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Synchronization of IMT-2020 TDD networks

M Series

Mobile, radiodetermination, amateur
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***Note**: This ITU-R Report was approved in English by the Study Group under the procedure detailed in Resolution ITU-R 1.*

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Synchronization of IMT-2020 TDD networks

(2021)

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1 Introduction and scope

More bands have been globally identified for IMT-2020 Time Division Duplex (TDD) networks. Considering the wider operating band and overlapped band definition, it will be a trend that more operators may use the same or adjacent spectrum to deploy IMT-2020 networks in TDD mode.

The operators who plan to deploy IMT-2020 TDD networks in the same frequency band (including co-channel and adjacent channel deployment) and same area will face the issue of network synchronization (synchronised, unsynchronised or semi-synchronised). On the one hand, cross link interference, e.g. DL to UL or UL to DL, may happen if unsynchronised or semi-synchronised operation is used, e.g. by using different DL/UL time slot ratio and/or unaligned transmission frame structures. Solutions, such as guard band, stricter RF emission requirements or isolation distance, could mitigate the cross-link interference to a certain extent, but it also comes with a price of sacrificing the spectrum efficiency, more costly equipment or site coordination and isolation. On the other hand, synchronised operation can avoid cross link interference and spectrum waste, but requires neighbouring operators to coordinate to select a compatible frame structure, and a common phase clock reference (e.g. UTC) with a requirement on the accuracy/performance, and a common understanding about the start of the frame with regards to the common phase clock reference.

Compared with IMT-Advanced (e.g. LTE-TDD) network, IMT-2020 networks operate with new frequency band, wider operating bandwidth, active antenna system (AAS) and higher UE transmit power, which may bring additional impacts on the cross-link interference and the system performance. Moreover, this interference issue due to unsynchronized operation may also exist between IMT-2020 TDD networks and IMT-Advanced (e.g. LTE-TDD) networks if different operators deploy both systems in the same frequency band and a same area.

Globally, interference issues due to unsynchronized operation between operators in the same district could be solved through consultation and coordination. This study is to provide observations on the performance impacts of synchronization of multiple IMT-2020 TDD networks for different operators in the same frequency bands and areas. And it suggests that try to use a synchronized operation mode between wide-area outdoor networks to reduce the interference.

The scope of this report is addressing the study on the aspects of synchronization operations of multiple IMT-2020 TDD networks in close proximity using the same frequency band, including analyses of coexistence issues when IMT operators utilize different synchronization modes, performance evaluation under different synchronization modes, and coexistence mitigation strategies. It is noted that system sharing and compatibility with other services and applications is not in the scope of this work.

2 Related ITU-R Recommendations and Reports

Recommendation ITU-R M.2150 – Detailed specifications of the terrestrial radio interfaces of International Mobile Telecommunications-2020 (IMT-2020)

Recommendation ITU-R M.2012 – Detailed specifications of the terrestrial radio interfaces of International Mobile Telecommunications Advanced (IMT-Advanced)

Report ITU-R M.2412 – Guidelines for evaluation of radio interface technologies for IMT-2020

3 Considerations on IMT-2020 TDD networks

3.1 Interference scenarios

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 UE) belonging to one network transmits while another BS (or UE) belonging to the other network receives (this will be referred to as ‘simultaneous UL/DL transmissions’ throughout this Report).

For a synchronised operation mode, the interference could be from BS downlink to neighbouring UE’s downlink receiving or from UE uplink to neighbouring BS’s uplink receiving, as followed in Table 1.

TABLE 1

Interference scenarios for synchronised operation

Aggressor	**Victim**
System A BS	System B UE
System A UE	System B BS
System B BS	System A UE
System B UE	System A BS

For an unsynchronised or semi-synchronised operation mode, beyond these scenarios in Table 1, the interference could also be from BS downlink to neighbouring BS’s uplink receiving or from UE uplink to neighbouring UE’s downlink receiving.

TABLE 2

Interference scenarios for unsynchronised/semi-synchronised operation

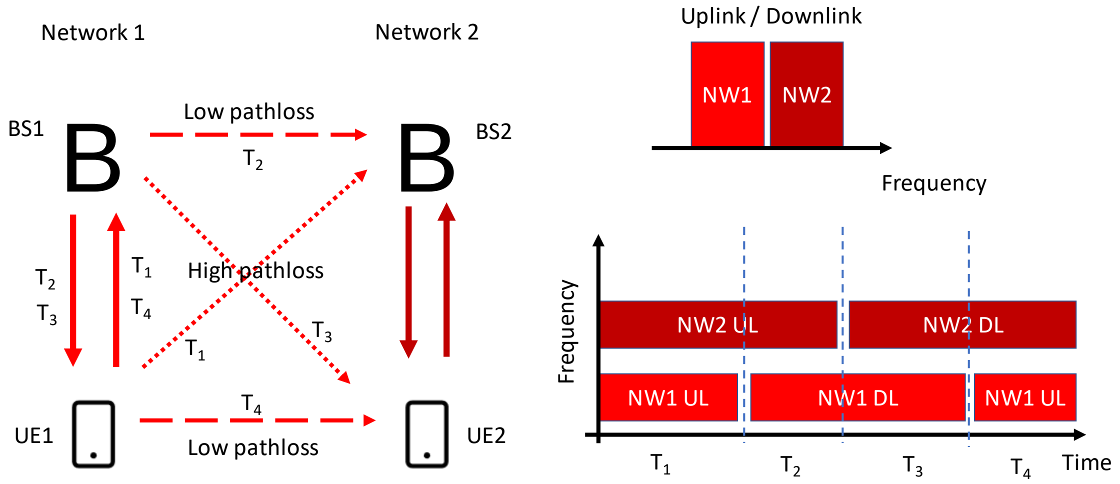
Aggressor	**Victim**
System A BS	System B UE
System A UE	System B BS
System A BS	System B BS
System A UE	System B UE
System B BS	System A UE
System B UE	System A BS
System B BS	System A BS
System B UE	System A UE

In TDD networks the same carrier frequency is used for transmitting from BS to UE as well as the other direction from UE to BS.

Since two links use the same frequency but at different times there is the possibility that there will be interference on the lower pathloss paths with carriers close in frequency. This is illustrated in Fig. 1 where two TDD networks are using the carrier frequencies next to each other and interleave the uplink and downlink in time. For example, in Fig. 1 below, during the time T_2 the BS in Network 1 is transmitting while the BS in Network 2 is receiving. In this case, the emissions are high since the carriers are close in frequency while the pathloss is low. This leads to a larger interference and has the possibility for a larger impact on network performance.

FIGURE 1

TDD links, frequencies and time dimension



One way to avoid the high interference paths is to schedule the transmissions in the networks so that they all use the downlink direction at the same time and the uplink direction at the same time synchronised mode. I.e. there is no time instant where the BS of one network is transmitting while the BS of the other network are receiving. The same also applies for UEs of different networks.

So far, nodes/links with different carrier frequencies have been discussed. But the same reasoning applies also for nodes/links using the same carrier frequency. The difference in this case is that there is no difference in carrier frequency that gives an isolation from one network to the other. In this case, the interference becomes larger.

In this Report, the assumption is made that all nodes in the same network are either transmitting in the downlink or that all nodes are transmitting in the uplink direction. One could of course imagine a scenario where parts of the network is transmitting in the uplink and other parts in the downlink. However, this will create quite a lot of interference between the nodes and we assume that this scenario is rarely (never) beneficial for the network operator. It is also assumed that all nodes are controlled by the same operator and that there are no practical problems in arranging transmissions in this way.

3.2 Synchronization modes for IMT-2020 TDD networks

Section 3.2 discusses definition of synchronised, unsynchronised and semi-synchronised operation as well as highlights benefits and challenges associated with each mode, and provides an overview on the interference mechanisms that characterise each operating mode.

3.2.1 Synchronised operation

Synchronisation defines time synchronisation at the frame level between TDD networks for interference mitigation purposes. Moreover, synchronised operation means operation of TDD in several different networks, where no simultaneous UL and DL transmissions occur, for example, 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 different operator context, operators need to reach agreement on some scheme(s), then some examples can be found below:

– A compatible frame structure (including TDD DL/UL ratio and frame length) in order to avoid simultaneous UL/DL transmissions (guard periods may be different).

- 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 IMT-Advanced and IMT-2020), either using their own equipment to provide the clock, or sharing the same phase / time clock infrastructure, and a common definition about 'start of frame' with regards to the common phase clock reference[1].
- 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).

In TDD networks, the maximum cell radius depends on the guard period between DL and UL transmissions, which means 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).

