Automotive Trials for Make-Before-Break 5G Edge Cloud Handover

Results and Takeaways from Joint Trials of
Toyota, Vodafone and Ericsson at the
Aldenhoven Testing Center

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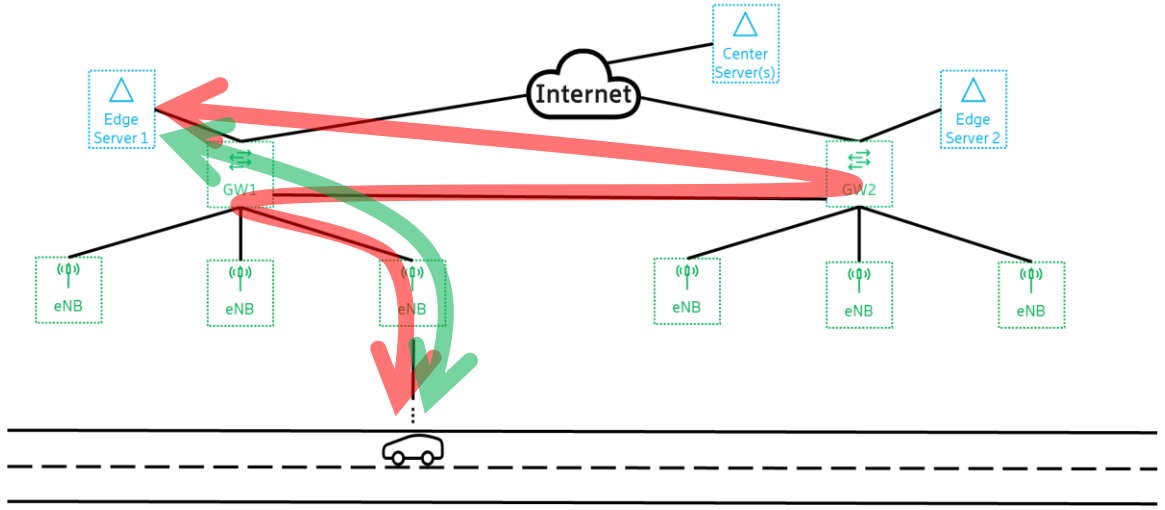
Outline

- Motivation
- Use case: HD Mapping
- 4G vs. 5G Packet Core gateway switching
- Emulating 5G Core make-before-break with a 4G System
- Scenario and results
- Summary, conclusion, and next steps

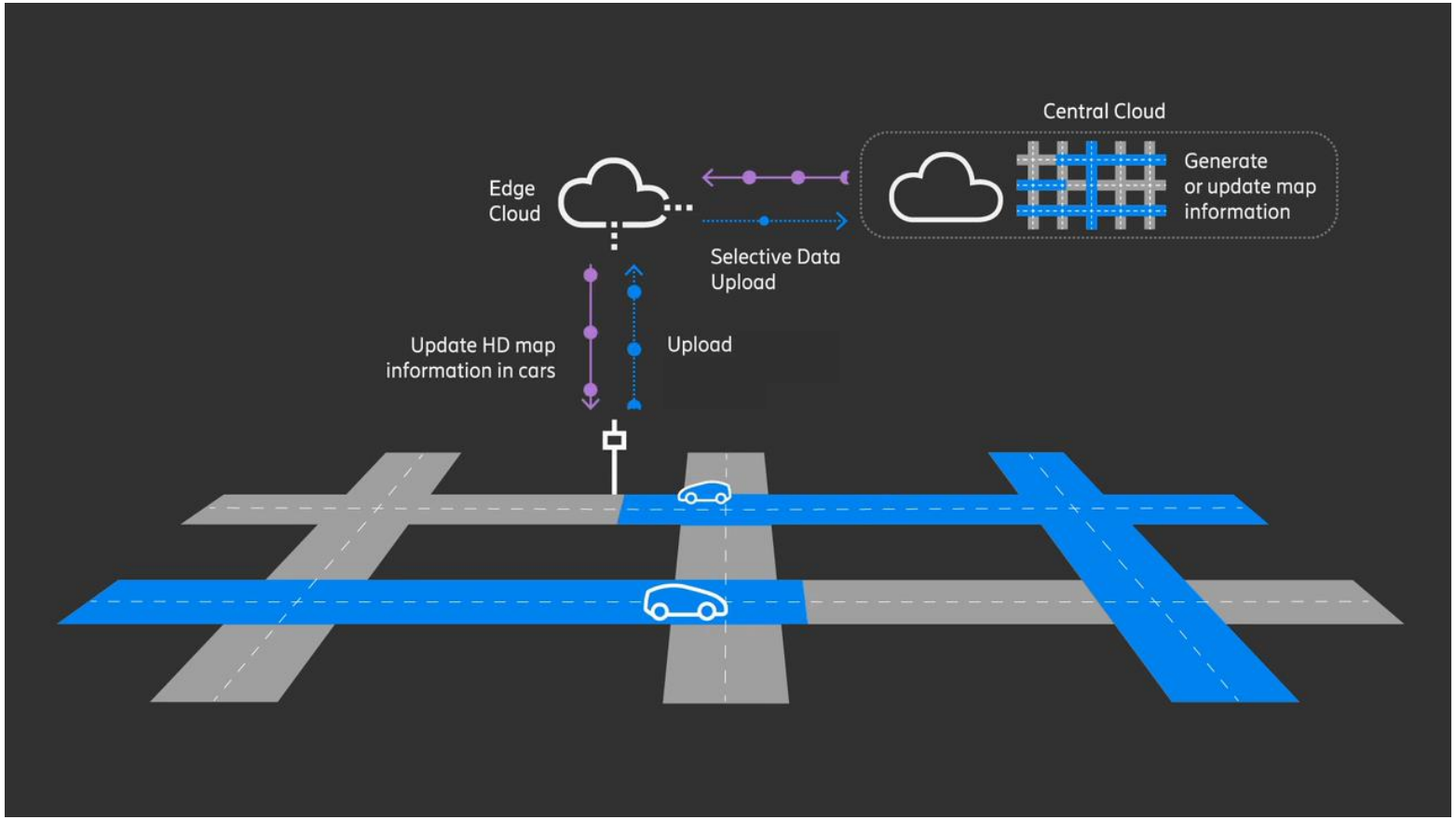
Motivation

- Edge computing provides computation and hosting close to the end user
- In automotive and transport domain vehicles are highly mobile
  - Closest edge server changes when vehicles move
  - When changing the server also a short route between vehicle and server must be assured
- It is not foreseen in 4G Evolved Packet Core (EPC) to change the gateway (Packet Data Network Gateway (P-GW)) of an ongoing session (red arrow)
- It is possible with **5G Core** without temporary loss of connectivity: **Make-before-break gateway switching** (green arrow)
- Research questions:
  - How long does it take for 4G EPC to switch the gateway?
  - What is the benefit of edge computing for the HD Mapping use case?



