and MS-MS interferences therefore allowing coexistence between adjacent networks without the need for guard bands or additional filters. This operating mode simplifies network deployment because no additional interference mitigation is required. Synchronised operation leads to the selection of a compatible frame structure, which determines a specific DL/UL transmission ratio and frame length which contribute to the network performance (e.g. latency, spectral efficiency, throughput and coverage[42]). A common phase clock reference (e.g. UTC) and accuracy/performance constraints that depend on the underlining technology (e.g. +/- 1.5 µs for LTE-TDD and 5G-NR) is required and those aspects and challenges are detailed in ECC Report 216 [1].

Unsynchronised operation does not require the adoption of a compatible frame structure among licensees. Licensees can select the most appropriate frame structure independently and can adapt the frame structure to service and end user requirements, which may change depending on the location and on time. However, in a multi-operator scenario, the flexibility in operators' frame structure selection leads to a number of interference scenarios that need to be assessed and managed.

Semi-synchronised operation is defined in ECC Report 281 as the operating mode which "corresponds to the case where part of the frame is consistent with synchronised operation as described above, while the remaining portion of the frame is consistent with unsynchronised operation as described above. This requires the adoption of a frame structure for all TDD networks involved, including slots where the UL/DL direction is not specified, as well as synchronising the beginning of the frame across all networks". This mode allows simultaneous UL/DL transmissions between networks in some defined parts of the frame. This leads to a degree of frame structure flexibility at the expense of some additional interference that can be controlled to some extent. A common phase clock reference (e.g. UTC) and accuracy/performance constraints that depend on the underlining technology (e.g. +/- 1.5 µs for LTE-TDD and 5G-NR) is required.

This Report has identified the following items that should be agreed at the national level to enable the three operating modes.

For **synchronised operation**, a common framework or a multilateral agreement has to be defined at the national level so that all MFCN licensees in the same band[43] use:

- A common phase clock reference (e.g. UTC), with proper accuracy/performance constraints and permanent monitoring and agreed remedies in case of accuracy loss;
- A compatible frame structure to avoid simultaneous UL/DL transmissions;

The feasibility and performance impacts of synchronised operation between different radio technologies have to be assessed on a case-by-case basis depending on the specific technologies[44]. The synchronised operation of 5G-NR and LTE-TDD may imply a cost in terms of user plane latency and performance, especially with regards to 5G URLLC latency targets. Operators may have the option to reduce the user

[42] For example: the size of the guard periods between DL and UL transmissions will have an impact on maximum cell radius. Increasing the number of UL transmissions has an impact on the UL coverage performance.

[43] Not limited to the licensees with adjacent blocks.

[44] ECC report 216 has assessed LTE-TDD/WiMAX cross-technology synchronisation feasibility. This report has assessed 5G-NR/LTE-TDD cross technology synchronisation. The case for 5G-NR/WiMAX cross-technology synchronisation has not been assessed but it is understood that every LTE-TDD configuration has at least one 5G-NR equivalent configuration, making it therefore theoretically feasible to align a 5G-NR carrier with an adjacent channel WiMAX carrier as assessed in ECC Report 216.

plane latency and RTT, under some circumstances, by using lower frequencies (e.g. 700, 800, 900, 1800 MHz) in combination with the 3400-3800 MHz band (e.g. through Carrier Aggregation or Supplemental Uplink schemes).

In case of **semi-synchronised operation**, a common framework or a multilateral agreement has to be defined at the national level so that all MFCN licensees in the same band[45] use:

- A common phase clock reference, as for synchronised operation;
- Partial frame alignment: the agreement shall define a default frame structure as for synchronised operation (for which UL/DL directions are defined across the whole frame) and at the same time the part of the frame where each operator is allowed to reverse the default transmission direction (flexible part);
- The terms and conditions under which the ECC baseline out of block power limit can be applied to the semi-synchronised operation.

Unsynchronised operation does not require the adoption of a compatible frame structure among licensees. Licensees can select the most appropriate frame structure. Licensees will need to agree on the terms and conditions under which the ECC baseline out of block power limit can be applied to the unsynchronised operation. Meaning that unsynchronised operation could be allowed at national level in specific cases where sufficient isolation between interferer and victim base stations exists (e.g. sufficient separation distance or adoption of low power indoor BSs) and in such cases the ECC baseline out of block power limit can be applied to the unsynchronised operation.

According to ECC Decision (11)06 (October 2018), in case of unsynchronised and semi-synchronised operation the EC restricted baseline limit[46] applies by default. In this case: the interfering BS transmitter requires custom filters and guard band.

Operator-specific filters would likely be necessary to meet the ECC restricted baseline emissions limit. Based on currently available technology, it is assumed that it will be challenging to implement operator-specific filters cost effectively in AAS BSs. Therefore, this Report provides an analysis on whether and under which conditions the unsynchronised and semi-synchronised operating modes can be used when base stations implement the ECC baseline out of block power limits[47]. Here follows a concise summary for the main options that have been identified noting that more details are provided in the "Toolbox Section" (Section 5).

With respect to unsynchronised operation with the ECC baseline out of block power limit, the following options are identified:

Unsynchronised Macro-cellular networks in the same area

- Without operator-specific filters, it may not be possible to rely on guard bands alone to enable unsynchronised operation between operators;
- **Separation distances** are therefore needed but a specific recommendation or single set of trigger values cannot be provided due to the dependency from various factors[48]. The studies show minimum distances required between unsynchronised Macro-cellular networks could be up to 60 km when co-channel operation and up to 14 km when operating in the adjacent channel.

Unsynchronised Micro BS networks and Macro-cellular networks in the same area

- The studies show that, in general, adjacent channel unsynchronised operation of Macro-cellular networks and Micro BS networks might not be feasible in the same area. Separation distances have not been assessed in this Report.

[45] Not limited to the licensees with adjacent blocks.

[46] See ECC Decision (11)06 (October 2018) Table 4.

[47] ECC baseline out of block power limit is defined in Table 3 of ECC Decision (11)06 (October 2018) with reference to the synchronised operation.

[48] Network technologies and topologies (LTE/5G-NR, non-AAS/AAS BS, BS antenna height), propagation environment and propagation model, frequency assignments, protection criteria (I/N or network throughput loss at x%, etc.….).

- If there is no Macro-cellular network, adjacent channel unsynchronised operation between two Micro BS networks might be feasible with careful planning avoiding line of sight between Micro BS.

Unsynchronised Indoor BS networks and Macro-cellular networks in the same area

- Under specific assumptions in the adjacent channel case, unsynchronised operation should be possible with careful installation[49] of the indoor BSs.
- Synchronised operation of indoor BS may be difficult in practice because of the challenges involved in distributing the common clock signal to indoor BS;
- In case of co-channel operation of Macro BSs and indoor BSs, the lack of out of block filtering on the Macro BS and on the indoor BS transmitters' sides will need to be considered.

With respect to **semi-synchronised operation with the ECC baseline out of block power limit**, it is useful to distinguish DL-to-UL and UL-to-DL modifications compared to the reference frame:

- **"DL to UL modifications"**: the default DL transmission direction in the flexible part is modified into UL:
  - From BS-BS interference perspective, the network that modifies the default DL into UL will not interfere the other network while it will receive additional interference from the other network;
  - In most circumstances, MS-MS interference will be negligible because terminals typically transmit intermittently and many will be mobile so any interference would be transient. It is expected that some 5G use cases will imply the deployment of MSs that are in fixed positions and close to each other[50]. No specific studies were performed on MS-MS interference. Therefore, in case of MSs that are in fixed positions and close to each other, no conclusion can be derived. In any case, MS RF requirements are handled by SDOs and associated harmonised standards.
- "**UL to DL modifications**": the default UL transmission direction in the flexible part is modified into DL:
  - From BS-BS interference perspective, the network that modifies the default UL transmission direction into DL will interfere the other network while it will not receive additional interference from the other network;
  - Coexistence is facilitated if semi-synchronised operation is applied to Micro and indoor BS but it could be technically challenging for indoor BS to be semi-synchronised with outdoor networks;
  - Coexistence could be more challenging if semi-synchronised operation is applied to Macro BS before efficient interference cancellation algorithms have been developed and implemented.

The actual coexistence feasibility for the different scenarios will depend on the specific circumstances and assumptions that can only be clarified at national level.

A general framework could be defined at the national level by Administrations wishing to do so specifying:

- The technical parameters for synchronised operation, and for semi-synchronised operation if appropriate (including reference clock and reference frame structure);
- The scope of synchronised, semi-synchronised and unsynchronised operation in terms of geographical areas and type of cells (e.g. whether indoor cells may operate in unsynchronised operation, and in which scenarios downlink slots may be unilaterally converted to uplink slots).

Administrations may facilitate the process to ensure fair and reasonable agreements.

Administrations could establish mechanisms through which the parameters characterising the synchronisation framework are periodically updated. This process could be triggered by the Administrations or by the licensees.

Administrations might want to consider consolidating similar systems together in specific portions of the 3400-3800 MHz band. Such measures will facilitate unsynchronised operation between 5G networks and

---

[49] For example "careful installation" would include measures like ceiling-mounted installation, placement of indoor BS away from windows, additional shielding around buildings in the worst case. Such measures may be more appropriate for professional installations which seem less suitable for consumer-type of scenario (without further mitigation schemes implemented in the indoor BS). Such measure seems to be feasible in case of industrial – type of use case (e.g. smart factory indoor coverage).

[50] E.g. crowded stadiums, trains, buses, (home) CPEs in fixed wireless access (FWA) systems.

existing MFCN networks by reducing the number of geographic and spectrum “boundaries” (see ECC Report 287 [9]).

In the case of regional/local assignments, Administrations might consider defining stable borders and coexistence conditions at those borders. Such measures will facilitate unsynchronised operation between networks not in the same area.

ANNEX 1: SYNCHRONISATION FRAMEWORKS IN RECENT C-BAND AWARD PROCEDURES

As stated in ECC Report 281: “Several LTE-TDD networks are currently providing services to millions of end users with hundreds of thousands of BSs deployed in the field adopting synchronisation and alignment of UL/DL transmissions between operators using adjacent frequency blocks. Such networks provide proven experience in the field that should be considered as the starting point for the definition of the regulatory framework for 5G-NR.

In Europe, the majority of legacy TDD networks deployment can be grouped in two categories:

- Based on synchronised operation when operators run their networks without relying on sufficient isolation (e.g. this is the case of LTE-TDD networks, comprising thousands of BS, in Italy operating in the 3400-3600 MHz band;
- Based on unsynchronised operation when there is sufficient isolation between operators running their networks on adjacent frequency blocks (e.g. one operator per region is often assumed).

Going forward, recent advances for newer TDD systems in a multi-operator context encourage synchronisation more strongly, therefore this situation is expected to evolve in the coming years.

ECC Report 216 section 3.3 describes some potential situations where inter-operator agreement relying solely on the market may be challenging in a multi-operator context (either at the time of auction, or later in time). Therefore regulators may get involved at some point in the process in order to ensure an efficient spectrum usage. This has already been done in the past, and ECC Report 216 ANNEX 3 already describes a few of them. Since then, some new auctions have happened:

Austria

The Austrian Administration is planning to start the assignment procedure for the 3410-3800 MHz range in Q1 ’19. The following provisions are described in the tender document from the Telekom-Control-Kommission [10].

The “LTE compatible” NR frame structure (DSUDDDSUDD) is defined as the “default frame structure” for which the ECC baseline out of block power limit applies. "Licence holders are responsible for ensuring that frames are based on a uniform reference time (+/- 1.5 µs), so that all of any licence holder’s frames are aligned equally and transmissions are consequently synchronised". "…Small cells inside buildings are exempt from synchronisation. The default BEM can be used for such small cells[51] in buildings, provided that no damaging interference occurs to other licence holders".

According to the tender document: "… the synchronisation frame specified here can be altered by the TKK to reflect technical and economic conditions when 5G reaches market maturity, in accordance with Art. 57 TKG 2003. If such modifications are indeed made, consideration will nonetheless have to be given in each case to the proportionality of the measure and the economic impact on the parties affected. Even if any such change is made, the spectrum holders will have the option of stipulating under private law a synchronisation frame".

The tender document also provides conditions associated with the use of the restrictive BEM when "other frame structures" are adopted.

Ireland

In its June 2017 Spectrum 3600 MHz band spectrum award [1] Ireland mandated the LTE-TDD frame configuration #2 with special sub-frame configuration #6 (or equivalent frame structures whose transmit and receive periods are aligned with this configuration) as the default frame structure which an operator must comply with in order to be allowed to comply with the "permissive Block Edge Mask". The operator must also ensure compliance with a common reference time of +/- 1.5µs.

Italy

[51] A small cell is defined as "a base station with a maximum EIRP of 24 dBm per 20 MHz of carrier".

In September 2018, a multiband 5G spectrum in Italy followed a light touch approach with respect to the definition of the synchronisation framework for the 3600-3800 MHz band. The auction rules [12] did not include specific provisions in relation to the synchronisation framework, leaving to operators the task to agree on the most suitable framework. Soon after the frequency assignment, the Italian Ministry has announced that it will facilitate the process by setting up a specific working group among operators that acquired licenses in the band.

United Kingdom

In its May 2015 statement on the award of the 3.4 GHz spectrum band [14], the UK decided on the LTE-TDD frame configuration #2 with special sub-frame configuration #6 (or equivalent frame structures whose transmit and receive periods are aligned with this configuration) as the "preferred frame structure" (see Figure 26) which an operator must comply with in order to be allowed to comply with the "permissive transmission mask. An operator unwilling to adopt the "preferred frame structure" must comply with the "restrictive transmission mask" and the "compatible frame structure" (see Figure 27), i.e. must comply with semi-synchronised operation.

Licensees are required to synchronise their networks in order to avoid interference to one another, so traffic alignment and the “preferred frame structure” for transmission with the limits of the "permissive transmission mask" are mandated to implement the synchronisation. Timeslots must have a duration of 1ms. LTE-TDD frame configuration #2 (3:1) is compatible with this frame structure.

DL/UL ratio	Subframe number									
	0	1	2	3	4	5	6	7	8	9
3:1	D	S	U	D	D	D	S	U	D	D

Figure 26: Preferred frame structure in UK award for the 3400-3600 MHz range in April 2018

DL/UL ratio	Subframe number									
	0	1	2	3	4	5	6	7	8	9
Any	D	S	U							

Figure 27: Compatible frame structure in UK award for the 3400-3600 MHz range in April 2018

Indoor base stations with a transmit power level below 24 dBm are exempt from synchronisation requirements unless they cause interference to the macro-cellular network, in which case they are required to synchronise.

In April 2018, Ofcom conducted the auction, and the 3.4 GHz band plan based on final auction results as below, as announced by Ofcom [15]. Ofcom will auction 3600-3800 MHz in second half of 2019.

Vodafone 3410-3460 MHz	H3G 3460-3480 MHz	UK Broadband 3480-3500 MHz	Telefónica 3500-3540 MHz	EE 3540-3580 MHz	UK Broadband 3580-3600 MHz

Figure 28: Outcome from UK award for the 3400-3600 MHz range in April 2018

China

For the first 2600 MHz TDD network in the world, China operators have agreed to coordinate their network. Finally, under the guideline of MIIT (Ministry of Industry and Information Technology) of China, the synchronisation among operators’ networks at the band 2600 MHz was implemented based on the same frame structure and the same DL/UL traffic ratio. China MIIT has been actively organising MNOs and relevant stakeholders to negotiate a single frame structure for synchronisation of 5G networks in the 3500 MHz band.

Japan

A public open hearing of potential operators for Japan 3400-3600 MHz band was held by MIC (Ministry of Internal Affairs and Communications) in January 2014. All operators presented a clear position in favour of the TDD duplex scheme, and advocated the necessity of operator's consensus for collaboration for realising TDD synchronised operation including the DL/UL configuration, ideally, in order to achieve no guard band for efficient usage of spectrum resources. All the operators have the same opinion of DL heavy frame configuration, by referring to the heavy data traffic in downlink side.

The MIC issued the draft guideline for the introduction of 4G for comments in July 2014 taking into account the opinions expressed at public hearing held in January 2014. The guidelines proposed that 3480-3600 MHz should be assigned for 3 operators (40MHz per operator) for TDD use, and proposed an obligation for licensees to agree with each other in advance about the matters for TDD synchronised operation, such as transmission time and frame structure. The draft was approved at the Council in September 2014, and MIC started to receive applications for the operation of the bands.

Three operators have submitted applications. As first step, regarding the synchronisation operation, NTT DoCoMo applied for DL/UL ratio of 8:1 or 3:1, while KDDI and Softbank both applied DL/UL ratio of 3:1. The three operators agreed to hold operator meeting after the band was granted to get mutual agreement on the UL/DL configuration and frame synchronisation.

In December 2014, the MIC issued the licenses to three applicants as follows based on the discussion results of Radio Regulatory Council.

NTT DOCOMO:	3480-3520 MHz
KDDI:	3520-3560 MHz
SOFTBANK MOBILE:	3560--3600 MHz

Finally, the three operators agreed with DL/UL 3:1 ratio and implemented the TDD synchronised operation based on a common 3:1 frame structure. All operators will cover around 50% population by the end of 2018, with around 57,000 base stations, as announced during the spectrum application procedure.

In April 2018, the MIC allocated the remaining spectrum in the 3400-3600 MHz band to 2 operators, and the two licenses are to synchronise with the existing networks in the same band. By the year 2022, around 60% population will be covered with around 33,000 base stations, as planned in the application materials.

SOFTBANK MOBILE:	3400-3440 MHz
NTT DOCOMO:	3440-3480 MHz

The MIC issued the draft guideline[52] for the introduction of 5G for comments in November 18. The guidelines proposed 3600-4100MHz, 4500-4600MHz and 27-28.2GHz, 29.1-29.5GHz for for TDD use, and proposed an obligation for licensees to agree with each other in advance about the matters for TDD synchronised operation such as transmission time and frame structure.

Korea

Korea completed an auction of the 3.5 GHz and 28 GHz bands.

LGU+:	3420-3500 MHz
KT:	3500-3600 MHz
SKT:	3600-3700 MHz

52 Official MIC weblink: http://www.soumu.go.jp/menu_news/s-news/01kiban14_02000358.html

ANNEX 2: TECHNICAL SOLUTIONS FOR NETWORK SYNCHRONISATION

Section 2.1.1 has provided the frequency and phase synchronisation requirements for LTE-TDD and 5G-NR. This annex provides a simple overview on the mainstream solutions to implement synchronisation.

Currently, the main solution for 5G-NR time synchronisation includes the following two major categories:

- Type 1: distributed synchronisation scheme based on satellite;
- Type 2: centralised synchronisation scheme based on 1588v2 system.

The main principles of these two types of synchronous solutions, advantages and disadvantages and applicable scenarios are described below.

Distributed synchronisation scheme based on satellite:

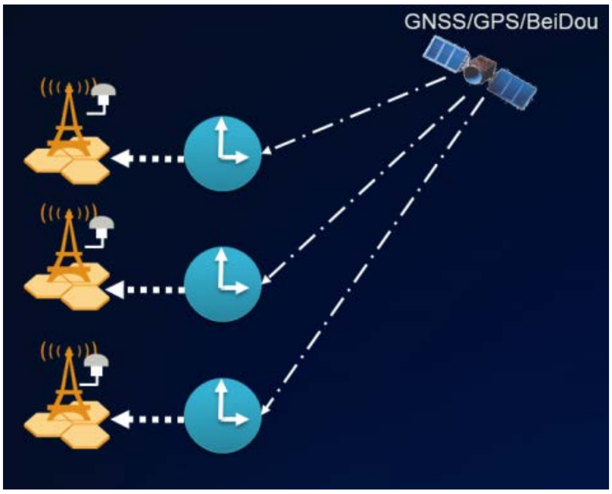


Figure 29: Distributed synchronisation scheme based on satellite

As shown in the Figure 29, GNSS signal receivers are directly deployed on base stations, each base station acquires the available satellite time signals (GPS, Beidou, GLONASS, etc.) to achieve the time synchronisation between different base stations and to ensure the maximum deviation of any two of the base stations.

Table 10: Applicability of the distributed synchronisation scheme based on satellite

Applicable scenarios	Inapplicable scenarios	Pros	Cons
▪ The node of transmission network does not support PTP (Precision Time Protocol); ▪ Base stations located in open area; ▪ Easy to install the GPS antenna.	▪ The base station location is surrounded by tall buildings that easily block GPS signals; ▪ Indoor base stations; ▪ Difficult to install the GPS antenna	▪ Single stations can be activated very efficiently; ▪ Sites that need time synchronisation can be directly deployed without the cooperation with the transmission network; ▪ The impact of a fault in a single station is small;	▪ Newly-installed GPS is difficult to construct, leading to high installation and maintenance costs; ▪ High failure rate of a single GPS; ▪ Poor maintainability and high installation and maintenance costs.

Centralised synchronisation scheme based on 1588v2 system:

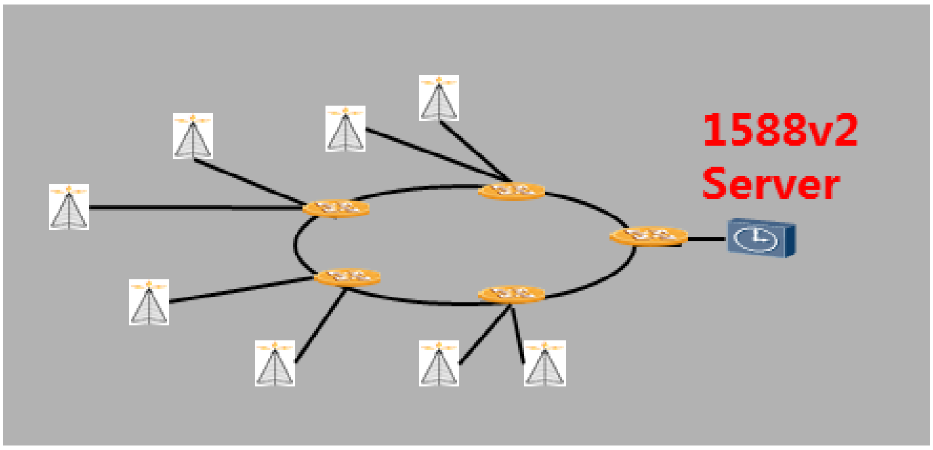


Figure 30: Centralised synchronisation scheme based on the 1588v2 system

The IEEE standards development organisation has proposed the IEEE 1588v2 accurate time transfer protocol, which can achieve sub-microsecond precision time synchronisation like the current GPS currency.

As shown in the Figure 30, the clock synchronisation information of the main time source is transmitted through the 1588v2 protocol packet on the transmission network. The base station can obtain time information from the transmission network through the 1588v2 interface to achieve synchronisation with the time source. The accuracy can reach ns level.

Table 11: Applicability of the centralised synchronisation scheme based on 1588v2 system

Applicable scenarios	Inapplicable scenarios	Pros	Cons
▪ Difficult to obtain the satellite signal; ▪ All transmission network nodes support PTP protocol.	▪ The transmission network nodes cannot support PTP; ▪ The transport network QoS is poor.	▪ Single site without additional antenna engineering; ▪ High reliability; ▪ Low maintenance costs.	▪ Requires all nodes of the bearer network to support PTP; ▪ Clock; synchronisation quality is affected by network QoS.

The two synchronisation methods described above have been widely used by operators around the world.

Operators will take decisions depending on the country and the network situation. For example, operators in Japan and other regions mainly use distributed synchronisation scheme based on satellite (GPS), and some operators in Europe choose the centralised synchronisation scheme (IEEE 1588v2). Some other operators will also consider adopting a combination of two synchronised approaches to improve reliability (e.g. China Mobile).

ANNEX 3: 5G-NR AND LTE-TDD FRAME STRUCTURES, OPTIONS AND ASSESSMENTS - STUDY #1 AND #2

A3.1 LTE TDD FRAME STRUCTURES AND OPTIONS

LTE-TDD frame structures are defined in [16].

Each radio frame of length 10ms consists of two half-frames of length 5ms each. Each half-frame consists of five sub-frames of length 1ms. The supported uplink / downlink configurations are listed in Table 12 where:

- "D" denotes the sub-frame which is reserved for downlink transmissions;
- "U" denotes the sub-frame which is reserved for uplink transmissions;
- "S" denotes a special "Subframe" with the three fields: Downlink Pilot Time Slot (DwPTS), Guard Period (GP) and Uplink Pilot Time Slot (UpPTS). The length of DwPTS and UpPTS is given by
- Table 13 subject to the total length of DwPTS, GP and UpPTS being equal to 1ms.

Uplink / downlink configurations with both 5ms and 10ms DL to UL switch-point periodicity are supported. In case of 5ms DL to UL switch-point periodicity, the special sub-frame exists in both half-frames. In case of 10ms DL to UL switch-point periodicity, the special sub-frame exists in the first half-frame only.

Sub-frames 0 and 5 and DwPTS are always reserved for downlink transmissions. UpPTS and the sub-frame immediately following the special sub-frame are always reserved for uplink transmissions.

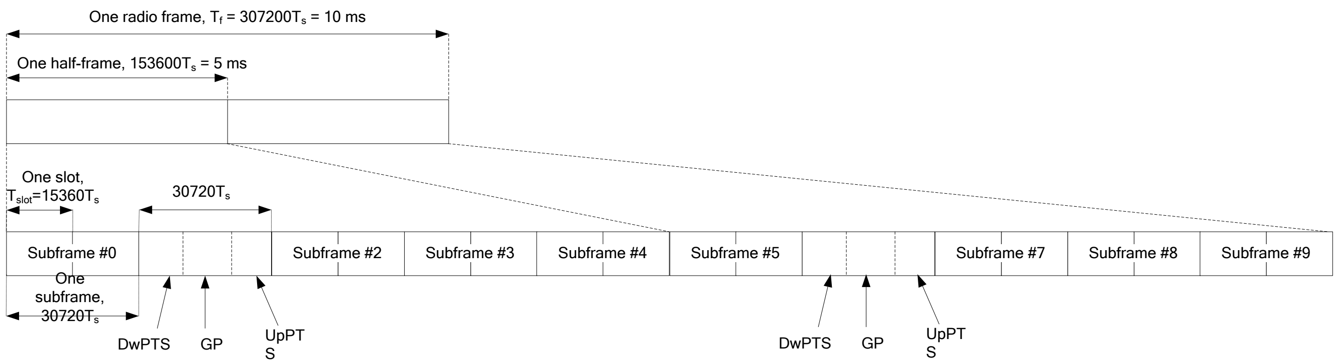


Figure 31: LTE-TDD frame structure (for 5ms switch-point periodicity)

Table 12: LTE-TDD uplink / downlink configurations

UL/DL configuration	DL to UL Switch-point periodicity	Sub-frame number									
		0	1	2	3	4	5	6	7	8	9
0	5ms	D	S	U	U	U	D	S	U	U	U
1	5ms	D	S	U	U	D	D	S	U	U	D
2	5ms	D	S	U	D	D	D	S	U	D	D
3	10ms	D	S	U	U	D	D	D	D	D	D
4	10ms	D	S	U	U	D	D	D	D	D	D
5	10ms	D	S	U	D	D	D	D	D	D	D
6	5ms	D	S	U	U	U	D	S	U	U	D

Table 13: Configuration of special sub-frame (lengths of DwPTS / GP / UpPTS)

<table>
<tr><th rowspan="3">Special sub-frame configuration</th><th colspan="3">Normal Cyclic prefix in downlink</th><th colspan="3">Extended cyclic prefix in downlink</th></tr>
<tr><th rowspan="2">DwPTS</th><th colspan="2">UpPTS</th><th rowspan="2">DwPTS</th><th colspan="2">UpPTS</th></tr>
<tr><th>Normal Cyclic prefix in uplink</th><th>Extended Cyclic prefix in uplink</th><th>Normal Cyclic prefix in uplink</th><th>Extended Cyclic prefix in uplink</th></tr>
<tr><td>0</td><td>6592.Ts</td><td rowspan="5">2192.Ts</td><td rowspan="5">2560.Ts</td><td>7680.Ts</td><td rowspan="4"></td><td rowspan="4"></td></tr>
<tr><td>1</td><td>19760.Ts</td><td>20480.Ts</td></tr>
<tr><td>2</td><td>21952.Ts</td><td>23040.Ts</td></tr>
<tr><td>3</td><td>24144.Ts</td><td>25600.Ts</td></tr>
<tr><td>4</td><td>26336.Ts</td><td>7680.Ts</td><td rowspan="3">4384.Ts</td><td rowspan="3">5120.Ts</td></tr>
<tr><td>5</td><td>6592.Ts</td><td rowspan="4">4384.Ts</td><td rowspan="4">5120.Ts</td><td>20480.Ts</td></tr>
<tr><td>6</td><td>19760.Ts</td><td>23040.Ts</td></tr>
<tr><td>7</td><td>21952.Ts</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td>8</td><td>24144.Ts</td><td>-</td><td>-</td><td>-</td></tr>
</table>

Ts=1/(15000x2048) seconds.

Selecting a synchronisation option for LTE-TDD requires:

- Selection of a timing reference (beginning of the frame);
- Selection of a frame structure;
- Selection of special sub-frame configuration.

