CONGESTION CONTROL FOR 4G/5G NETWORKS

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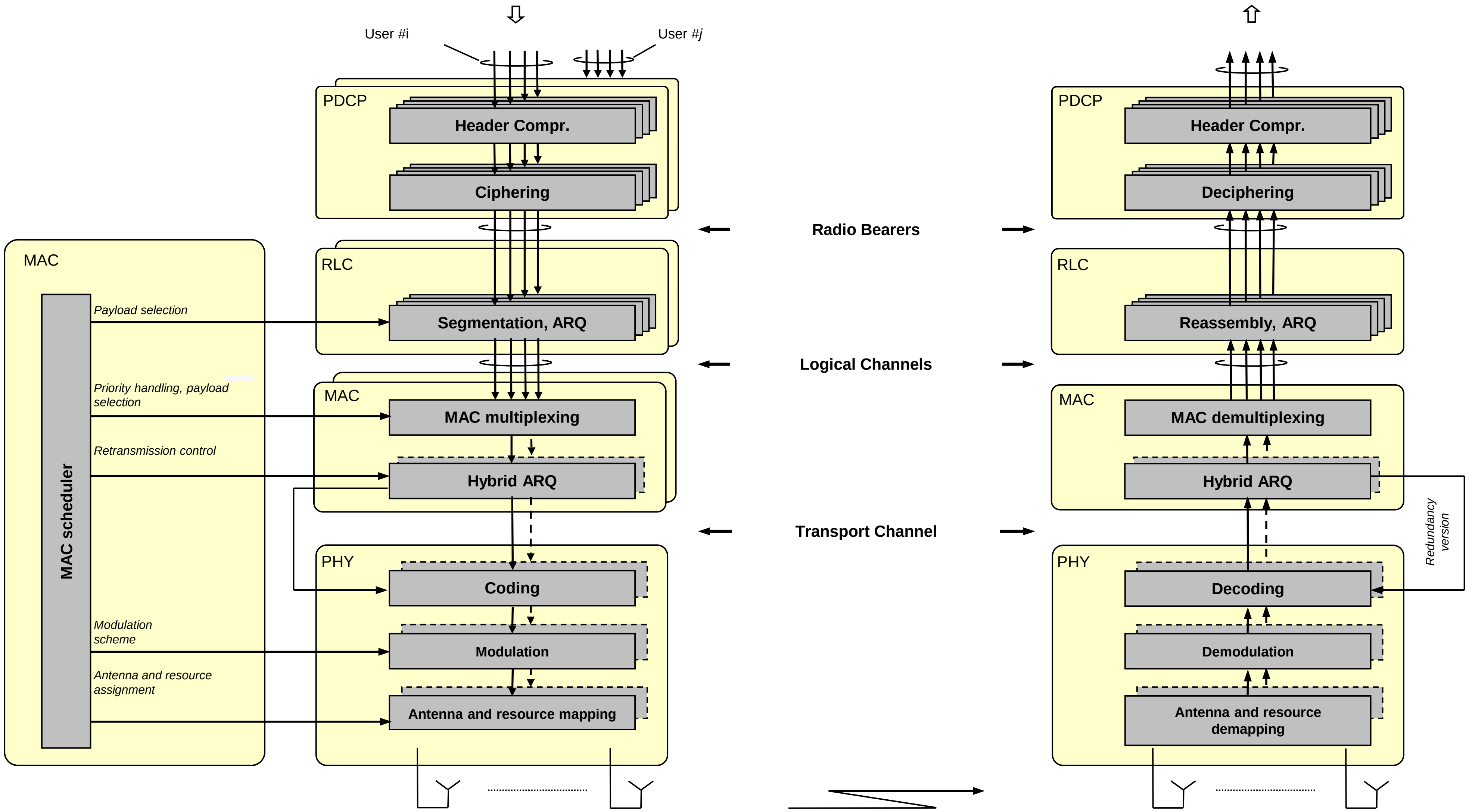
CONGESTION CONTROL FOR 4G/5G SOME CONSIDERATIONS