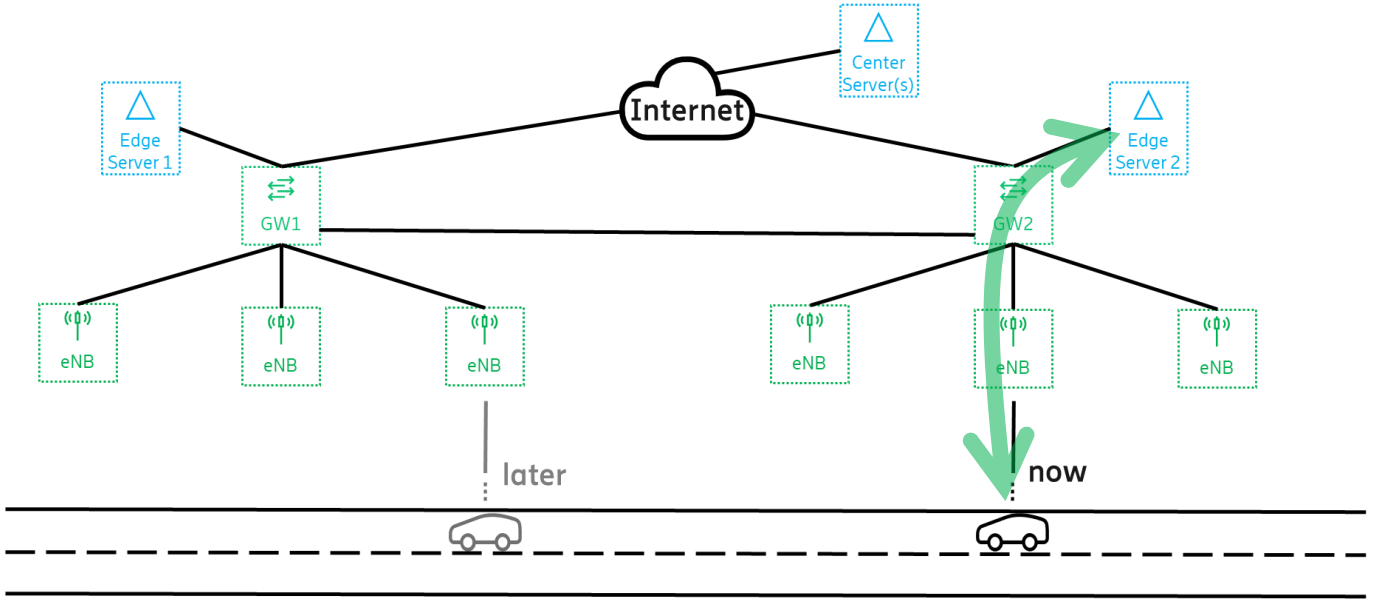
Use case: HD Mapping

- Lane-accurate map showing automated vehicles where they are (not) allowed to drive
- HD map download: most current information
- HD map update upload: crowd sourcing
- **Technically, it is just webserver file down- / upload**



4G vs. 5G Packet Core gateway switching

- 5G Core introduces Session and Service Continuity mode 3 (SSC mode 3)
- It is also called "make-before-break"
- 4G EPC:
  - Trigger gateway switching by disconnect / connect (SSC mode 1 in 5G Core)
  - Selective IP Traffic Offloading above RAN (also disconnect/connect (SSC mode 2 in 5G Core))
- These trials were only about "session continuity" within the domain specified by 3GPP
- More challenges for "service continuity" (e.g. TCP connections)



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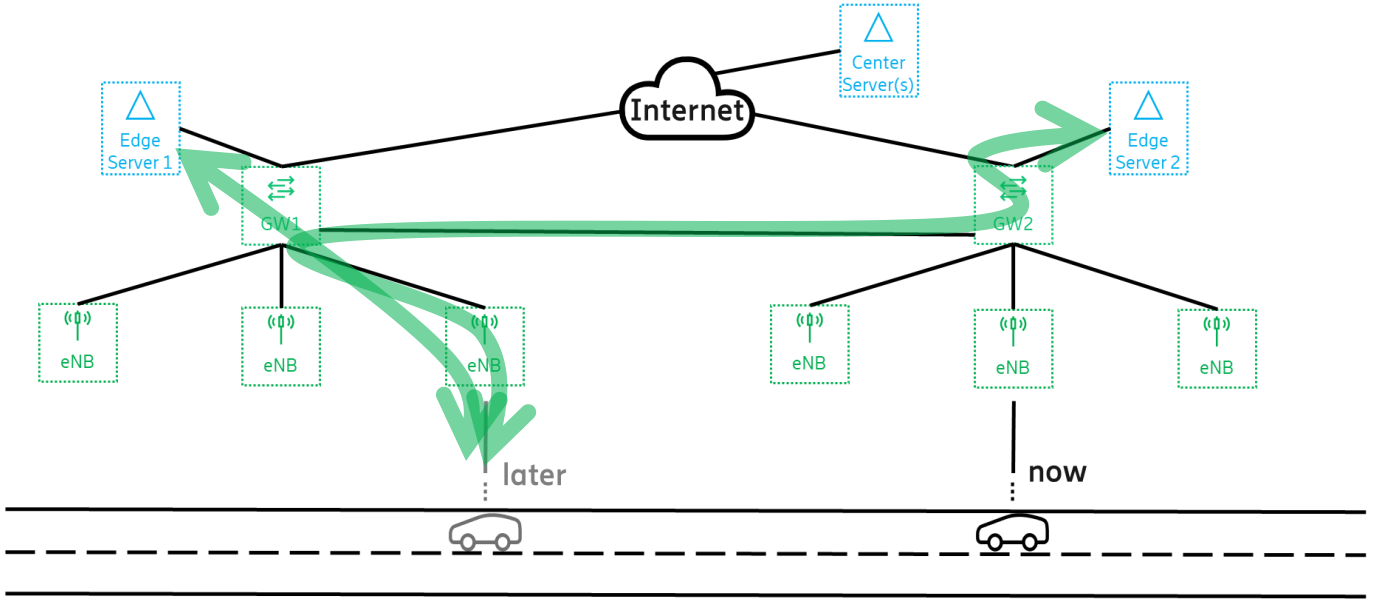