A3.2 5G-NR FRAME STRUCTURE AND OPTIONS

5G-NR frame structures are defined in [17].

Downlink and uplink transmissions are organised into frames with 10 ms duration, each consisting of ten sub-frames of 1 ms duration. The number of consecutive OFDM symbols per sub-frame is given by:

$$N_{\mathrm{symb}}^{\mathrm{subframe},\mu} = N_{\mathrm{symb}}^{\mathrm{slot}} N_{\mathrm{slot}}^{\mathrm{subframe},\mu}.$$

$N_{\mathrm{symb}}^{\mathrm{slot}}$ is the number of OFDM symbols in a slot

$N_{\mathrm{slot}}^{\mathrm{frame},\mu}$ is the number of slots in a frame

$N_{\mathrm{slot}}^{\mathrm{subframe},\mu}$ is the number of slots in a sub-frame

Each frame is divided into two equally-sized half-frames of five sub-frames each with half-frame 0 consisting of sub-frames 0 – 4 and half-frame 1 consisting of sub-frames 5 – 9.

Slots are defined within a frame depending on the subcarrier spacing configuration μ, according to Table 14 and Table 15.

Table 14: 5G-NR number of OFDM symbols per slot, slots per frame, and slots per sub-frame for normal cyclic prefix.

Subcarrier spacing configuration μ	N_{symb}^{slot}	$N_{slot}^{frame,\mu}$	$N_{slot}^{subframe,\mu}$
0	14	10	1
1	14	20	2
2	14	40	4
3	14	80	8
4	14	160	16

Table 15: 5G-NR number of OFDM symbols per slot, slots per frame, and slots per sub-frame for extended cyclic prefix

Subcarrier spacing configuration μ	N_{symb}^{slot}	$N_{slot}^{frame,\mu}$	$N_{slot}^{subframe,\mu}$
2	12	40	4

As shown in Table 16, the UL or DL transmissions are configured within each slot. OFDM symbols in a slot can be classified as:

- "D" denoting the OFDM symbol which is reserved for downlink transmissions;
- "U" denotes the sub-frame which is reserved for uplink transmissions;
- "X" denoting a flexible symbol for which transmission can either be un downlink or uplink

Table 16: 5G-NR slot formats for normal cyclic prefix

Format	Symbol number in a slot													
	0	1	2	3	4	5	6	7	8	9	10	11	12	13
0	D	D	D	D	D	D	D	D	D	D	D	D	D	D
1	U	U	U	U	U	U	U	U	U	U	U	U	U	U
2	X	X	X	X	X	X	X	X	X	X	X	X	X	X
3	D	D	D	D	D	D	D	D	D	D	D	D	D	X
4	D	D	D	D	D	D	D	D	D	D	D	D	X	X
5	D	D	D	D	D	D	D	D	D	D	D	X	X	X
6	D	D	D	D	D	D	D	D	D	D	X	X	X	X
7	D	D	D	D	D	D	D	D	D	X	X	X	X	X
8	X	X	X	X	X	X	X	X	X	X	X	X	X	U
9	X	X	X	X	X	X	X	X	X	X	X	X	U	U
10	X	U	U	U	U	U	U	U	U	U	U	U	U	U

Format	Symbol number in a slot												
11	X	X	U	U	U	U	U	U	U	U	U	U	U	U
12	X	X	X	U	U	U	U	U	U	U	U	U	U	U
13	X	X	X	X	U	U	U	U	U	U	U	U	U	U
14	X	X	X	X	X	U	U	U	U	U	U	U	U	U
15	X	X	X	X	X	X	U	U	U	U	U	U	U	U
16	D	X	X	X	X	X	X	X	X	X	X	X	X	X
17	D	D	X	X	X	X	X	X	X	X	X	X	X	X
18	D	D	D	X	X	X	X	X	X	X	X	X	X	X
19	D	X	X	X	X	X	X	X	X	X	X	X	X	U
20	D	D	X	X	X	X	X	X	X	X	X	X	X	U
21	D	D	D	X	X	X	X	X	X	X	X	X	X	U
22	D	X	X	X	X	X	X	X	X	X	X	X	U	U
23	D	D	X	X	X	X	X	X	X	X	X	X	U	U
24	D	D	D	X	X	X	X	X	X	X	X	X	U	U
25	D	X	X	X	X	X	X	X	X	X	X	U	U	U
26	D	D	X	X	X	X	X	X	X	X	X	U	U	U
27	D	D	D	X	X	X	X	X	X	X	X	U	U	U
28	D	D	D	D	D	D	D	D	D	D	D	D	X	U
29	D	D	D	D	D	D	D	D	D	D	D	X	X	U
30	D	D	D	D	D	D	D	D	D	D	X	X	X	U
31	D	D	D	D	D	D	D	D	D	D	D	X	U	U
32	D	D	D	D	D	D	D	D	D	D	X	X	U	U
33	D	D	D	D	D	D	D	D	D	X	X	X	U	U
34	D	X	U	U	U	U	U	U	U	U	U	U	U	U
35	D	D	X	U	U	U	U	U	U	U	U	U	U	U
36	D	D	D	X	U	U	U	U	U	U	U	U	U	U
37	D	X	X	U	U	U	U	U	U	U	U	U	U	U
38	D	D	X	X	U	U	U	U	U	U	U	U	U	U
39	D	D	D	X	X	U	U	U	U	U	U	U	U	U
40	D	X	X	X	U	U	U	U	U	U	U	U	U	U
41	D	D	X	X	X	U	U	U	U	U	U	U	U	U
42	D	D	D	X	X	X	U	U	U	U	U	U	U	U
43	D	D	D	D	D	D	D	D	D	X	X	X	X	U
44	D	D	D	D	D	D	X	X	X	X	X	X	U	U
45	D	D	D	D	D	D	X	X	U	U	U	U	U	U
46	D	D	D	D	D	D	X	D	D	D	D	D	D	X
47	D	D	D	D	D	X	X	D	D	D	D	D	X	X

Format	Symbol number in a slot													
48	D	D	X	X	X	X	X	D	D	X	X	X	X	X
49	D	X	X	X	X	X	X	D	X	X	X	X	X	X
50	X	U	U	U	U	U	U	X	U	U	U	U	U	U
51	X	X	U	U	U	U	U	X	X	U	U	U	U	U
52	X	X	X	U	U	U	U	X	X	X	U	U	U	U
53	X	X	X	X	U	U	U	X	X	X	X	U	U	U
54	D	D	D	D	D	X	U	D	D	D	D	D	X	U
55	D	D	X	U	U	U	U	U	U	X	U	U	U	U
56	D	X	U	U	U	U	U	D	X	U	U	U	U	U
57	D	D	D	D	X	X	U	D	D	D	D	X	X	U
58	D	D	X	X	U	U	U	D	D	X	X	U	U	U
59	D	X	U	U	U	U	U	D	X	U	U	U	U	U
60	D	X	X	X	X	X	U	D	X	X	X	X	X	U
61	D	D	X	X	X	X	U	D	D	X	X	X	X	U
62-255	reserved													

It can be noted that, apart from slot formats 0 - 2, all slot formats contain a mix of D, U and X symbols.

Selecting a synchronisation / semi-synchronisation option for 5G-NR requests:

- Selection of a timing reference (beginning of the frame);
- Selection of normal or extended prefix;
- Selection of a subcarrier spacing configuration;
- Selection of a slot configuration.

A3.3 STUDIES ASSESSING THE IMPACT OF THE 5G-NR FRAME STRUCTURE ON 5G PERFORMANCE

A3.3.1 STUDY #1

ECC Report 281 states: “Although complete alignment of UL/DL transmissions between LTE-TDD and 5G-NR can be achieved…, this would have implications on the minimum latency achievable by 5G-NR. Full synchronisation of the 5G-NR slot structure and LTE-TDD configuration brings significant drawbacks to the 5G-NR implementation. Many of the benefits of 5G-NR are linked precisely to the frame structure. Reverting to the LTE-TDD structure would imply higher latency, higher MS memory cost, TCP performance loss, mobility performance loss and spectral efficiency loss, although networks could be designed to overcome some of these drawbacks.”

This Section provides additional elements to qualify the statement from ECC Report 281.

A3.3.1.1 Impact on latency

When 5G-NR frame structure is aligned with LTE-TDD, the UL occurrences are spaced out, matching the LTE-TDD format. The MS must wait for the next UL opportunity to send the HARQ response, which may be several slots (TTIs) later. Assuming 30 kHz subcarrier spacing, the timeline of 5G-NR is aligned with LTE-TDD Configuration 2 as shown in Figure 32.

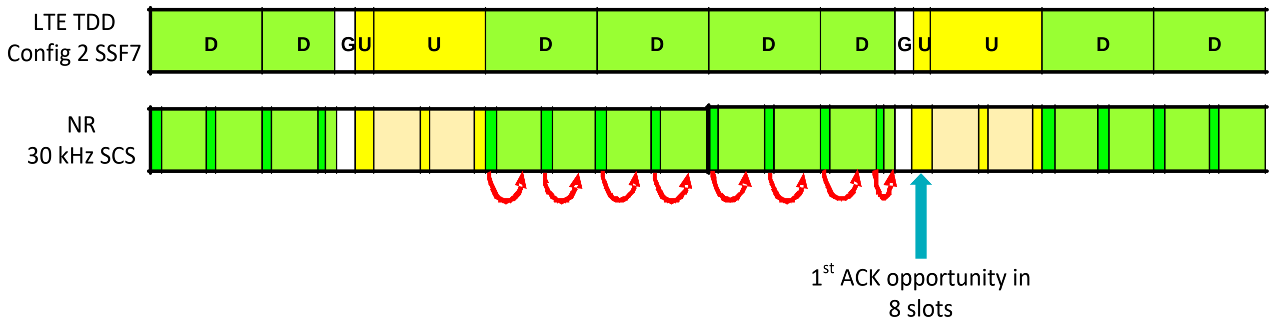


Figure 32: HARQ timeline when 5G-NR frame structure is aligned with LTE-TDD frame configuration #2

As shown, there are seven consecutive DL-only slots without any UL control block. The earliest opportunity to send the HARQ response is the UL symbols at the end of the 8th slot.

Similarly, for UL traffic, the consecutive DL slots will also block scheduling requests (SR) and UL data transmission.

Considering scheduling and MS/network processing latency, this frame structure will lead to L1 latency > 4ms. Note that IMT-2020 eMBB latency requirement is 4ms and URLLC latency requirement is 0.5ms. When 5G-NR deployments follow the LTE-TDD frame structure for coexistence purposes, they would not be able to meet the IMT-2020 requirements and most importantly deployment of innovative services such as URLLC would not be possible.

Simulations were performed on the impact of the 5G-NR frame structure on latency. The 5G-NR DDDDDDDSUU multi slot structure (30 kHz SCS, start shifted to the first DL slot) is with respect to timing and UL/DL configuration an identical match with LTE-TDD frame configuration #2 also known as DSUDDDSUDD.

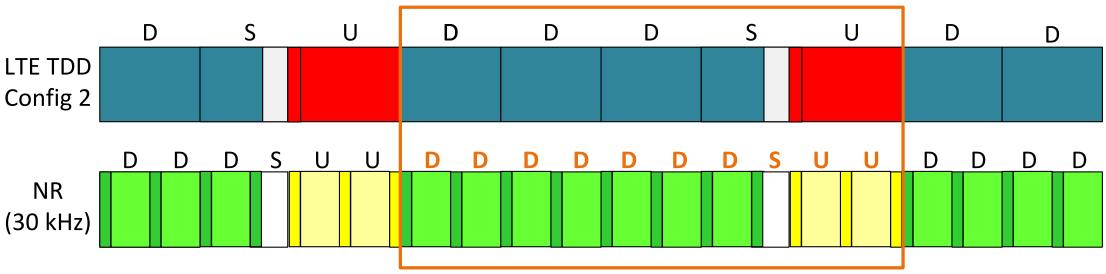


Figure 33: LTE-TDD – 5G-NR slot matching assumption

Figure 34 depicts the possible HARQ timeline and the transmission opportunities of the two multi-slot structures. Figure 34 summarises the timing relations and constants for each sub-process.

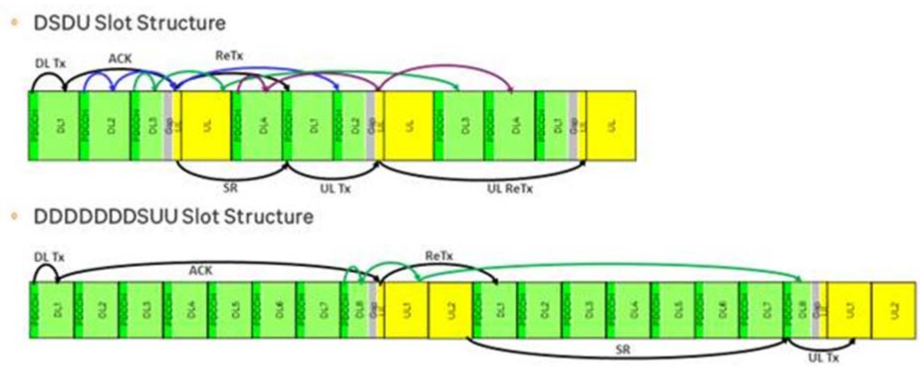


Figure 34: HARQ timeline and transmission opportunities comparisons

Table 17: Timing relations and constants

	DSDU Delay in slots	DDDDDDDSUU (*) Delay in slots
K0: DL Grant to DL Tx	0	0
K1: DL Tx to DL ACK	1	1
K2: UL Grant to UL Tx	1	1
K3: DL NACK to DL re-Tx grant	3	3
K4: UL Tx to UL re-Tx grant	3	3
K5: SR to UL grant	2	2
DL HARQ processes	4	8
SR periodicity	1ms	5ms
(*) LTE-TDD-like TDD configuration still assumes typical 5G-NR processing delays With the given assumptions, the DSDU configuration shows significant benefits over DDDDDDDSUU with respect to HARQ RTT and UL scheduling delay.		

Table 18: Simulation analysis – latency

	DSDU	DDDDDDDSUU
# required HARQ processes	4	8
DL HARQ RTT	2-3 ms	5ms
UL HARQ RTT	2ms	5ms
UL scheduling delay	1-2 ms	4.5-9.5 ms

The HARQ Round Trip Time (RTT) gives the minimum periodicity for the transmission of a new data packet (transport block) including ACK in one HARQ process.

Due to fewer UL ACK or data transmission opportunities in DDDDDDDSUU, the simulations result in more than twice the time (5ms) that is needed to complete one HARQ round trip as compared to DSDU (2-3 ms). In the case of HARQ retransmissions this delay would multiply.

The UL scheduling delay determines the time needed to send the first high priority/low latency data packet when no UL grant is given. It consists of the following steps:

1 Packet arrives at transmit buffer;

2 Wait for opportunity to send scheduling request (SR);

3 Send scheduling request;

4 Wait for UL grant;

5 Send UL data using granted resources.

The considerations show the significant benefits of the DSDU scheduling delay (1-2 ms) over the time required in the case of LTE-TDD synchronisation (4.5-9.5 ms). This is achieved by more frequent transmit opportunities for UL SR and UL data, and suitable to multiplex URLLC services with existing eMBB traffic.

A3.3.1.2 Impact on capacity

The increased flexibility of 5G-NR frame structure also has a direct impact on the overall capacity of the network.

The more frequent UL opportunities, for instance, also allows a higher spectral efficiency due to fast channel feedback. The UL symbols every 1ms allows MS to send sounding reference signals (SRS) and channel quality information (CQI), allowing the gNB to have an up-to-date estimate of the channel conditions. More accurate channel estimation allows for a more efficient usage of beamforming and better rate control through more accurate modulation and coding scheme (MCS) selection. The result is improved cell capacity.

As the cell coverage is typically defined by PDSCH SE (spectral efficiency) at the cell edge, improved beamforming efficiency implies a coverage improvement too – as the same cell edge SE can be reached at higher path loss conditions.

On the other hand, when 5G-NR and LTE-TDD transmission direction is aligned, UL symbols are available less frequently, leading to less accurate channel state information and reduction in capacity.

Simulations compare the latency, the spectral efficiency and the user-perceived throughput for a 5G-NR DDDDDDDSU vs. 5G-NR DSDU slot configuration.

System simulations have been conducted to determine the benefits of the short 1ms switching of DSDU vs. 5ms of DDDDDDDSU with respect to spectral efficiency and user-perceived throughput.

The assumptions in Table 19 were used for the simulations.

Table 19: Simulation inputs

Parameter	Value
Scenario	UMi, ISD = 200 m
Layout	57 cells w/wraparound, 10 MSs/cell
# Antenna elements, # TXRU	BS: (M, N, Mg, Ng, P) = (8, 8, 1, 1, 2) with 64 TXRU
Outdoor MSs	(2 V elements combined) (X-pol) 4 Rx at MS (X-pol)
Carrier frequency	20%
Bandwidth	3.5 GHz
Numerology	Sys bandwidth = 100 MHz, Sim bandwidth = 10 MHz
BS antenna down tilt	30 kHz SCS, 0.5ms slot
BS antenna spacing	14 degrees
Antenna gain	dH = 0.5 λ, dV = 0.8 λ
Max Tx power (over 100 MHz)	BS: 44 dBm; MS: 26 dBm
Noise figure	BS: 5 dB; MS: 9 dB
Processing gain for SRS	Based on Link-Sim
MS antenna spacing	0.5λ linear array (X-pol)
Doppler	3 kmph (Indoor), {10,30,60,90,120} kmph (Outdoor)
Penetration loss	According to 38.901 (low-loss model)
Guard band overhead	10% (Useful bandwidth: 25 RBs of 360 kHz each over 10 MHz)
UL SRS power control	Targets -5 dB UL SNR
Traffic model	Full buffer and Bursty FTP model 3, 0.5 MB file size
Scheduler	MU MIMO + sub-band p-fair scheduling (5 sub-bands)
Channel estimation	Realistic

To analyse the impact to the spectral efficiency, an outdoor user running a full buffer DL traffic pattern has been simulated with different moving speeds. More frequent opportunities to transmit sounding reference signals (SRS) lead to better spectral efficiency over the PDSCH symbols in a fast fading channel. Faster sounding allows better tracking of channel fluctuations, thus allowing improved demodulation performance. Figure 35 compares the simulated spectral efficiency at 5ms and 1ms SRS transmission opportunities.

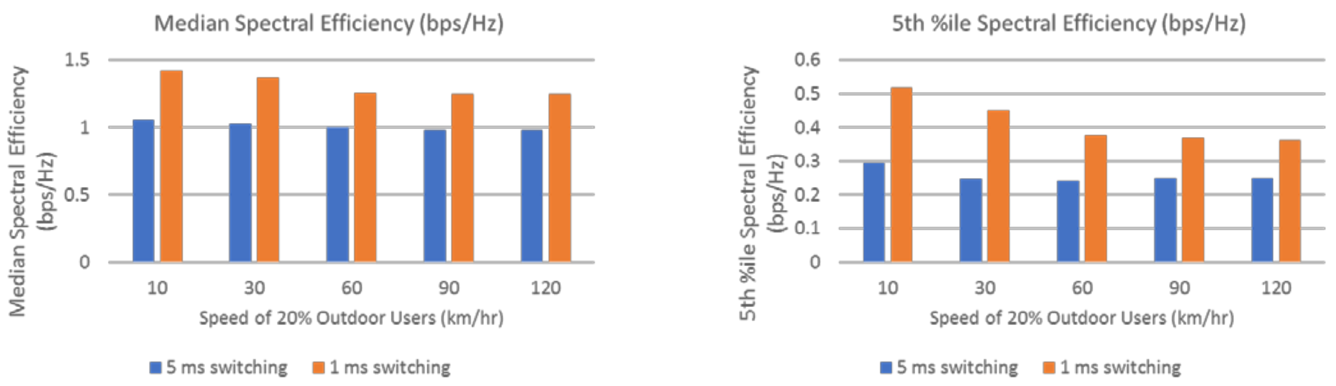


Figure 35: Spectral efficiency gains vs. speed

It can be seen that the fast switching of DSDU achieves a better spectral efficiency across all speeds as compared to LTE-TDD compatible DDDDDDDSUU frame structure. While the median gain is 30% to 40%, the gain at the lower percentile (e.g., cell edge conditions) rises to 70%.

To simulate the effect of the slot structure on user perceived throughput in a realistic scenario, a bursty traffic pattern (Bursty FTP model 3, 0.5 MB file size, variable file arrival time) was simulated. The shorter DL/UL switching periodicity of DSDU creates more transmission opportunities. The improved spectral efficiency enables the use of larger transport blocks. With these advantages, the gain of the median throughput can be as high as 50% (593 Mbps DSDU vs. 394 Mbps DDDDDDDSUU). Even in cell edge conditions, a 23% gain can still be achieved.

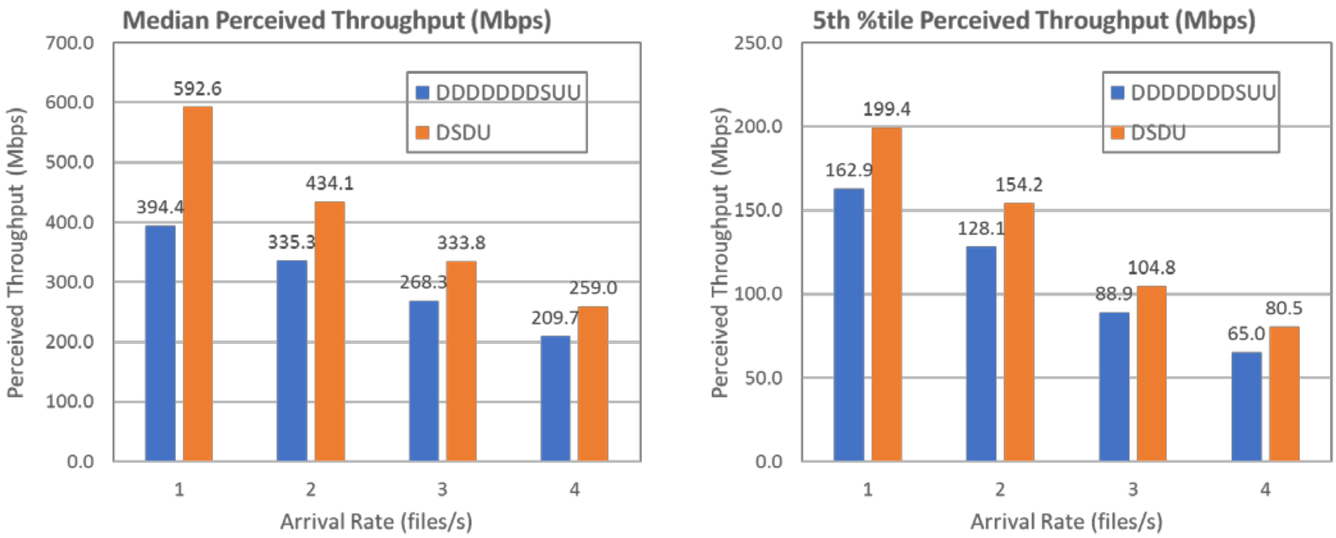


Figure 36: Bursty traffic – perceived throughput vs. file arrival rate

The simulations show that latency and spectral efficiency significantly benefit from the DSDU configuration. These advantages justify the additional DL/UL guard period overhead incurred by the more frequent DL/UL switching.

A3.3.2 STUDY #2

The following Sections provide an assessment in terms of latency and capacity performance for the three frame structures provided in Figure 37.

Among the three frames that are addressed in this study, the DDDDDDDSUU frame structure is the only one to be LTE-TDD compatible.

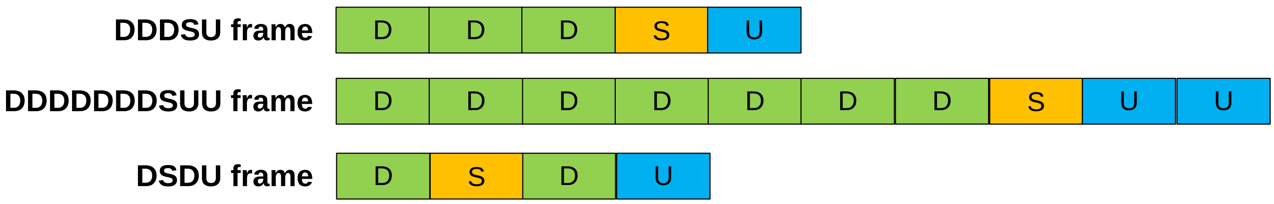


Figure 37: 5G-NR frame structures for evaluation – slot level

Differently from LTE-TDD, 5G-NR allows for the assignment of DL and UL transmission directions at OFDM symbol level (in LTE-TDD the UL/DL assignment is done at sub-frame level), the assessment therefore depends on the specific choices at OFDM symbol level which are illustrated in Figure 38.

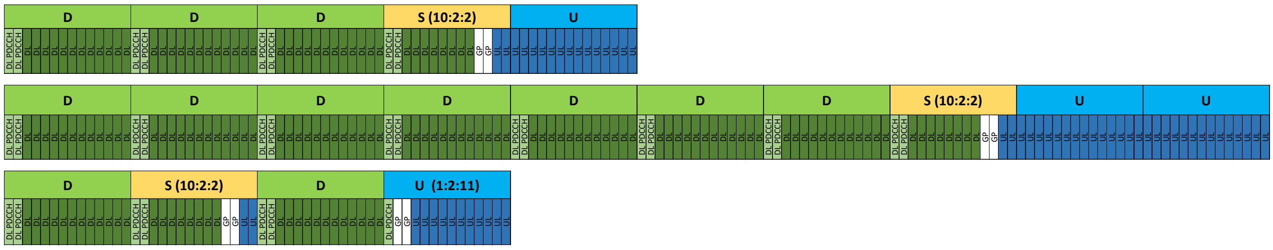


Figure 38: 5G-NR frame structures for evaluation – OFDM symbol level

A3.3.2.1 Latency assessment (grant-free UL transmissions)

The latency assessment results in Table 4[53] account for the “grant-free” UL transmissions feature (also known as “configured grant”) which is an optional feature for 5G-NR in 3GPP. The “grant-free” UL is beneficial for low latency since it avoids the need to first transmit a scheduling request on UL followed by a scheduling grant on downlink before UL data transmission can take place

It is to be noted that decisions to mandate features for Rel-15 5G-NR MSs were made in consideration of eMBB services, which are the first targets on the 5G market. Most of the features related to low latency and/or reliability are optional. This includes not only the “grant-free” feature, but also other features such as the mini-slots (frequency control monitoring and short transmission durations), MS processing capability #2 (necessary for the "self-contained" slot operation), dynamic signalling of slot format (see Table 16), etc.

Simulations results with grant-free based UL transmission are valuable in deriving the lowest possible user plane latency performance.

According to Report ITU-R M.2410 [18], the user plane latency is the contribution of the radio network to the time from when the source sends a packet to when the destination receives it (in ms). It is defined as the one-way time it takes to successfully deliver an application layer packet/message from the radio protocol layer 2/3 SDU ingress point to the radio protocol layer 2/3 SDU egress point of the radio interface in either uplink or downlink in the network for a given service in unloaded conditions, assuming the mobile station is in the active state.

Based on the definition and the evaluation method provided in Report ITU-R M.2412 [19], the components of user plane latency are listed in Table 20.

[53] In case of grant-based transmission, the latency is expected to be higher.

Table 20: Components of user plane latency

ID	Component	Notations
1	MS processing delay	$t_{UE} = t_{UE,rx} + t_{UE,tx}$ For DL: $t_{UE,rx}$ is the time interval between when the PDSCH is received and when the data is decoded; $t_{UE,tx}$ is the time interval between when the data is decoded, and when the ACK / NACK packet is generated. For UL: $t_{UE,tx}$ is the time interval between when the data arrived, and when the packet is generated; $t_{UE,rx}$ is the time interval between when the ACK is received and when the ACK is decoded.
2	Frame alignment (transmission alignment)	$t_{FA,DL}$ or $t_{FA,UL}$ It includes the waiting time (e.g. in TDD, data transmission needs to wait for the next available DL/UL non-slot/slot)
3	TTI for data packet transmission	$t_{data\_duration}$
4	HARQ retransmission	t_{HARQ}
5	BS processing delay	$t_{BS} = t_{BS,rx} + t_{BS,tx}$ For UL: $t_{BS,rx}$ is the time interval between when the PUSCH is received and when the data is decoded; $t_{BS,tx}$ is the time interval between when the data is decoded, and when the ACK/NACK packet is generated. For DL: $t_{BS,tx}$ is the time interval between when the data arrived, and when the packet is generated; $t_{BS,rx}$ is the time interval between when the ACK is received and when the ACK is decoded.
-	Total one way user plane latency for DL	$t_{UP} = (t_{BS,tx} + t_{FA,DL}) + t_{data\_duration} + t_{UE,rx} + n{\times}t_{HARQ}$ where: $t_{HARQ} = (t_{UE,tx} + t_{FA,UL}) + t_{data\_duration} + t_{BS,rx} + (t_{BS,tx} + t_{FA,DL}) + t_{data\_duration} + t_{UE,rx}$, n is the number of re-transmissions (n≥0)
	Total one way user plane latency for UL	$t_{UP} = (t_{UE,tx} + t_{FA,UL}) + t_{data\_duration} + t_{BS,rx} + n{\times}t_{HARQ}$ where: $t_{HARQ} = (t_{BS,tx} + t_{FA,DL}) + t_{data\_duration} + t_{UE,rx} + (t_{UE,tx} + t_{FA,UL}) + t_{data\_duration} + t_{BS,rx}$, n is the number of re-transmissions (n≥0)

The role of the described components in a BS-to-MS data transmission procedure is illustrated in Figure 39.

