Performance analysis of 5G handovers (SA-SA, NSA-NSA, NSA-SA) using NetSim

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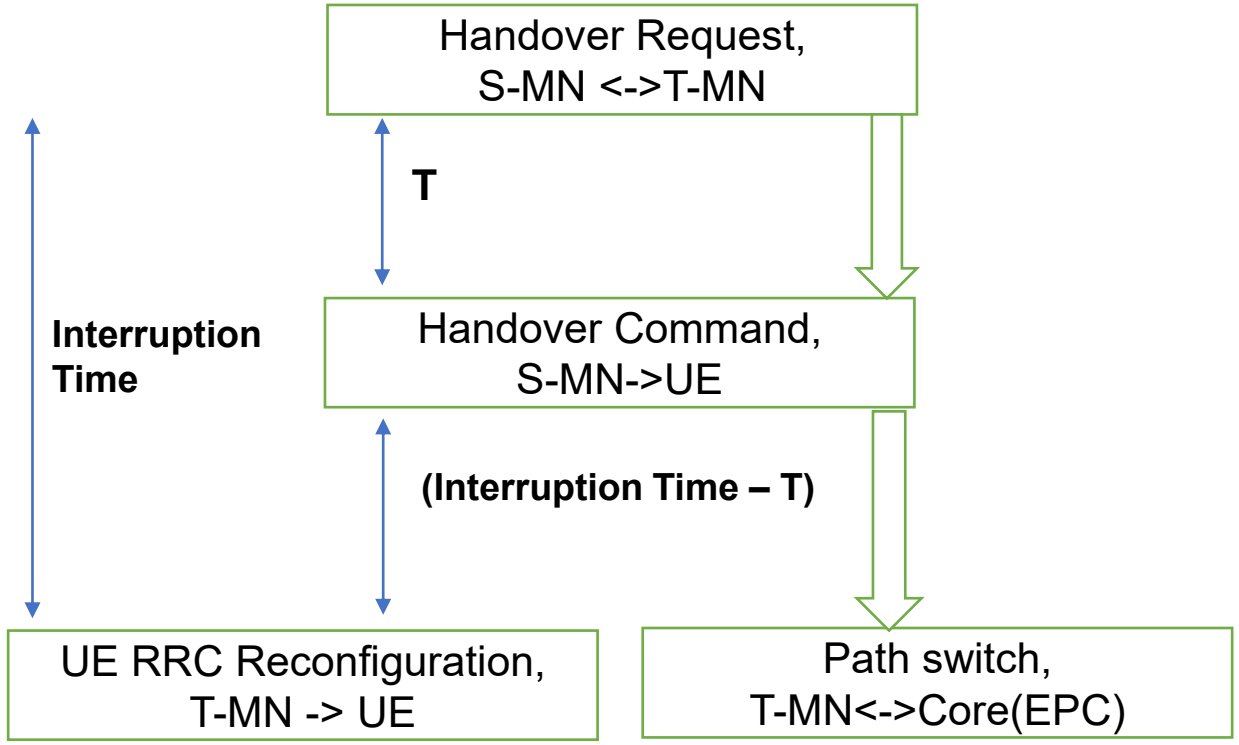
Handover model and assumptions

- The handover process in NetSim is based on event A3 i.e., the target signal strength is offset (3 dB) higher than the source signal strength.
  - In case of CA & MIMO the average SNR is taken across all carriers and all layers
- Since UE measurement reports in NetSim are periodic (ever 120 ms), the handover is triggered upon receipt of the immediate next measurement report.
- Time-to-Trigger (also known as Hysteresis or Threshold-in-time), the duration for which target SNR should be offset higher than source SNR, is not yet modeled in NetSim;
- No control packet losses during handover
- No data packet losses before/after the handover.
  - The MCS algorithm chooses the modulation order and coding scheme based on the SNR, in such a way that the data is decoded successfully at the receiver.
- T-gNB admission control is always successful.

Handover interruption time in NetSim

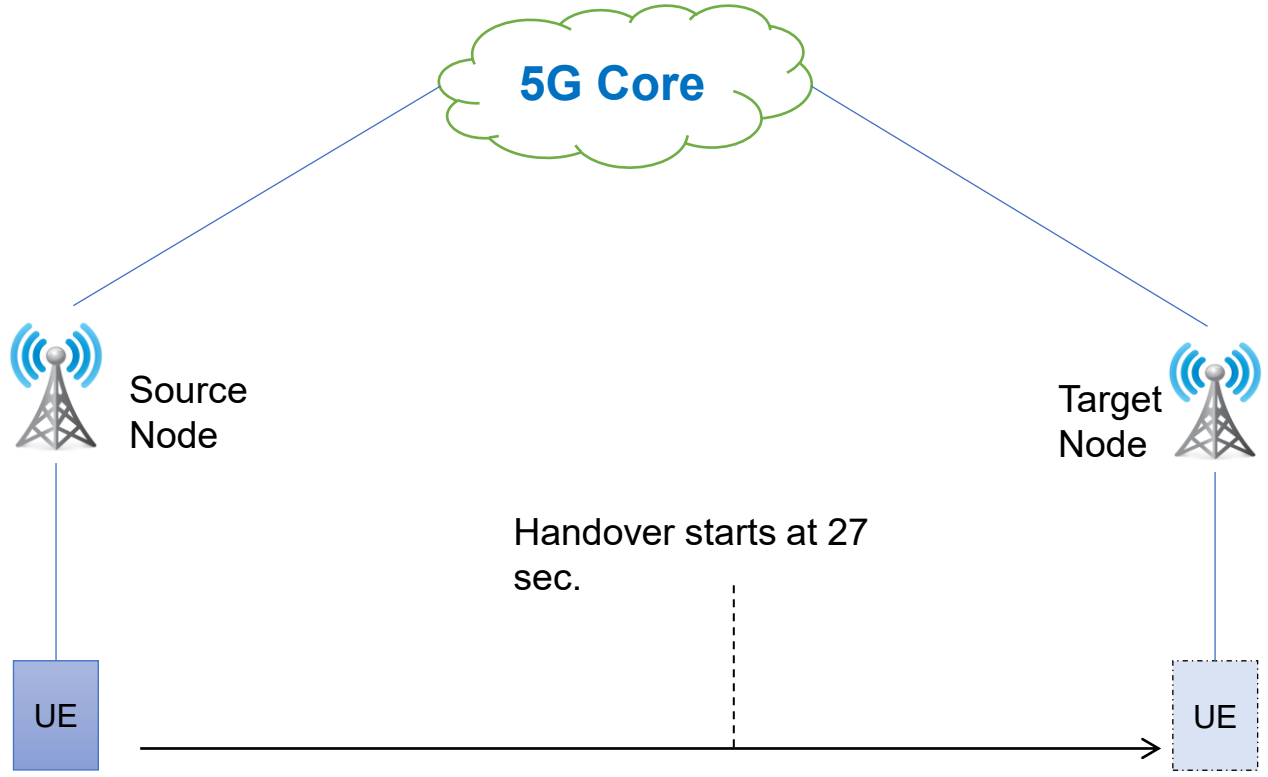
Packet	Source	Destination
UE Measurement Report	UE	S-gNB
Handover Request	S-gNB	T-gNB
Handover Request Ack	T-gNB	S-gNB
Handover Command	S-gNB	UE
Path Switch	T-gNB	AMF
Modify Bearer Request	AMF	SMF
Modify Bearer Response	SMF	AMF
Path Switch Ack	AMF	T-gNB
UE Context Release	T-gNB	S-gNB
UE Context Release Ack	S-gNB	T-gNB
RRC Re-Configuration	New S-gNB	UE
UE Measurement Report	UE	New S-gNB



