GTI 5G White Paper

Multiple Operator Network Coexistence in the Same Frequency bands

Multiple Operators Coexistence in the Same 5G Frequency Bands

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Annex A: Document History

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Abstract

1 Introduction

This white paper introduces the issues of multiple operators coexistence in the same 5G frequency bands in the same geographic area and target to study the coexistence conditions and requirement for multiple operators in adjacent TDD 5G bands without interference to each other.

Key findings for coexistence recommendation:

- Impact analysis of the interference of unsynchronized and semi-sychronized 5GNR networks' performance
- Technical requirements for unsynchronized networks and semi-sychronized networks
- Based on interference coexistence study, synchronization would be recommended for multiple network operator coexistence in the same frequency band for most scenarios due to the performance impact of interference from unsynchronized networks.
- Semi-synchronization is a special case of synchronous to provide certain flexibility for operators in special scenarios.
- Synchronization solutions are proposed by this white paper.

1.1 Background

GTI has finished its white paper on sub-6GHz spectrum and refarming last year to promote a global harmonized 5G spectrum for GTI member companies'5G deployment, taking into different market requirement and pushing for synergy towards our future spectrum and product deployment. After one year work, more and more countries and regions have already made their frequency arrangement plan and auctions. And spectrum assignment to operators has happened in some countries. We see more and more countries will follow the trend to make decision on spectrum assignment, and the technical requirement for coexistence. In the GTI promoted frequency bands, there is technical issue to take into account how to deal with the multiple operators' network coexistence in the same frequency bands e.g. in 3.5GHz, 2.6GHz and 4.9GHz bands in the same geographic area. Appropriate synchronization framework is worth to be studied and form a GTI recommendation to guide our GTI operators 5G network deployment in the circumstance of coexistence with other operators in the same frequency bands.

1.2 Objectives of this white paper

The objectives of the white paper are

- To give a recommended synchronization framework for GTI member companies' consideration for their coexistence with other operators in the same frequency bands in the same geographic area and future network deployment.
- Also to have a GTI position for lobbying to the administrations for a suitable synchronization framework at the national level.

The white paper will include an analysis for performance impact for un-synchronized operation, an analysis for the scenarios under which the unsynchronized operation could be allowed and under which the semi-synchronized operation could be allowed.

1.3 Terminology

Term	Description
AAS	Adaptive Antenna System
ACIR	Ajacent Channel Interference Power Ratio

ACLR	Ajacent Channel Leakage Ratio
CQI	Channel Quality Information
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
ISD	Inter-Site Distance
LOS	Line of Sight
MCS	Modulation and Coding Scheme
MFCN	Mobile Fixed Communication Network
NLOS	Non Line of Sight
PRTC	Primary Reference Time Clock
SRS	Sounding Reference Signal
TRP	Total Radiated Power
UTC	Universal Time Coordinated

Synchronized operation in the context of this Report means operation of TDD in several different networks, where no simultaneous UL and DL transmission occur, ie. 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 synchronizing the beginning of the frame across all networks.

Figure 1 Example of Synchronizations Slot Allocation

The unsynchronized operation refers to 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 synchronize of the radio frame.

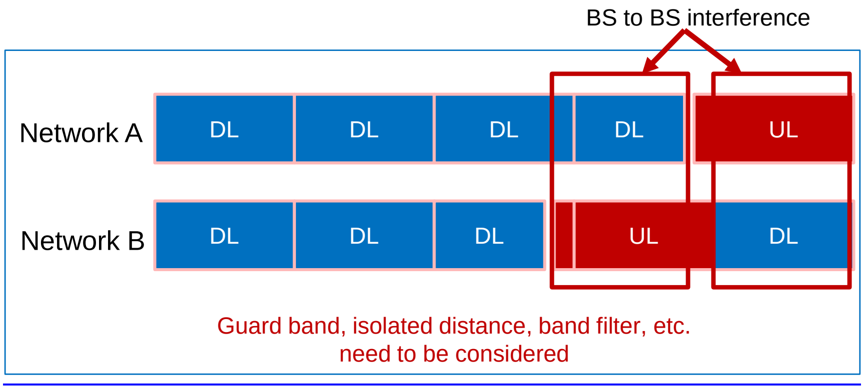


Figure 2 Example of Un-synchronous Slot Allocation

Semi-synchronized operation is a mode of operation similar to synchronized operation. It requires the timing synchronization of the radio frame of different operators while the DL and UL configuration are not exactly the same at some given time. As the illustrative figure - Figure below, the frame structure contains 3 parts – fixed DL, fixed UL, and flexible parts can be configured to be either DL or UL.

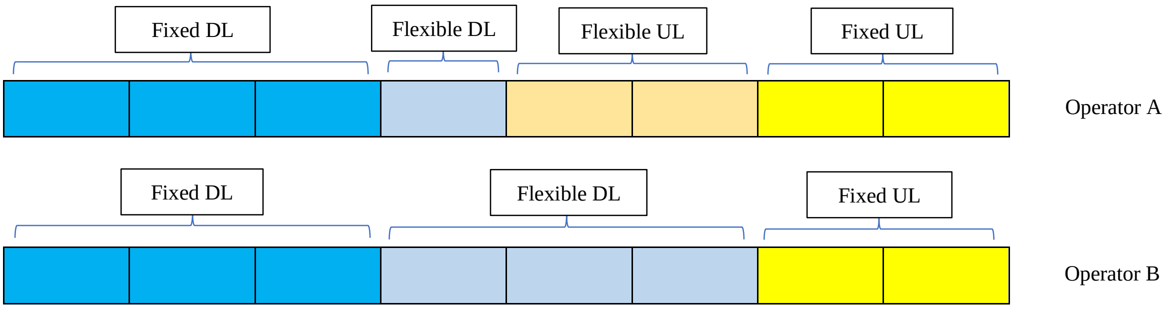


Figure 3 Example of semi-synchronous slot allocation

2 Frequency Arrangement potential for multiple operator coexistence in 5G frequency bands

2.1 Frequency Arrangement 5G

2600MHz, 3300-3800MHz, 3300-4200MHz, 4400-5000MHz are the GTI operator interested bands listed in the GTI white paper of sub-6GHz 5G spectrum and refarming. Several countries have already allocated and licensed their 5G frequency bands in these bands.

Sprint announed their plan for 2600MHz (band 41) for 5G NR. They will introduce 5G-NR in part of the 2600MHz, coexisting with current LTE-Advanced network in the band.

Many countries in Europe have auctioned C-band for 5G, the frequency arrangement is like the following:

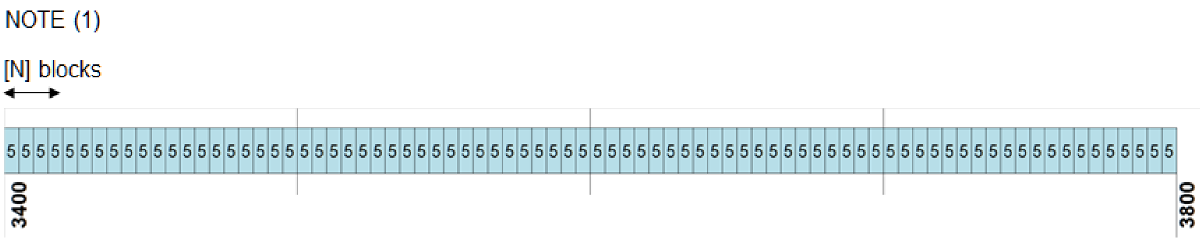


Figure 4

2515-2675MHz, 3400-3600MHz and 4800-4900MHz were approved as 5G test spectrum in China. The frequency arrangement is as follows.

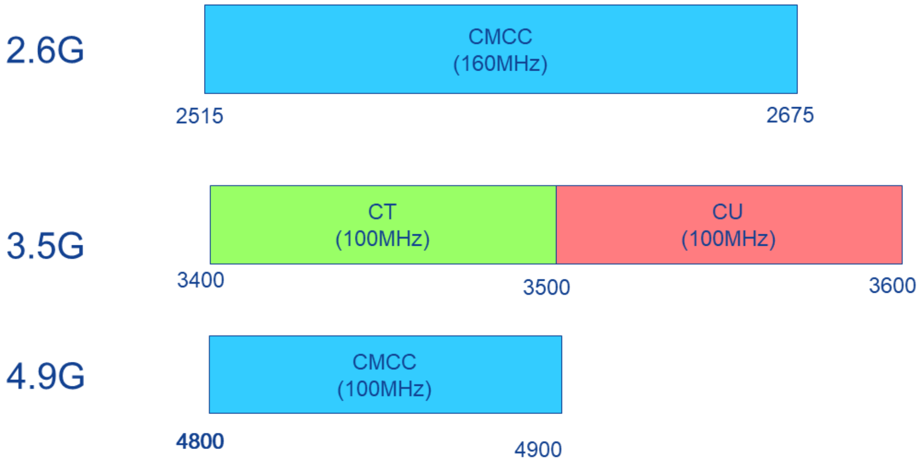


Figure 5

Japan has allocated 5 x 100MHz for 3.7GHz and 1 x 100MHz for 4.5GHz for operators, Each operator can apply up to 200MHz CBW in 3.7/4.5GHz. 4800-5000MHz and 26.5-27.0GHz are candidates for allocation in 2H 2020.

Korea has allocated 3.5GHz and 28GHz for 5G operation. Each operator obtains 80-100MHz in 3.5GHz and 800MHz in 28GHz band. 3.7-4.0GHz is identified as candidate for the additional spectrum.

2.2 Challenges of coexistence

Multiple licenses already or will be allocated on each 5G band and operators will deploy 5G NR in the same geographic area on adjacent channels in the same geometry. Meanwhile, some operators will deploy 5G on the same band of their LTE network and coexistence is required for two different systems on adjacent channels.

Lack of coordination of inter-network timing may result in unexpected cross link interference between networks, and further performance impact by UE-UE and BS-BS interference.

3 Sharing study for Multiple Operator Coexistence Scenarios

This chapter describers the interference scenarios and studies the interference impacts for the different interference scenarios.

