GTI
URLLC Evaluation White Paper (PhaseII)

URLLC Evaluation WHITE PAPER

Phase2

V1

Version	V1
Deliverable Type	□Procedural Document √Working Document
Confidential Level	□ Open to GTI Operator Members □Open to GTI Partners √Open to Public
Program Name	GTI 5G ENS Program
Working Group	
Project Name	URLLC Evaluation
Source members	CMCC
Support members	Huawei, ZTE, Samsung, vivo, CATT
Editor	
Last Edit Date	2020.4
Approval Date	

Document History

Date	Meeting #	Version #	Revision Contents
2020-01-02		0.1	Skeleton Draft
2020-01-10		0.2	Simulation assumptions updated
2020-01-13		0.3	Simulation assumptions updated
2020-04-08		0.9	Draft version
2020-04-20		1.0	Refined the wording and format

Contents

1. Introduction

Compared to 4G and the previous generation, 5G is aimed to connect everything and enable verticals. URLLC is an important feature of 5G to accomplish this goal. Starting from 3GPP Release15, lots of standard work has been done to support URLLC communication services. With the global promotion of 5G commercial, the verticals have high interest to fastly adapt 5G networks. They are eager to know what performance 5G network can provide for them and whether the performance can meet their requirements. Considering vertical needs, a performance evaluation has been done in [1].

This URLLC evaluation task was kicked off on Jun.2019, and mainly focused on some scenarios and techniques that haven't been evaluated but operators and vendors have great interest in.

Phase1 focuses on two pre-commercial vertical scenarios (RMG in port which is a typical outdoor case and AGV in factory which is a typical indoor case) and pre-commercial product realization, frequency band, duplex mode, etc.; the output will be in two dimensions (Network capability is evaluated by given Inter-site Distance and number of station is calculated by given requirements). The URLLC Evaluation White Paper (PhaseⅠ) has been released on Nov.2019, and the published Whitepaper can be downloaded on GTI official website through the link (http://www.gtigroup.org/Resources/rep/).

Phase2 involves more vertical, such as Differential protection in electrical power distribution and motion control in factory automation. And more simulation assumptions are adopted, such as FDD, new frequency band (700MHz), new frame structure, etc.

We are looking forward to enabling verticals by 5G network, and hope this report can help operators create new business more efficiently.

2. Terminology and Abbreviation

Term	Description
3GPP	3rd Generation Partnership Project
URLLC	Ultra-Reliable and Low Latency Communication
DP	Differential protection
DTU	distribution termination units

3. Use Cases and Requirements

Two use cases will be presented in this chapter: Differential Protection in electrical power distribution and Motion Control in factory automation. These two cases have been introduced in 3GPP and NGMN URLLC study. This report follows the description in [2][3] and the requirements in [1].

3.1. Electrical Power Distribution

As described in [2] [3], Differential protection (DP) is a typical use case in distribution grids. Several distribution termination units (DTUs) compose the protection zone of DP. All DTUs exchange their current values with neighbour DTUs in a strictly cyclic pattern. A timestamp is associated with each current value, and the time stamp indicates when the current value was sampled. If a fault occurs outside the protection zone, the differential current among all DTUs is almost zero. If the fault occurs inside the protection zone, the differential current exceeds a threshold, protection is released, and the circuit breaker cuts off the circuit. By so doing the fault is isolated.

In this case, Synchronisation between the DTUs measurement with the voltage phase is very important. 5G network is required to provide sufficiently low transmission latency, small jitter and high time synchronization accuracy.

The network architecture requirements:

- High time synchronization accuracy.
- Ultra low jitter.
- High-frequency connectivity.
- Special attention to security/privacy of concerned data.

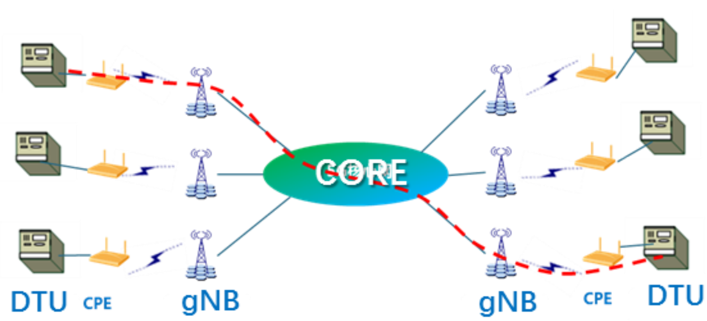


Fig. 1 Differential Protection in electrical power distribution

In order to support Differential Protection in Electrical Power Distribution, the requirements on communications services are as follows:

Table 3-1: Requiremaents of Electrical Power Distribution

Use case	Reliability (%)	Latency	Data packet size and traffic model	Description
electrical power distribution	99.999	**E2E latency**: 15ms *Note:* air interface latency: UL/DL: 6ms *Note2*: assuming core network is local	DL & UL:250 Bytes Periodic and deterministic with arrival interval 0.833 ms Random offset between UEs	Differential protection

Note: E2E latency is defined as the time that takes to transfer a given piece of information from a source endpoint device to a destination endpoint device, measured at the application service access points, from the moment it is transmitted by the source endpoint device to the moment it is successfully received at the destination endpoint device. See details in [2].

3.2. Factory Automation

As described in [2][3], motion control is among the most challenging and demanding closed-loop control applications in industry. A motion control system is responsible for controlling moving and/or rotating parts of machines in a well-defined manner, for example in printing machines, machine tools or packaging machines. Due to the movements/rotations of components, wireless communications based on powerful 5G systems constitutes a promising approach.

In this case, the reliability of the transmissions has to be very high: the measurements need to be received successfully and any commands sent to the actuator must also be received successfully, all within tight latency bounds.

The network architecture must fulfill following characteristics for motion control in factory:

- No need for dynamic scalability
- Mobility at standard values
- Frequent connectivity
- High security mechanism will be requested

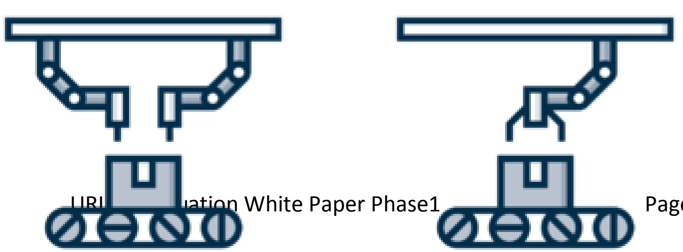


Fig. 2 Motion control in factory

In order to support Motion Control in factory, the requirements on communications services are as follows:

Table 3-2: Requirements of Factory Automation

Use case	Reliability (%)	Latency	Data packet size and traffic model	Description
factory automation	99.9999	**air interface latency:** ● DL/UL:1ms	**UL/DL:** 32 bytes Periodic deterministic traffic model with data arrival interval 2.5 ms	Motion control

4. Performance metric

According to [1], the performance metric for the system level evaluations in this white paper, including evaluation of the baseline performance achievable with Rel-15 NR URLLC and evaluation of the performance achievable with potential enhancement(s) for Rel-16 URLLC, is either option 1 or option 2 as below:

- **Option 1**: Percentage of users satisfying reliability and latency requirements
  - Intend for the case with fixed number of UEs and fixed traffic model per UE
- **Option 2**: URLLC capacity
  - Definition: URLLC system capacity is calculated as follows:
    - C(L, R) is the maximum offered cell load under which Y% of URLLC UEs in a cell operate with target link reliability R under L latency bound
    - X= (100 – Y) % is the percentage of UEs in outage
    - A UE in outage is defined as the UE cannot meet both latency L and link reliability R bound
    - Companies report their assumption on X (either ~5% or 0%)
  - Intend for the case that the number of UEs and/or the data arrival rate is adjustable
    - Adjusting the number of UEs should be applied to periodic deterministic traffic model

5. System level simulation assumptions

Detailed simulation assumptions will be presented in this chapter. In phaseⅡ, FDD & TDD are both involved, and three carrier frequency (700M Hz、3.5G Hz and 4.9G Hz) will be evaluated. Different frame structure will be adopted in 3.5G and 4.9G as Fig.3 and Fig.4 show. Fig.5 illustrates an optional TDD frame structure with 1ms switch-point periodicity which also can be used in 4.9G Hz evaluation.

