# GTI Vertical Spectrum Strategy White Paper

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# 1 Executive Summary

This white paper provides a GTI companies' initial study for the spectrum sharing issue for the operators to serve the vertical industry markets with their existing spectrum. The study assesses the overall system level performance for coexistence scenarios where a local vertical industry use e.g a URLLC factory network has to fulfil the desired latency and reliability requirements while being interfered by the overlaid operator macro network offering wide area coverage in the same frequency band. The interference scenarios include both synchronized TDD operation and unsynchronized TDD operation for both co-channel and adjacent channel deployment for coexistence of the networks. The study is made through a system level performance analysis from both coverage and capacity point of view. The main focus is on the impact of the eMBB network interference on the performance of the factory network. However, the impact on the performance of the eMBB network is also briefly discussed.

The study results have shown that the high downlink interference from the macro base stations towards the micro factory BS results in a reduction of the downlink URLLC capacity and service availability in case of synchronized TDD and a reduction of the uplink URLLC capacity and service availability in case of unsynchronized TDD. The results confirm that a promising case for co-existence is the adjacent channel allocation, for both synchronized and unsynchronized TDD deployments.

The study gives initial recommendation for operators for their future operation deployment. A local factory URLLC network can co-exist with an eMBB network when a total isolation of approximately 73 dB is guaranteed to protect the URLLC network in the worst-case scenario where the factory is located next to a macro site. Some of the requirements for isolation can be met by increasing spatial isolation., such as increased wall penetration loss (considering metal-coated or thick concrete building walls), factory site densification, and larger separation distance,.  While the remaining isolation can be handled by interference solution, which will be further studied.

For unsynchronised eMBB macro BS and URLLC macro BS, results have shown that the separation distance of 60~120km km is required to reach the throughput loss of less than 5% when ACIR=0dB. Considering the curvature of the earth, the base station is 30 meters high and the corresponding maximum distance of LOS is 45km. Considering the phenomenon of atmospheric waveguide, interference distance may exceed 45km.
with the ACIR value increases, the required separation distance decreases significantly, when ACIR=45dB, 3~9km separation distance is needed to meet the protection criteria based on the simulation assumptions above.

Further study could be made with more cases and comprehensive assessment to support future operator trials and more practical deployment, therefore the study results could be further revisited in future.

# 2 References

[1] 3GPP, “Study on channel model for frequencies from 0.5 GHz to 100 GHz”, 3GPP TR 38.901, V15.0.0, Jun. 2018.

[2] E. Semaan, F. Harrysson, A. Furuskär, and H. Asplund, “Outdoor-to-indoor coverage in high frequency bands”, in Proc. IEEE Globecom 2014 Workshop – Mobile Communications in Higher Frequency Bands, Austin, TX, USA, Dec. 2014.

[3] 3GPP TS 38.101, “NR; User Equipment (UE) radio transmission and reception; Part 1: Range 1 Standalone”, June 2017.

# 3 Abbreviations

| | |
|---|---|
| ACIR | Adjacent Channel Interference Ratio |
| ACLR | Adjacent Channel Leakage Ratio |
| BS | Base Station |
| eMBB | enhanced Mobile Boradband |
| ISD | Inter Sites Distance |
| OFDM | Orthogonal Frequency Division Multiplexing |
| QAM | Quadrature Amplitude Modulator |
| QoS | Quality of Service |
| QPSK, | Quadrature Phase Shift Keying |
| TDD | Time Division Duplex |
| TTI | Transmission Time Interval |
| UE | User Terminal |
| URLLC | Ultra-Reliable Low-Latency Communication |

# 4 Introduction

MNO 5G network provides services to different industry users, this usage have been consider as key trends to expand use cases of 5G network. It will bring beneficial to reuse operator existing network, accelerate new 5G infrastructure implementation, and also facilitate digital industry transformation. GTI has created the new program of enterprise network solution to study the technical solutions for servicing vertical industries.

How to use operator IMT spectrum to provide industry use cases for vertical industry is one of the important aspects that GTI needs to study. This white paper will study the spectrum sharing issue for operator to serve the vertical industry markets. An important vertical market use case for URLLC is factory automation with latency requirement of 1ms and reliability requirement of 99.999%. It is crucial to assess the overall system level performance for coexistence scenarios where a local factory network has to fulfil the desired latency and reliability requirements while being interfered by the overlaid macro network offering wide area coverage in the same frequency band.