The purpose of synchronised operation is to prevent BS-BS and UE-UE 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 UEs), 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 also lead to some requirements, such as:

- Setup of the clock reference: operator(s) 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(s) 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 This report makes the assumption that it is possible arrange for time alignment of frames and that the practical problems can be solved using existing technologies, but do not go into details how this should be handled in practice.

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[1] E.g. some standards such as WiMAX define 'start of frame' as 'start of downlink', while some other standards such as 3GPP LTE and NR have a different approach where 'start of frame' (in terms of control symbols and definition) can be different from start of downlink or can be flexible.

- 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, 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). Therefore, the selection of a compatible frame structure, 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), will provide the same contribution to the performance of all operators involved, with similar impacts on the services to end users.
  - 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.

All issues above apply in all cases of TDD coexistence, including in both IMT-2020 systems (e.g. NR) and between IMT-2020 and IMT-Advanced (e.g. LTE-TDD) coexistence cases.

It should be noted that ‘synchronized operation’ only avoids BS-BS and UE-UE interferences within a ‘synchronized area’ that depends on the size of the guard period:

- The GP must be larger than 2x propagation time + time needed for switching from DL to UL inside the UE. This means that the capacity loss and overhead of the guard period is higher for large cells, noting that this overhead occur at every DL/UL switching point and therefore is higher for shorter frame (which are needed for low-latency).
- GP must also be larger than the propagation time between the interferer BS and the farthest base station that might be interfered. Otherwise, the end of DL will start to hit the beginning of UL of the victim (noting that such interference can be mutual).

For example, in the case of LTE subframe S#7, GP is 2*OFDM symbols i.e. 142.7 µs, therefore the farthest UE can be at 21.5 km since the signal can travel 43 km during that time, and this also means that synchronized operation only avoids BS-BS interferences to victims within 43 km and does not completely avoid those interferences to BS farther away.

In those cases where site configurations (including azimuth and tilt) and propagation conditions (e.g. overseas) might enable interferences between BS far away, the GP should be adjusted accordingly (noting that this can increase the capacity loss due to the GP overhead).

3.2.2 Unsynchronised operation

The unsynchronised operation defines that 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 means that even networks transmit in opposite directions a small part of the time are viewed as unsynchronized. 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 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.

Moreover, Spectral leakage from the interfering BS transmitter side is a challenge to the scenario. 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.

Secondly, Blocking of the victim BS receiver also should be solved, because 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.

Therefore, unsynchronised operation requires all of the operators in a band in the same geographical area to comply with the restricted 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, which are expensive and not practical.

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

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 UE activity is more intermittent than BSs', and by the fact that statistical factors mitigate the criticality of the UE-UE interference mechanism since devices are typically mobile.

For the purposes of this Report, the notion of unsynchronized operation is limited to the special case of two networks where one network is always transmitting in the uplink while the other is transmitting in the downlink. It can be understood that this is the worst case since the interference is larger when networks transmit in different direction than when they transmit in the same direction. From this, it can be noted that the worst case happens when the 'opposite direction' criteria occur all the time.

One advantage with unsynchronized operation in the general case is that there is no need to agree on a compatible frame structure or a common time reference. If two networks have not agreed on this, there will be some time instances when they transmit in the same directions and other when they transmit in opposite directions. It is easy to realise that the performance will be better in this case than the worst case outlined above. Exactly how much better will depend on what fraction of the time the networks transmit in opposite directions.

3.2.3 Semi-synchronised operation

The semi-synchronised operation corresponds to the case where part of the frame is consistent with synchronised operation as described in § 3.2.1, while the remaining portion of the frame is consistent with unsynchronised operation as described in § 3.2.2. 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.

Therefore, 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. Semi-synchronised operation aims to trade-off 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 UE-UE interference with respect to both leakage and blocking interference mechanisms, 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 allows for some degree of frame structure flexibility when compared with synchronised operation.

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

Operators may find a balance between frame flexibility and risk of interference.

In semi-synchronised operation, part of the frame with flexible UL/DL transmissions may suffer from BS-BS and UE-UE interference with respect to both leakage and blocking interference mechanisms.

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.

4 Evaluation and analysis of IMT-2020 TDD networks

The parameters presented in this Report are for illustrating the performances of different synchronization operations of multiple IMT-2020 TDD networks in close proximity using the same frequency band. These parameters have been chosen to be representative of a typical view of IMT-2020 TDD networks but are not intended to be specific to any particular implementation of an IMT-2020 technology. They should not be considered as the values that must be used in any deployment of any IMT-2020 system nor should they be taken as the default values for any other or subsequent study in ITU or elsewhere.

This procedure deals only with evaluating the aspect of synchronization operations of multiple IMT-2020 TDD networks. It is not intended for evaluating system aspects (including those for satellite system aspects).

The conclusion from this study is intended to provide observations and suggestions to facilitate the deployments of TDD networks and do not impact any other or subsequent study in ITU or elsewhere.

4.1 NR frame structures

The frame structure is one of the major factors that decide the network performance. The influence on some KPIs, e.g. latency and capacity allocation, is independent of the carrier frequency, while other aspects are frequency dependent, e.g. coverage aspects.

The performance of the network is not only dependent on selection of frame structure in a specific network. The network performance also depends on the frame structure selected in other networks since the interference situation is dependent on the frame structure in adjacent networks.

It is also noted that the selected frame structure has an impact on the network on a specific carrier frequency. In practice operators may have access to several carrier frequencies where the and the performance characteristics may be different depending on carrier frequency. By combining there is a possibility to draw on the strengths from each component to create a better overall experience. One example is where a lower carrier frequency is used to ensure coverage while higher carrier frequencies are used to provide capacity.

However, this Report do not dig deeper into how different carrier frequencies can be combined to achieve desired network performance in network with multiple carrier frequencies. Partly because the topic is quite complex, partly because the situation will be very specific for each operator and partly because there are so many different objectives that can be maximised for. Combining several carriers in different bands is left as an exercise for the interested reader.

Finally, it is worth stressing that since the frame structure evaluations are done for a single network in isolation there is no concept of synchronisation (or not). This means that the results apply regardless of the synchronisation mode.

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 IMT frequency bands (e.g. 700, 800, 900, 1 800 MHz or mmWave) will have the possibility to use jointly such frequencies with the 3 400-3 800 MHz band through the Carrier Aggregation (CA) or Supplemental UpLink schemes (SUL). Such combined use will provide additional ways to meet the target network characteristics.

In NR system, HARQ process works per cell, so the initial transmission and retransmission should be in the same cell. Carrier Aggregation (CA) is a technique that aggregates various component bands into an overall wider bandwidth by introducing different cells. Supplementary UpLink (SUL) makes it possible to supplement another frequency carrier for NR UL transmission instead of only NR’s dedicated UL carrier in a switchable manner within one cell. So, SUL and CA are similar but different technologies.

– With inter-band CA, the user plane latency in DL can be improved in both DL and UL. Moreover, CA can support simultaneous data transmissions in multiple carriers for both UL and DL thus increasing the achievable data rates.

– SUL can reduce the RTT of TDD structure in one cell. Higher date rate can be achieved with SUL than without SUL by dynamic TDM switching better carrier, notwithstanding unlike CA concept, SUL does not support simultaneous data transmissions in multiple carriers.

4.1.1 Allocation of time to uplink and downlink

The frame structure determines how large fraction of the time a carrier is used for uplink and downlink. This gives a high level understanding of how much of the network capacity that is allocated to the uplink and the downlink. However, this is only a first order approximation and further details can be found later in the Report.

It should be noted that part of the time is allocated to the guard period (GP). The GP is necessary to account for switching times in the transceivers and also to allow for propagation delays between the BS and the UE.

Table 3 gives the split for several commonly discussed frame structures. The comparison assumes a 30 kHz subcarrier spacing and a (10DL:2GP:2UL) symbol allocation in the "S" slot.

TABLE 3

Time allocation for a few select frame structures

Pattern	Downlink fraction	Uplink fraction	Comments
DDDDDDDSUU DDDSUUDDDD	77%	21%	Compatible with LTE TDD config 2
DDDSU	74%	23%	
DDSU	68%	29%	
DSDU	68%	29%	

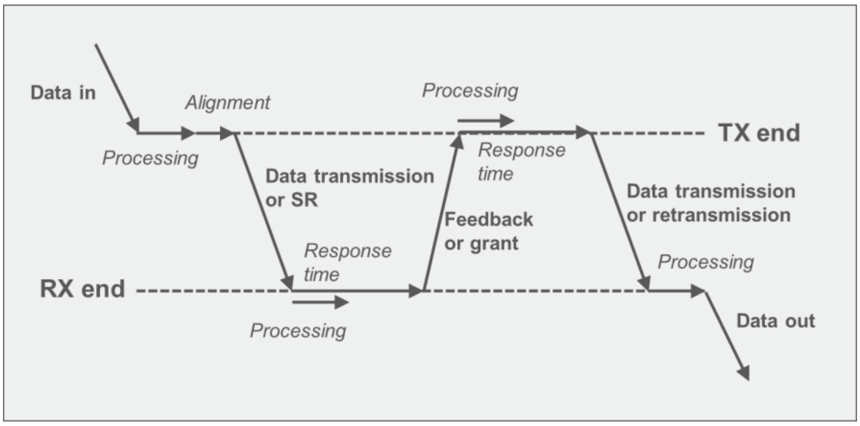
4.1.2 Latency

User plane latency is determined as the network latency from when packet is delivered to/from the radio protocol stack for scheduled DL, UL, and configured grant UL transmissions.

