3GPP TSG RAN WG1 email discussion [5G-ACIA]

February 22 – 26, 2021

**Source: Nokia, Nokia Shanghai Bell**

**Title: Final round of simulation results for 5G-ACIA evaluation**

**Document for: Discussion and Decision**

# Introduction

In RAN1#102-e, RAN1 received an LS from 5G-ACIA requesting RAN1 to carry out an URLLC and IIOT performance evaluation, using Rel-16 URLLC/IIOT features as a baseline [1]. The LS was treated in RAN Plenary #89, which agreed on the following way forward [2]:

|  |
| --- |
| [**RP-202069**](https://www.3gpp.org/ftp/tsg_ran/TSG_RAN/TSGR_89e/Docs/RP-202069.zip)                **Way forward and RAN work for 5G ACIA requested simulations**  ***Ericsson***                  result of email discussion [89E][03][5GACIA\_simulation]                    proposal:                  - Start an offline email-based activity to provide evaluation results for 5G-ACIA                  - One company volunteers as moderator                    - Proposes a work plan to follow                    - Ericsson is willing do this                  - Discussions are on the RAN1\_NR reflector                    - Email activity only during short periods (< week) distributed across the time allocated to the activity                    - No email activity in weeks before/during/after RAN1 meetings or RAN defined inactive periods                    - All companies should strive to limit email activity as much as possible                    - Outcome of the offline discussion will directly go to RAN without need for discussion in RAN1 nor need for LS                      from RAN1 to RAN                    - Target completion by RAN#91                    - At RAN#91, RAN will decide on a response LS to 5G-ACIA |

Afterwards, the moderator (Ericsson) shared the following schedule in the RAN1\_NR reflector:

1. 12-16 October 2020
   * Discussion on which URLLC features to include in the evaluations and simulation assumptions
2. 14-18 December 2020
   * First round of simulation results
3. **22-26 February 2021**
   * **Second round of simulation results**
4. 8-12 March 2021
   * Finalization of the report to RAN#91

The discussion regarding the simulation assumptions and URLLC features, as well as the first round of simulation results took place in the weeks described above. In Appendix A and B, we summarize the corresponding agreements (including agreed simulation assumptions) and conclusions that were reached during each of these weeks. In this contribution, we build on our [previous work](https://www.3gpp.org/ftp/tsg_ran/TSG_RAN/TSGR_91e/Inbox/Drafts/5G-ACIA%20December/Company%20Inputs/NOKIA%20-%205G-ACIA%20First%20round%20of%20simulation%20results.zip) and provide additional simulation results following the previous agreements on the 5G-ACIA evaluation. Section 2 presents simulation results on frequency range 1 (FR1), whereas Section 3 include results for frequency range 2 (FR2). Finally, conclusions are presented in Section 4.

# Simulation results for 30 kHz SCS (FR1)

Simulation assumptions can be found in Table 4 in the appendix C. We focus on the case with random uniformly-distributed traffic arrival (i.e. option-1 as described in the LS [1]) and symmetric TDD configuration consisting of 1 special (S) slot with S = DDDDDDGGUUUUUU. Since there is no time for 1 HARQ retransmission within the 1 ms latency interval (even with 2-symbol transmission duration), the uplink (UL) and downlink (DL) scheduling is performed with a mini-slot duration of 6 symbols. For each 6-symbol transmission, it is further assumed that 2 OFDM symbols are used by control and reference signals, resulting in 33% relative overhead. For reference, distribution of the coupling gain and DL geometry is shown in Figure 1.

For each PDSCH and PUSCH transmission, the gNB selects the MCS according to the UE’s CQI reports and SRS transmissions, respectively, where the first transmission BLER target is 1E-5. One key challenge identified while performing the simulations is related to the fast interference fluctuations which make it difficult to accurate select a proper MCS fulfilling the BLER target. For these reasons, some improvements were applied to the gNB link adaptation algorithms as follows:

* In DL, the UE is configured to periodically report a CQI per sub-band. A conservative link-adaptation implementation at the gNB side is considered where the worst CQI, out of the *N* reported sub-band CQIs is used to derive the MCS for the PDSCH.
  + On top, the gNB applies an *offset* (in dB) to the UE’s worst CQI report and also limits the maximum MCS for DL scheduling to a certain *max\_MCS*. Thus, the PDSCH MCS is selected as follows:

*MCS\_PDSCH* = min(*worst\_CQI* - *offset* , *max\_MCS*).