The white paper is to assess the performance of the co-existence of a macro and a local factory network under two scenarios:

(i) Synchronized TDD operation scenario, in which both victim (local factory network) and interfering networks (macro public mobile network) follow the same TDD TTI configuration;

(ii) Unsynchronized TDD operation scenario, in which the macro public mobile network and the local factory network follow different TDD TTI configuration (i.e., the macro network follows an eMBB-optimized TDD TTI configuration, while the local factory network follows an URLLC-optimized TDD TTI configuration).

We consider both a co-channel and an adjacent channel deployment of the co-existing networks and provide a system-level performance analysis from both the coverage and the capacity point of view.



## 4.1 Background

GTI has established new program of enterprise network solution to study the technical solutions for serving vertical industries. The strategy is to use operator existing spectrum to serve the vertical industry and build a private network. Since operator spectrum is valuable property for their business development, efficiently using the spectrum for both public user and vertical industry users is crucial and the performance of for public macro coexistence with local factory network need to be studied first.

## 4.2 Objectives

The objectives of the white paper are:

- To study the co-channel and adjacent channel coexistence between the operator public mobile network and local vertical using network with both synchronized and unsynchronized TDD operation.
- Give recommendation for future operation deployment for their industry use cases within the same frequency band with public mobile network operation

# 5 Interference Scenarios and System Assumption Model

## 5.1 Assumption of deployments for macro and local network:

In this study it was assumed some example of deployment for operator macro network and local factory network. It considers an area of 1500×1500 $m^2$, as illustrated in Fig. 1, in which a macro and a local factory network are deployed. The macro network providing wide area eMBB coverage consists of seven tri-sectored sites with inter-site distance of 500 m (with wrap-around) and base station antenna height of 25 m. Meanwhile, for the local factory network offering URLLC connectivity, we consider a single factory of 100×100×10 $m^3$ with one tri-sectored ceiling-mounted site deployed in the middle of the factory, pointing horizontally with a specific down-tilt.

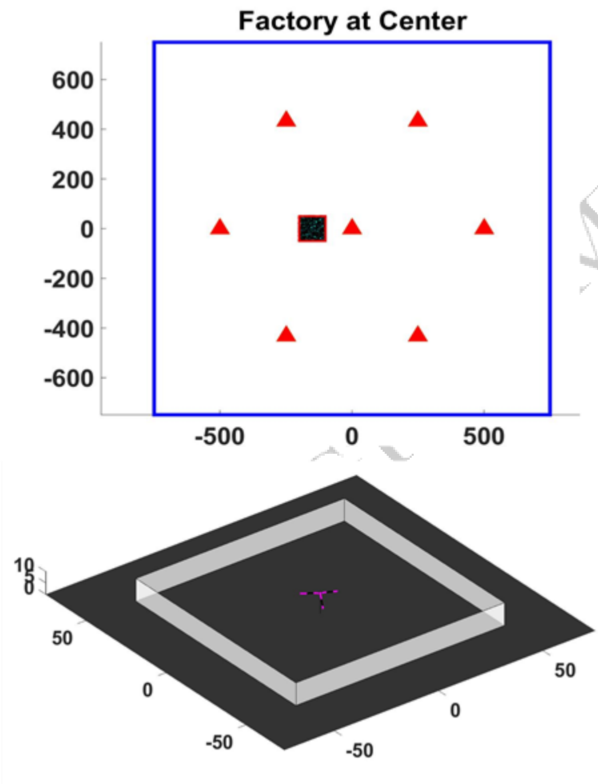


Fig. 1. Assumed network layout with seven tri-sectored macro sites (triangles) and one factory (rectangle, see also the figure below) with one tri-sectored site deployed in the middle of the factory.

We assume that the URLLC users are uniformly distributed inside the factory, while all the eMBB users are located outdoors and no eMBB users are located inside the factory. Moreover, we consider three different factory locations, thus realizing the different impact from/to the macro network: cell-edge, center, and near-BS(where center would be in the middle of ISD 500m, so 200 meters from wall to BS, and the near was basically no separation (or 1m).

We assume that the macro and the factory networks are operating in the 4.9GHz frequency band and apply TDD as the duplexing method. Two different TDD deployments are evaluated:

- Unsynchronized TDD: The macro network follows a DDDU TDD pattern while the local factory network follows a DUDU TDD pattern.
- Synchronized TDD: Both networks follow a DUDU TDD pattern.