Different latency components are taken into account in the evaluation as shown in Fig. 2, where details of each component are given in the respective DL and UL latency sections.

FIGURE 2

Latency components in the evaluations

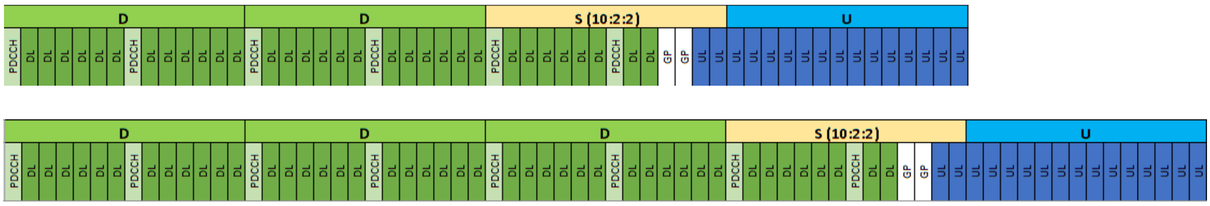


Apart from data transmission time over the air itself, there exist other latency components such as gNB and UE processing time as well as some waiting time for slot boundary alignment, DL and UL symbols in TDD pattern, PDCCH/PUCCH/PDSCH/PUSCH transmission opportunities, etc.

In this evaluation, focus is made on latency evaluation for two TDD patterns, namely, DDSU and DDDSU, where the special slot S = (10DL:2GP:2UL) as shown in Fig. 3. The analysis can be generalized to any TDD pattern of interest.

FIGURE 3

Frame structures for evaluation – OFDM symbol level, assuming PDCCH periodicity of 7os (symbols)



As one of the latency components, the minimum UE processing time required from the end of PDSCH to transmission of HARQ-ACK, and the minimum time from scheduling PDCCH to PUSCH transmission are defined in the specification. The UE processing time mainly consist of values N1 (for DL) or N2 (for UL) with some additional factor depending on the transmission duration, DMRS configuration, etc. The values N1 and N2 also depend on SCS and processing capability as shown in Table 4. Specifications defines two different capabilities according to the implementation of UE. The UE of Capability #2 has a higher computing capability but shorter processing time. And the UE of Capability #1 has a lower computing capability and a longer processing time.

TABLE 4

UE processing time (symbols) for processing capabilities #1 and #2

μ	**N1 (no additional DMRS)**		**N2**	
	Capability # 1	**Capability # 2**	**Capability # 1**	**Capability # 2**
0	8	3	10	5
1	10	4.5	12	5.5
2	17	9 (for FR1)	23	11 (for FR1)
3	20	-	36	-

In the following sections, DL and UL latency is evaluated for:

– slot-based scheduling (representing eMBB) in terms of DL and UL average latency for:
  - a single-shot transmission; and
  - transmission with HARQ retransmission probability of $p = 0.1$;

– non-slot-based scheduling (representing URLLC) in terms of the worst-case DL and UL latency for:
  - a single-shot transmission;
  - one HARQ retransmission.

Apart from the average and worst-case latency, HARQ RTT for different cases are also provided. The results are summarised in Table 5 for the downlink and Table 6 for the uplink. The assumption used to derive these results are further detailed in the following sections.

TABLE 5

DL latency (30 kHz SCS, TDD), Study 1

Slot/non-slot based scheduling	DL latency (ms)		TDD pattern		
			DDSU	DDDSU	DDDSUUDDDD/ DDDDDDDSUU (1)
eMBB: 14os slot-based (type A) scheduling with UE capability#1	Average user plane latency	1 transmission	1.52	1.44	1.44
		when the error probability of the first HARQ retransmission p = 0.1	1.76	1.71	1.84
	RTT		2.38	2.70	3.95
URLLC: 2os non-slot based (type B) scheduling with UE capability#2	Worst-case latency	1 transmission	0.98	0.98	1.48
		2 transmissions	2.98	3.48	6.48
	Maximum RTT		2.00	2.50	5.00

(1) The latency for the frame structure DDDSUUDDDD/ DDDDDDDSU is the same as they share the same slot sequence.

TABLE 6

DL latency (30 kHz SCS, TDD), Study 2

Slot/non-slot based scheduling	DL latency (ms)		TDD pattern			
			DDSU	DDDSU (1)	DDDSU +SUL	DDDDD DDSUU
eMBB: 14os slot-based (type A) scheduling with UE capability#1	Average user plane latency	1 transmission	1.29	1.26	1.26	1.31
		when the error probability of the first HARQ retransmission p=0.1	1.50	1.50	1.42	1.67
	RTT		2.48	2.73	1.70	3.53
URLLC: 2os non-slot based (type B) scheduling with UE capability#2	Worst-case latency	1 transmission	0.94	0.94	0.94	1.58
		2 transmissions	2.94	3.44	1.44	6.58
	Maximum RTT		2.35	2.85	1.17	5.42

(1) The DDDSU latency can be also decreased with inter-band carrier aggregation in a similar manner as DDDSU+SUL column.

TABLE 7

UL latency (30 kHz SCS, TDD), Study 1

Slot/non-slot based scheduling	UL latency (ms)		Frame structure		
			DDSU	DDDSU	DDDSUUDDDD/ DDDDDDDSUU (1)
eMBB: 14os SR-based UL with UE capability#1	Average user plane latency	1 transmission	3.68	4.93	8.18
		when the error probability of the first HARQ retransmission p=0.1	3.88	3.18	8.68
	RTT		2.00	2.50	5.00
URLLC: 2os configured grant UL with UE capability#2	Worst-case latency	1 transmission	1.75	2.25	4.25
		2 transmissions	3.75	4.75	9.25
	Maximum RTT		2.00	2.50	5.00

(1) The latency for the frame structure DDDSUUDDDD/DDDDDDDSU is the same as they share the same slot sequence.

TABLE 8

UL latency (30 kHz SCS, TDD), Study 2

Slot/non-slot based scheduling	UL latency (ms)		Frame structure Study 2			
			DDSU	DDDSU (1)	DDDSU+ SUL	DDDDD DDSUU
eMBB: 14os SR-based UL with UE capability#1	Average user plane latency	1 transmission	3.95	5.41	2.80	8.45
		when the error probability of the first HARQ retransmission p=0.1	4.15	5.66	2.96	8.95
	RTT		2.00	2.50	1.60	5.00
URLLC: 2os configured grant UL with UE capability#2	Worst-case latency	1 transmission	1.78	2.28	0.35	4.20
		2 transmissions	3.78	4.78	1.53	9.20
	Maximum RTT		2.31	2.81	1.24	5.31

(1) The DDDSU latency can be decreased with inter-band carrier aggregation in a similar manner as DDDSU+SUL column.

In general, it can be seen that the achievable latency is impacted by DL and UL transmission opportunities of the TDD pattern. For DL, having more frequent DL transmission opportunities can provide lower latency for a single-shot DL transmission. However, for DL HARQ retransmission, an UL transmission opportunity for sending HARQ-ACK information is also important. As can be seen, the HARQ RTT and worst-case latency of one retransmission of the 2os-PDSCH under DDSU pattern are in fact lower than those of DDDSU pattern due to shorter turn-around time from DL to UL slots of the DDSU pattern. For UL, DDSU pattern has lower UL latency than DDDSU for all cases due to more frequent UL transmission opportunities. It is noted that for retransmission cases, although DL opportunities are needed for sending an UL grant for scheduling the retransmission, it is less crucial in the considered DL-heavy TDD patterns.

It should also be noted that due to the Guard Period (which can be large especially in the case of large cells), there is a trade-off between latency (which is improved with short frames) and capacity loss due to GP overhead (which is increased with short frames, especially in the case of large cells).

4.1.2.1 Downlink latency

The components of the DL latency considered in the evaluation are outlined in the Tables below.

