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Pre-Commercial Networks Trials - Major Conclusions

- NGMN 5G Trial and Testing Initiative

v2.0

PRE-COMMERCIAL NETWORKS TRIALS MAJOR CONCLUSIONS

by NGMN Alliance

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List of Operators that shared their initial 5G trial results with NSA and SA architecture

***DT and TMUS

CONTENT

1 INTRODUCTION

The NGMN 5G Trial & Testing Initiative (TTI) Project consists of four phases summarized as follows:

- Tests of technology building blocks: (e. g. Massive MIMO, new waveforms...) The member companies may be individually evaluating candidate technologies during the pre-5G deployment period.
- Proof of concept (PoC): The basic features of the radio interface, core network and 5G architectural components as specified by the Third Generation Partnership Project (3GPP). The PoC may be performed using solutions which may be partially proprietary.
- Interoperability phase includes testing of the network aspects and device/network interoperability.
- Pre-commercial networks trials phase with equipment close to commercial quality standard. This phase focuses on an initial planning phase (including test specifications), followed by the trials (with pre-commercial equipment installed on sites).

This document focuses on the Pre-commercial network trials phase actual trial results.

2 SCOPE

Pre-commercial networks trials project has two phases:

- Planning & Test specifications: Developing a testing framework for 5G NR based on 3GPP standards allowing the harmonization of the testing methodologies between the different partners. It includes definition of trials setup, requirements, and test cases.
- Version 3 of the framework document is already released and available from the following web link. Definition of the Testing Framework for the NGMN 5G Pre-Commercial Networks Trials
- Performing trials: Installation and setup of trial network and testing and performance reporting of the results.

This document focuses on performing trials phase. The main purpose is to assess and benchmark the performance of the 3GPP compliant 5G NR (release 15) in live field conditions with pre-commercial equipment.

3 EXECUTIVE SUMMARY

Given the freeze of 3GPP Release 15 5G standards and the onset of some initial 5G commercial deployments in countries such as South Korea, many operators accelerated their 5G trials in 2019.

As a part of NGMN 5G Trial and Testing Initiative (TTI) project, NGMN operators, whose names are given above, shared their initial 5G trial results.

Pre-commercial network trials phase of 5G TTI aims to consolidate the results from different operators and reach some major conclusions. In order to achieve this, trials shall be done based on testing framework document which was designed for this purpose. In the framework document, available from above link in scope section, all test requirements, procedures, and success criteria (if possible) are clearly stated. Due to the infancy of solutions from some vendors, equipment limitations and site constraints, not all tests were executed as per the framework document. Where possible, some of the results are consolidated with a fair approach and for some independent tests, the results are shared by referring operator's name. For each section, the owners of the trials are stated as rapporteurs. The results are evaluated by either explicitly stating they are passed according to NGMN criteria or stating the observation of trial.

Although there are more test sections for NSA and SA configuration in the framework document, eight of them attracted more attention by operators and related results are shared within this document. These are the most important aspects of mobile communication to show its characteristics, therefore we hope it will take great attention by the ecosystem.

With the second version, more SA results as well as Dynamic Spectrum Sharing on FDD NR and other special trial results (e.g. speed impact) have been added to the document. Due to the Covid-19 effect, latter trials could be performed with some delay from the planned date. Anyway, NGMN partners did their best to complete the trials and bring interesting results.

Overall, this consolidation effort, which gathers Trial reports mostly performed using a common methodology, draws some very promising conclusions on the performances of early 5G implementations. Additionally, it brings some observations that could lead to future improvements.

4 TRIAL RESULTS

9 operators shared their initial 5G trial results with NSA and SA networks for main scenarios below:

- Mobility
- Inter-RAT procedures
- Cell capacity
- Latency
- Voice services
- User throughput
- Spectral efficiency
- Coverage

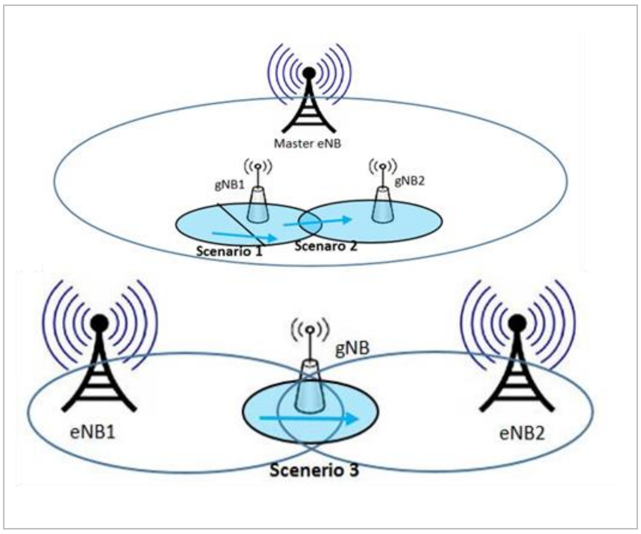
4.1 MOBILITY

This section focuses on intra-cell mobility and inter-cell mobility (handover) scenarios.

Only packet switched data scenarios are considered. Standalone (SA) and Non- Standalone (NSA) configurations are both covered in this section.

4.1.1 NSA MOBILITY

Rapporteurs:



Functional tests:
All inter-cell mobility tests passed!

- Scenario 1: same MeNB, same SgNB, different SCG
- Scenario 2: same MeNB, different SgNB
- Scenario 3: different MeNB, same SgNB
- Scenario 4: different MeNB, No SgNB

*Handover interruption time: Time during which the user is not able to receive any user plane data.

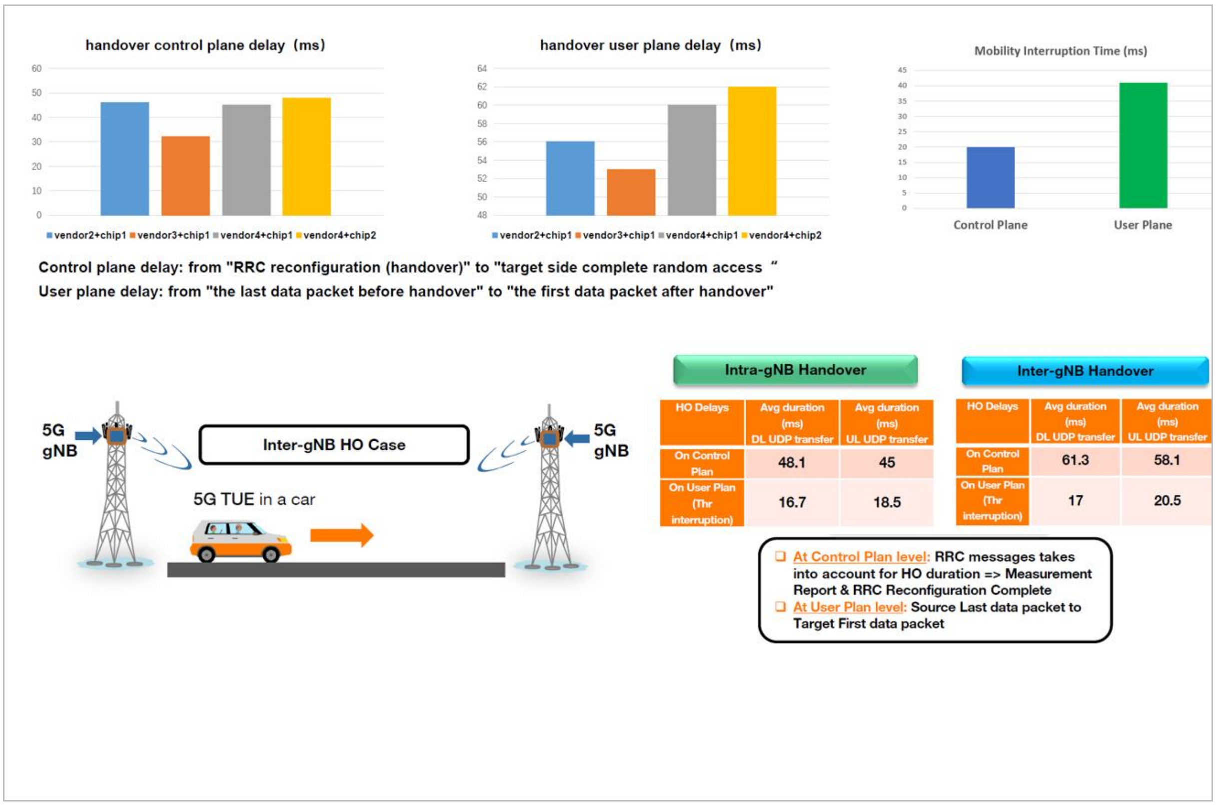
Key Observations:

- Some vendors still don't support NR cell mobility in NSA, NR cell is deleted and re-added during NR and/or Master LTE cell change.
- Small amount of user plane interruption time (less than 20ms) is observed even for NR-NR change. DL PDCP aggregation between LTE & NR leverages almost continuous data transfer.
- Control plane interruption time for intra/inter eNodeB Master LTE handover is between 20ms and 60ms which is similar to LTE.

4.1.2 SA MOBILITY

Rapporteurs:

TURKCELL | 中国移动 China Mobile | orange



Key Observations:

- Intra and inter gNodeB handover tests are successfully completed in SA mode.
- Control plane handover interruption time is between 15 ms and 45 ms.
- User plane handover interruption time is between 17 ms and 62 ms.
- The results vary from vendor to vendor and the gap is huge. The Standalone architecture ecosystem is not still mature at time of trials performed by different operators.
- The minimum values observed during trials (e.g. 17-20ms) seem acceptable for eMBB case but for URLLC, improvements need to be done. (e.g. UE supports simultaneous Tx/Rx with the source cell and the target cell).

4.1.3 5G/4G INTER-RAT MOBILITY

Rapporteurs:

orange

5G -> 4G Handover

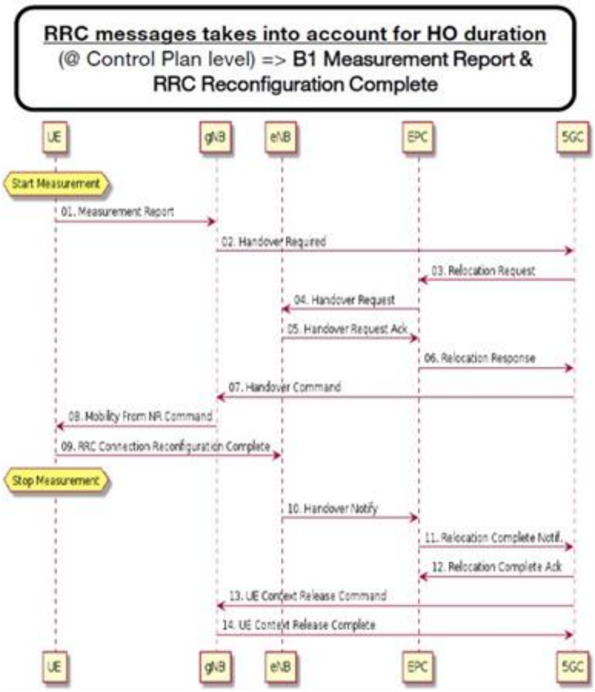
HO Delays	Avg duration (ms) DL UDP transfer	Avg duration (ms) UL UDP transfer
On Control Plan	109	113.4
On User Plan (Thr interruption)	51.8	52.8

4G -> 5G Handover

HO Delays	Avg duration (ms) DL UDP transfer	Avg duration (ms) UL UDP transfer
On Control Plan	178.8	154.5
On User Plan (Thr interruption)	36.9	19

Key Observations:

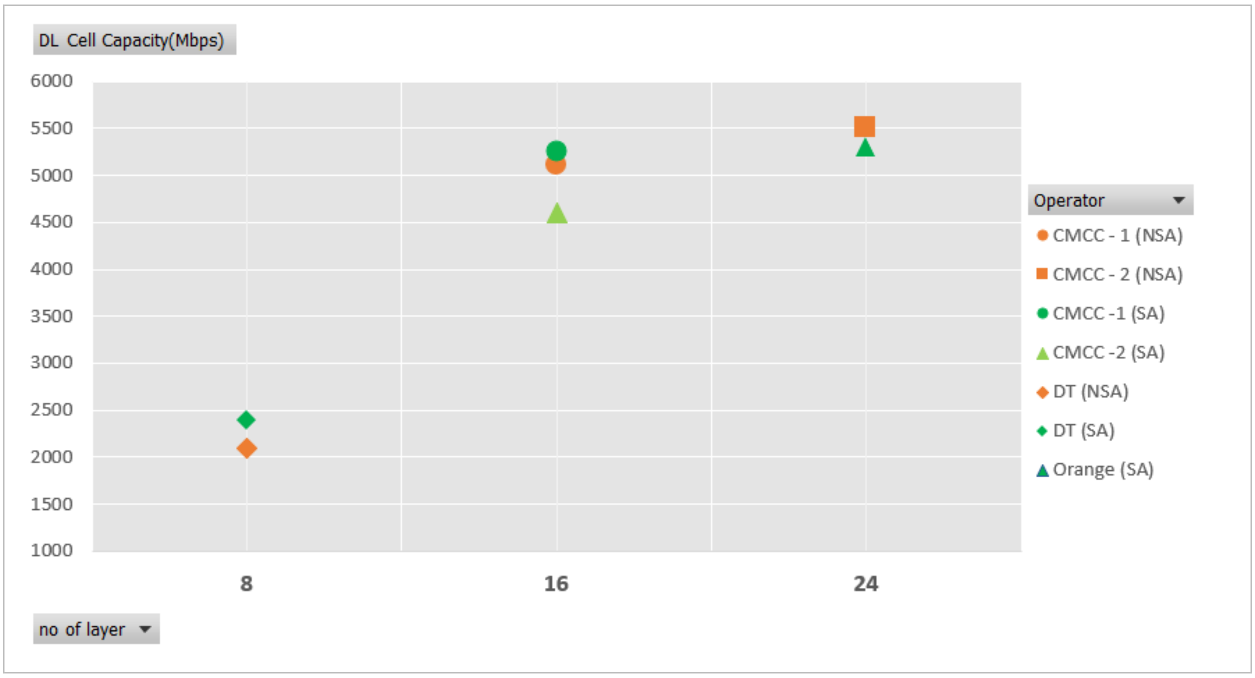
- Both 5G -> 4G Handover and 4G <- 5G Handover tests are completed successfully.
- Interruption times are similar to LTE handovers
- Without N26 interface which is between 5GC and EPC, interruption time is very high compared to a case with N26 interface.