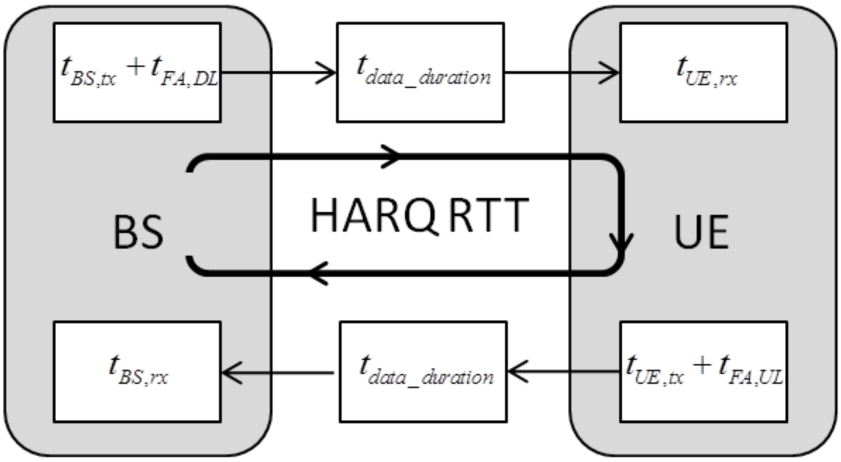


Figure 39: illustration of User Plane latency components

It is noted that the values of the above components depend on the frame structure and numerology, MS capability on processing, as well as PDSCH / PUSCH mapping type. These impact factors are further subject to duplexing schemes like FDD, TDD and TDD+SUL (Supplemental UpLink).

The MS processing time, t_{UE}, has been agreed in 3GPP RAN1#90bis, known as “MS capability 1” (PDSCH processing capability 1). For different numerologies, the value of t_{UE} is expressed in terms of OFDM symbols (OS), say K OS, as listed in Table 21 (see Section 5.3 in [20]).

Table 21: MS processing time (PDSCH processing capability 1)

µDL	Sub-carrier spacing	PDSCH decoding time N1 [symbols]	
		No additional PDSCH DM-RS configured	Additional PDSCH DM-RS configured
0	15 kHz	8	13
1	30 kHz	10	13
2	60 kHz	17	20
3	120 kHz	20	24

The BS processing time (t_{BS}) is assumed to be the same as that of MS’s. For this evaluation, it is further assumed that the two parts of t_{MS} and t_{BS}, that is, $t_{X,rx}$ and $t_{X,tx}$, are equal. Based on these assumptions, one has

$t_{BS,rx} = t_{BS,tx} = t_{UE,rx} = t_{UE,tx} = K/2$

If the number of OFDM symbols per TTI is M, then $t_{data\_duration} = M$. Taking FDD as an example, the average user plane latency is calculated as below,

$$D_{UP}[\text{symbol}] = K + M + p \times 2 \times (K + M)$$

Where p is the error probability of the first HARQ retransmission.

For TDD, the extra frame alignment delay for both DL and UL, $t_{FA,DL}$ and $t_{FA,UL}$, might be larger than 0 due to the DL/UL configuration (the time needed to wait for the next available DL/UL TTI).

The following assumptions were made as basis for this evaluation:

- The MS processing time is determined with the assumption of MS capability 1 and no additional DMRS configured;
- PDSCH / PUSCH mapping Type B is employed, which is more flexible to support non-slot based scheduling;
- Additionally, the packet is assumed to be arrived randomly in any symbol in any slot.

Based on the assumptions above, the average latencies for DL and UL for different frame structures are illustrated in Table 22and Table 23.

Due to the shorter DL/UL switching period, the user plane latency and round-trip time (RTT) of DSDU frame is lower in most cases.

The user plane latency and RTT associated with DDDSU and DDDDDDDSUU frames can be further reduced by using lower frequencies (e.g. 700, 800, 900, 1800 MHz) in combination with the 3400-3800 MHz band (e.g. through Carrier Aggregation or Supplemental Uplink schemes). The resulting RTT will meet the most stringent latency requirement for URLLC and eMBB simultaneously.

Table 22: DL latency evaluation results for 5G-NR frame structures (SCS = 30 kHz)

Slot / non-slot based scheduling	Latency		Frame structure (GP: 2 OFDM symbols)		
			DDDSU	DDDDDDDSUU	DSDU
2OS non-slot based scheduling	User plane latency (ms)	p=0	0.53	0.57	0.52
		p=0.1	0.71	0.88	0.63
	RTT (ms)		1.77	3.02	1.12
Slot-based scheduling	User plane latency (ms)	p=0	0.87	0.93	0.90
		p=0.1	1.07	1.25	1.04
	RTT (ms)		1.98	3.24	1.42

Table 23: UL latency evaluation results for 5G-NR frame structures (SCS = 30 kHz)

Slot / non-slot based scheduling	Latency		Frame structure (GP: 2 OFDM symbols)		
			DDDSU	DDDDDDDSUU	DSDU
Non-slot based scheduling	User plane latency (ms)	p=0	1.22	2.01	0.78
		p=0.1	1.39	2.30	0.88
	RTT (ms)		1.71	2.95	1.05
Slot-based scheduling	User plane latency (ms)	p=0	1.61	2.40	1.46
		p=0.1	1.80	2.72	1.62
	RTT (ms)		1.90	3.14	1.69

A3.3.2.2 Latency assessment in case of support from lower frequency bands (grant-free UL transmissions)

If the lower frequency bands are used in combination (e.g. Carrier Aggregation or Supplemental Uplink schemes) with the 3400-3800 MHz band with DDDDDDDSUU, the RTT delay will be significantly reduced based on the analysis in Section A3.3.2.1, and the performance will be improved for 5% UPT in case of SUL.

In this evaluation, it was assumed that one MS always uses either the SUL for all its UL transmissions, or always uses the 3400-3800 MHz UL for all its UL transmissions, based on measured RSRP. NR specifications allow configuring the MS to use both uplinks in a TDM manner, which provides more flexibility in the operation than simulated here. With this respect, the simulation results can be taken as a best case. Accounting for partial resources availability for NR users in the SUL band (or in the uplink portion of the band in case of CA) would reduce the gain in latency to some extent.

It is to be noted, that licensees for the 3400-3800 MHz frequencies do not necessarily have access to lower frequency bands.

While the 1800 MHz SUL band and the 3400-3800 MHz frequencies may be related by second-order inter-modulation products, such interference can be always avoided by ensuring the MS always uses one of the two uplinks only. When configured with the two uplinks, the MS is configured with timing patterns that ensure uplink transmissions only in time-division multiplexing manner, as specified in 3GPP. Other choices of SUL frequencies are also available in bands specified by 3GPP (e.g. 700, 800 or 900 MHz), where second-order inter-modulation products would not appear in the 3400-3800 MHz band. TDM patterns to avoid the same inter-modulation products are also specified in 3GPP for LTE-NR dual connectivity with or without the use of a SUL.

Table 24: DL latency evaluation results for 5G-NR frame structures (SCS = 30 kHz)

Slot / non-slot based scheduling	Latency		Frame structure (GP: 2 OFDM symbols)	
			DDDSU + SUL	DDDDDDDSUU + SUL
2OS non-slot based scheduling	User plane latency (ms)	p=0	0.53	0.57
		p=0.1	0.60	0.66
	RTT (ms)		0.78	0.82
Slot-based scheduling	User plane latency (ms)	p=0	0.87	0.92
		p=0.1	0.99	1.04
	RTT (ms)		1.12	1.17

Table 25: UL latency evaluation results for 5G-NR frame structures (SCS = 30 kHz)

Slot / non-slot based scheduling	Latency		Frame structure (GP: 2 OFDM symbols)	
			DDDSU + SUL	DDDDDDDSUU + SUL
Non-slot based scheduling	User plane latency (ms)	p=0	0.49	0.50
		p=0.1	0.58	0.58
	RTT (ms)		0.82	0.86
Slot-based scheduling	User plane latency (ms)	p=0	0.92	0.92
		p=0.1	1.06	1.08
	RTT (ms)		1.43	1.59

A3.3.2.3 DL Capacity assessment (grant-based UL transmissions)

The following aspects have an impact on the 5G-NR frame structure performance in terms of system capacity:

Guard Period (GP) overhead:

GP is introduced at the DL/UL switching point. Frequent DL/UL switching will introduce larger GP overhead, which determines system capacity reduction.

UL slot availability:

The UL slot availability affects the Channel State Information (CSI) feedback and ACK / NACK feedback delay. The more frequent availability of UL sub-frames will reduce the CSI and ACK / NACK feedback delays. The reduced CSI feedback delay is beneficial for system capacity for fast varying channels. The reduced ACK / NACK feedback delay is beneficial for reducing RTT delay, and increasing user perceived throughput in some cases.

DL and UL ratio:

The DL and UL ratio associated with a certain frame structure should be consistent with the DL and UL traffic pattern. Otherwise, the DL or UL system capacity will be degraded.

Considering the above aspects, it is observed that the DSDU frame structure performance benefits from fast CSI measurement and feedback, however the frequent DL/UL switching that characterise this frame structure leads to extra overhead.

On the other hand, the DDDSU and DDDDDDDSUU frame structures may suffer from a relatively slower CSI feedback, yet benefiting from reduced GP transmission overhead.

Taking into account the channel varying nature that depends on the device moving speed distribution (adopted assumptions: 80% indoor users with 3km/h and 20% outdoor users with larger moving speeds), the trade-off of the CSI feedback and the overhead introduced by DL/UL switching point needs to be carefully evaluated for different candidate frame structures.

In this study, the spectral efficiency and the user-perceived throughput (UPT) are evaluated for the DDDDDDDSUU, DDDSU, and DSDU frame structures. The detailed assumptions for this study are provided in Section A3.3.2.6.

Based on the evaluation assumptions listed in Table 26, the total overhead for the different frame structures are provided in Table 27. In Table 27, DSDU is associated with the highest overhead due to the increased CSI-RS and GP overhead for the fast CSI measurement and DL/UL switching. As the length of GP increases from 2 to 4 OFDM symbols, the difference in the total overhead for the DSDU frame and for the DDDSU frame will be further increased. The DDDSU frame structure provides good balance for overhead and CSI acquisition.

Table 26: Assumptions for overhead calculations for different frame structures in DL

Overhead assumption	DDDSU	DDDDD DDSUU	DSDU
PDCCH	2 complete symbols in the downlink dominant slot	2 complete symbols in the downlink dominant slot	2 complete symbols in the downlink dominant slot; 1 complete symbol in the uplink dominant slot
DMRS	Type II DMRS, dynamic calculation according to paired layer number	Type II DMRS, dynamic calculation according to paired layer number	Type II DMRS, dynamic calculation according to paired layer number
CSI-RS	4 ports per MS with 5 slots period; 40 REs/PRB for 10 users	4 ports per MS with 10 slots period; 40 REs/PRB for 10 MSs	4 ports per MS with 4 slots period; 40 REs/PRB for 10 MSs
SSB	8 SSBs per 20 ms	8 SSBs per 20 ms	8 SSBs per 20 ms

Overhead assumption	DDDSU	DDDDD DDSUU	DSDU
TRS	2 burst consecutive slots per 20ms, bandwidth with 51 PRBs	2 burst consecutive slots per 20ms, bandwidth with 51 PRBs	2 burst consecutive slots per 20ms, bandwidth with 51 PRBs
GP	2/4 symbols	2/4 symbols	2/4 symbols

Table 27: Overhead calculation for different frame structures in DL

Overhead	GP (2 symbols)			GP (4 symbols)		
	DDDSU	DDDDD DDSUU	DSDU	DDDSU	DDDDD DDSUU	DSDU
PDCCH	0.15	0.15	0.16	0.15	0.15	0.16
DMRS	0.10	0.10	0.09	0.10	0.10	0.09
CSI-RS	0.06	0.03	0.08	0.06	0.03	0.08
SSB	0.03	0.03	0.03	0.03	0.03	0.03
TRS	0.002	0.002	0.002	0.002	0.002	0.002
GP	0.04	0.02	0.09	0.07	0.04	0.19
Total overhead	0.38	0.33	0.46	0.41	0.35	0.55

For spectrum efficiency evaluation, the performance under downlink full buffer traffic with different moving speeds is illustrated in Figure 40 and Figure 41. It should be noted that the moving speeds indicated in Figure 40 and Figure 41 apply to 20% outdoor users, and the moving speed of 80% indoor users is kept to 3 km/h.

According to Figure 40 and Figure 41, the cell average spectrum efficiency for DDDSU and DDDDDDDSUU are comparable. The DDDDDDDSUU frame structure can attain higher cell average spectrum efficiency and cell-edge spectrum efficiency due to the lower overhead, for the low speed scenario in particular.

When the speed of outdoor users is 10 km/h, the cell average and cell-edge spectrum efficiency can achieve 15% and 23% gain for DDDDDDSUU vs. DSDU, respectively. This is determined by the slow channel variation due to the low speed users and in this case, the fast CSI measurement and feedback cannot bring significant gain.

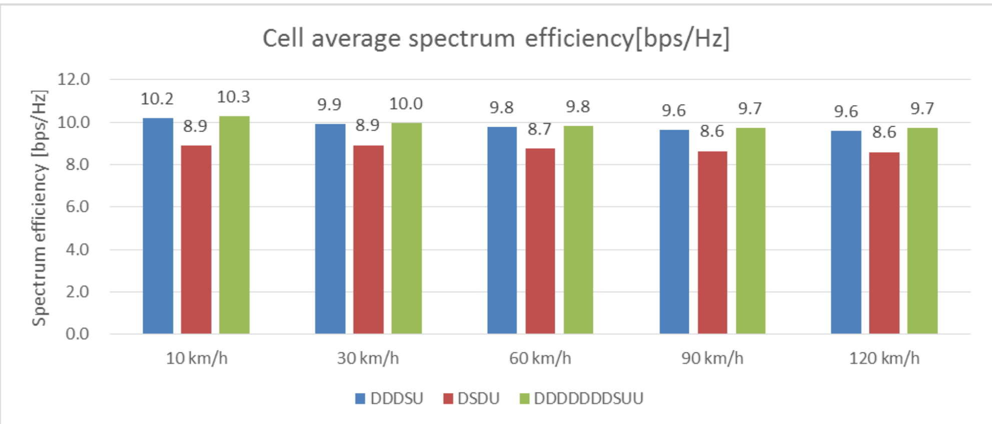


Figure 40: DL spectrum efficiency with different speeds - cell average spectrum efficiency

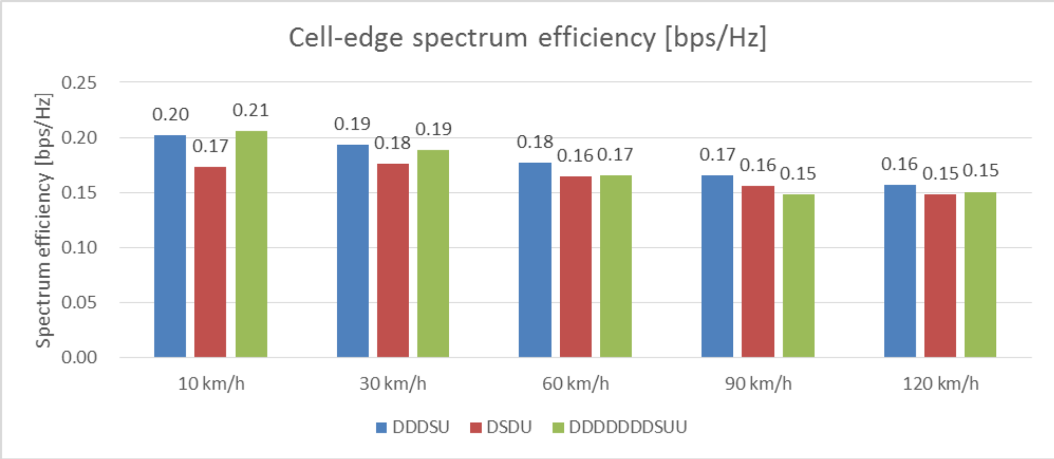


Figure 41: DL spectrum efficiency with different speeds - cell-edge spectrum efficiency

The assessment of the User Perceived Throughput (UPT) is provided for downlink burst traffic. It is noted that UPT in this evaluation is defined on the basis of a data packet, i.e., UPT = (packet size) / (time to complete the transmission of this packet). Therefore the UPT performance statistic is conducted per data packet basis, which offers the assessment on data packet throughput distribution.

In Figure 42, Figure 43, Figure 44 and Figure 45 the UPT performance with different arrival rates is illustrated to evaluate the performance under different traffic loads.

In the evaluation, the speed of the 20% outdoor users is assumed to be 30 km/h and the 80% indoor users again keep the moving speed of 3km/h.

With the good balance of overhead and feedback delay, DDDSU frame structure has better performance in most cases and the gain compared to DSDU can be achieved by more than 10%. Due to the lower overhead, the frame structure DDDDDDDSUU also can obtain gain for average UPT and 95% UPT (up to 20% gain), where re-transmission is less needed.

For 5% UPT, it is observed that DSDU has around 5% gain over DDDDDDDSUU. This is due to the fact that these poor packets are usually transmitted via re-transmissions. In this case, the RTT delay is a major factor that impacts UPT, and DSDU can outperform by reduced RTT delay. However, the gain is not significant after the trade-off with the GP overhead is taken into account.

Besides, if the lower frequency bands are used in combination (e.g. Carrier Aggregation and Supplemental Uplink schemes) with the 3400-3800 MHz band with DDDDDDDSUU, the RTT delay will be significantly reduced based on the analysis in section A3.3.2.1, and the performance will be improved for 5% UPT in case of SUL.

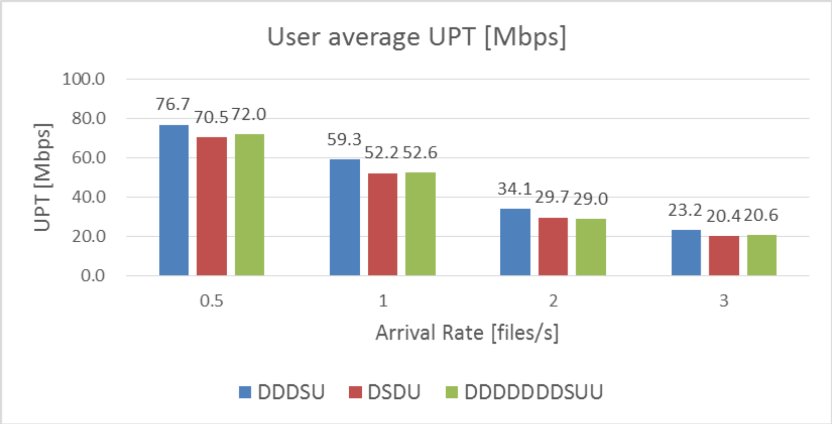
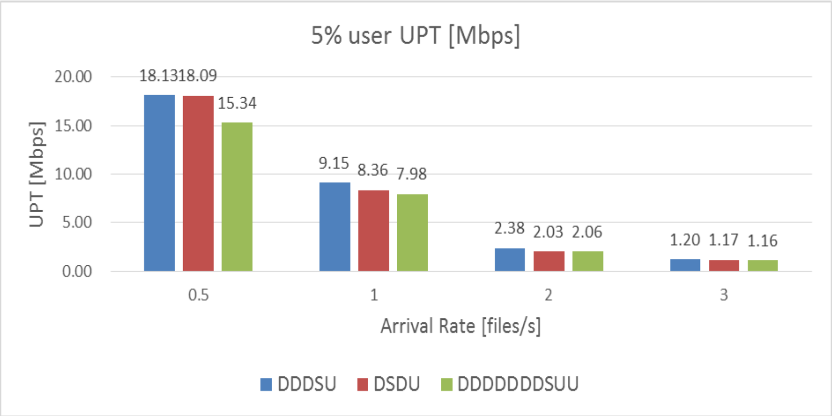


Figure 42: DL UPT with different arrival rates in burst traffic - user average UPT



e

Figure 43: DL UPT with different arrival rates in burst traffic - 5% UPT

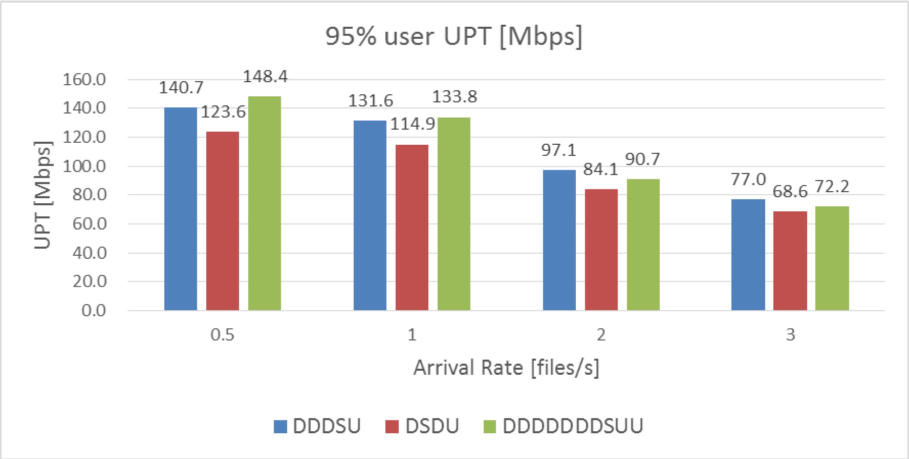


Figure 44: DL UPT with different arrival rates in burst traffic - 95% UPT

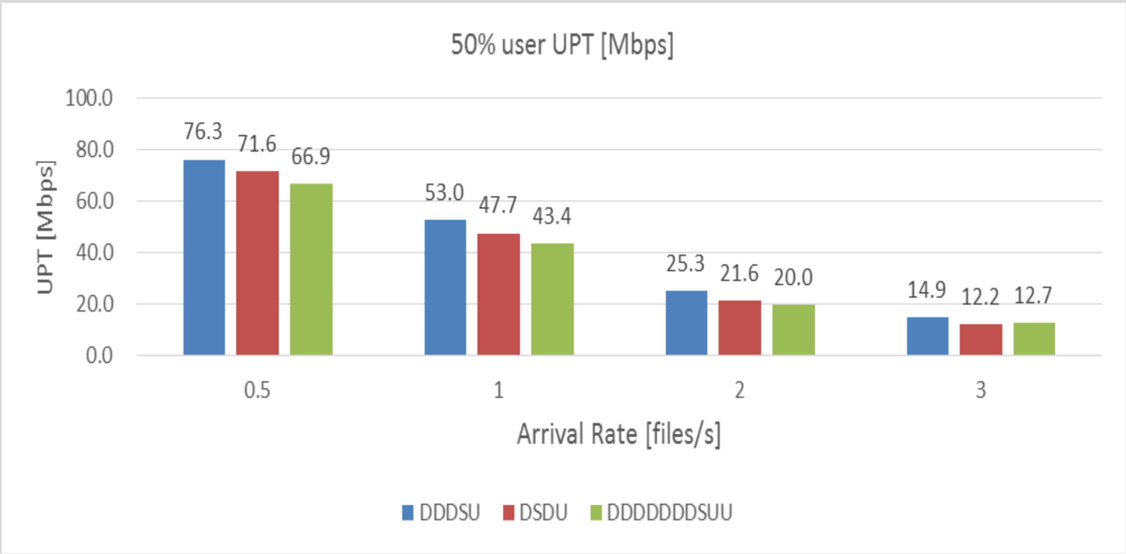


Figure 45: DL UPT with different arrival rates in burst traffic - 50% UPT

Based on the above evaluation for latency and capacity, the study demonstrates that the frame structures of DDDSU and DDDDDDDSUU can introduce good system capacity and high user perceived throughput. The study also shows that, in case of DDDDDDDSUU frame structure, the combined use of the 3400-3800 MHz band with low frequencies with SUL scheme can further reduce the latency and boost the lower part (i.e. cell edge) of user perceived throughput.

A3.3.2.4 UL Capacity assessment (grant-based UL transmissions)

Similarly to the capacity assessment in DL, here follows an assessment for the UL overhead, spectral efficiency, and UPT for the different 5G-NR frame structures.

Based on the evaluation assumptions listed in Table 28, the total UL overhead for the different frame structures are provided in Table 29 and Table 27. For DMRS overhead assumption in Table 28, 2 complete OFDM symbols are assumed to acquire good performance of channel estimation. In Table 29, DSDU frame structure has the highest overhead resulted by the frequent SRS and DMRS transmission. As the length of GP increases, the valid UL resource for DSDU will be further reduced and the overhead increases. On the contrary, the DDDSU frame structure provides good balance for overhead, UL CSI acquisition, and RTT delay.

Table 28: Overhead assumption for different frame structures in UL

Overhead assumption	DDDSU	DDDDDDDSUU	DSDU
PUCCH	7 OFDM symbols; 2 PRBs/symbol	7 OFDM symbols; 2 PRBs/symbol	7 OFDM symbols; 2 PRB/symbol
DMRS	2 complete OFDM symbols	2 complete OFDM symbols	2 complete OFDM symbols
SRS	2 OFDM symbols per 5 slots	2 OFDM symbols per 10 slots	2 OFDM symbols per 4 slots

Table 29: Overhead calculation for different frame structures in UL

Overhead	GP (2 symbols)			GP (4 symbols)		
	DDDSU	DDDDD DDSUU	DSDU	DDDSU	DDDDD DDSUU	DSDU
PUCCH	0.017	0.018	0.021	0.017	0.018	0.025
DMRS	0.125	0.133	0.154	0.125	0.133	0.182
SRS	0.125	0.067	0.154	0.125	0.067	0.182
Total overhead	0.267	0.218	0.329	0.267	0.218	0.389

For UL spectrum efficiency evaluation, the performance under full buffer traffic with different moving speeds is illustrated in Figure 46 and Figure 47. Similarly to what was observed in DL, the cell average and cell-edge spectrum efficiency for DDDSU and DDDDDDDSUU are better than that of DSDU due to the combined effect from overhead and the fast CSI acquisition. The cell average and cell-edge spectrum efficiency can achieve 14% and 15% gain for DDDDDDSUU vs. DSDU, respectively, when the speed of outdoor users is 10 km/h.

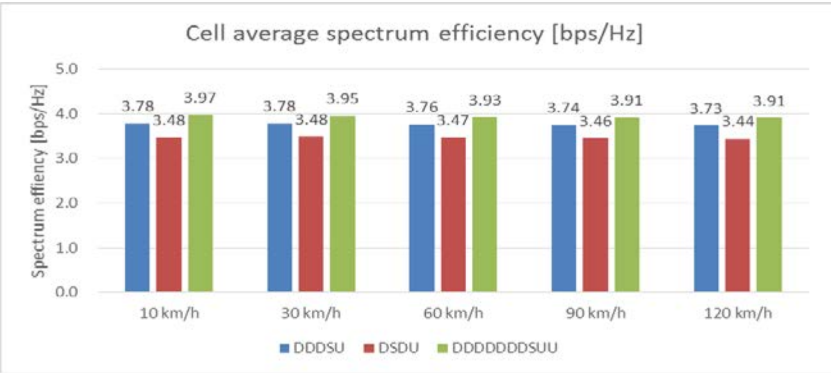


Figure 46: UL spectrum efficiency with different speeds - cell average spectrum efficiency

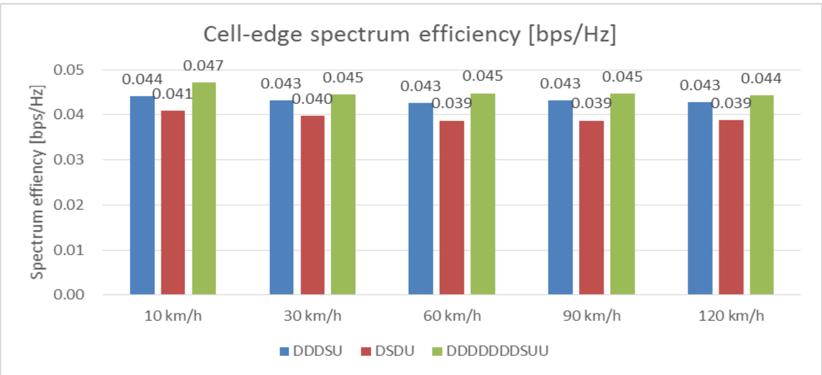


Figure 47: UL spectrum efficiency with different speeds – cell-edge spectrum efficiency

In Figure 48 and Figure 51, the UL UPT performance with different arrival rates is presented under different traffic loads. In the evaluation, the speed of the 20% outdoor users is assumed to be 30 km/h and the 80% indoor users still keep the moving speed of 3km/h.

Under different traffic loads, DDDSU frame structure has the best performance in most cases. Compared to DSDU with 3 files/s arrival rate, the frame structure DDDDDDDSUU can obtain 14% and 12% gain for average UPT and 95% UPT, respectively, where re-transmission is less needed.