TABLE 9

Components of DL user plane latency

ID	Component	Notations
1	UE processing delay	$t_{UE} = t_{UE,rx} + t_{UE,tx,}$ $t_{UE,rx}$ 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.
2	Alignment delay	$t_{FA,DL}$: the waiting time for valid DL transmission opportunity (e.g. in TDD, data transmission needs to wait for the next available DL/UL symbol/slot, and PDCCH opportunity); $t_{FA,UL}$: the waiting time for valid UL transmission opportunity (e.g. in TDD, data transmission needs to wait for the next available DL/UL symbol/slot, and PUCCH opportunity)
3	TTI for data packet transmission	$t_{data\_duration}$
4	HARQ retransmission	t_{HARQ}
5	BS processing delay	$t_{BS} = t_{BS,rx} + t_{BS,tx,}$ $t_{BS,tx}$ is the time interval between when the data arrived, and when the packet is generated; $t_{BS,rx}$ is the time interval between when ACK/NACK packet is received and when the ACK/NACK 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: $t_{HARQ} = (t_{UE,tx} + t_{FA,UL}) + t_{PUCCH\_duration} + t_{BS,rx} + (t_{BS,tx} + t_{FA,DL}) + t_{data\_duration} + t_{UE,rx},$ n is the number of re-transmissions ($n \geq 0$)

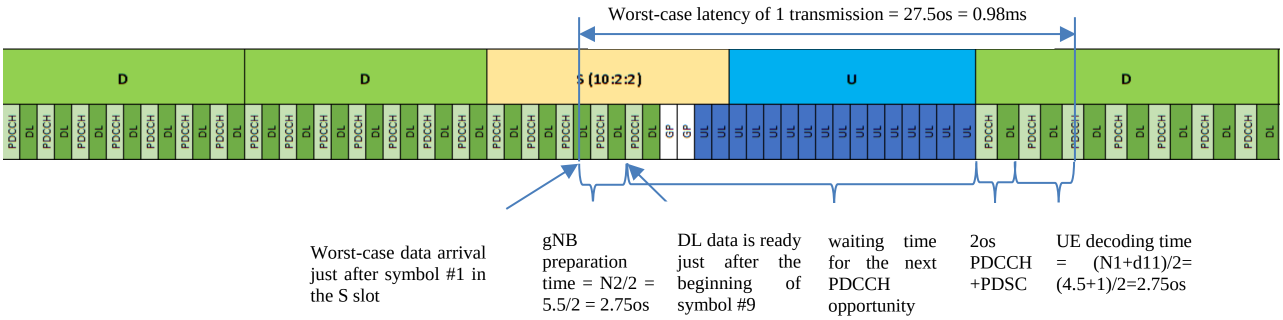
TABLE 10

Assumptions of processing time and other latency components

	eMBB	**URLLC**
Subcarrier spacing (SCS)	30 kHz	30 kHz
Mapping type and PDSCH duration	Type A with 14os PDSCH	Type B with 2os PDSCH
UE capability	Capability #1	Capability #2
$t_{UE,rx}$	(N1+d11)/2	(N1+d11)/2
$t_{UE,tx}$	(N1+d11)/2	(N1+d11)/2
d11	0	#overlapping symbol of PDCCH and PDSCH, i.e. d11 = 1
DMRS	Only front-loaded DMRS	Only front-loaded DMRS
gNB processing time	assumed to have the same capability as UE	assumed to have the same capability as UE
$t_{BS,rx}$	N2/2	N2/2
$t_{BS,tx}$	N2/2	N2/2
PDCCH monitoring occasion pattern in D or S slot	PDCCH periodicity of 14os: 10000000000000	PDCCH periodicity of 2os: 10101010101010
PDCCH duration	1os (overlapped with the first symbol of PDSCH)	1os (overlapped with the first symbol of PDSCH)
PUCCH opportunity pattern in U or S slot	PUCCH periodicity of 14os: 10000000000000	PUCCH periodicity of 2os: 10101010101010
PUCCH duration	14os	2os
Slot boundaries	Transmission of PDCCH, PDSCH and PUCCH do not cross the slot boundary	Transmission of PDCCH, PDSCH and PUCCH do not cross the slot boundary
Data arrival alignment	average symbol alignment = 0.5os	worst-case symbol alignment = 1os

FIGURE 4

Illustration of the worst-case DL latency for 1 transmission of 2os PDSCH in DDSU pattern



4.1.2.2 Uplink latency

TABLE 11

Components of UL user plane latency

ID	Component	Notations
1	UE processing delay	$t_{UE} = t_{UE,rx} + t_{UE,tx}$ For UL: $t_{UE,rx}$ is the time interval between when the PDCCH is received and when the PDCCH is decoded; $t_{UE,tx}$ is the time interval between when the data arrived, and when the packet is generated.
2	Alignment delay	$t_{FA,UL}$: the waiting time for valid UL transmission opportunity (e.g. in TDD, data transmission needs to wait for the next available DL/UL symbol/slot, and PUCCH opportunity) $t_{FA,DL}$: the waiting time for valid DL transmission opportunity (e.g. in TDD, data transmission needs to wait for the next available DL/UL symbol/slot, and PDCCH opportunity)
3	TTI for data packet transmission	$t_{data\_duration}$
4	HARQ retransmission	t_{HARQ}
5	BS processing delay	$t_{BS} = t_{BS,rx} + t_{BS,tx}$ $t_{BS,rx}$ 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 PDCCH is generated.
6	SR and UL grant processing delay	$t_{SR} = (t_{SR,tx} + t_{FA,UL}) + t_{SR\_duration} + (t_{SR,rx} + t_{BS,tx} + t_{FA,DL}) + t_{PDCCH\_duration} + t_{UE,rx}$, where: $t_{SR,tx}$ is the time interval between when the data arrived and when the SR is generated; $t_{SR,rx}$ is the time interval between when the SR is received and when the SR is decoded; $t_{BS,tx}$ here is the time interval between when the SR is decoded, and when the PDCCH is generated.
-	Total one way user plane latency for UL	For SR-based UL, $t_{UP} = t_{SR} + (t_{UE,tx} + t_{FA,UL}) + t_{data\_duration} + t_{BS,rx} + n \times t_{HARQ},$ For configured grant UL, $t_{UP} = (t_{UE,tx} + t_{FA,UL}) + t_{data\_duration} + t_{BS,rx} + n \times t_{HARQ},$ where: $t_{HARQ} = (t_{BS,tx} + t_{FA,DL}) + t_{PDCCH\_duration} + t_{UE,rx} + (t_{UE,tx} + t_{FA,UL}) + t_{data\_duration} + t_{BS,rx},$ n is the number of re-transmissions ($n \geq 0$)

TABLE 12

Assumptions of processing time and other latency components

	eMBB	**URLLC**
Subcarrier spacing (kHz)	30	30
Mapping type and PUSCH duration	Type A with 14os PUSCH	Type B with 2os PUSCH
d21	d21 = 0, First symbol of PUSCH consists of DMRS only	d21 = 0, First symbol of PUSCH consists of DMRS only
UE capability	Capability #1	Capability #2
$t_{UE,rx}$	N2/2	N2/2
$t_{UE,tx}$	N2/2	N2/2
gNB processing time	assumed to have the same capability as UE	assumed to have the same capability as UE
$t_{BS,rx}$	N2/2	N2/2
$t_{BS,tx}$	N2/2	N2/2
Scheduling request (SR) periodicity	4 slots for DDSU, 10 slots for DDDSU and DDDSUUDDDD (cf. 3GPP TS.38.331, for 30 kHz SCS, the minimum allowed SR periodicity matching with the UL slot of the ‘DDDSU’ TDD pattern is 10 slots.)	N/A
Scheduling request (SR) duration	14 os	N/A
$t_{SR,tx}$	0	N/A
$t_{SR,rx}$ + $t_{BS,tx}$	N1	N/A
Configured grant (CG) periodicity	N/A	2os
PDCCH monitoring occasion pattern in a slot	PDCCH periodicity of 14os: 10000000000000	PDCCH periodicity of 2os: 10101010101010
PDCCH duration	1os	1os
Slot boundaries	Transmission of PUSCH and PDCCH do not cross the slot boundary	Transmission of PUSCH and PDCCH do not cross the slot boundary
Data arrival alignment	average symbol alignment = 0.5os	worst case symbol alignment = 1os

4.1.3 Peak data rate

This section provides the downlink and uplink peak data rates for a limited set of frame structures. This does not preclude other frame structures to be used.

4.1.3.1 Downlink peak data rate

A range of configurations are considered in the evaluation of downlink peak data rate. Peak data rate is calculated according to subclause 4.1.2 in TS 38.306 [2] where the ratio of DL/UL symbols of the TDD pattern is taken into account in the calculation to obtain the average peak data rate value

(G symbols are assumed to be unavailable). Scaling factor of 1 is assumed. Number of PRBs corresponding to the BW for each SCS follows the maximum transmission bandwidth defined in TS 38.101-1 [3] (for FR1) and TS 38.101-2 [4] (for FR2). The peak data rate can be improved further with wider carrier bandwidth and/or when features like carrier aggregation are used. 5G-NR allows aggregating up to 16 component carriers within the same or different bands, thereby enabling improvement in the achievable data rate.