## 5.2 TTI configuration for synchronized and unsynchronized TDD operation :

The TTI slot borders are assumed to be aligned for both synchronized and unsynchronized TDD configuration. Finally, the resulting probabilities for the different inter-network interference scenarios are given in Table I. Here, it is important to note that the considered TDD patterns are chosen as an example for comparison purposes of synchronized and unsynchronized TDD. Another reasonable TDD pattern is to consider an eMBB-optimized DDDU pattern for both networks for the case of synchronized TDD.  eMBB DDDU DL interference with UL URLLC DUDU probability is calculated with 3/4×1/2=37.5% and URLLC DL interference eMBB uplink proability is 1/4×1/2=12.5%.

TABLE I. PROBABILITIES OF THE DIFFERENT INTER-NETWORK INTERFERENCE SCENARIOS

| | Synchronized TDD | | Unsynchronized TDD | |
|---|---|---|---|---|
| | From eMBB to URLLC | From URLLC to eMBB | From eMBB to URLLC | From URLLC to eMBB |
| DL-to-DL (BS-to-UE) | 50% | 50% | 37.5% | 37.5% |
| DL-to-UL (BS-to-BS) | 0% | 0% | 37.5% | 12.5% |
| UL-to-UL (UE-to-BS) | 50% | 50% | 12.5% | 12.5% |
| UL-to-DL (UE-to-UE) | 0% | 0% | 12.5% | 37.5% |



## 5.3 Propagation model for coexistence study

We assume the 3GPP Urban Macro propagation model [1] for the links between the macro base stations and the eMBB users, and the 3GPP Indoor Hotspot Open Office model [1] for the links between the factory base stations and the indoor URLLC users. Furthermore, the path losses between the macro base stations and the users or base stations inside the factory are calculated as a combination of the 3GPP Urban Macro propagation model, wall penetration loss and an indoor loss. Meanwhile, the path losses between the factory base stations or users and the outdoor eMBB users are calculated as a combination of the 3GPP Urban Micro propagation model [11], wall penetration loss and an indoor loss. The wall penetration loss is modeled as a function of the wall material and frequency band and it accounts for the angular loss that is a function of the incident angle [2]. In this study, we assume that the wall penetration loss (for perpendicular penetration) is equal to 3 dB, corresponding to an average loss for a wall consisting approximately of 93% concrete and 7% traditional two-pane windows [1]. Furthermore, the simulation results are compared against “full isolation” in which case the wall loss has been assumed to be equal to infinity. Finally, the indoor loss is expressed as D din where D is 0.5 dB/m as in [1] and din is the travelled indoor distance.

## 5.4 URLLC performance metrics used for coexistence performance assessment

The URLLC users are assumed to be successfully served if they can fulfill the reliability requirement of 99.999% within a latency bound of 1 ms. In practice, the desired QoS cannot be guaranteed if a) the maximum achievable user bit rate is less than what would be required to transmit the message payload during one TTI, or b) the system does not have enough radio resources to successfully serve the total network offered load. For the performance evaluation, we consider the following URLLC metrics:

- URLLC service availability: Percentage of locations within the factory floor where the desired QoS can be guaranteed. We consider a uniform sampling across the factory floor where *i* corresponds to a particular sample and N is the total number of samples. The URLLC service availability, $SA_{URLLC}$, can be expressed as:

$$SA_{URLLC} = \left(\frac{\sum_{i=1}^{N} x_i}{N}\right) \times 100$$

  where $x_i$=1 if the desired QoS can be guaranteed and $x_i$=0 otherwise.
- URLLC system capacity: Maximum packet arrival rate at which the 100% URLLC service availability can still be reached. Service availability equal to 100% is essential for factory applications to guarantee continuous service throughout the factory floor.



## 5.5 Deployment scenarios for the coexistence performance assessment:

For performance assessment, we consider both a co-channel and an adjacent channel deployment. First, the impact of the inter-network interference on the coverage i.e., URLLC service availability and the average eMBB bit rates is evaluated for a co-channel deployment, assuming a fixed level of offered area traffic for both networks. Second, the impact of the inter-network interference on the URLLC system capacity is evaluated for an adjacent channel deployment.

# 6 Simulation Results and Analysis

This section includes coexistence study between macro BS and micro BS in section 6.1 for both co-channel and adjacent channel development scenarios.
In addition, coexistence study for unsynchronized case between macro BSs for eMBB and URLLC is included in section 6.2

## 6.1 Coexistence study between Macro BS and micro BS

In this section, we summarize the main findings for the assumed co-existence scenario between a local URLLC factory network and an overlaid macro eMBB network. The main focus of the study is on the impact of the eMBB network interference on the performance of the factory network. However, the impact on the performance of the eMBB network is also briefly discussed.