3.1 Interference Scenarios

Figure 6 illustrates the interference scenarios from simultaneous UL/DL transmissions, BS-BS and UE-UE. Interference happens for the cases of unsynchronized Figure 7 and semi-synchronized operation Figure 8

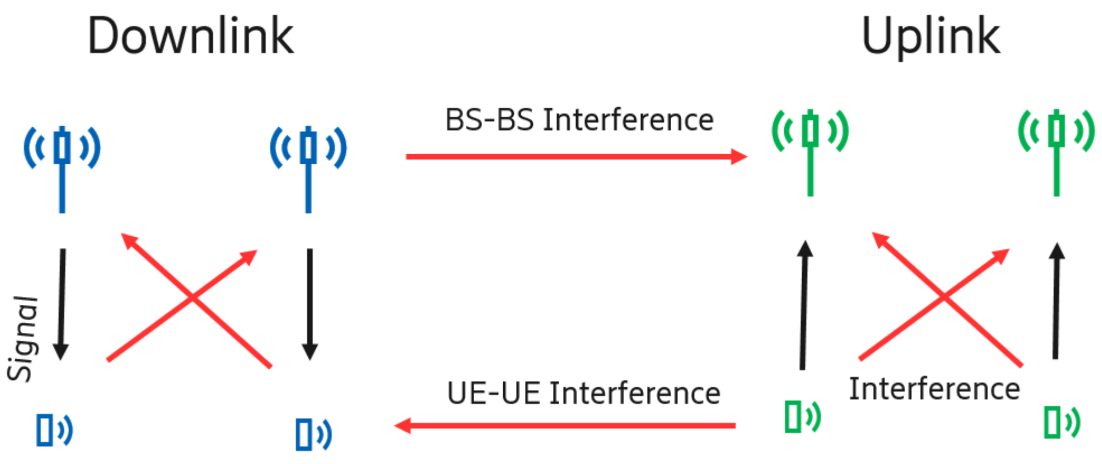


Figure 6

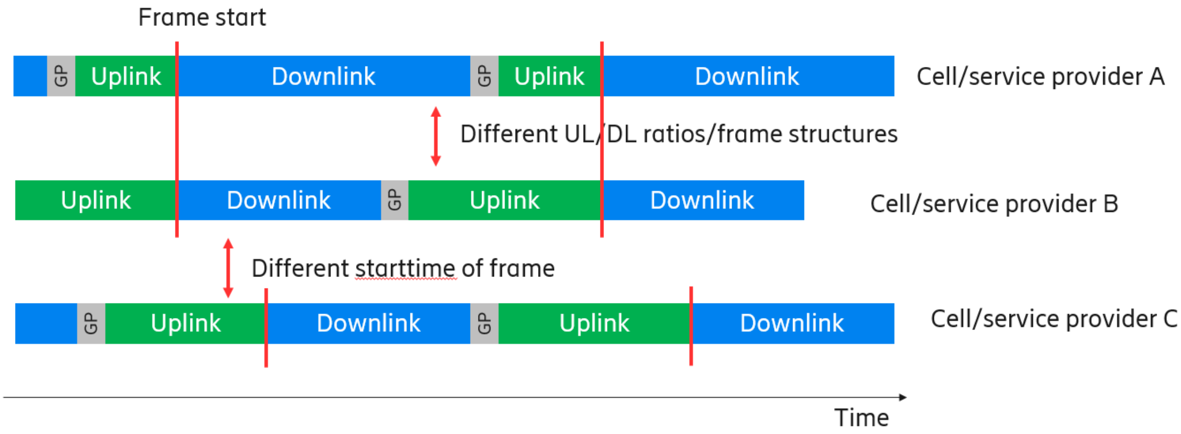


Figure 7

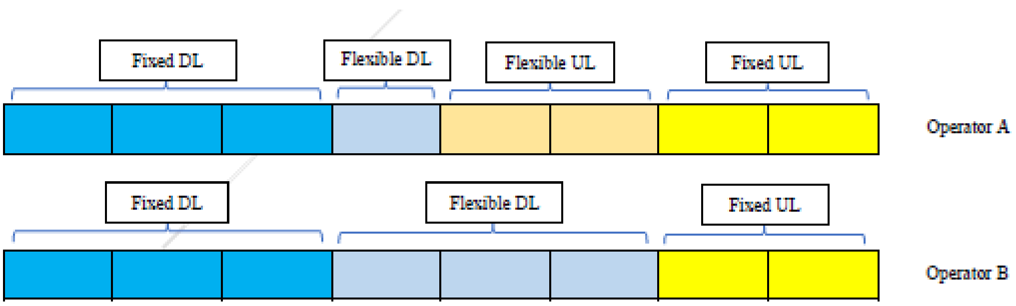


Figure 8

3.2 Coexistence study for unsyncronized operation of two Macro BS

According to the draft ECC Report 296 [1], they consider two cases for the deployments of the interfering and victim BSs

- The two networks operating in adjacent frequency channels
- The two networks operating in the same frequency channels

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

- Interference from AAS BSs to non-AAS BSs;
- Interference from AAS BSs to AAS BSs

The required separation distance based on many different elements, .e.g cellular network topology (LTE-TDD or 5G-NR, non-AAS or AAS, BS antenna height, environment, cell range).

As an example the simulated results show that:

1) in co-channel case,the required separation distance is about 50-60km.
2) in adjacent channel case the required separation distance is between 12km and 15km.

This makes operator coexistence in co-chanel and adjacent chanel difficult for the two marco BS

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

Interference use to unsynchronized operation can be partly mitigated through the following solutions individually or in combination:

- Adoption of a guard band 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 topoloties to Macro-cellular networks
    - o Micro BS networks;

  - Indoor BS networks;
- Semi-synchrozied operation

The impacts of the above mentioned mitigation techniques will be assessed in the following chapters.

3.3 Coexistence study for unsynchronized operation for Micro BS and Macro BS

In the draft ECC Report 296, they study:

- Impact on Micro BS network from Macro BS network
- Impact on Macro cellular network from Micro BS

3.3.1 Impact on Micro BS network from Marco BS network

They give the impact on throughput loss in the micro BS network from Macro BS interence. All figures of the results are averaged over many different snapshots of UE locations. The results are averaged over all Micro BSs for several realizations of Macro BS-Micro BS propagations.

In Figure 9, the results are averaged over all Micro BSs for several realisations of the Macro BS — Micro BS propagations.

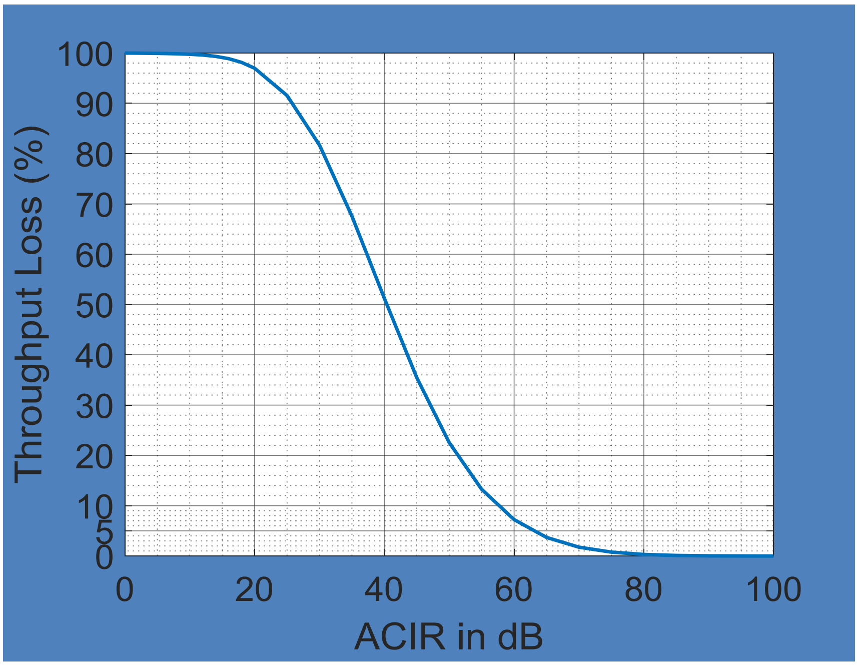


Figure 9: Average uplink throughput loss for the Micro BS network. Throughput loss averaged over different Macro BS – Micro BS propagation realisations and the interfering Macro BS serving different users

In Figure 10 separate curves are shown for each realisation of Micro BS - Macro BS propagation. Finally, in Figure 11 only the results from the centre BS are shown.

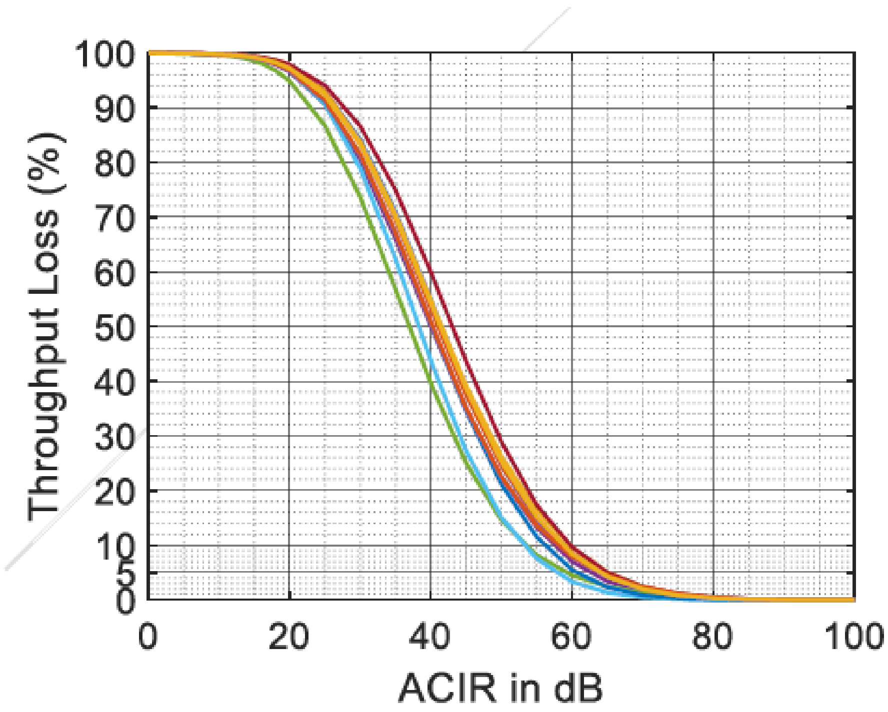


Figure 10 Average uplink throughput loss for the Micro BS network. Throughput loss averaged over many realisations of Macro BS serving different users

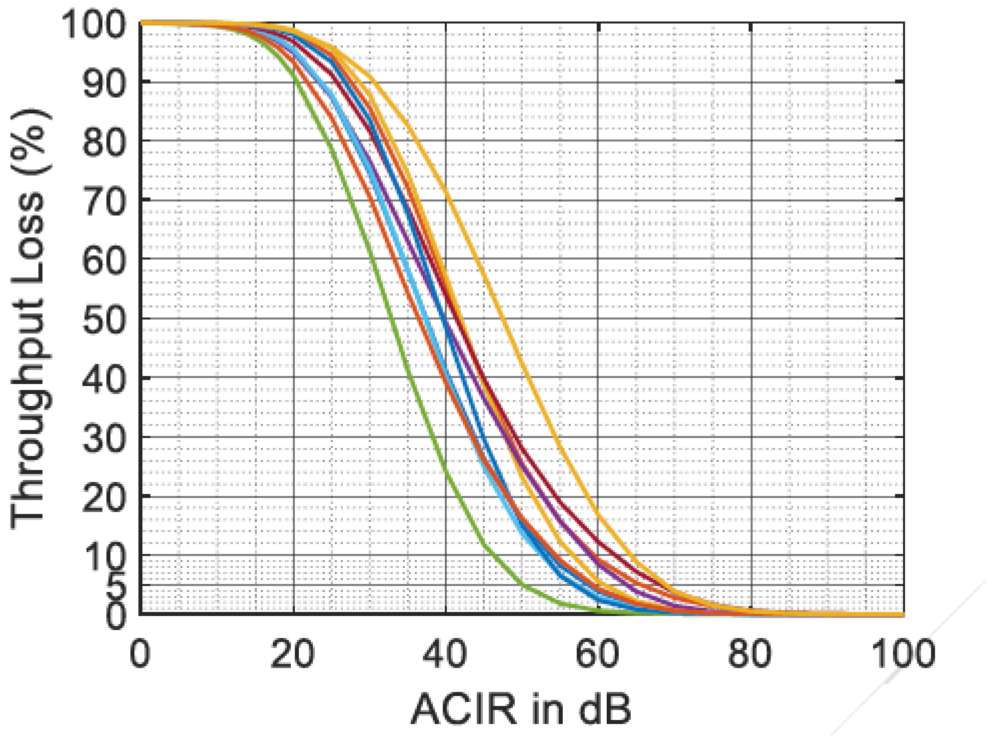


Figure 11 Average uplink throughput loss for the Micro BS in the centre (worst case). Throughput loss averaged over many realisations of Macro BS serving different users

The worse case shows that 10 – 30 dB extra isolation needed for 5% throughput loss

3.3.2 Impact on Marco BS network from Micro BS network

The impact on Macro-cellular network shows the throughput loss vs ACIR for the BS in the center of micro BS network. i.e. the BS most impacted by the micro BS network for different realizations of micro BS to Macro-cellular networks propagation.