4.2 CELL CAPACITY

4.2.1 CELL PEAK DL THROUGHPUT

Rapporteurs:

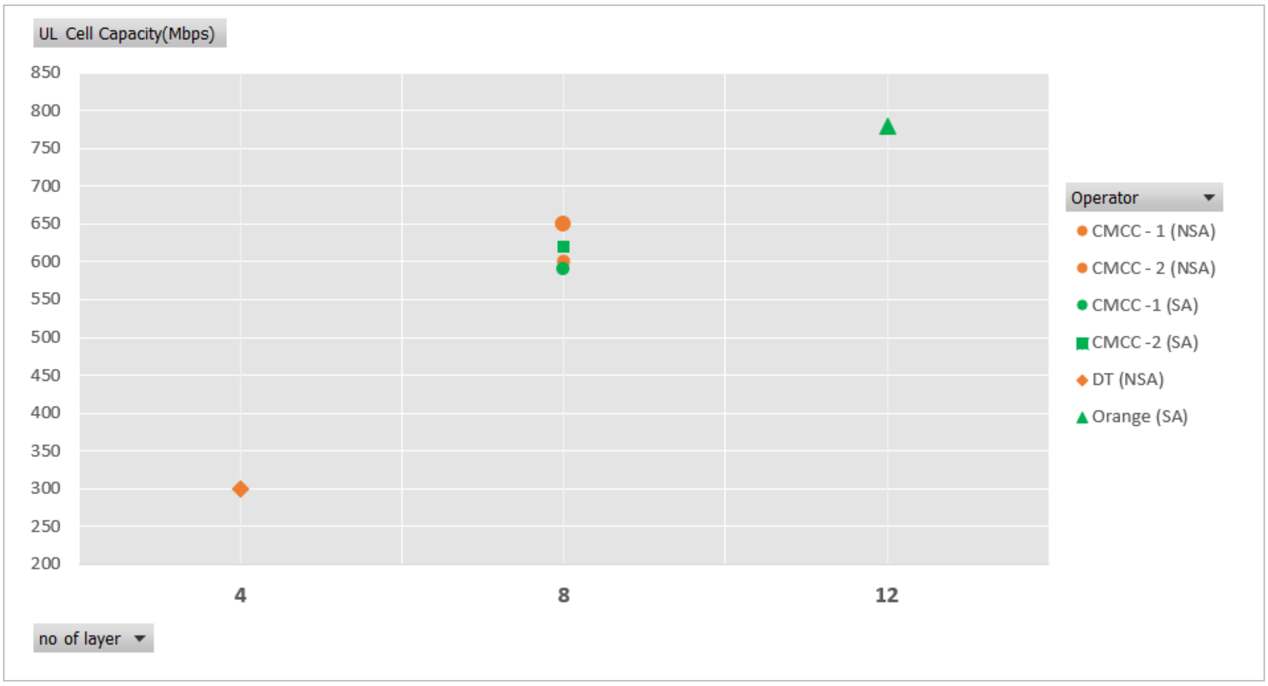


Key Observations:

- With MU-MIMO, 5 to 5.5 Gbps maximum DL throughputs can be achieved as DL cell capacity. Cell bandwidth is 100 MHz on FR1 (below 6 GHz) and TDD DL/UL ratio is %70 vs %30.
- This is 3 to 3,5 times larger than SU-MIMO user DL peak rate with 4 layers in DL.
- Similar performances are observed between Standalone (SA) and Non-StandAlone (NSA) architectures.
- Increasing number of layers from 16 to 24 (%50 percent) does not have proportional effect over maximum DL cell capacity.
- The number of UE's used in the tests varies from 8 to 24.
- UE DL layer number (1 or 2) does not affect maximum cell capacity for MU-MIMO case.

4.2.2 CELL PEAK UL THROUGHPUT

Rapporteurs:

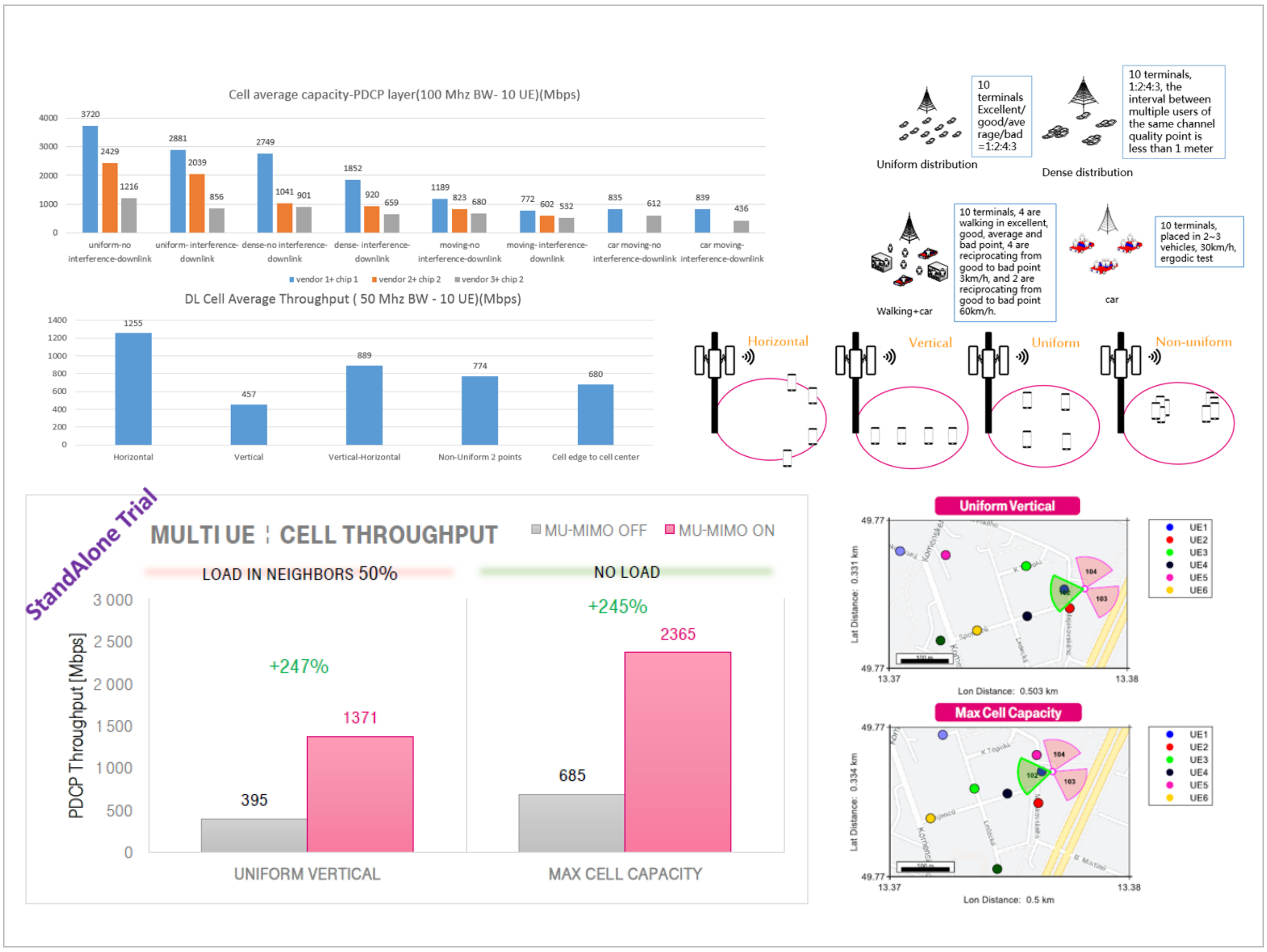


Key Observations:

- With MU-MIMO, 600 to 800 Mbps maximum UL throughputs can be achieved as UL cell capacity.
- This is 3 to 4 times larger than SU-MIMO user UL peak rate with 2 layers in UL.
- Similar performances are observed between Standalone (SA) and Non-StandAlone (NSA) architectures.
- Increasing number of layers from 4 -> 8 -> 12 has major affect over maximum UL cell capacity.
- The number of UE's used in the tests varies from 4 to 8.

4.2.3 CELL AVERAGE THROUGHPUT

Rapporteurs:



Key Observations:

- From uniform to non-uniform distribution, average DL cell throughput is reduced by 25% to 60% since multi-user pairing performance is degraded because of worse space isolation between users.
- For mobility scenarios, multi-user pairing performance is degraded, the rate is about 500~800Mbps, which is 45% ~ 75% lower than the static uniform scenario. Multi-user pairing and scheduling algorithms under different conditions still need to be optimized.
- There is a huge gap between different vendors and chipsets, whole ecosystem is still not mature at the time of trials.
- No major performance differentiation in SA architecture. Consistent gain about 250% of MU-MIMO over SU-MIMO is observed.

4.3 LATENCY

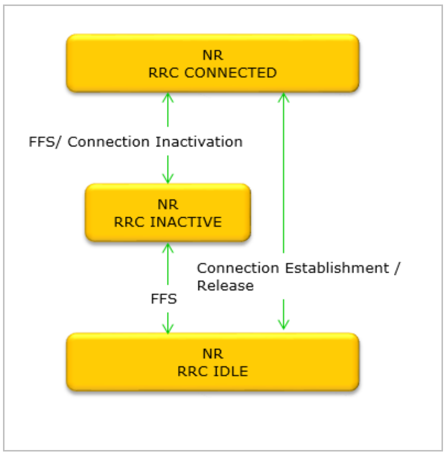
Latency is a very important parameter for enabling 5G use cases, particularly the URLLC use case for Latency-critical applications, such as, factory or home automation, automated vehicles, gaming services, remote computing…

This section brings early 5G Latency performance reports with pre-commercial 5G solutions (infrastructure, transport and devices) through most significant testing configuration cases. Both control plane and user plane latencies are considered.

4.3.1 CONTROL PLANE LATENCY

Rapporteurs:

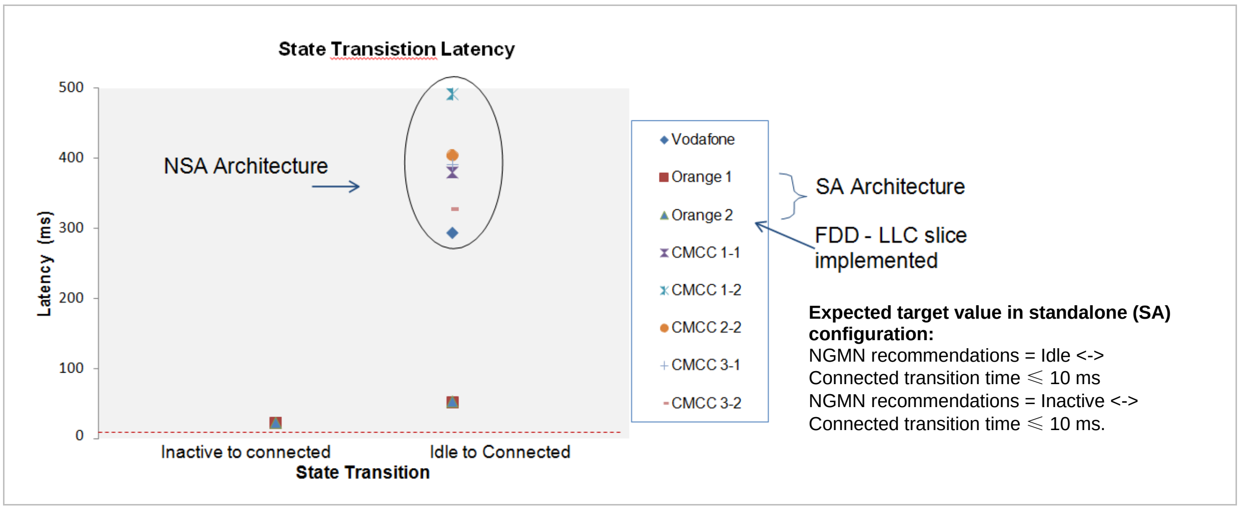
中国移动 China Mobile | orange | vodafone



These tests are intended to validate different mobility state transitions (control plane) and their transitions times.

More specifically, tests aim to:

- Quantify "Idle to Connected"/ "Connected to Idle", and "Inactive
- to Connected"/ "Connected to Inactive" state transition times.
- Verify the associated process for each type of state transition.



Initial conclusions:

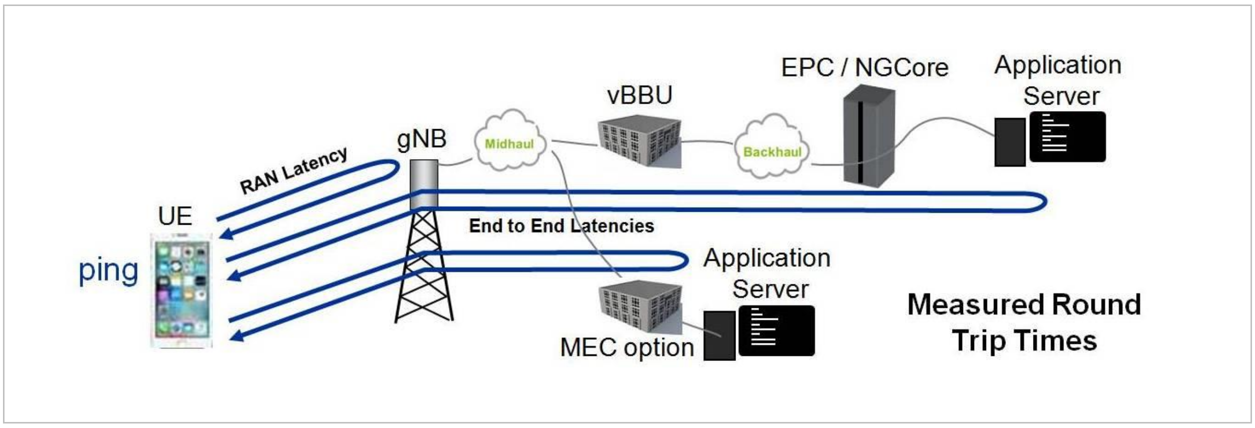
- NGMN objectives in SA are not yet met. In SA architecture, about 23ms and 45ms control plane latency is observed for Inactive to connected and Idle to Connected respectively.
- The implementation of a specific Low Latency Communication slice has no influence on call setup times.

4.3.2 USER PLANE E2E LATENCY (IN CONNECTED MODE)

Rapporteurs:

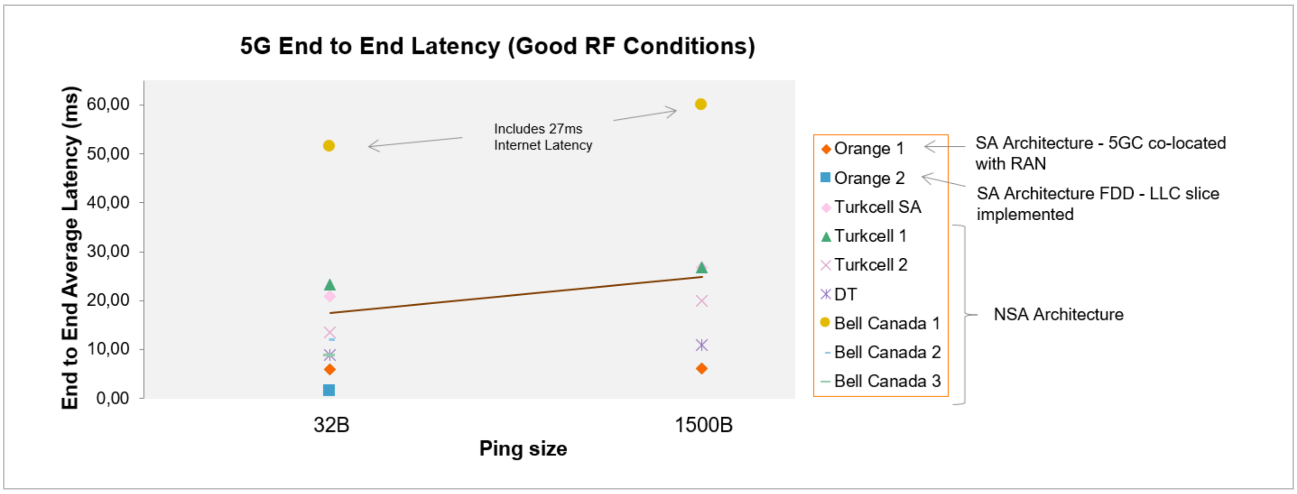
Bell | T · · | orange | TURKCELL

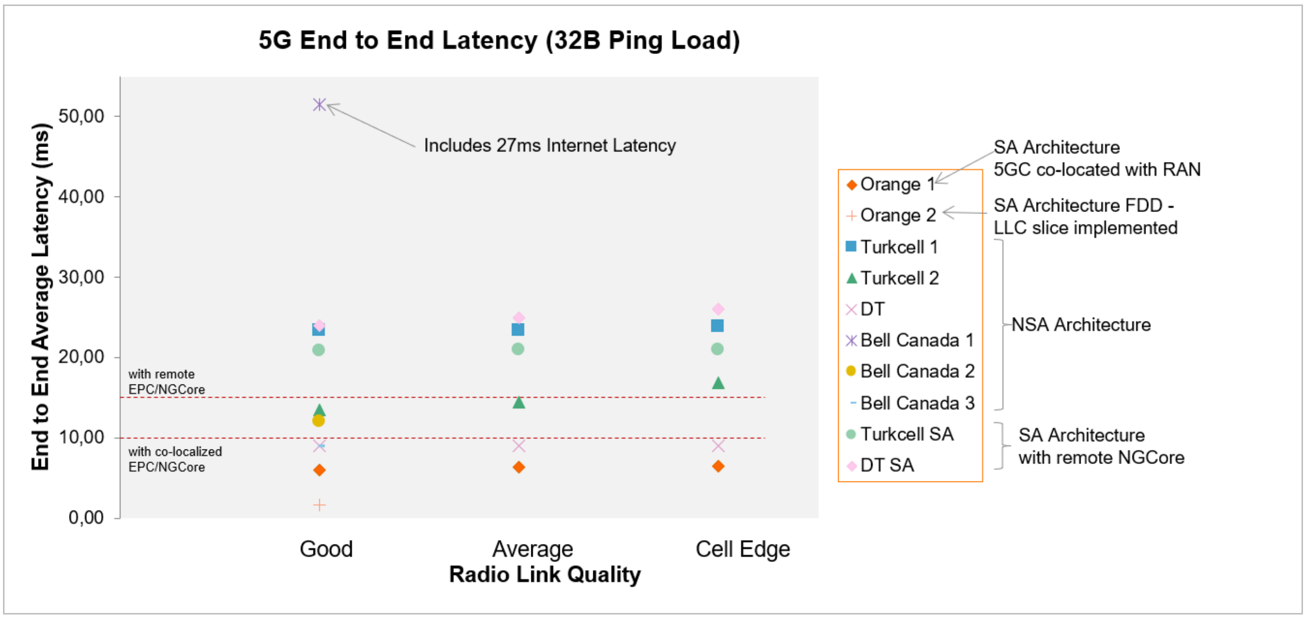
For the sake of clarity, Round Trip Times (RTT) for both RAN and End to End Latencies were considered.



Success criteria for eMBB:

- RAN latency ≤ 8 ms
- E2E latency with 200 km distance between NR node and EPC/NGCore + Application server ≤ 10-15 ms





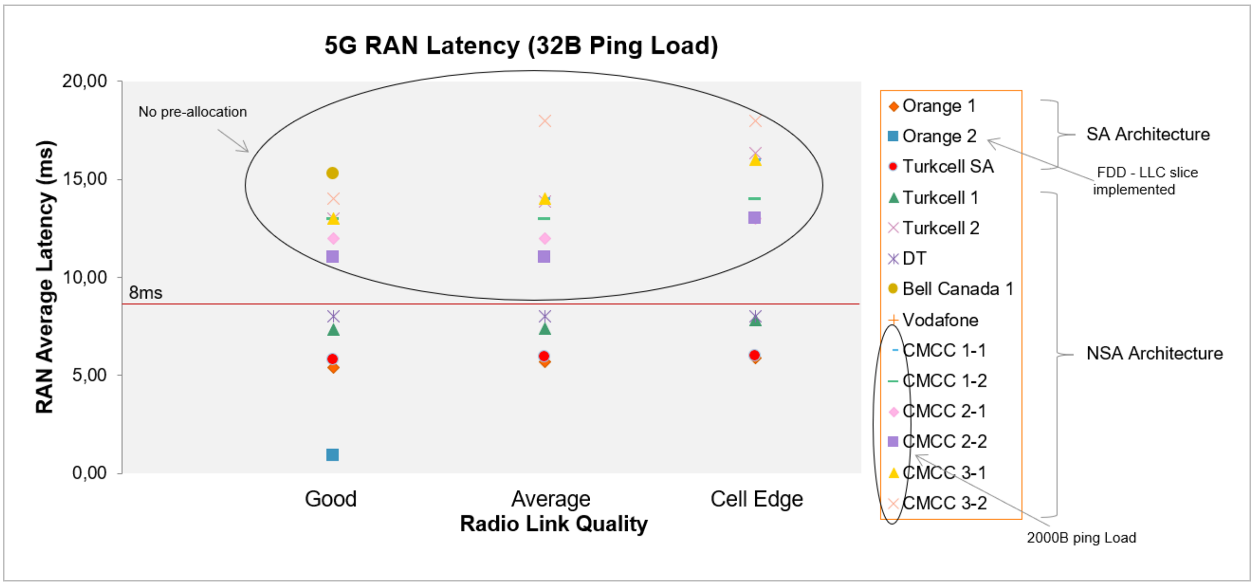
Initial conclusions:

- The End to End Latency slightly increases with the packet size.
- The radio link quality has a low impact of on the End to End Latency for low packet sizes.
- Early results in SA architecture are very promising.
- Core – RAN distance plays a key role in the e2e latency results, which reveals the need for MEC.

4.3.3 USER PLANE RAN LATENCY (IN CONNECTED MODE)

Rapporteurs:

Bell | China Mobile | T-Mobile | orange | TURKCELL | vodafone



Initial Conclusions:

- The radio link quality has a low impact of on the End to End Latency for small packet sizes.
- The optimization of the network and the implementation of specific features (e.g. pre- allocation, slicing) have a significant impact on the Latency results, regardless of the architecture.
- TDD framing format will also influence latency timing. As the switch period from DL to UL is reduced, NR latency can see improved results.
- Early results in SA architecture are very promising.
- Latency results were obtained with one single user. However, when the network is not congested, the number of users (up to 10 in a cell) has no impact on the Latency.

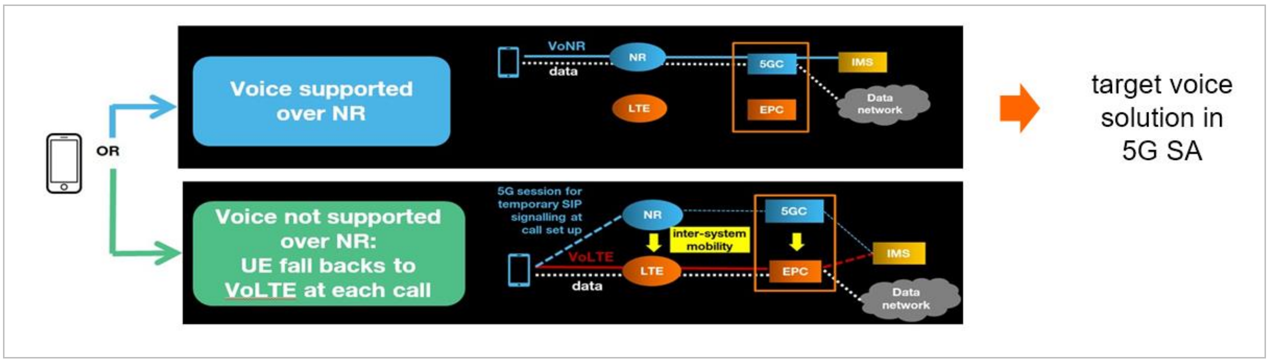
4.4 VOICE SERVICES

4.4.1 VOICE SERVICES (VONR & EPS FALLBACK)

Rapporteurs:

orange | 中国移动 China Mobile

2 ways to support voice services in 5G SA were tested.



And 2 key aspects of voice in 5G SA were tested with or without N26 interface (between AMF & MME):

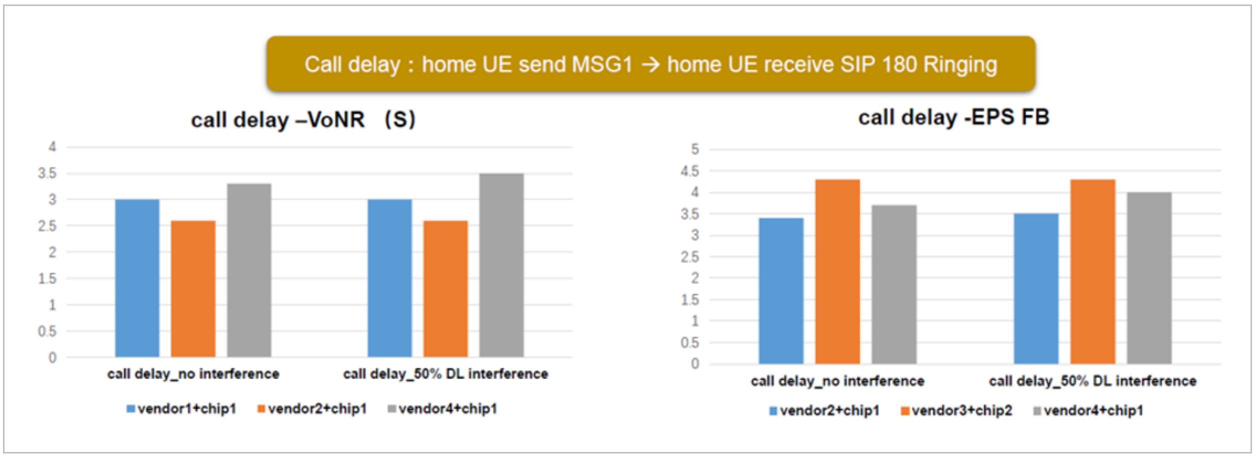
- The impact of 5G-4G mobility procedure on Voice Service
  During a VoNR call, when 5G coverage is no more available, the call has to be seamlessly moved to 4G.
- The impact of EPS Fallback (EPS-FB) on Call Set up Time (CST)
  EPS-FB triggers inter-system Hand Over during call establishment which impacts the CST

VoNR: Voice over New Radio & 5GC – **EPS:** Evolved Packet System; 4G – **AMF:** Access and Mobility Management Function, 5G

4.4.2 E2E VOICE TESTING RESULTS

Rapporteurs:

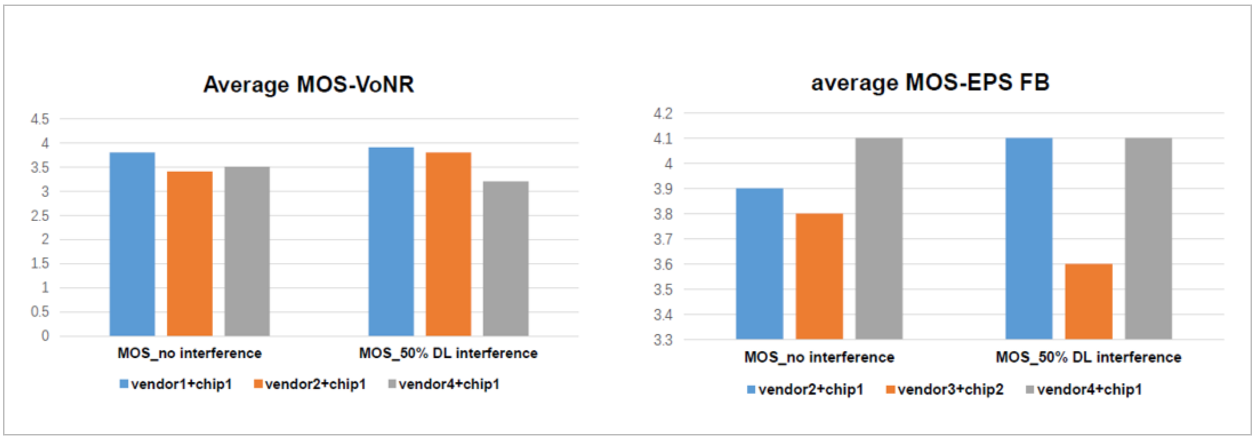
Test case	Type of Voice call	Observations
Mobility	5G (VoNR) to 4G (VoLTE) mobility	With N26 interface voice interruption time is ≈ 70ms Without N26 interface, the interruption time is ≈ 700ms (recommended limit for a voice call = 300ms)
Call set up time	Originating 5G (EPS-FB) to 4G (VoLTE) Originating 5G (VoNR) to 4G (VoLTE)	With EPS-FB, the Call Setup Time is ≈ 1s more than with VoNR (with N26) and still slightly increased without N26 (+ 0,5s).



Initial Conclusions:

- VoNR & EPS Fallback calls successfully passed in 5G Standalone Architecture mode
- Standardization requirements seem correctly implemented
- Performance and voice quality seem good in initial trials
- VoNR Call Setup Time is expected to be at least as good as for VoLTE (2 - 3,5 sec).
- Increase of Call Setup Time for voice with EPS-FB is expected to stay limited: ~1 sec. more than VoNR (with N26) which should have a limited impact on the end user experience
- N26 is needed for best seamless voice continuity in mobility. Without N26, 10 times larger mobility interruption time is observed (70ms vs 700ms)
- EPS-FB needs to fallback from 5G to 4G network, therefore the coverage of 4G and 5G will affect EPS-FB voice service performance

- Ecosystem is not mature (terminal, network, optimization…) for VoNR so average MOS of VoNR perceived by users is slightly less than MOS of VoLTE at time of trials