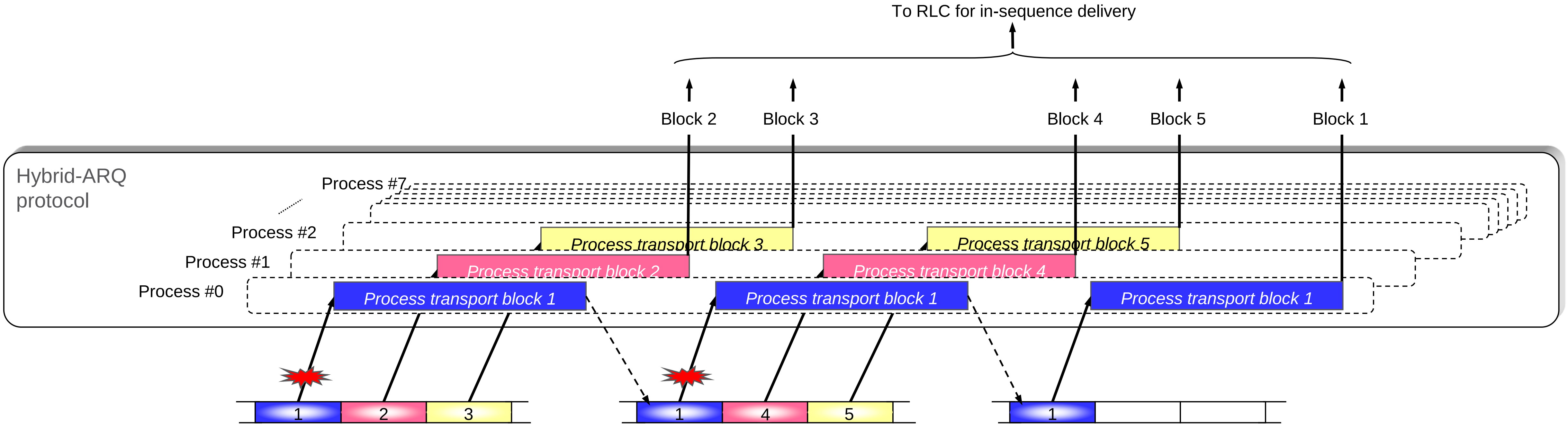
- Don’t rely too much on RTT measurements
- Inter-arrival estimates may be noisy
- Packet pacing improves stability
- Delay based CC’s can be good fallback to combat bufferbloat
- High peak throughput or low latency (under load) ?, pick one
- *Warm up your device before ping measurements*

THE LTE PROTOCOL STACK



MAC LAYER HARQ
HYBRID-ARQ WITH SOFT COMBINING

› Parallel stop-and-wait processes
  – 8 processes ➡ 8 ms roundtrip time
› ~10% probability of retransmission on MAC layer
  – Gives 8ms extra latency
  – RLC implements in sequence delivery