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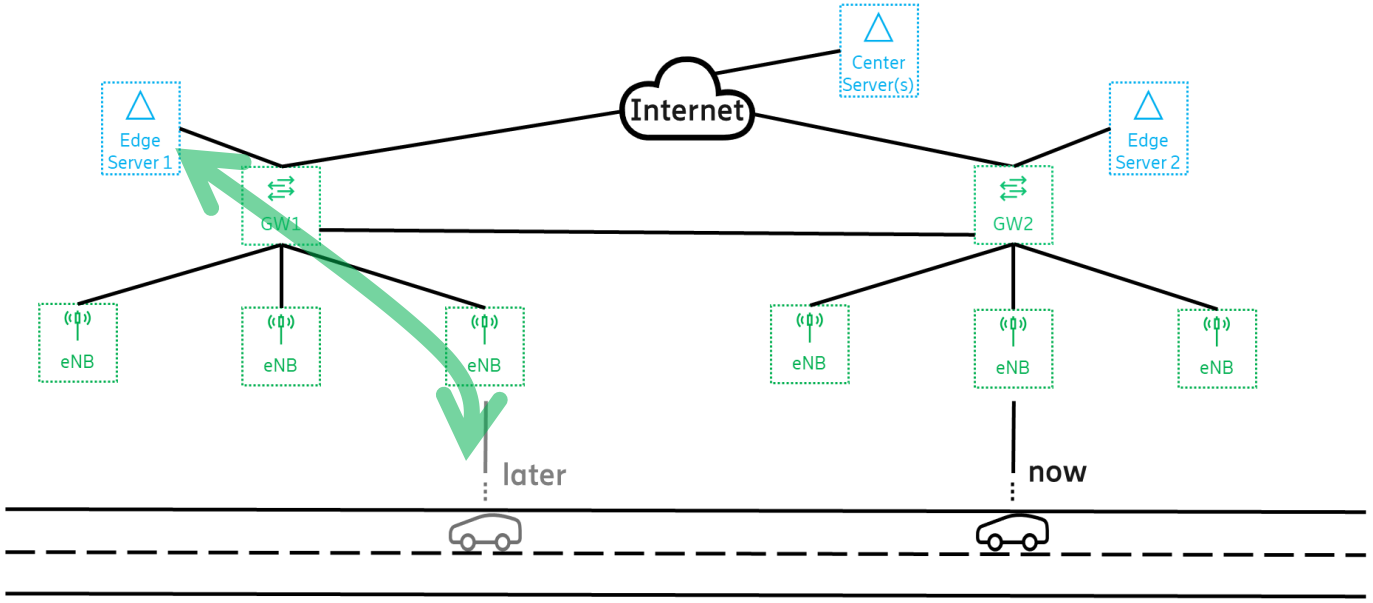

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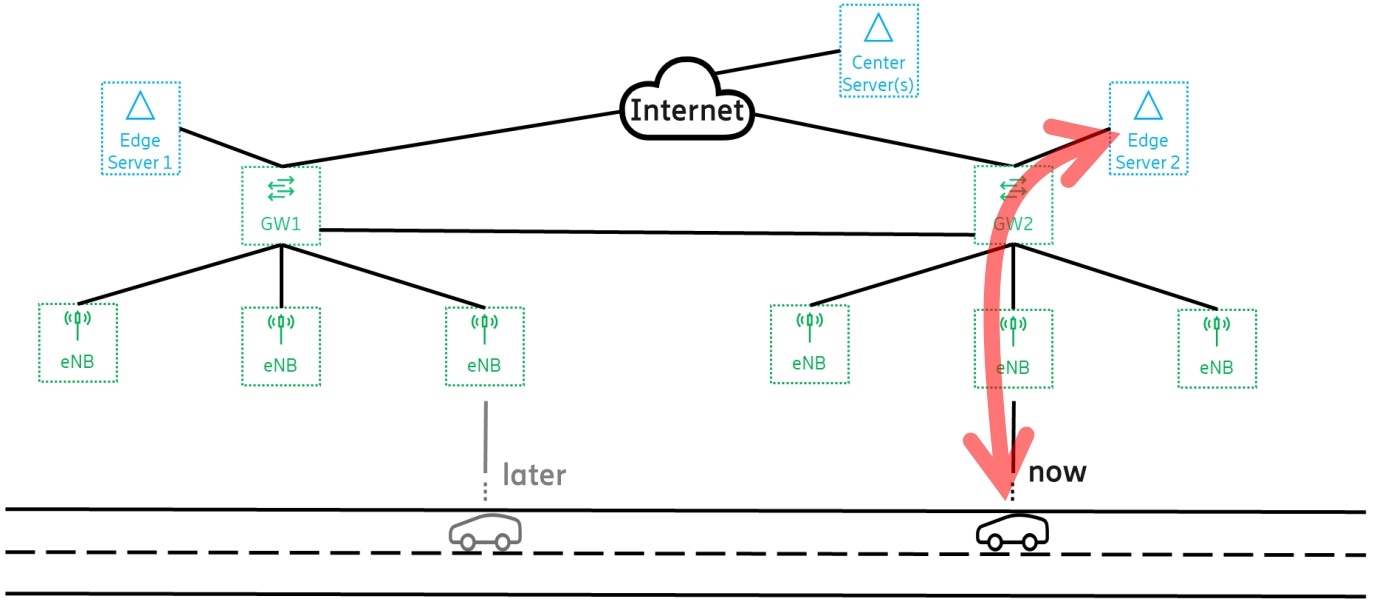