### 6.1.1 Simulation Assumptions and Parameters:

For performance evaluation, a simulator is used where the eMBB and URLLC networks are modeled with some statistical model and considering different traffic models and packet arrival rates.

TABLE I. SIMULATION PARAMETERS

| Parameter | Factory Network | Macro Network |
|---|---|---|
| Radio access technology | NR | NR |
| Frequency [GHz] | 4.9 | 4.9 |
| Bandwidth [MHz] | 50 | 50 |
| Duplex:<br>Synchronized TDD<br>Unsynchronized TDD | <br>DUDU<br>DUDU | <br>DUDU<br>DDDU |
| DL:UL traffic ratio | 1:1 | 1:1 |
| Sectors per site | 3 | 3 |
| BS transmit power [dBm] | 27 | 50 |
| UE transmit power [dBm] | 23 | 23 |
| UE Antenna Gain [dBi] (isotropic) | 0 | 0 |
| BS noise figure [dB] | 5 | 5 |
| UE noise figure [dB] | 9 | 9 |
| Max BS antenna element gain [dBi] | 8 | 8 |
| BS antenna array V x H x (Vs x Hs x Ps) | 2x4x(2x1x2) | 8x8x(1x1x2) |
| SNR-based uplink power control | Alpha=0.8 target SNR=10dB | Alpha=0.8 target SNR=10dB |



Table II provides a summary of the main simulation parameters for both networks considering NR at 4.9GHz, transmit power of factory BS is 27dBm and Macro Network transmit power is 50dBm. For the URLLC network, a subcarrier spacing of 30 kHz and packet size of 32 Bytes are assumed. A transmission time interval (TTI) length of 143 µs is considered with 4 OFDM symbols per TTI. Moreover, we consider QPSK, 16 QAM, and 64 QAM for the available modulation and coding schemes of the URLLC network with the corresponding (1/20, 1/10, 1/5, 1/3), (1/3, 1/2, 2/3), and (2/3, 3/4) code rates, respectively. Next, we summarize the main findings considering both a co-channel and an adjacent channel deployment.

### 6.1.2 Simulation Results for Co-channel Deployment

For a co-channel deployment, the local factory and the macro networks are assumed to be sharing the same channel, and the main objective is to evaluate both the URLLC service availability inside the factory and the average eMBB bit rates outside the factory. During the evaluations, the level of the offered area traffic is fixed to 5 packets/s/$m^2$ for the URLLC network and 100 Mbps/$Km^2$ (low eMBB) or 300 Mbps/km2 (high eMBB) for the eMBB network.

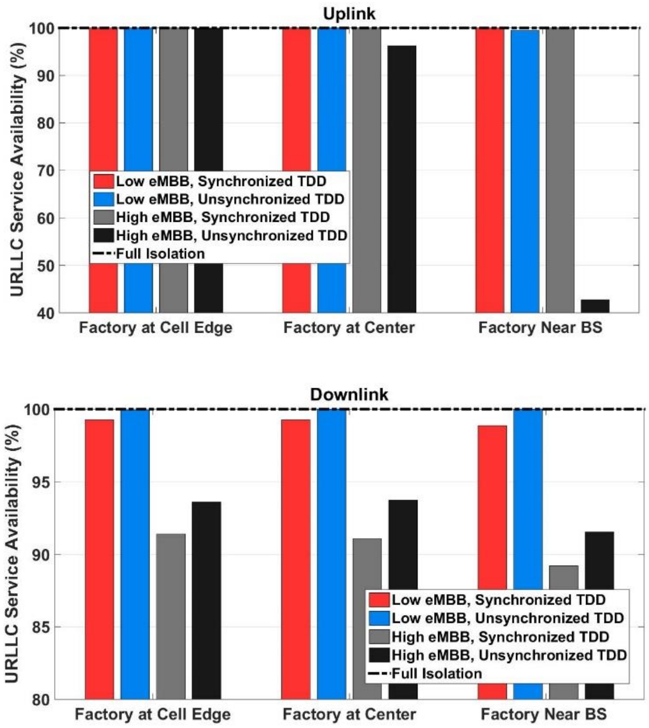


Fig. 2. Downlink and uplink URLLC service availability for the different factory locations.