TABLE 13

NR DL peak data rate (Study 1)

Duplexing	**Subcarrier space (kHz)**		**Per CC BW (MHz)**	**Peak data rate per CC (Gbit/s)**
TDD (DDDSU)	FR1 ($N_{layer} = 8$)	15	50	1.81
		30	100	3.68
		60	100	3.62
	FR2 ($N_{layer} = 6$)	60	200	5.33
		120	400	10.7
TDD (DSUUD, S slot= 11DL:2GP:2UL)	FR1 ($N_{layer} = 8$)	15	50	1.32
		30	100	2.69
		60	100	2.64
	FR2 ($N_{layer} = 6$)	60	200	3.86
		120	400	7.81
TDD (DSUUD, S slot= 6DL:2GP:6UL)	FR1 ($N_{layer} = 8$)	15	50	1.13
		30	100	2.30
		60	100	2.26
	FR2 ($N_{layer} = 8$)	60	200	4.38
		120	400	8.76
TDD (DDDDDDDSUU, S slot= 6DL:4GP:4UL)	FR1 ($N_{layer} = 8$)	15	50	1.77
		30	100	3.58
		60	100	3.52

NOTE – FR1 is lower or around 6GHz frequency band. FR2 is larger than 6GHz, such as 26 GHz to 28 GHz.

TABLE 14

DL peak data rate (Study 2)

Duplexing (Note 1)	**Subcarrier space (kHz)**		**Per CC BW (MHz)**	**Peak data rate per CC (Gbit/s)**
TDD (DDDSUUDDDD) S slot= 3DL:8GP:3UL)	FR1 ($N_{layer} = 4$)	15	50	0.8337
		30	100	1.6860
		60	100	1.6675

TABLE 14 (*cont.*)

Duplexing (Note 1)	**Subcarrier space (kHz)**		**Per CC BW (MHz)**	**Peak data rate per CC (Gbit/s)**
TDD (DDDSUUDDDD) S slot= 6DL:4GP:4UL)	FR1 ($N_{layer} = 4$)	15	50	0.8585
		30	100	1.7361
		60	100	1.7170
TDD (DDDSUUDDDD) S slot= 4DL:6GP:4UL)	FR1 ($N_{layer} = 4$)	15	50	0.8420
		30	100	1.7027
		60	100	1.6840
TDD (DDDS$_1$UUDS$_2$UU) S$_1$ slot= 6DL:4GP:4UL) S$_2$ slot= 10DL:4GP:0UL)	FR1 ($N_{layer} = 4$)	15	50	0.5943
		30	100	1.2019
		60	100	1.1887
TDD (DDDSUUUUDD) S slot= 6DL:4GP:4UL)	FR1 ($N_{layer} = 4$)	15	50	0.6274
		30	100	1.2687
		60	100	1.2547
TDD (DDDSU) S slot= 10DL:2GP:2UL)	FR1 ($N_{layer} = 4$)	15	50	0.8585
		30	100	1.7361
		60	100	1.7170
	FR2 ($N_{layer} = 8$)	60	200	6.4030
		120	400	12.8059
TDD (DDDSU) S slot= 0DL:2GP:12UL)	FR1 ($N_{layer} = 4$)	15	50	0.6934
		30	100	1.4022
		60	100	1.3868
	FR2 ($N_{layer} = 8$)	60	200	5.1716
		120	400	10.3432
TDD (DDSUU) S slot= 12DL:2GP:0UL)	FR1 ($N_{layer} = 4$)	15	50	0.6604
		30	100	1.3354
		60	100	1.3208
	FR2 ($N_{layer} = 8$)	60	200	4.9254
		120	400	9.8507
TDD (DSUUU) S slot= 10DL:2GP:2UL)	FR2 ($N_{layer} = 8$)	60	200	2.9552
		120	400	5.9104

NOTE 1 – Different special slot configurations may be used other than the ones listed.

4.1.3.2 Uplink peak data rate

A range of configurations are considered in the evaluation of uplink peak data rate. Peak data rate is calculated according to subclause 4.1.2 in TS 38.306 [2] where the ratio of DL/UL symbols of the TDD pattern is taken into account in the calculation to obtain the average peak data rate value (G symbols are assumed to be unavailable). Scaling factor of 1 is assumed. Number of PRBs corresponding to the BW for each SCS follows the maximum transmission bandwidth defined in

TS 38.101-1 [3] (for FR1) and TS 38.101-2 [4] (for FR2). The peak data rate can be improved further with wider carrier bandwidth and/or when features like carrier aggregation are used. 5G-NR allows aggregating up to 16 component carriers within the same or different bands, thereby enabling improvement in the achievable data rate.

TABLE 15

NR UL peak data rate (Study 1)

Duplexing	**SCS (kHz)**		**Per CC BW (MHz)**	**Peak data rate per CC (Gbit/s)**
TDD (DDDSU) + SUL[Note 1]	FR1 (N_{layer} = 4)	15	50	1.12~1.18
		30	100	2.28~2.39
		60	100	2.27~2.38
TDD (DSUUD, S slot =11DL:2GP:2UL)	FR1 (N_{layer} = 4)	30	100	1.06
		60	100	1.05
	FR2 (N_{layer} = 4)	60	200	1.91
		120	400	3.85
TDD (DSUUD, S slot =6DL:2GP:6UL)	FR1 (N_{layer} = 4)	30	100	1.05
		60	100	1.04
	FR2 (N_{layer} = 4)	60	200	2.02
		120	400	4.04
TDD (DDDDDDDSUU, S slot= 6DL:4GP:4UL)	FR1 (N_{layer} = 4)	30	100	0.612
		60	100	0.610

NOTE 1 – The peak data rate with SUL is larger as additional UL bandwidth is available in FR1 than without SUL. The same additional UL bandwidth can be achieved by carrier aggregation of a carrier with UL bandwidth and DL bandwidth, in which DL or UL bandwidth of carrier aggregation is the same with bandwidth as the SUL.

NOTE 2 – FR1 is lower or around 6 GHz frequency band. FR2 is larger than 6 GHz, such as 26 GHz to 28 GHz.

TABLE 16

UL peak data rate (Study 2)

Duplexing (Note 1)	**Subcarrier space (kHz)**		**Per CC BW (MHz)**	**Peak data rate per CC (Mbit/s)**
TDD (DDDSUUDDDD) S slot= 3DL:8GP:3UL)	FR1 (N_{layer} = 2)	15	50	136.8746
		30	100	276.7909
		60	100	273.7492
TDD (DDDSUUDDDD) S slot= 6DL:4GP:4UL)	FR1 (N_{layer} = 2)	15	50	141.2899
		30	100	285.7196
		60	100	282.5798

TABLE 16 (*cont.*)

Duplexing (Note 1)	**Subcarrier space (kHz)**		**Per CC BW (MHz)**	**Peak data rate per CC (Mbit/s)**
TDD (DDDSUUDDDD) S slot= 4DL:6GP:4UL)	FR1 ($N_{layer} = 2$)	15	50	141.2899
		30	100	285.7196
		60	100	282.5798
TDD (DDDS$_1$UUDS$_2$UU) S$_1$ slot= 6DL:4GP:4UL) S$_2$ slot= 10DL:4GP:0UL)	FR1 ($N_{layer} = 2$)	15	50	264.9186
		30	100	535.7243
		60	100	529.8372
TDD (DDDSUUUUDD) S slot= 6DL:4GP:4UL)	FR1 ($N_{layer} = 2$)	15	50	264.9186
		30	100	535.7243
		60	100	529.8372
TDD (DDDSU) S slot= 10DL:2GP:2UL)	FR1 ($N_{layer} = 2$)	15	50	141.2899
		30	100	285.7196
		60	100	282.5798
	FR2 ($N_{layer} = 1$)	60	200	270.2938
		120	400	540.5875
TDD (DDDSU) S slot= 0DL:2GP:12UL)	FR1 ($N_{layer} = 2$)	15	50	229.5961
		30	100	464.2944
		60	100	459.1922
	FR2 ($N_{layer} = 1$)	60	200	439.2274
		120	400	878.4547
TDD (DDSUU) S slot= 12DL:2GP:0UL)	FR1 ($N_{layer} = 2$)	15	50	247.2574
		30	100	500.0093
		60	100	494.5147
	FR2 ($N_{layer} = 1$)	60	200	473.0141
		120	400	946.0282
TDD (DSUUU) S slot= 10DL:2GP:2UL)	FR2 ($N_{layer} = 1$)	60	200	743.3078
		120	400	1486.6157

NOTE 1 – Different special slot configurations may be used other than the ones listed.