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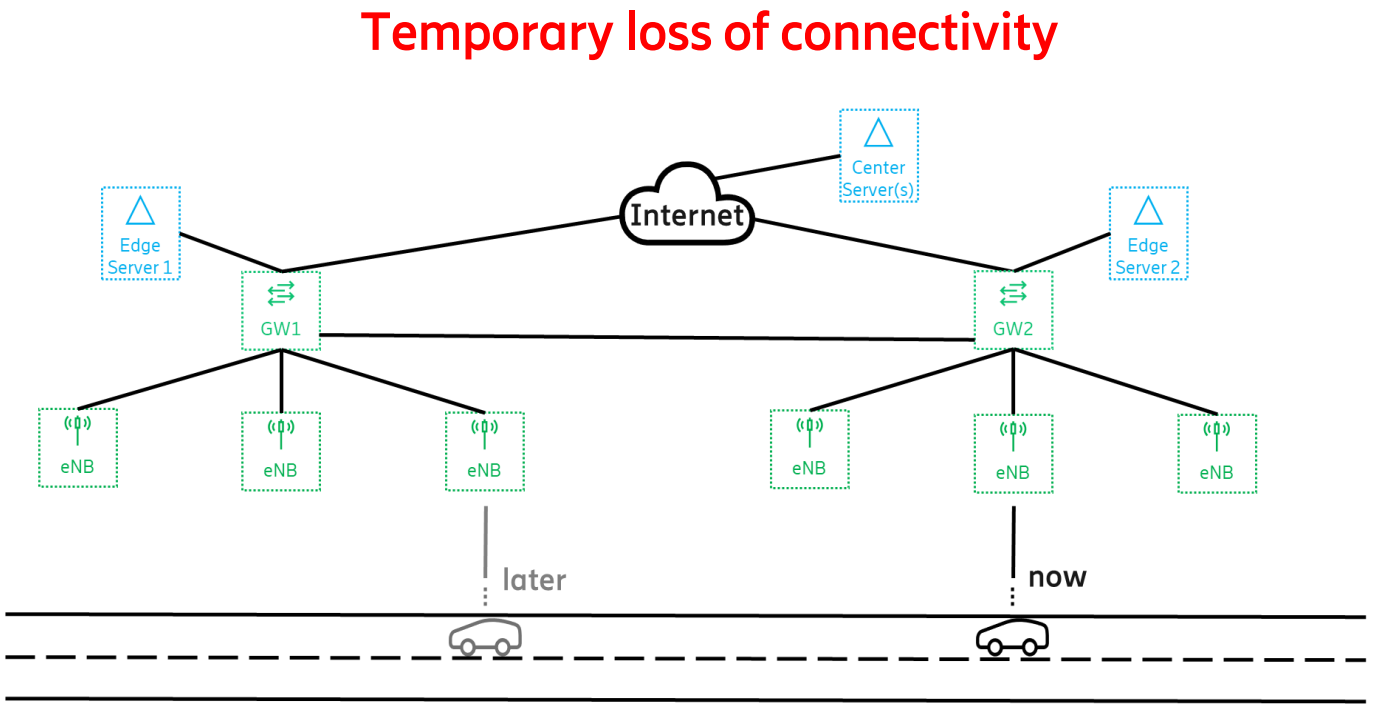

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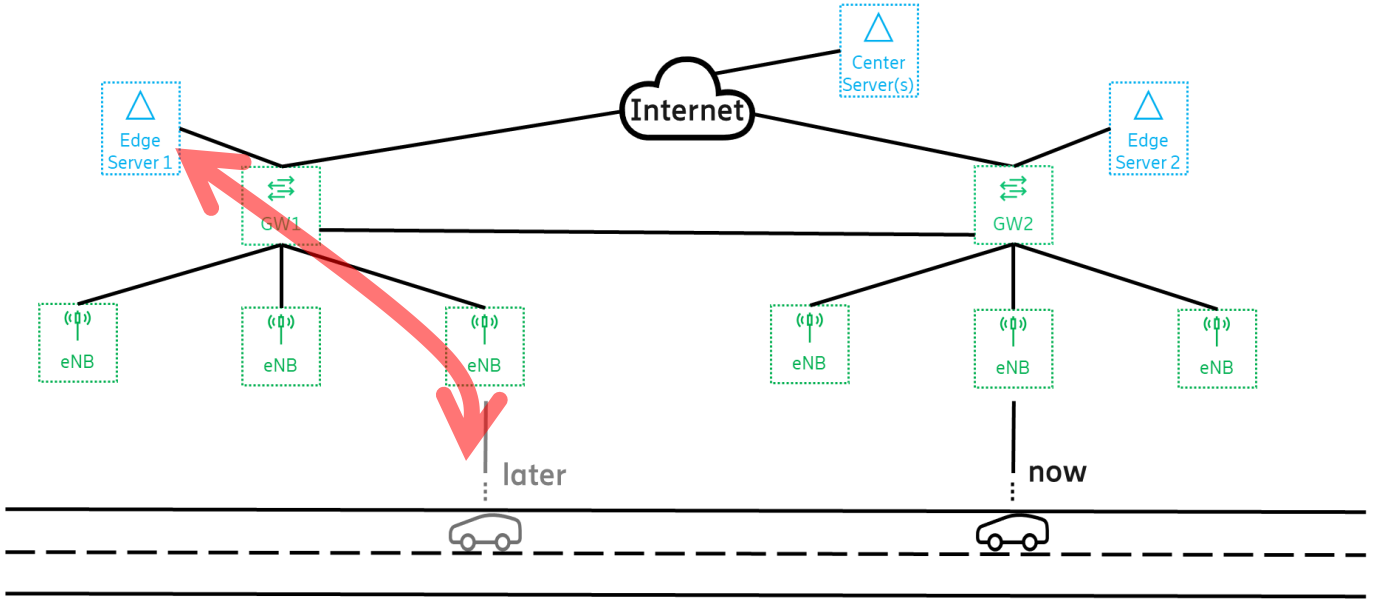