The average of the throughput loss vs ACIR for all the Macro BSs and realizations of Micro BS to Macro BS propagation is in the following figure, Figure 12.

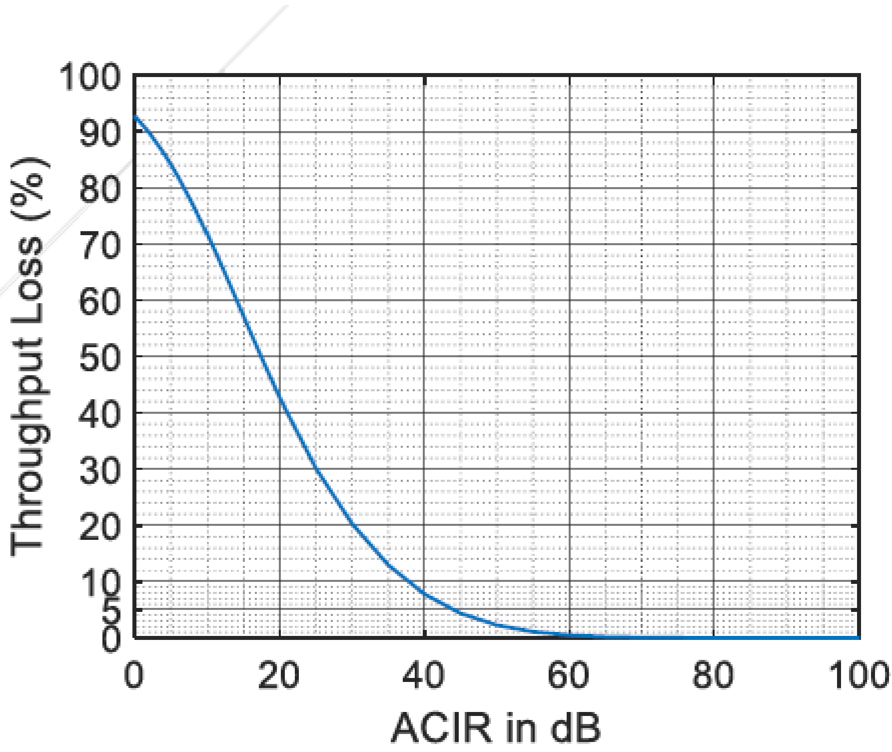


Figure 12 Average uplink throughput loss for the Macro-cellular network. Throughput loss averaged over different Macro BS - Micro BS propagation realisations and the interfering Micro BS serving different users

Figure 13 shows the average uplink throughput loss for the Macro-cellular network. Throughput loss averaged over many realisations of Micro BS serving different users

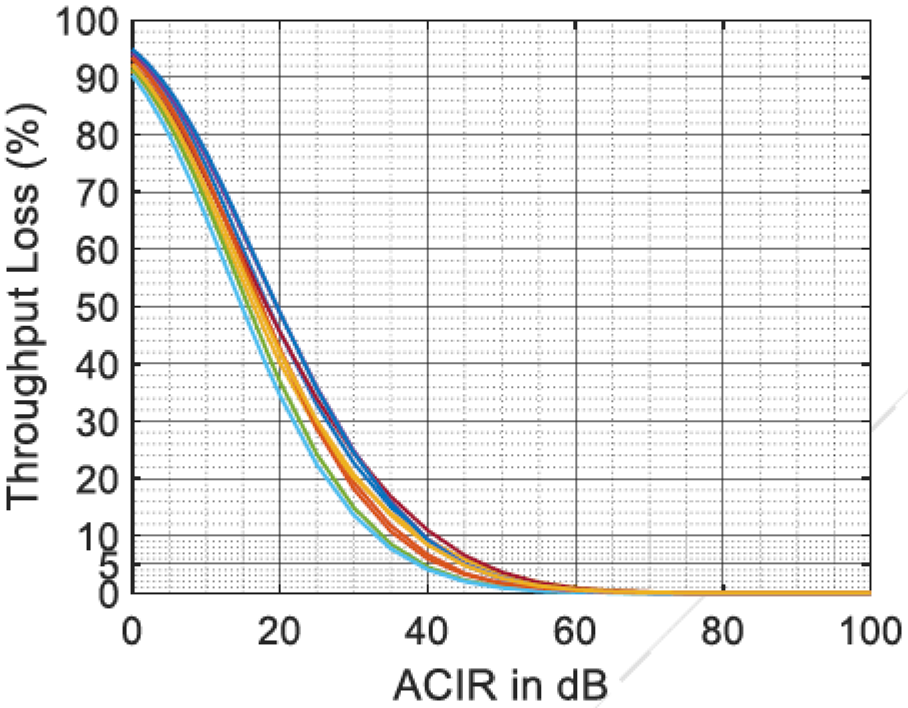


Figure 13: Average uplink throughput loss for the Macro-cellular network. Throughput loss averaged over many realisations of Micro BS serving different users

Figure 14 shows 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.

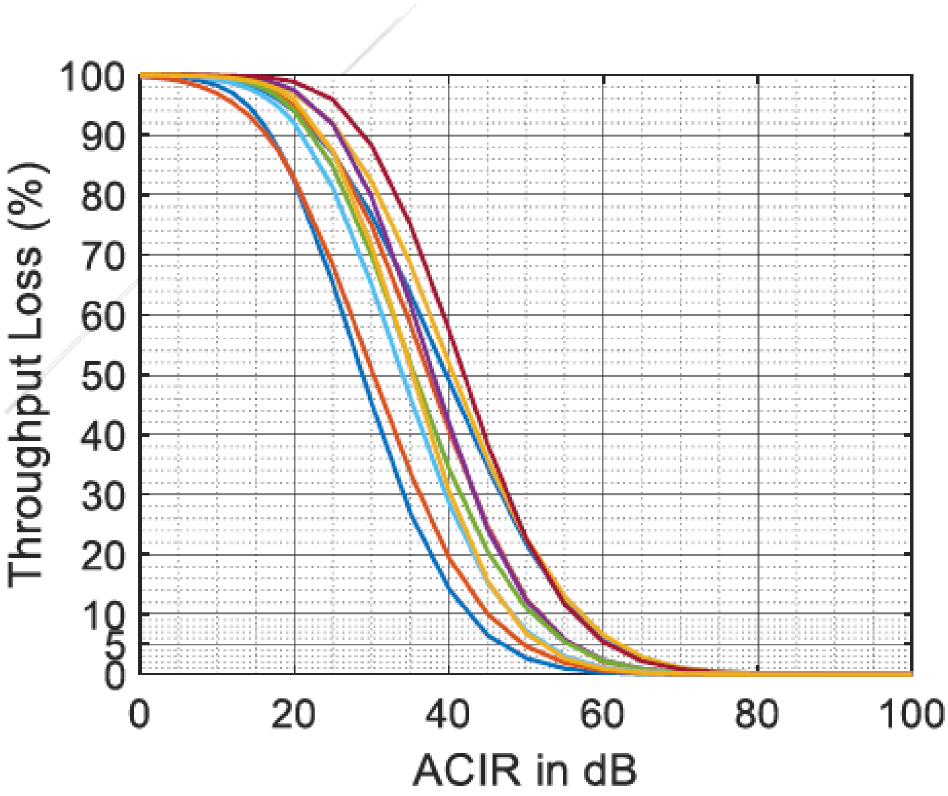


Figure 14 Average uplink throughput loss for the Macro BS in the centre (worst case). Throughput loss averaged over many realisations of Micro BS serving different users.

The Worst case (Center) cell scenario shows 5 – 20 dB extra isolation needed for 5% throughput loss

3.4 Coexistence study for unsynchronised Indoor BS and Macro BS

In the draft ECC report 296, they study the macro BS vs Indoor BS scenario which models the interference between one building and hexagonal Macro cellular network.
Two cases of building oritentation are studied for one with the building short wall toward the BS and the other one with long wall toward the BS.

For Case 1 where the short edge of the building is 70m away from the Macro BS and oriented such that the broadside of the antenna beam is towards the short edge of the building. Both results shows the throughput loss is averaged over many realisations of UE locations and consequently the direction of the interfering BS beam.

Figure 15 shows the results with averaged over several realizations of the outdoor-to-indoor channel model and Figure 16 illustrates the different realization results.

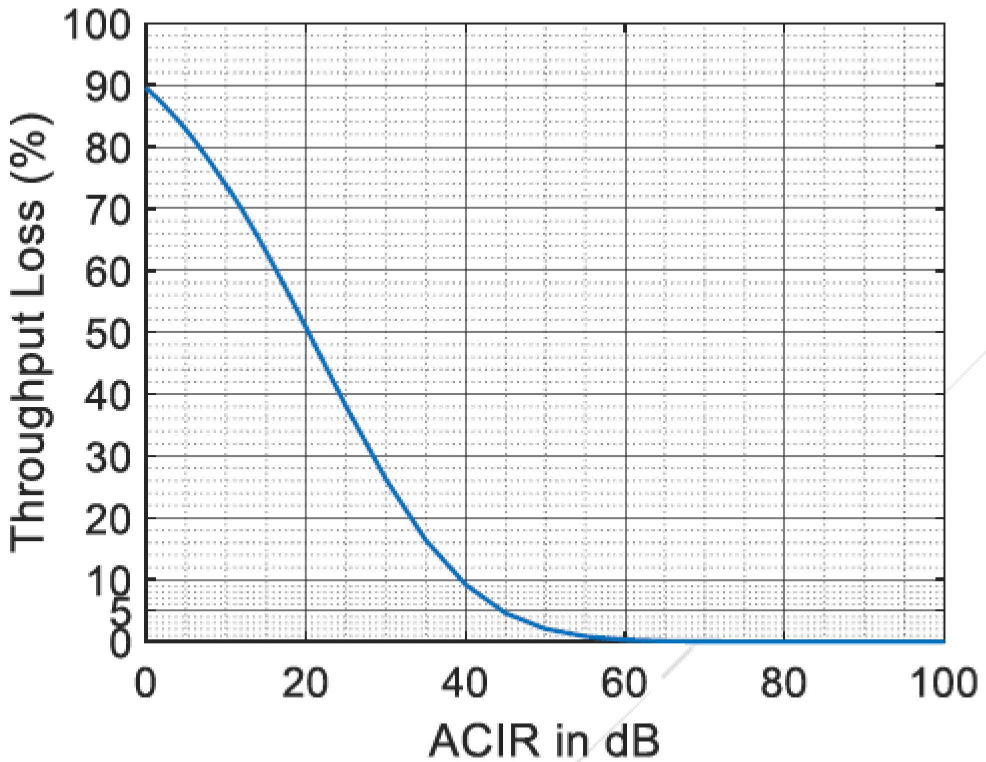


Figure 15 Average uplink throughput loss for the Indoor network in Case 1. Throughput loss averaged over different O2I channel realisations and the interfering Macro BS serving different users

