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

▪ How is interruption time modeled in NetSim?
▪ Understanding what happens during handovers (with interruption time) by observing throughput and latency.
  ▪ SA to SA
  ▪ NSA to NSA
▪ Modeling the NSA to SA handover, and assumptions made
▪ Results for NSA to SA handover with interruption time (eNB DL capacity is 15 Mbps and gNB DL capacity is 30 Mbps)
  ▪ Input traffic Rate 20 Mbps. Throughput vs. time, Latency vs. time
  ▪ Input traffic Rate 30 Mbps. Throughput vs. time, Latency vs. time
  ▪ Input traffic Rate 3 Mbps. Throughput vs. time, Latency vs. time
▪ Observations
▪ Application areas for NetSim users
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

<table>
<thead>
<tr>
<th>Packet</th>
<th>Source</th>
<th>Destination</th>
</tr>
</thead>
<tbody>
<tr>
<td>UE Measurement Report</td>
<td>UE</td>
<td>S-gNB</td>
</tr>
<tr>
<td>Handover Request</td>
<td>S-gNB</td>
<td>T-gNB</td>
</tr>
<tr>
<td>Handover Request Ack</td>
<td>T-gNB</td>
<td>S-gNB</td>
</tr>
<tr>
<td>Handover Command</td>
<td>S-gNB</td>
<td>UE</td>
</tr>
<tr>
<td>Path Switch</td>
<td>T-gNB</td>
<td>AMF</td>
</tr>
<tr>
<td>Modify Bearer Request</td>
<td>AMF</td>
<td>SMF</td>
</tr>
<tr>
<td>Modify Bearer Response</td>
<td>SMF</td>
<td>AMF</td>
</tr>
<tr>
<td>Path Switch Ack</td>
<td>AMF</td>
<td>T-gNB</td>
</tr>
<tr>
<td>UE Context Release</td>
<td>T-gNB</td>
<td>S-gNB</td>
</tr>
<tr>
<td>UE Context Release Ack</td>
<td>S-gNB</td>
<td>T-gNB</td>
</tr>
<tr>
<td>RRC Re-Configuration</td>
<td>New S-gNB</td>
<td>UE</td>
</tr>
<tr>
<td>UE Measurement Report</td>
<td>UE</td>
<td>New S-gNB</td>
</tr>
</tbody>
</table>

#### Diagram

- **Handover Request, S-MN <-> T-MN**
  - **Interruption Time**
  - **Handover Command, S-MN->UE**
    - **(Interruption Time – T)**
    - **UE RRC Reconfiguration, T-MN -> UE**
    - **Path switch, T-MN<->Core(EPC)**
Handover with interruption time. 5G SA to 5G SA

Properties of Source and Target Nodes:

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

- 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

- 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

**DL Traffic Rate**: 20Mbps
**Peak DL Capacity**: 31.5Mbps
**Interruption Time**: 400 ms
Handover with interruption time. 5G SA to 5G SA

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

- Delay starts once UE moves towards "cell edge". Capacity falls below traffic rate
- No packet received during interruption time
- Three different slopes corresponding to three rates in the throughput plot

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

Throughput doesn’t fall as the UE moves away from source gNB because throughput = Min (traffic rate, link capacity)

Buffers emptied in a very short period.

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

Contact us: sales@tetcos.com
Visit: www.tetcos.com