4.5 USER THROUGHPUT AND SPECTRAL EFFICIENCY

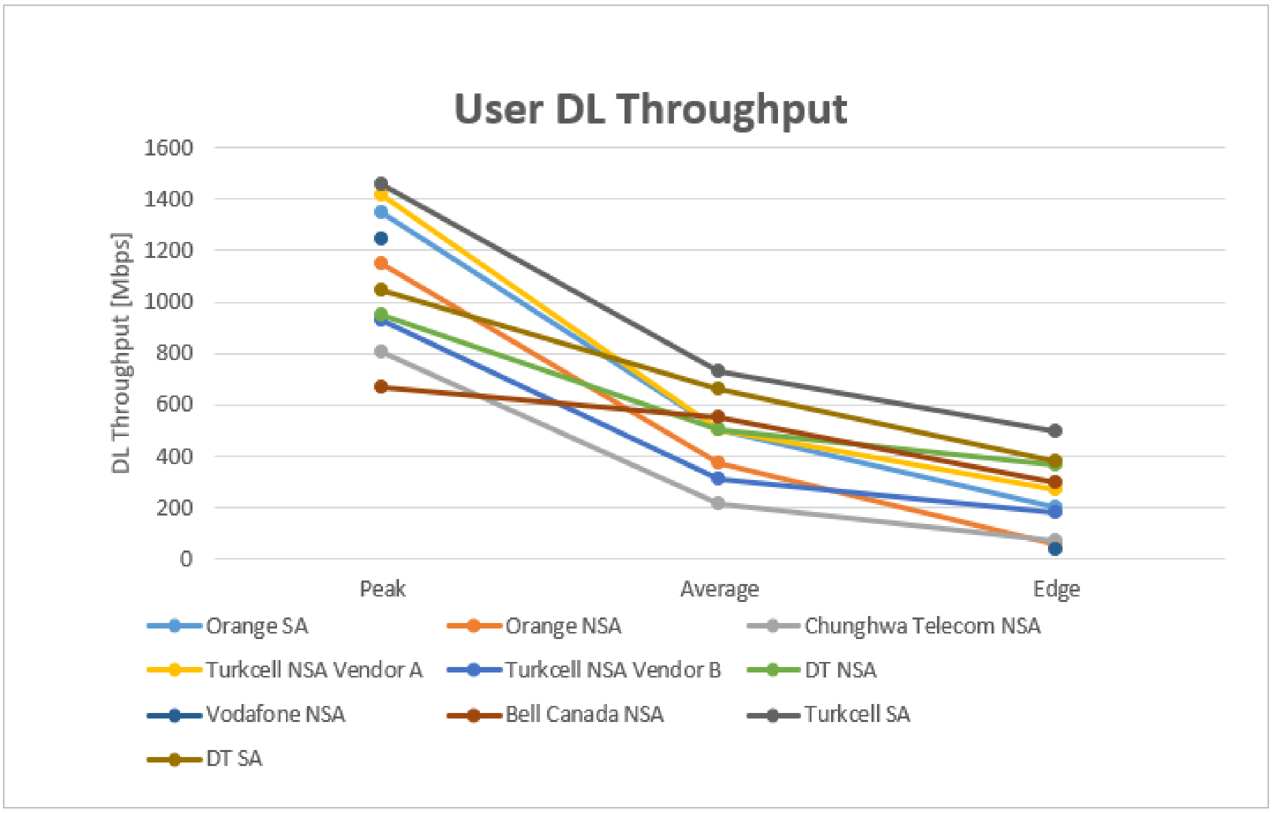
4.5.1 USER DOWNLINK / UPLINK THROUGHPUT

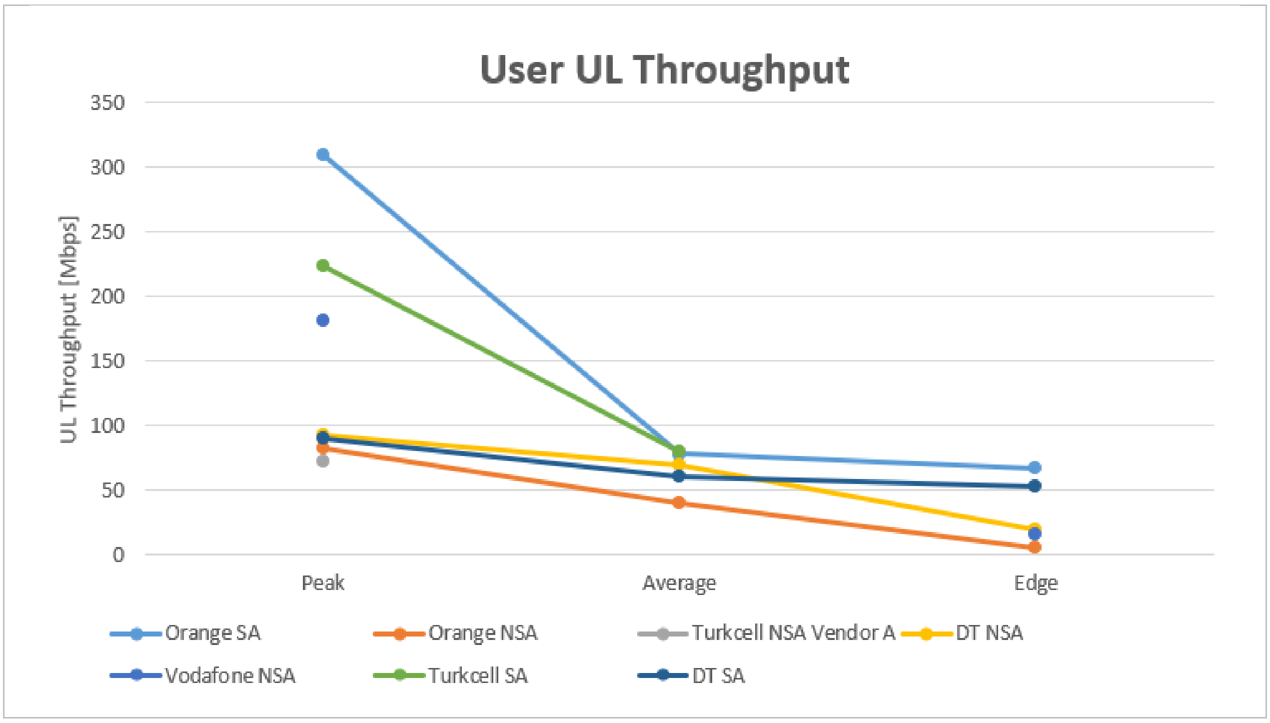
Rapporteurs:

Bell, 中華電信 Chunghwa Telecom, T, orange, TURKCELL, vodafone

Success criteria ([eMBB use case]; < 6GHz, 100 MHz BW; dense-urban environment)

- For 4x4 DL MIMO, 5G should deliver around 1.75 Gbps DL peak rate with DDDSU slot configuration.
- For UL assuming 2x2 UL MIMO, 5G should deliver around 200 Mbps UL peak rate with DDDSU slot configuration and 64QAM modulation.
- NGMN: 100X improvement over LTE (3GPP Release-12) for UL/DL data rate on cell edge (assuming centralized architecture) (NGMN White Paper 6: 50 Mbps and 25 Mbps).





Initial Conclusions:

- There are differences between the results due to the different conditions of individual trials, which were also done in different stages of the NR implementation development.
- SA and NSA trial DL throughput results are similar for peak values as expected. However, the average and edge DL throughput results are superior in SA than NSA. This is mainly due to fact

that the SA trials are performed at least one year later than NSA trials and terminal, network and optimization features are becoming more mature day by day.

- SA UL throughput performance is improved at least by double thanks to the uplink MIMO in UEs.
- TDD frame structure plays a key role for UL/DL throughput results.
- For peak measurement we can see that the results are close to the target but still need some improvements.
- The target values for average and edge user throughput were mostly reached during the trials however tests should be repeated under loaded 5G networks.

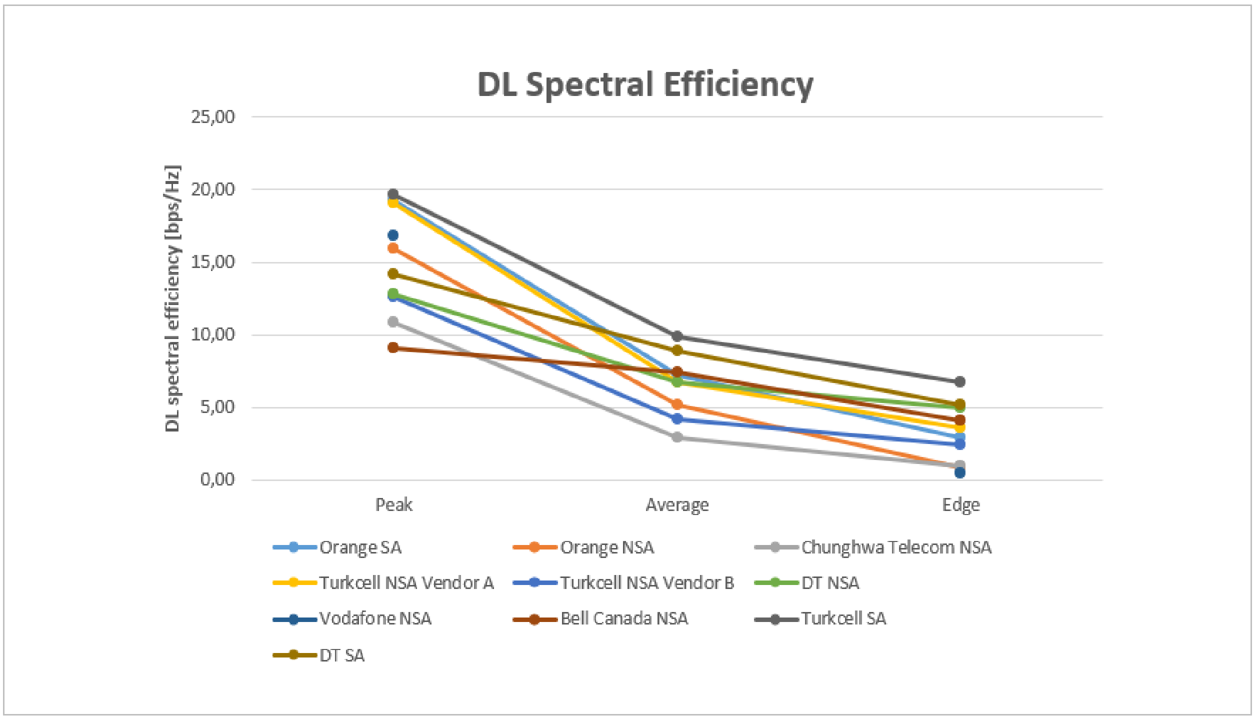
4.5.2 SPECTRAL EFFICIENCY

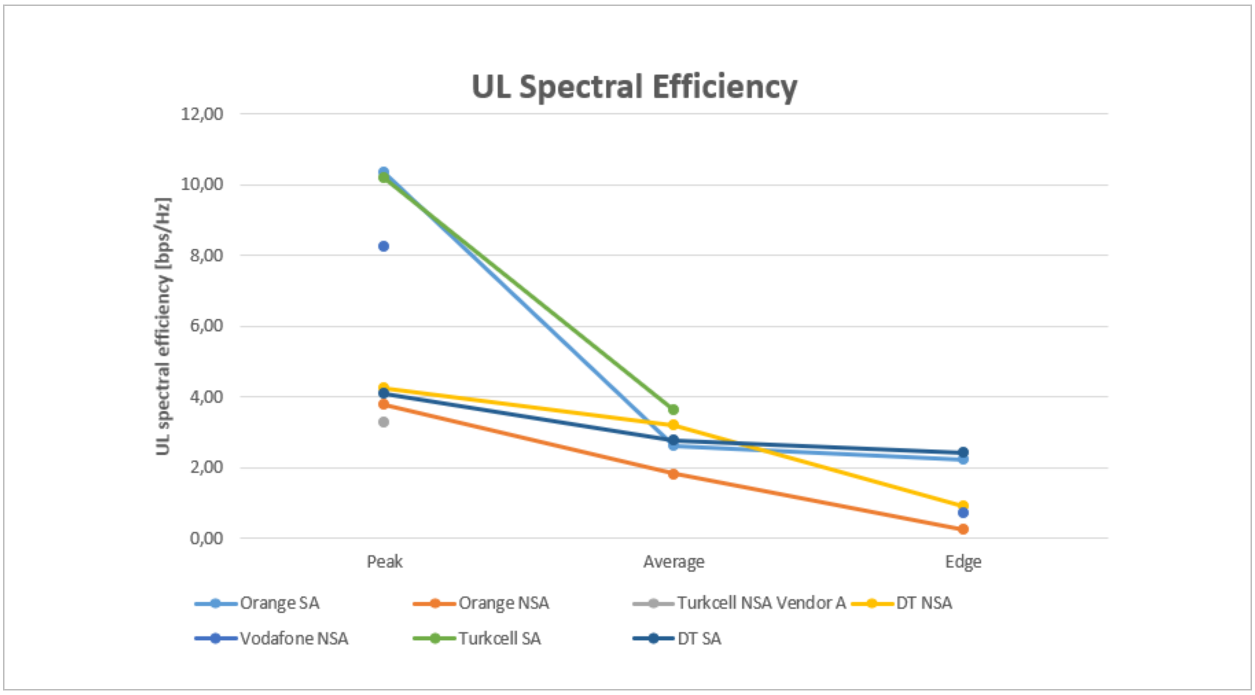
Rapporteurs:

Bell | 中華電信 Chunghwa Telecom | T · · | orange | TURKCELL | vodafone

Success criteria (eMBB use case)

- 3GPP peak spectral efficiency targets (eMBB use case): 30 Bit/s/Hz for DL(8X8MIMO), 15 Bit/s/Hz for UL
- ITU-R medium spectral efficiency targets (eMBB use case): 7.8 Bit/s/Hz for DL, 5.4 Bit/s/Hz for UL
- ITU-R cell edge spectral efficiency targets (eMBB use case): 0.225 Bit/s/Hz for DL, 0.15 Bit/s/Hz for UL





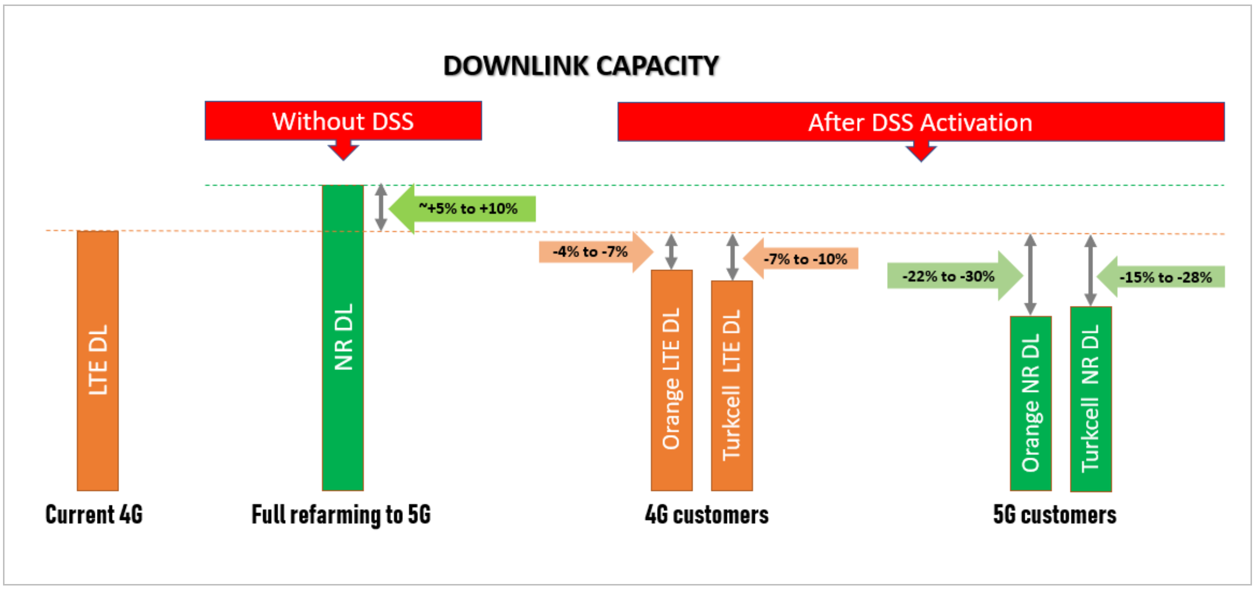
*Results are recalculated based on TDD frame structure

Initial Conclusions:

- There are differences between the results due to the different conditions of individual trials, which were also done in different stages of the NR implementation development.
- Downlink peak spectral efficiency targets are close however because of commonly deployed single uplink transmitter for NR in NSA devices, UL spectral efficiency targets are far away to be met in live 5G NSA networks.
- Uplink peak spectral efficiency is approximately 2.4 times better in SA trials thanks to the uplink MIMO and 256 QAM.
- The values for average and edge throughput were mostly reached during the trials.