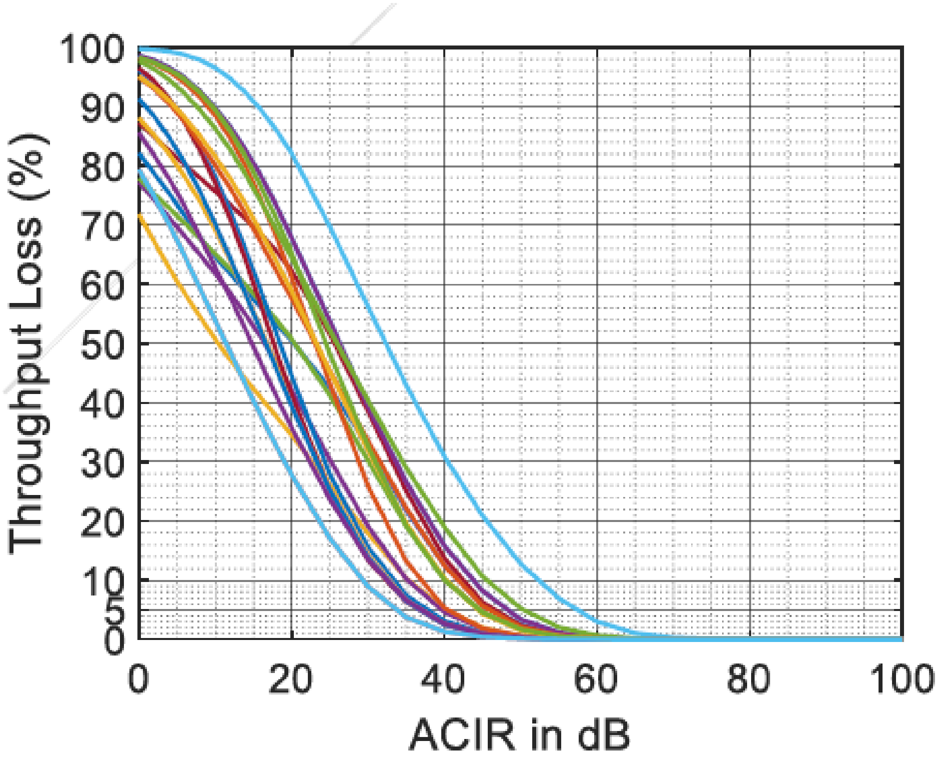


Figure 16 Uplink throughput loss for the Indoor network in Case 1. Throughput loss in each curve averaged over many realisations of the Macro BS serving different users

The results for Case 2 studies when the long edge of the building is facing the outdoorMacro BS. Figure 17 shows the results with averaged over several realizations of the outdoor-to-indoor channel model and Figure 18 illustrates the different realization results.

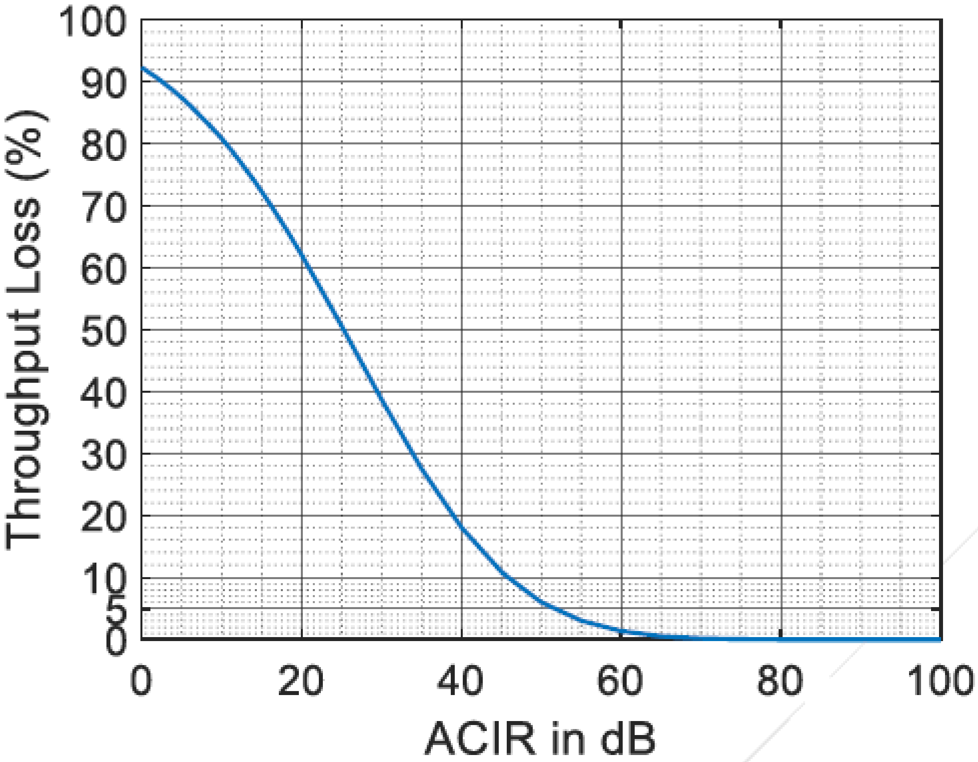


Figure 17 Average uplink throughput loss for the Indoor network in Case 2. Throughput loss averaged over different O2I channel realisations and the interfering Macro BS serving different users

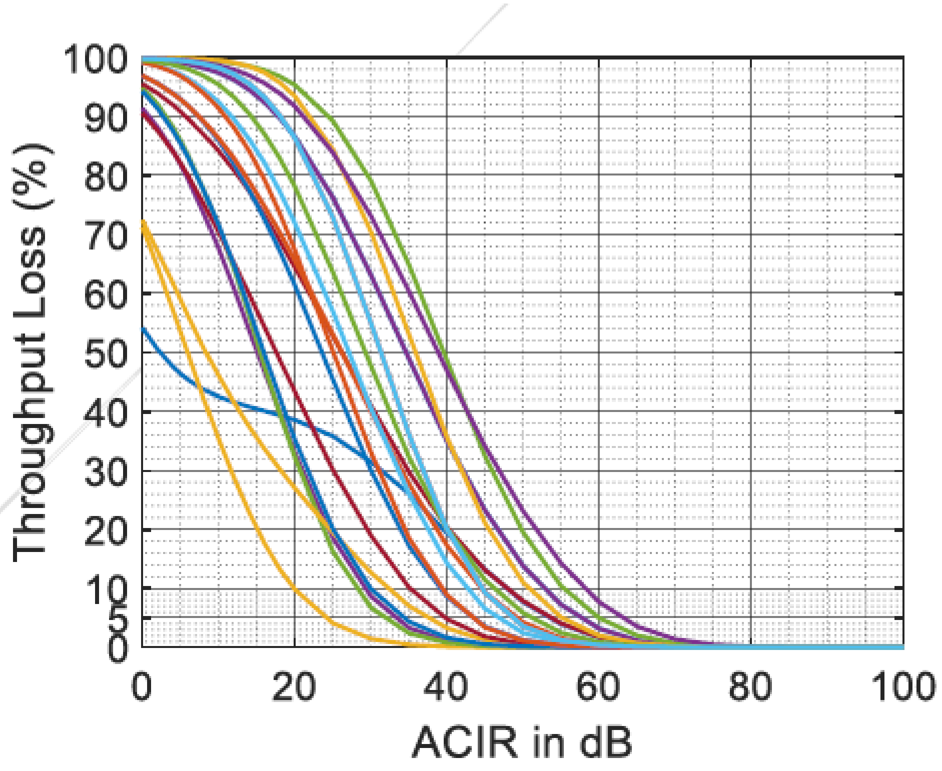


Figure 18 Uplink throughput loss for the Indoor network in Case 2. Throughput loss in each curve averaged over many realisations of the Macro BS serving different users

The reverse case where the Macro-cellular network is the victim has not been simulated. However we can observe that the indoor system has lower output power, which means that we should see 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 aggregated interference.

3.5 Semi-synchronised Operator Networks

In this section, 2 scenarios are studied as

- Macro BS to Macro-cellular networks:
- Micro BS to Micro BS networks:

Semi-synchronised operation in the case 50%, 20% and 10% misaligned DL and UL of the all the frame is designed for flexible operation. The assumption is not exactly aligned with the frame structure in Figure as the max mis-aligned DL/UL are 37.5%. 50% assumption here is to demonstrate the potential worst case for illustrative purpose.

Figure shows the impact of Adjacent Channel Interference (ACI) on victim network performance in terms of average throughput loss for Macro-to-macro deployment. As expected the impact diminishes when the operators have unsynchronized duplex directions for smaller portion of the frame.

Results show that with the baseline requirement for synchronized MFCNs in ECC Report 281 [3] performance degradation is ~9% for 10% unsynchronized 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.

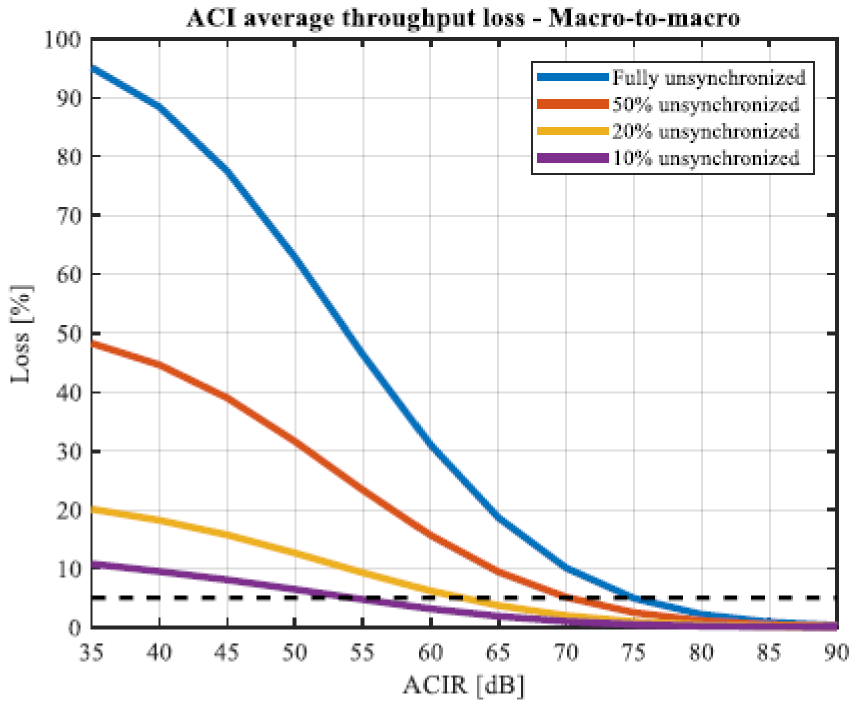


Figure 19 ACI impact on network performance-average throughput loss for Macro BS to Macro BS deployment and different semi-sychronised operation cases

Differently from the approach for the above 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 simuliations 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 Micro BSs change their locations with respect to building. And coexistence between the Macro-cellular network and the Micro BS network was not assessed by the ECC study.