Fig. 2 presents the results for downlink and uplink URLLC service availability for the different factory locations with respect to the macro site. Assuming an unsynchronized TDD deployment, full URLLC service availability can be achieved in the downlink for all factory locations if a low eMBB load is assumed (corresponding to an average macro cell utilization of approximately 20%), while with a high level of inter-network interference (average macro cell utilization of approximately 90%) the URLLC service availability drops to 92-94%. If a synchronized TDD deployment is assumed instead, the downlink URLLC service availability becomes clearly worse, and the full URLLC service availability cannot be observed for any of the factory locations, not even with the low level of eMBB load. There are two main reasons why the synchronized TDD results in a worse downlink URLLC performance compared to the unsynchronized TDD: a) the URLLC downlink is constantly interfered by high-power macro base stations, and b) the average downlink cell utilization of the macro network is increased from 20% to 30% (low eMBB) or from 90% to 100% (high eMBB) as a result of the change in the TDD pattern from DDDU to DUDU. Therefore, the level of the inter-network interference towards the URLLC downlink is increased at the time instances of downlink transmissions, resulting in worse downlink SINR values, and consequently in a worse downlink URLLC service availability as some of the users will not be able to reach their minimum required downlink bit rates.

Meanwhile, the situation looks the opposite for the uplink URLLC service availability. In case of unsynchronized TDD, the factory base stations are part of the time interfered by the downlink transmissions from the high-power macro base stations (cross-link interference between the base stations), which can have a very large negative impact on the uplink URLLC service availability in particular when the factory is located close to the macro site and if the load in the macro network is high. However, if the networks are synchronized, full uplink URLLC service availability can be secured for all three factory locations. Again, there are two main reasons why synchronized TDD is so beneficial for the URLLC uplink performance in this case: a) factory base stations are interfered only by the power-controlled eMBB users located outside the factory, b) the amount of uplink time domain resources is doubled for the eMBB users resulting in considerably reduced average macro cell utilizations (reduced from 100% to 60% in case of low eMBB). As a result, the level of inter-network interference experienced by the factory base stations becomes considerably lower, improving the uplink SINR values, and finally improving the URLLC service availability since more users can reach their minimum required uplink bit rates.

When it comes to the impact of the inter-network interference towards the macro network, we consider the scenario with a low eMBB load (100 Mbps/$km^2$). The impact on downlink performance is evaluated by looking at the average bit rate of the eMBB users within a 15 m polygon surrounding the factory, while the impact on the uplink performance is evaluated by looking at the average bit rate of the closest macro sector.

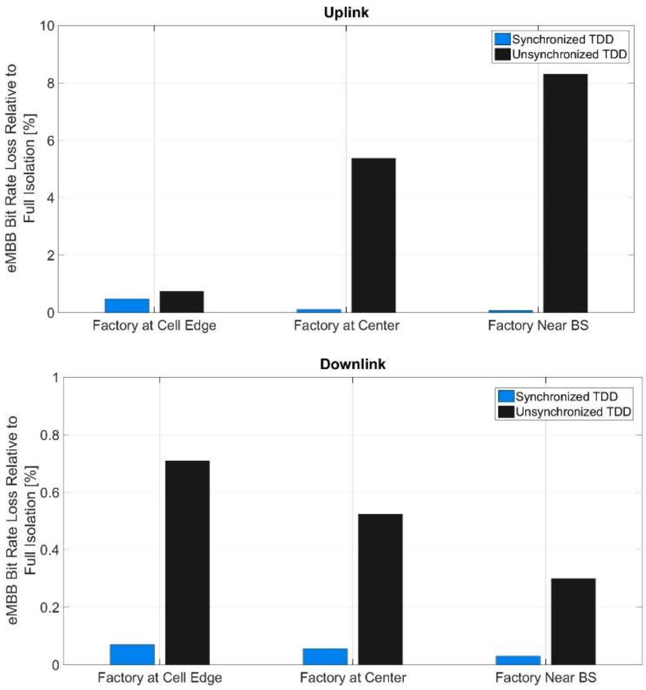


Fig. 3. Downlink and uplink eMBB performance losses for the different factory locations.