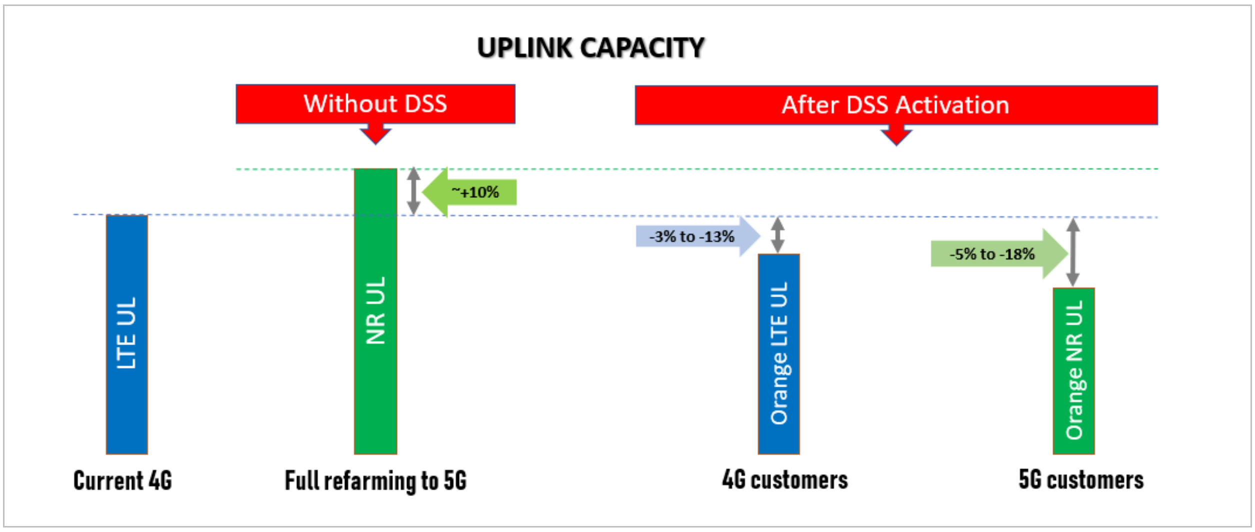
4.5.3 DYNAMIC SPECTRUM SHARING ON FDD NR

Rapporteurs:



Initial Conclusions about Downlink Performance:

- 4 to 10 percent LTE DL throughput degradation because of NR control channels overhead compared to current LTE cell downlink capacity
- 15 to 30 percent NR DL throughput degradation because of LTE control channels (especially CRS) overhead compared to FDD frequency downlink capacity which is refarmed to NR
- Additional DL performance degradation on NR due to interference from LTE neighbor cells on DSS band is expected (the percentage of degradation is under study)
- This is mainly due to non-support of interference cancellation of 4G signalization by 5G UEs (contrary to 4G UEs)



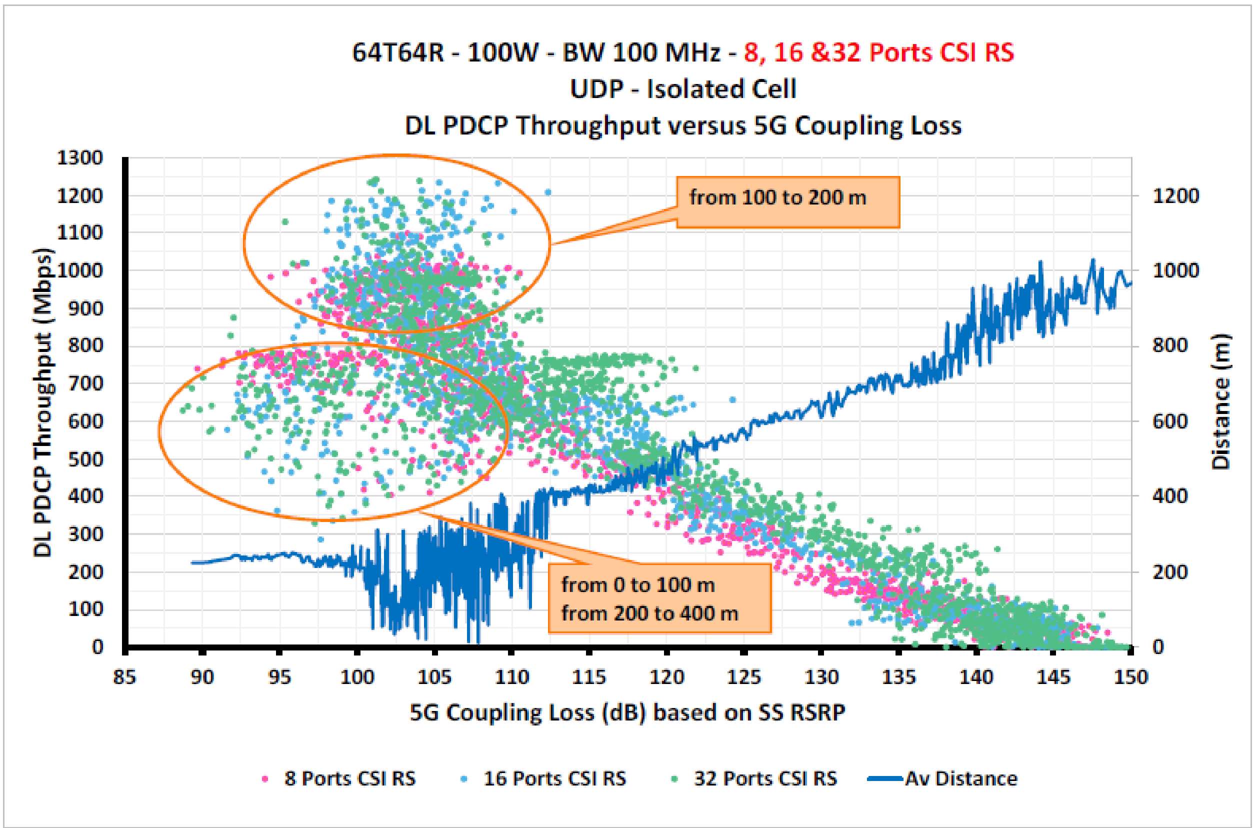
Initial Conclusions about Uplink Performance:

- 3 to 13 percent LTE UL throughput degradation because of NR overhead compared to current LTE cell uplink capacity
- 5 to 18 percent NR UL throughput degradation because of LTE overhead compared to FDD frequency uplink capacity which is refarmed to NR

4.5.4 CSI-RS PORT EFFECT ON DL THROUGHPUT PERFORMANCE

Rapporteurs:

orange



(Ref 8 ports)	Cell center 90 to 110 dB	Cell Middle 110 to 135 dB	Cell Edge 135 to 149 dB
8 Ports	852 Mbps	382 Mbps	70 Mbps
16 Ports	856 Mbps (+0.4%)	459 Mbps (+20%)	70 Mbps (0%)
32 Ports	805 Mbps (-5%)	525 Mbps (+37%)	84 Mbps (+20%)

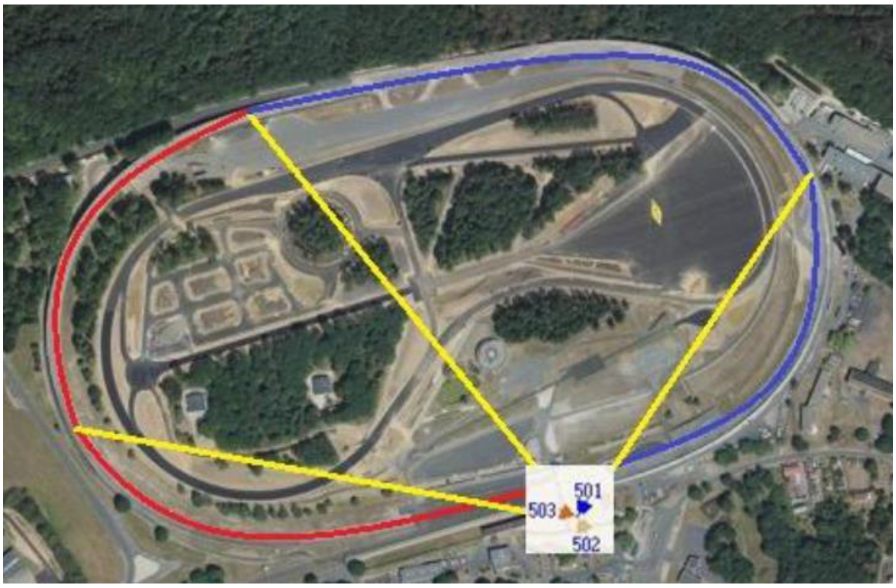
Key Observations:

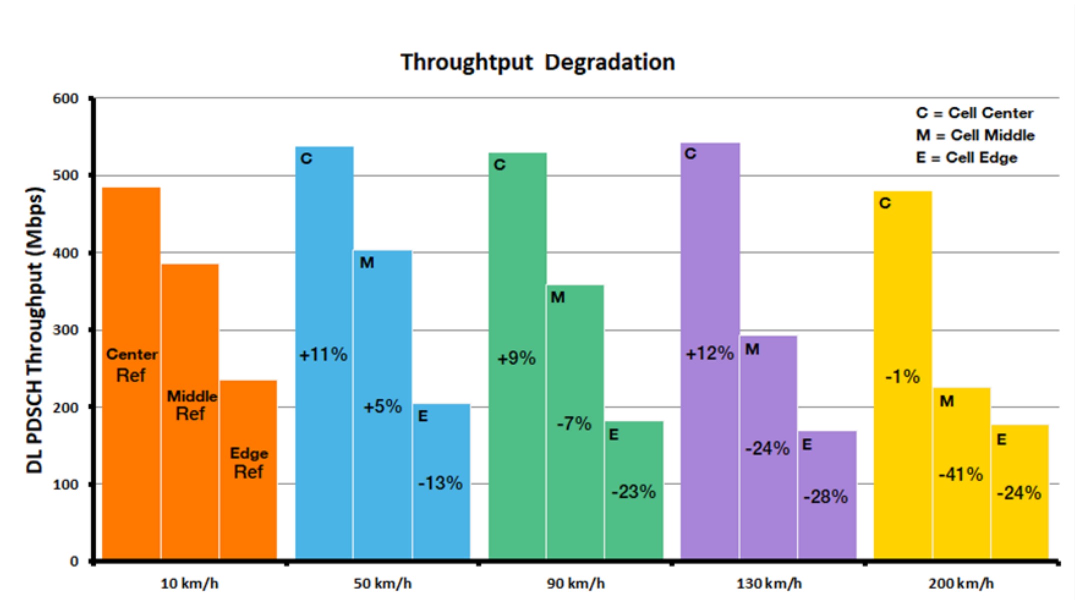
- 16 and 32 Ports CSI-RS compared to 8 ports increase the DL throughput performance significantly at cell middle.
- No gain is observed at cell center.
- The gain is only visible with 32 ports at cell edge.

4.5.5 SPEED IMPACT

Rapporteurs:

orange





Cell Center : [80 – 105]
Cell Middle : [105 – 115]
Cell Edge : [115 – 140]

Trial Setup:

- Speed tests are carried out on the oval race track.
- Tracks are recorded all over the circuit at different speeds ranging from 10km/h to 200 km/h for 10 minutes each

- Full buffer UDP traffic is sent during the test
- NR at 3,5GHz with 100 MHz bandwidth & LTE Anchor at 700 MHz with 10 MHz bandwidth

Key Observations:

- Degradation of throughput due to speed is not as important as expected
- Cell center performances are still constant even at high speeds due to the circuit topology
- Good performances are observed from center to the edge of the cell
- At 200 km/h speed, cell edge performance is around 193 Mbps
- Performances are sensitive to speed but the impact is device dependent

4.5.6 CARRIER AGGREGATION COMBINATION ON EN-DC

Rapporteurs:

Bell

Peak Downlink Throughput with PDCP Split

CA Combo	BW	Peak Throughput	Samsung	LG	OEM #3
B13_ B2_B7_B7	65MHz	1.22Gbps	Yes	No	No
B2_B7_B7_B66a	75MHz	1.46Gbps	No	Yes	Yes
n66	10MHz	163Mbps	Yes	Yes	Yes
Total Peak Thp			1.38Gbps	1.62Gbps	1.62Gbps

Peak Uplink Throughput with PDCP Split

Uplink in EN-DC	BW	Peak Throughput	Samsung	LG	OEM #3
B2 or B7	20MHz	75Mbps	No	Yes	Yes
B66a	15MHz	56Mbps	No	No	Yes
B13	5MHz	18Mbps	Yes	No	No
n66	10MHz	44Mbps	Yes	Yes	Yes
Total Peak Thp			62Mbps	119Mbps	119/100Mbps

Key Observations:

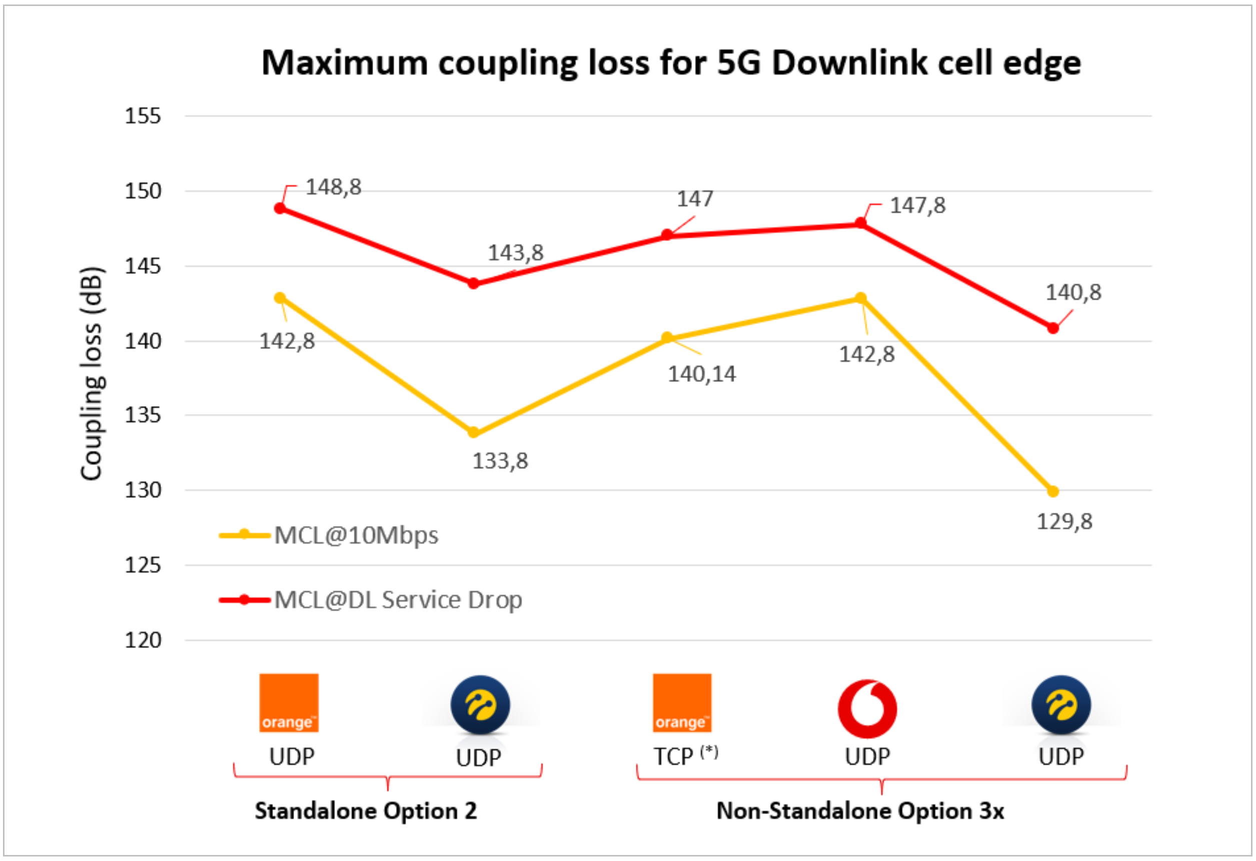
- Achievable peak throughput depends on CA combinations supported by UE in EN-DC.
- Especially for NR in low-bands case, in order to make total observed throughput by UE competitive with /superior to current LTE Advanced scenario, many CA combination in EN-DC should be supported by ecosystem.