Micro BS to Micro BS network deployment

Figure 20 shows the impact of Adjacent Channel Interference (ACI) on victim network performance in terms of average throughput loss for micro-to-micro deployment. As expected the impact diminishes when the operators have unsynchronized duplex directions for smaller portion of the frame.

Results show that it is possible to achieve 5% average throughput loss with ACIR ~38 dB in the case the two operators have unsynchronized duplex directions for 20% of the frame. Current baseline requirement in ECC Report 281 for synchronized BSs is fully satisfied implying possibility to use the synchronized BEM mask when the operators are unsynchronized for less than 20% of the frame.

It is again important to notice that results are preliminary and do not consider any interference mitigation technique that would likely bring degradation down.

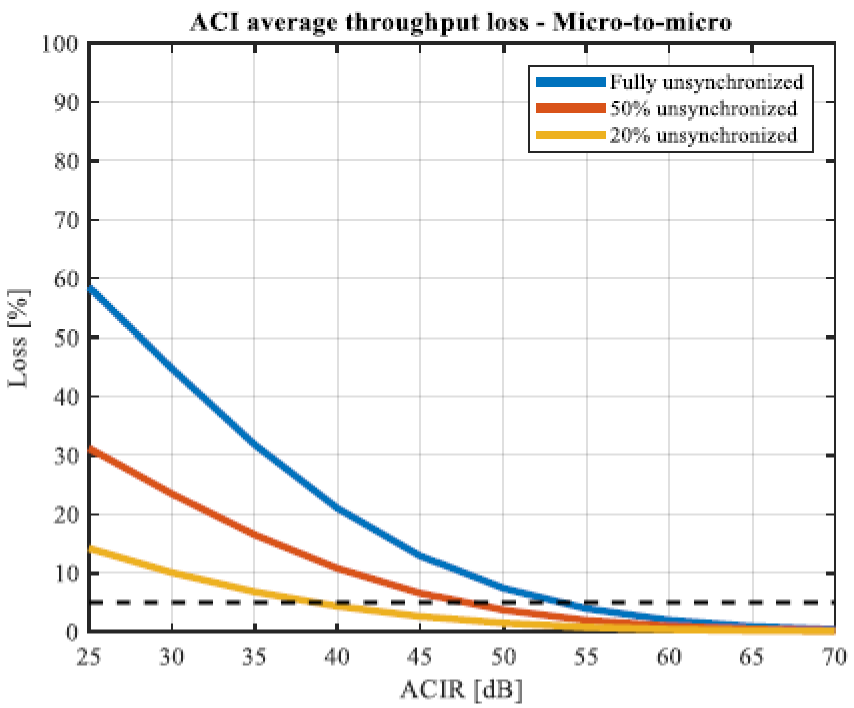


Figure 20 ACI impact on network performance-average throughput loss for Micro BS to Micro BS deployment and different semi-sychronised operation cases

3.6 UE-to-UE Co-existence

Section 3.1 -3.5 discussed and analyzed co-existence scenarios under unsynchronized and semi synchronization operation. The discussion was mostly from eNB/gNB perspective (Macro / Micro), but it did not discuss / analyze UE-UE co-existence scenario and its impact. It is equally important to look at the impact of unsynchronized operation from the UE perspective since some of the solutions (i.e custom filter at Tx and Rx) discussed for unsynchronized operation at eNB/gNB may not help with interference at the UE.

3GPP in the past had discussed/studied (TR 36.828) various interference mitigation techniques (at the eNB) where the eNB adjusts the scheduling strategies e.g. link adaptation, resource allocation, transmit power, transmission direction of a subframe, considering e.g. the DL and

UL channel quality, the eNB-to-eNB interference, traffic load, etc. This assumed the capability to support Realtime inter-cell co-ordination mechanisms. It was also discussed to reuse the interference mitigation schemes and procedures from eICIC/FeICIC (HetNet) to account for TDD UL-DL reconfiguration based on traffic adaptation, e.g., almost blank subframes, restricted RLM/RRM measurements, dual CSI measurement reports, etc. However, these schemes have not been efficient and beneficial for wide scale adaption. Rel 16 is expected to specify basic support of cross-link interference mitigation schemes for duplexing flexibility with paired and unpaired spectrum, mainly to introduce UE-to-UE measurements (CLI-RSSI and/or CLI-RSRP) for CLI (Cross link Interference) and define network co-ordination mechanisms using the same. However, it would be difficult to co-ordinate among different operators for UE-to-UE interference measurement and scheduling. Furthermore, the 3GPP RAN4 specifies requirements for ACLR (adjacent channel) to support co-existence. However, such requirement may or may not be sufficient to meet the performance needs since it was defined with the assumption of systems being synchronized. Outside of 3GPP, there could be other custom solutions (i.e device custom channel specific filters) designed but may deem to be expensive and may not be feasible for global device SKUs.

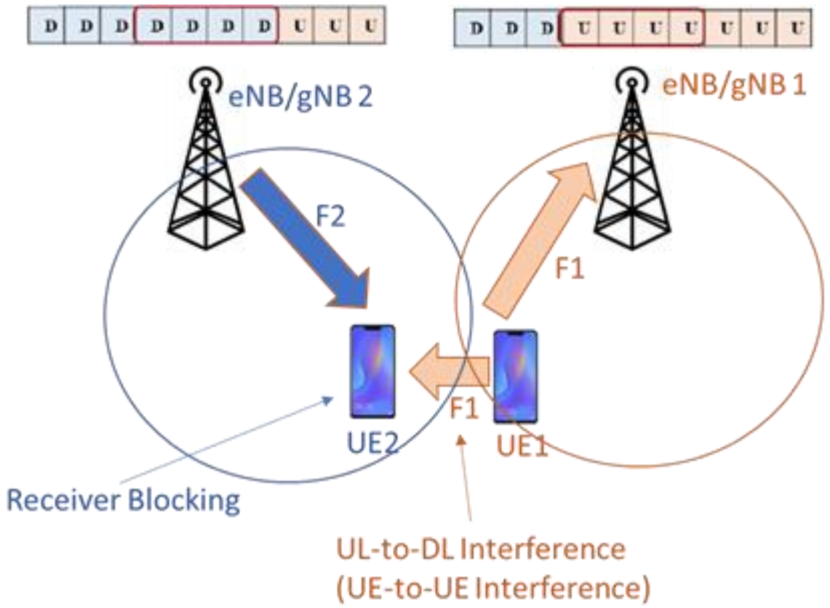


Figure 21

Figure above illustrates 2 eNB/gNBs operating in an unsynchronized scenario such that part of UL slots of Cell 1 (orange) aligns with DL slots of adjacent Cell 2 (blue). Here, UE1 is transmitting and is adjacent to UE2 (receiving in the same time slot) in an unsynchronized network. The UE1 would cause interference (receiver desensitization / blocking) for the receiving UE2 during those unsynchronized time slots. This interference can also occur when UE2 is transmitting and UE1 is receiving. Such interference is known as UL-to-DL interference or UE-to-UE interference. It is understandable that the interference would be worse when the UE is transmitting close to max power. The UEs further away from the cell (Cell edge) are required to transmit at higher / max power. Furthermore, based on market statistics (https://www.nokia.com/blog/options-building-wireless-deployments/), 70% of UEs are indoors. Hence, such high UE Tx power inbuilding scenario would be common when served by outdoor macros, particularly in higher frequency networks (>2GHz) due to its propagation characteristics. It is therefore important to analyze UE-UE interference under Max UE Tx power scenario.

It should be mentioned that UE-to-UE coexistence has been looked at in the past by various operators according to their deployment needs. Sprint / Clearwire had also performed some studies in this area. Couple of related studies are mentioned below.

Clearwire (now Sprint) did a trial as a part of early LTE deployment and co-existence with WiMAX in the year 2010, to better understand the impact of B7 UL (FDD) on WiMAX (B38 LTE FC1 alike) performance. Tests were performed outdoor and indoors in a stationary cell edge environment, using USB Dongle devices. There was 10MHz gap between LTE UL and WiMAX system. Various type of traffic (such as UL Iperf, ping, web browsing) was run on the B7 UL and its impact on WiMAX connectivity and WiMAX DL performance was measured. This trial concluded that there was performance degradation when in close proximity (<10ft) and could be avoided if the devices were more than 12 ft away from each other.

Sprint had also performed in-dept testing on Wi-Fi - Band 41 (FC1) co-existence and impacts in year 2012 due to the proximity of Wi-Fi channels to lower part of B41, the need for simultaneous LTE-WiFi operations and Wi-Fi / LTE Co-existence out of scope for 3GPP. The testing covered Lab and Field testing of In-Device LTE/Wi-Fi Coexistence performance as well as LTE/Wi-Fi proximity performance. The configuration included the use five different 20MHz B41 LTE channel and four static Wi-Fi channels (Channel 1,6,11 and 13). Wi-Fi Channel 13 was specifically selected since it was closest (34.8MHz) from B41 lowest channel. The testing used GTI personal hotspot device positioned under varying LTE RF conditions and performed

DL/UL throughput. The in-device coexistence testing can be considered worst case of UE-to-UE interference since the antennas are co-located within the same device. The results were presented in a IWPC conference (Download). Based on this testing, it was concluded that the performance (of LTE and Wi-Fi) minimally affected even in extreme test scenario (i.e. multiple devices co-located within 2.5 ft from each other).

Based on testing results above, it can be concluded that there would be performance impact due to UE-to-UE interference if UL and DL slots are not aligned. The interference impact could be minimized if the UEs are more than 10 feet apart, with some guard band (i.e. up to 10MHz) but this cannot always be guaranteed. It should also be noted that most of the above studies were performed with different RAT and older software releases. It would therefore be better to perform additional trials using latest LTE / NR test environments and determine the overall performance impact due to unsynchronized / partial synchronized operation.

4 Technical Requirement for multiple operator coexistence scenarios

4.1 Technical Requirements for Synchronized Networks

Key Network Prinicples of Synchronised MFCNs Without Interference Impact

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), 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 to decide 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 synchronize 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 has an impact on network performance (latency, spectral efficiency, throughput, coverage). Therefore, the selection of a common frame structure will have common impacts across all operators involved on key aspects of performance, which have impact on the services to end users.

The common frame structures can be renewed over time, subject to the agreement. There are already precedents for this (e.g. Italian operators Tiscali and Linkem in the range of 3400-3600MHz). 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 average across operators' needs.

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.

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 could be impacted in terms of performance of 5G (latency). One gives an evaluation about possible performance impacts in the next paragraph of the current chapter.