Fig. 3 shows the observed eMBB performance loss for synchronized and unsynchronized TDD compared to full isolation. As can be seen, the impact of the inter-network interference on the eMBB users is in general small in the downlink. The downlink performance losses are higher when the networks are unsynchronized, which can be explained by a lower level of the intra-network interference (due to a lower level of average cell utilization) resulting in a higher impact of the inter-network interference. Furthermore, the performance losses are the higher, the further away from the serving macro base station the victim users are located. However, even though the impact of the inter-network interference is higher for unsynchronized TDD, the overall eMBB downlink performance is still better due to the larger amount of time domain resources compared to the synchronized TDD. This can be clearly seen from Table III which summarizes the difference between the average eMBB bit rate for unsynchronized TDD relative to synchronized TDD for the case of full isolation, i.e., when the impact of the inter-network interference is ignored.

Looking at the uplink results for unsynchronized TDD, it can be noticed that the impact of the inter-network interference is clearly higher compared to the downlink. This is caused by the cross-link interference from the factory base stations towards the macro base stations. Furthermore, another disadvantage of the unsynchronized TDD is that the amount of time domain uplink resources is halved compared to the synchronized TDD, which results in clearly worse average eMBB bit rates even when a full isolation between the networks is assumed, as demonstrated by the values in Table III.

TABLE III. AVERAGE EMBB BIT RATE (GAIN IN DOWNLINK AND LOSS IN UPLINK) FOR UNSYNCHRONIZED TDD COMPARED TO SYNCHRONIZED TDD FOR THE CASE OF FULL ISOLATION.

| | Factory Location | | |
|---|---|---|---|
| | **Cell Edge** | **Center** | **Near BS** |
| **Downlink** | +76.8 % | +66.2 % | +55.4 % |
| **Uplink** | -53.7 % | -57.3 % | -54.4 % |

## 6.1.3 Simulation Results for Adjacent Channel Deployment

For an adjacent channel deployment, we study the required level of isolation between the networks so that the maximum URLLC system capacity is not affected by the inter-network interference. Here, we assume a fully-loaded macro network. Results for the downlink and uplink URLLC system capacity with respect to a scenario with full isolation between the networks are shown in Fig. 4.

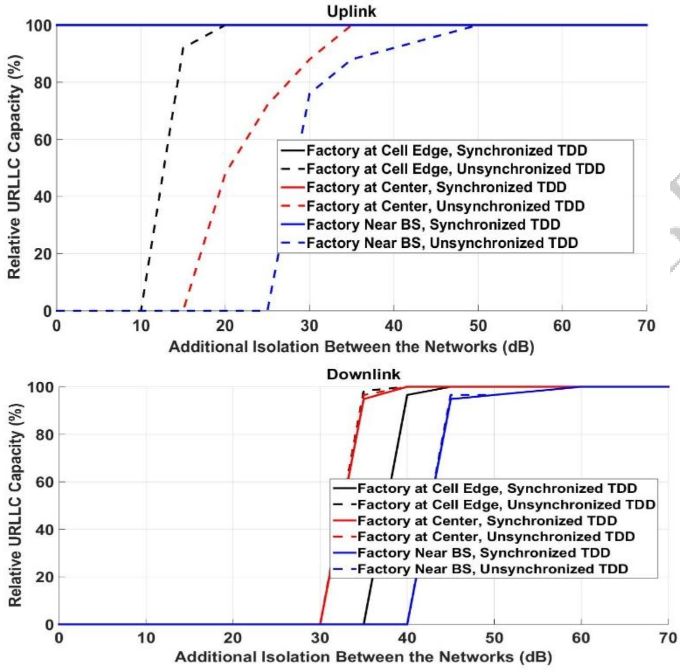


Fig. 4. Relative downlink and uplink URLLC system capacity as a function of the additional isolation between the networks on top of the assumed wall loss of 13 dB.

As can be noticed, a slightly lower level of isolation is required in the downlink for the case of unsynchronized TDD compared to synchronized TDD. It becomes also clear that the highest level of additional isolation, approximately 60 dB, is required when the factory is located next to the macro site. In uplink, however, a much higher level of isolation is required for the unsynchronized TDD compared to synchronized TDD. In case of synchronized TDD, the assumed wall penetration loss of 13 dB is sufficient to protect the URLLC network from any capacity losses, while in case of unsynchronized TDD an additional isolation of 55 dB is required when the factory is located next to the macro site.