Handover with interruption time. 5G SA to 5G SA

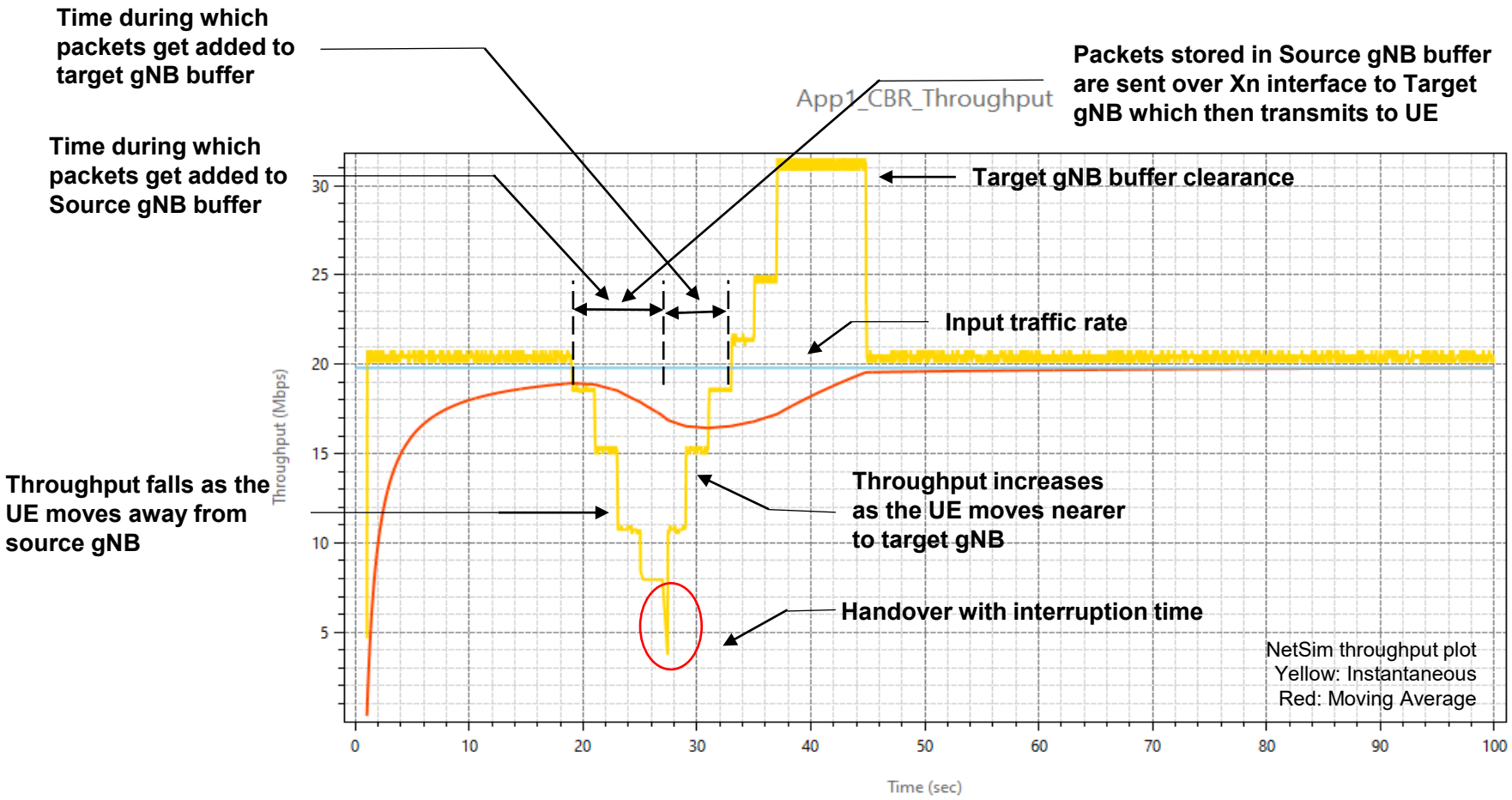
Properties of Source and Target Nodes:

Parameter	Value
MIMO setting	1 TX 1 RX (gNB and UE)
Bandwidth (MHz)	10
Tx Power (dBm)	40
Duplex Mode	TDD
DL : UL	4:1
Numerology	0
Frequency Range	3.5 GHz (n78) 5G
Modulation Table	QAM64
CQI Table	Table1
Pathloss Model	3GPPTR38.901-7.4.1
Fading	No
LOS Probability	1



- Arbitrary distance between source and target of 6400 m.
- UE-9 moves uniformly from left to right (400m to 6000m) in a straight line
- Handover starts at 27s. A3 event.
- A high interruption time of 400ms is assumed. During this time there is no data plane traffic flow to the UE from the source/target. Data flow resumes from t-gNB after this 400ms.