Fig. 3 TDD Frame structure used in 3.5G Hz (2.5ms dual switch-point periodicity, S:10:2:2)--mandatory

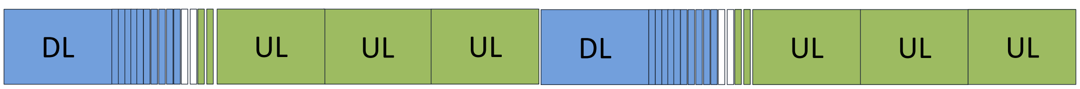


Fig. 4 TDD Frame structure used in 4.9G Hz (2.5ms switch-point periodicity, S:10:2:2)--mandatory

Fig. 5 TDD Frame structure used in 4.9G Hz (1ms switch-point periodicity, S: 2:12)--optional

Like phase Ⅰ, two types of layout will be evaluated. Fig.6 shows the typical layout which is used usually in indoor scenario. There are 12 BSs for 120m*50m, and per BS means one cell, as Fig.6 shows. But according to Logistics customers, the actually used layout is that 1 BS (with 12 sets of distributed antennas) for 120*50m and one cell per BS, as Fig.7 shows.

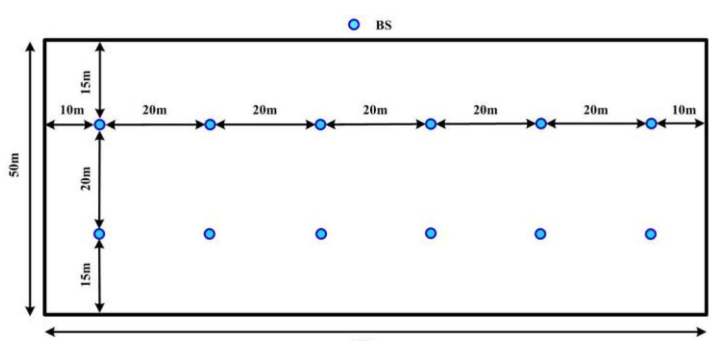


Fig. 6 Indoor layout in TR38.824[1] (layout1)

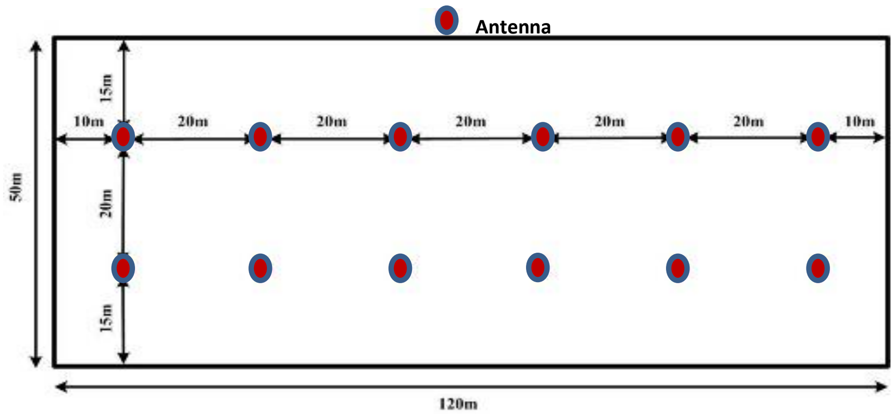


Fig. 7 New indoor layout (layout2)

5.1. Simulation assumptions for Electrical Power Distribution

Table 5-1 shows the detailed simulation assumptions for Electrical Power Distribution.

Table 5-1: System-level simulation assumptions for Electrical Power Distribution

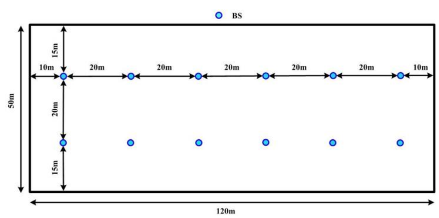
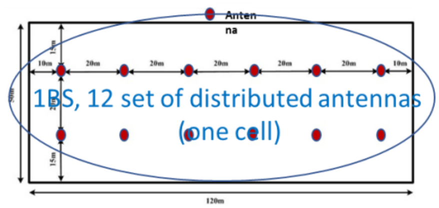
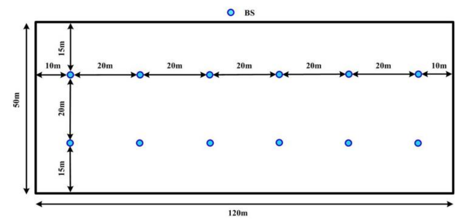
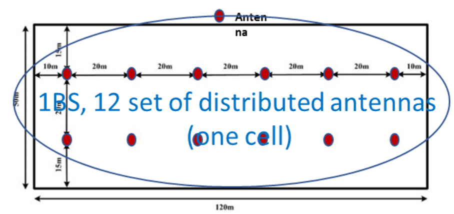
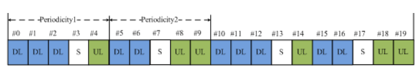
Parameters	Value
Layout	Single layer - Macro layer: Hex. Grid 7 sites, 21cells
Inter-BS distance	700m,350m
Carrier frequency	700MHz
Duplex mode	FDD
Channel model	UMa in TR 38.901
UE Tx power	23dBm
BS antenna configurations	4 Tx/4 Rx antenna ports (M, N, P, Mg, Ng; Mp, Np) = (1, 2, 2, 1, 1; 1, 2) for 4 Tx/4 Rx antenna ports; dH = 0.5λ, dV = 0.7λ; Companies report the antenna tilt
BS antenna height	25m
BS antenna element gain + connector loss	8 dBi
BS receiver noise figure	3.5dB
OTA	4dB
UE antenna configuration	1 Tx/2 Rx antenna ports 2Rx with 0°,90° polarization， half-wavelength spaced;
UE antenna height	1.5m
UE antenna gain	0dBi as starting point
UE receiver noise figure	7 dB
Total transmit power per TRxP	49 dBm (20M)
BS receiver	MMSE-IRC as the baseline receiver Note: Advanced receiver is not precluded.
Number of UEs per cell	Up to 20 (ISD700m) Up to 10 (ISD350m) Note: The number of users per cell in this table is the number of pure URLLC UEs.

Simulation bandwidth	20MHz
SCS	15 kHz Note: Other values for evaluation are not precluded.
UE distribution	100% of users are outdoors UE speed: 3km/h
UE power control	Companies report the PC mechanisms used for URLLC.
HARQ/repetition	Companies report (including HARQ mechanisms).
Channel estimation	Realistic
SRS/CSI configuration	Realistic, Companies report
Handover margin	3dB

5.2. Simulation assumptions for Factory Automation

Table 5-2 shows the detailed simulation assumptions for Factory Automation.

Table 5-2: System-level simulation assumptions for Factory Automation

Parameters	Value	Value
Layout	Single layer as defined in 38.802 Indoor floor: 120 m x 50 m Case 1: 12BSs (one cell per BS) Case 2: 1BS (with 12 sets of distributed antennas, one cell per BS)  	Single layer as defined in 38.802 Indoor floor: 120 m x 50 m Case 1: 12BSs (one cell per BS) Case 2: 1BS (with 12 sets of distributed antennas, one cell per BS)  
Inter-BS distance	20m	20m
Carrier frequency	3.5GHz	4.9 GHz,
Duplex mode	TDD	TDD
Frame structure	Mandatory: 2.5ms dual TDD-UL-DL-Pattern，S:10:2:2 	Mandatory: 2.5ms TDD-UL-DL-Pattern，S:10:2:2  Optional: 1ms TDD-UL-DL-Pattern，S:2:12 
Channel model	InF(R16 IIOT indoor factory) for 3.5 GHz sub-scenario 4 is adopted h_c = 6,r=0.6 Blockage modelling is optional. If Blockage model B is adopted, the maximum speed of obstacle should be	InF(R16 IIOT indoor factory) for 4.9 GHz sub-scenario 4 is adopted h_c = 6,r=0.6 Blockage modelling is optional. If Blockage model B is adopted, the maximum speed of obstacle should be