In case of an adjacent channel deployment between the two networks, part of the required isolation is offered by the adjacent channel leakage ratio (ACLR) and the adjacent channel selectivity (ACS) of the involved transmitters and the receivers, respectively. In case of the synchronized TDD, the overall adjacent channel interference ratio (ACIR) would be limited to approximately 30 dB for both the downlink and the uplink due the UE characteristics (assuming for simplicity that the ACLR and ACS values are equal to 45 dB for the BS and 30 dB for the UE [3]). This means that the remaining 30 dB of the required isolation between the networks should be taken care of by an additional wall penetration loss or some other means. In case of unsynchronized TDD, a separate ACIR value would be applied for each inter-network interference scenario: 30 dB for downlink-to-downlink (BS-to-UE) and uplink-to-uplink (UE-to-BS), 42 dB for downlink-to-uplink (BS-to-BS) and 27 dB for uplink-to-downlink (UE-to-UE). In general, this means that in case of downlink where the required isolation is in the order of 60 dB for the worst-case deployment to cope with the high level of interference from the macro base stations towards the URLLC users, approximately 30 dB can be taken care of by the ACIR, while the remaining 30 dB have to be taken care of by other means. In case of unsynchronized TDD in uplink, the problems are related to the very high level of cross-link interference from the macro base stations towards the factory base stations. Here, most of the required isolation of 55 dB can be taken care of by the ACIR (42 dB), while the remaining 13 dB must be taken care of by some other means, such as increased wall penetration loss, factory site densification, and uplink power control.

However, it is also worth highlighting that the results presented here assume already a concrete wall with fairly small window areas. For a solid concrete wall, or assuming that the traditional windows would be replaced by modern energy-efficient windows, the wall loss would increase to approximately 19 dB [11], i.e., proving an additional isolation of 6 dB compared to the results shown above. Hence, in order to be able to protect the URLLC system capacity even within the worst-case deployment, some other means to either reduce the level of the inter-network interference, or to reduce the impact of the inter-network interference are required. As an example, the level of the inter-network interference can be lowered for example with metal-coated building walls, by avoiding deploying high-power macro sites close to the factory building, or by pointing the close-by macro base station antennas away from the factory. Furthermore, the impact of the inter-network interference can be reduced by densifying the factory network, or by increasing the transmission power of the factory base stations and the URLLC UEs.

## 6.2 Coexistence study coexistence between Macro BS and Macro BS

In this section, we provide the co-existence studies between eMBB macro BS and URLLC macro BS. The impact on the performance of both eMBB and URLLC are evaluated.

### 6.2.1 Simulation Assumptions and Parameters

Table 6.2-1 parameters

| **Simulation assumption** | **Macro cell** |
|---|---|
| Deployments | 3 sectors per cell |
| ISD | 500m |
| BS antenna height | 25m |
| down tilt | $12^{o}$ |
| Center frequency | 4.85GHz |
| Bandwidth | 100MHz |
| BS TX power | 53dBm |

| | |
|---|---|
| BS Antenna gain | (12,8,2,1,1)<br>5.5 dBi per element<br>Horizontal 0.5 lambda<br>Vertical 0.7 lambda<br>beamforming |
| Noise figure | 5 dB |
| OTA and Body loss | 7 dB (4+3) |
| UE height | 1.5m |
| Protection criteria | throughput loss < 5% |

BS-BS pathloss：

$$L_{BS-BS} = \begin{cases} -27.56 + 20\log(f) + 20\log(d) & 1 \le d \le d_{break} \\ -27.56 + 20\log(f) - 20\log(d_{break}) + 40\log(d) & d > d_{break} \end{cases}$$

Where, $d_{break} = \frac{4*h_{tx}*h_{rx}}{\lambda}$ , $\lambda$ is the wavelength.

Co-existence scenarios are shown as below in figure 6.1-1 and 6.1-2. There are 19 eMBB BSs with 57 sectors, and only one URLLC BS with 3 sectors. The red sectors are aggressor, the block sectors are victims.