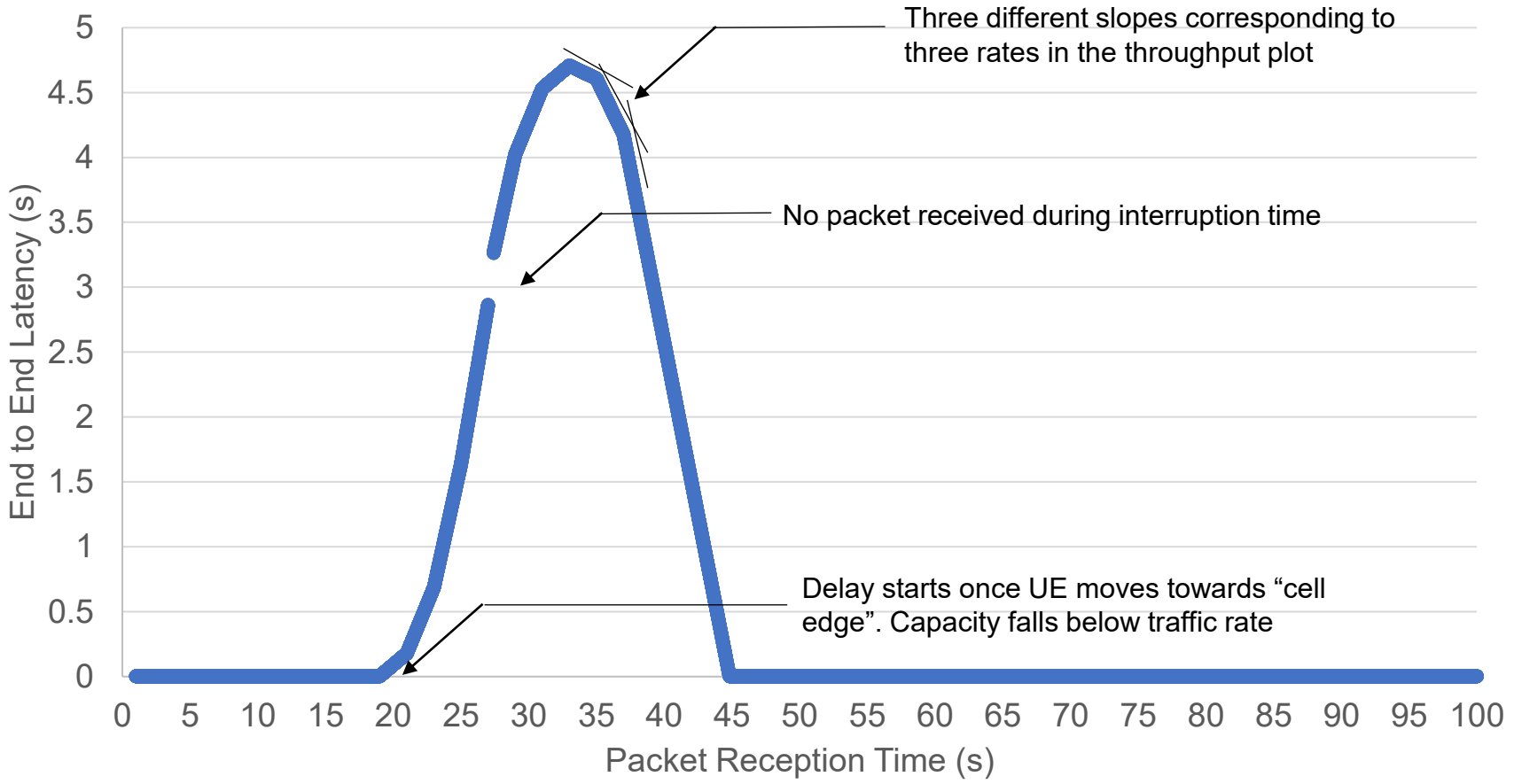
Handover with interruption time. 5G SA to 5G SA



DL Traffic Rate: 20Mbps
Peak DL Capacity: 31.5Mbps
Interruption Time: 400 ms

- Handover interruption time (HIT) is added at the time of handover command is delivered to the UE
- The sharp dip in the above plot is due to zero packet transmissions to the UE during the interruption time
- Assumption: All traffic is flowing DL to a single UE, and this utilizes the link capacity

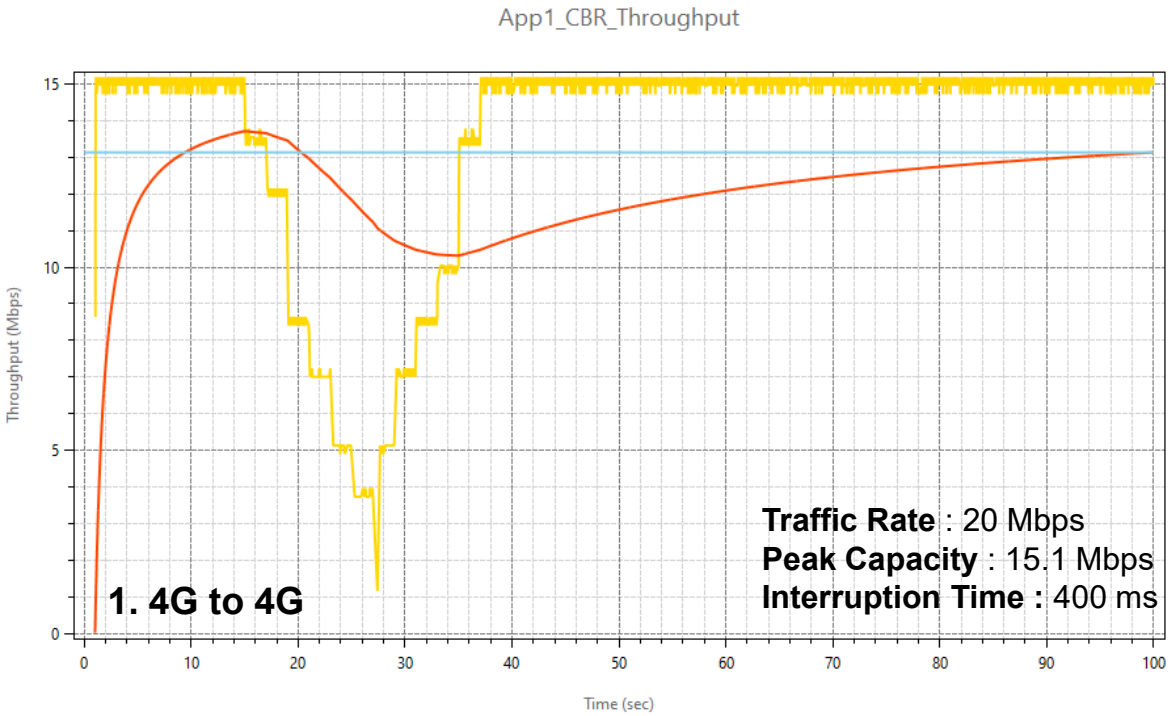
Handover with interruption time. 5G SA to 5G SA