Performance Highlights for LTE-TDD / 5G-NR synchronised operation

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 "DDDDDDDSUU" frame structure with 30 kHz subcarrier spacing (SCS) is the only 5G-NR frame structure that can be aligned to LTE-TDD "DSUDD" frame structure with 15 kHz SCS (LTE-TDD frame configuration #2). This means that for the study considered in this report, **the "DDDDDDDSUU" frame configuration is representative of the performance that 5G-NR would have in case of synchronised operation with a neighbour LTE-TDD network.**

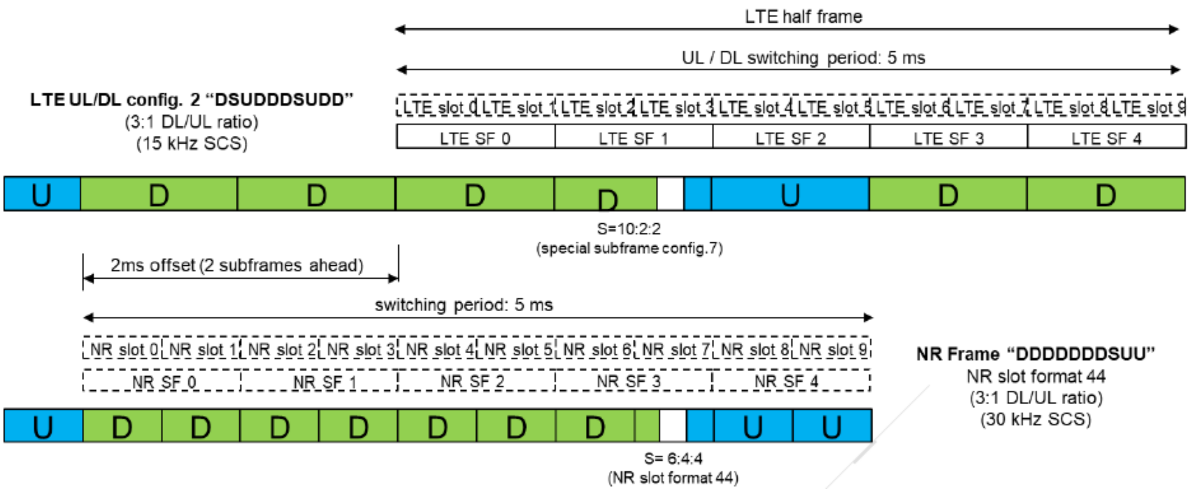


Figure 22: Synchronised operation of 5G-NR ("DDDDDDDSUU" frame) and LTE-TDD ("DSUDD" frame)

Let's make an assessment about the performance (latency and capacity) of 5G-NR in case of adoption of the "LTE-TDD compatible" frame structure is provided.

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

This study provides an assessment in terms of latency and capacity performance for two frame structures provided, namely DSDU and LTE-TDD compatible DDDDDDDSUU.

Latency Assessment

A summary of the latency analysis results are shown in the following table.

Table 1

	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

Source: **ECC Report titled** "*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*"; Chapter 3.3

Table: Simulation Results Analysis

It can be observed that when 5G-NR is aligned with LTE-TDD by using DDDDDDDSUU slot sequence, the timeline of 5G-NR is aligned with LTE-TDD configuration #2. Considering scheduling and MS / network processing latency, this frame structure will lead to L1 latency > 4ms (as already mentioned, the that IMT-2020 eMBB latency requirement is 4ms and URLLC latency requirement is 0.5ms), therefore if 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 (on the same band).

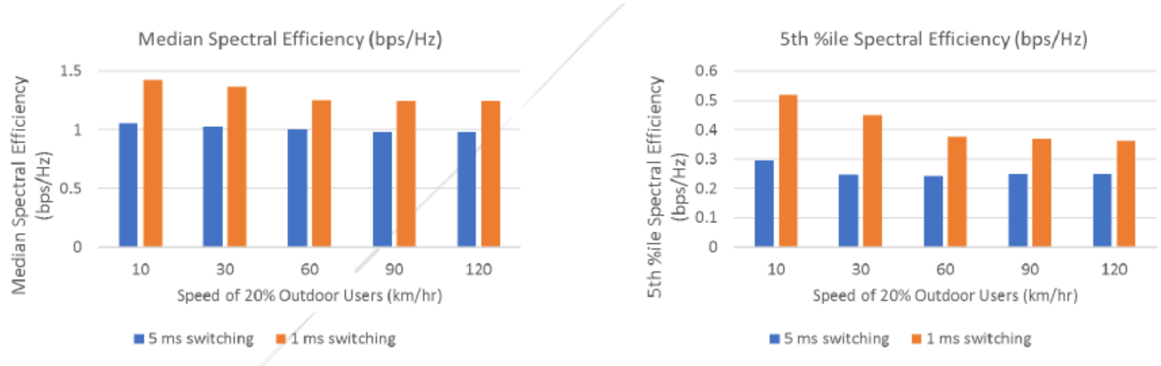
With the assumptions of ECC Report ("*National synchronization regulatory framework options in 3400-3800 MHz: a toolbox for coexistence of MFCNs in synchronised, unsynchronised and semi-synchronised operation in 3400-3800 MHz*"; Annex A3.3.1), the DSDU configuration shows significant benefits over DDDDDDDSU with respect to HARQ RTT and UL scheduling delay, as reported in Table 3. 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).

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 low latency services with existing eMBB traffic.

Capacity Assessment

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 allow a higher spectral efficiency due to the 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. 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 in the following figure. This figure has been obtained considering an outdoor user with different moving speeds running a full buffer DL traffic pattern. More frequent opportunities to transmit sounding reference signals (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. This figure compares the simulated spectral efficiency at 5ms and 1ms SRS transmission opportunities. The median and 5%-tile spectral efficiency are shown in the following figure as well. 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 DDDDDDDSUU 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%.



Source: **ECC Report titled** "*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*"; Chapter 3.3

Figure 23: Spectral efficiency gains vs. speed (Full Buffer)

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 the next figure. 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.

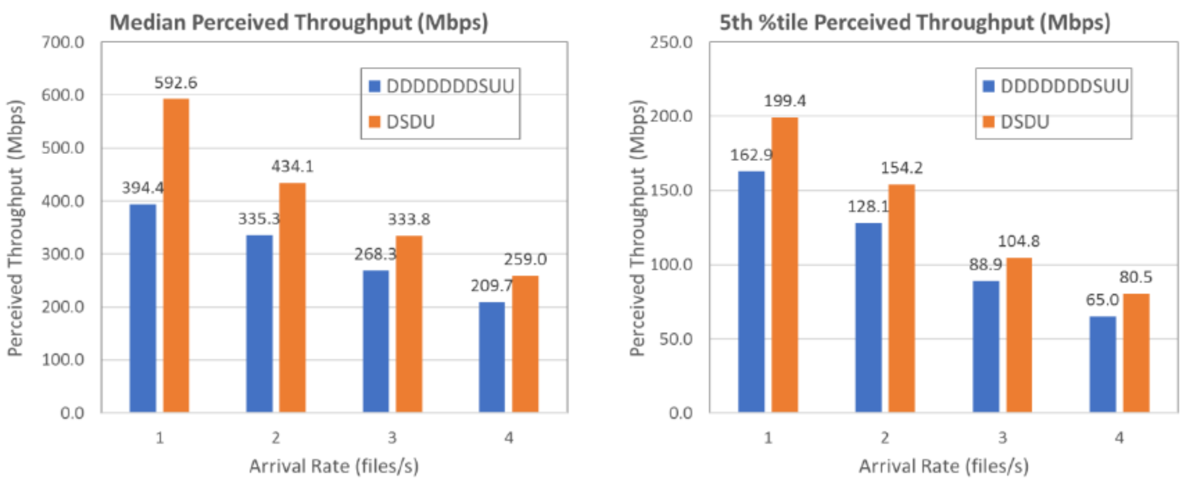


Figure 24: Perceived throughput vs. file arrival rate (Bursty Traffic)

4.2 Technical Requirement of unsynchronized network

Europe 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 Table 4).
Interference due to unsynchronised operation can be partly mitigated by adopting the following solutions individually or in combination:

- **Adoption of a guard band** 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:
    - o Micro BS networks;
    - o Indoor BS networks;
- **Semi-synchronised operation**

The following paragraphs of Chapter 4.2 assess the impact in terms of interference mitigations from the adoption of the above techniques. The main results from coexistence studies are introduced while leaving the full set of studies to the ANNEXes of the ECC Report titled "***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***".

4.2.1 Guardband Requirement for Unsynchronized Operation

For non-AAS, Europe ECC report 203 says that a 5 MHz guard band and 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 filtering would be required for unsynchronised non-AAS TDD networks. Europe ECC Report 281 says that, using current filtering technology, about 20 MHz guard band and internal filters would be required for AAS to meet the baseline to protect radars below 3400MHz. A similar size of guard band and similar internal operator-specific filters may be required for AAS to meet the ECC restrictive baseline out of block power limit.

Blocking effect can happen within the whole band regardless of any frequency separation within that band and is not restricted to the adjacent channel. Cross link interference will take place as long as two operators are within the same 3GPP band i.e. same RF frontend filter, no matter how large the frequency separation is between the two operators. On the Tx side, no economically feasible AAS solution can be implemented to comply with ECC unsynchronized baseline requirement. From Rx blocking perspective, the increesing noise level may not prevent the receiver from working but may impact the received data rate.

Filter banks in a AAS base stations to isolate sub-bands are not economically feasible in practice.

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. Blocking effect can happen within the whole band regardless of any frequency separation within that band and is not restricted to the adjacent channel.

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.

4.2.2 Networks Geographic Separation

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

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 Draft ECC Decision (11)06 Table 3.

4.2.2.1 Proposed methodology

Here one discusses and proposes the methodology to be used at national level when coordinating two unsynchronised TDD Macro-cellular networks. There are two possible approaches to deal with coexistence among 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 trigger value at the nearest victim BS

Note that these two approaches are equivalent and either one of them can be applied.
With reference to the BS technology options, three possible cases can be considered:

1. Non-AAS Network A to non-AAS Network B, representing two LTE-TDD FWA networks;
2. AAS Network A to non-AAS Network B, representing one 5G-NR network and another LTE-TDD FWA network;
3. AAS Network A to AAS Network B, representing two 5G-NR networks.

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

- For 5% average UL throughput loss at the nearest victim BS or a network cluster;
- 50% mean UL throughput loss measured at the nearest victim BS;
- I/N=-6 dB at the nearest victim BS.

Method #1: Separation distance calculation

The separation distance is defined between the two nearest BSs in network A and network B considering following options:

- Separation distance between Networks A and B – adjacent channel
- 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 average UL throughput loss (e.g. 5% network cluster average UL throughput loss or 50% nearest cell 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 average UL throughput loss (e.g. 5% network cluster average UL throughput loss or 50% nearest cell UL throughput loss) between the two concerned mobile operators.

Method #2: Trigger Values calculation

An alternative approach is to define a trigger value (dBuV/m/5MHz) at the nearest BS receiving antenna or at 3m height above the ground. 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 of the ECC Report titled "***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***" (Annex 5: Section A5.2.7).

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

$E = P_R + 20 * LOG_{10}(F) + 77,2$ (1)

$P_R = P_{TX} + G_1 – PL$ (2)

Where:

F (MHz): frequency;

P_R (dBm): received power level at the receiving BS antenna (before antenna);

P_{TX} (dB): transmit power before antenna;

G_1 (dB): interfering BS antenna gain including feeder loss in the direction of the receiving antenna;

PL (dB): path loss at the distance D.

4.2.2.2 Summary of the studies

Two studies (for details assumptions to refer to ECC Report titled "***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***") have presented the simulation results in terms of separation distance between two unsynchronised Macro-cellular networks. The simulation results are summarised in the following table.