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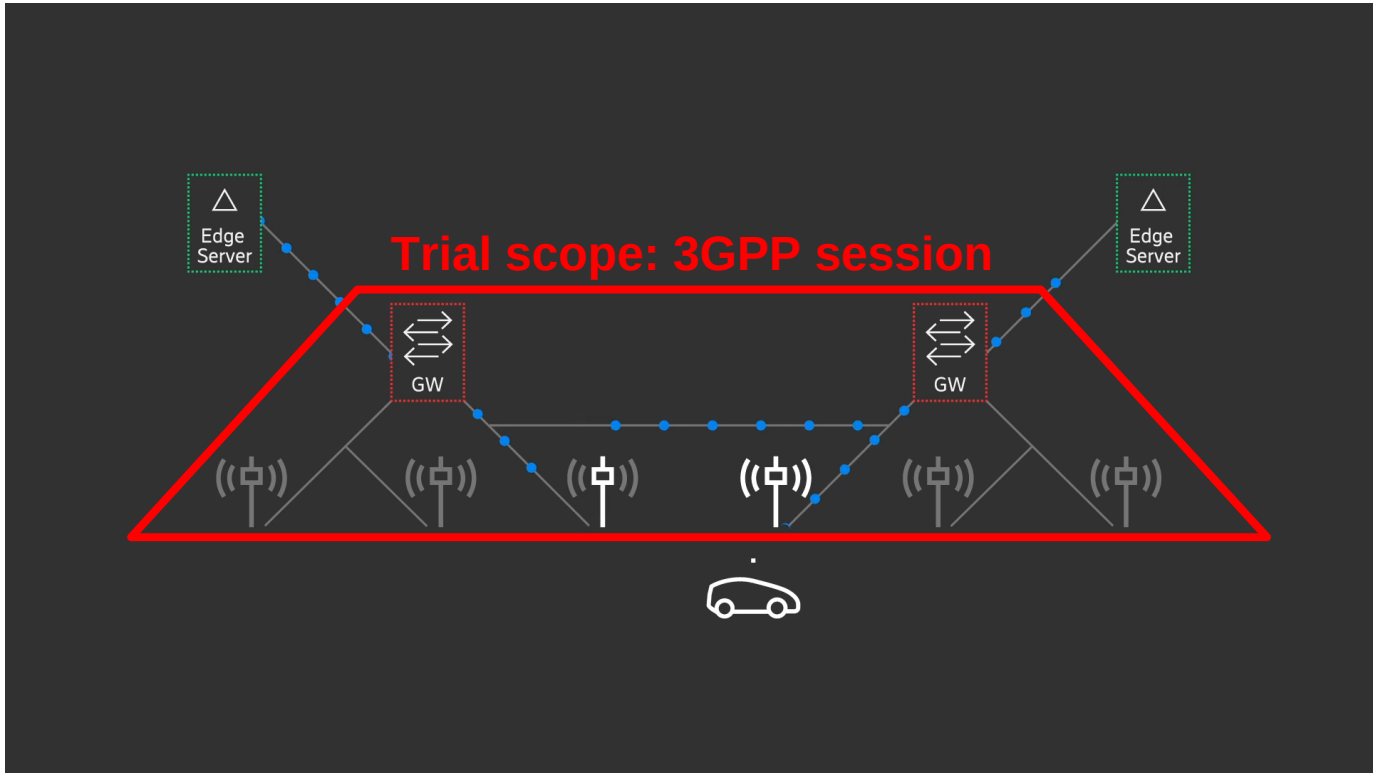
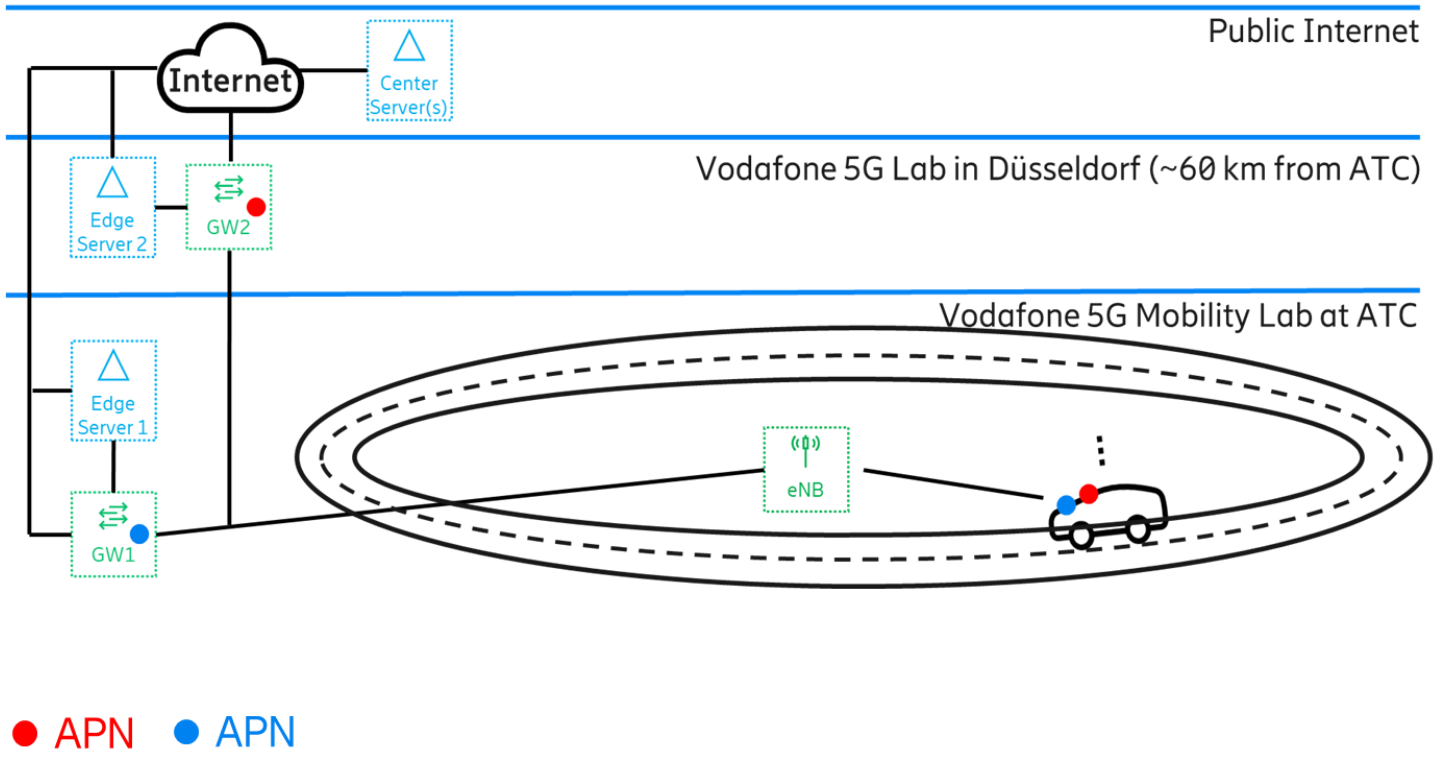