* In UL, similar method is applied but in SINR domain. That is, the gNB estimates UL SINR from the UL SRS transmission, and applies an *offset* as well as a *max\_MCS* restriction before selecting the MCS for the PUSCH transmissions (note that the applied offset could be different for DL and UL link adaptation). For power control, we assume an aggressive power control strategy where the UE’s transmission power is fixed to 23 dBm (i.e. maximum power), and the power spectral density varies according to the number of PRBs allocated to the PUSCH.

 

Figure 1: CDF of the DL Geometry and coupling gain. FR1 – 30 kHz SCS.

Performance results are presented in the following. We simulate cases with 50 and 60 UEs per service area and collect approximately 1 million latency samples per UE. Figure 2 shows cumulative distribution function (CDF) of the per-packet latency collected from all UEs for both downlink and uplink directions. For 50 UEs per service area, the 1 ms latency target is achieved with 99.999% reliability in both UL and DL, whereas a fraction of approximately 3E-6 in DL and 6E-6 in UL of the packets are not correctly received due to bad SINR conditions, high interference, etc. For 60 UEs per service area, more congestion/queueing delay occurs in the network resulting in a non-neglible amount of packets (1E-3 in DL and 2E-5 in UL) exceeding the 1 ms target latency. The latency performance is slightly worse in DL than in UL likely due to the quite different power control scheme.

Figure 3 shows the distribution of the packet error rate (PER) per UE. It is observed that a large majority of the simulated UEs experience packet error (or delay violations) during the simulation; however, most of these packet error are ‘single-packet error’ cases thus not exceeding the application’s survival time. This is reflected in Figure 4 where we show Communication Service Availability (CSA) statistics per UE. For CSA, the target requirement is 99.9999% (see Table 3 in Appendix A) which corresponds to an CSA outage probability of 1E-6 or less. For 50 UEs per service area, around 1% of the UEs experience more than 1 consecutive packet error across the simulation; however, this occurs very seldom and thus the 1E-6 CSA outage target is still satisfied by all the UEs in DL and by 99.96% of the UEs in the UL. The performance gets significantly worse when increasing the number of UEs per service area to 60; in fact, around 12% of the UEs experience two or more consecutive transmission errors multiple times during the simulation, thus not meeting CSA target.

In Table 1, we show the average PRB utilization for the different evaluated settings. For 50 UEs per service area, it is observed the system can reach up to 40%-60% load while still achieving reasonable performance. This relatively high load is partly due to the *uniform* periodic traffic model which is significantly less bursty as compared as e.g. traditional FTP3 traffic.

**Observation 1: For the FR1 deployment with InF-DH and random traffic offset (option 1), the network can support 50 UEs in both DL and UL directions, while keeping the 99.999% percentile of the latency CDF (collected from all the UEs) below the 1 ms target. Under such load conditions, 100% and 99.96% of the simulated UEs meet the 99.9999% CSA requirement in DL and UL, respectively.**



Figure 2: CDF of the per-packet latency collected from all the simulated UEs. Not-correctly received packets have infinite delay. FR1 – 30 kHz SCS.

 

Figure 3: CDF of the packet error rate per UE. FR1 – 30 kHz SCS.

 

Figure 4: CDF of one minus the communication service availability (CSA) per UE. FR1 – 30 kHz SCS. Note that samples with 1 – CSA equal to 0 are not directly visible in the plot due to the log-scale in the y-axis.

Table 1: PRB utilization statistics. FR1 – 30 kHz SCS.

|  |  |
| --- | --- |
| Setting | Average PRB utilization [%] |
| DL, 50 UEs per service area | 50.5% |
| UL, 50 UEs per service area | 38.9% |
| DL, 60 UEs per service area | 61.7% |
| UL, 60 UEs per service area | 49.3% |

# Simulation results for 120 kHz SCS (FR2)

Simulation assumptions can be found in Table 5 in the appendix D. We assume the same TDD configuration S = DDDDDDGGUUUUUU and link adaptation enhancements as described in Section 2. We simulate cases with 40 and 50 UEs per service area and collect approximately 100.000 latency samples per UE. On the transmission scheme, each gNB has a total of four beams (with 2 polarizations per beam) pointing to different fixed azimuth and elevation angles, and we consider cases where the gNB can transmit/receive on a single beam or on two beams per scheduling interval/mini-slot.