	30km/h and the probability of the influence of obstacle movement on UE small-scale fading should be 0.2. Companies report the modification of the channel model	30km/h and the probability of the influence of obstacle movement on UE small-scale fading should be 0.2. Companies report the modification of the channel model
UE Tx power	26dBm	26dBm
BS antenna configurations	4 Tx/4 Rx antenna ports Omnidirectional antenna (M, N, P, Mg, Ng; Mp, Np) = (2, 2, 1, 1, 1; 2, 2)	4 Tx/4 Rx antenna ports Omnidirectional antenna (M, N, P, Mg, Ng; Mp, Np) = (2, 2, 1, 1, 1; 2, 2)
BS antenna height	10 m	10 m
BS antenna element gain + connector loss	2 dBi	2.5 dBi
BS receiver noise figure	5dB	5dB
OTA	4dB	4dB
UE antenna configuration	2 Tx/4 Rx antenna ports Panel model 1: Mg=1, Ng=1, P=2, d_H=0.5 (M, N, P, Mg, Ng; Mp, Np) = (1, 2, 2, 1, 1; 1, 2) for 4 Rx; (M, N, P, Mg, Ng; Mp, Np) = (1, 1, 2, 1, 1; 1, 1) for 2 Tx;	2 Tx/4 Rx antenna ports Panel model 1: Mg = 1, Ng = 1, P = 2, dH = 0.5 (M, N, P, Mg, Ng; Mp, Np) = (1, 2, 2, 1, 1; 1, 2) for 4 Rx; (M, N, P, Mg, Ng; Mp, Np) = (1, 1, 2, 1, 1; 1, 1) for 2 Tx;
UE antenna height	1.5m	1.5m
UE antenna gain	0dBi as starting point	0dBi as starting point
UE receiver noise figure	9 dB	9 dB
Total transmit power per TRxP	30 dBm (100 MHz)	30 dBm (100 MHz)
BS receiver	MMSE-IRC as the baseline receiver Note: Advanced receiver is not precluded.	MMSE-IRC as the baseline receiver Note: Advanced receiver is not precluded.
Number of UEs per 120m*50m	For both case1 & case2: Up to 250 the number of users for evaluation can be 50, 100, 150, 200, 250. Note: The number of users per cell in this	For both case1 & case2: Up to 250 the number of users for evaluation can be 50, 100, 150, 200, 250. Note: The number of users per cell in this

	table is the number of pure URLLC UEs	table is the number of pure URLLC UEs
Simulation bandwidth	100 MHz Note: For TDD, 100 MHz for DL/UL.	100 MHz Note: For TDD, 100 MHz for DL/UL.
SCS	30 kHz Note: Other values for evaluation are not precluded.	30 kHz Note: Other values for evaluation are not precluded.
UE distribution	100% of users are indoor: 20 km/h UE-speed	100% of users are indoor: 20 km/h UE-speed
UE power control	Companies report the PC mechanisms used for URLLC.	Companies report the PC mechanisms used for URLLC.
HARQ/repetition	Companies report (including HARQ mechanisms).	Companies report (including HARQ mechanisms).
Channel estimation	Realistic	Realistic
SRS/CSI configuration	Realistic, Companies report	Realistic, Companies report
Guard band ratio	1.72% for 100M	1.72% for 100M
Handover margin	3dB	3dB

6. Evaluation Results

6.1. Evaluation on Electrical Power Distribution

Five sources evaluate the performance achievable with Rel-16 NR for DP, with the evaluation results as shown in Table 6-1 (ISD700m) and Table 6-2 (ISD350m).

1) ISD700m

As Table 6-1 shows,

- Three sources show that the percentage of UEs satisfying the latency (i.e. 6ms for UL/DL) and reliability (i.e. 99.999%) requirements by Rel-16 NR is higher than 95% for uplink transmission for DP assuming 10 users per cell, 700MHz (FDD).
- Two sources show that the percentage of UEs satisfying the latency (i.e. 6ms for UL/DL) and reliability (i.e. 99.999%) requirements by Rel-16 NR is higher than 95% for downlink transmission for DP assuming up to 10 users per cell, 700MHz (FDD).

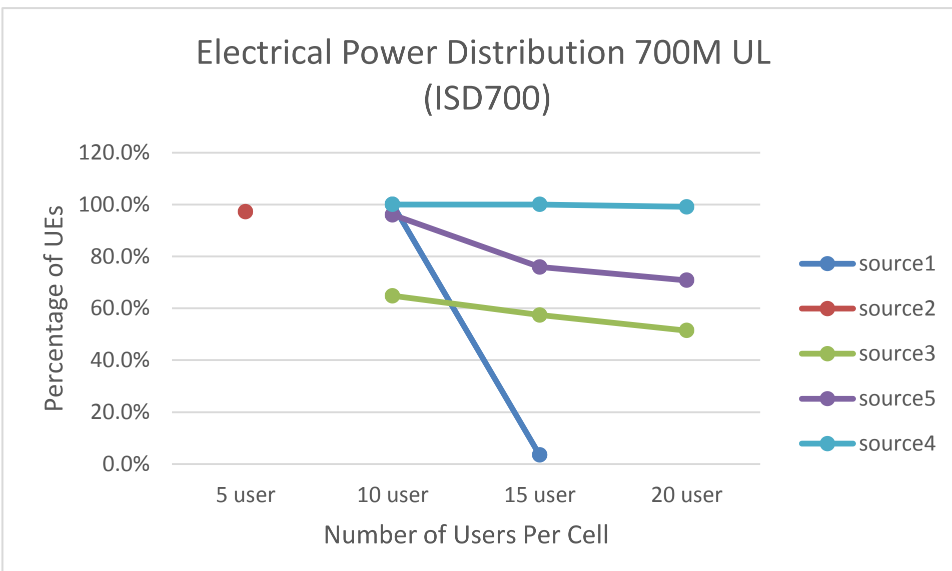


Fig. 8 UL Performance of DP 700MHz (ISD700)

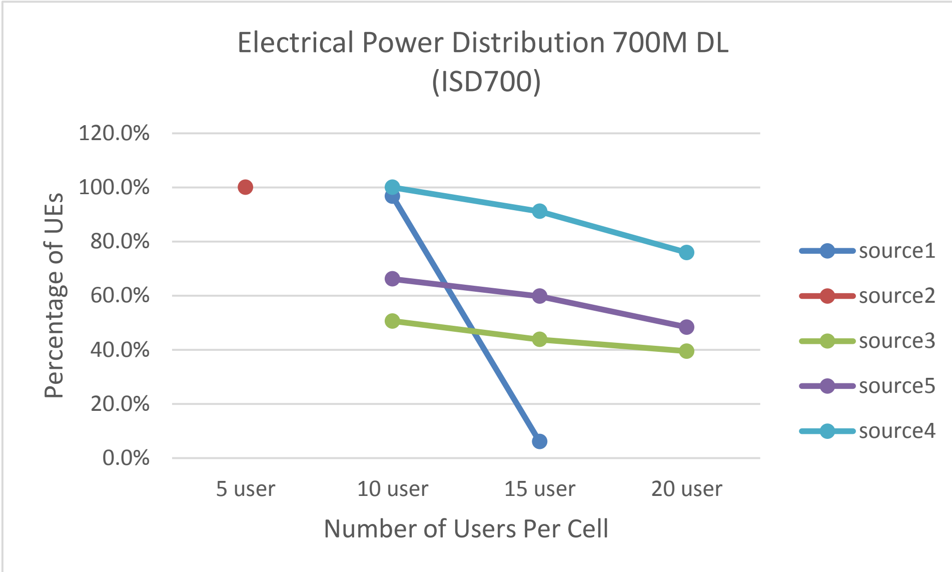


Fig. 9 DL Performance of DP 700MHz (ISD700)

Table 6-1: The percentage of UEs satisfying requirements for Electrical Power Distribution (ISD700m)