For 5% UPT, it is observed that DSDU has around 2% gain over DDDDDDDSUU. This is similar to the observation in DL 5% UPT, which resulted by the higher RTT delay for DDDDDDDSUU. However, the gain is not significant after the trade-off with the GP overhead is taken into account.

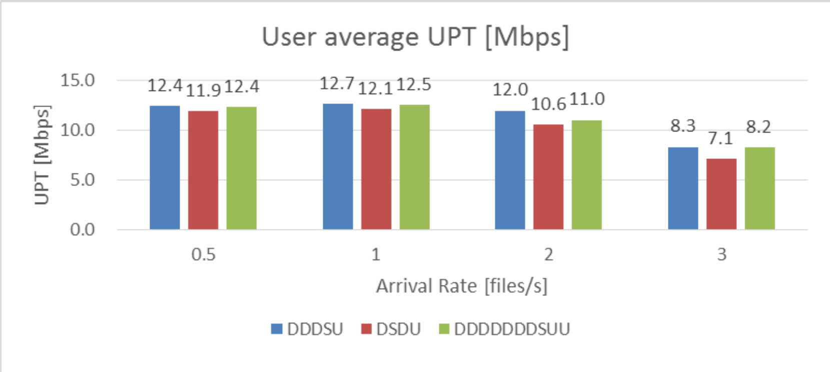


Figure 48: UL UPT with different arrival rates in burst traffic - user average UPT

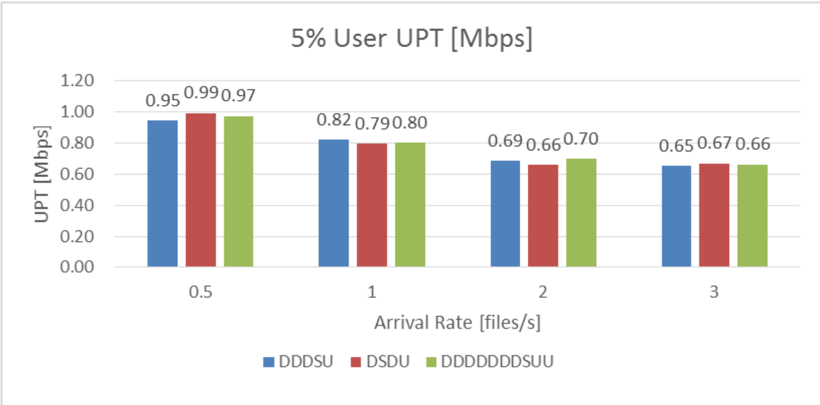


Figure 49: UL UPT with different arrival rates in burst traffic – 5% UPT

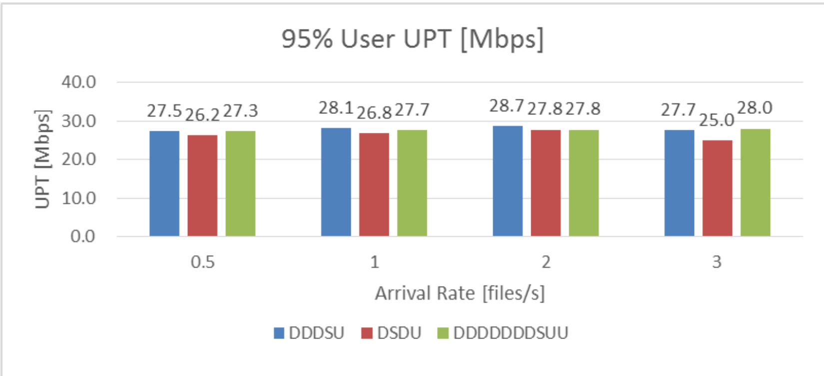


Figure 50: UL UPT with different arrival rates in burst traffic – 95% UPT

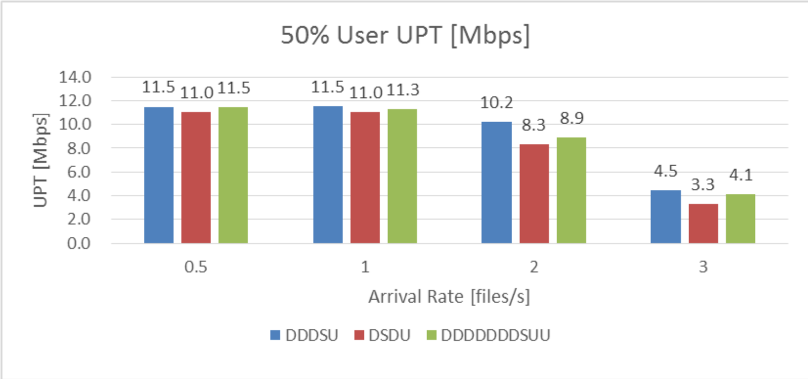


Figure 51: UL UPT with different arrival rates in burst traffic – 50% UPT

A3.3.2.5 UL Capacity assessment in case of support from lower frequency bands (grant-based UL transmissions)

The combined use of lower frequency bands with the 3400-3800 MHz band (e.g. via Carrier Aggregation and Supplemental Uplink schemes) allows to enhance the 5G-NR uplink coverage providing good UL performance under the same inter-site distance used for the lower frequency bands.

It is to be noted, that licensees for the 3400-3800 MHz frequencies do not necessarily have access to lower frequency bands.

In general terms, the evaluation procedure for the 5G-NR multi-band operation with TDD band + SUL is summarised hereafter.

a) Step 1: users are dropped across the network coverage area, each user selects its serving cell and frequency band f_i (i=1 or 2) based on RSRP. gNB configures MS's frequency band f_i (i=1 or 2);

b) Step 2: Data transmission simulation on each frequency band;

c) Step 3: Collect each user's simulated throughput on specific band;

d) Step 4: Generate the CDF of user throughput from all users on frequency band f_1 and f_2, and take the 5^{th} percentile point of the user throughput CDF as the cell-edge data rate.

For frequency bands f_1 and f_2, the carrier frequency 3500 MHz (TDD band) and 1800 MHz (SUL band) are used, respectively. For SUL band, the duplexing mode FDD is used.

Since the channel bandwidth in the TDD band (100 MHz) and SUL band (20 MHz) are different in the evaluation, the spectrum efficiency metric cannot intuitively present the performance difference. Hence the cell average throughput and cell-edge throughput metrics are selected to evaluate the SUL capacity.

In Figure 52 and Figure 53, the UL throughput for TDD band only and TDD+SUL band is provided. In the evaluation, the speed of the 20% outdoor users is assumed to be 30 km/h and the 80% indoor users keep the moving speed of 3km/h.

For cell average throughput, using the SUL band allows for about 40% gain due to the bandwidth increase. More spectrum resources can be allocated to the 70% users in the TDD band when the 30% users are offloaded to the SUL band. Up to 5-times gain can be reached for cell-edge users exploiting the SUL band due to the fact that such users benefit from the lower path loss and the sufficient bandwidth,

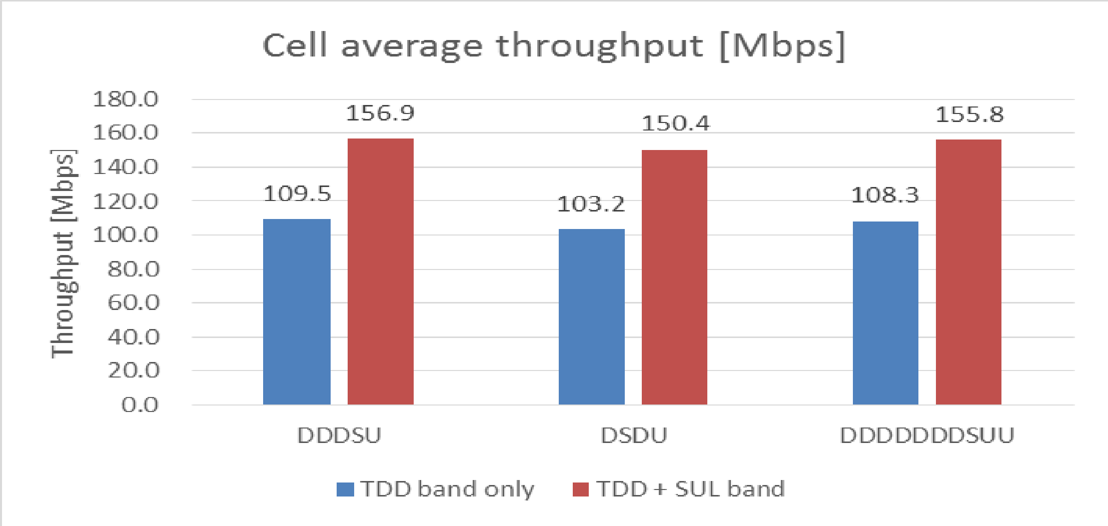


Figure 52: UL throughput with TDD+SUL band - cell average throughput

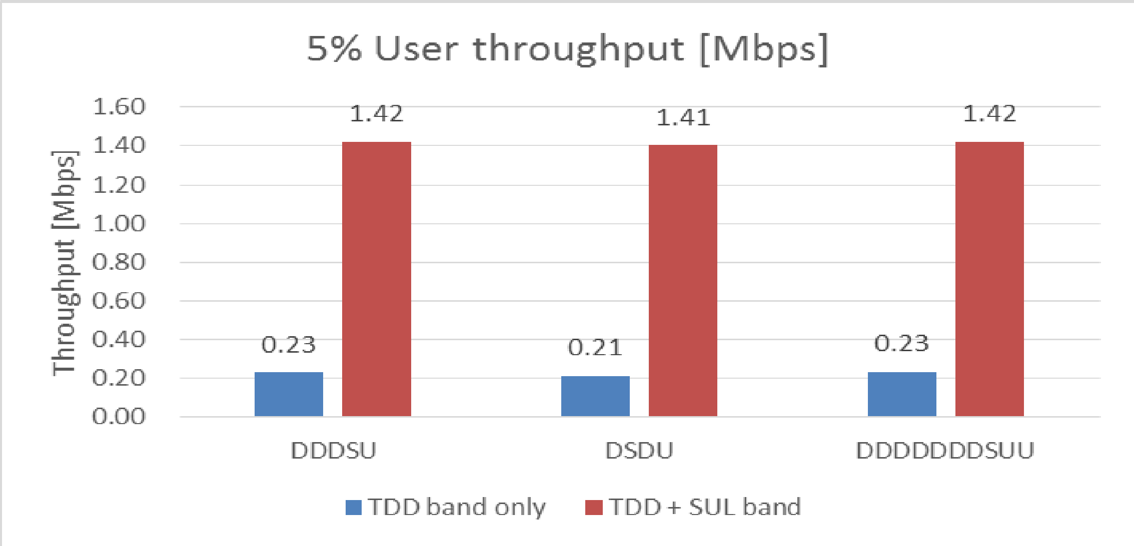


Figure 53: UL throughput with TDD+SUL band – cell-edge throughput

A3.3.2.6 Assumptions

The system configuration parameters for the Macro BS Urban test environment are illustrated in Table 30 and the technical parameters are illustrated in Table 31 and Table 32.

Table 30: Simulation parameters for Macro BS Urban test environment

System configuration parameters	Values
Test environment	Macro BS Urban
Carrier frequency	3.5GHz (1 Macro BS layer) Lower frequency band: 1.8GHz (when applicable)
BS antenna height	20m
Total transmit power per TRxP	46 dBm

System configuration parameters	Values
MS power class	23 dBm
Inter-site distance	500 m
User distribution	Indoor: 80% Outdoor: 20%
MS speeds of interest	Indoor users: 3 km/h Outdoor users: 10/30/60/90/120 km/h
Inter-site interference modelling	Explicitly modelled
BS noise figure	5 dB
MS noise figure	9 dB
BS antenna element gain	8 dBi
MS antenna element gain	0 dBi
Thermal noise level	-174 dBm/Hz
Traffic model	Full buffer; Burst buffer: file size 0.5 Mbytes, arrival rate 0.5/1/2/3
MS density	10 MSs per TRxP
MS antenna height	Outdoor MSs: 1.5 m Indoor UTs: 3(nfl – 1) + 1.5; nfl ~ uniform(1,Nfl) where Nfl ~ uniform(4,8)
Channel model variant	Channel model A (follow TR36.873)
TRP number per site	3
Mechanic tilt	90 degree in GCS (pointing to horizontal direction)
Electronic tilt	100 degree
Handover margin (dB)	1
UT attachment	Based on RSRP from port 0
Wrapping around method	Geographical distance based wrapping
Minimum distance of TRxP and MS	Follow corresponding channel model variant
Polarised antenna model	Model-2 in TR 36.873
frequency reuse	1
Antenna pattern	Follow TR 36.873
Below rooftop BS antenna deployment	0%
Indoor user terminal penetration loss	Follow channel model A in TR 36.873

Table 31: Technical configuration parameters in DL

Technical configuration Parameters	Values
Waveform	OFDM-based
Multiple access	OFDMA
Duplexing	TDD
Network synchronisation	Synchronised

Technical configuration Parameters		Values
Modulation		Up to 256 QAM
Numerology		30kHz SCS
Guard band ratio on simulation bandwidth		8.2% (for 20 MHz)
Simulation bandwidth		20 MHz (51 PRBs)
Frame structure		DDDSU, DDDDDDDSUU, DSDU
Transmission scheme		Closed SU/MU-MIMO adaptation
DL CSI measurement		Precoded CSI-RS based, non-PMI
DL codebook		N/A
MU dimension		Up to 12 layers
SU dimension		Up to 4 layers
SRS transmission		Non-precoded SRS, 4 Tx ports, 8 PRBs per symbol, 2 symbols per 10 slots for DDDDDDDSUU, 2 symbols per 5 slots for DDDSU, 2 symbols per 4 slots for DSDU
CSI feedback		CQI/RI feedback every 10 slots for DDDDDDDSUU, CQI/RI feedback every 5 slots for DDDSU, CQI/RI feedback every 4 slots for DSDU, Non-PMI feedback, Sub-band based
Interference measurement		SU-CQI
Max CBG number		1
ACK/NACK delay		N+1
Re-transmission delay		the next available DL slot after receiving NACK
Antenna configuration at TRxP		32 TxRU, (8,8,2,1,1;2,8), (dH, dV)=(0.5, 0.8)λ, Vertical 1 to 4.
Antenna configuration at MS		4 TXRU, (1,2,2,1,1; 1,2) (dH, dV)=(0.5, N/A)λ
Scheduling		PF
Receiver		MMSE-IRC
Channel estimation		Non-ideal
Overhead	PDCCH	2 symbols
	SSB	8 SSB / 20ms
	CSI-RS	DDDDDDDSUU: 4 ports per MS with 10 slots period (MS-specific beamformed CSI-RS); DDDSU: 4 ports per MS with 5 slots period (MS-specific beamformed CSI-RS); DSDU: 4 ports per MS with 4 slots period (MS-specific beamformed CSI-RS); 40 REs/PRB for 10 users per cell
	DMRS	Type II, up to 12 ports

Technical configuration Parameters		Values
	TRS	2 burst consecutive slots per 20ms, bandwidth 51 PRBs
	GP	2 symbols

Table 32: Technical configuration parameters in UL

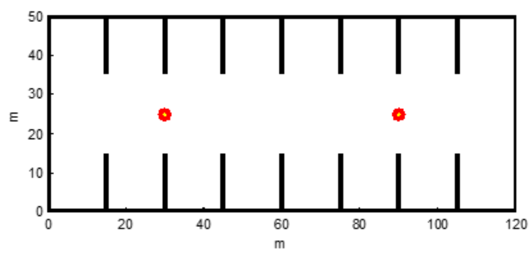
Technical configuration Parameters		Values
Waveform		OFDM-based
Multiple access		OFDMA
Duplexing		TDD, FDD
Network synchronisation		Synchronised
Modulation		Up to 256 QAM
Numerology		TDD: 30kHz SCS; FDD: 15Hz SCS
Guard band ratio on simulation bandwidth		TDD: 8.2% (for 20 MHz), 1.8% (for 20 MHz); FDD: 4.6% (for 20 MHz)
Simulation bandwidth		TDD: 20 MHz, 100 MHz FDD: 20MHz
Frame structure		DDDSU, DDDDDDDSUU, DSDU, UUUUU
Transmission scheme		SU adaptation
UL CSI measurement		Non-precoded SRS and wideband PMI
UL codebook		Codebook based
SU dimension		Up to 2 layers
SRS transmission		Non-precoded SRS, 2 Tx ports, 8 PRBs per symbol, 2 symbols per 10 slots for DDDDDDDSUU, 2 symbols per 5 slots for DDDSU, 2 symbols per 4 slots for DSDU, 2 symbols per 5 slots for FDD
Max CBG number		1
Antenna configuration at TRxP		32 TxRU, (8,8,2,1,1;2,8), (dH, dV)=(0.5, 0.8)λ, Vertical 1 to 4.
Antenna configuration at MS		2 TXRU, (1,1,2,1,1; 1,2) (dH, dV)=(0.5, N/A)λ
Power control parameters		P0 = -60 dBm, alpha = 0.6
Power backoff		Continuous PRB allocation model: follow TS 38.101; Non-continuous PRB allocation: additional 2 dB reduction
Scheduling		PF
Receiver		MMSE-IRC
Channel estimation		Non-ideal
Overhead	PUCCH	7 symbols, 2 PRBs per symbol
	DMRS	2 complete symbols
	SRS	2 symbols per SRS transmission period

ANNEX 4: MFCN PARAMETER VALUES AND ASSUMPTIONS FOR SIMULATIONS

The following tables list the parameters that have been agreed for the coexistence studies at the basis of this Report.

Table 33: 5G-NR BS and User Equipment parameters

Parameter	Value	Remarks
Carrier Frequency	3.5 GHz	
Channel bandwidth	60 MHz (for Macro, Micro and indoor BS deployments)	
Handover margin	3 dB	
MACRO-CELLULAR NETWORK PARAMETERS		
Layout	Hexagonal grid	
Number of sites	19	
Number of cells per site	3 cells/site	
Inter-Site Distance (ISD)	500 m (3GPP Case 1)	
Network shift (Macro BS ↔ Macro BS case)	**Baseline: 70m** **Additional for reference: 288 m**	
BS antenna height	25 m	
BS antenna mechanical down tilt	10 degrees	ECC Report 281
BS antenna horizontal 3 dB beam-width	65°	
BS antenna vertical 3 dB beam-width	80°	
BS antenna element gain	8 dBi	
BS antenna array	8x8 array	
BS Element spacing (X, Y)	0.5 λ , 0.5 λ	
BS antenna beamforming	Beamforming towards MSs with (8x8) array	
BS noise figure	5 dB	
BS max transmitted power	51 dBm	
Inter-site fading correlation	0.5	
Maximum Coupling Gain	-70 dB (i.e. ~= 30m from BS)	
Scheduler (# active MSs / cell)	OPTION 1: Proportional Fairness OPTION 2: Round robin	
# active MSs / BS	OPTION 1: 3 active MSs / cell OPTION 2: 1 active MSs / cell	For reference: 10 active MSs / Cell (Macro BS to Macro BS)
MICRO DEPLOYMENT PARAMETERS		
BS antenna type	3D direction antenna	
Layout	Hexagonal grid	
# sites	19	

Parameter	Value	Remarks
# sectors per site	Option 1: 1 cell / site Option 2: 3 cells / site	
Inter-Site Distance (ISD)	166 m	
BS antenna height	6 m	
BS antenna mechanical down tilt	Option 1: 10 degrees Option 2: 0 degrees	ECC Report 281
BS antenna horizontal 3 dB beam-width	65°	
BS antenna vertical 3 dB beam-width	80°	
BS antenna element gain	8 dBi	
BS antenna array	8x8 array	
BS Element spacing (X, Y)	0.5 λ , 0.5 λ	
BS antenna beamforming	Beamforming towards MSs with (8x8) array	
BS noise figure	8 dB	
BS max transmitted power	40 dBm	3GPP TS 38.104 Table 6.2.1-1: defines the rated output power for Medium Area BS as <= 38dBm. 40dBm value is kept since no significant difference is expected in the simulations results.
Maximum Coupling Gain	-53 dB (i.e. @ 3m from BS)	
Min. separation distance between Macro BS and Micro BS	**30m**	
INDOOR BS NETWORK PARAMETERS		
# floors / building	One floor (50x120 m) 	3GPP TR 36.873 (Related to the small cell transmission power)
Floor layout	Recommendation ITU-R M. 2101-0 (02/2017) - Figure 5 "Modelling and simulation of IMT networks and systems for use in sharing and compatibility studies)" From 3GPP TR 36.873 ("Study on 3D channel model for LTE-TDD): 50m x 120m	Also addressed in From 3GPP TR 38.901 ("Study on channel model for frequencies from 0.5 to 100 GHz") Table 7.2-2
# INDOOR BS / floor	2	3GPP TR 36.873
% ceiling mounted INDOOR BS in the building	100%	Other configurations could be considered with clear setup description

Parameter	Value	Remarks
Floor height (antenna height for ceiling mounted INDOOR BS)	3 m	
Min. distance between Macro BS and building (outer wall)	70 m	
OPTION 1 (challenging case: small distance, BS antenna panel azimuth pointing towards the building)		
# buildings / Macro BS	1	
Indoor penetration loss	Recommendation ITU-R P.2109 ("Prediction of building entry loss") Traditional building: 100% Thermally efficient building: 0%	
OPTION 2 (statistical with random drop of buildings in a cell)		
# buildings / sector	3	
Minimum distance between buildings	70 m	
# sectors / INDOOR BS	1 panel / site	
Inter Site Distance (ISD)	60 m	
INDOOR BS antenna height	3 m	3GPP TR 36.873
INDOOR BS antenna mechanical tilt	90 deg (ceil mount)	
INDOOR BS antenna element gain	5 dBi	
INDOOR BS antenna array	4x4	
INDOOR BS Element spacing (X, Y)	0.5 λ , 0.5 λ	
INDOOR BS antenna beamforming	Beamforming towards MSs with (4x4) array	
Ohmic loss	3 dB	
INDOOR BS noise figure	5 dB	
INDOOR BS max TRP	24 dBm	3GPP TS 38.104 Table 6.2.1-1: defines the rated output power for Local Area BS as <= 24dBm.
MS PARAMETERS		
MS max transmitted power	23 dBm	
MS antenna type	Omni directional (3 dimensional)	
MS antenna gain	-4 dBi	
MS antenna height	1.5 m (if connected to Macro and Micro) 1 m (if connected to indoor BS)	
MS noise figure	9 dB	
UL Power Control parameters	NOTE: parameters are chosen to maximise the network performance: maximise the 5% and average t-put network performance (for a single operator)	

Parameter	Value	Remarks
MSs connected to Macro BS	OPTION 1: (Set 1 in 3GPP TR 36.942) CLxile = 94 dB, γ = 1 5% MSs transmitting at full power OPTION 2: P0 = -92 dBm, γ = 0.8	
MSs connected to Micro BS	OPTION 1: (Set 1 in 3GPP TR 36.942) Clxile = 82 dB, γ = 1 1% MSs transmitting at full power OPTION 2: P0 = -86dBm, γ = 0.8	
MSs connected to Indoor BS	OPTION 1: (Set 1 in 3GPP TR 36.942) CLxile = 94 dB, γ = 1 5% MSs transmitting at full power	
MS distribution		
MSs connected to Macro BS	Uniform MS distribution (excluding the area of the building with indoor BS) OPTION 1: 80% indoor – see 3GPP 38.802 table 8.2.1-1 **OPTION 2:** 0% indoor	
MSs connected to Micro BS	Uniform MS distribution OPTION 1: 70% indoor (urban) - see ECC Rep. 281, ITU-R M.2292 **OPTION 2:** 7% indoor	
MSs connected to indoor BS	Uniform MS distribution over the floor - Indoor MSs: 100 %	Low power Indoor BS assumed, targeting indoor coverage only.

Table 34: Radio channel parameters

Channel parameters		
Propagation models		
Macro BS -> Macro BS	Free space path loss	
Macro BS -> Macro MS (same network)	3D UMa Indoor penetration (to reach indoor MSs) according to Table 7.4.3-3	3GPP TR 38.901 ("Study on channel model for frequencies from 0.5 to 100 GHz")
Macro BS -> Micro BS	3D Uma	
Micro BS -> Micro BS Micro BS -> Micro MS (same network)	3D UMI	
Macro BS -> INDOOR BS	3D UMa	

Channel parameters		
MS connected to Macro BS <-> MS connected to INDOOR BS	3D UMi	
Macro BS -> MS (indoor propagation)	InH – Office	3GPP TR 38.901
Outdoor to indoor penetration loss	For MS connected to Macro BS: according to 3GPP TR 38.901 – Clause 7.4.3.1 “O2I building penetration loss”, parameter settings in Table 7.4.3-3. “O2I building penetration loss model for single-frequency simulations <6 GHz”	3GPP TR 38.901
LoS probability model	Indoor - Open office	3GPP TR 38.901

Table 35: 5G MFCN Antenna element and array parameters

Parameter	Values
Vertical cut of the radiation pattern (dB)	$A''_{dB}(\theta'', \phi''=0°) = -\min\left\{12\left(\frac{\theta''-90°}{\theta_{3dB}}\right)^2, SLA_V\right\}$ with $\theta_{3dB}=65°, SLA_V=30\,\text{dB}$ and $\theta'' \in [0°, 180°]$
Horizontal cut of the radiation pattern (dB)	$A''_{dB}(\theta''=90°, \phi'') = -\min\left\{12\left(\frac{\phi''}{\phi_{3dB}}\right)^2, A_{max}\right\}$ with $\phi_{3dB}=65°, A_{max}=30\,\text{dB}$ and $\phi'' \in [-180°, 180°]$
3D radiation pattern (dB)	$A''_{dB}(\theta'', \phi'') = -\min\{-(A''_{dB}(\theta'', \phi''=0°) + A''_{dB}(\theta''=90°, \phi'')), A_{max}\}$
Maximum directional gain of an antenna element G_E dBi	8 dBi
Number of beamforming antenna elements	$(N_V, N_H) = (8,8)$
Element spacing	0.5λ horizontal separation 0.5λ vertical separation

ANNEX 5: UNSYNCHRONISED OPERATION OF TWO MACRO BS MFCN NETWORKS NOT IN THE SAME AREA- STUDY #3 AND #4

A5.1 STUDY #3

Coexistence between unsynchronised Macro BSs at 3400-3800 MHz is assessed when additional isolation is available.

More specifically the objective is to derive the minimum isolation, expressed in terms of separation distance, required between two unsynchronised networks when all deployed BSs meet the ECC baseline out of block power limits as defined in ECC Report 281.

The following two cases have been considered for the deployments of the interfering and victim BSs, see Figure 54 and Figure 55:

- The two networks operating in adjacent frequency channels;
- The two networks operating in the same frequency channel.

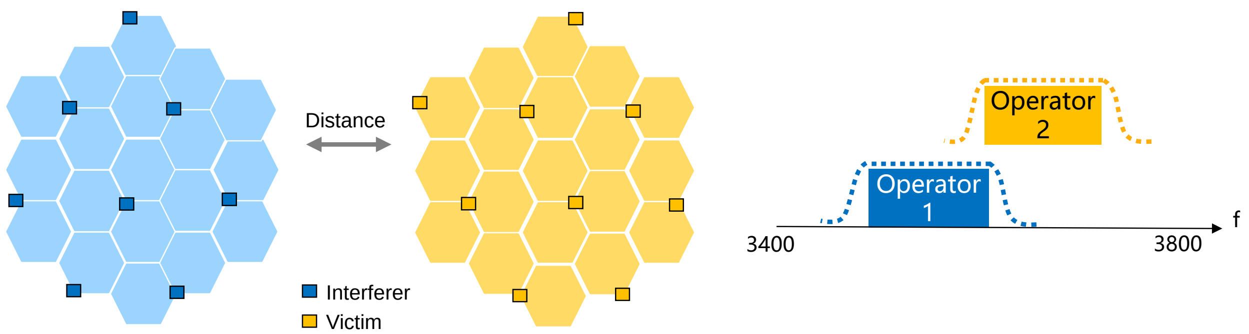


Figure 54: Unsynchronised operation of two MFCN networks not in the same area – adjacent channel

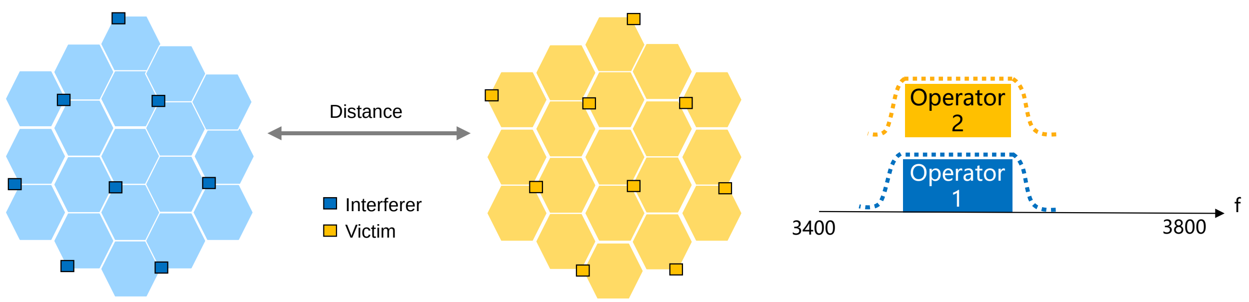


Figure 55: Unsynchronised operation of two MFCN networks not in the same area – co-channel

The impact of BS-BS interference due to simultaneous UL and DL transmissions is taken into account.