Emulating 5G Core make-before-break with a 4G System

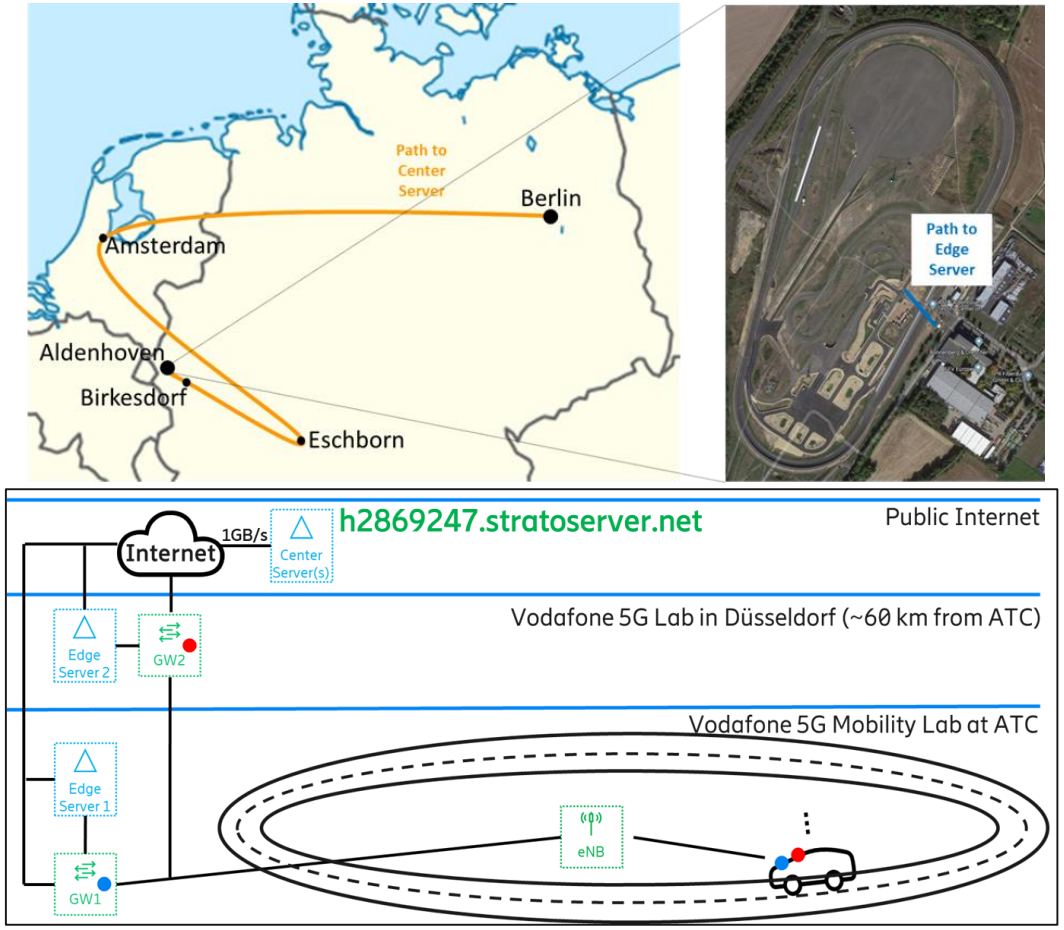
- Every network has many gateways
  - P-GWs in 4G EPC / PSA UPFs[1)] in 5G Core
- The network name is used to select a set of gateways
  - Access Point Name (APN) in 4G EPC
  - Data Network Name (DNN) in 5G Core
- The gateway within the APN/DNN set is selected base on criteria like **location** and/or load
- APN/DNN are provided by the vehicle (modem control software) ➔ vehicle-side influence on gateway selection
- **One cell (eNB) with two gateways, each with different APN**
- Modem (Sierra Wireless MC7430) allows to use two gateways with different APNs simultaneously



1) PSA UPF: Protocol Data Unit Session Anchor User Plane Function

Scenario and results: Scenario

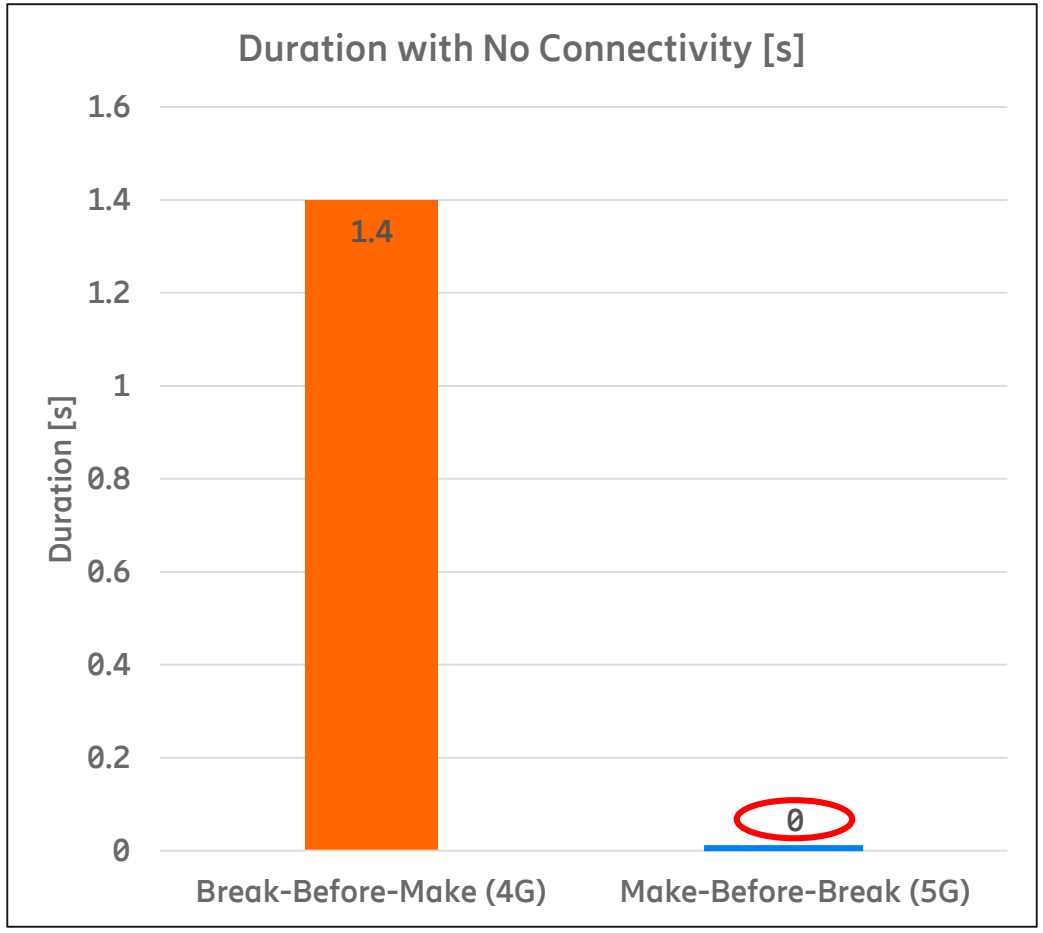
- Central bare metal server with 1GB/s connection in Berlin
- Two edge servers with collocated 4G gateways (P-GWs)
  - One on site in Aldenhoven
  - One very close in Düsseldorf (with the rest of the EPC)
  - Logically they are very similar and **ultra low delay was not the scope of this trial**
- Experiment 1:
  - Change gateway every 30 s
  - 4G break-before-make vs. 5G make-before-break gateway switching
- Experiment 2:
  - File download / upload with 1 – 2 s random pause between and of transmission and new request
  - Edge vs. central server upload / download performance