For reference, distribution of the coupling gain and DL geometry is shown in Figure 5. Here, it is observed that the coupling gain is significantly degraded as compared to the FR1 deployment in Section 2. This is a consequence of only having 4 beams which does not allow to properly cover the factory layout. On the other hand, DL geometry improves as a consequence of more directive transmissions which result in lower inter-cell interference.

 

Figure 5: CDF of the DL Geometry and coupling gain. FR2 – 30 kHz SCS.

Figure 6 shows the CDF of the UL and DL delay for 40 and 50 UEs per service area. It is observed that the number of simultaneous beams that can be scheduled by the gNB is the main performance-determining factor. With single beam per mini-slot, the latency at the 1E-5 percentile is approximately 1 ms and 1.2 ms for DL and UL, respectively, whereas it is in the order of 0.7-0.8 ms when two beams can be simultaneously used for transmission/reception by the gNB. This additional delay with single-beam case is a consequence of the gNB only being able to schedule a subset of the UEs at each scheduling interval. Naturally, increasing the number of UEs per service area from 40 to 50 increases the delay, especially in the UL direction. In contrast to the FR1 results, the latency performance is slightly better in the DL than in the UL, which is due to the poorer channel quality/SINR in UL and a more conservative UL link adaptation strategy to ensure a latency outage probability below 1E-5.

Figure 7 and Figure 8 show the PER and CSA statistics for the different evaluated cases. Similarly as for the latency statistics, the achieved CSA and PER performance is significantly worse in the UL direction. In fact, as much as 50% of the UEs cannot meet the 1E-6 CSA outage target for the case of 50 UEs per service area and one gNB Rx beam at a time. Doubling the number of Rx beams clearly improves the UL performance and reduces the CSA outage probability to only 2.4%. In DL, the percentage is generally good even for single beam cases where only around 0.4% of the UEs cannot reach the CSA target. Note that, for some of the configurations, no consecutive error was observed during the simulation and thus some curves are not visible in the plots in Figure 8.

Table 2 shows the average PRB utilization as well as the percentage of UEs reaching a CSA of 100%. Note that, as compared to FR1 results, the system ends up operating at lower PRB utilization to be able to fulfil the 1 ms latency with 99.999% reliability target. This is because the latency performance is impacted not only by queuing delay and interference but also by limitations to user multiplexing imposed by beamforming operation itself. A multi-planel antenna and increased number of antenna ports could be used to mitigate this.

**Observation 2: For the FR2 deployment and assuming that the gNB can transmit/receive on two beams per mini-slot, 50 UEs can be supported per service area in both DL and UL while keeping the 99.999% percentile of the latency CDF (collected from all the UEs) below the 1 ms target. Under such load conditions, approximately 0.4% and 2.4% of the UEs in DL and UL, respectively, do not meet the 99.9999% CSA requirement.**

 

Figure 6: CDF of the per-packet latency collected from all the simulated UEs. Not-correctly received packets have infinite delay. FR2 – 120 kHz SCS.

 

Figure 7: CDF of the packet error rate per UE. FR2 – 120 kHz SCS.

 

Figure 8: CDF of one minus the communication service availability (CSA) per UE. FR2 – 120 kHz SCS. Note that samples with 1 – CSA equal to 0 are not directly visible in the plot due to the log-scale in the y-axis

Table 2: CSA and PRB utilization statistics. FR2 – 120 kHz SCS.

|  |  |
| --- | --- |
| Setting | Average PRB utilization [%] (2 beams case) |
| DL, 40 UEs per service area | 20.3% |
| UL, 40 UEs per service area | 38.5% |
| DL, 50 UEs per service area | 25.4% |
| UL, 50 UEs per service area | 48.4% |