Source 1 : Electrical Power Distribution (700MHz) Reliability of 99.999%, 6ms (DL/UL) air interface, 700MHz, FDD, 4Tx/4Rx at gNB and 1Tx/2Rx at UE, realistic channel estimation, ISD700m, Uma			
		Percentage of UEs	Resource utilization
20 users per cell	DL:	N/A	N/A
	UL:	N/A	N/A
15 users per cell	DL:	6.0317%	97.736%
	UL:	3.49%	95.976%
10 users per cell	DL:	96.67%	56.98%
	UL:	100%	54.12%
Source 2 : Electrical Power Distribution (700MHz) Reliability of 99.999%, 6ms (DL/UL) air interface, 700MHz, FDD, 4Tx/4Rx at gNB and 1Tx/2Rx at UE, realistic channel estimation, ISD700m, Uma			
		Percentage of UEs	Resource utilization
20 users per cell	DL:		
	UL:		
15 users per cell	DL:		
	UL:		
10 users per cell	DL:		
	UL:		
5 users per cell	DL:	100%	38.04%
	UL:	97.14%	49.33%
Source 3 : Electrical Power Distribution (700MHz) Reliability of 99.999%, 6ms (DL/UL) air interface, 700MHz, FDD, 4Tx/4Rx at gNB and 1Tx/2Rx at UE, realistic channel estimation, ISD700m, Uma			
		Percentage of UEs	Resource utilization
20 users per cell	DL:	39.5	90.9
	UL:	51.4	92.1
15 users per cell	DL:	43.8	88.9
	UL:	57.4	89.1
10 users per cell	DL:	50.6	85.8
	UL:	64.8	81.6
Source 4 : Electrical Power Distribution (700MHz) Reliability of 99.999%, 6ms (DL/UL) air interface, 700MHz, FDD, 4Tx/4Rx at gNB and 1Tx/2Rx at UE, realistic channel estimation, ISD700m, Uma			
		Percentage of UEs	Resource utilization
20 users per cell	DL:	75.95%	89.46%
	UL:	99.05%	94.77%
15 users	DL:	91.11%	67.85%

per cell	UL:	100%	70.79%
10 users per cell	DL:	100%	41.98%
	UL:	100%	47.19%
Source 5 : Electrical Power Distribution (700MHz) Reliability of 99.999%, 6ms (DL/UL) air interface, 700MHz, FDD, 4Tx/4Rx at gNB and 1Tx/2Rx at UE, realistic channel estimation, ISD700m, Uma			
		Percentage of UEs	Resource utilization
20 users per cell	DL:	48.37%	60.22%
	UL(2reps):	70.79%	83.34%
15 users per cell	DL:	59.77%	53.71%
	UL(2reps):	75.87%	63.40%
10 users per cell	DL:	66.14%	36.64%
	UL(2reps):	96%	70.11%

2) ISD350m

As Table 6-2 shows,

- Four sources show that the percentage of UEs satisfying the latency (i.e. 6ms for UL/DL) and reliability (i.e. 99.999%) requirements by Rel-16 NR is higher than 95% for uplink transmission for DP assuming 5 users per cell, 700MHz (FDD).
- Three sources show that the percentage of UEs satisfying the latency (i.e. 6ms for UL/DL) and reliability (i.e. 99.999%) requirements by Rel-16 NR is higher than 95% for downlink transmission for DP assuming up to 5 users per cell, 700MHz (FDD).
- Three sources show that the percentage of UEs satisfying the latency (i.e. 6ms for UL/DL) and reliability (i.e. 99.999%) requirements by Rel-16 NR is higher than 95% for uplink transmission for DP assuming 10 users per cell, 700MHz (FDD).
- Two sources show that the percentage of UEs satisfying the latency (i.e. 6ms for UL/DL) and reliability (i.e. 99.999%) requirements by Rel-16 NR is higher than 95% for downlink transmission for DP assuming up to 10 users per cell, 700MHz (FDD).

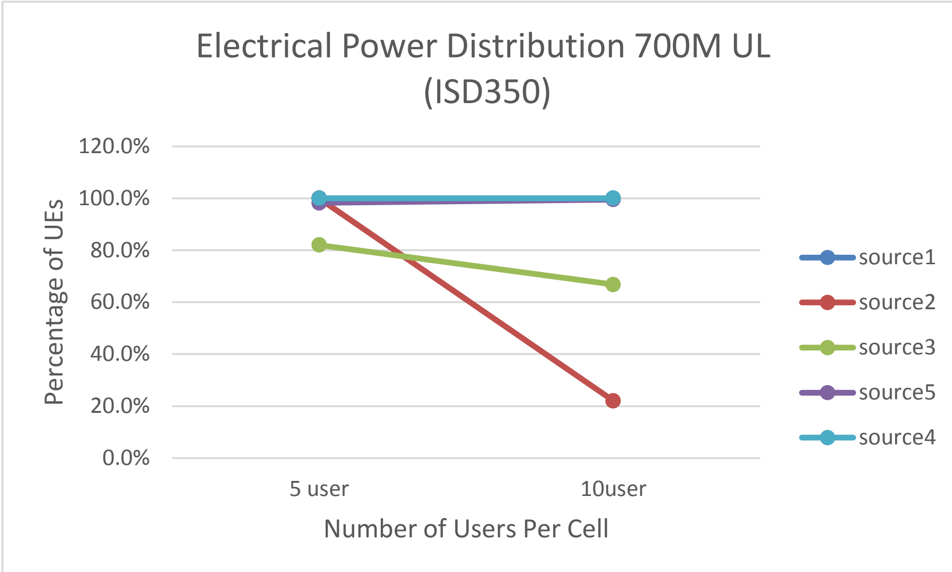


Fig. 10 UL Performance of DP 700MHz (ISD350)

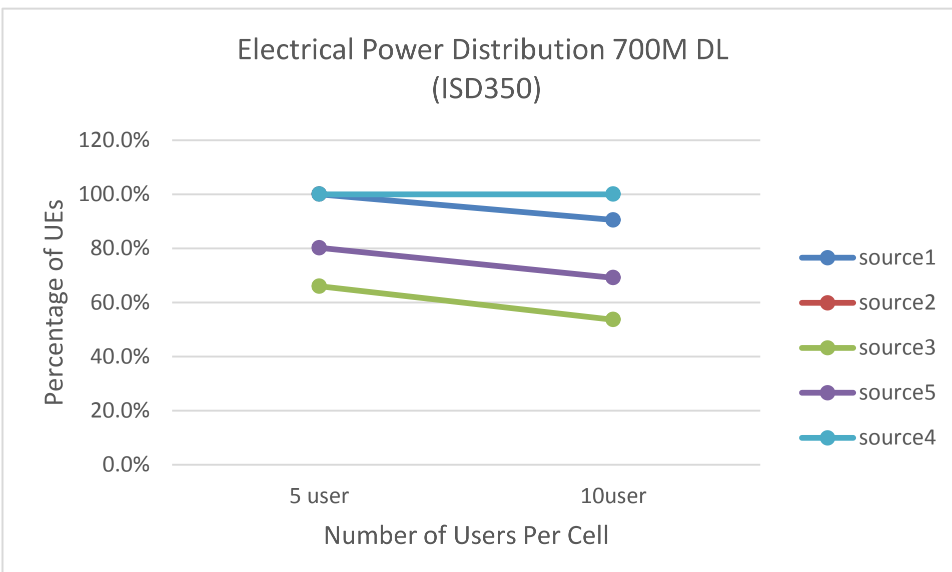


Fig. 11 DL Performance of DP 700MHz (ISD350)

Table 6-2: The percentage of UEs satisfying requirements for Electrical Power Distribution (ISD350m)