4.2 Network layout

4.2.1 Indoor hotspot

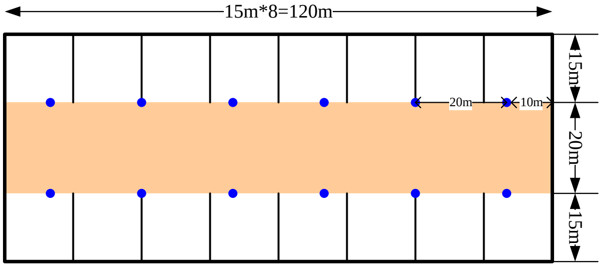
The indoor hotspot network targets isolated cells at office or in hotspot base on pedestrian and stationary mobile stations. Moreover, the test environment will face some huge challenges, such as smallest cells, higher user data rate and user density, which mainly focus on eMBB and URLLC usage scenarios.

Currently, a specific indoor network layout can be found for IMT-2020, which has been published in the 3GPP (3rd Generation Partnership Project) for 5G radio access system(s) and Report ITU M.2412.

More specifically, the model can be described as one floor of a building, which includes 16 rooms of 15 m × 15 m and a long hall of 120 m × 20 m, and the height of the floor is 3 m. Furthermore, with regard to Base station deployment scheme, 12 small cells are placed in the corridor: 6 along one long edge and 6 more along the other long edge. The ISD (Inter-site distance) is 20 m, while the first small cell in each edge is placed at 10 m with respect to the left side of the building. The network topology can be found in Fig. 5.

FIGURE 5

Network topology about Indoor isolated environment

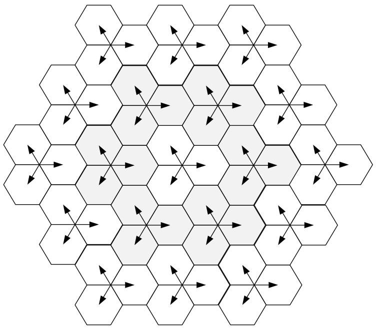


4.2.2 Urban macro

The Urban macro mainly considers continuous coverage and large cells (e.g. ISD=500 m/1 732 m). Then it is an interference-limited and radio access points of base station above rooftop level in homogeneous macro-cellular environment.

FIGURE 6

Network topology about Urban Macro



As to some details of topology structure, it is notable seen that Base stations are placed in a regular grid, following hexagonal layout. A basic hexagon layout for the example of three cells per site is shown in Fig. 6. In particular, when simulation model are considered, a wrap-around configuration of 19 sites, each of three cells, is more acceptable. Moreover, all mobile stations are dropped randomly and uniformly over the whole area; and mobility of mobile station is from pedestrian up to fast vehicular users.

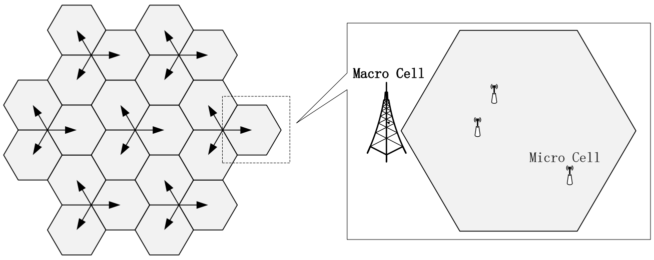
As a classical test environment, during the 5G period, although the test environment also is important for eMBB usage scenario, some potential URLLC or/and mMTC usage scenarios will be evaluated in the Urban Macron network topology.

4.2.3 Urban micro

Urban micro is an urban heterogeneous micro-cellular environment with higher user density focusing on pedestrian and slow vehicular users, which mainly focus on eMBB usage scenario.

FIGURE 7

Network topology on Urban micro



Furthermore, this test environment focuses on small cells and high user densities and traffic loads in city centres. More specifically, the kind of network topology can be found from Fig. 7; and it is significantly similar with Urban Macro but with reduce site-to-site distance to 200 m and the antennas of macro cell above rooftops, in which 3 to 9 small cells are possibly randomly distributed into each macro cell. The main advantage is effectively improving data rate of mobile stations in the edge of macro cell; but interference limited also is simultaneously introduced.

Other key characteristics of this test environment are both outdoor and outdoor-to-indoor coverage, in which base station of small cell shall be below rooftop level.

4.3 Interference evaluation of Multiple IMT-2020 TDD Networks operating in adjacent channel and co-channel

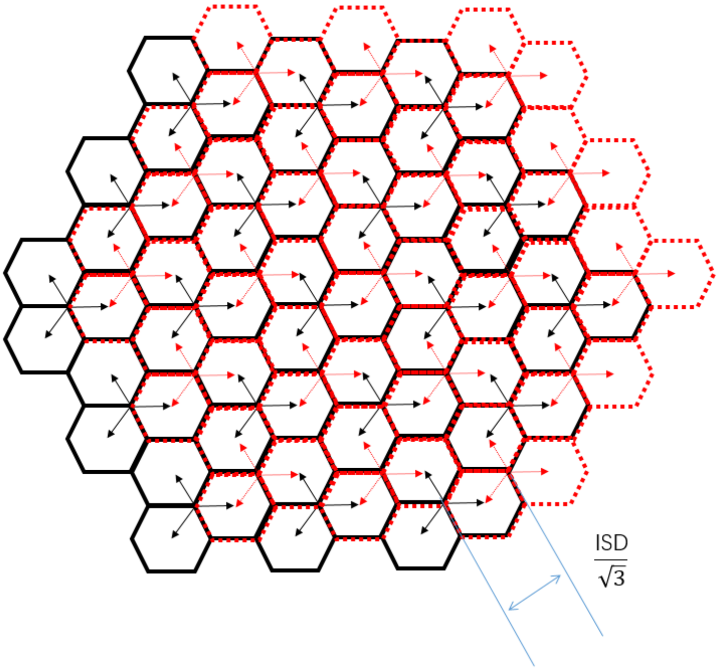
4.3.1 Mid band Macro cell to Macro cell

4.3.1.1 Scenario 1

For the first phase deployment, IMT-2020 system would be deployed in the mid band. And Macro cell would be main force to provide basic coverage. In this section, we provide the simulation results of TDD synchronization performance. Within the simulation, 2.6 GHz centre frequency and 350 m ISD are assumed. Nineteenth cells and three sectors per cell are considered to simulate the interference between cells and networks. The deployment is illustrated as below. The detailed simulation assumptions could be found in Annex 1. Synchronized and unsynchronized operations are compared. And the throughput loss is assumed as performance metric.

FIGURE 8

2.6 GHz Macro cell to Macro cell interference scenario



The metric for the degradation of a victim system by the presence of an interfering system on adjacent channel in the present document is the throughput loss in dependence of Adjacent Channel Interference Ratio (ACIR). ACIR is defined as

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

ACLR is the adjacent channel leakage power ratio of the interfering systems transmitter and ACS is the corresponding receiver requirement on adjacent channel selectivity of the victim system receiver. It is assumed that the throughput loss of the victim system shall not exceed 5%.

The simulation results are as below.

TABLE 17

Mid band synchronization performance evaluation results (cell average throughput loss ratio) in adjacent channel case

Interference	**ACIR (Adjacent channels without guard band)**	**Study 1**		**Study 2**
		Case #1	**Case #2**	**Case #2**
BS TX ➔ BS RX	42	100%	57.91%	54.3%
BS TX ➔ UE RX	32.7	0.12%	0.55%	0.72%
UE TX ➔ BS RX	30.8	0.02%	0.10%	1.3%

TABLE 18

The assumptions of ACLR and ACS in the mid-band simulations

	ACLR	**ACS**
UE	31	33
BS	45	45

Case #1 presents the base station of Network A locate at the same position of Network B, such as reusing a same antenna pole. Case #2 presents the situation in Fig. 8. The base station of Network A locates ISD/sqrt(3) away from the base station of Network B. The ACLR, ACS and ACIR assumptions are listed in the above tables. The cross-link interference happens under this situation. In Case #1, the interference from downlink transmission will induce 100% uplink throughput loss of the victim network. In Case #2 that is around 288 m isolation distance, the interference from downlink could also cause 54.3% and 57.91% throughput loss of the uplink in the victim network. Significant performance losses are observed when two Macro cell networks work under different uplink and downlink configurations, even when they are deployed in the adjacent frequency bands. Hence, for better frequency utilization efficiency and performance, the two TDD networks need to work under a same uplink and downlink slot configuration. Or interference cancellation mechanisms and additional isolations should be introduced.