4.6 COVERAGE

4.6.1 5G DOWNLINK MAX COUPLING LOSS

Rapporteurs:

orange | TURKCELL | vodafone



(*) Results for tests with 80W cell power for 60MHz bandwidth. The difference in downlink results could be related to uplink max transmitted power reached earlier with TCP vs UDP. The TCP to UDP gap is incremental as the cell power is increased from 80W to 120W and 200W

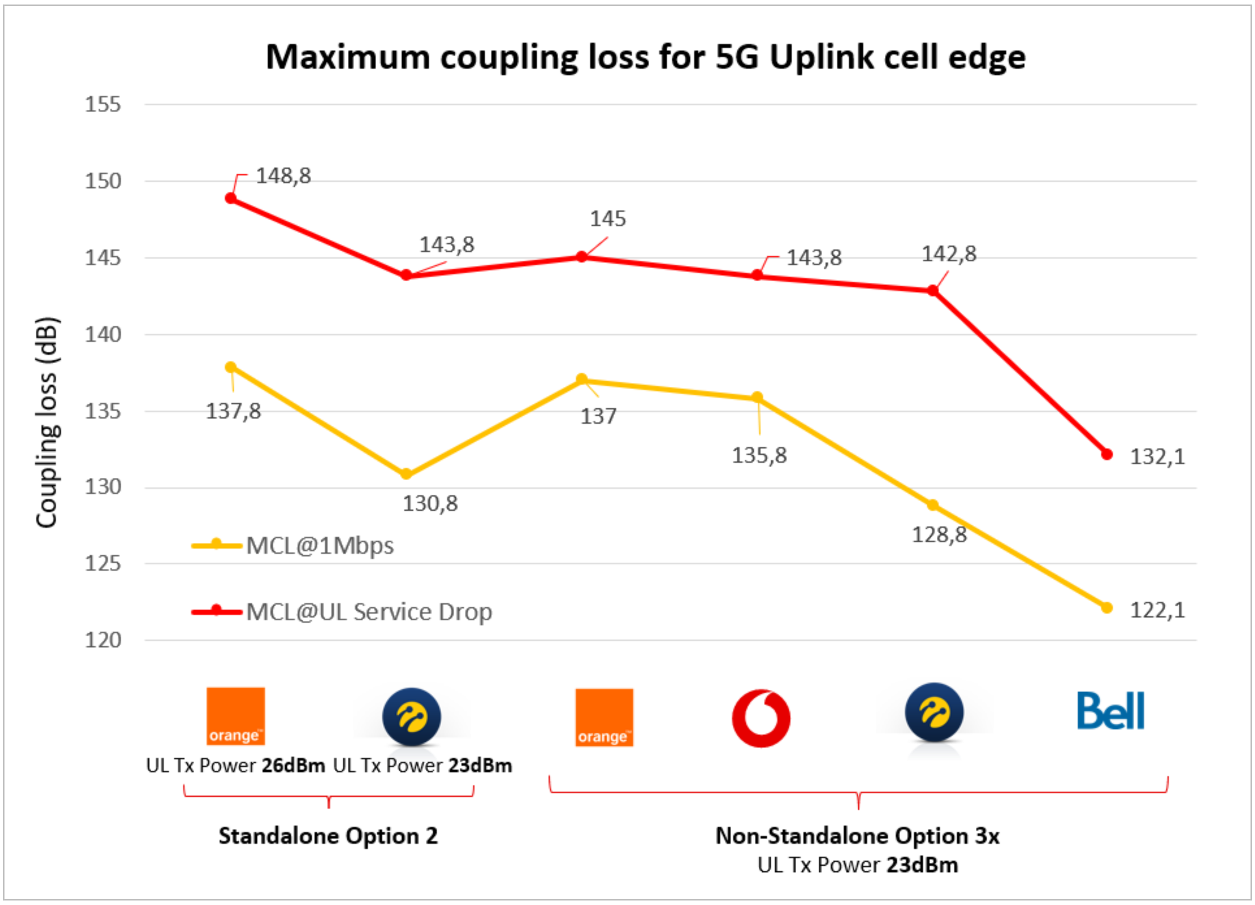
Key Observations:

- 5G Downlink maximum coupling loss ranges from 140.8 to 148.8 dB
- DL 10Mbps is observed at 4-11 dB less
- No major difference between SA and NSA

4.6.2 5G UPLINK MAX COUPLING LOSS

Rapporteurs:

Bell | orange | TURKCELL | vodafone



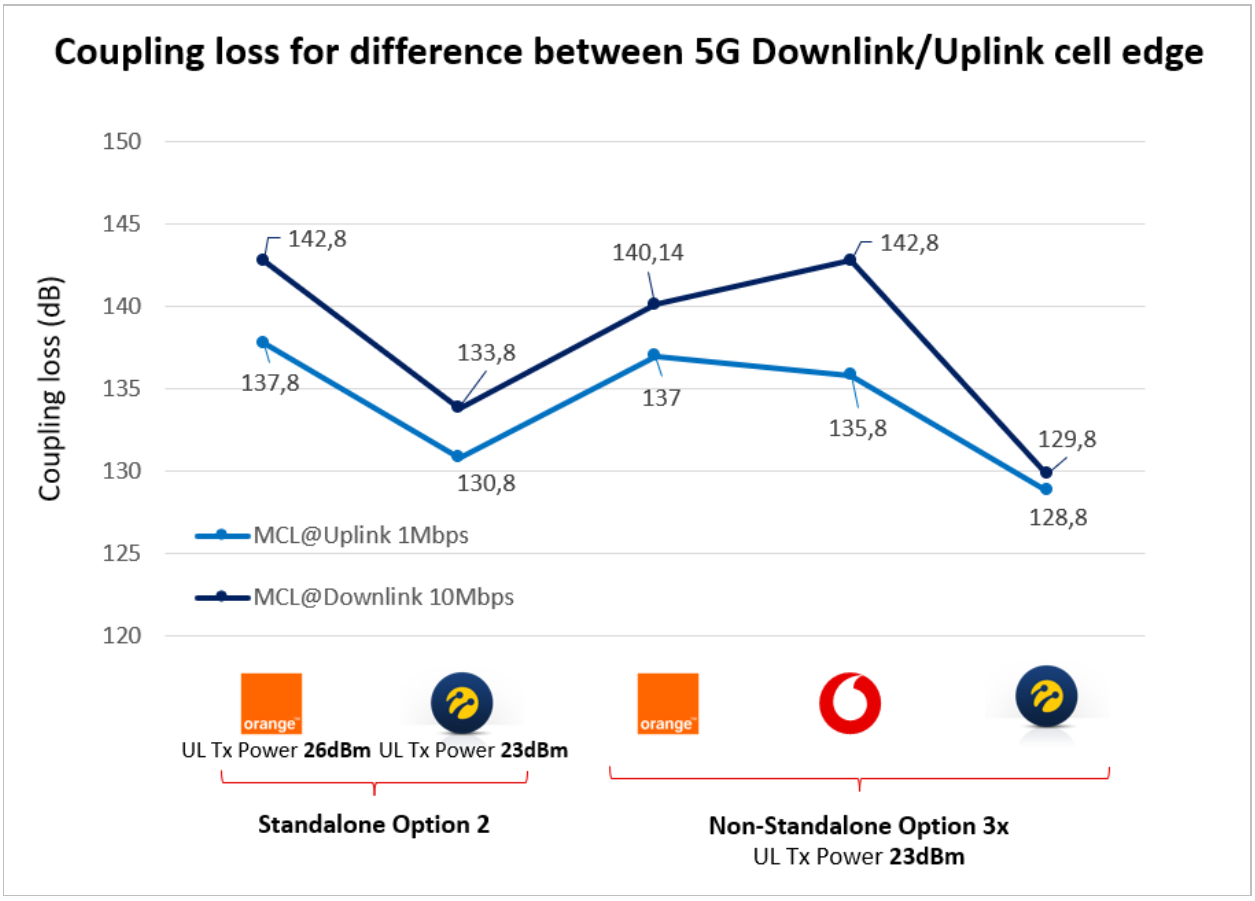
Key Observations:

- 5G Uplink maximum coupling loss ranges from 132 to 148 dB
- UL 1Mbps is observed at 8-14 dB less
- Option 2 reaches 3dB more MCL thanks extra UL power

4.6.3 5G UPLINK VS. DOWNLINK COUPLING LOSS GAP

Rapporteurs:

orange TURKCELL vodafone

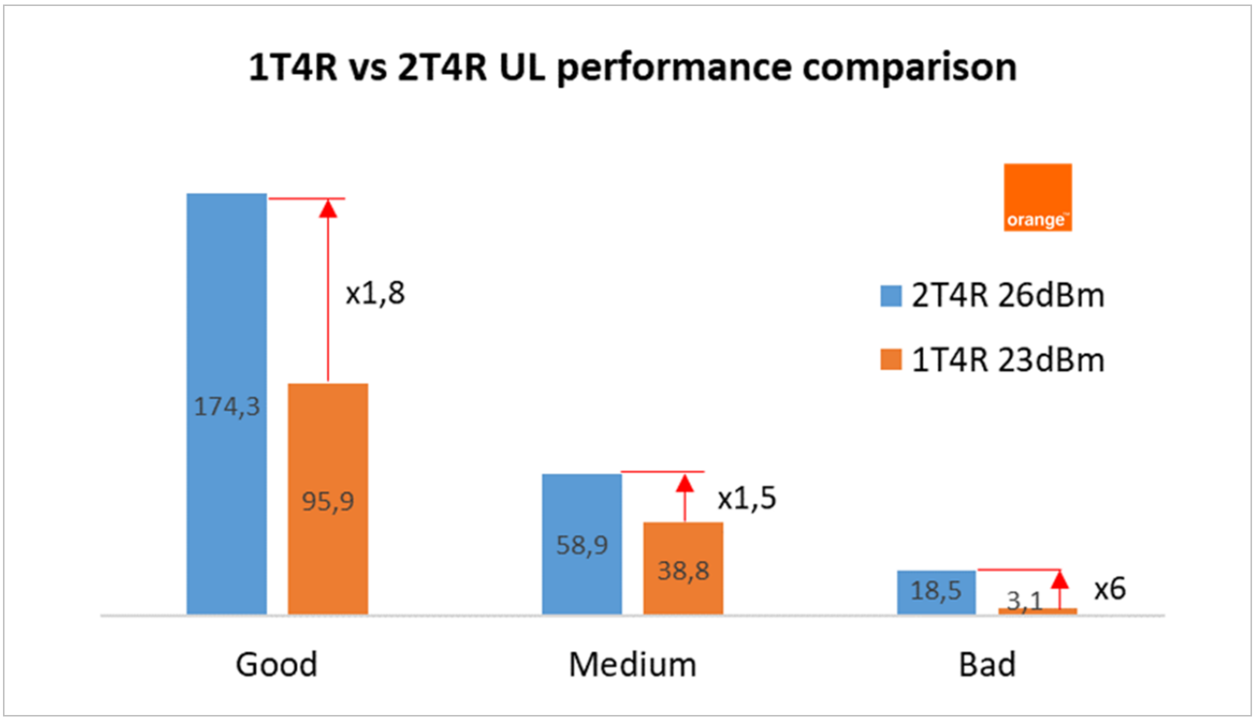


Key Observations:

- 1-7dB 5G Uplink coupling loss gap vs 5G Downlink for 10/1Mbps DL/UL throughput targets

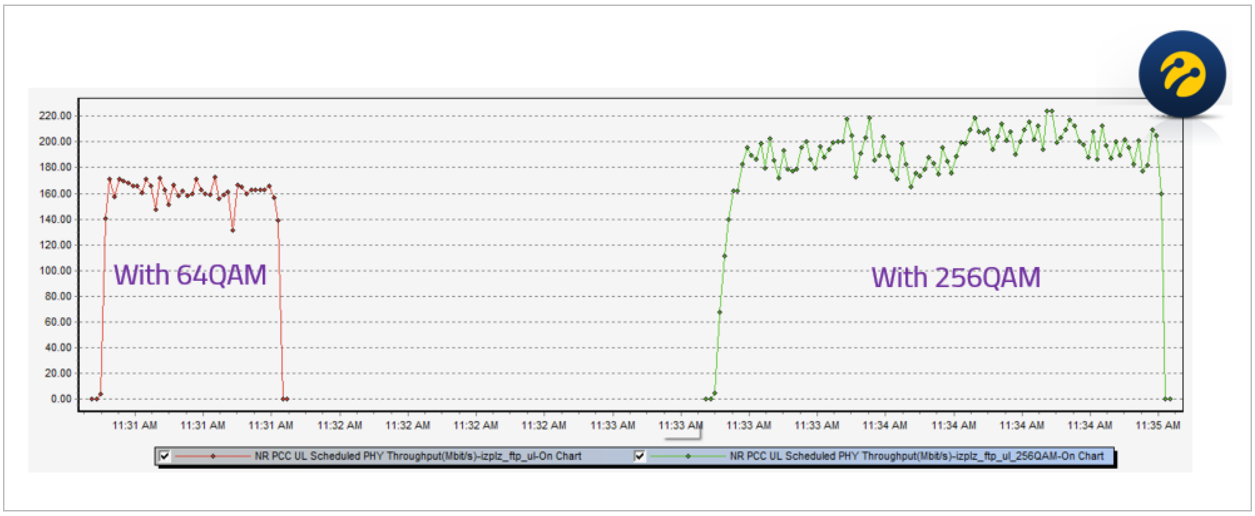
4.6.4 5G UPLINK 2 TRANSMITTERS

Rapporteurs:



Key Observations:

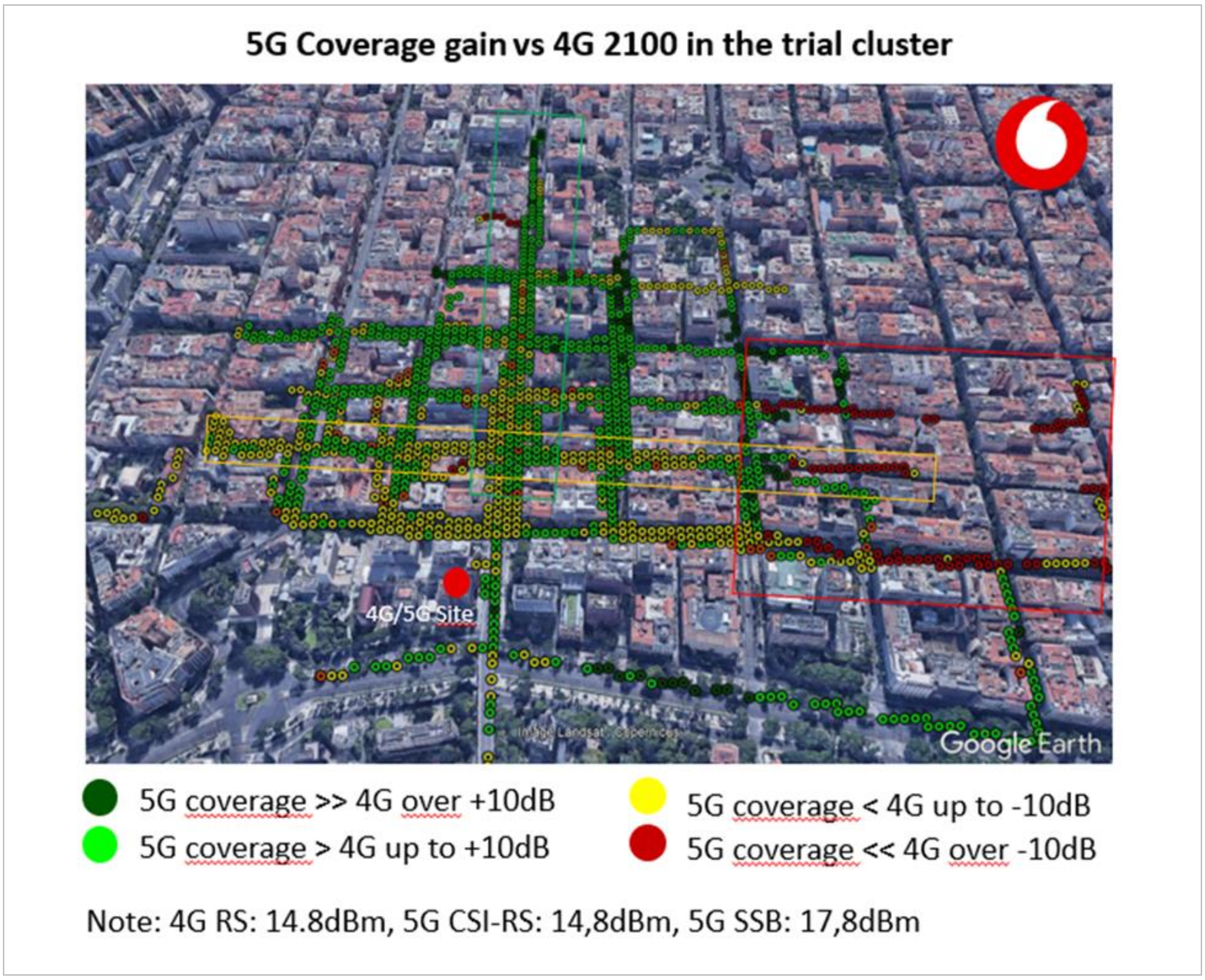
- Up to 6 times UL throughput at bad radio conditions when using 2 transmitters in device with +3dB transmitted power vs 1 transmitter
- With 256QAM and 2 transmitters in the uplink, up to 2.4 times peak uplink throughput can be observed