Source 1 : Electrical Power Distribution (700MHz) Reliability of 99.999%, 6ms (DL/UL) air interface, 700MHz, FDD, 4Tx/4Rx at gNB and 1Tx/2Rx at UE, realistic channel estimation, ISD350m, Uma			
		Percentage of UEs	Resource utilization
10 users per cell	DL:	90.48%	54.21%
	UL:	100%	52.33%
5 users per cell	DL:	100%	20.69%
	UL:	100%	20.43%
Source 2 : Electrical Power Distribution (700MHz) Reliability of 99.999%, 6ms (DL/UL) air interface, 700MHz, FDD, 4Tx/4Rx at gNB and 1Tx/2Rx at UE, realistic channel estimation, ISD350m, Uma			
		Percentage of UEs	Resource utilization
10 users per cell	DL:		
	UL:	22%	68.65%
5 users per cell	DL:	100%	33.88%
	UL:	100%	48.11%
Source 3 : Electrical Power Distribution (700MHz) Reliability of 99.999%, 6ms (DL/UL) air interface, 700MHz, FDD, 4Tx/4Rx at gNB and 1Tx/2Rx at UE, realistic channel estimation, ISD350m, Uma			
		Percentage of UEs	Resource utilization
10 users per cell	DL:	53.6	86.0
	UL:	66.8	87.5
5 users per cell	DL:	66.0	75.9
	UL:	82.0	66.6
Source 4 : Electrical Power Distribution (700MHz) Reliability of 99.999%, 6ms (DL/UL) air interface, 700MHz, FDD, 4Tx/4Rx at gNB and 1Tx/2Rx at UE, realistic channel estimation, ISD350m, Uma			
		Percentage of UEs	Resource utilization
10 users per cell	DL:	100%	40.99%
	UL:	100%	47.19%
5 users per cell	DL:	100%	21.49%
	UL:	100%	23.60%
Source 5 : Electrical Power Distribution (700MHz) Reliability of 99.999%, 6ms (DL/UL) air interface, 700MHz, FDD, 4Tx/4Rx at gNB and 1Tx/2Rx at UE, realistic channel estimation, ISD350m, Uma			
		Percentage of UEs	Resource utilization
10 users per cell	DL:	69.14%	33.34%
	UL(2reps):	98.2%	68.63%
5 users per cell	DL:	80.18%	19.02%
	UL(2reps):	99.5%	35.3%

6.2. **Evaluation on Factory Automation**

Four sources evaluate the performance achievable with Rel-16 NR for Motion Control in factory (layout case1), with the evaluation results as shown in Table 6-3. Four sources evaluate the performance achievable with Rel-16 NR for Motion Control in factory (layout case2), with the evaluation results as shown in Table 6-4.

- **Two** sources show that the percentage of UEs satisfying the latency (i.e. 1ms for UL/DL) and reliability (i.e. 99.9999%) requirements by Rel-16 NR is higher than 95% for both downlink and uplink transmission for Motion Control (layout case1) assuming up to 200 URLLC users without any eMBB users per 120m*50m, 3.5GHz (TDD).
- **Three** sources show that the percentage of UEs satisfying the latency (i.e. 1ms for UL/DL) and reliability (i.e. 99.9999%) requirements by Rel-16 NR is higher than 95% for uplink transmission for Motion Control (layout case1) assuming up to 250 URLLC users without any eMBB users per 120m*50m, 4.9GHz (TDD).
- **Two** sources show that the percentage of UEs satisfying the latency (i.e. 1ms for UL/DL) and reliability (i.e. 99.9999%) requirements by Rel-16 NR is higher than 95% for downlink transmission for Motion Control (layout case1) assuming up to 150 URLLC users without any eMBB users per 120m*50m, 4.9GHz (TDD).
- Compared with layout case1, **three** sources show that the downlink and uplink performance can be improved significantly in layout case2.

1) Case1

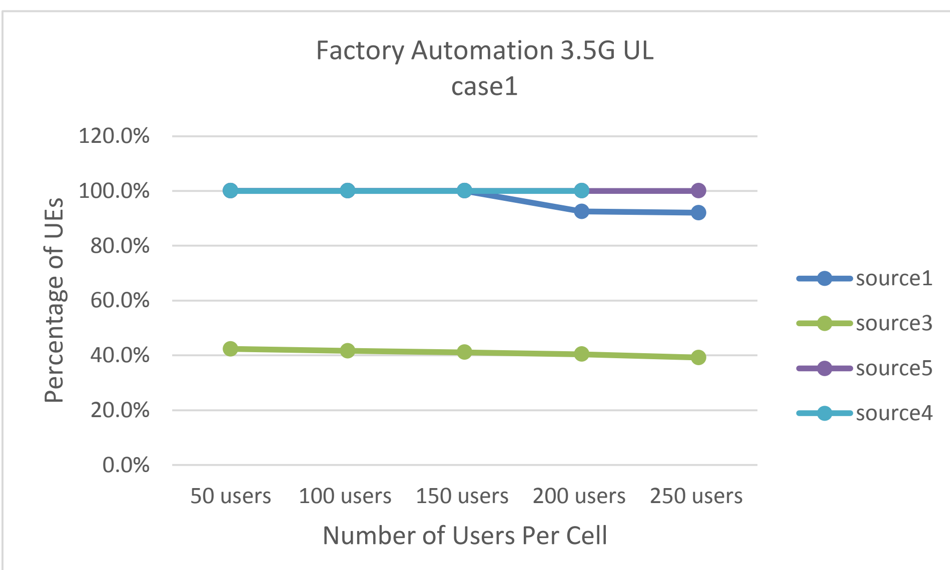


Fig. 12 UL Performance of Motion Control 3.5GHz (case1)

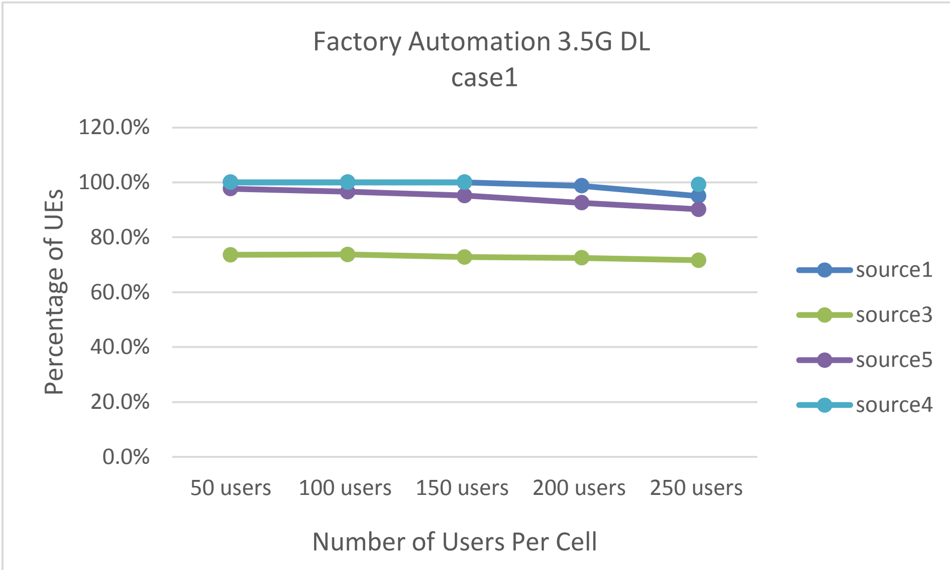


Fig. 13 DL Performance of Motion Control 3.5GHz (case1)

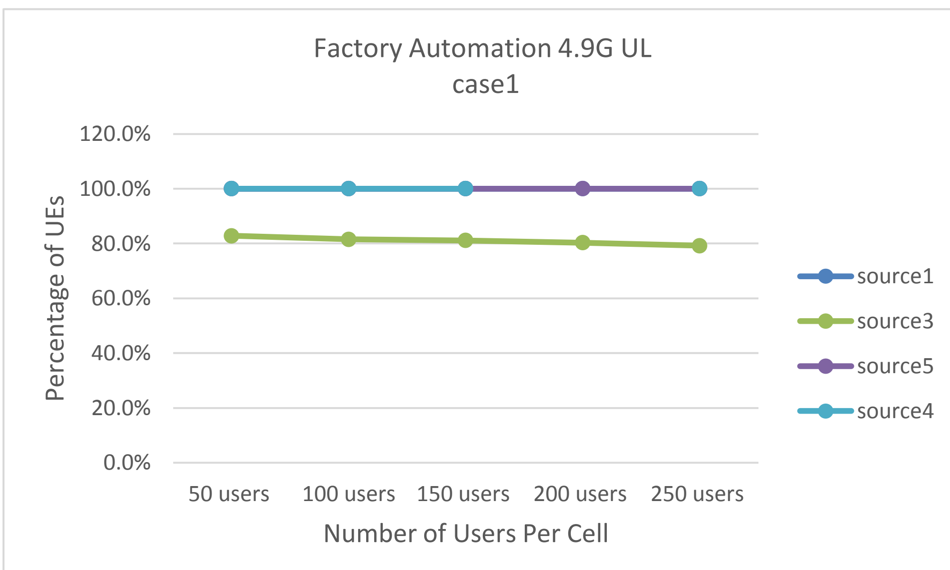


Fig. 14 UL Performance of Motion Control 4.9GHz (case1)