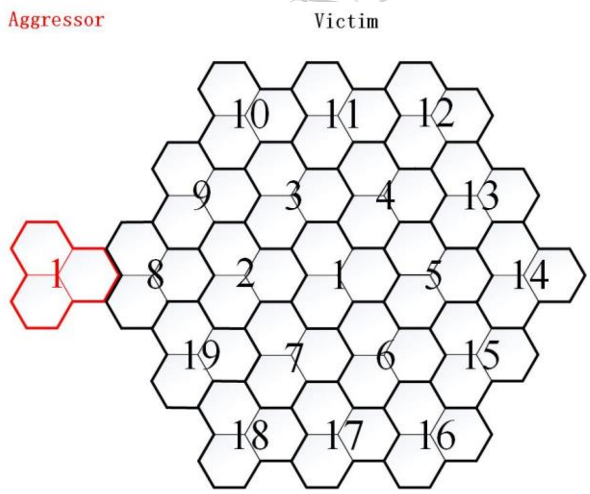


Figure 6.2-1 URLLC macro BS interfere eMBB macro BS

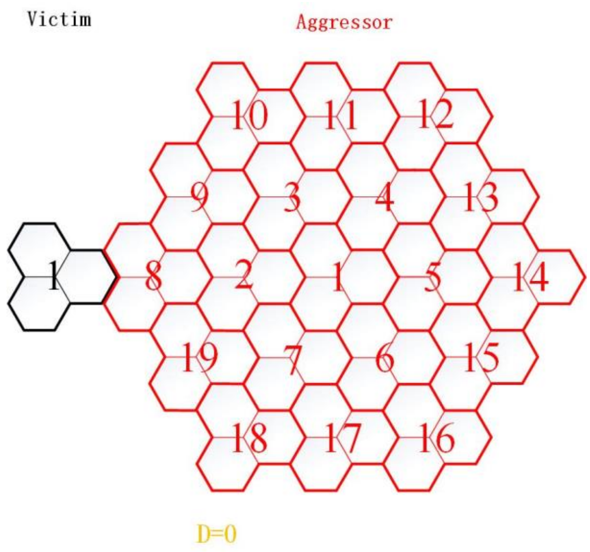


Figure 6.2-2 eMBB macro BS interfere URLLC macro BS

### 6.2.2 Simulation Results

Ensure that the throughput loss of the victim cells is less than 5%, the respective isolation distances for different ACIRs are shown in the table below.

Table 6.2-2 URLLC macro BS interfere eMBB macro BS

| ACIR(dB) | separation distance(m) | Throughput loss |
|---|---|---|
| 0 | 60 000 | 4.9% |
| 40 | 5 000 | 4.9% |
| 45 | 3 000 | 4.6% |

Table 6.2-3 eMBB macro BS interfere URLLC macro BS

| ACIR(dB) | separation distance(m) | Throughput loss |
|---|---|---|
| 0 | 120 000 | 4.9% |
| 40 | 12 000 | 4.3% |
| 45 | 9 000 | 4.4% |

# 7 Recommendations and Conclusions

This paper include coexistence between

- eMBB macro BS and URLLC micro BS case ( co-channel , and adj-channel cases)
- unsynchronised eMBB macro BS and URLLC macro BS (co-channel , and adj-channel case)

For eMBB macro BS and URLLC micro BS case

We have evaluated the performance of a co-existence scenario between an eMBB macro network and a local URLLC factory network with different network load levels as well as with different TDD patterns for both networks. Results have shown that the high downlink interference from the macro base stations towards the factory results in a reduction of the downlink URLLC capacity and service availability in case of synchronized TDD and a reduction of the uplink URLLC capacity and service availability in case of unsynchronized TDD. Furthermore, the results confirm that a promising case for co-existence is the adjacent channel allocation, for both synchronized and unsynchronized TDD deployments. A local factory URLLC network can co-exist with an eMBB network when a total isolation of approximately 73 dB is guaranteed to protect the URLLC network in the worst-case scenario where the factory is located next to a macro site. Here, most of the required isolation can be taken care of by the adjacent channel attenuation (42 dB), while the remaining isolation can be handled by some other means, such as increased wall penetration loss (considering metal-coated or thick concrete building walls), factory site densification, uplink power control, larger separation distance, and band pairing.

For unsynchronised eMBB macro BS and URLLC macro BS

Results have shown that the separation distance of 60~120km km is required to reach the throughput loss of less than 5% when ACIR=0dB, with the ACIR value increases, the required separation distance decreases significantly, when ACIR=45dB, 3~9km separation distance is needed to meet the protection criteria based on the simulation assumptions above. Further simulation of more casess would be needed to give a more comprehensive assessment Therefore, it is difficult to have support this scenario in practical development.

As part of future work, it is important to investigate and evaluate interference coordination mechanisms both in time and frequency domain (i.e., coordinated scheduling avoiding the most harmful collisions between the neighboring networks) and in power domain (i.e., controlling the base station and UE powers so that the interference between the networks can be limited to reduce both the level and the impact of the inter-network interference). Moreover, it is crucial to assess a co-existence scenario with a denser factory network, as well as a scenario with adjacent channel eMBB users located inside the factory.