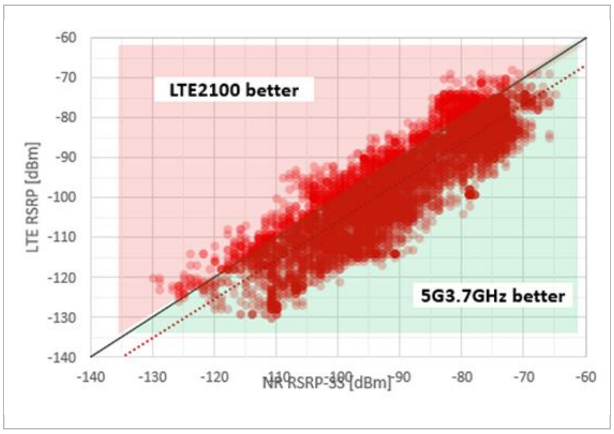


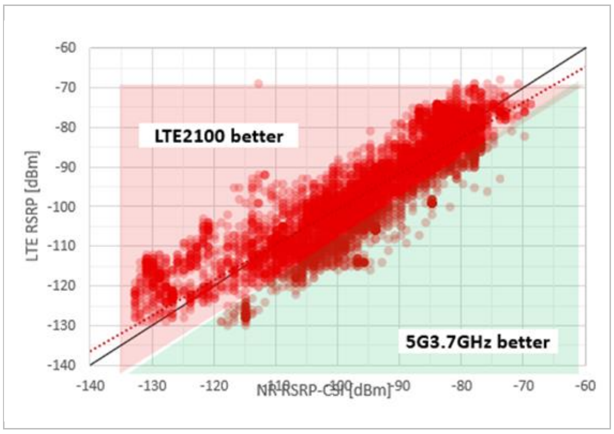
4.6.5 OUTDOOR COVERAGE

Rapporteurs:

TURKCELL | vodafone







Key Observations:

- The 5G NR signal level has an average coverage gain about +1dB vs 4G2100 but gain is not positive near base station
- Because of different beamforming characteristics of CSI-RS and SSB signals, CSI-RS Signal to Interference Noise (SINR) is much better than SSB SINR.
- Different CSI-RS and SSB implementations are observed between vendors.

Test Duration	No of Samples	LTE (1800 Mhz) RSRP (average)	5G NR (3700 Mhz) CSI-RS RSRP (average)	5G NR (3700 Mhz) SS-RSRP (average)
20 minutes	1200	**-77,4**	**-79,8**	**-83,4**

Test Duration	No of Samples	5G NR SSB SINR (dB)	5G NR CSI-RS SINR (dB)
20 minutes	1200	**18.2**	**34.3**

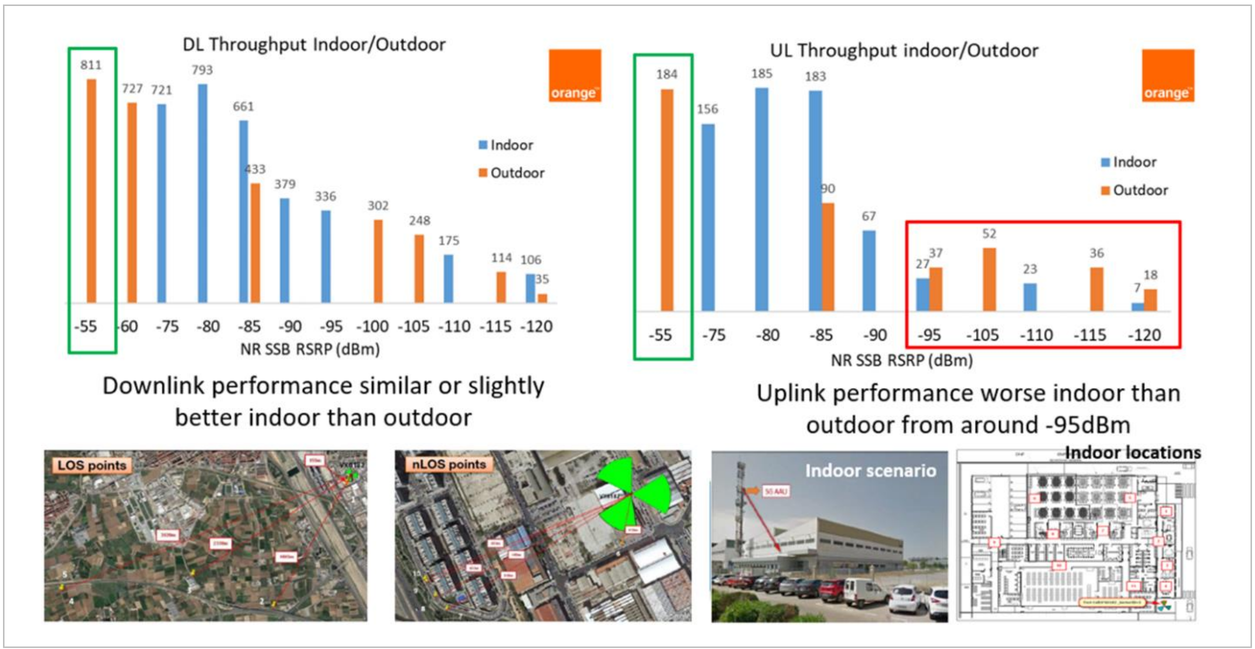
Test conditions:

- NSA Option 3x
- 3.7GHz 100MHz 30KHz SCS 4:1 DL/UL pattern
- 4x4MIMO 256QAM DL/ 2x2MIMO 64QAM UL
- gNb power 200W, UE UL Tx power TBC
- 7 SSB Beams configured
- Outdoor & Mobility condition (max 50 Km/h)
- Isolated cell
- Full buffer UDP

4.6.6 INDOOR COVERAGE

Rapporteurs:

orange



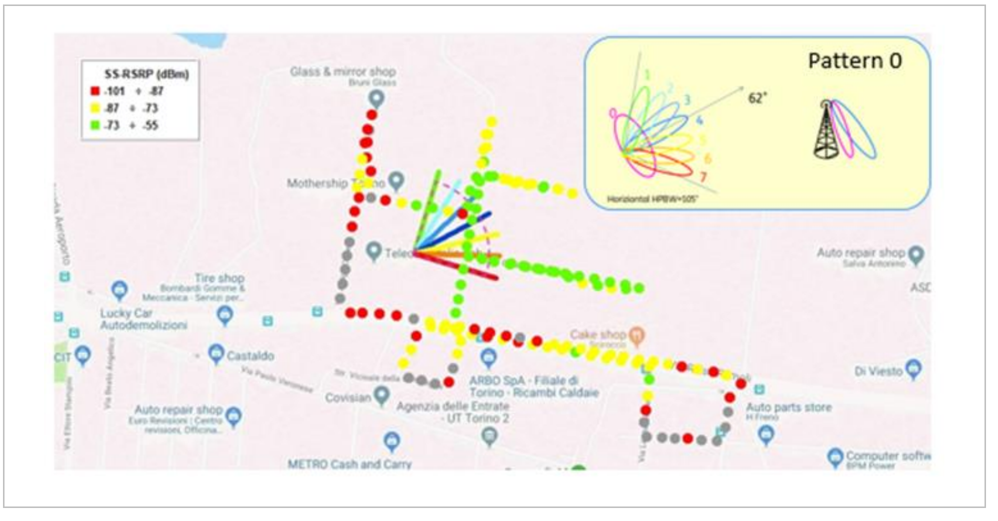
Key Observations:

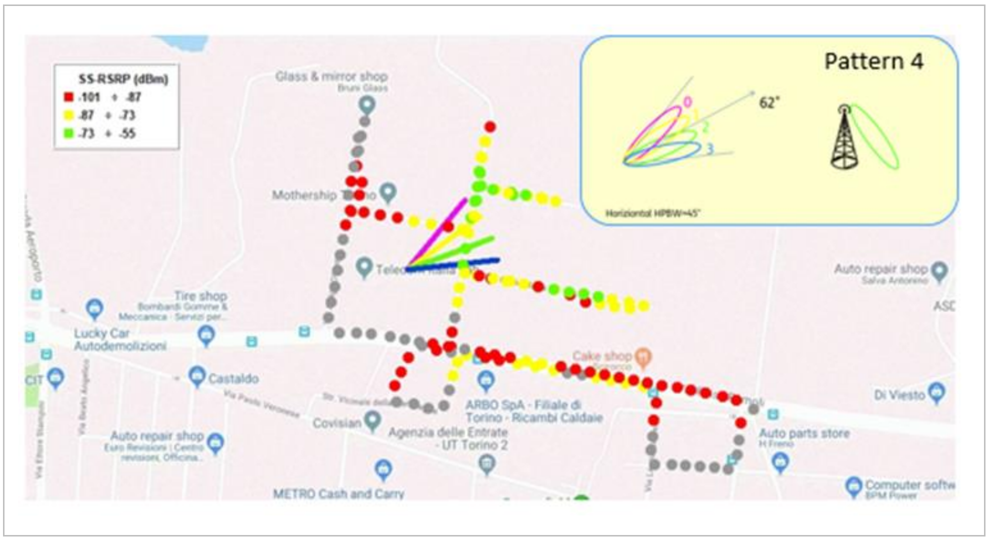
- Full range of RSRPs up to -120dBm (indoor starting at -75dBm and outdoor starting at -55dBm) are observed during trial.
- Indoor downlink performance is similar or slightly better than outdoor.
- Indoor uplink performance is worse than outdoor for RSRP values less than -95 dBm.

4.6.7 5G COVERAGE COMPARISON AMONG PATTERNS

Rapporteurs:

TIM





Key Observations:

- Pattern 0 maximizes the coverage area at ground level as expected since horizontal antenna width is 105°, while pattern 4 and 16 having a smaller horizontal antenna width reduce the coverage extension.

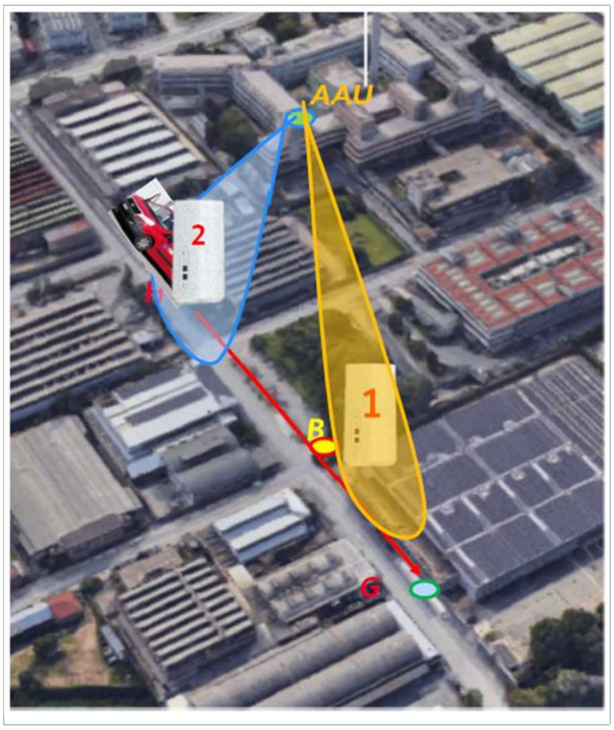
Test conditions:

- NSA Option 3x
- 3.7GHz 80MHz 30KHz SCS 8:2 DL/UL pattern
- 4x4MIMO 256QAM DL/ 2x2MIMO 64QAM UL
- gNB power 66W, UE UL Tx power TBC
- Different beam patterns measured
- Outdoor & Mobility condition (max 50 Km/h)
- Isolated cell
- Full buffer UDP

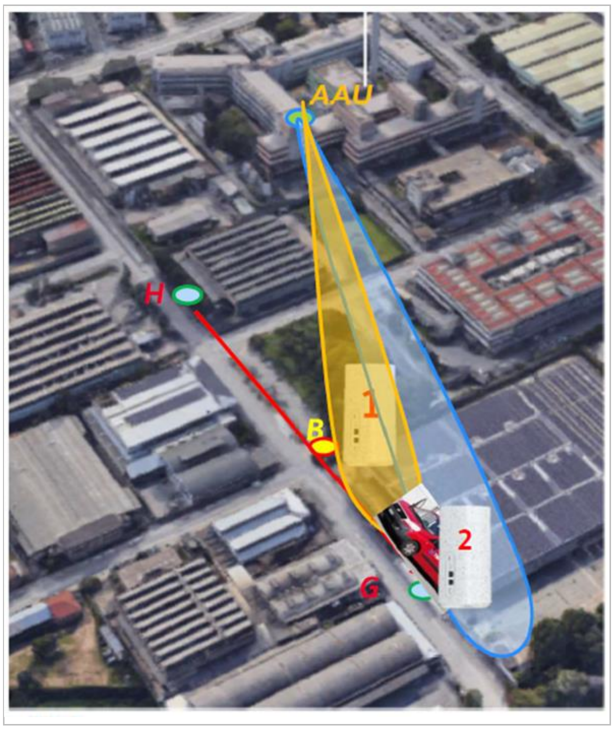
4.6.8 5G BEAMFORMING & RESSOURCE ALLOCATION

Rapporteurs:

TIM



1 Initial State



2 Final State

Trial Setup:

- 2 UE's continuously downloading 400 Mbps UDP
- UE 1 is static at location B
- UE 2 is moving from point H to point G.