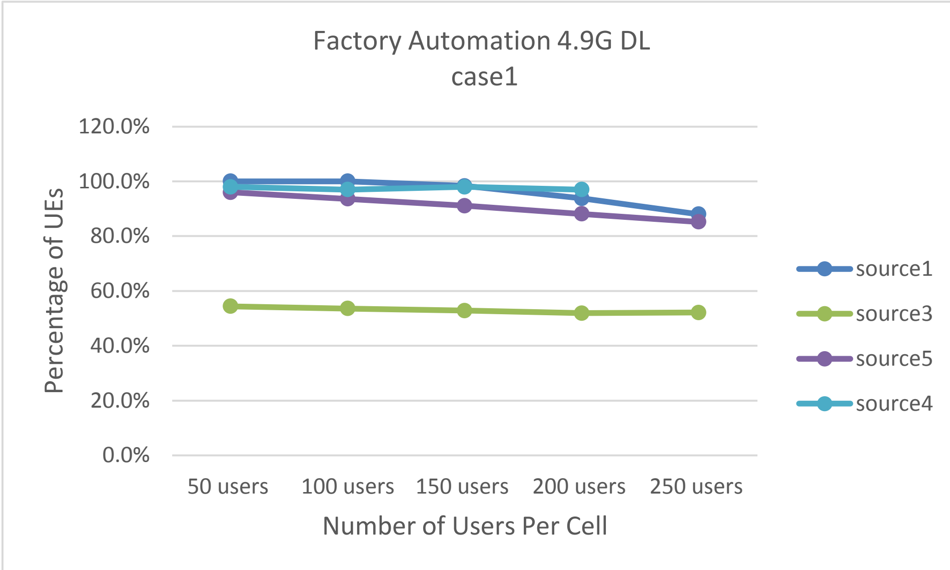


Fig. 15 DL Performance of Motion Control 4.9GHz (case1)

Table 6-3: The percentage of UEs satisfying requirements for Factory Automation (layout case1)

Source 1 : Factory Automation (3.5GHz) Reliability of 99.9999%, 1ms air interface, 3.5GHz, TDD, 4Tx/4Rx at gNB and 2Tx/4Rx at UE, realistic channel estimation, ISD20m, case1, InF channel model			
		Percentage of UEs	Resource utilization
50 users per 120m*50m	DL:	100%	59.12%
	UL:	100%	45.94%
100 users per 120m*50m	DL:	100%	59.06%
	UL:	100%	45.74%
150 users per 120m*50m	DL:	100%	59.06%
	UL:	100%	45.71%
200 users per 120m*50m	DL:	98.75%	57.25%
	UL:	92.5%	45.18%
250 users per 120m*50m	DL:	95%	55.439%
	UL:	92%	44.92%
Source 1 : Factory Automation (4.9GHz) Reliability of 99.9999%, 1ms air interface, 4.9GHz, TDD, 4Tx/4Rx at gNB and 2Tx/4Rx at UE, realistic channel estimation, ISD20m, case1, InF channel model			
		Percentage of UEs	Resource utilization
50 users per 120m*50m	DL:	100%	69.1%
	UL:	100%	69.16%
100 users per 120m*50m	DL:	100%	63.23%
	UL:	100%	69.14%
150 users per 120m*50m	DL:	98.33%	68.8%
	UL:	100%	68.14%
200 users per 120m*50m	DL:	93.75%	68.45%
	UL:	100%	68.92%
250 users per 120m*50m	DL:	88%	65.152%
	UL:	100%	68.93%
Source 3 : Factory Automation (3.5GHz) Reliability of 99.9999%, 1ms air interface, 3.5GHz, TDD, 4Tx/4Rx at gNB and 2Tx/4Rx at UE, realistic channel estimation, ISD20m, case1, InF channel model			
		Percentage of UEs	Resource utilization
50 users per 120m*50m	DL:	73.6	5.8
	UL:	42.3	7.6
100 users per 120m*50m	DL:	73.7	11.1
	UL:	41.6	15.0
150 users per 120m*50m	DL:	72.8	16.6
	UL:	41.1	22.3
200 users per	DL:	72.5	21.8

120m*50m	UL:	40.4	29.0
250 users per 120m*50m	DL:	71.6	26.9
	UL:	39.2	35.2
Source 3 : Factory Automation (4.9GHz) Reliability of 99.9999%, 1ms air interface, 4.9GHz, TDD, 4Tx/4Rx at gNB and 2Tx/4Rx at UE, realistic channel estimation, ISD20m, case1, InF channel model			
		Percentage of UEs	Resource utilization
50 users per 120m*50m	DL:	54.4	6.9
	UL:	82.8	6.4
100 users per 120m*50m	DL:	53.6	13.3
	UL:	81.5	12.3
150 users per 120m*50m	DL:	52.8	19.6
	UL:	81.1	18.5
200 users per 120m*50m	DL:	51.9	25.5
	UL:	80.3	24.2
250 users per 120m*50m	DL:	52.1	31.9
	UL:	79.2	30.0
Source 4 : Factory Automation (3.5GHz) Reliability of 99.9999%, 1ms air interface, 3.5GHz, TDD, 4Tx/4Rx at gNB and 2Tx/4Rx at UE, realistic channel estimation, ISD20m, case1, InF channel model			
		Percentage of UEs	Resource utilization
50 users per 120m*50m	DL:	100%	3.82%
	UL:	100%	7.46%
100 users per 120m*50m	DL:	100%	7.63%
	UL:	100%	14.92%
150 users per 120m*50m	DL:	100%	11.44%
	UL:	100%	22.38%
200 users per 120m*50m	DL:		
	UL:	100%	29.84%
250 users per 120m*50m	DL:	99.2%	19.06%
	UL:		
Source 4 : Factory Automation (4.9GHz) Reliability of 99.9999%, 1ms air interface, 4.9GHz, TDD, 4Tx/4Rx at gNB and 2Tx/4Rx at UE, realistic channel estimation, ISD20m, case1, InF channel model			
		Percentage of UEs	Resource utilization
50 users per 120m*50m	DL:	98%	7.15%
	UL:	100%	4.90%
100 users per 120m*50m	DL:	97%	14.30%
	UL:	100%	7.80%

150 users per 120m*50m	DL:	98%	21.45%
	UL:	100%	11.70%
200 users per 120m*50m	DL:	97%	28.60%
	UL:		
250 users per 120m*50m	DL:		
	UL:	100%	19.50%
Source 4 : Factory Automation (4.9GHz) Reliability of 99.9999%, 1ms air interface, 4.9GHz, TDD, 4Tx/4Rx at gNB and 2Tx/4Rx at UE, realistic channel estimation, ISD20m, case1, InF channel model，optional frame structure			
		Percentage of UEs	Resource utilization
50 users per 120m*50m	DL:	100%	4.58%
	UL:	100%	4.90%
100 users per 120m*50m	DL:	100%	9.15%
	UL:	100%	9.80%
150 users per 120m*50m	DL:	100%	13.73%
	UL:	100%	14.71%
200 users per 120m*50m	DL:	100%	18.30%
	UL:	100%	19.61%
250 users per 120m*50m	DL:	98.8%	22.88%
	UL:	100%	24.51%
Source 5 : Factory Automation (3.5GHz) Reliability of 99.9999%, 1ms air interface, 3.5GHz, TDD, 4Tx/4Rx at gNB and 2Tx/4Rx at UE, realistic channel estimation, ISD20m, case1, InF channel model			
		Percentage of UEs	Resource utilization
50 users per 120m*50m	DL:	97.68%	0.79%
	UL(2reps):	100%	4.27%
100 users per 120m*50m	DL:	96.58%	1.34%
	UL(2reps):	100%	8.54%
150 users per 120m*50m	DL:	95.15%	1.96%
	UL(2reps):	100%	12.81%
200 users per 120m*50m	DL:	92.54%	2.49%
	UL(2reps):	100%	17.08%
250 users per 120m*50m	DL:	90.18%	3.11%
	UL(2reps):	100%	21.35%
Source 5 : Factory Automation (4.9GHz) Reliability of 99.9999%, 1ms air interface, 4.9GHz, TDD, 4Tx/4Rx at gNB and 2Tx/4Rx at UE, realistic channel estimation, ISD20m, case1, InF channel model			
		Percentage of UEs	Resource utilization
50 users per	DL:	95.99%	1.53%