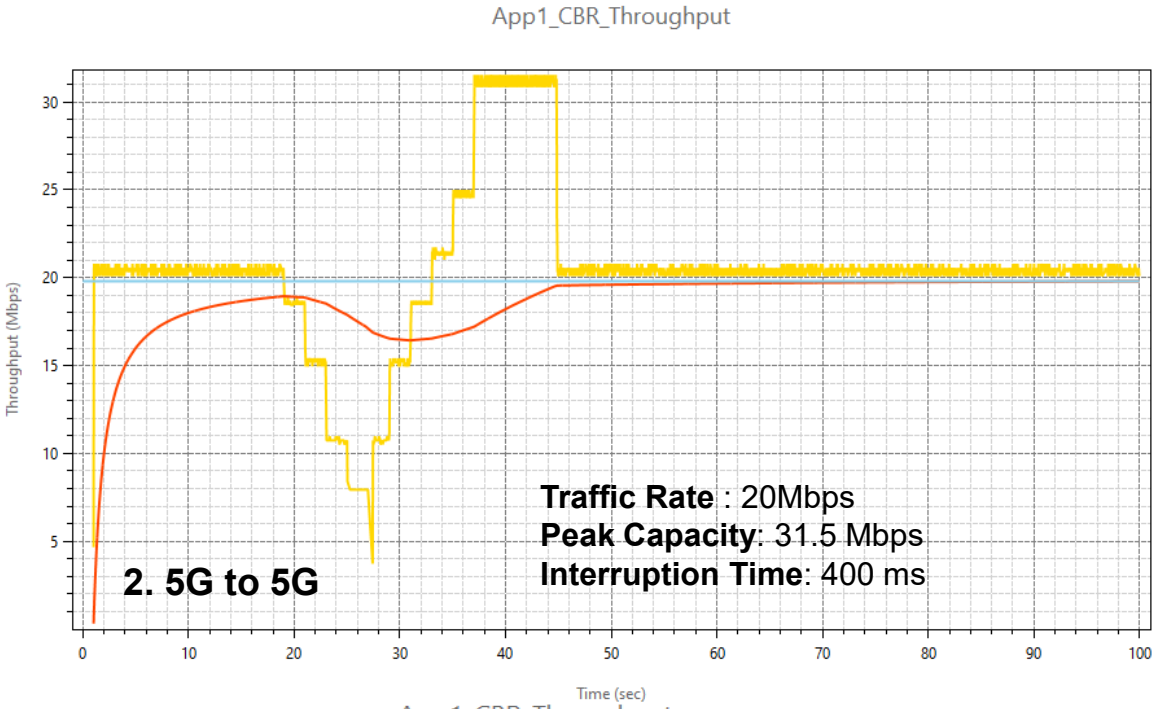


DL Traffic Rate: 25Mbps
Peak DL Capacity: 31.5Mbps
Interruption Time: 400 ms

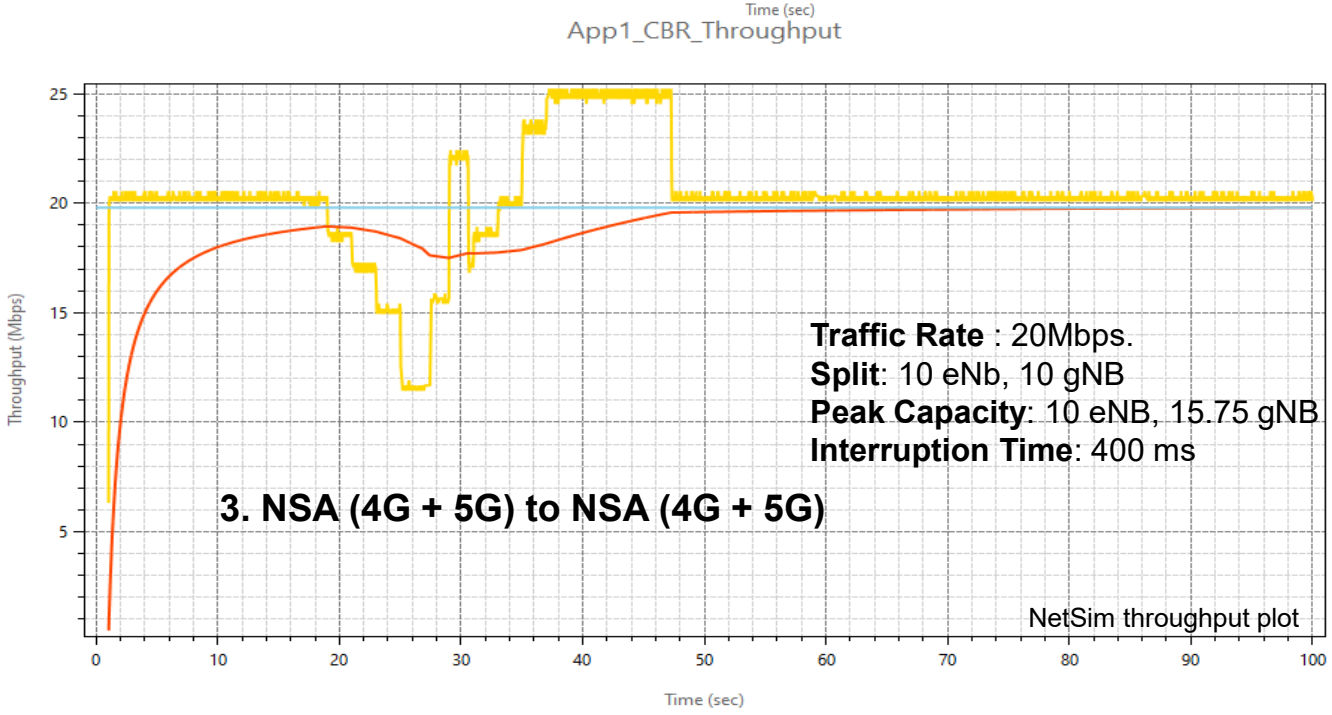
Plot generated from NetSim’s packet trace

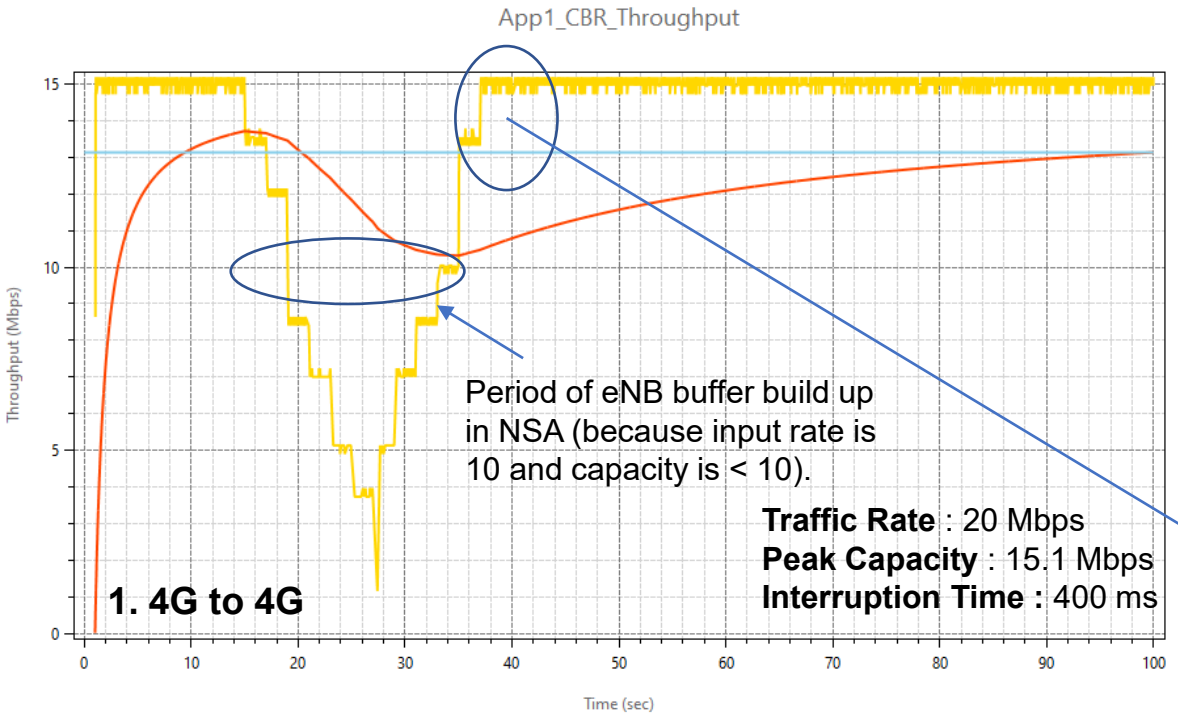
- Plot is consistent with the throughput plot
- When operating at 80% capacity (25/31.5) a 400 ms interruption time leads to a Max delay of 4.7 s.
- This delay is due to a combination of cell edge throughput drop and interruption time