Key Observations:
Initial state:

- Each CPE is managed by the scheduler of gNB as «single user in cell independent from the other»
- full time resources (1600)
- 144 RB (assigned by gNB scheduler)
- rank 2 (two polarizations)

Final state:

When CPEs get closer to each other, beams cannot be separated anymore. CPEs start sharing resource in time and frequency, and gNB scheduler starts to work on RB allocation and MIMO ranks:

- half of time resources (1600 → 800)
- full RB (144 → 208)
- rank 2 → 3 → 4

5 APPENDIX

5.1 5G DOWNLINK COVERAGE PERFORMANCE - SUMMARY

- Maximum Coupling Loss (MCL) from 140.8 to 148.8 dB to drop the service based on different trial results
- 10Mbps Cell edge throughput level is reached with a range between 4-11dB less
- At 1,33W/MHz cell power, there is almost no difference between TCP and UDP at 3,33W/MHz a gap appears between TCP and UDP performance due to UL coverage limitation
- Because of different beamforming characteristics of CSI-RS and SSB signals, CSI-RS Signal to Interference Noise (SINR) is much better than SSB SINR. Different CSI-RS and SSB implementations are observed between vendors.
- 3 Different horizontal/vertical beam patterns were tested by Tim, results as expected
- Indoor coverage: full range of RSRPs up to -120dBm indoor starting at -75dBm from -55dBm outdoor reference
- No differences between SA and NSA are reported by the trials performed by Orange

5.2 5G UPLINK COVERAGE PERFORMANCE – SUMMARY

- Maximum coupling loss from 130 to 145 dB to drop the service based on different trial results
- 1Mbps Cell edge throughput is reached with a range between 8-14 dB less
- Up to 7dB 5G uplink coupling loss gap vs 5G downlink for 10/1Mbps DL/UL throughput targets. Dynamic 5G UL data fallback to LTE is required to extend downlink coverage
- Option 2 reaches 3dB more MCL thanks to extra 3dB UL power
- Up to 6 times UL throughput at bad radio conditions when using 2 transmitters in device with +3dB transmitted power vs 1 transmitter

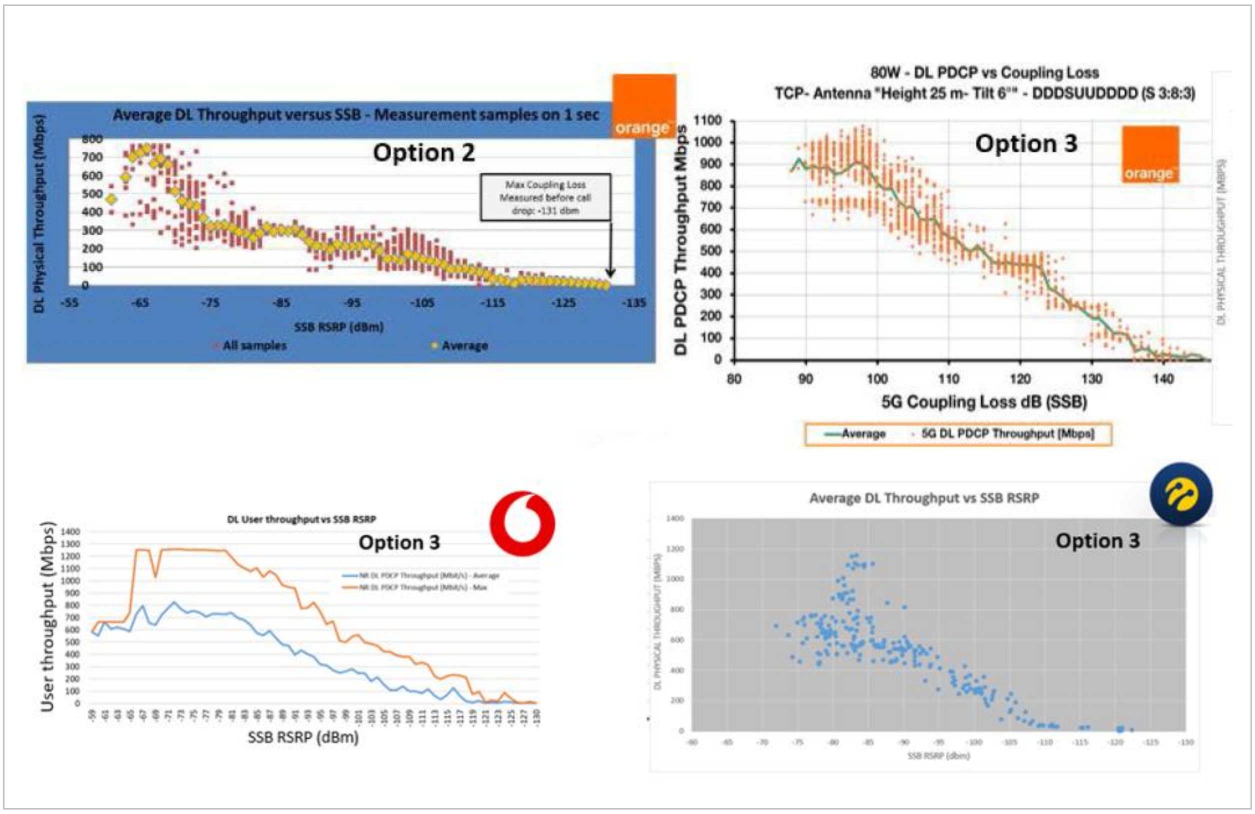
5.3 5G VS. 4G COVERAGE - SUMMARY

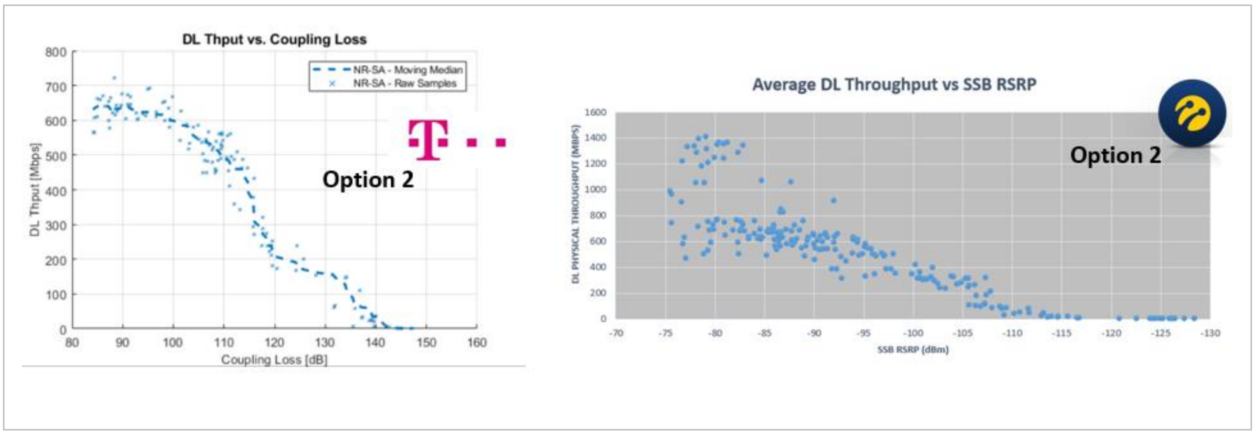
- Results are not conclusive but there is an agreement on describing the 5G NR 3.5-3.7GHz downlink coverage somewhere between the 1800MHz and 2100MHz bands, real value is very dependent on several factors like urban/sub-urban scenario, vendor beamforming capabilities, device maturity and TDD settings
- Especially controversial is the definition on whether the SSB-RSRP or CSI-RS should be used as reference for 4G coverage gain estimation
- Vodafone: Aprox 2dB better signal strength was observed vs 4G2100 RS when using the SSB at the Vodafone trial. As for the CSI-RS as reference, the gain is positive from coupling loss aprox. 120dB but negative below which would mean there is a positive gain at medium/cell edge but negative closer to the base station, probably related to beamforming maturity
- Turkcell: C-Band 5G NR coverage seems close to LTE 1800 coverage. CSI-RS RSRP is 4dB better than SSB RSRP
- Bell: Average 7dB stronger SINR in test cluster of 5G SSB vs 4G RS is reported by Bell

5.4 5G DL THROUGHPUT VS. PATHLOSS

Rapporteurs:

- Orange Option 2 (SA): drop at -131dBm, 10Mbps@-125dBm
- Orange Option 3 (NSA): drop at -131dBm, 10Mbps@-124dBm
- Vodafone Option 3 (NSA): Min RSRP -130dBm, 10Mbps@-125dBm
- Turkcell Option 2 (SA): Min RSRP -126dBm, 10Mbps@-116dBm
- Turkcell Option 3 (NSA): Min RSRP -123dBm, 10Mbps@-112dBm
- DT Option 2 (SA): drop at -130dBm, 10Mbps@-128dBm
- While LOS shows generally better throughput vs NLOS vs distance, there are some areas where this is not the case. It is dependent on the radio environment (mainly reflections)
- 5G peaks reached with SSB RSRP between -65dBm and -80dBm due to 4x4MIMO allocation, up to 150m distance
- 5G drops due to poor 4G anchor signal quality: 5G NR requires a wider 4G anchor cell layout

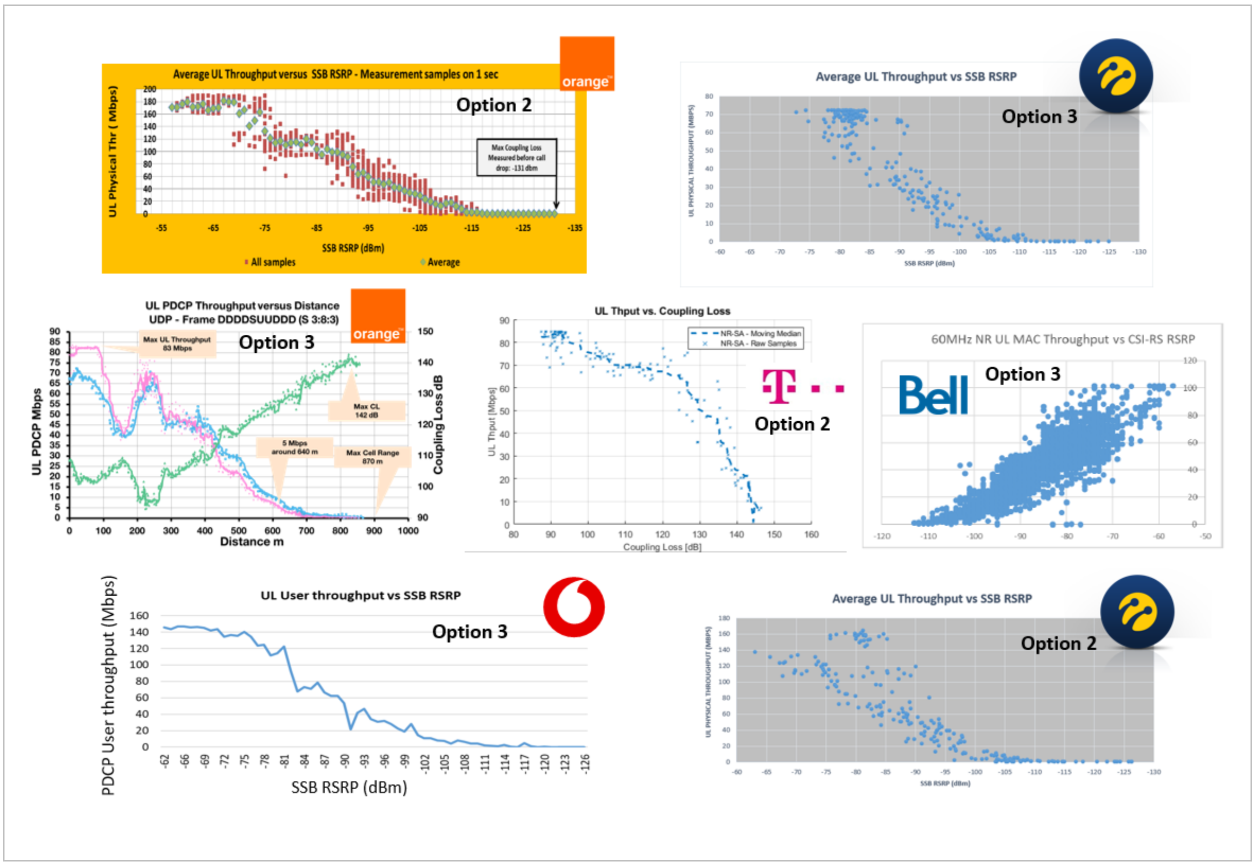




5.5 5G UL THROUGHPUT VS. PATHLOSS

Rapporteurs:

- Orange Option 2: drop at -131dBm, 1Mbps@-115dBm
- Orange Option 3: drop at -124dBm, 1Mbps@-116dBm
- Vodafone Option 3: Min RSRP -126dBm, 1Mbps@-118dBm
- Bell Option 3: Min RSRP at -113dBm, 1Mbps@-110dBm
- Turkcell Option 2: Min RSRP -126dBm, 1Mbps@-113dBm
- Turkcell Option 3: Min RSRP -125dBm, 1Mbps@-111dBm
- DT Option 2: drop at -133dBm, 1Mbps@-130dBm
- UL peaks stable up to approx. -75dBms, 300m distance, thanks to good 2x2MIMO performance
- Gap between NR DL and UL is 7-10dB



6 ABBREVIATIONS

3GPP	Third Generation Partnership Project
AMF	Access and Mobility Management Function
AR	Augmented reality
AS	Access stratum
BLER	Block error rate
BS	Base station
CDF	Cumulative distribution function
CN	Core network
CP	Carrier prefix
CPE	Customer premises equipment
CQI	Channel quality indicator
CSI-RS	Channel state information reference signal
DC	Dual connectivity
DMRS	Demodulation reference signal
eMBB	Enhanced mobile broadband
EPC	Evolved packet core
E-UTRAN	Evolved UMTS Terrestrial Radio Access
eV2X	Enhanced vehicle to everything
FDD	Frequency division duplex
FTP	File transfer protocol
gNB	5G NodeB
GPS	Global positioning system
GTP	GPRS tunnelling protocol

GUI	Graphical user interface
HARQ	Hybrid automatic repeat request
IoT	Interference over thermal
IP	Internet protocol
KPI	Key performance indicator
LOS	Line of sight
LTE	Long term evolution
MCG	Master cell group
MCS	Modulation and coding scheme
MEC	Multi-access edge computing
MIMO	Multiple input multiple output
mMTC	Massive machine type communication
MOS	Mean opinion score
MTU	Max transfer unit
NAS	Non-access stratum
NGC	Next generation core network
NGMN	Next generation mobile networks
NLOS	Non-line of sight
NR	New radio
NSA	Non-standalone
OSI	Open Systems Interconnection
PBCH	Physical broadcast channel
PDCCH	Physical downlink control channel
PDCP	Packet Data Convergence Protocol
PDN	Packet data network
PDSCH	Physical downlink shared channel
PING	Packet internet groper
PLR	Packet loss rate
PoC	Proof of concept
PRB	Physical resource block
PSS	Primary synchronization signal
PUCCH	Physical uplink control channel
PUSCH	Physical uplink shared channel
QoS	Quality of service
RAN	Radio access network
RAT	Radio access technology
RLC	Radio link control
RRC	Radio resource control
RSRP	Reference Signal Received Power
RSRQ	Reference Signal Received Quality
RTT	Round trip time
SA	Standalone
SCG	Secondary cell group
SINR	Signal to interference and noise ratio
SNR	Signal to noise ratio
SRS	Sounding reference signal
SSS	Secondary synchronization signal
TCP	Transmission control protocol
TDD	Time division duplex
TTI	Trial & Testing Initiative
UDP	User datagram protocol
UE	User equipment
uRLLC	Ultra-reliable low latency communications
vBBU	Virtualized baseband unit
VR	Virtual reality