120m*50m	UL(2reps):	100%	2.31%
100 users per 120m*50m	DL:	93.62%	3.25%
	UL(2reps):	100%	4.61%
150 users per 120m*50m	DL:	91.07%	4.47%
	UL(2reps):	100%	6.92%
200 users per 120m*50m	DL:	88.12%	5.81%
	UL(2reps):	100%	9.23%
250 users per 120m*50m	DL:	85.21%	7.13%
	UL(2reps):	100%	11.54%

2) Case2

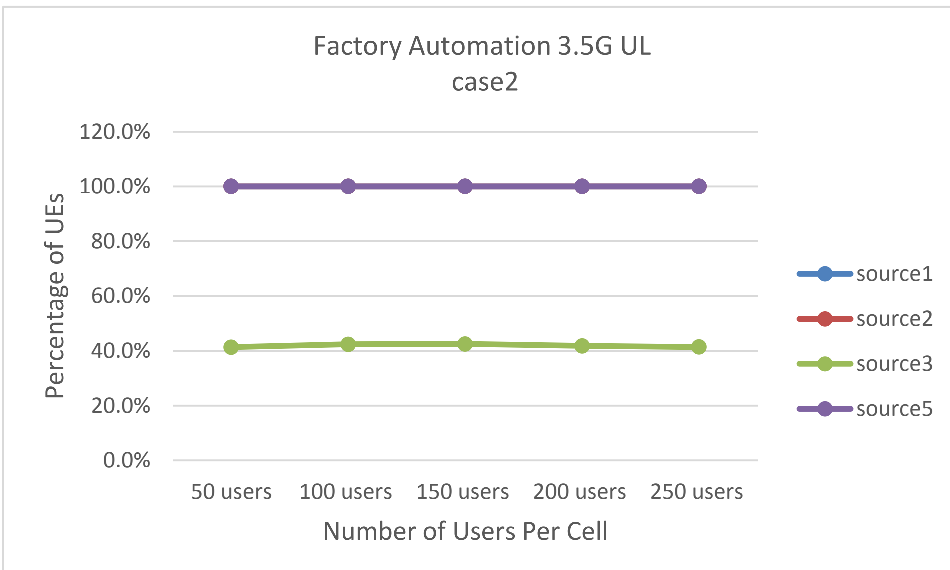


Fig. 16 UL Performance of Motion Control 3.5GHz (case2)

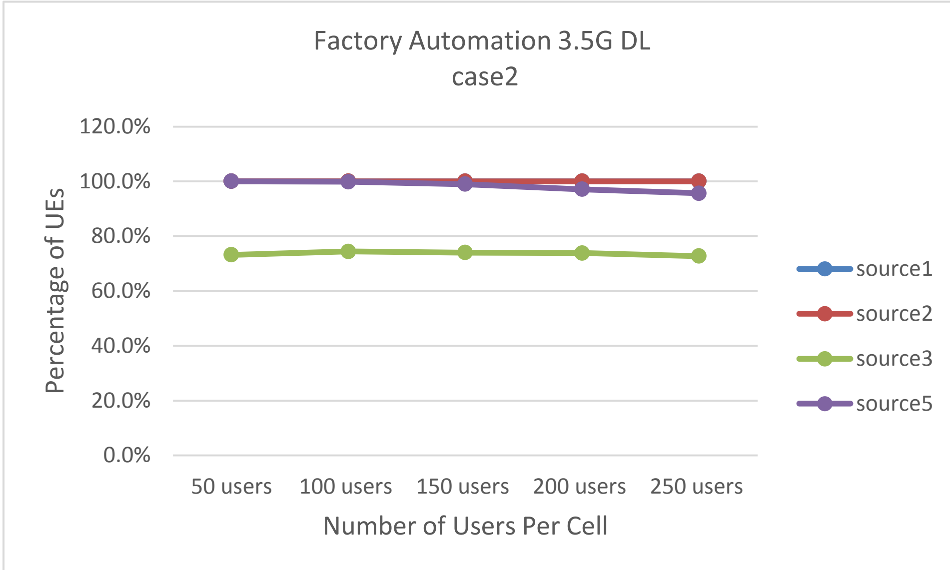


Fig. 17 DL Performance of Motion Control 3.5GHz (case2)

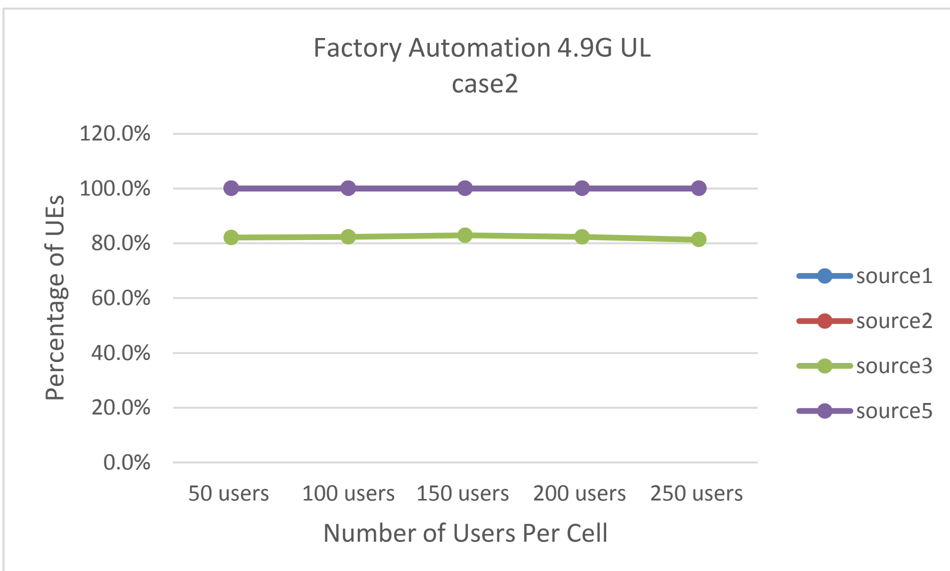


Fig. 18 UL Performance of Motion Control 4.9GHz (case2)

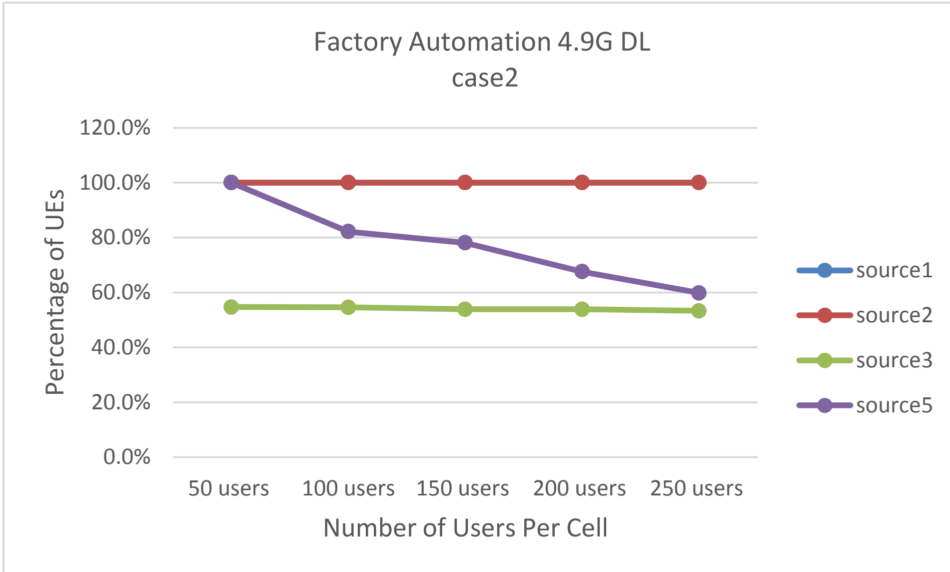


Fig. 19 DL Performance of Motion Control 4.9GHz (case2)