Table 2

		Study 1 (5% avg. throughput loss, ITU-R P.452 20% time)	**Study 2** (5% avg. throughput loss, ITU-R P.452 50% time)
Co-Channel	AAS - AAS	60KM	50KM
	Non-AAS - Non-AAS		50KM
Adjacent Channel	AAS - AAS	10KM	14KM
	Non-AAS - Non-AAS		15KM

Table. Summary of the simulation results of separation distance between 2 macro networks

4.2.2.3 Conclusions from studies

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

- ECC-Rec(15)01 may be used to deal with the case of two unsynchronised Macro-cellular networks within a given country, when the physical borderline are defined between two networks within a country;
- Two methodologies described in this Section (either based on the separation distance or on the electric field trigger value). Specific value can be defined at national level based on the specific circumstances. This is justified by the fact that the required separation distance and electric field trigger values calculation depend on many factors:
  - o Cellular network topology (LTE-TDD or 5G-NR, non-AAS or AAS, BS antenna height, environment, cell range);
  - o Propagation environment and propagation model;
  - o Frequencies and overlap of the channels, e.g. full overlap as co-channel case, or partial overlap, or adjacent channel);
  - o Protection ratio, e.g. I/N, or edge cell throughput loss or network average throughput loss at x%, etc.

4.2.3 Co-existence Between Unsynchronized Micro and Macro BS Deployments

4.2.3.1 Coexistence between unsynchronised Micro BSs and Macro BSs – Study #1

A study about the interference between Micro and Macro BSs has been detailed in the ECC Report titled "***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***" (to refer to Annex A6.1 for assumptions and study parameters).

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

The propagation between BSs 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. According to the study, in order to limit the throughput loss to maximum 5% the ACIR (adjacent channel interference ratio) 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 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 standard has an ACIR of slightly less than 45dB. 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. This indicates that for this type of scenarios synchronisation is needed.

4.2.3.2 Coexistence between unsynchronised Micro BSs and Macro BSs – Study #2

This Section provides the main conclusions from the study which has been developed in the ECC Report titled "***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***" (to refer to Annex A6.2). It 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 placed outdoors) is operating as the interferer and the Micro BS network(hexagonal grid placed outdoors) is interfered,
- Micro BS network(hexagonal grid placed outdoors) 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)

All network topologies and main assumptions are included into Chapter 4.3.2.1 (ECC report titled titled "***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”).

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.
Note that both victim BS and interferer base stations are assumed to operate with 60MHz channel bandwidth.
It is important to highlight that the study:

- Did not account for blocking effect on the victim BS receiver;
- Did not account for MS-MS interference.

Interference from AAS Macro-cellular network and AAS Micro BS network
An ACIR greater than 68dB is required to ensure a mean uplink throughput degradation smaller than 5%.

Interference from AAS Micro BS network and AAS Macro BS network
An ACIR greater than 55dB is required to ensure a mean uplink throughput degradation smaller than 5%.

Interference between two AAS Micro BSs
With reference to the topology being studied (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 being studied (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 being studied (30, 50 or 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 separation distance is 50m, 45dB ACIR can satisfy the requirement of 3GPP.

With reference to the topology being studied (100m separation distance and 100% LoS probability (same street). An ACIR greater than 70dB is required to ensure a mean uplink throughput degradation smaller than 5%.

4.2.4 Co-existence Between Unsynchronized Indoor BS and Macro BS

A study about the the impact on an indoor system from a macro-cellular network has been done in the ECC Report titled "***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***" (to refer to Annex A7.1 for assumptions and study parameters).

Based on the study, in order to limit the throughput loss 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 standard has 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, synchronisation is needed if no coordination is done and, if careful coordination of the BS locations is done, unsynchronised operation may be possible.
It is worth noting that the performance criteria is maximum 5% throughput loss.
For URLLC use cases 5% loss is not acceptable. For these use cases the relevant throughput loss level to use is closer to 0%. From the results we see that this will require somewhere in the order of 20-25 dB additional isolation compared to the 5% loss results.

4.3 Technical Requirement for semi-synchronized network

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 controlled interference.

As a sub case of synchronized network, semi-synchronization has fine timing alignement between operators and only parts of the DL and UL configuration are mis-aligned to pursue better performance (e.g. latency or throughput). Based on the observation in 3.5, the following observation can be achived for Micro to Micro:

- for small portion of DL/UL configuration misalignment (e.g. 20% and below), no additional protection is required for micro-micro scenario
- 50% misalignment is actually even worse than the worst possible case (37.5% in Figure) according to the assumption in Figure . For this case, the simulation reveal around 3dB additional ACIR is required to follow 5% degradation metric. In practical this could be provided by margine of BS implementation. Even for the worst case, we made some rough estimation according to the unwanted emission limit defined in 3GPP TS38.104 standard regarding ACLR shift with the guard band. The real product can perform better, therefore the guard band could be less. The guard band can be around 3MHz for different channel bandwidth as follows. (Note: the calculations can be used as some example, but should not be treated as any absolute regulatory recommendation on the guard band.)

Table 3 example guard band for addtional protection

5G NR system bandwidth (MHz)	Guard band (MHz)	
	2dB ACLR increase	3dB ACLR increase
60	2.3	3.7
80	2.5	4.5
100	2.8	5.1

Note the calculation is based on the Table 6.6.4.2.1-1 Wide Area BS operating band unwanted emission limits (NR bands below 1 GHz) for Category A from TS38.104

5 Solution Options for Multiple Operator Network Coexistence

Nowadays, new 5G AAS systems can neither achieve cost-effectively restricted baseline out of block power limit on the transmitter side, nor implement the required custom filters to protect from blocking on the receiver side, both in adjacent and non-adjacent channels in the same band. Moreover, 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 block power limit.

Table 4: ECC baseline out of block power limits for unsynchronised MFCN networks, for non-AAS and AAS base stations

Baseline	Below -10MHz offset from lower block edge. Above 10 MHz offset from upper block edge Within 3400-3800MHz	Min(PMax−43,13)	Min(PMax'-43,1)

Table5: Restricted baseline power limits for unsynchronised and MFCN networks, for non-AAS and AAS base stations

Restricted Baseline	Unsynchronised and semi-synchronised blocks. Below the lower block edge. Above the upper block edge. Within 3400-3800 MHz	-34	-43

Additional interference mitigation techniques shall be required to ensure unsynchronised operation with such type of AAS equipment. Considering that it may not be possible to rely on guard bands alone to enable unsynchronised operation between operators, in case of AAS BSs, coexistence shall rely on other solutions such as synchronised (or semi-synchronised) operation or proper interference mitigation techniques (including separation distances, alternative network topologies, etc.).

If interference mitigation due to unsynchronised operation relies on separation distances, the actual minimum distances required to be applied in practice highly depends on assumptions such as network topology and the radiowave propagation environment and will need to be discussed at the national level. With this respect, the results from the coexistence studies summarized in Chapter 4 of this Whitepaper show that those distances between unsynchronised Macro cells could be up to 60 km in case of co-channel operation and up to 14 km opertioing in adjacent-channel.

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. The synchronised operation is accompanied with some challenges, among others, related to the selection of common clock and frame structure (e.g. a common DL/UL transmission ration, and common potentially optimal performance).

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 controlled degree of flexibility at the expense of some controlled interference. Compared to unsynchronised operation, semi-synchronised operation reduces the impact from BS-BS and MS-MS interferences, while ensuring some flexibility on the frame structure. The interference impact on network performance associated with semi-synchronised operation is reduced when the amount of 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, when dealing with semi-synchronised networks, there will be a need for a common accurate phase / time synchronization and for an agreement on a common default frame structure to which flexibility is added.

The Whitepaper is going to identify the following items that will need to be agreed between GTI licensees to enable the three operating modes.

Note: 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 block power limit. According to ECC Decision (11)06, in case of unsynchronised operation the ECC restricted baseline limit applies by default. In this case:

- The interfering BS transmitter requires custom filters and guard band;
- The victim BS receiver also requires custom filters to avoid blocking.

5.1 Case of Synchronisation operation

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 therefore simplifies the network deployment relatively to interference mitigation. Synchronised operation leads to the selection of a common frame structure, which determines a specific DL / UL transmission ratio and has an impact on network performance (latency, spectral efficiency, throughput, coverage).

In case of synchronised operation the following issues should be agreed at national level with a general framework involving all GTI licensees in the band and in the same geographic area. 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), accuracy/performance constraints with permanent monitoring and agreed remedies in case of accuracy loss;
- A compatible frame structure to avoid simultaneous UL / DL transmissions

- The terms & conditions where cross-operator synchronisation must apply and/or may not be required (including the geographical areas and type of cells. See the following text on unsynchronised and semi-synchronised operation);
- Mechanisms to ensure the periodic review of the agreed conditions

Synchronised operation between 5G-NR and LTE-TDD / WiMAX systems implies a cost in term of user plane latency and throughput performance. 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). It is to be noted that operators may not have access to additional spectrum in lower FDD bands with available capacity (e.g. verticals and some mobs) and the user terminals supporting these functionalities may not be available in short term.

5.2 Case of Unsynchronisation operation

Unsynchronised operation does not require the adoption of a common frame structure among licensees. Licensees can select the most appropriate frame structure. 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.

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 multi-lateral agreements among all mobile operator licensees in the same geographic area in the band in a fair and timely manner. Such agreements could account for the following options:

A. Options for Unsynchronized Macro cellular networks in the same area

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 from various factors). Chapter 4 provides the methodology to support Administrations and mobile operator licensees in deriving specific values for separation distances and/or trigger values at national level. Mobile operator licensees need those values to establish an agreement when their networks are not synchronised fully or partially.

The results from the coexistence studies summarized in Chapter 4 of this White paper demonstrate that separation distances could be up to 60 km for co-channel operation and up to 14 km for adjacent-channel (e.g. for a flat terrain environment). Moreover, 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 should be defined in administrations side.

B. Options for Unsynchronized Micro BS networks and Macro cellular networks in the same area

Based on the studied in Chapter 4, the studies show that, in general, unsynchronised operation might not be feasible in this scenario of involving Micro BS networks in the same geographic area.

From Micro BS – to – Micro BS perspective, there could be very specific circumstances where two Micro BSs could coexist between each other while respecting 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) and are separated by a minimum distance that depends on the specific deployment setup. These Micro BSs might still face coexistence issues with the Macro-cellular network coverage layer above them (in both directions).

C. Options for Unsynchronized Indoor BS networks and Macro cellular networks in the same area

Based on Chapter 4, the following results can be found:

- Under specific assumptions in the adjacent channel case, unsynchronised operation should be possible with careful installation of the indoor BSs.
- It is noted that the synchronised operation of Macro BS and Indoor BS may lead to technical implementation challenges relatively to the distribution of the common clock signal to all BS involved;

- 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.

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

5.3 Case of Semi-synchronisation operation

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 controlled degree of flexibility at the expense of some controlled interference. Compared to unsynchronised operation, semi-synchronised operation reduces the impact from BS-BS and MS-MS interferences, while ensuring some flexibility on the frame structure.

In order to deploy semi-synchronised operation of TDD mobile networks in a multi-network context (without guard bands or operator-specific custom filters), IMT 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 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 out of block power limit can be applied to the semi-synchronised operation.

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

Based on Chapter 4, the following results can be found:

- If no changes are applied to the default frame structure, the semi-synchronized 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 to 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 to BS interference compared to the synchronous case.

"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;
- When the MS-MS interference can be neglected, the out of block power limit can be adopted without requiring regulatory intervention. It is expected that some 5G use cases will imply the deployment of MSs that are in fixed positions and close to each other. No specific studies were performed on MS-MS interference.