The impact of interference is assessed by evaluating the degradation in the mean uplink throughput of the victim MFCN.

For each of the two cases, the two scenarios are addressed according to whether the interferer and victim BSs use AAS technology or not, namely:

- Interference from AAS BSs to non-AAS BSs;

- Interference from AAS BSs to AAS BSs.

Accounting for the propagation loss as a function of distance, this analysis shows how the mean UL throughput loss decreases with the distance increase between the victim and interferer networks.

Since this analysis assumes fixed ACIR (given by 3GPP SEM), the required guard band remains unchanged regardless of the distance between victim and interferer networks.

Note that an AAS BS is considered to form a beam towards a MS (assumed to be uniformly distributed within a cell), whereas a non-AAS BS is assumed to have a fixed antenna directional pattern.

A5.1.1 SIMULATION PARAMETERS

Table 36 and Table 37 show parameters used in simulating the various scenarios.

The antenna directional pattern for non-AAS BSs is modelled as per described in ECC Report 203. Table 3 shows the antenna array characteristics modelled for AAS BSs, aligned with earlier agreements in the PT1 correspondence group.

Table 36: Parameters for “AAS to non-AAS” scenario

Interferer		Victim	
Beamforming towards MSs with (8×8) array. MSs uniformly distributed in each hexagonal cell.		Fixed directional pattern (effectively single antenna)	
Network Deployment	Hexagonal cells ISD = 500m.	Network Deployment	Hexagonal cells ISD = 500m.
Element gain	8 dBi	Maximum antenna gain	18 dBi
Channel bandwidth	60 MHz	Channel bandwidth	20 MHz
Effective channel bandwidth	90%	Effective channel bandwidth	90%
Tx (conducted) power	51 dBm/(60 MHz)	Noise figure	5 dB
ACLR	45 dB (from 3GPP for 60MHz ch. BWBWBWBWBWBWBWBW.W)	ACS	46 dB (from 3GPP for 20MHz channel bandwidth)

Table 37: Parameters for “AAS to AAS” scenario

Interferer		Victim	
Beamforming towards MSs with (8×8) array. MSs uniformly distributed in each hexagonal cell.		Beamforming towards MSs with (8×8) array. MSs uniformly distributed in each hexagonal cell.	
Network deployment	Hexagonal cells ISD = 500m.	Network deployment	Hexagonal cells ISD = 500m.
Element gain	8 dBi	Element gain	8 dBi
Channel bandwidth	60 MHz	Channel bandwidth	60 MHz
Effective channel bandwidth	90%	Effective channel bandwidth	90%
Tx (conducted) power	51 dBm/(60 MHz)	Noise figure	5 dB
ACLR	45 dB	ACS	46 dB

Interferer		Victim	
	(from 3GPP for 60MHz channel bandwidth)		(from 3GPP for 60MHz channel bandwidth)

Table 38: Antenna radiation pattern

Antenna radiation pattern	
Antenna element directional pattern $a_{E\,dB}(\theta,\varphi)$	According to 3GPP TR 37.840 (Section 5.4.4.2): $$a_{E\,dB}(\theta,\varphi) = -\min\{-[A_{E,V\,dB}(\theta) + A_{E,H\,dB}(\varphi)], A_{m\,dB}\},$$ $$A_{E,H\,dB}(\varphi) = -\min\left\{12\left(\frac{\varphi}{\varphi_{3dB}}\right)^2, A_{m\,dB}\right\},$$ $$A_{E,V\,dB}(\theta) = -\min\left\{12\left(\frac{\theta-90°}{\theta_{3dB}}\right)^2, SLA_{V\,dB}\right\},$$ where 3 dB elevation beam width θ3dB = 65°, 3 dB azimuth beam width φ3dB = 80°, Front-to-back ratio Am = 30 dB, Side-lobe ratio SLAV = 30 dB. NOTE: $a_E(\theta,\varphi) \leq 1$. NOTE: Each antenna element is larger in size in the vertical direction, and so θ3dB < φ3dB . See 3GPP TR 37.840.
Antenna element gain $G_{E\,dB}$	8 dBi
Number of BS beamforming elements (NV, NH)	(8,8)
Element spacing	0.9λ vertical separation. 0.6λ horizontal separation. NOTE: Larger vertical spacing provides narrower array beam width in elevation. See 3GPP TR 37.840 (Table 5.4.4.2.1-1).

The following propagation model is used from an interfering BS to a victim BS: Recommendation ITU-R P.452 20% time percentage, smooth earth path loss – for both co-channel and adjacent channel case.

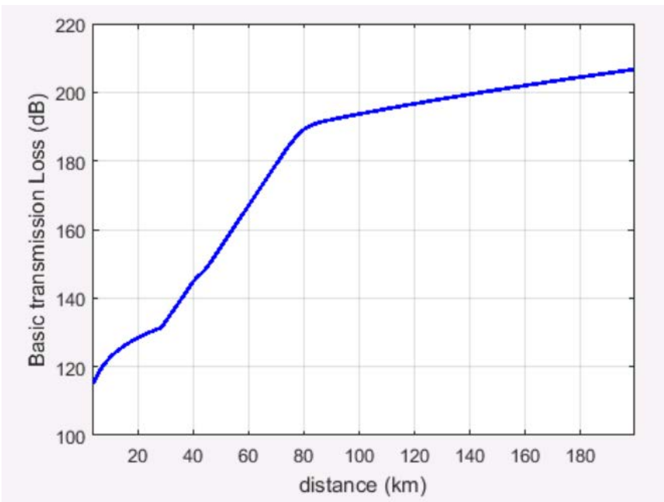


Figure 56: ITU-R P.452 P=20% propagation loss (smooth earth, Tx/Rx antenna height = 25 m)

A5.1.2 SIMULATION RESULTS

The studies have characterised the impact of BS-BS interference between MFCNs with simultaneous UL/DL transmission in terms of the resulting degradation in UL throughput of the victim MFCN. Specifically, the co-channel and the adjacent channel operation of the interfering and victim networks was considered. For each of the two cases, the “AAS to non-AAS” and “AAS to AAS” interferer to victim scenarios have been addressed.

A5.1.2.1 Unsynchronised operation of two MFCN networks not in the same area – adjacent channel

AAS to AAS scenario

Assuming all BSs meet the baseline limit defined in ECC Report 281, the minimum required separation distance of ca. 10.5km is required to ensure mean UL throughput degradation of ca. 5%

The following figure shows the relationship between the mean uplink throughput loss and distance.

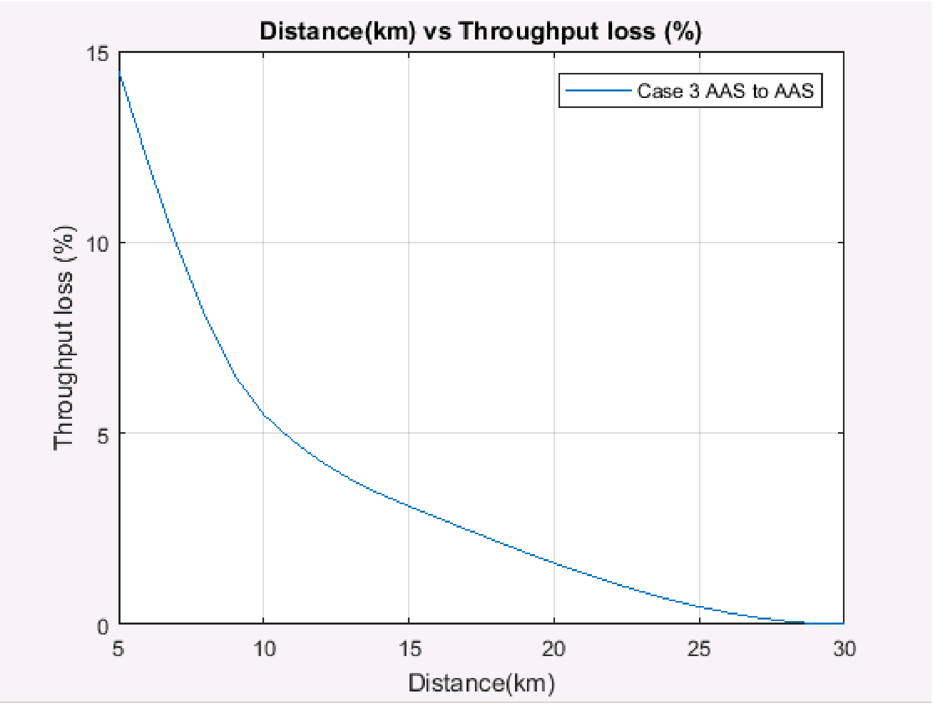


Figure 57: Mean UL throughput loss (%) vs. separation distance for the AAS to AAS case – adjacent channel

AAS to non-AAS scenario

- Assuming all BSs meet the baseline limit defined in ECC Report 281.

The minimum required separation distance of ca. 14km is required to ensure mean UL throughput degradation of ca. 5%.

The following figure shows the relationship between the mean uplink throughput loss and distance.

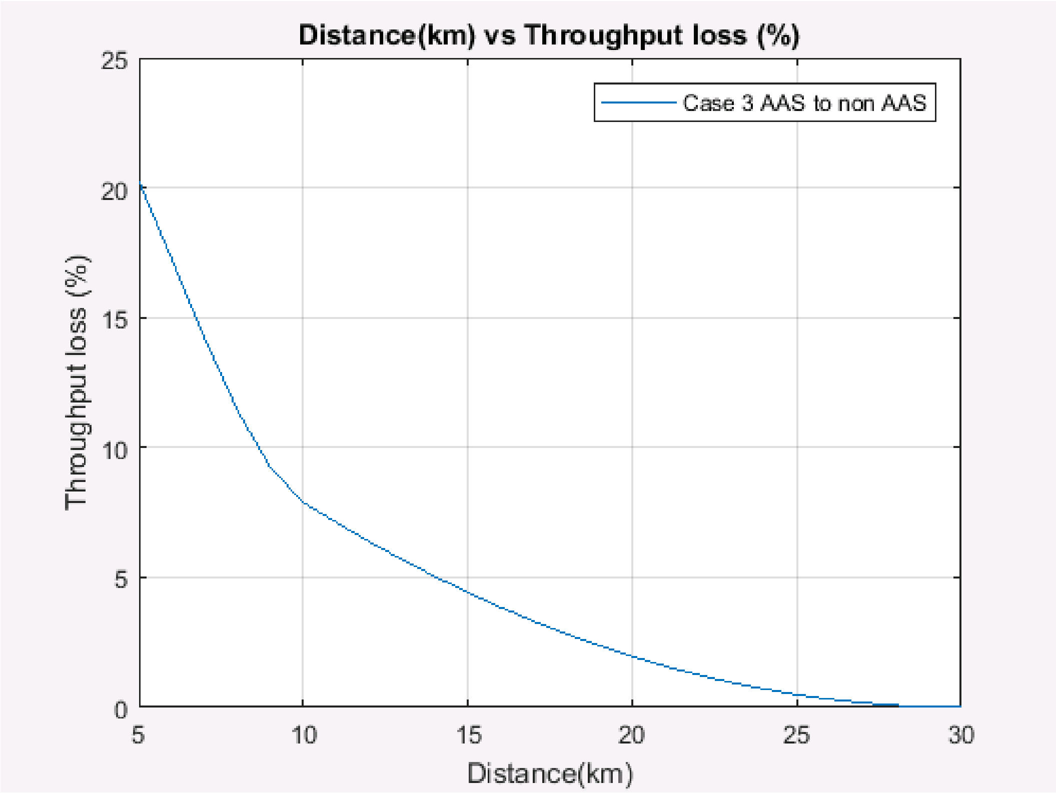


Figure 58: Mean UL throughput loss (%) vs. separation distance for the AAS to non-AAS case – adjacent channel

A5.1.2.2 Unsynchronised operation of two MFCN networks not in the same area – co-channel

When the two networks operate on the same channel, compared with adjacent channel results, additional 42.5 dB loss is required to guarantee uplink throughput loss below 5%. Larger separation distances will therefore be required in this case.

With larger separation distances, different terrain environments will significantly affect the propagation loss, impacting the actual separation distance to a significant extent. As described in Section 2 of, the ITU-R P.452, the specified propagation model with 20 % time percentage considers smooth-earth path loss.

AAS to AAS scenario

Assuming all BSs meet the baseline limit defined in ECC Report 281.

The minimum required separation distance of ca. 60 km is required to ensure mean UL throughput degradation of ca. 5%.

The following figure shows the relationship between the mean uplink throughput loss and distance.

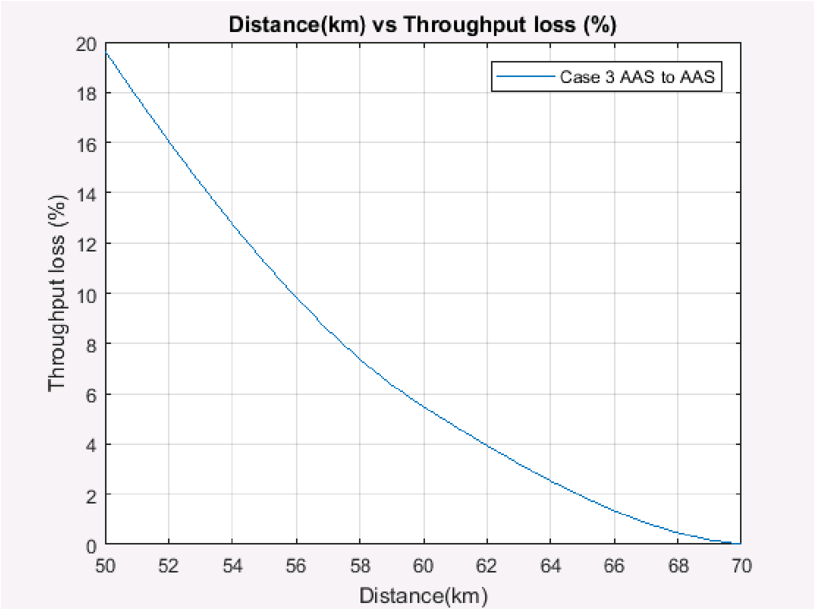


Figure 59: Mean UL throughput loss (%) vs. separation distance for the AAS to AAS case – co-channel

AAS to non-AAS scenario

Assuming all BSs meet the baseline limit defined in ECC Report 281.

The minimum required separation distance of ca. 60km is required to ensure mean UL throughput degradation of ca. 5%

The following figure shows the relationship between the mean uplink throughput loss and distance.

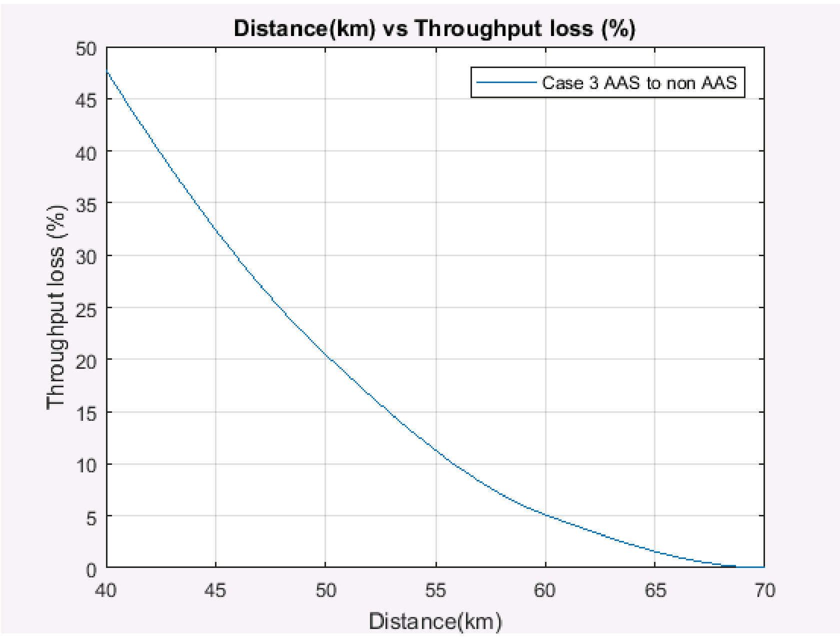


Figure 60: Mean UL throughput loss (%) vs. separation distance for the AAS to non-AAS – co-channel

A5.1.3 CONCLUSIONS FROM RESULTS

The following conclusion can therefore be derived from the results above for the unsynchronised operation of Macro BSs meeting the baseline ECC out of block power limits as defined in ECC Report 281, belonging to different networks in different areas:

- AAS to AAS scenario:
  - Adjacent channel case: assuming all BSs meet the baseline limit defined in ECC Report 281, the minimum required separation distance of ca. 10.5km is required to ensure mean UL throughput degradation of ca. 5%;
  - Co-channel case: assuming all BSs meet the baseline limit defined in ECC Report 281, the minimum required separation distance of ca. 60km is required to ensure mean UL throughput degradation of ca. 5%.
- AAS to non-AAS scenario:
  - Adjacent channel case: assuming all BSs meet the baseline limit defined in ECC Report 281, the minimum required separation distance of ca. 14 km is required to ensure mean UL throughput degradation of ca. 5%;
  - Co-channel case: assuming all BSs meet the baseline limit defined in ECC Report 281, the minimum required separation distance of ca. 60km is required to ensure mean UL throughput degradation of ca. 5%.

A5.2 STUDY #4

A5.2.1 SIMULATION SCENARIOS AND ASSUMPTIONS

Simulation scenario is illustrated in Figure 61. Network A and Network B are two unsynchronised macro-cellular networks separated at a distance D which is the distance between the two nearest sites of the network A and B.

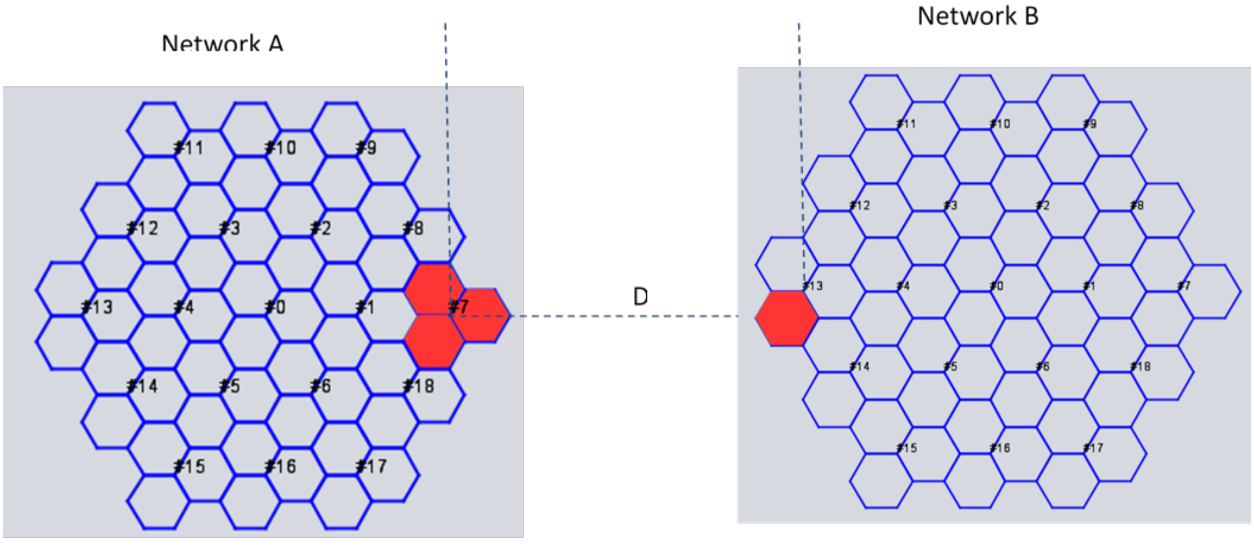


Figure 61: Simulation scenario between two networks (Network A and Network B)

Three possible cases are

1 Non-AAS Network A to non-AAS Network B

This case represents two LTE-TDD FWA networks in the C-band (3400-3800 MHz)

2 AAS Network A to non-AAS Network B

This case represents the situation of 5G-NR AAS network to a non-AAS LTE-TDD FWA network in the C-band (3400-3800 MHz)

3 AAS Network A to AAS Network B

This case represents the situation of two 5G-NR AAS networks in the C-band (3400-3800 MHz)

The system parameters and network assumptions are summarised in Table 39below.

Table 39: IMT System parameters and assumptions

Channel bandwidth (MHz)	20
BS antenna height (m)	25
Cell Range (m)	300
Non-AAS BS Tx Power (dBm)	49
Non-AAS BS antenna gain (dBi)	18
AAS BS Tx Power (dBm)	46,2
AAS antenna element	8x8

A5.2.2 SIMULATION RESULTS FOR THE CASE NON-AAS TO NON-AAS WITH PROPAGATION MODEL ITU-R P.2001-2.

The simulation results of co-channel interference and adjacent channel interference for the case of Non-AAS Network A to non-AAS Network B are given in Table 40 and Table 41.

Table 40: Co-channel interference simulation results (non-AAS to non-AAS)

D (km)	Throughput Loss (%)	
	Ref_Cell	Network
60	2,163	0,985
55	10,5	5
52	25,1	12,4
50	40,2	21,3
49	48,2	26,3
48	58,4	32,1
45	91,5	55,6
30	100	100
10	100	100

For the co-channel interference case where two networks A and B are in urban area, and the separation zone between the two networks are in rural environment, based on reference cell 5% throughput loss protection threshold, the required separation distance is about 58 km. Based on reference cell 50% throughput loss protection threshold, the required separation distance is about 49 km.

Table 41: Adjacent interference simulation results (non-AAS to non-AAS)

D (km)	Throughput Loss (%)	
	Ref_Cell	Network
33	2,9	1,4
32	4,1	2
31	5,7	2,7
30	7,7	3,7
20	27,3	15,6
15	39	23,1
12	50,2	30,2
10	60,1	36,4

For the adjacent channel interference case where two networks A and B are in urban area, and the separation zone between the two networks are in rural environment, based on reference cell 5% throughput loss protection threshold, the required separation distance is about 31 km. Based on reference cell 50% throughput loss protection threshold, the required separation distance is about 12 km.

A5.2.3 SIMULATION RESULTS FOR THE CASE NON-AAS TO NON-AAS WITH PROPAGATION MODEL ITU-R P.452-16

The simulation results for the case of non-AAS to non-AAS in co-channel case are presented in Table 42. The results for adjacent channel are presented in Table 43. These results were obtained with the propagation model Recommendation ITU-R P.452-16 [21] at 50% time.

Table 42: Co-channel simulation results with P.452-16

D (km)	Network capacity loss	iRSS_unwanted
50	4,96%	-92,1

Table 43: Adjacent channel simulation results with Recommendation ITU-R P.452-16

D (km)	Network capacity loss	iRSS_unwanted	iRSS_Blocking
15	4,90%	-94,2	-99,5
10	9,58%	-90,6	-95,9

A5.2.4 SIMULATION RESULTS FOR THE CASE AAS TO AAS WITH PROPAGATION MODEL ITU-R P.452-16

The simulation results for the case of AAS to AAS in co-channel case are presented in Table 44. The results for adjacent channel are presented in Table 44 and Table 45. These results were obtained with the propagation model P.452-16 [21] at 50% time.

Table 44: Co-channel simulation results with Recommendation ITU-R P.452-16

D (km)	Network capacity loss	iRSS_unwanted
52	2,73%	-91,4
50	4,99%	-88,6
49	6,30%	-87,1
40	34,90%	-72,5
30	64,40%	-60
20	77,10%	-53,2

Table 45: Adjacent channel simulation results with Recommendation ITU-R P.452-16

D (km)	Network capacity loss	iRSS_unwanted	iRSS_Blocking
15	4,51%	-89,9	-95
12	6,10%	-88,6	-93,9
10	7,37%	-87,3	-92,6
5	16,20%	-80,2	-87,3

A5.2.5 SEPARATION DISTANCE CALCULATION BASED ON I/N PROTECTION RATIO

The required separation distances based on I/N protection ratio using the propagation model ITU-R P.2001-2 are given in Table 46. Based on I/N=-6 dB, the required separation distance is 44 km. This approach is valid only for the case non-AAS to non-AAS. For the case AAS to AAS or AAS to non-AAS, due to the dynamic moving of AAS antenna radiation pattern, the antenna gain in the direction of the victim BS is not constant.

Table 46: Required separation distance based on I/N protection ratio for non-AAS to non-AAS

I/N (dB)	Ptx (dBm)	G1 (dB)	G2 (dB)	BW (MHz)	NF (dB)	N (dBm/18 MHz)	I (dBm/18 MHz))	PL (dB)	D (km)
-6	49	2,4	2,4	18	5	-96,4	-102,4	156,2	44

A5.2.6 APPLICATION OF TRIGGER VALUES

Between two neighbouring countries, there exists a physical borderline, the field strength trigger value is defined at borderline, the C-Band trigger values are given in the ECC Recommendation (15)01.[4].

Between two unsynchronised networks within a given country the physical borderline does not exist, ECC Recommendation (15)01 cannot be applied directly to deal with the case between two unsynchronised TDD networks within a country. There are two possible ways to deal with the two unsynchronised TDD networks within a country:

1 Define a separation distance;

2 Define a trigger value at the victim network side.

These two approaches should be equivalent; there is no need to define both together.

The trigger value can be defined at the victim network edge towards the interfering network, such as the reference cell shown in figure 1. It can be defined at the BS antenna height, e.g. 25 m, or at 3 m similar to the receiving antenna height used in the ECC Recommendation (15)01.

A5.2.7 ANTENNA HEIGHT CONVERSION FACTOR

There is no analytical formula for converting the field strength level between 25 m and 3 m, the differences of path losses calculated with different receiving antenna heights of 25 m and 3 m with the propagation model ITU-R P.2001-2 [22] at the frequency 3600 MHz and transmitting antenna height at 25 m in the rural environment are given in Table 47.

Table 47: Differences of Path losses at 25 m and 3m (ITU-R P.2001-2)

ITU-R P.2001-2		f=3600 MHz	Diff
D (km)	Hrx=25 m	Hrx=3 m	
10	123.64	124.22	0.58
20	129.75	141.56	11.81
30	135.79	157.4	21.61
40	150.08	173.1	23.02
50	165.4	188.24	22.84
60	180.63	195.2	14.57

Propagation model ITU-R P.1546-5 (Land) is valid for frequency range until 3 GHz. The differences of path losses calculated with different receiving antenna heights of 25 m and 3m with the propagation model Recommendation ITU-R P.1546-5 (Land) at the frequency 3000 MHz and transmitting antenna height at 25 m in the rural environment are given in Table 48.

Table 48: Differences of Path losses at 25 m and 3m (ITU-R P.1546-5 Land)

ITU-R P.1546-5 (Land)		f=3000 MHz	Diff
D (km)	Hrx=25m	Hrx=3m	
10	142.5	165.61	23.11
20	159.1	182.31	23.21
30	169.6	192.02	22.42
40	176.8	199.09	22.29
50	180.63	203.28	22.65
60	183.06	205.43	22.37

Based on the calculation results in Table A5-9 and A5-10, it is proposed to use a conversion factor of 22 dB between 25 m and 3 m.

A5.2.8 CALCULATION OF TRIGGER VALUES

The relation between field strength E (dBuV/m) and power level Pr (dBm) can be expressed as:

$$E=Pr+20*\log_{10}(F)+77{,}2 \quad (3)$$

Where F is the frequency in MHz.

$$Pr=Ptx+G1 - PL \quad (4)$$

Pr is the received power level at the receiving BS antenna (before antenna), Ptx is the transmit power before antenna, G1 is interfering BS antenna gain including feeder loss in the direction of the receiving antenna, PL is the path loss at the distance D.

Using equation (3) and (4), the calculated trigger value at 25 m and 3 m are summarised in Table 49 and Table 50 for co-channel case and in Table 51 for adjacent channel case.

Table 49: Calculated trigger value at 25 m and 3 m for co-channel case with ITU-RP.2001-2

Rx Antenna Height (m)	Ptx (dBm)	G1 (dB)	D (km)	PL (dB)	Pr (dBm)	E (dBuV/m/20 MHz)
25	49	2.4	49	163.8	-112.4	35.9
3	49	2.4	49	186.8	-135.4	12.9

Table 50: Calculated trigger value at 25 m and 3 m for co-channel case with ITU-R P.2001-2

Rx Antenna Height (m)	Ptx (dBm)	G1 (dB)	D (km)	PL (dB)	Pr (dBm)	E (dBuV/m/20 MHz)
25	49	2.4	44	156.2	-104.8	43.5
3	49	2.4	44	179.2	-127.8	20.5

The results in Table 49 correspond the protection ratio of 50% reference cell throughput loss. The results in Table 50 correspond the protection ratio of I/N=-6 dB at reference cell BS.