3) Table 6-4: The percentage of UEs satisfying requirements for Factory Automation (layout case2)

Source 1 : Factory Automation (3.5GHz) Reliability of 99.9999%, 1ms air interface, 3.5GHz, TDD, 4Tx/4Rx at gNB and 2Tx/4Rx at UE, realistic channel estimation, ISD20m, case2, InF channel model			
		Percentage of UEs	Resource utilization
50 users per 120m*50m	DL:	100%	5.25%
	UL:	100%	12.3%
100 users per 120m*50m	DL:	100%	10.5%
	UL:	100%	24.51
150 users per 120m*50m	DL:	100%	15.76%
	UL:	100%	36.76%
200 users per 120m*50m	DL:	100%	21%
	UL:	100%	49%
250 users per 120m*50m	DL:	100%	27.45%
	UL:	100%	64.02%
Source 1 : Factory Automation (4.9GHz) Reliability of 99.9999%, 1ms air interface, 4.9GHz, TDD, 4Tx/4Rx at gNB and 2Tx/4Rx at UE, realistic channel estimation, ISD20m, case2, InF channel model			
		Percentage of UEs	Resource utilization
50 users per 120m*50m	DL:	100%	9.19%
	UL:	100%	6.13%
100 users per 120m*50m	DL:	100%	18.38%
	UL:	100%	12.25%
150 users per 120m*50m	DL:	100%	27.57%
	UL:	100%	18.38%
200 users per 120m*50m	DL:	100%	36.76%
	UL:	100%	24.51%
250 users per 120m*50m	DL:	100%	45.96%
	UL:	100%	30.64%

Source 2: Factory Automation (3.5GHz) Reliability of 99.9999%, 1ms air interface, 3.5GHz, TDD, 4Tx/4Rx at gNB and 2Tx/4Rx at UE, realistic channel estimation, ISD20m, case2, InF channel model			
		Percentage of UEs	Resource utilization
50 users per 120m*50m	DL:	100%	2.35%
	UL:	100%	6.96%
100 users per 120m*50m	DL:	100%	4.67%
	UL:	100%	13.92%
150 users per 120m*50m	DL:	100%	7%
	UL:	100%	21.84%
200 users per 120m*50m	DL:	100%	9.36%
	UL:	100%	32.76%
250 users per 120m*50m	DL:	100%	11.7%
	UL:	100%	43.68%
Source 2 : Factory Automation (4.9GHz) Reliability of 99.9999%, 1ms air interface, 4.9GHz, TDD, 4Tx/4Rx at gNB and 2Tx/4Rx at UE, realistic channel estimation, ISD20m, case2, InF channel model			
		Percentage of UEs	Resource utilization
50 users per 120m*50m	DL:	100%	3.97%
	UL:	100%	5.64%
100 users per 120m*50m	DL:	100%	7.93%
	UL:	100%	11.28%
150 users per 120m*50m	DL:	100%	11.9%
	UL:	100%	17.04%
200 users per 120m*50m	DL:	100%	15.9%
	UL:	100%	22.56%
250 users per 120m*50m	DL:	100%	19.8%
	UL:	100%	28.2%
Source 3 : Factory Automation (3.5GHz) Reliability of 99.9999%, 1ms air interface, 3.5GHz, TDD, 4Tx/4Rx at gNB and 2Tx/4Rx at UE, realistic channel estimation, ISD20m, case2, InF channel model			
		Percentage of UEs	Resource utilization
50 users per 120m*50m	DL:	73.2	5.4
	UL:	41.3	6.6
100 users per 120m*50m	DL:	74.4	11.0
	UL:	42.4	13.3
150 users per 120m*50m	DL:	74.0	16.4
	UL:	42.5	20.1
200 users per	DL:	73.8	21.7

120m*50m	UL:	41.8	26.5
250 users per 120m*50m	DL:	72.7	26.9
	UL:	41.4	32.8
Source 3 : Factory Automation (4.9GHz) Reliability of 99.9999%, 1ms air interface, 4.9GHz, TDD, 4Tx/4Rx at gNB and 2Tx/4Rx at UE, realistic channel estimation, ISD20m, case2, InF channel model			
		Percentage of UEs	Resource utilization
50 users per 120m*50m	DL:	54.7	6.7
	UL:	82.1	5.5
100 users per 120m*50m	DL:	54.6	13.3
	UL:	82.3	11.0
150 users per 120m*50m	DL:	53.9	19.7
	UL:	82.9	16.6
200 users per 120m*50m	DL:	53.9	36.3
	UL:	82.3	22.0
250 users per 120m*50m	DL:	53.3	32.5
	UL:	81.3	27.2
Source 5 : Factory Automation (3.5GHz) Reliability of 99.9999%, 1ms air interface, 3.5GHz, TDD, 4Tx/4Rx at gNB and 2Tx/4Rx at UE, realistic channel estimation, ISD20m, case2, InF channel model			
		Percentage of UEs	Resource utilization
50 users per 120m*50m	DL:	100%	6.39%
	UL(2reps):	100%	24.18%
100 users per 120m*50m	DL:	99.83%	12.78%
	UL(2reps):	100%	48.36%
150 users per 120m*50m	DL:	98.99%	19.18%
	UL(2reps):	100%	72.54%
200 users per 120m*50m	DL:	97.12%	25.57%
	UL (1rep):	100%	48.50%
250 users per 120m*50m	DL:	95.66%	31.96%
	UL (1rep):	100%	60.58%
Source 5 : Factory Automation (4.9GHz) Reliability of 99.9999%, 1ms air interface, 4.9GHz, TDD, 4Tx/4Rx at gNB and 2Tx/4Rx at UE, realistic channel estimation, ISD20m, case2, InF channel model			
		Percentage of UEs	Resource utilization
50 users per 120m*50m	DL:	100%	9.37%
	UL(2reps):	100%	12.95%
100 users per 120m*50m	DL:	82.16%	18.05%
	UL(2reps):	100%	25.90%

150 users per 120m*50m	DL:	78.09%	26.48%
	UL(2reps):	100%	38.86%
200 users per 120m*50m	DL:	67.60%	35.08%
	UL(2reps):	100%	51.81%
250 users per 120m*50m	DL:	59.80%	41.48%
	UL(2reps):	100%	64.76%

7. Conclusion and recommendation

For high-frequency connectivity, big package size and low latency scenarios, e.g. Differential protection, the performance is mainly limited to system resources. **Lots of enhanced techniques and optimizations should be introduced**, e.g. MU-MIMO, mini-slot, interference coordination, power control and so on.

For small package size and delay is ultra-low (within 1ms) scenarios, e.g. Motion Control, very **high initial transmission accuracy is needed**. Some enhanced techniques for reliability, like LowSE MCS table and some scheduling optimization (e.g. restriction on maximum MCS) should be involved.

For interference-limited and resource-unlimited system, e.g. motion control in factory, **sufficient performance can be achieved in case2**. Vertical customers could take layout case2 into account due to the better interference control between cells.

Frame structure has great influence on delay sensitive scenarios. For the traffic that the uplink load is similar with the downlink load, e.g. motion control, frame structure with short switch-point periodicity and equal UL/DL resources should be considered.

Reference

[1]. 3GPP, TR 38.824, “Study on physical layer enhancements for NR ultra-reliable and low latency case (URLLC)”

[2]. NGMN, ”Verticals URLLC Use Cases and Requirements”

[3]. 3GPP TR 22.804, “Study on Communication for Automation in Vertical Domains”.