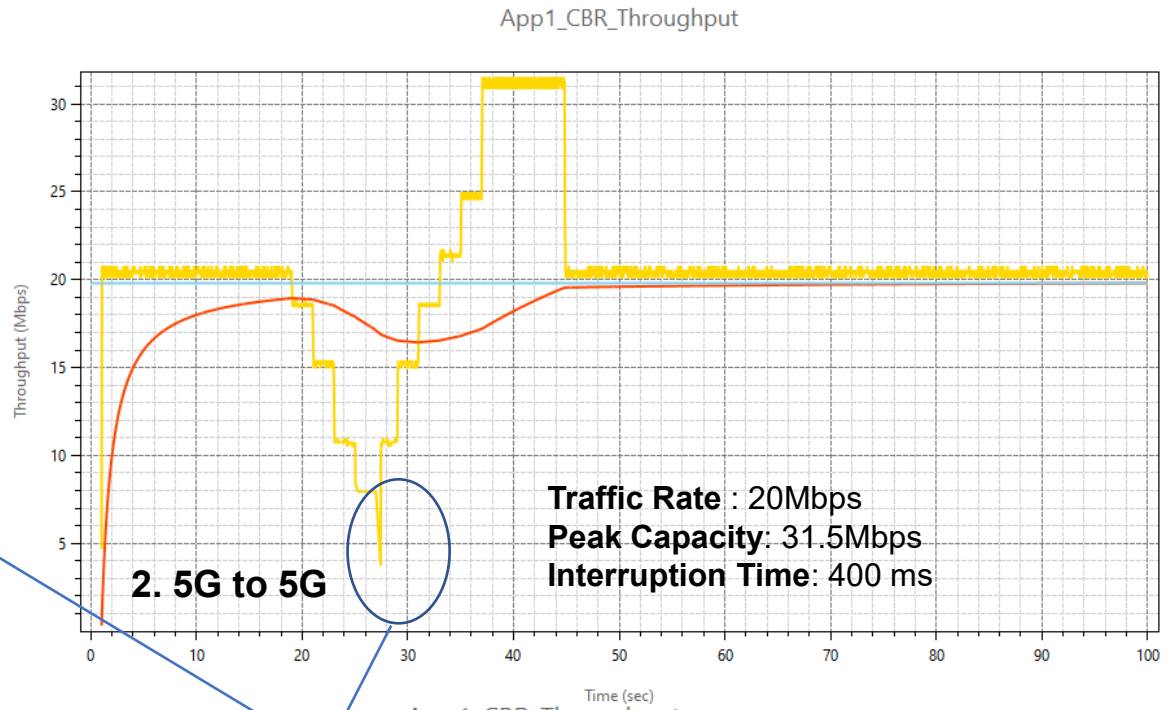




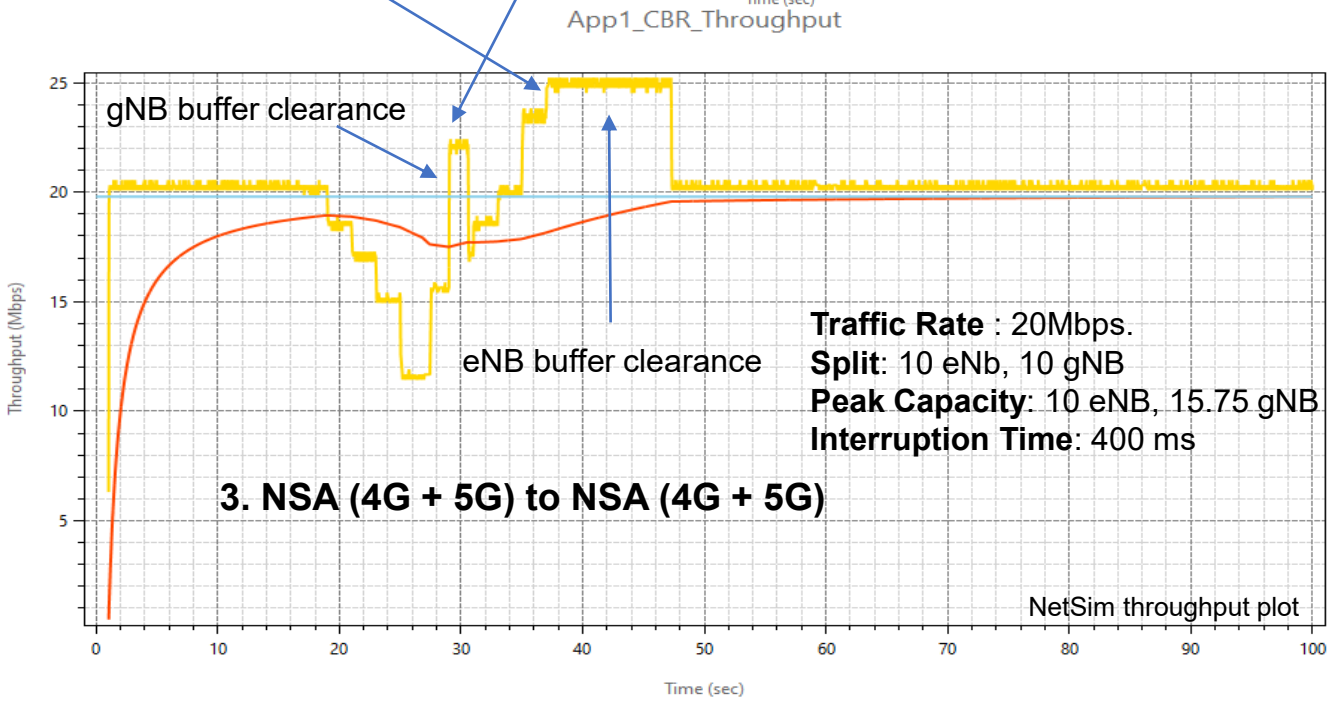
- Understand plot 3 from plots 1 and 2
- Plot 1: 4G to 4G H/O. Throughput vs. Time
- Plot 2: 5G to 5G H/O. Throughput vs. Time
- Plot 3: NSA to NSA H/O. Throughput vs. Time
  - 4G:5G traffic split is 1:1
  - Equivalent to Plot 1 + Plot 2
- RAN Throughput:
  - Min (traffic rate, link capacity)
  - Traffic rate = inbound rate + buffer fill