Table 51: Calculated trigger value at 25 m and 3 m for adjacent channel case with ITU-R P.2001-2

Rx Antenna Height (m)	Ptx (dBm)	G1 (dB)	D (km)	PL (dB)	Pr (dBm)	E (dBuV/m/20 MHz)
25	49	2.4	12	125.2	-73.8	74.5
3	49	2.4	12	128.2	-76.8	71.5

In Table 51, the trigger value for 3 meters receiving antenna height is calculated with the propagation model ITU-R P.2001-2. When using the conversion factor of 22 dB, the field strength level at 3m height is 74.5-22 = 52.5 dBuV/m/20 MHz.

A5.2.9 Conclusions from results

- ECC Recommendation (15)01 may be used to deal with the case of two unsynchronised macro-cellular networks within a given country, when the physical borderline is defined between two networks within a country.
- The required separation distance and trigger values calculation depend many elements:
  - Cellular network topology (LTE-TDD or 5G-NR, non-AAS or AAS, BS antenna height, environment or cell range);
  - Propagation environment and propagation model;
  - Frequencies and overlap of the channels, e.g. full overlap as co-channel case, or partial overlap or adjacent channel;

  - Protection ratio, e.g. I/N, or network throughput loss at x%, etc. As an example, the simulated results show that in a co-channel case the required separation distance is about 50 km and in an adjacent channel case the required separation distance is between 12 and 15 km;
- A conversion factor of 22 dB can be used for the field strength conversion between 25 m and 3 m. For different antenna height the conversion factor is different.

ANNEX 6: COEXISTENCE STUDIES BETWEEN UNSYNCHRONISED MICRO BSS AND MACRO BSS - STUDY #5 AND #6

A6.1 STUDY #5

A6.1.1 MACRO BS VS. MICRO BS NETWORKS

A6.1.1.1 Assumptions

The Macro BS vs. Micro BS scenario models the interference between one building and a hexagonal macro-cellular network.

Macro-cellular network assumptions

The assumptions used for the macro-cellular network are identical to the Macro BS - Indoor BS study in section 2.

The only difference is that in this study there is no building area that should be avoided when dropping the Macro users.

Micro BS network assumptions

Table 52: BS parameters for the Micro BS network

BS parameters	Value	Source / reference
BS Element gain	8 dBi	
BS Antenna array	8x8 array	
BS Element spacing (Horizontal, Vertical)	0.5 λ , 0.5 λ	
BS antenna beamforming	Beamforming towards MSs with (8´8) array	
BS noise figure	8 dB	C-band synch toolbox – studies and assumptions v0.11
BS transmit power	40 dBm	C-band synch toolbox – studies and assumptions v0.11
BS mechanical down tilt	10 deg.	ECC Report 281 [2]

Table 53: MS parameters for the Micro BS network

MS parameters	Value	Source / reference
MS max transmitted power	23 dBm	
MS antenna type	Isotropic, -4 dBi	ITU-R M.2292-0 [23]
MS noise figure	9 dB	
Power control: CLxile	94 dB	Correspondence group discussions
Power control: gamma	1	Correspondence group discussions

Table 54: System related parameters for the Micro BS network

e	Value
Channel bandwidth	60 MHz
Layout	Hexagonal grid
Number of sites	19
Number sectors per site	1 sector/site (Random orientation)
Inter-Site Distance (ISD)	166 m
BS antenna height	6 m
MS antenna height	1.5 m
MS distribution	Uniform over the area
Fraction of MSs that are indoor	70%

Table 55: Propagation parameters for propagation in the Micro BS network

Propagatione	Value	Source / reference
Propagation model (BS-MS within the system)	UMi	3GPP TR 38.901 [24]
Indoor penetration model parameters for Macro MS	According to Table 7.4.3-3	3GPP TR 38.901 [24]

Macro-cellular network vs. Micro BS network parameters

Table 56: Parameters related to inter-system deployment

System parameters	Value
Macro BS vs. Micro BS distance	30m (min. distance)

Table 57: Propagation parameters for inter-system propagation

Propagation	Value	Source / reference
Propagation model Macro BS vs. Micro BS	UMa	3GPP TR 38.901 [24]
Propagation model Macro MS vs. indoor MS	ITU-UMi	

Figure 62shows the one snapshot of the deployment of the micro and macro-cellular networks. The centre BS in the macro-cellular network is located 30m from the centre BS in the Micro BS network.

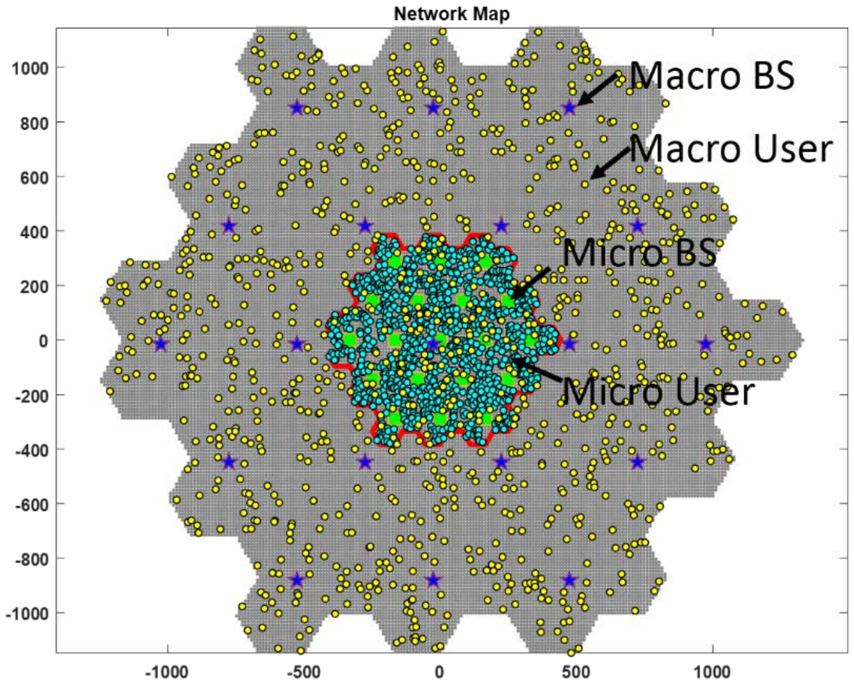


Figure 62: Deployment of micro and macro-cellular networks

A6.1.1.2 Simulation results – Impact on micro BS network

The impact on the throughput loss in the Micro BS network is shown in Figure 63 to Figure 65. In all figures the results are averaged over many different snapshots of MS locations.

In Figure 63, the results are averaged over all Micro BSs for several realisations of the Macro BS - Micro BS propagations. In Figure 64Figure 63: Mean uplink throughput loss for the Micro BS network. , separate curves are shown for each realisation of Micro BS - Macro BS propagation. Finally, in Figure 65 only the results from the centre BS are shown.

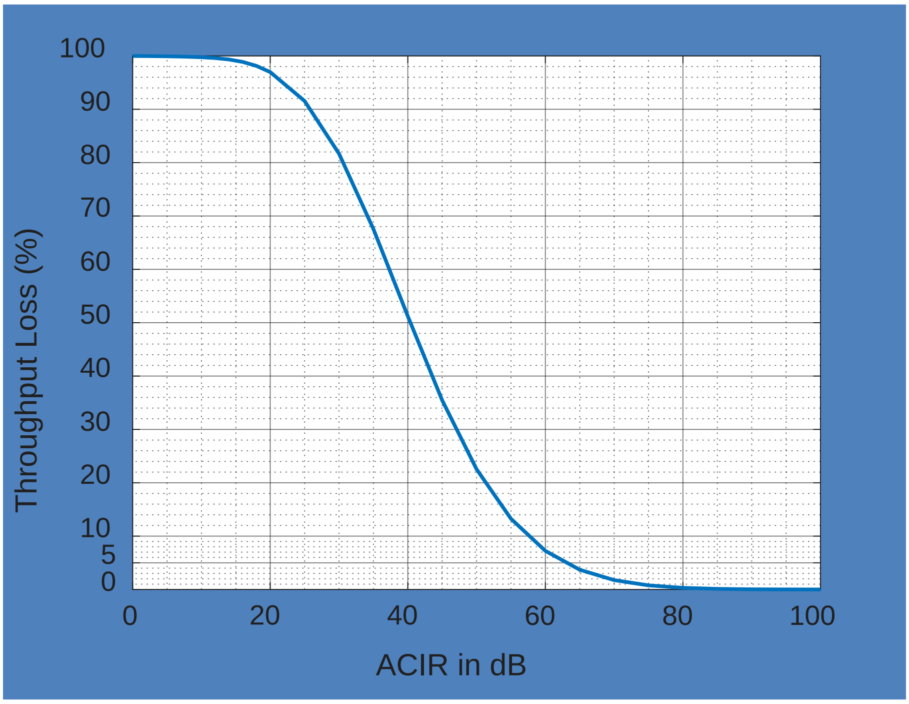


Figure 63: Mean uplink throughput loss for the Micro BS network. Throughput loss averaged over different Macro BS – Micro BS propagation realisations and the interfering Macro BS serving different users

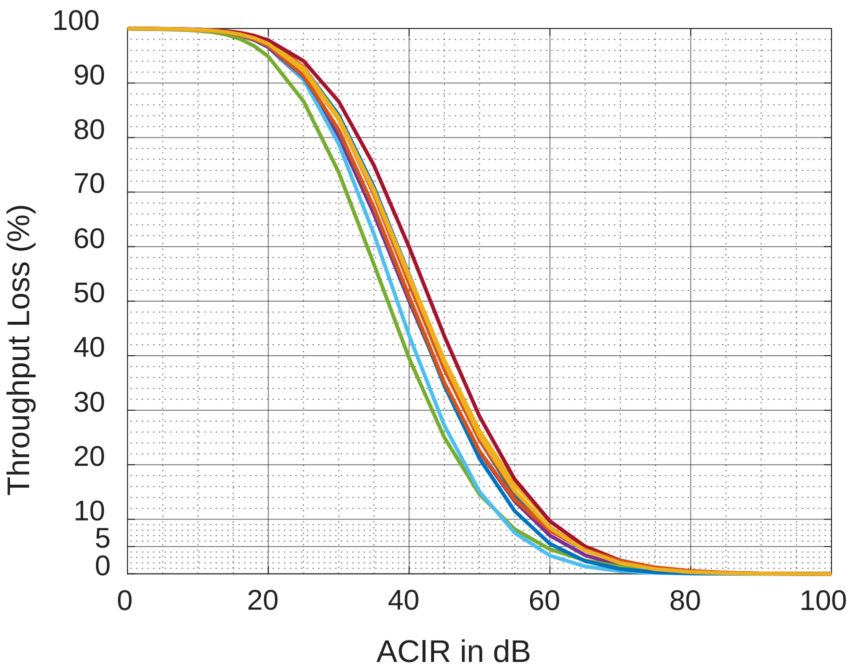


Figure 64: Mean uplink throughput loss for the Micro BS network. Throughput loss averaged over many realisations of Macro BS serving different users

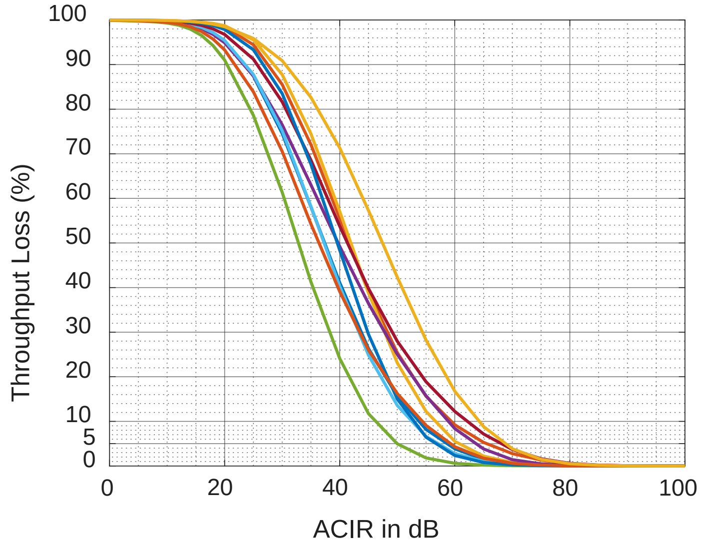


Figure 65: Mean uplink throughput loss for the Micro BS in the centre (worst case). Throughput loss averaged over many realisations of Macro BS serving different users

A6.1.1.3 Simulation results - Impact on macro-cellular networks

Figure 66 shows the throughput loss vs. ACIR for the BS in the centre of the Micro BS network. I.e. the BS most impacted by the Micro BS network for different realisations of Micro BS to macro-cellular networks propagation.

Figure 67 depicts the averages the throughput loss vs. ACIR for all the Macro BSs and realisations of Micro BS to Macro BS propagation, while Figure 68 shows the throughput loss for all Macro BSs for each realisation of Micro BS to Micro propagation.

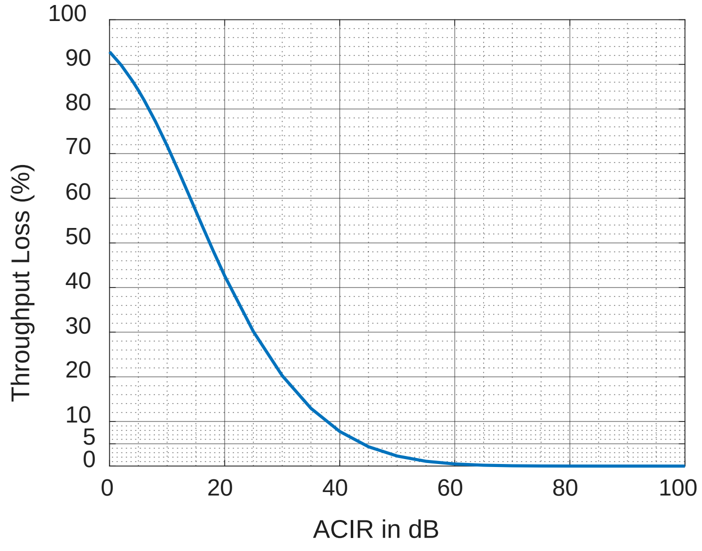


Figure 66: Average uplink throughput loss for the macro-cellular network. Throughput loss averaged over different Macro BS - Micro BS propagation realisations and the interfering Micro BS serving different users

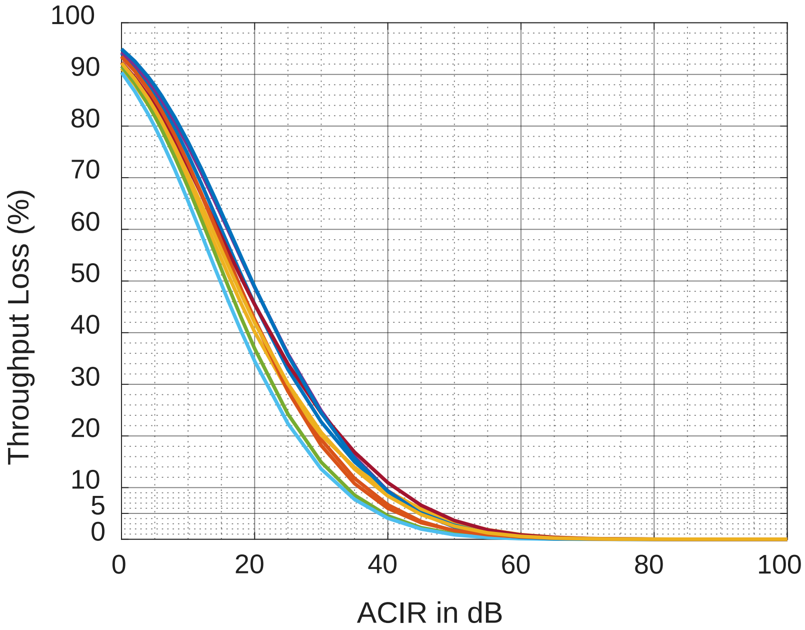


Figure 67: Average uplink throughput loss for the macro-cellular network. Throughput loss averaged over many realisations of Micro BS serving different users

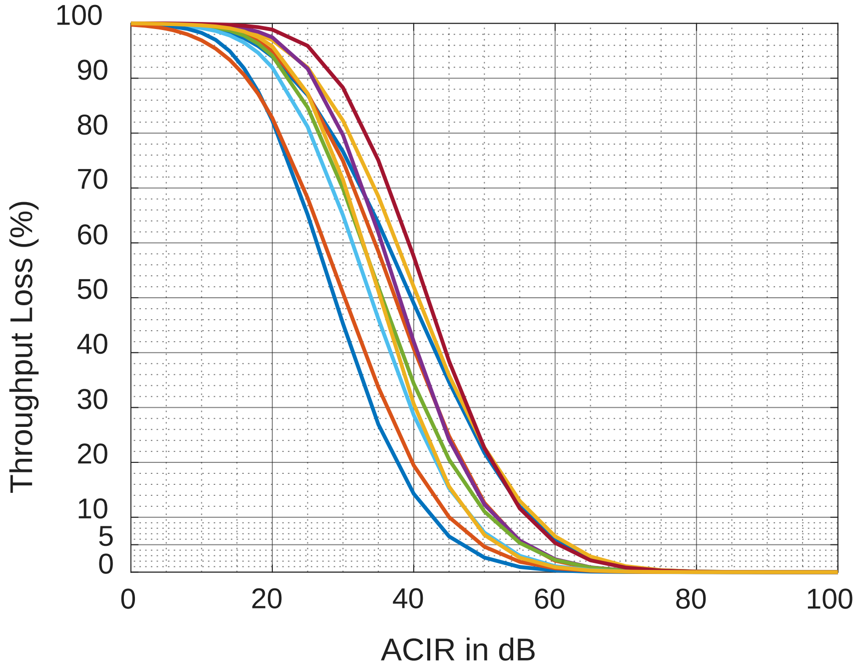


Figure 68: Average uplink throughput loss for the Macro BS in the centre (worst case). Throughput loss averaged over many realisations of Micro BS serving different users

A6.2 STUDY #6

This study considers the impact of BS-BS interference between MFCNs with simultaneous UL/DL transmission in terms of the resulting degradation in the mean UL throughput of the victim MFCN. The MFCNs consist of Macro and Micro BSs.

The study addresses two scenarios according to the specific class of base stations, namely:

- Macro-cellular network (hexagonal grid placed outdoors) operates as the interferer and the Micro BS network (hexagonal grid placed outdoors) is interfered;
- Micro BS network(hexagonal grid placed outdoors) operates as the interferer and the Macro BS (placed outdoors) is interfered;
- Interference from one Micro BS to another Micro BS (both base stations are placed outdoors)

The two interfering deployments operate in the same geographic area on adjacent frequency channels.

All Micro and Macro BSs are assumed to be AAS base stations forming a beam towards a MS (MSs are assumed to be uniformly distributed within a cell).

The Macro BSs have 25m high antennas and comprise three sectors per site; the Micro BSs are placed 6 meters above ground, comprising one sector per site with random boresight.

See Section A6.2.3 for the full list of assumptions and parameters.

A6.2.1 INTERFERENCE BETWEEN MACRO-CELLULAR NETWORKS AND MICRO BS NETWORKS

Figure 69 provides the topology used for the coexistence studies in case of a macro-cellular network (placed outdoors) operating as the interferer towards a Micro BS network (hexagonal grid placed outdoors).

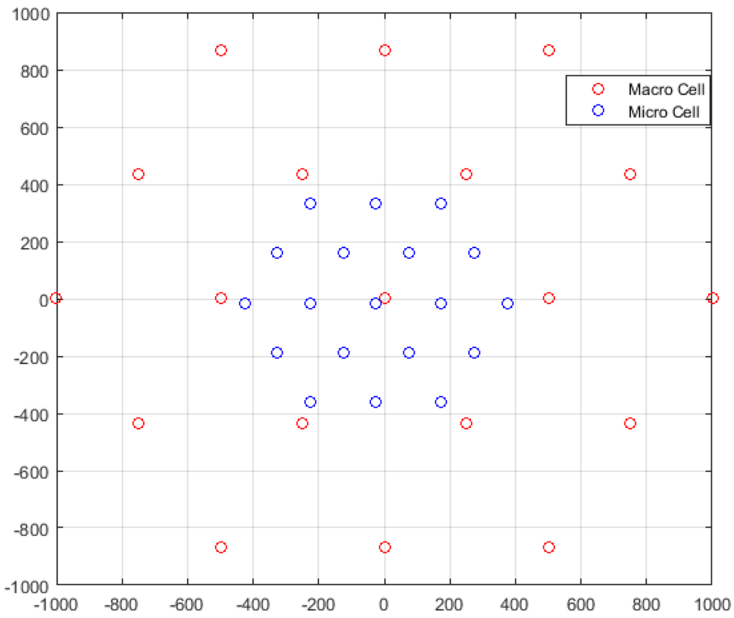


Figure 69: Topology for the Macro BS to Micro BS interference scenario

Figure 70 provides the topology used to support coexistence studies in case of a Micro BS network (hexagonal grid placed outdoors) operating as the interferer towards the macro-cellular network (hexagonal grid placed outdoors). In line with ECC Report 203[54], the simulations address one Macro BS that is completely surrounded by the Micro BSs grid.

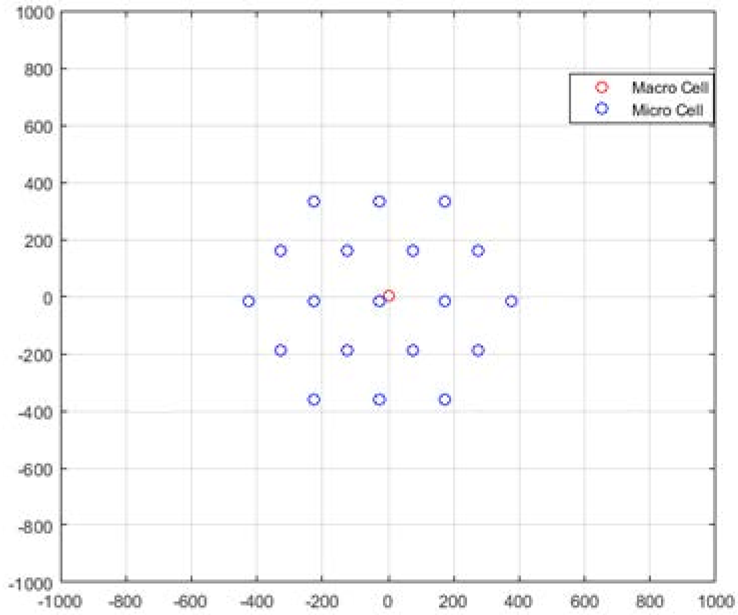


Figure 70: Topology for the Micro BS to Macro BS interference scenario

A6.2.2 INTERFERENCE FROM AAS MICRO BSS TO AAS MICRO BSS

Approach 1: In this analysis, the separation distance between the Micro BSs is an input parameter, the UMi path loss model determines the associated Line-of-sight probability.

The following two settings have been considered:

- Case 1a: 30m separation distance between the two Micro BSs leading to 80% LoS probability based on the UMi path loss model (the smaller the distance, the greater the probability the two Micro BSs will be along the same street),

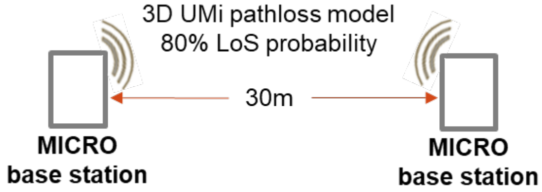


Figure 71: Micro BS to Micro BS interference scenario topology - Case 1a:
30m separation distance leading to 80% LoS probability based on UMi path loss model

- Case 1b: 100m separation distance between the two Micro BSs leading to 25% LoS probability based on the UMi path loss model (the larger the distance, the greater the probability the two Micro BSs will be located in different streets),

---

[54] ECC Report 203 [5] page 26: "One important thing to note here is that the results contained in Table 17 are for one reference cell in the macro-cellular network, which is overlapped completely by the Micro BS network (Manhattan) grid (see Figure 19)."

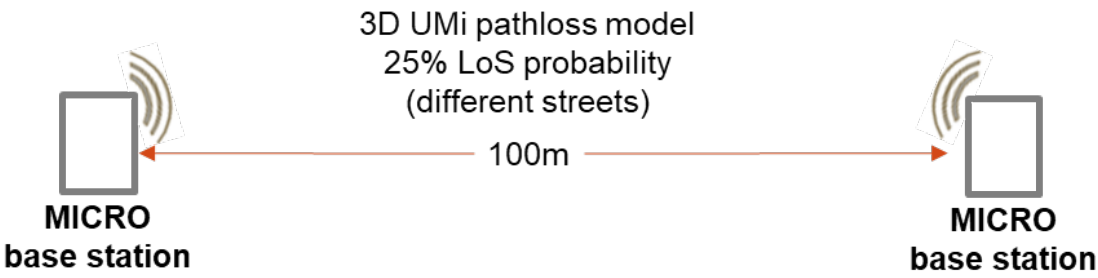


Figure 72: Micro BS to Micro BS interference scenario topology - Case 1b: 100m separation distance leading to 25% LoS probability based on UMi path loss model

Approach 2: in this analysis the separation distance between the Micro BSs is an input parameter as well as the line-of-sight probability.

This approach accounts for the fact that it is difficult to carry out meaningful simulations to assess the interference between two Micro BS networks in the same urban area since the interference scenario will be strongly impacted by the LoS/NLoS conditions which radically change as the Micro BSs change their locations with respect to buildings.

The study therefore considers two specific set of cases for the deployments of the interfering and victim base stations:

- Cases 2a, 2b and 2c: two Micro BSs located in different streets at 30m, 50m and 75m separation distance with 0% LoS probability

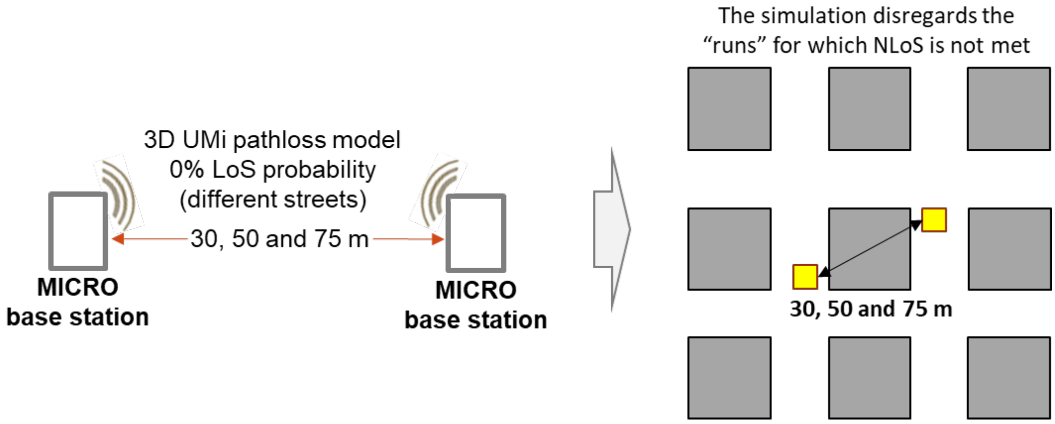


Figure 73: Micro BS to Micro BS interference scenario topology. Case 2a, 2b and 2c: 30m separation distance and 0% LoS probability (different streets)

- Case 2d: two Micro BSs located along the same street (100% LoS probability) at 100 m separation distance.