# Conclusions

In this contribution, we have provided system-level simulation results for a factory automation scenario following the agreements reached in 3GPP related to the last phase of performance evaluation targeted at correspondence with 5G-ACIA. The presented results show that it it possible to support the required 50 UEs per service area in both FR1 and FR2 frequency ranges with only a very small probability of not fulfilling 99.9999% CSA requirement: 0.04% of the UEs in FR1, and 2.4% of the UEs in FR2. The following observations were made:

**Observation 1: For the FR1 deployment with InF-DH and random traffic offset (option 1), the network can support 50 UEs in both DL and UL directions, while keeping the 99.999% percentile of the latency CDF (collected from all the UEs) below the 1 ms target. Under such load conditions, 100% and 99.96% of the simulated UEs meet the 99.9999% CSA requirement in DL and UL, respectively.**

**Observation 2: For the FR2 deployment and assuming that the gNB can transmit/receive on two beams per mini-slot, 50 UEs can be supported per service area in both DL and UL while keeping the 99.999% percentile of the latency CDF (collected from all the UEs) below the 1 ms target. Under such load conditions, approximately 0.4% and 2.4% of the UEs in DL and UL, respectively, do not meet the 99.9999% CSA requirement.**

# References

1. [R1-2006953](https://www.3gpp.org/ftp/tsg_ran/WG1_RL1/TSGR1_102-e/Docs/R1-2006953.zip) LS on 3GPP NR Rel-16 URLLC and IIoT performance evaluation, 5G ACIA
2. [RP-202069](https://www.3gpp.org/ftp/tsg_ran/TSG_RAN/TSGR_89e/Docs/RP-202069.zip) Way forward and RAN work for 5G ACIA requested simulations, Ericsson

# Appendix A: Agreements during week 1 discussions

**Agreements:**

* The simulation assumptions given in the table are agreed
* Additional simulation parameters are taken from TR 38.824.

For the Rel-15 baseline, the following is agreed:

* Rel-15 URLLC features included in the baseline are as follows, while it is up to each proponent to decide which Rel-15 features are used, and detail this when providing the results:
  + UE Processing capability 2
  + UL Configured grant
  + DL Semi-persistent scheduling

Regarding Rel-16 features, the following is agreed:

* It is up to each proponent to decide on which Rel-16 features to provide simulations results for in addition to the Rel-15 baseline
* This can be revisited after the first round of simulations have been provided in December.

Table 3: Simulation assumptions agreed during week 1 discussions

|  |  |  |
| --- | --- | --- |
| Parameters | 5G-ACIA LS | **Agreement** |
| Factory hall size | 120x50 m | As in 5G-ACIA LS |
| Room height | 10 m | As in 5G-ACIA LS |
| Inter-BS/TRP distance | Depending on the number of TRPs, which are evenly deployed in the factory hall. Simulation company should provide the number of BSs/TRPs used in the simulation. | According to proposed layout below |
| BS/TRP antenna height | 1.5 m for InF-SL and InF-DL 8m for InF-SH and InF-DH | As in 5G-ACIA LS |
| Layout – BS/TRP deployment | Depending on the number of TRPs | 12 TRPs within area with the same 2D placement as in TR 38.901 and TR 38.824. |
| Channel model | UC-2: InF-DH > InD-DL > InF-SH > InF-SL | Mandatory: InF-DH  Optional: InD-DL, InF-SH, InF-SL |
| Carrier frequency and simulation bandwidth | TDD 4 GHz: 100 MHz 30 GHz: 160 MHz | As in 5G-ACIA LS |
| TDD DL-UL configuration | Simulation company should report the used DL-UL configuration. | Companies should report the used DL-UL configuration. 1:1 DL-UL configuration is recommended. |
| Number of UEs per service area | Up to 50 per service area, e.g., 10, 20, 40, and 50 | As in 5G-ACIA LS |
| UE distribution | All UEs randomly distributed within the respective service area. | As in 5G-ACIA LS |
| Message size | 48 bytes | 48 bytes |
| DL traffic model | DL traffic arrival with option-1, option-2, and option-3. | 5G-ACIA Option 1 is mandatory. Companies are also encouraged to provide results for option 3 |
| UL traffic model | UL traffic is symmetric with DL, and DL-UL traffic arrival time relationship with option-1 and option-2 | As in 5G-ACIA LS with Option 1 as mandatory |
| CSA requirements | UC-#2: 99.9999% | UC-#2: 99.9999% |
| Performance metrics | 1) CSA: single CDF of CSA distribution of all UEs in factory hall 2) Latency: single CDF of latency distribution of all UEs in factory hall 3) Percentage of UEs satisfying requirements  4) resource utilization | As in 5G-ACIA LS with 3) and 4) as low priority  Note: For metric 2) it is clarified that a packet transmission cannot be performed after the latency deadline. The collected statistics cannot exceed the latency requirement. The packets exceeding the deadline are visible in the UE packet error statistics |
| E2E latency & air interface latency | E2E latency: 1 ms for UC#2 | E2E latency: 1 ms for UC#2  Air interface latency: 1ms |
| UE speed | Linear movement | Linear movement: 75 km/h  No explicit UE mobility (nor handovers) are modeled in the evaluations. |
| BS antenna mount |  | Option 1 (1 sector per BS) from 38.824 is used |