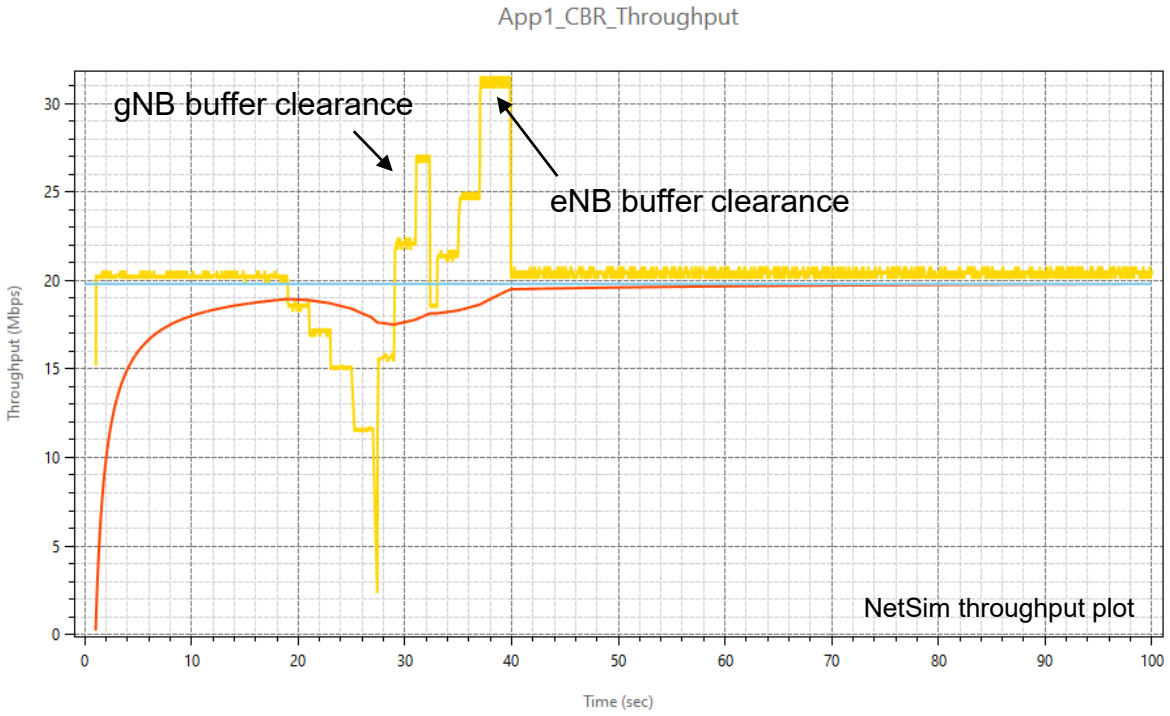
- Traffic rate is 20 Mbps
- eNB capacity 15 Mbps and gNB is 31 Mbps
- Throughput starts falling since CQI drops
- Observe plot 3
  - First peak of 22 Mbps.
    - Due to gNB buffer transfer. 22 = 15 (eNB) + 7 (gNB)
  - Second peak of 25 Mbps.
    - Due to eNB buffer transfer. 25 = 15 (eNB) + 10 (gNB)



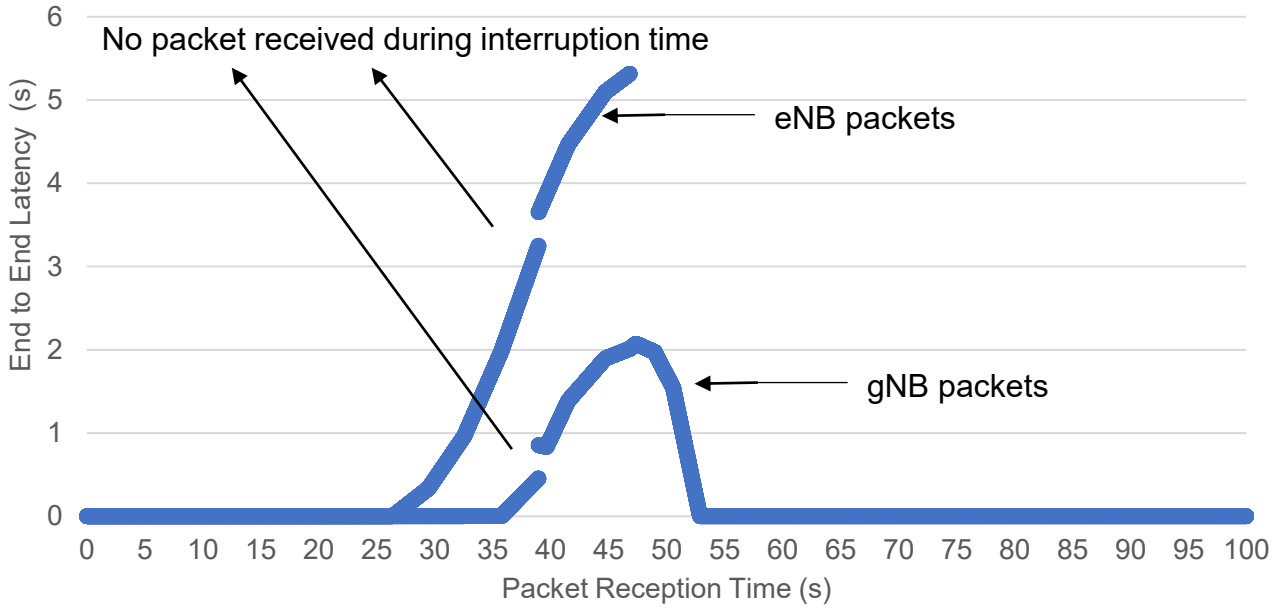
Modelling NSA to SA handover

- Assumptions
  - S-cell capacity: 45 Mbps. 15 Mbps eNB + 30 Mbps gNB.
  - T-cell capacity: 30 Mbps. 0 Mbps eNB + 30 Mbps gNB
  - In NSA-to-NSA Handover, packets in buffer during HO are transferred eNB to eNB and gNB to gNB.
  - NSA-to-SA handover is modeled using NSA-to-NSA handover but setting the split ratio as 0:1 (all packets flow via gNB).
  - s-eNB/s-gNB buffers are transferred over Xn interface to the t-gNB
- gNB and UE MIMO settings in the simulations are 1Tx 1Rx
- Application latency components
  - Xn transport + processing time which includes interruption time,
  - Bandwidth latency across the entire network including the s-RAN and t-RAN,
  - Queuing delays, if any, at the s-gNB and t-gNB buffers.
- The times taken for various control packets to flow between the s-gNB, t-gNB, AMF, SMF. would be negligible since these are small packets being transported over high-speed (Ex 10GBps) core links.