"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,
- Coexistence could be more challenging if semi-synch operation is applied to Macro BS before some efficient interference cancellation algorithms being developed and implemented.

It is also expected that semi-synchronised operation will be facilitated for cells that are **not fully loaded**. The actual coexistence feasibility for the different scenarios will depend on the specific circumstances and assumptions that can only be clarified at national level.

5.4 Options for administrations

It is notable that the administrations have not decided to set up a synchronization framework before the auction to avoid having an impact on the value of spectrum to its perspective licensees.

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

- The technical parameters for synchronised 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 whether and in which types of scenario downlink slots may be unilaterally converted to uplink slots).

If mobile operators prove not to be able to reach agreements, Administrations may need to get involved in the process to ensure fair and reasonable agreements.

Administrations could establish mechanisms to periodically update (e.g. every few years) the parameters characterizing the synchronization framework which require agreements among licensees. Such updates may be necessary to cope with evolving technology and market requirements. The arrival of new networks should be handled with special care to ensure the continued operation of the established synchronization framework.

In the case of incumbent mobile operator systems, Administrations might want to consider to consolidate those systems in specific portions of the band like 3400-3800MHz. Such measures will facilitate unsynchronised operation between new 5G networks and existing IMT networks by reducing the number of geographic and spectrum boundaries.

5.5 Cross-Boader Operation

There are still ongoing discussion from various region and countries for policy implemented in case of unsynchronized TDD or TDD/FDD at the border e.g. in dBuV/m or separation distance, GTI is monitoring these policies making. According to our study above 60km separation for co-channel and 14km for adjacent channel in the 3400-3800 MHz band would be requied for un-sychronized networks. However there are of course mitigation techniques that can be used. For example lower power in the border regions, avoiding pointing antennas toward the other country (either mechanically or electrically) and also accepting lower performance in the border region.

5.6 Common configuration for LTE-TDD and 5G-NR synchronization operation

In Section 4.1 it shows the impact of a suboptimal latency for the potential URLLC use-cases which require short latency. For the current for example CMCC deployment plan for their 5G system in 2.6GHz which will co-exist with their existing LTE-TDD system, they decided to synchronize the 2 networks with common configuration for the same geographical area. It will align 5G timings with adjacent-channel (or co-channel) 4G timings.That aligning with LTE may increase latency compared to an optimized NR TDD pattern, however eMBB use case would still be doable. In case of URLLC type of use cases, band pairing could be a solution for specific URLLC use cases. It is expected that they will eventually migrate their 4G spectrum to 5G next in future. There is no multiple operator 4G/5G synchronization scenario in China.

5.7 Inter-Operator Synchronization Example

This section gives some examples for the existing Inter-Operator Synchronization deployment requirement from different countries.

Korea operators agreed to have synchronization with 4:1 configuration (DDDSU, S=slot format 32) for both 3.5 and 28GHz band. Additional configuration can be added depending on agreements among operators.

China Ministry of Information Industry Technology made the decision that the operators need to align their frame structure in adjacent frequency band in 3.5GHz in order to avoid the unnecessary guard band for interference between each other. It defines 2.5ms +2.5ms (DDDSU + DDSUU) for 3.5GHz. The frame start also align the same with GPS.

CMCC will use 5ms frame structure, in order to align with their existing TD LTE network in 2.6GHz.

In Japan 5G licensing guideline which was used by the regulator to allocate 3.7/4.5 GHz and 28 GHz bands, operators who got spectrum needs to discuss with each other and make an agreement about TDD timing, before they start TDD operation. The ratio of UL/DL and measures for synchronization (e.g. GPS or others) are up to MNOs. Currently the all applicants submitted the identical configuration (DL:UL:SS = 7:2:1 for 3.7GHz and DL:UL:SS = 3:1:1 for 28GHz). The method of delivering the clock is GPS from each operator.

6 Synchronization Framework

This chapter describes how mobile operators deploy synchronised TDD mobile networks in a multi-operator situation.

6.1 Synchronization Requirement

In order to synchronize their networks, operators need to reach agreement on:

- 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. When losing the primary reference time clock (PRTC) equipment may continue operation for some duration ("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 shutdown until the PRTC is recovered);
- A compatible frame structure (including TDD DL / UL ratio, subcarrier spacing and start of frame) in order to avoid simultaneous UL / DL transmissions (guard periods may be different, as illustrated in Figure 21).

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

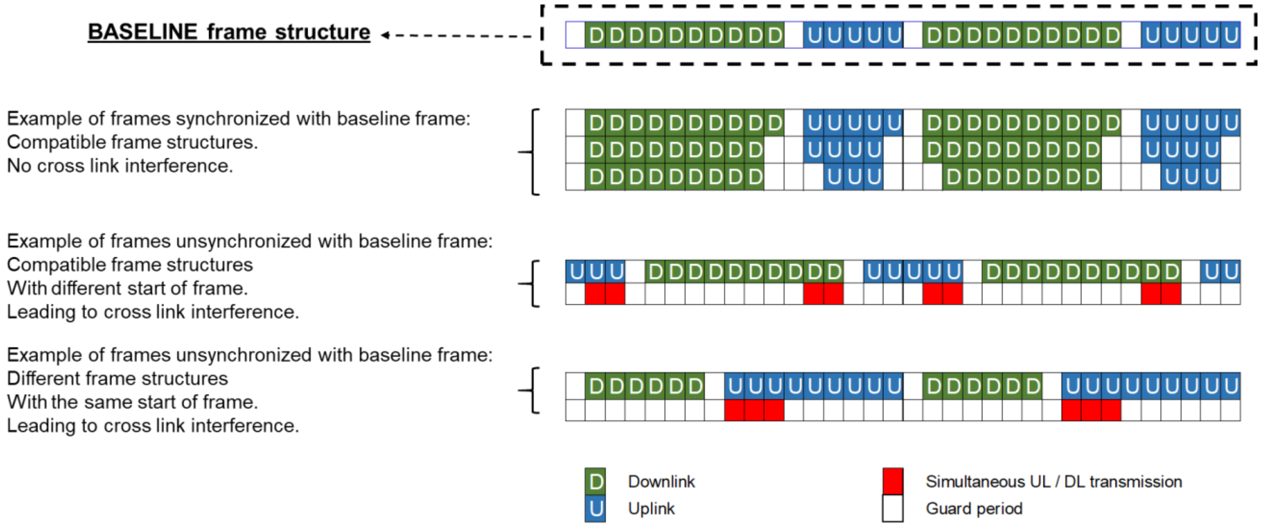


Figure 25: Examples of simultaneous UL / DL transmissions in TDD networks

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

The ECC has defined the baseline and transition region out of block power limits for synchronised operation of mobile operator BSs (see ECC Decision (11)06 Table 3 **错误!未找到引用源。**). The ECC baseline accounts for the fact that BS-BS and MS-MS interference scenarios do not take place in case of synchronised operation.

6.2 Technical Solutions for Network Synchronization

This section gives a overview of 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.

Distributed synchronisation scheme based on satellite:

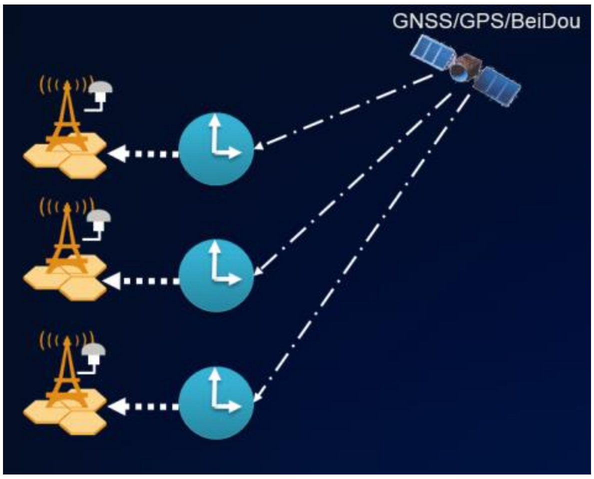


Figure 26: Distributed synchronisation scheme based on satellite

As shown in the Figure 26, GNSS signal receivers are directly deployed on base stations, each base station acquires the available satellite time signals (GPS, Beidou, Glaness, etc.) to achieve the time synchronisation between different base stations and to ensure the maximum deviation of any two of the base stations.

Table 6: 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:

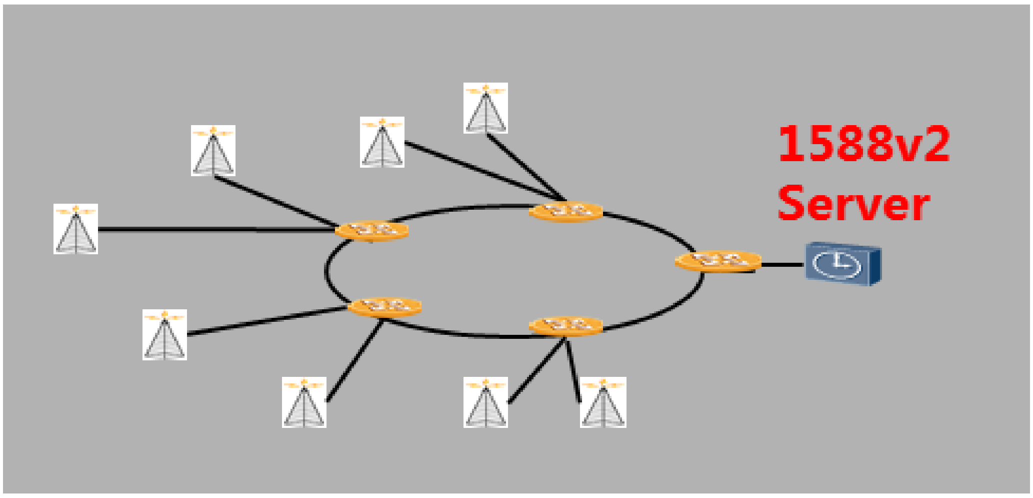


Figure 27: Centralised synchronisation scheme based on the 1588v2 system

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 27, 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 7: Applicability of the centralised synchronisation scheme based on 1588v2 system

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

Applicable scenarios	un-applicable scenarios	Pros	Cons
support PTP protocol.		▪ low maintenance costs.	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).

7 Recommendations

Based on the above coexistence study, synchronization would be recommended for multiple network operator coexistence in the same frequency band for most scenarios due to the performance impact of interference from unsynchorinzed networks. Semi-synchronization is a sub-case of synchronous to provide certain flexibility for operators in special scenairos.

In order to synchronize their networks, operators need to reach agreement on:

- 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. When losing the primary reference time clock (PRTC) equipment may continue operation for some duration ("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 shutdown until the PRTC is recovered);

- A compatible frame structure (including TDD DL / UL ratio, subcarrier spacing and start of frame) in order to avoid simultaneous UL / DL transmissions (guard periods may be different, as illustrated in Figure 21).

8 Reference

[1] Draft ECC Report 296 National synchronisation regulatory framework options in 3400-3800 MHz: a toolbox for coexistence of MFCNs in synchronised, unsynchronised and semi-synchronised operation in 3400-3800 MHz

[2] ECC Decision (11) (06)Harmonised frequency arrangements and least restrictive technical conditions (LRTC) for mobile/fixed communications networks (MFCN) operating in the band 3400-3800MHz.

[3] ECC Report 281 Analysis of the suitability of the regulatory technical conditions for 5G MFCN operation in the 3400-3800MHz band.