# Appendix B: Conclusions during week 2 discussions

Conclusion on colleting simulation assumptions:

* The final Excel sheet can be found [here](https://www.3gpp.org/ftp/tsg_ran/TSG_RAN/TSGR_91e/Inbox/Drafts/5G-ACIA%20December/Final%20Summary/Simulation%20assumptions%20for%20calibration%20Final.xlsx).

Conclusion on FR2 antenna assumptions:

* 2RX/TX is still the baseline
* Results for additional configurations can be provided

Conclusion on cell coordination:

* No coordination is baseline
* Results with cell coordination can be provided

Conclusion on MU-MIMO:

* SU-MIMO is baseline
* Results with MU-MIMO can be provided

Agreement for latency:

* For FR1 companies are encouraged to provide simulation results for one-shot transmission

Noted proposal for latency

* For the E2E latency, following assumptions are made:
  + Components from table 5.7.1.1.1.-1 for DL and table 5.7.1.1.2.-1 for UL from TR 37.910 are used to calculate the E2E latency
    - In case re-tx is simulated, the alignment delay for the re-TX at the gNB side (which is not included in the tables from the TR 37.910) should also be added to the latency
  + Companies report the UE processing delay and gNB processing delay, for other components, the values from table 5.7.1.1.1.-1 for DL and table 5.7.1.1.2.-1 for UL from TR 37.910 are assumed
* Supported by Intel, Huawei/HiSilicon, vivo, ITRI, ZTE

Conclusion on additional simulation assumptions:

* No consensus on CSA metric with no consecutive errors is mandatory
* Narrow down channel model to InF-DH explicitly
* Option-1 for DL traffic and Option-1 for UL traffic relationship to DL is still baseline. Additional results can be submitted
* Number of samples, minimum number of packets per UE and minimum number of UEs / network drops modelled are left to companies’ choice

Conclusions on format for submissions to round 2

* Companies will provide
  + CDF of packet error rate for UL and DL
  + CDF of CSA for UL and DL
  + Tabulated values for percentage of UEs satisfying 1ms latency and 99.9999% reliability/CSA requirement for each simulated case
  + CDF for coupling loss and geometry for calibration