The BS TX to UE RX and UE TX to BS RX in Table 17 represents the DL to DL interference and UL to UL interference of two networks. The cell throughput loss due to the DL-DL and UL-UL interference is below 5%.

The co-channel interference evaluations under the same deployments are carried out. The evaluation results are as below.

TABLE 19

Mid band synchronization performance evaluation results (cell average throughput loss ratio) in co-channel

Interference	**ACIR (Adjacent channels without guard band)**	**Study 1**		**Study 2**
		Case #1	**Case #2**	**Case #2**
BS TX ➔ BS RX	0	100%	100.00%	99.9%
BS TX ➔ UE RX	0	17.87%	30.88%	29.5%
UE TX ➔ BS RX	0	10.02%	22.20%	24.7%

Under the co-channel situation, as the two networks located too close to each other, the un-synchronized operation would induce almost 100% performance losses. And for even the synchronized operation but without any protection from the interference, the performance losses are severe.

In conclusion, when two outdoor TDD mid-band Macro cell networks are deployed closely, the networks should work under the synchronized operation mode Considering the wide coverage of the mid-band Macro cells, semi-synchronized operation and unsynchronized operation could not work under this situation. In the situation of co-channel deployments, the performance loss could be almost 100% based on the simulations. The even in the synchronized operations, the performance loss is severe. Considering the interference situation under co-channel deployments, the networks should avoid being deployed in such a close proximity.

4.3.1.2 Scenario 2

When the two TDD mid-band macro cell networks are deployed not closely, they may be in unsynchronized operation, and the Table below gives order of magnitude of the required minimum separation distances associated with different throughput losses.

Monte-Carlo simulations have been performed for BS TX ➔ BS RX in various scenarios in the 3.5 GHz band, both with AAS and non-AAS, with ‘worst-case’ (i.e. fully unsynchronised, where aggressor is simulated with 100% downlink and victim with 100% uplink) and ‘average case’ (where the throughput loss is assumed to be half of the worst case because of partial duplex misalignment), and for suburban and rural configurations. The detailed simulation assumptions could be found in Annex 3. The results are as follows.

TABLE 20

Scenario	**Co-channel (worst-case, fully unsynchronised)**						**Co-channel (average case, partial duplex misalignment)**						**Adjacent-channel (worst-case, fully unsynchronised)**		
	Suburban			**Rural**			**Suburban**			**Rural**			**Suburban**		
UL TP loss (%)	10	20	30	10	20	30	10	20	30	10	20	30	10	20	30
D(km), AAS to AAS	28.51	19.9	16.76	64.22	46.38	37.52	19.9	13.91	9.318	46.38	29.91	19.77	4	2.632	1.96
D(km), AAS to non-AAS	32	26.5	23	60	45	38	26.5	20.5	17	45	30	28	5.5	4.4	3.5
D(km), non-AAS to AAS	38	30	26	80	54	44	30	22	15	54	37	23	3	2,3	1,7

Within this separation area, systems with proper compatible configurations might still be deployed (e.g. with solutions such as downlink symbol blanking where only non-overlapping U/D symbols are enabled, which is essentially equivalent to synchronized operation with some capacity loss)[2].

4.3.2 Millimetre wave Micro cell to Indoor hotspot

The millimetre wave system could bring extreme high user data experience. But coverage of mmW is limited and sensitive to the blockage. The initial thinking is that mmW could be deployed as Micro cell for outdoor and the inter-site distance could be around 200 m. The indoor hotspot could be another scenario for the first phase deployment of mmW. Seven site Micro cells and three sectors per cell are assumed for the evaluation. And the indoor hotspot is located in the middle of the Micro cell networks. The building size of indoor hotspot is 120 m × 50m and the inter site distance of Micro cells is 200 m. Considering that, three candidate locations are assumed for the evaluation, i.e. 20 m, 40 m, 60 m distance from the left wall of InH to the centre of Cell#1. The deployment scenario could be found in Fig. 9. The traffic in the Micro cells is downlink dominant. And the traffic in the indoor

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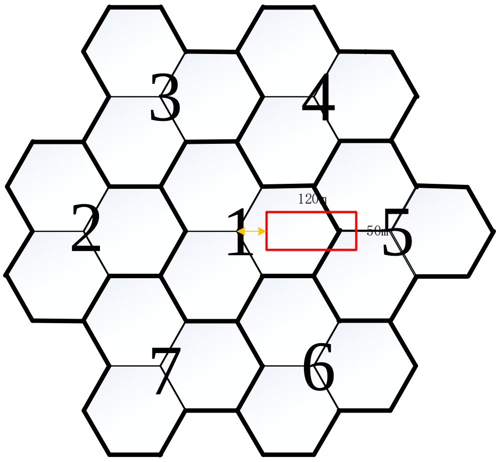
[2] DSB allows the base stations’ schedulers to switch off transmissions (‘blanking’) for those downlink symbols (‘blanked DL symbols’) of each network that correspond to simultaneous uplink reception or simultaneous gap symbols for the other network. By avoiding simultaneous DL/UL transmissions in the geographic ‘DSB implementation zone’, DSB allows the deployment of non-compatible frame structures across operators, benefiting from the advantages of synchronized operation with some degree of downlink capacity loss and some loss in coverage, depending on the implementation. This allows to avoid geographic isolation between two networks due to the fact that DL transmissions will not collide with UL reception from the other network.

hotspot could be more flexible and the uplink slot could occupy a relative higher ratio. The detailed simulation assumptions could be found in the Annex 2.

FIGURE 9

26 GHz Micro cell to indoor hotspot interference scenario



The simulation results could be found below. Low penetration loss and high penetration loss from [1] are used.

TABLE 21

mmW synchronization performance evaluation results in adjacent channel case

Low penetration loss = 17.4 dB

Interference	**Distance (m)**	**ACIR assumption (dB)**	**Throughput loss (%)**
BS TX ➔ BS RX	20	26	4.75
	40	25	3.56
	60	27	1.72

High penetration loss = 37.3 dB

Interference	**Distance (m)**	**ACIR assumption (dB)**	**Throughput loss (%)**
BS TX ➔ BS RX	20	6	4.88
	40	5	3.66
	60	6	2.21

For the mmW, only the cross link interferences are simulated. The main interference is from Micro cell downlink to the indoor hotspot uplink. Due to the high propagation loss and penetration loss of mmW, the cross link interference from the outdoor network seems controllable. Under the low penetration loss assumption, e.g. 17.4 dB, the ACIR requirement is around 27 dB and the throughput loss is below 5%. And in the case of high penetration loss, e.g. 37.3 dB, the ACIR requirement could be even lower, around 5 dB to 6 dB. Please note that, the ACIR assumption in the low penetration loss table is closer to the ACIR requirements to the mmW base station specifications. And the ACIR assumption in the high penetration loss case is more like under which condition could the throughput loss less than 5% could be maintained. When the ACIR assumption in the high penetration case is assumed the same as low penetration case, the performance loss will be far lower than 5%. Thus, under this condition, the outdoor Micro cell network and the indoor network could work in the semi-synchronized operation mode and un-synchronized operation mode. However, if the material of the building is uncertain, the alignment of slot/subframe boundary between two networks can facilitate further isolation enhancement or interference cancellation mechanisms.

The co-channel interference evaluations under the same deployments are carried out. The evaluation results are as below.

TABLE 22

mmW synchronization performance evaluation results in co-channel case

Low penetration loss = 17.4 dB

Interference	**Distance (m)**	**ACIR assumption (dB)**	**Throughput loss (%)**
BS TX ➔ BS RX	20	0	96.47
	40	0	96.28
	60	0	97.78

High penetration loss = 37.3 dB

Interference	**Distance (m)**	**ACIR assumption (dB)**	**Throughput loss (%)**
BS TX ➔ BS RX	20	0	35.89
	40	0	34.24
	60	0	43.97

Under the co-channel situation, as the two networks located too close to each other, the un-synchronized operation would induce above 95% performance losses in the low penetration loss case. In the high penetration loss case, the performance loss of indoor system could be lower, but still around 34.24% to 43.97%. The micro cell network and the indoor system deployed in the co-channel situation could not work under the un-synchronized operation without enough isolation. A similar issue would happen under the semi-synchronized operations. More isolations are required if both networks would work in the co-channel deployments, compared with adjacent deployments.