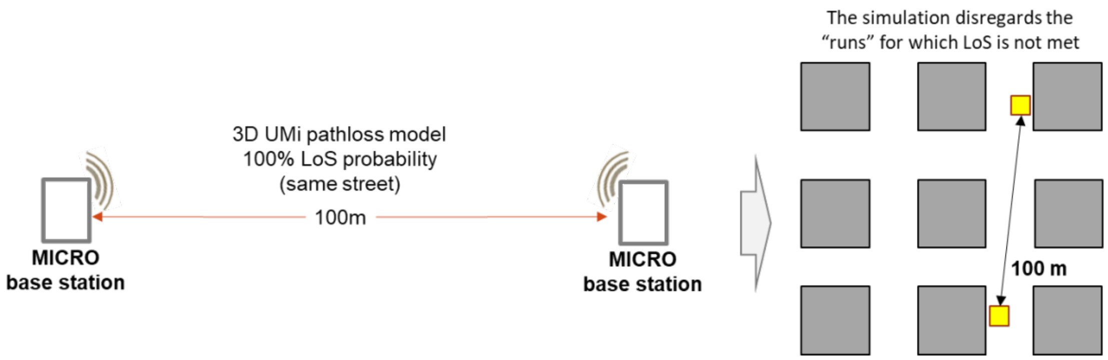


Figure 74: Micro BS to Micro BS interference scenario topology. Case 2d: 100m separation distance and 100% LoS probability (same street)

A6.2.3 SIMULATIONS PARAMETERS

The assumptions used the basis for the coexistence studies are as in Table 33 in ANNEX 4, with the following options used:

Table 58: Simulation Parameters

Parameter	Value	
MACRO-CELLULAR NETWORK DEPLOYMENT PARAMETERS		
Scheduler (# active MSs / cell)	Proportional Fairness scheduling	Option 1 in Table 33
# active MSs / BS	3 active MSs / CELL	Option 1 in Table 33
MICRO DEPLOYMENT PARAMETERS		
#sectors per site	1 cell/site	Option 1 in Table 33
BS antenna tilt	10 degrees	Option 1 in Table 33
MS PARAMETERS		
MS max transmitted power	23 dBm	
UL Power Control	NOTE: parameters are chosen to maximise the network performance: maximise the 5% and average t-put network performance (for a single operator)	
	Macro MS: P0 = -92dBm, ɣ = 0.8 Micro MS: P0 = -86dBm, ɣ = 0.8	Option 2 in Table 33
MS distribution		
Macro ↔ Macro	80% indoor (aligned with RAN1 3GPP 38.802 table 8.2.1-1)	Option 1 in Table 33
Macro ↔ Micro	Macro MSs: - Indoor: 70 %, outdoor: 30 %	Option 1 in Table 33

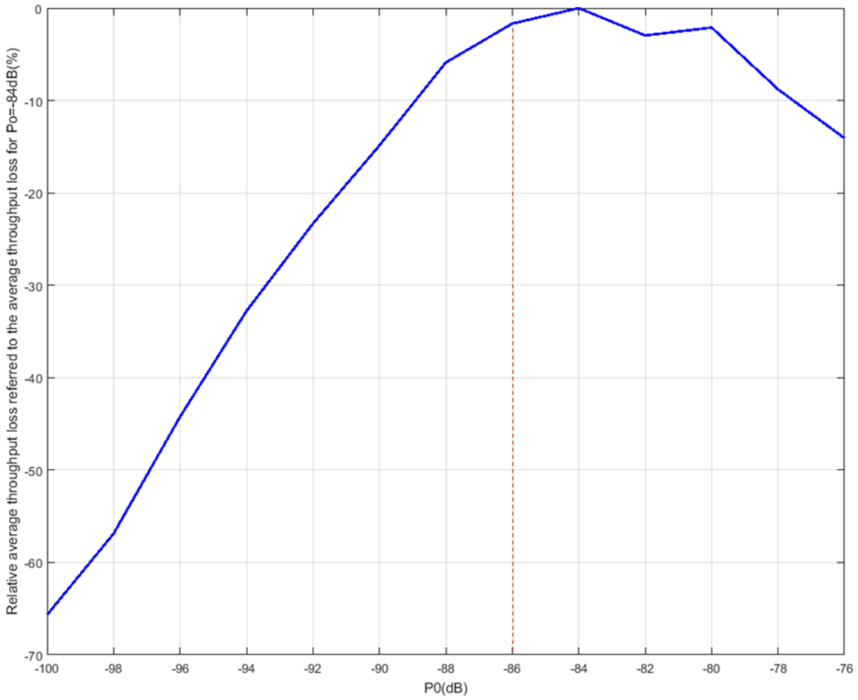
A6.2.3.1 MS Power Control parameters selection

As shown in Table 58, the following MS power control parameters are chosen for the MSs connected to the Micro BS network:

P0 = -86 dBm , ɣ = 0.8

This section shows how the selected parameters maximise the network performance in terms of the average uplink throughput and on the 5% edge throughput loss (for a single operator).

Impact on the average uplink throughput:



7

Figure 75: Relationship between Po and average uplink throughput, ɣ = 0.8

Impact on the cell edge uplink throughput loss:

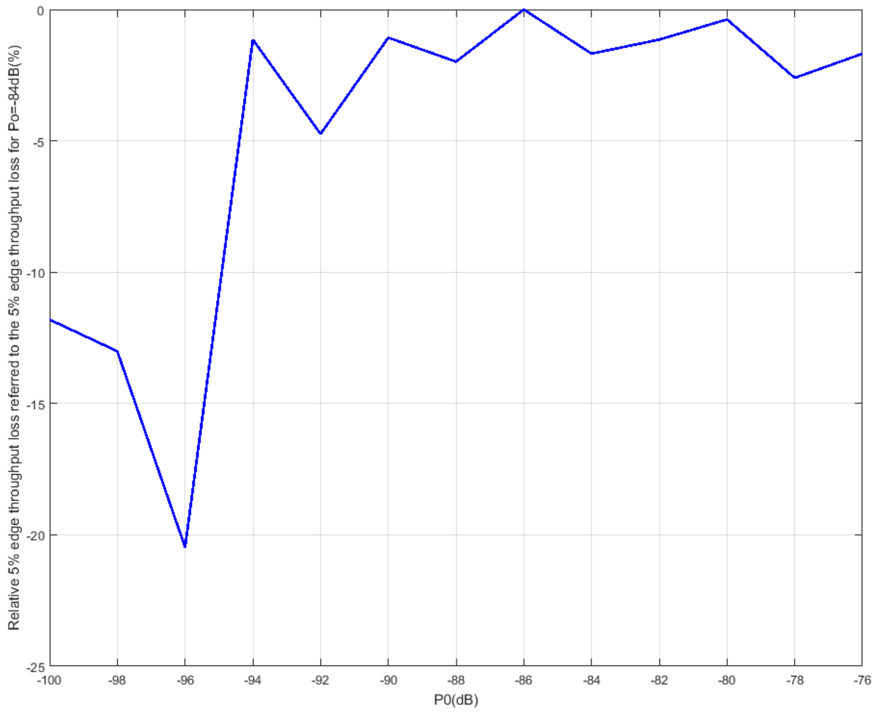


Figure 76: Relationship between Po and edge UL average throughput, ɣ = 0.8

The 5G MFCN antenna element and array parameters were as in Table 38 in ANNEX 5.

A6.2.4 SIMULATIONS RESULTS

The following sections present the simulations results expressed in terms of degradation of the mean uplink throughput of the victim MFCN due to base station to base station interference from the interfering MFCN, presented as a function of ACIR. In general terms, as expected, the impact of interference on network performance diminishes with increasing values of ACIR.

Note that the required ACLR is assumed to be nominally equal to the required ACIR, with the understanding that interference is not dominated by the adjacent channel selectivity (ACS) of the victim base station.

Note that both victim BS and interferer base stations are assumed to operate with 60 MHz channel bandwidth.

It is important to highlight that the following were not accounted for:

- blocking effect on the victim BS receiver;
- MS – MS interference.

A6.2.4.1 Macro-cellular network interferes with Micro BS network

The results presented in this section refer to the topology proposed in Figure 69.

Figure 77 shows how an ACIR greater than 68 dB is required to ensure a mean uplink throughput degradation smaller than 5%.

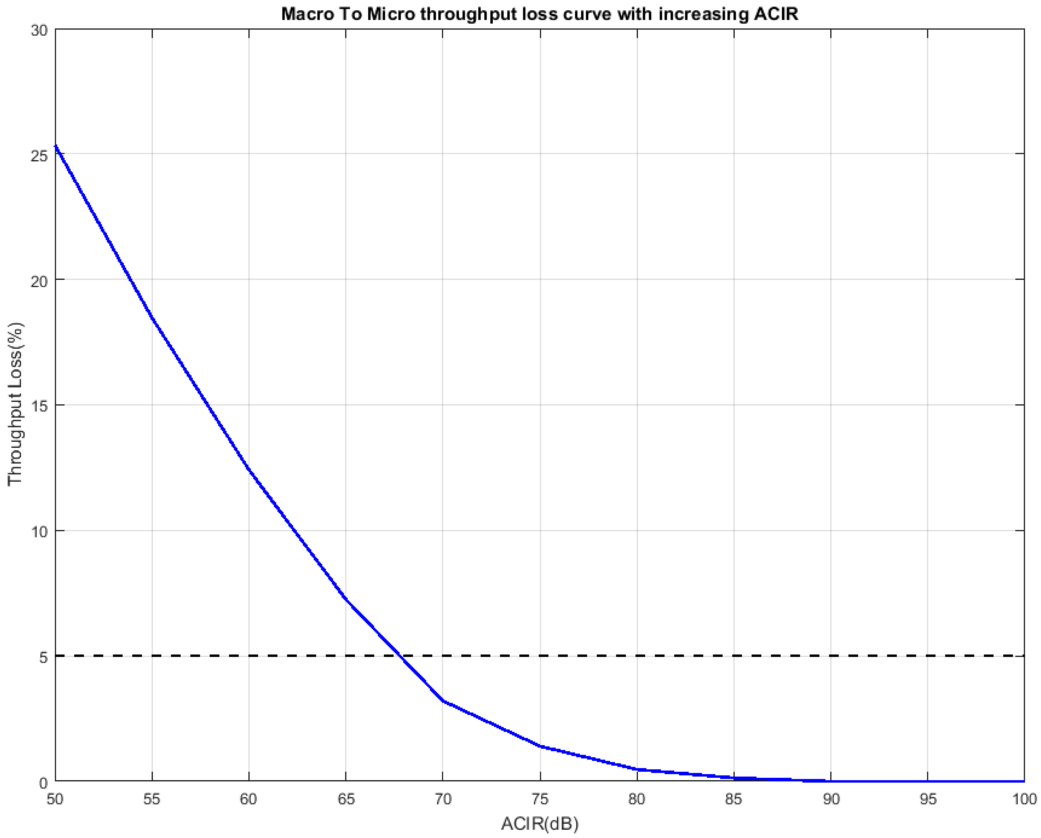


Figure 77: Impact of the macro-cellular network interference to Micro BS network In terms of mean uplink throughput

A6.2.5 MICRO BS NETWORK INTERFERES WITH MACRO-CELLULAR NETWORK

The results presented in this section refer to the topology proposed in Figure 21.

Figure 78 shows how an ACIR greater than 55 dB is required to ensure a mean uplink throughput degradation smaller than 5%.

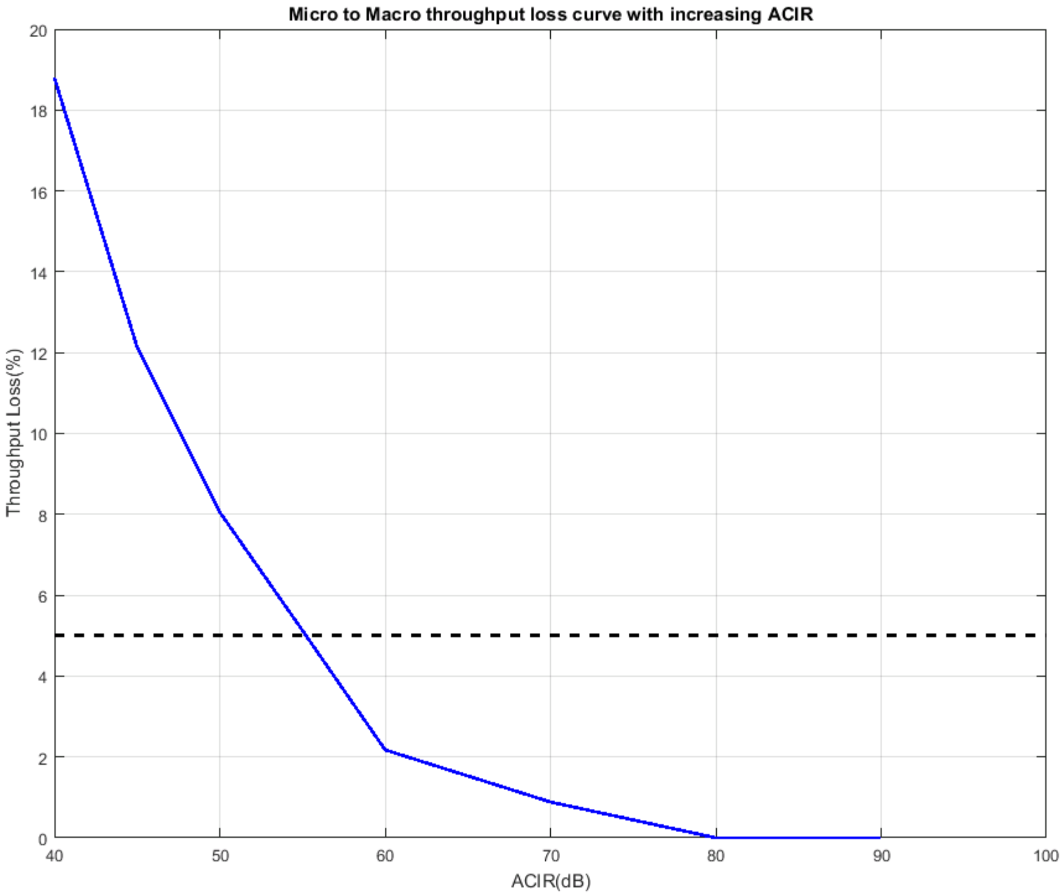


Figure 78: Impact of the Micro BS network interference to macro-cellular network In terms of mean uplink throughput

A6.2.5.1 Micro BS interferes with another micro BS

The results presented in Figure 79 refer to the topology proposed in Figure 71.

Figure 79 shows how an ACIR greater than 63dB is required to ensure a mean uplink throughput degradation smaller than 5%.

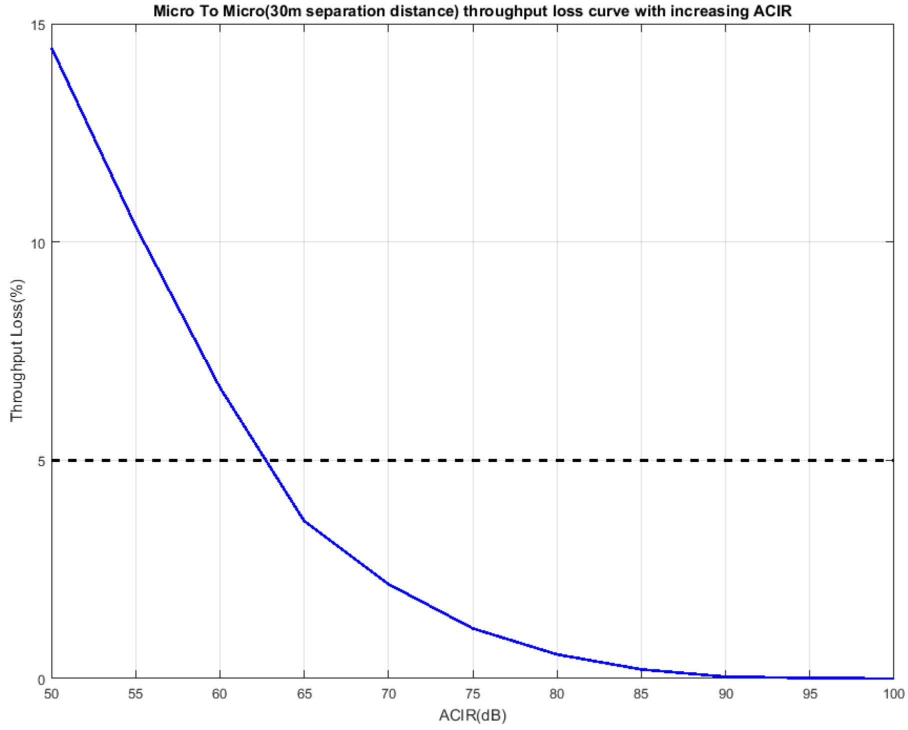


Figure 79: Micro BS to Micro BS interference scenario simulation results - Case 1a: 30m separation distance leading to 80% LoS probability based on UMi path loss model

Figure 80: shows how an ACIR greater than 54dB is required to ensure a mean uplink throughput degradation smaller than 5%.

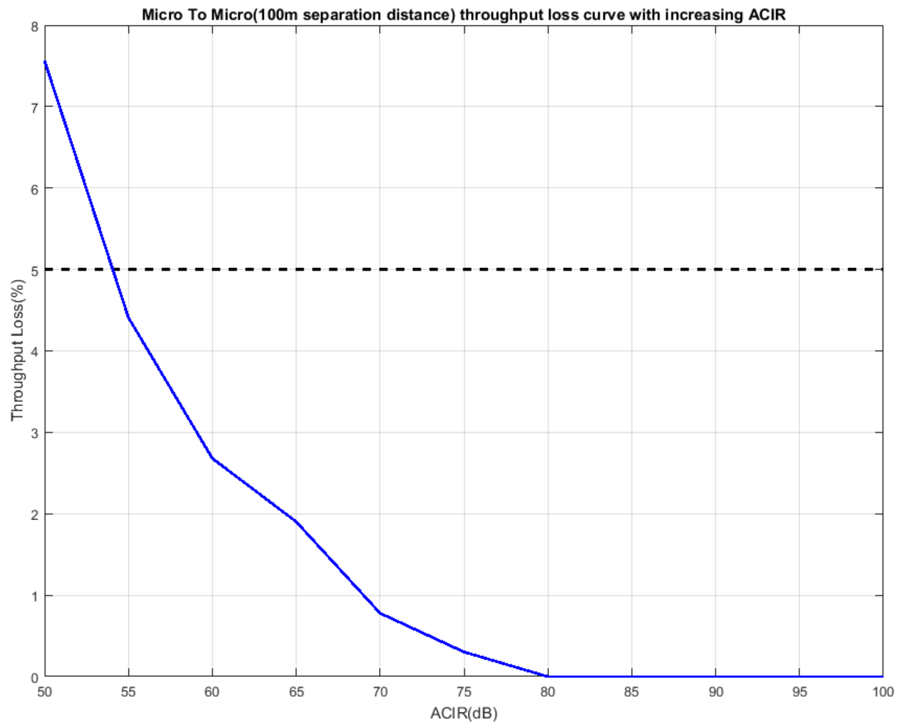


Figure 80: Micro BS to Micro BS interference simulations results - Case 1b: 100m separation distance leading to 25% LoS probability based on UMi path loss model

Figure 81 shows how an ACIR greater than 49 dB is required to ensure mean uplink throughput degradation smaller than 5% for 30 m separation distance. If separation distance is 50 m, 45 dB ACIR can satisfy the requirement of 3GPP.

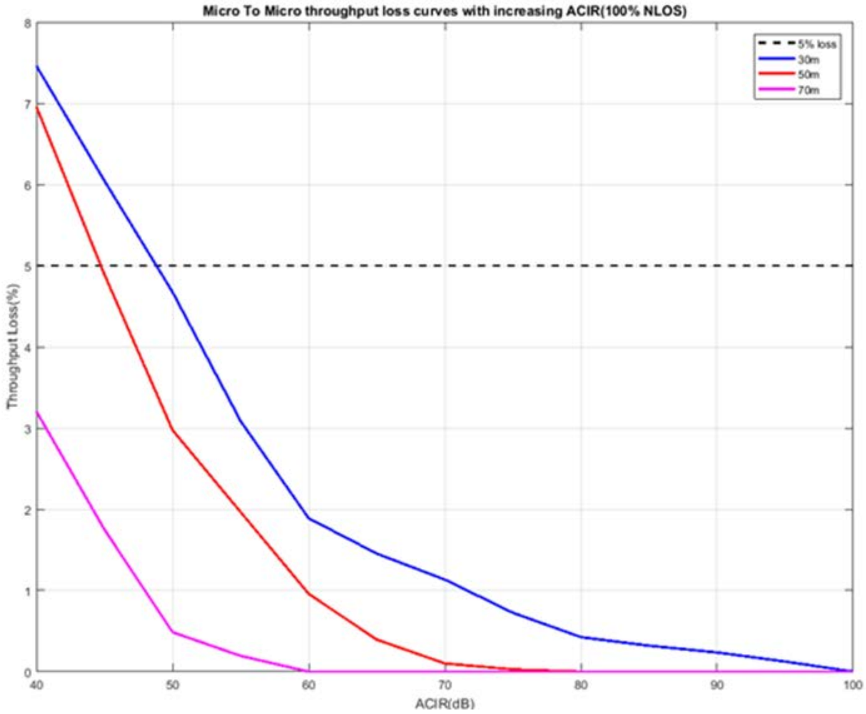


Figure 81: Micro BS to Micro BS interference scenario simulations results – Case 2a, 2b and 2c: 30 m, 50 m and 75 m separation distance and 0% LoS probability (different streets)

Figure 82 shows how an ACIR greater than 70 dB is required to ensure a mean uplink throughput degradation smaller than 5%.

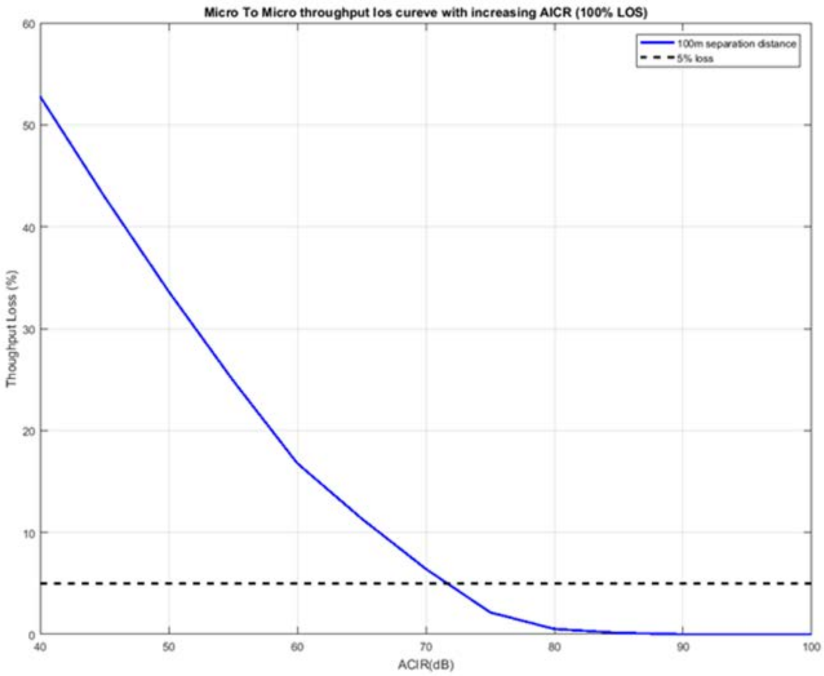


Figure 82: Micro BS to Micro BS interference scenario simulations results – Case 2b: 100 m separation distance and 100% LoS probability (same street)

ANNEX 7: COEXISTENCE STUDY BETWEEN UNSYNCHRONISED INDOOR BS AND MACRO BASE STATIONS - STUDY #7

A7.1 ASSUMPTIONS

A7.1.1 MACRO BS VS. INDOOR BS

The Macro BS vs. Indoor BS scenario models the interference between one building and a hexagonal macro-cellular network.

Macro-cellular network assumptions

Table 59: BS parameters for the macro-cellular network

BS parameter	Value	Source / reference
BS Element gain	8 dBi	
BS Antenna array	8x8 array	
BS Element spacing (Horizontal, vertical)	0.5 λ , 0.5 λ	
BS antenna beamforming	Beamforming towards MSs with (8´8) array	
BS noise figure	5 dB	
BS transmit power	51 dBm	
BS mechanical down tilt	10 deg.	ECC Report 281 [2]

Table 60: MS parameters for the macro-cellular network

MS parameter	Value	Source / reference
MS max transmitted power	23 dBm	
MS antenna type	Isotropic, -4 dBi	ITU-R M.2292-0 [23]
MS noise figure	9 dB	
Power control: CLxile	94 dB	
Power control: gamma	1	

Table 61: System related parameters for the macro-cellular network

System parameters	Value	Source / reference
Channel bandwidth	60 MHz	
Layout	Hexagonal grid	
Number of sites	19	
Number sectors per site	3 sectors/site	
Inter-Site Distance (ISD)	500 m	
BS antenna height	25 m	
MS antenna height	1.5 m	

System parameters	Value	Source / reference
MS distribution	Uniform over the area (excluding the area of the building). NOTE: Uniform distribution is commonly used, but how the area occupied by the building is handled should be discussed.	
Fraction of MSMS that are indoor	80%	

Table 62: Propagation parameters for propagation in the macro-cellular network

e	Value	Source / reference
Propagation model (BS-MS within the system)	UMa	3GPP TR 38.901 [24]
Indoor penetration model parameters for Macro MS	According to Table 7.4.3-3	3GPP TR 38.901 [24]

Indoor system assumptions

Table 63: BS parameters for the Indoor system

BS parametere	Value	Source / reference
BS Element gain	8 dBi	
BS Antenna array	4x4 array	
BS Element spacing (X, Y)	0.5 λ , 0.5 λ	
BS antenna beamforming	Beamforming towards MSs with (4x4) array	
BS noise figure	5 dB	
BS transmit power	24 dBm	3GPP TR 36.873 [26]
BS mechanical down tilt	90 deg. (ceil mount)	3GPP TR 36.873 [26]

Table 64: BS parameters for the Indoor system

MS parameters	Value	Source / reference
MS max transmitted power	23 dBm	
MS antenna type	Isotropic, -4 dBi	ITU-R M.2292-0 [23]
MS noise figure	9 dB	
Power control: CLxile	94 dB	Correspondence group discussions
Power control: gamma	1	Correspondence group discussions

Table 65: System related parameters for the Macro BS network

System parameters	Value	Source / reference
Building layout	1 floor 50x120 m building	3GPP TR 36.873 [26]

System parameters	Value	Source / reference
Number of sites	2, ceiling mount	3GPP TR 36.873 [26]
Number sectors per site	1 panel/site	3GPP TR 36.873 [26]
Inter-Site Distance (ISD)	60 m	3GPP TR 36.873 [26]
BS antenna height	3 m	3GPP TR 36.873 [26]
MS antenna height	1 m	3GPP TR 36.873 [26]
MS distribution	Uniform over the floor	
Fraction of MS that are indoor	100%	

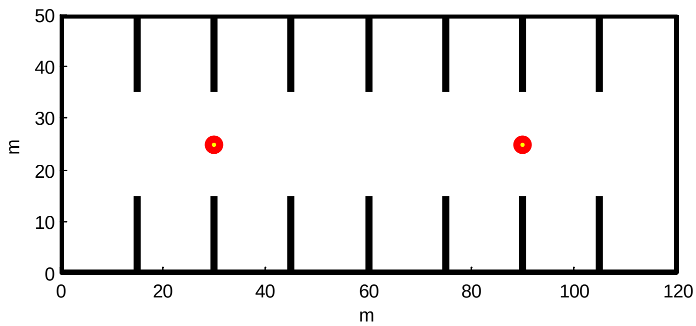


Figure 83: Building and the Indoor BS layout

Table 66: Propagation parameters for propagation in the macro-cellular network

Propagation	Value	Source / reference
Propagation model indoor BS-MS	InH - Office	3GPP TR 38.901 [24]
LoS probability model	Indoor - Open office	3GPP TR 38.901 [24]

Macro-cellular network vs. indoor BS network parameters

Table 67: Parameters related to inter-system deployment

System parameters	Value	Source / reference
Macro BS vs. building distance (outer wall)	70 m	
Building orientation	Case 1: Short wall facing BS Case 2: Long wall facing BS	

Table 68: Propagation parameters for inter-system propagation

Propagation	Value	Source / reference
Propagation model Macro BS vs. indoor BS	UMa	3GPP TR 38.901 [24]
Propagation model Macro MS vs. indoor MS	UMa	3GPP TR 38.901 [24]

Two cases of building orientation are studied. One when the building has the short wall toward the BS and one when the BS has the long wall toward the BS.

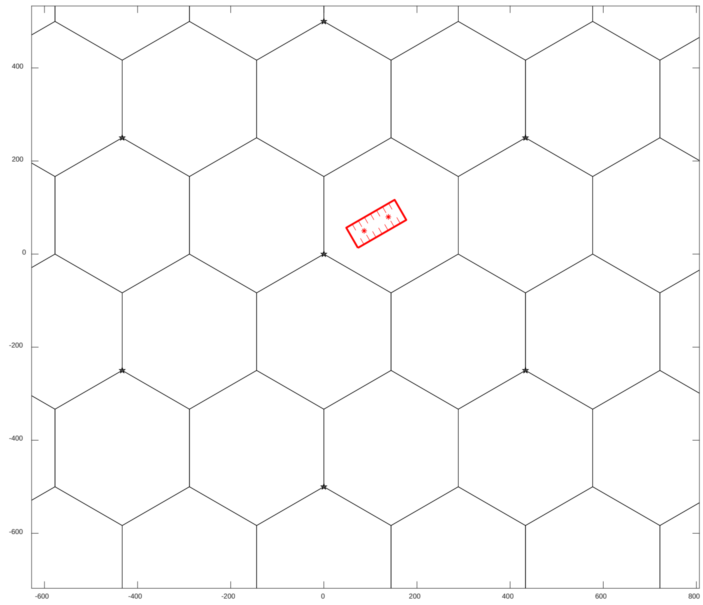


Figure 84: Case 1: Short wall facing the BS

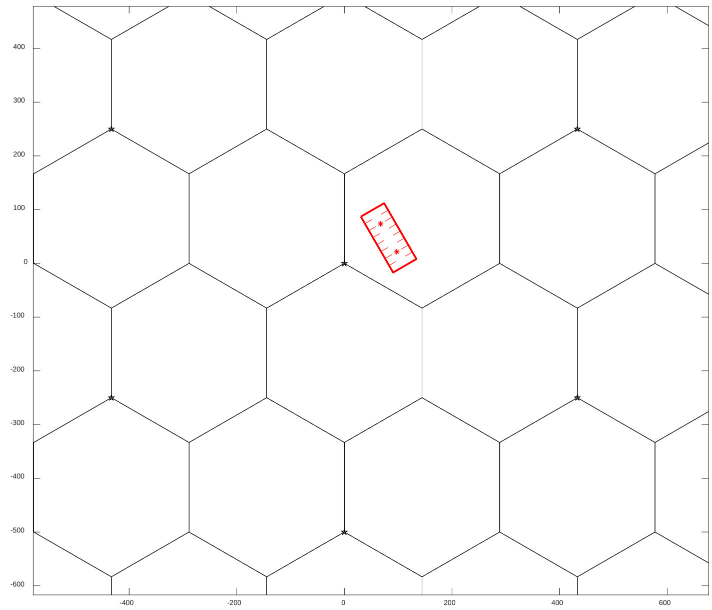


Figure 85: Case 2: Long wall facing the BS

A7.1.2 SIMULATION RESULTS – IMPACT ON INDOOR NETWORKS

The results for Case 1 where the short edge of the building is 70 m away from the Macro BS and oriented such that the boresight of the antenna beam is towards the short edge of the building, is shown in Figure 84 and Figure 85. In both figures the throughput loss is averaged over many realisations of MS locations and consequently the direction of the interfering BS beam.