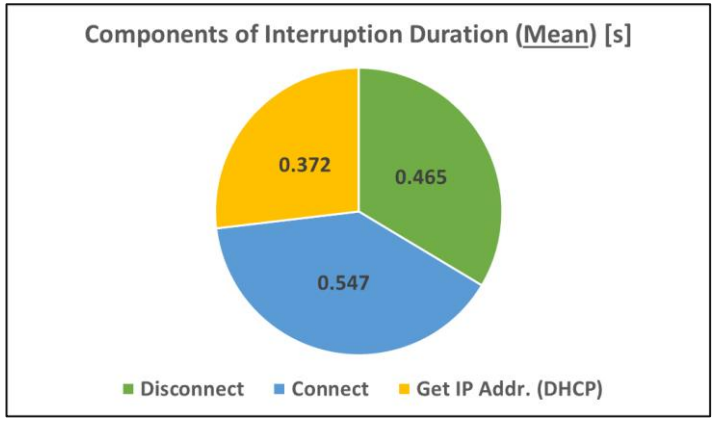


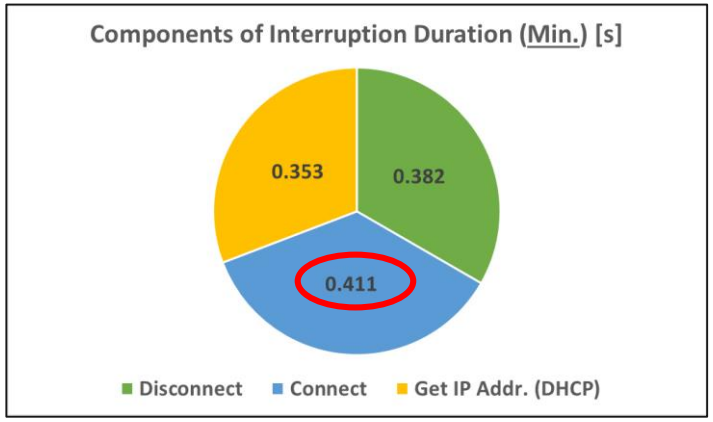
Scenario and results: Experiment 1

Gateway switching:

- **No loss of connectivity** with make-before-break (5G SSC mode 3)
- 1.4 s average loss of connectivity duration with break-before-make
- Modem and software are not optimized for this
  - Could be reduced, but likely not below ~300 ms

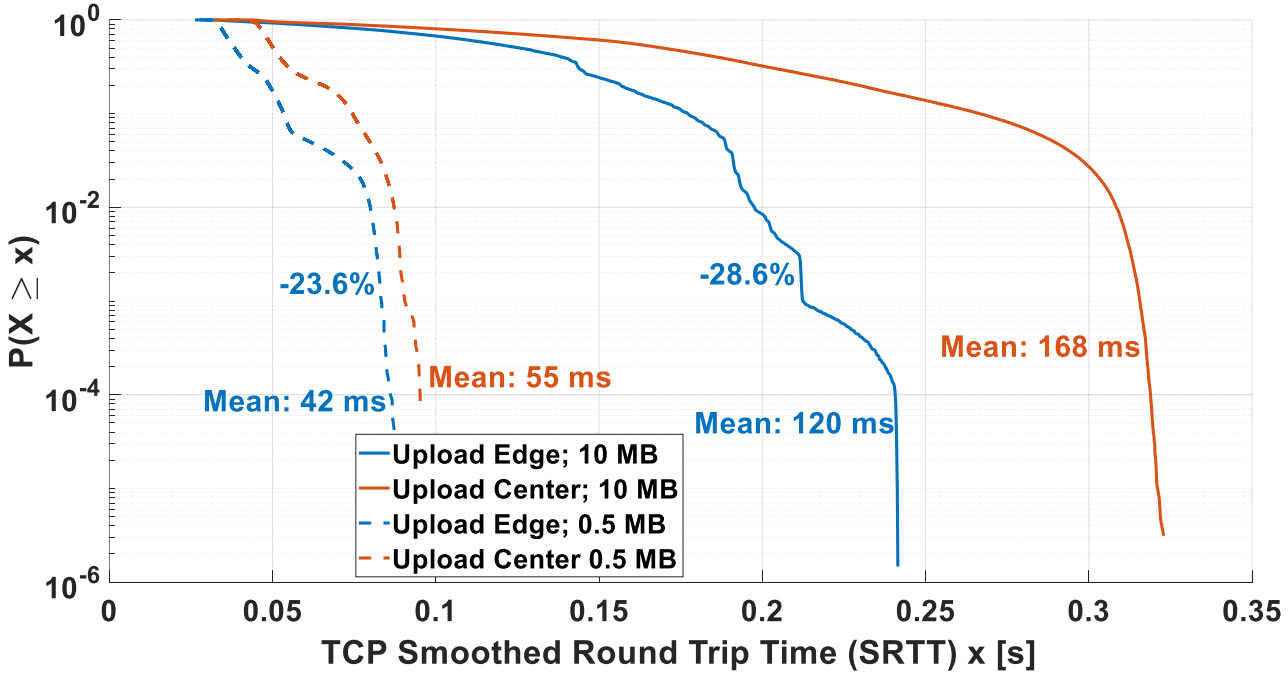


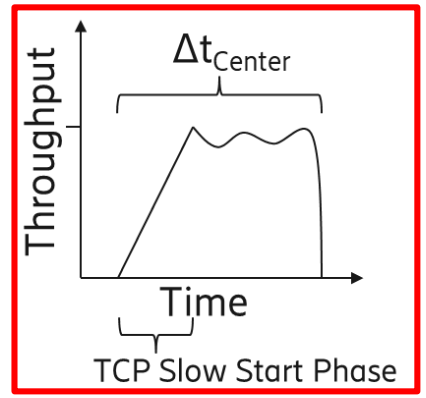


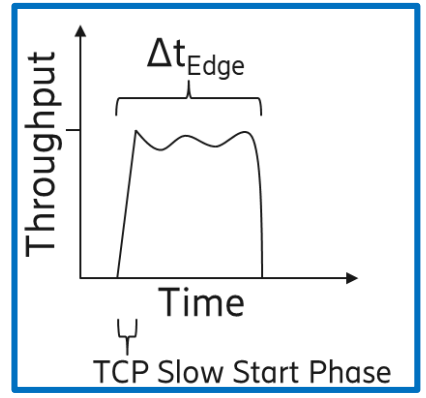


Scenario and results: Experiment 2

- Hypothesis: Reduced packet round-trip-time (RTT) allows TCP to faster reach maximum throughput
  - 57 Mbit/s downlink
  - 22 Mbit/s uplink
- TCP (Smoothed) RTT (SR)RTT is dominated by queueing delays
- Still, edge server shows ~25 % lower SRTT
- Delay much higher for larger file (10 MB) as most of the time bottleneck queue is full (normal TCP behavior)
- Queue does not fully fill up for small file (0.5 MB)