In conclusion, when the one mmW Micro cell network and one indoor network are deployed in close proximity, both unsynchronized operation and semi-synchronized operation are feasible under adjacent channel deployments if the indoor network is sufficiently isolated. Under the co-channel deployments, the performance loss is more severe and more isolation would be required, e.g with additional geographic separation. Due to the uncertainty of deployment conditions and the uncertainty of building materials, the physical isolations may not be sufficient to depress the interference. Hence, alignment of slot/subframe boundary between two networks can facilitate further isolation enhancement or interference cancellation mechanisms in the adjacent channel deployments. Since outdoor networks typically experience larger interference as compared to indoor networks, mmW outdoor networks need to be synchronized unless there is sufficient geographic separation between the networks.

5 Summary

In this Report, the multiple synchronization operations are studied for the IMT-2020 TDD networks, when they are deployed in a close proximity using the same frequency band. As the one of the main issues under this situation is the interference from the other networks, the interference scenarios and multiple synchronization operations are discussed. The synchronized operation could avoid the cross-link interference between networks and provide the excellent performance in an economic and efficient way.

And in the evaluation part, the multiple frame structures and their performance of transmission latency are analysed for both uplink and downlink. Different configurations of frame structure could be used serving different targets, such as diverse uplink and downlink traffic loads, various latency requirements and different coverages. After that, the typical network layouts are elaborated, which are used for the interference evaluations.

Mid band of Macro cell to Macro cells are evaluated in both co-channel and adjacent channels. The performance loss under the un-synchronized operation could be beyond 50% when the two networks are deployed too close and even in the adjacent channel. Thus, when two outdoor TDD mid-band Macro cell networks are deployed closely, the networks should work under the synchronized operation mode. Considering the wide coverage of the mid-band Macro cells, semi-synchronized operation and unsynchronized operation could not work under this situation. And in the co-channel deployments, for even synchronized operation, the performance losses are severe and not acceptable. Thus, it is proposed to avoid such short distance deployment of two networks in co-channels.

Further, interference from millimeter wave Micro cell to indoor hotspot are studied. When the one-millimetre Micro cell network and one indoor network are deployed in close proximity, both unsynchronized operation and semi-synchronized operation are feasible under adjacent channel deployment if the indoor network is sufficiently isolated. Under this situation, Micro cell and indoor network could be configured with diverse uplink and downlink ratios to fit to different kind services. Under the co-channel deployments, the performance loss is more severe and more isolation would be required, e.g. with additional geographic separation. Since outdoor networks typically experience larger interference as compared to indoor networks, mmW outdoor networks need to be synchronized unless there is sufficient geographic separation between the networks.

References

[1] Report ITU-R M.2412-0 (10/2017) – Guidelines for evaluation of radio interface technologies for IMT-2020.

[2] 3GPP TS 38.306: 3rd Generation Partnership Project; Technical Specification Group Radio Access Network; NR; User Equipment (UE) radio access capabilities (Release 16).

[3] 3GPP TS 38.101-1: 3rd Generation Partnership Project; Technical Specification Group Radio Access Network; NR; User Equipment (UE) radio transmission and reception; Part 1: Range 1 Standalone (Release 16).

[4] 3GPP TS 38.101-2: 3rd Generation Partnership Project; Technical Specification Group Radio Access Network; NR; User Equipment (UE) radio transmission and reception; Part 2: Range 2 Standalone (Release 16).

Annex 1

Simulation assumptions for 2.6 GHz Macro cell to Macro cell scenario in Scenario 1

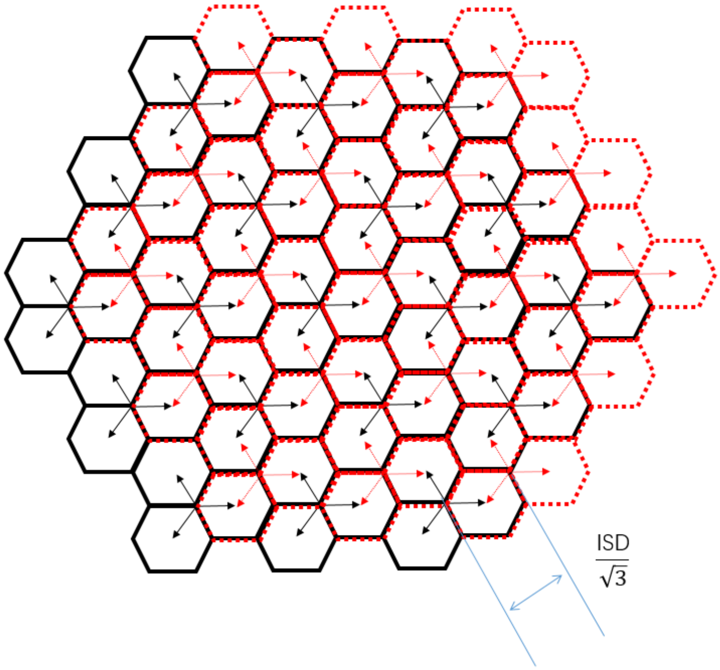
A1.1 Interference scenario

For lower frequency band such as 2.6 GHz, only Macro cell to Macro cell interference are evaluated. Both networks consider 19 cells and 57 sectors deployments. And the distance between the base stations of two networks is ISD/sqrt(3), in which networks A’s base stations locate at the cell edge of network B. Both synchronized and semi-synchronized situation will be evaluated.

The definition of macro cell could refer to § 4.2.2.

FIGURE 10

2.6 GHz Macro cell to Macro cell interference scenario



A1.2 Simulation assumption

The detailed simulation assumption under this scenario is as below.

evaluation
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Annex 2

Simulation assumptions for 26 GHz Micro cell to Indoor hotspot scenario in Scenario 1

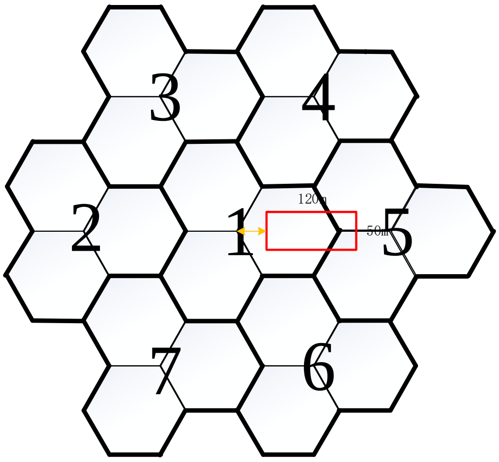
A2.1 Interference scenario

Due to the propagation loss of millimetre wave, 7-site Micro cells with inter-site distance of 200 meters are considered. And the indoor hotspot deployment is located between the Cell #1 and #5. The distance between Cell #1 and the left side of indoor hotspot is 40 metres. The traffic in the Micro cells is downlink dominant. But the traffic in the indoor hotspot scenario is assumed downlink and uplink equally dominant or uplink dominant.

The definition of micro cell and indoor hotspot could refer to §§ 4.2.3 and 4.2.1.

FIGURE 11

26 GHz Micro cell to indoor hotspot interference scenario



A2.2 Simulation assumption

The detailed simulation assumption under this scenario is as below.

evaluation
assumptions of m

Annex 3

Simulation assumptions for 3.5 GHz Macro cell to Macro cell unsynchronised operation in Scenario 3

A3.1 Interference scenario

Similarly to Study 1, simulations have been performed where networks consider 19 cells and 57 sectors deployments. However an additional separation distance D is inserted between the closest cells of the two networks. Simulations are performed for various combinations of scenarios where aggressor and victim networks are either using AAS or non-AAS.

Successive iterations are made with those Monte-Carlo simulations in order to determine the distance D where the victim network uplink throughput loss is below a defined threshold (10%, 20% and 30%). Within this separation area, systems with proper compatible configurations might still be deployed (e.g. with solutions such as downlink symbol blanking where only non-overlapping U/D symbols are enabled, which is essentially equivalent to synchronized operation with some capacity loss)[3].

Simulations were first performed with worst-case where networks are fully unsynchronized, i.e. where the aggressor network has 100% downlink and the victim networks has 100% uplink. Then for ‘average case’ the simulation results of ‘worst-case’ have been reused with a scaling factor of 0.5 on the UL throughput loss considering the assumptions that only half of the UL slots of the victim would face a corresponding DL slot from the aggressor at the same time.

A3.2 Simulation assumption

The detailed simulation assumption under this scenario is as below.

Parameters.xlsx

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[3] DSB allows the base stations’ schedulers to switch off transmissions (‘blanking’) for those downlink symbols (‘blanked DL symbols’) of each network that correspond to simultaneous uplink reception or simultaneous gap symbols for the other network. By avoiding simultaneous DL/UL transmissions in the geographic ‘DSB implementation zone’, DSB allows the deployment of non-compatible frame structures across operators, benefiting from the advantages of synchronized operation with some degree of downlink capacity loss and some loss in coverage, depending on the implementation. This allows to avoid geographic isolation between two networks due to the fact that DL transmissions will not collide with UL reception from the other network