In Figure 86 the results are also averaged over several realisations of the outdoor-to-indoor channel model, while in Figure 87 each realisation is plotted individually.

The corresponding results for Case 2 when the long edge of the building is facing the outdoor Macro BS are shown in Figure 88 and Figure 89 respectively. The performance is slightly worse in this case. The reason is that in this case there are two BS relatively close to the victim, while in case 1 the other BS is farther away.

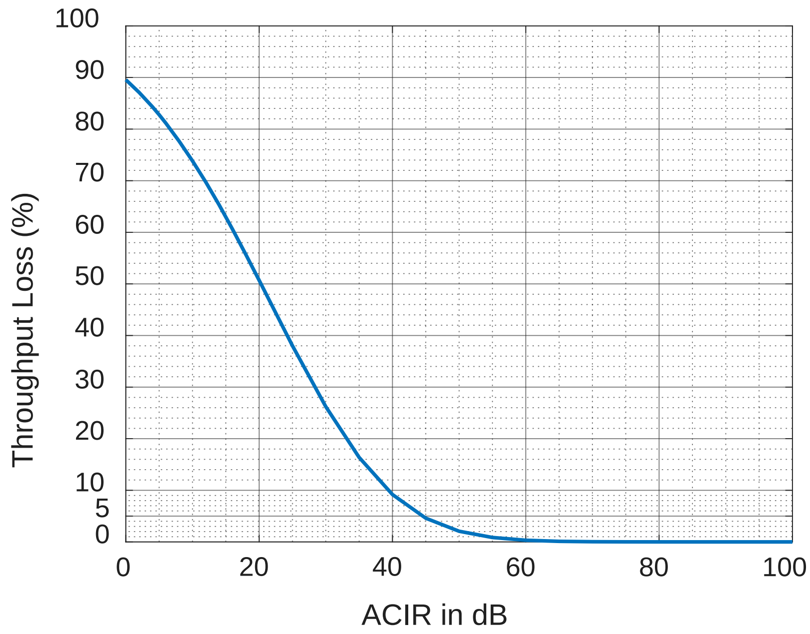


Figure 86: Average uplink throughput loss for the Indoor network in Case 1. Throughput loss averaged over different O2I channel realisations and the interfering Macro BS serving different users

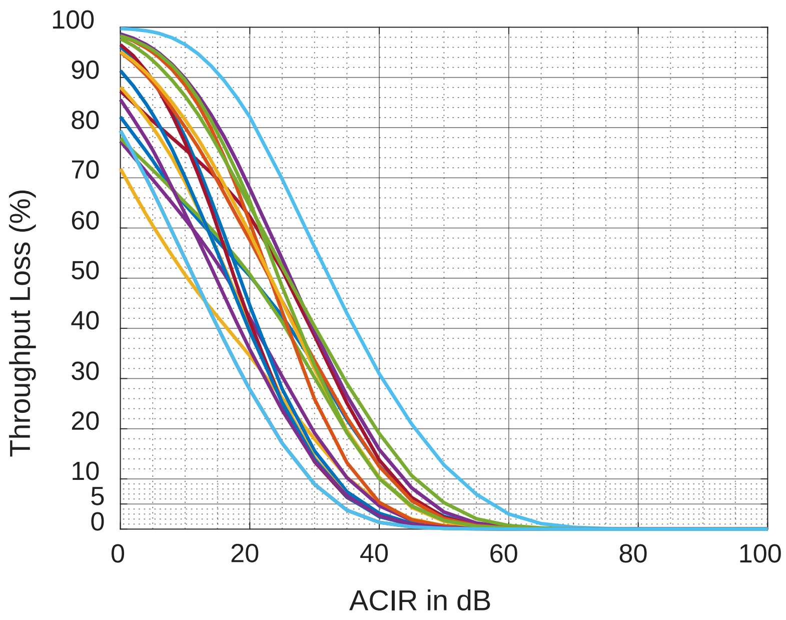


Figure 87: Uplink throughput loss for the Indoor network in Case 2. Throughput loss in each curve averaged over many realisations of the Macro BS serving different users

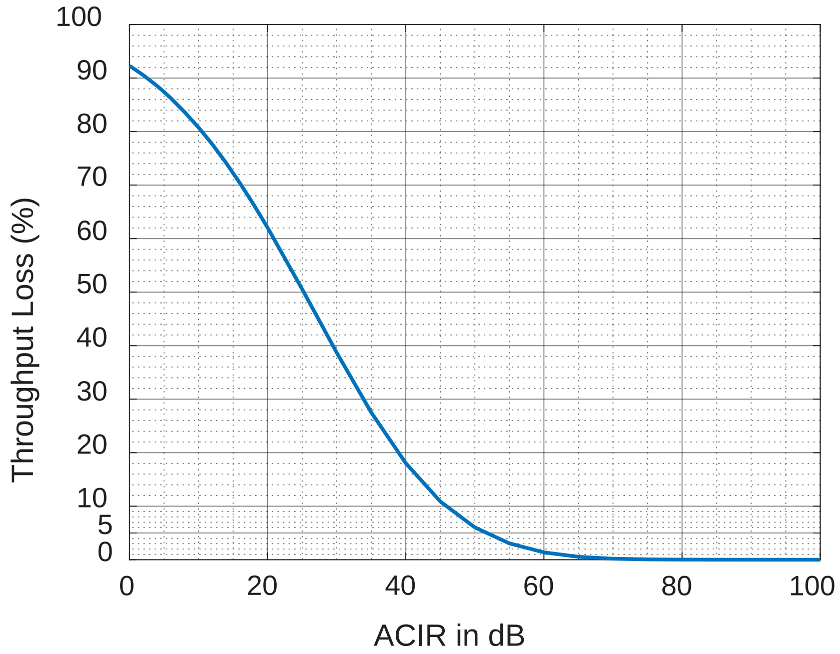


Figure 88: Average uplink throughput loss for the Indoor network in Case 2. Throughput loss averaged over different O2I channel realisations and the interfering Macro BS serving different users

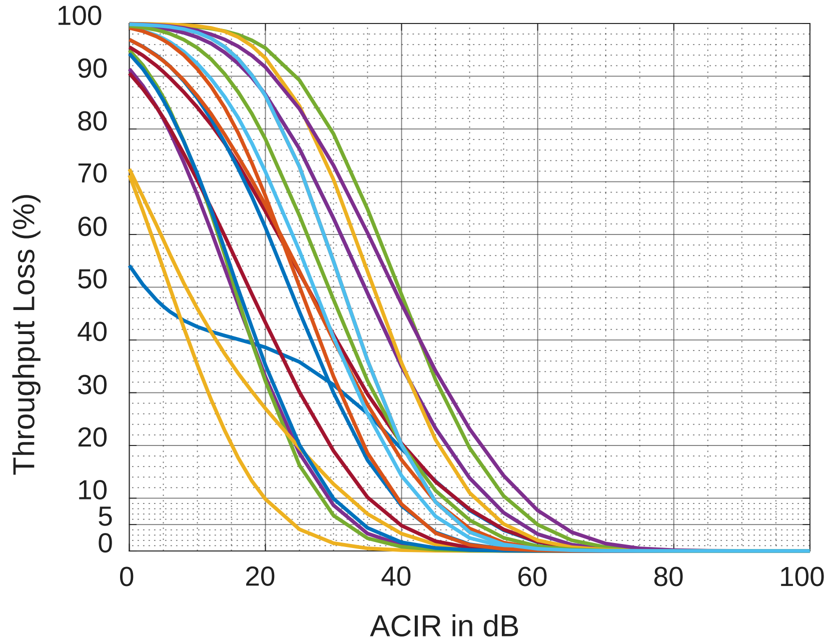


Figure 89: Uplink throughput loss for the Indoor network in Case 2. Throughput loss in each curve averaged over many realisations of the Macro BS serving different users

A7.1.3 IMPACT ON MACRO BS NETWORK

The reverse case where the macro-cellular network is the victim has not been simulated. However it can be observed that the indoor system has lower output power, which means that there should be lower impact from the indoor system. On the other hand if there are several buildings with indoor systems deployed there is a need to consider the effect of the aggregate interference.

ANNEX 8: COEXISTENCE BETWEEN SEMI-SYNCHRONISED MFCN NETWORKS - STUDY #8

Simulation results are presented, focusing on the following scenarios:

- Macro BS to macro-cellular networks:
  - Fully unsynchronised operation: Operator A and Operator B have simultaneous UL/DL transmissions for the whole frame duration. This is the worst-case scenario that becomes realistic only when the operators choose to have unsynchronised duplex directions for the whole frame duration;
  - Semi-synchronised operation in case only 50% of the frame is designated for flexible operation and operators have unsynchronised duplex directions in all flexible slots;
  - Semi-synchronised operation in case only 20% of the frame is designated for flexible operation and operators have unsynchronised duplex directions in all flexible slots;
  - Semi-synchronised operation in case only 20% of the frame is designated for flexible operation and operators have unsynchronised duplex directions in 50% of the flexible slots - in the following such a case will be referred to as 10% unsynchronised operation.
- Micro BS to Micro BS networks:
  - Same semi-synchronised operation cases as for Macro BS to macro-cellular networks.

A8.1 SIMULATION ASSUMPTIONS

Simulations were performed based on the set of assumptions in Table 33 with the exception of the parameters specified in Table 69 for macro-cellular network to macro-cellular network and Table 70 for Micro BS network to Micro BS network.

They are consistent with several coexistence studies in 3400-3800 MHz band (e.g.3GPP TR 36.942 [27], ECC Report 203 [5]).

Table 69: Macro-cellular network to macro-cellular network simulation assumptions

Parameter	Value
Deployment	
Networks shift	288 m
BS / MS parameters	
Uplink Power Control	PC Set 1 in 3GPP TR 36.942 CLxile = 94 dB, Gamma = 1

Table 70: Micro BS network to Micro BS network simulation assumptions

Parameter	Value
BS / MS parameters	
Uplink Power Control	PC Set 1 in 3GPP TR 36.942 CLxile = 82 dB, Gamma = 1

Uplink power control settings are derived from 3GPP TR 36.942 and scaled to account for a different Carrier Frequency, Channel bandwidth and deployment scenario.

With reference to the assumptions above;

- As shown in Figure 15, the 288 m network shift assumption between macro-cellular networks represents a best case assumption. Similarly, the 96 m network shift assumption between micro-cellular networks represents best-case assumptions.

- Differently from the approach followed in this study, the recommended approach is to use the separation distance and the line-of-sight probability as input parameter during the coexistence studies between the Macro-cellular network and the Micro BSs network. This approach accounts for the fact that it is difficult to carry out meaningful simulations to assess the interference between two Micro BS networks in the same urban area since the interference scenario will be strongly impacted by the LoS/NLoS conditions which radically change as the Micro BSs change their locations with respect to buildings.
- Coexistence between the macro-cellular network and the Micro BS network was not assessed by this study.

Antenna radiation pattern is as in 3GPP TR 38.901 [24] and is shown in Table 35 of ANNEX 4.

A8.2 SIMULATION RESULTS

This Section presents simulation results for the semi-synchronised operation scenarios listed above for the macro-cellular network to macro-cellular network case and for Micro BS network to Micro BS network deployment case.

A8.2.1 MACRO BS TO MACRO-CELLULAR NETWORKS

Figure 90 below shows the impact of Adjacent Channel Interference (ACI) on victim network performance in terms of average throughput loss for macro-cellular network to macro-cellular network. As expected, the impact diminishes when the operators have unsynchronised duplex directions for smaller portion of the frame.

Results show that with the baseline requirement for synchronised MFCNs in ECC Report 281 [2] performance degradation is ~9% for 10% unsynchronised operation among operators. It is important to notice that results are preliminary and do not consider any interference mitigation technique that would likely bring degradation down.

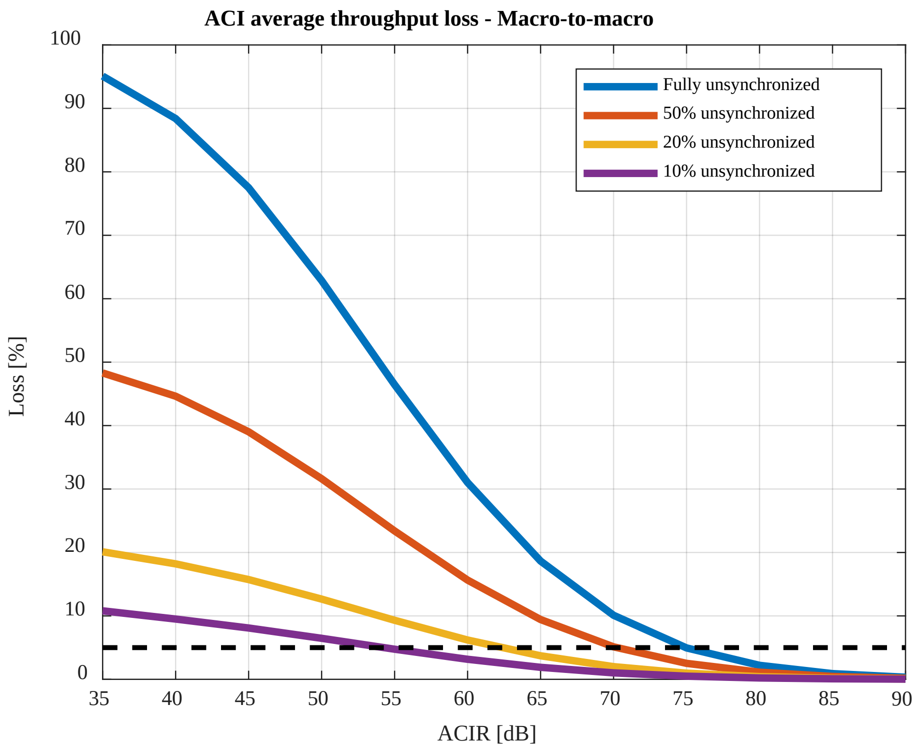


Figure 90: ACI impact on network performance - average throughput loss for Macro BS to Macro BS deployment and different semi-synchronised operation cases

A8.2.2 MICRO BS TO MICRO BS NETWORK DEPLOYMENT

Figure 91 shows the impact of Adjacent Channel Interference (ACI) on victim network performance in terms of average throughput loss for Micro BS to Micro BS network deployment. As expected, the impact diminishes when the operators have unsynchronised duplex directions for smaller portion of the frame.

Results show that it is possible to achieve 5% average throughput loss with 38 dB ACIR in the case the two operators have unsynchronised duplex directions for 20% of the frame. In this case it will be possible to use the current baseline requirement in ECC Report 281 [2] for synchronised BSs without additional throughput degradation.

It is again important to notice that results are preliminary and do not consider any interference mitigation technique that would likely bring degradation down.

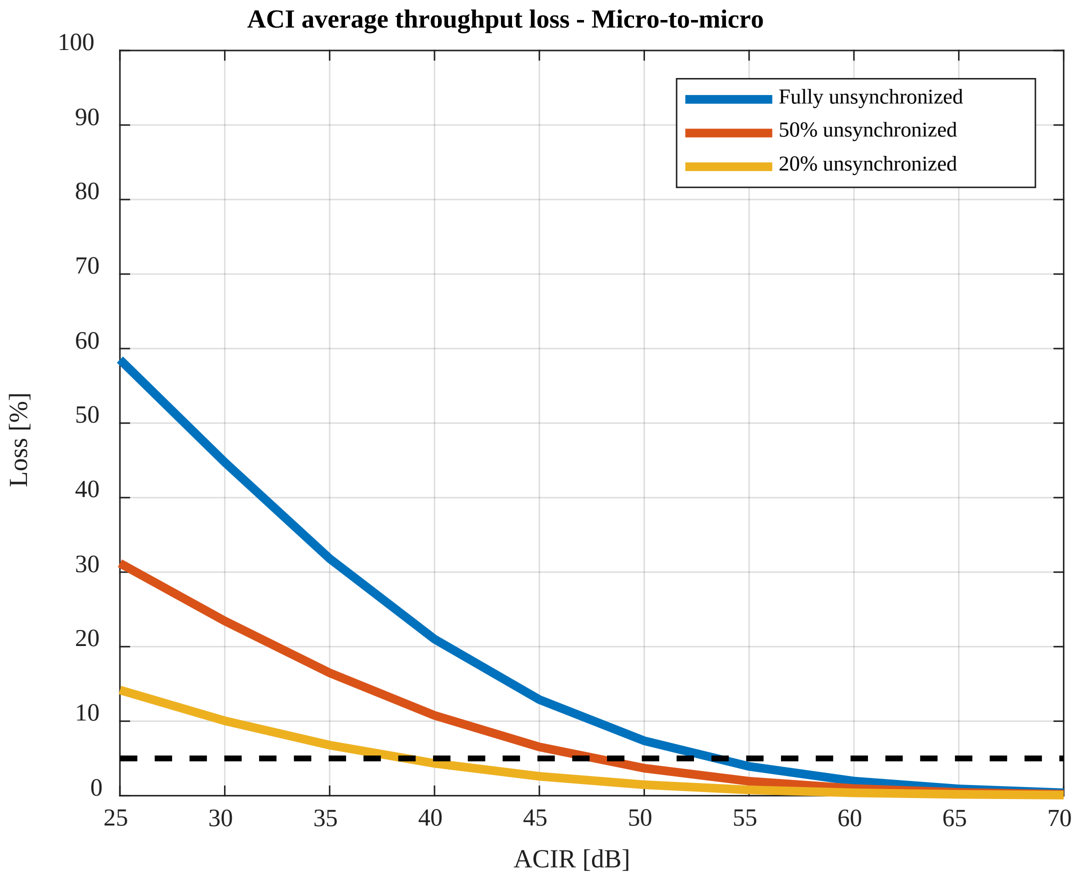


Figure 91: ACI impact on network performance - average throughput loss for Micro BS to Micro BS deployment and different semi-synchronised operation cases

ANNEX 9: STATUS OF UNSYNCHRONISED AND SEMI-SYNCHRONISED OPERATION IN 3GPP

The 5G-NR core RF requirements in 3GPP Release 15 were derived with the assumption of synchronised operation between two TDD systems. This follows the same approach adopted during LTE-TDD requirements specification.

During the course of Rel-14 5G-NR SI and Rel-15 5G-NR WI, 3GPP TSG RAN4 has not studied the 5G-NR RF requirements that can be applied for unsynchronised or semi-synchronised operation between two TDD systems on adjacent channels, where simultaneous UL/DL transmissions occur. However, RAN4 specifications allow the possibility to support unsynchronised or semi-synchronised operation across adjacent channels and/or operators, e.g. when either the two TDD systems are sufficiently isolated or some interference mitigation schemes are deployed. Furthermore, 5G-NR has the design flexibility to operate with full bandwidth in some time instances and narrower bandwidth in other time instances. Therefore, this may allow simultaneous transmissions to be operated instantaneously with a narrower bandwidth to provide isolation in frequency from adjacent channels. This type of operation has some restriction however, and will lead to spectrum efficiency impacts during those simultaneous UL/DL feedback on the amount of support in Release 15 5G-NR specifications for the unsynchronised or semi-synchronised operations described in the ECC Report 281. In the following, synchronisation between two networks or two BSs means the same beginning of the slot and the alignment of transmission directions (DL, UL), as in the definitions from CEPT.

3GPP TSG RAN1 has taken a general approach when specifying 5G-NR, enabling support for synchronised, semi- and unsynchronised deployment. It is RAN1 understanding that there is no coexistence issue due to adjacent channel interference among TDD networks in case of synchronised operation of multiple TDD networks on adjacent channels.

Unsynchronised or semi-synchronised 5G-NR operation may occur in the context of two scenarios:

Operators choose to use semi-statically configured DL / UL partitioning but use different DL / UL patterns

One or more operators choose to use dynamic DL / UL partitioning

The air-interface specifications developed by RAN1 support that each slot can be dynamically scheduled to transmit on either uplink or downlink, or the slot could include both a DL part and an UL part. Slots (and symbols within a slot) can be semi-statically configured to be UL or DL or an ‘undefined’ state that can be dynamically allocated to UL or DL. In the presence of the semi-static configuration, the dynamic allocation applies only to the ‘undefined’ part, while the slots and symbols indicated as DL or UL can only be used in the indicated duplex direction.

The air-interface specifications developed by RAN1 allow adjusting the bandwidth occupied by the modulated waveform (note that LTE-TDD is not capable of this since there are always-on wideband common reference signals in LTE-TDD). More specifically, 5G-NR can adapt by scheduling the DL and UL bandwidths occupied by physical channels and signals, and those bandwidths can be different in different symbols and between DL and UL.

RAN1 will not determine what would be the exact conditions for 5G-NR to allow synchronised, unsynchronised and semi-synchronised operation. The current available tools that RAN1 sees to mitigate BS-BS and MS-MS interference are sufficient guard bands, sufficient geographical separation, sufficient physical isolation (such as outdoor to indoor propagation isolation), or applicable transmission power.

3GPP in the past has studied inter-operator coexistence for LTE-TDD on adjacent channels [28][29]. The study in [28] concluded that significant BS-BS coexistence challenges have been observed to apply different TDD UL-DL configurations in different cells without any interference mitigation mechanisms for scenario 7, which represents inter-operator coexistence on adjacent channels in macro-cellular networks. It was also noted that in Macro BS to Macro BS coexistence (scenario 7 in [28]), only the uplink exhibited degradation. There was no study in [28] or conclusion on the coexistence feasibility with interference mitigation mechanisms for scenario 7. The study in [28]was completed at RAN#56 (June 2012), and did not include other techniques specified subsequently, e.g., AAS. There has been no further studies on coexistence feasibility of inter-operator MBS Macro BS deployments with unsynchronised or semi-synchronised operation on adjacent channels and using the techniques specified since June 2012, e.g., AAS.

When LTE-TDD is present and used in the same band as 5G-NR then, depending on the scenario such as large cell vs. small cell deployments or geographical separation, sufficient physical isolation, restrictions on the transmission directions may be necessary between the LTE-TDD and 5G-NR carriers to avoid the use of fixed guard bands. Likewise, similar restrictions on the transmission directions of 5G-NR Macro BSs would be necessary between neighbour 5G-NR networks in adjacent frequencies, although the constraints in terms of DL and UL patterns might be different than for coexistence with LTE-TDD.

However, RAN1 believes that such restrictions on the transmission directions are only required for certain types of deployments such as Macro BSs, and may be relaxed in more deployments with appropriate cross-link interference mitigation techniques. RAN1 believes that enabling 5G-NR deployments in the above three types of operation (either in earlier or later deployments) is important for achieving the full potential of 5G-NR TDD in areas/scenarios where sufficient conditions are met to mitigate 5G-NR BS-BS and 5G-NR MS-MS interference.

3GPP TSG RAN has approved a Release 16 work item [30] on cross-link interference handling and Remote Interference Management (RIM) for 5G-NR, which is relevant to deployments where interference occurs between uplink and downlink of two networks. The target completion date of the work item is June 2019. The work item should specify cross-link interference mitigation techniques to support flexible resource adaptation.

The detailed objectives for cross-link interference mitigation to support flexible resource adaptation for unpaired 5G-NR cells are:

- Specify cross-link interference measurements at a MS (e.g., CLI-RSSI and/or CLI-RSRP) (RAN1 and RAN4);
- Identify when cross-link interference mitigation techniques based on such measurement(s) provide benefits with practical RF performance (RAN4);
- Specify network coordination mechanism(s) including at least exchange of intended DL/UL configuration (RAN and RAN3);
- Perform coexistence study to identify conditions of coexistence among different operators in adjacent channels (RAN4);
- Target no or very minimal impact on RF requirement.

ANNEX 10: LIST OF REFERENCES

[1] ECC Report 216: "Practical guidance for TDD networks synchronisation", August 2014
[2] ECC Report 281: “Analysis of the suitability of the regulatory technical conditions for 5G MFCN operation in the 3400-3800 MHz band”, July 2018
[3] ECC Decision (11)06: "Harmonised frequency arrangements and least restrictive technical conditions (LRTC) for mobile/fixed communications networks (MFCN) operating in the band 3400-3800 MHz", amended October 2018
[4] ECC Recommendation (15)01: “Cross-border coordination for mobile / fixed communications networks (MFCN) in the frequency bands: 694-790 MHz, 1452-1492 MHz, 3400-3600 MHz and 3600-3800 MHz, March 2014
[5] ECC Report 203: "Least Restrictive Technical Conditions suitable for Mobile/Fixed Communication Networks (MFCN), including IMT, in the frequency bands 3400-3600 MHz and 3600-3800 MHz", November 2013
[6] ECC Report 131: "Derivation of a Block Edge Mask (BEM) for terminal stations in the 2.6 GHz frequency band (2500-2690 MHz)", February 2009
[7] ITU-R M.2374: “Coexistence of two time division duplex networks in the 2 300-2 400 MHz band”
[8] 3GPP TS 38.104
[9] ECC Report 287: “Guidance on defragmentation of the frequency band 3400-3800 MHz”, October 2018
[10] Tender Document F 7/16: “Procedure for Spectrum Award in the 3410 to 3800 MHz range”, Telekom-Control-Kommission Austria, September 2018: https://www.rtr.at/en/tk/5G-Auction-Tender-Documents/Tender_Documents_3_4_-_3_8_GHz_EN.pdf
[11] ComReg 17/46: “Results of the 3.6 GHz Band Spectrum Award – Information Notice”, June 2017: https://www.comreg.ie/publication/results-3-6-ghz-band-spectrum-award-2/
[12] AGCOM (Autorità per le Garanzie nelle Comunicazioni) Resolution No. 231/18/CONS – May ‘18 “Assignment procedures and rules for the use of the frequencies available in the 694-790 MHz, 3600-3800 MHz and 26.5-27.5 GHz bands for terrestrial systems of electronic communications in order to favor the transition to 5G technology, under the Law 27 December 2017, n. 205”;
[13] void
[14] Ofcom “Public Sector Spectrum Release: Award of the 2.3 and 3.4 GHz spectrum bands – Statement and consultation”, May 2015: https://www.ofcom.org.uk/__data/assets/pdf_file/0027/68337/Public_Sector_Spectrum_Release_statement.pdf
[15] Ofcom “Award of 2.3 and 3.4 GHz spectrum bands - Publication under regulation 111 of the Wireless Telegraphy (Licence Award) Regulations 2018 of results of auction” ”, April ‘2018
[16] 3GPP TS 36.211: “3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA); Physical Channels and Modulation”
[17] 3GPP TS 38.213 “3rd Generation Partnership Project; Technical Specification Group Radio Access Network; NR; Physical layer procedures for control (Release 15)” section 11.1
[18] Report ITU-R M.2410-0 (11/2017): “Minimum requirements related to technical performance for IMT-2020 radio interface(s)”
[19] Report ITU-R M.2412-0 (10/2017): “Guidelines for evaluation of radio interface technologies for IMT-2020”
[20] 3GPP TS 38.214 V15.0.0, “NR; Physical layer procedures for data (Release 15)”, December, 2017.
[21] Recommendation ITU-R P.452-16: "Prediction procedure for the evaluation of interference between stations on the surface of the Earth at frequencies above about 0.1 GHz"
[22] Recommendation ITU-R P.2001-2: "A general purpose wide-range terrestrial propagation model in the frequency range 30 MHz to 50 GHz"
[23] Report ITU-R M.2292-0: "Characteristics of terrestrial IMT-Advanced systems for frequency sharing/interference analyses"
[24] 3GPP TR 38.901: "Study on channel model for frequencies from 0.5 to 100 GHz"
[25] 3GPP TR 38.802: "Study on new radio access technology Physical layer aspects"
[26] 3GPP TR 36.873: "Study on 3D channel model for LTE"
[27] 3GPP TR 36.942: "Evolved Universal Terrestrial Radio Access (E-UTRA); Radio Frequency (RF) system scenarios"
[28] 3GPP TR36.828: “Further enhancements to LTE Time Division Duplex (TDD) for Downlink-Uplink (DL-UL) interference management and traffic adaptation, Rel-11”

[29] 3GPP TR36.825: “Feasibility study on possible additional configuration for LTE Time Division Duplex (TDD), Rel-13”

[30] 3GPP RP-181431: “New WID on Cross Link Interference (CLI) handling and Remote Interference Management (RIM) for NR”, LG Electronics, June 2018