$$SRTT_{i+1} = 0.875 \times SRTT_i + 0.125 \times RTT_{i+1}$$

RTT measured from sending packet until receiving ACK

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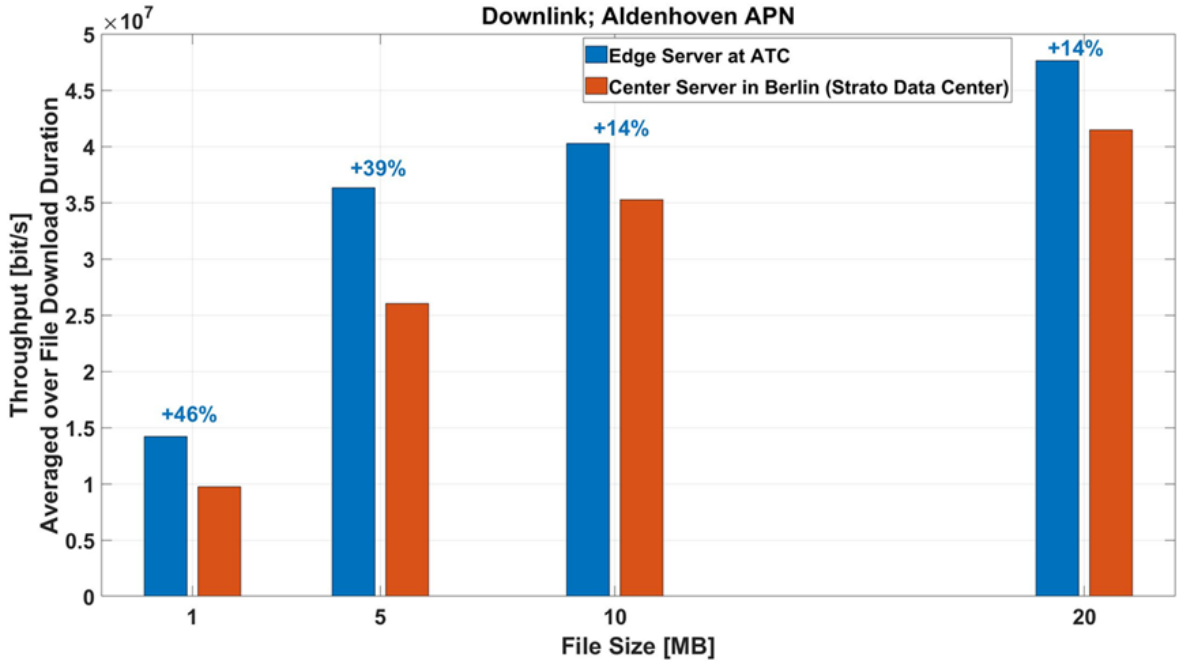
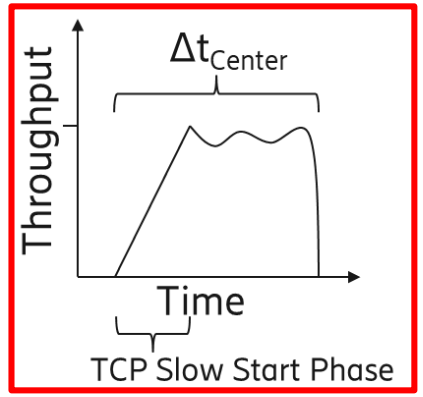
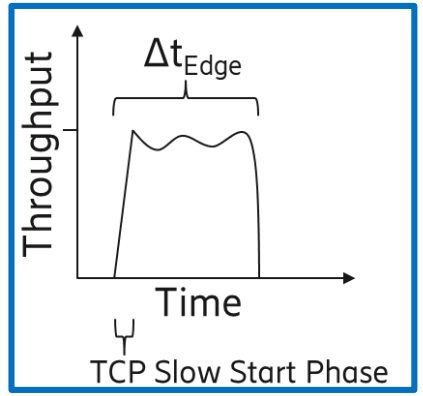
  - 57 Mbit/s downlink
  - 22 Mbit/s uplink
- **Download / upload time reduced with edge server**
- **We saw up to 46% improvement for downlink**
- Smaller files benefit more as TCP Slow Start Phase dominates for them
- Downlink benefits more because higher capacity needs to be reached



File Size	1 MB	5 MB	10 MB	20 MB
DL Throughput improvement	46%	39%	14%	14%

File Size	500 KB	1 MB	2MB	5 MB	10 MB
UL Throughput improvement	35%	25%	15%	7%	4%

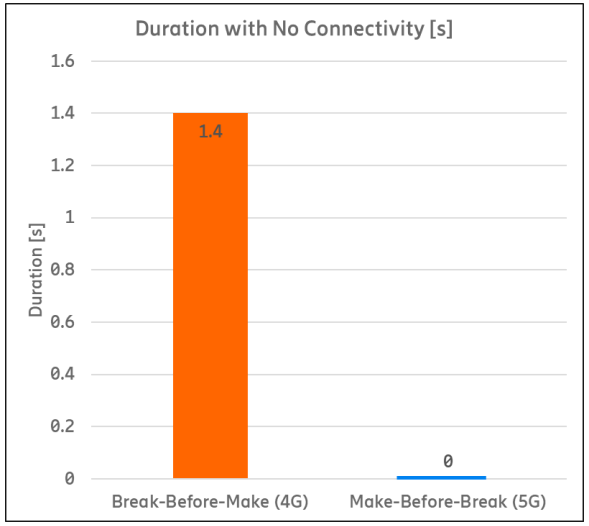




Summary, conclusion, and next steps

- Toyota, Vodafone and Ericsson successfully conducted experiments to show…
  - … temporary loss of connectivity with 4G EPC break-before-make gateway switching
  - … no loss of connectivity with 5G Core make-before-break gateway switching
  - … substantial reduction of TCP download / upload time for edge servers compared to central servers

- **Make-before-break handover reduced temporary loss of connectivity from 1.4 s to 0 s (no loss)**
- **TCP benefits from reduced RTT by faster approaching maximum throughput** during TCP Slow Start Phase
  - Benefit higher for smaller files
    - **46% / 14%** for file size 1 MB / 20 MB downlink
  - Benefit higher for smaller maximum throughput
    - **46% / 25%** for file size 1 MB downlink (57 Mbit/s max.) / 1 MB uplink (22 Mbit/s max.)
- Possible next step: Repeat with real 5G Core
  - Currently no support on end-device side: Might need to do some "tricks" in the modem manager again
  - Include higher layer mechanisms in solution for true end-to-end service continuity



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