Handover with interruption time. NSA to 5G SA

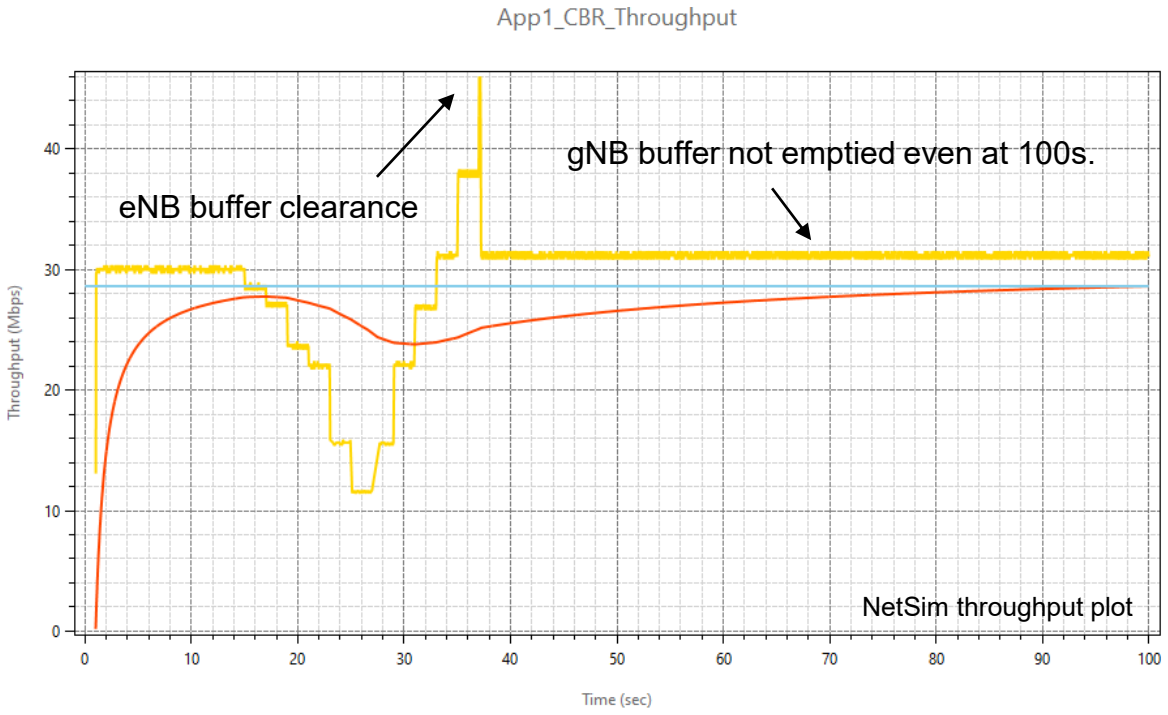


Traffic Rate : 20 Mbps
Peak Capacity: 31.3 Mbps
Interruption Time : 400 ms

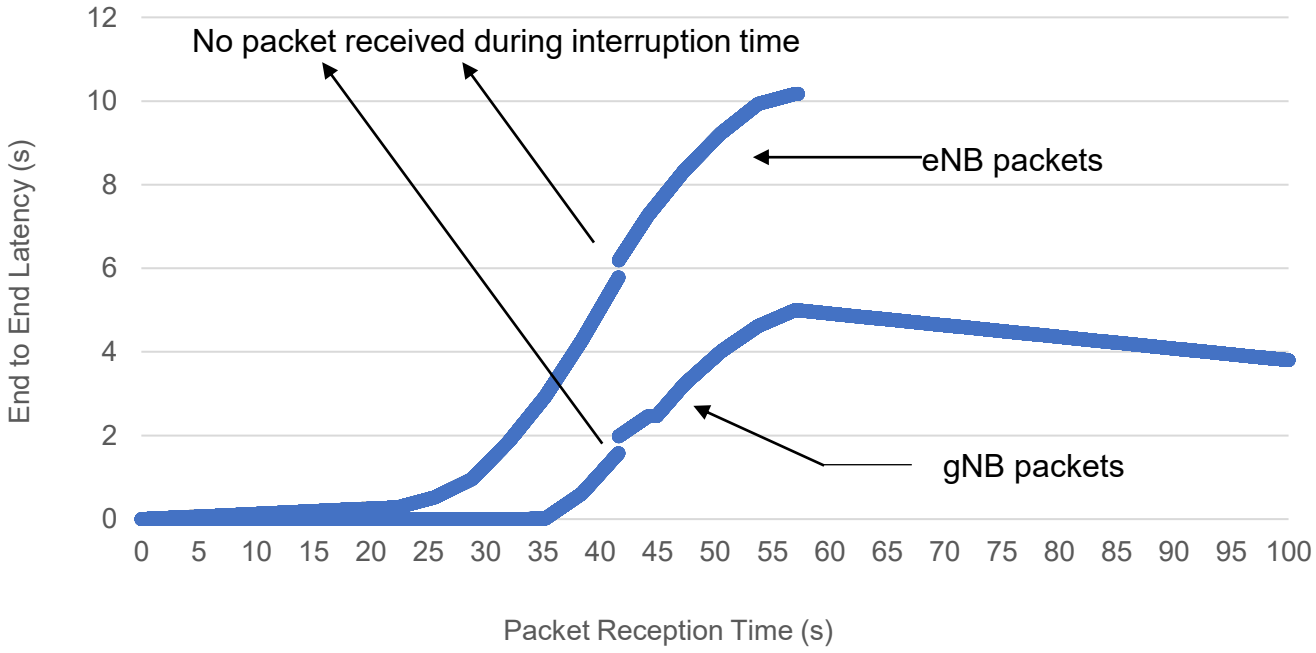


Plot generated from NetSim's packet trace

Handover with interruption time. NSA to 5G SA

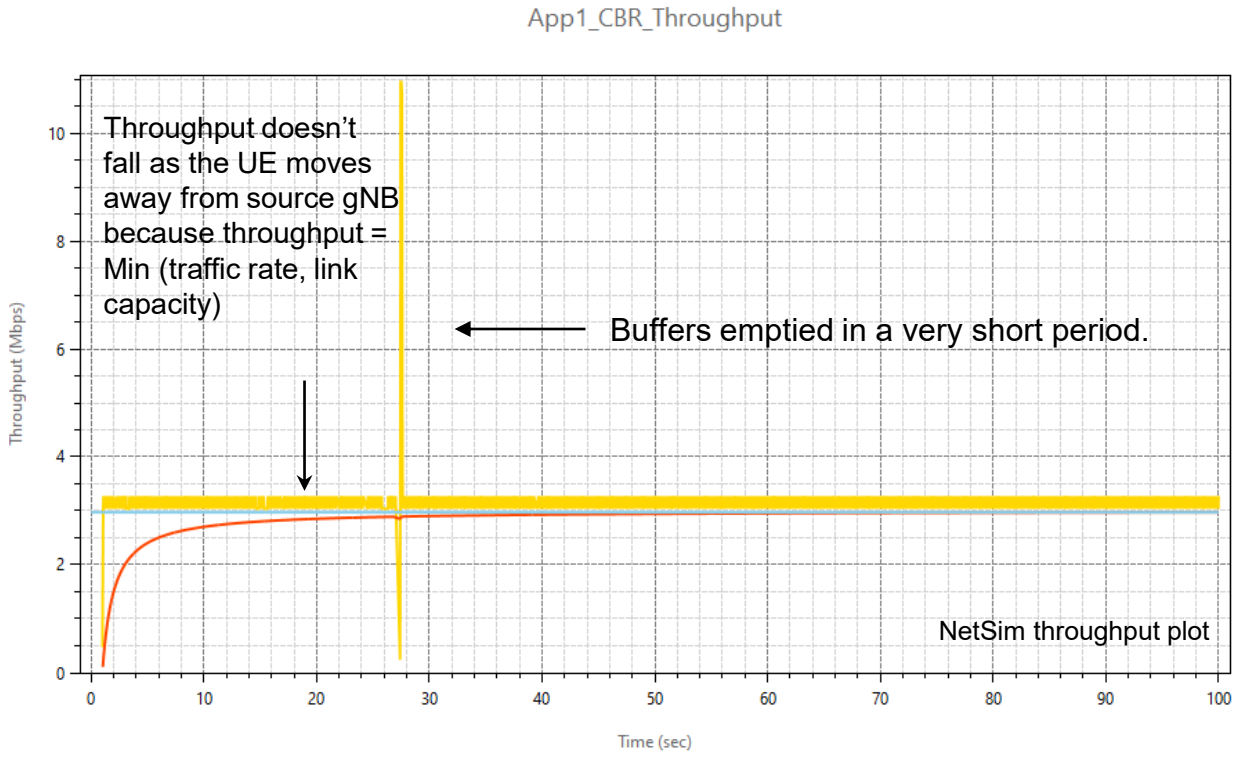


Traffic Rate : 30 Mbps
Peak Capacity: 37.1 Mbps
Interruption Time : 400 ms

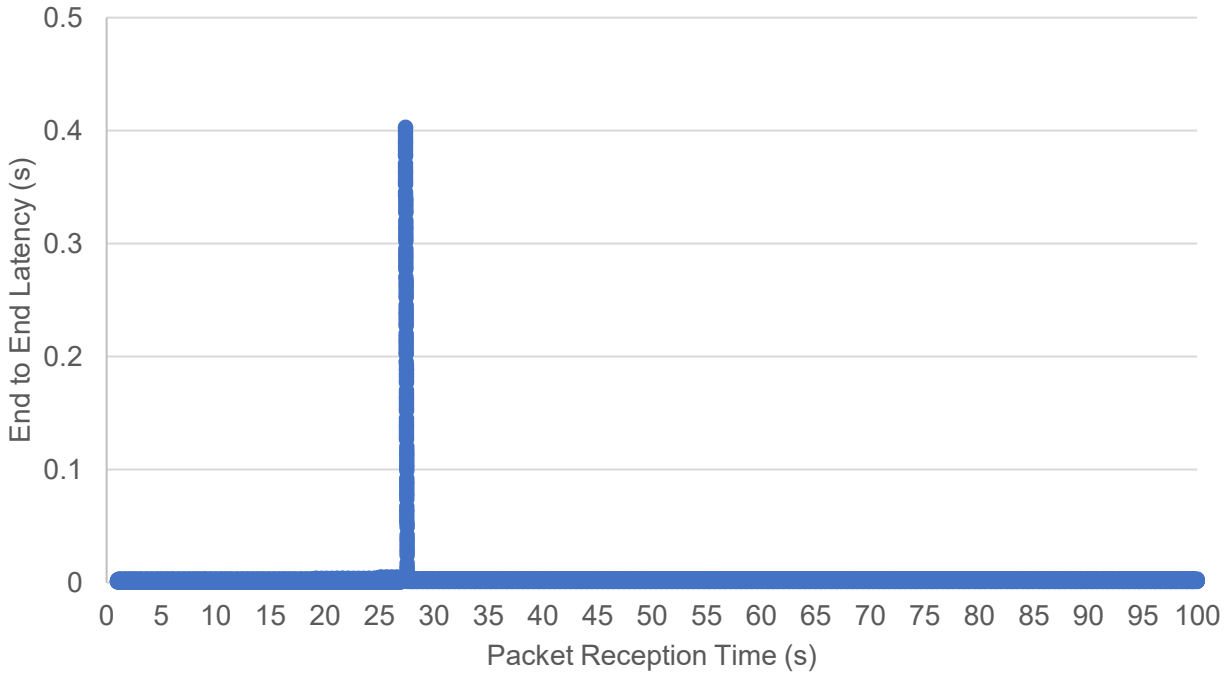


Plot generated from NetSim's packet trace

Handover with interruption time. NSA to 5G SA



Traffic Rate: 3 Mbps
Peak Capacity: 37.1 Mbps
Interruption Time : 400 ms



Plot generated from NetSim's packet trace

Observations for UDP DL traffic during handover

- At low input traffic rates (as a % of peak system capacity):
  - The maximum application delay is slightly higher than the interruption time
  - Application delays persist for a short time
- At moderate input traffic rates:
  - The application delays increase considerably
    - First component of delay is the UE moving to cell edge where traffic rate is greater than capacity
    - Second component is the buffer build up due to interruption time
    - Packets queued in the eNB buffer (and then transferred to the t-gNB) experience a higher delay than packets queued in the gNB buffer.
  - High application delays are seen for a few seconds
- At high input traffic rates:
  - The application delays are very high
  - gNB buffer takes a long time to clear
  - High application delays persist for a long time

* UDP DL Traffic implies there is no higher layer (transport/application) layer flow control.

Application areas for NetSim users

- NetSim users can utilize the framework provided for studying network performance during handovers. These could cover:
- Simulation
  - Results for different source and target settings
  - Parameter variations
    - Interruption time
    - Handover margin
    - Time for which node is in cell edge (capacity < input traffic rate)
    - Different application models and rates
  - Compare results with and without HIT
- Development
  - Add packet losses during handover
- Analysis
  - Separation of the delay components (capacity limitations at edge and HIT)

Thank you

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