# Appendix C: Simulation assumptions for 30 kHz/FR1 case

Table 4: Simulation assumptions for 30 kHz/FR1 case

|  |  |
| --- | --- |
| Parameters​ | Value​ |
| Factory layout size | 120 x 50 x 10 m3 |
| Layout/Inter-BS distance​ | 12 TRPs with 20 m​eter ISD. Same placement as in TR 38.824 |
| BS antenna mount | 1 sector BS |
| Carrier frequency​ | 4 GHz​ |
| UE Tx power​ | 23dBm​ |
| BS antenna element gain + connector loss​ | 5 dBi​ |
| BS receiver noise figure​ | 5 dB​ |
| BS antenna configurations​ | (M, N, P, Mg, Ng; Mp, Np) = (1, 2, 2, 1, 1; 1, 2) for 4 Tx/4 Rx antenna ports​ |
| UE antenna configuration​ | (M, N, P, Mg, Ng; Mp, Np) = (1, 2, 2, 1, 1; 1, 2) for 4 Tx/4 Rx antenna ports​  Isotropic antenna element |
| UE antenna height​ | Follow the modelling of TR 38.901 (e.g. 1.5m)​ |
| UE antenna gain​ | 0 dBi as starting point​ |
| BS Tx power​ | 31 dBm​ |
| BS receiver​ | MMSE-IRC as the baseline receiver​ |
| UE Tx power | 23 dBm |
| UE receiver noise figure​ | 9 dB​ |
| SCS ​ | 30 kHz, i.e. 28 symbols per TTI​ |
| Simulation bandwidth ​ | 100 MHz @ 4GHz​ |
| Channel model ​ | InF-DH (dense clutter 0.6, high BS 8 m)​ |
| Traffic model​ | 1 ms packet inter-arrival time. Random offset​ |
| Number of UEs per service area (12 service areas)​ | 50, 60 |
| UE distribution​ | 100% of users are indoor, 75 km/h​. Random distribution across the service area. |
| UE power control​ | Constant max power |
| HARQ/repetition​ | No HARQ/repetition​ |
| Channel estimation | Ideal |
| MIMO | Rank 1 |
| TDD config​ | TDD frame with single slot S = DDDDDDGGUUUUUU and 6-symbol mini-slot scheduling |
| Inter gNB coordination | No |
| Number of collected latency samples per UE | 1 million |
| gNB and UE processing times | 5 symbols in total (2.75 for TB preparation time, and 2.25 for PDSCH/PUSCH decoding) |

# Appendix D: Simulation assumptions for 120 kHz/FR2 case

Table 5: Simulation assumptions for 120 kHz/FR2 case

|  |  |
| --- | --- |
| Parameters | Value |
| Inter-BS distance | 20m |
| Factory layout size | 120 x 50 x 10 m3 |
| Layout/Inter-BS distance​ | 12 TRPs with 20 m​eter ISD. Same placement as in TR 38.824 |
| BS antenna mount | 1 sector BS |
| Carrier frequency​ | 30 GHz​ |
| UE Tx power​ | 23dBm​ |
| BS antenna element gain + connector loss​ | 5 dBi​ |
| BS receiver noise figure​ | 7dB​ |
| BS antenna configurations​ | 2 Tx/Rx ports, (M,N,P,Mg,Ng;Mp,Np) = (4,4,2,1,1;1,1) |
| UE antenna configuration​ | 2 Tx/Rx ports. 2 panels facing opposite directions  (M,N,P,Mg,Ng;Mp,Np) = (2,4,2,1,2;1,1).  Directive antenna elements with 90 degree beamwidth and 25dB front-to-back ratio |
| UE antenna height​ | Follow the modelling of TR 38.901 (e.g. 1.5m)​ |
| UE antenna gain​ | 5 dBi as starting point​ |
| BS Tx power​ | 26 dBm​ |
| BS receiver​ | MMSE-IRC as the baseline receiver​ |
| UE Tx power | 23 dBm |
| UE receiver noise figure​ | 10 dB​ |
| SCS ​ | 120 kHz, i.e. 112 symbols per TTI​ |
| Simulation bandwidth ​ | 160 MHz @ 30GHz​ |
| Channel model ​ | InF-DH (dense clutter 0.6, high BS 8 m)​ |
| Traffic model​ | 1 ms packet inter-arrival time. Random offset​ |
| Number of UEs per service area (12 service areas)​ | 40, 50 |
| UE distribution​ | 100% of users are indoor, 3 km/h​. Random distribution across the service area. |
| UE power control​ | Constant max power |
| HARQ/repetition​ | No HARQ/repetition​ |
| Channel estimation | Ideal |
| MIMO | Rank 1 |
| TDD config​ | TDD frame with single slot S = DDDDDDGGUUUUUU and 6-symbol mini-slot scheduling |
| Inter gNB coordination | No |
| Number of collected latency samples per UE | 100.000 |
| gNB and UE processing times | 28 symbols in total (18 for TB preparation time, and 10 for PDSCH/PUSCH decoding) |