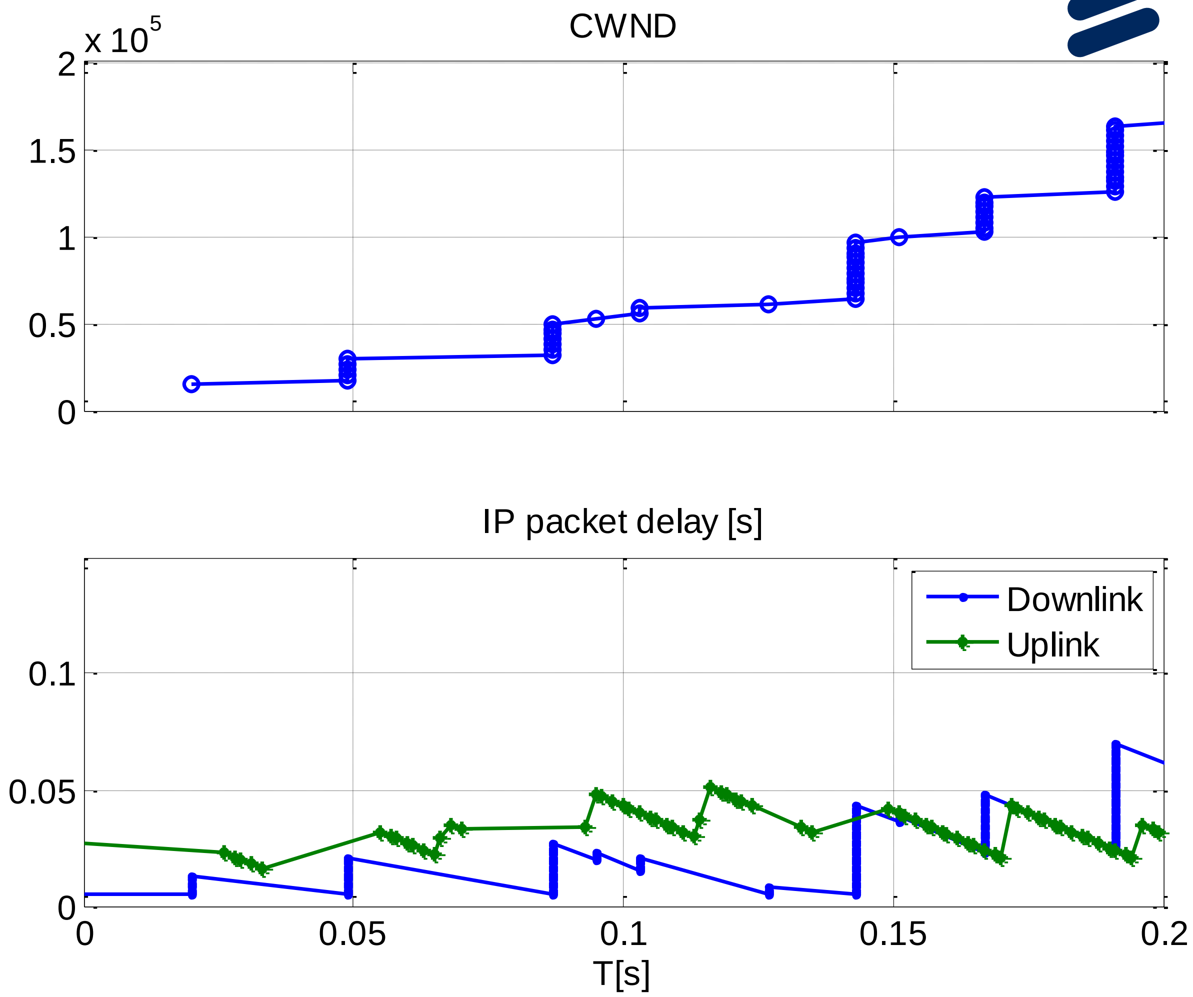
DL AND UL SCHEDULING

- Scheduler behavior is not standardized, implementations are vendor specific
- Different kinds of schedulers
  - Delay : VoLTE (voice)
  - Proportional fair, Round Robin : Default (=best effort) bearers
  - Max CQI..

- Scheduling has impact on IP packet delay characteristics

EXAMPLE 1

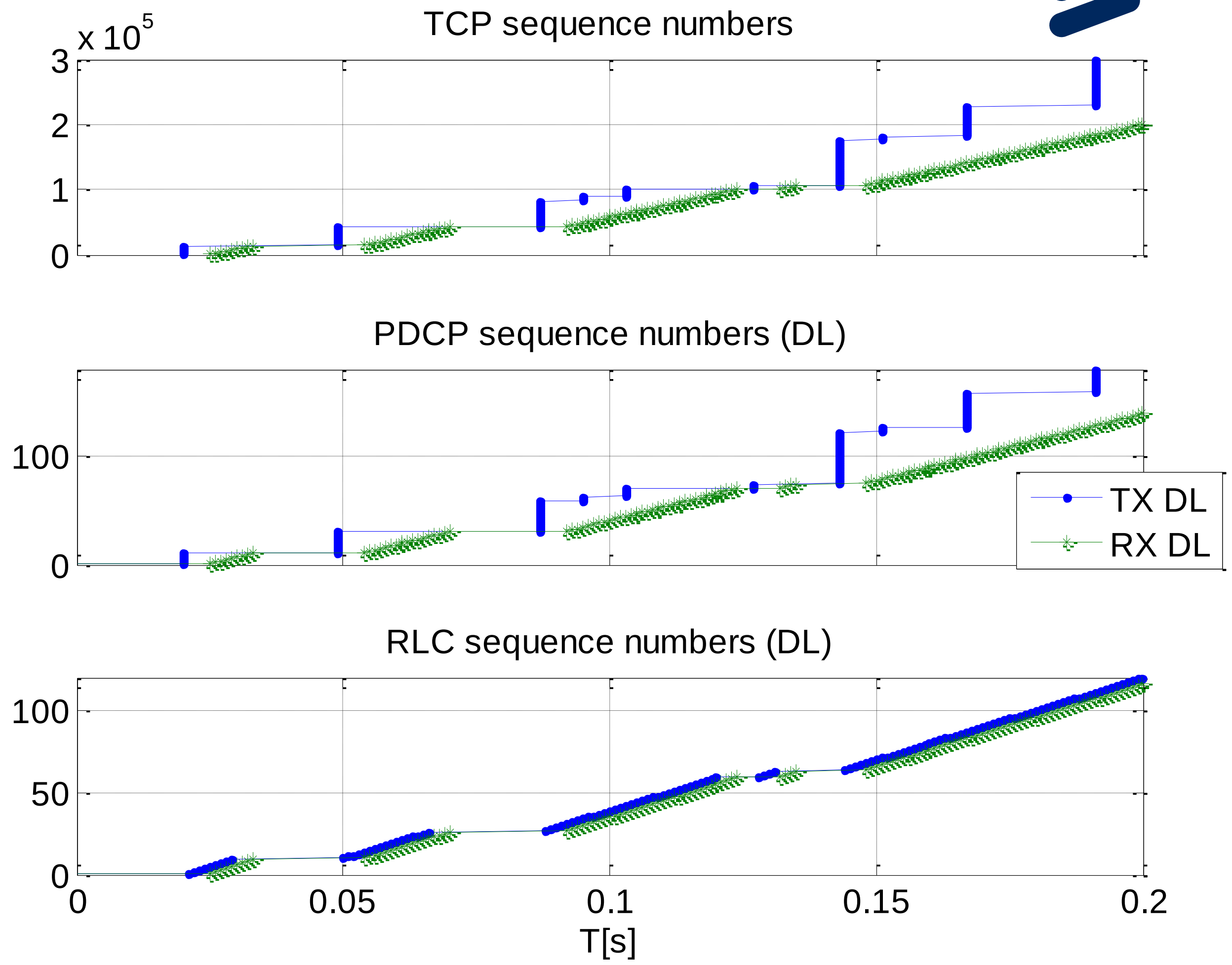
› Downlink queuing delay show little tendency to increase
› Uplink delay is however relatively large, why ?



EXAMPLE 1, SEQUENCE NUMBERS DL

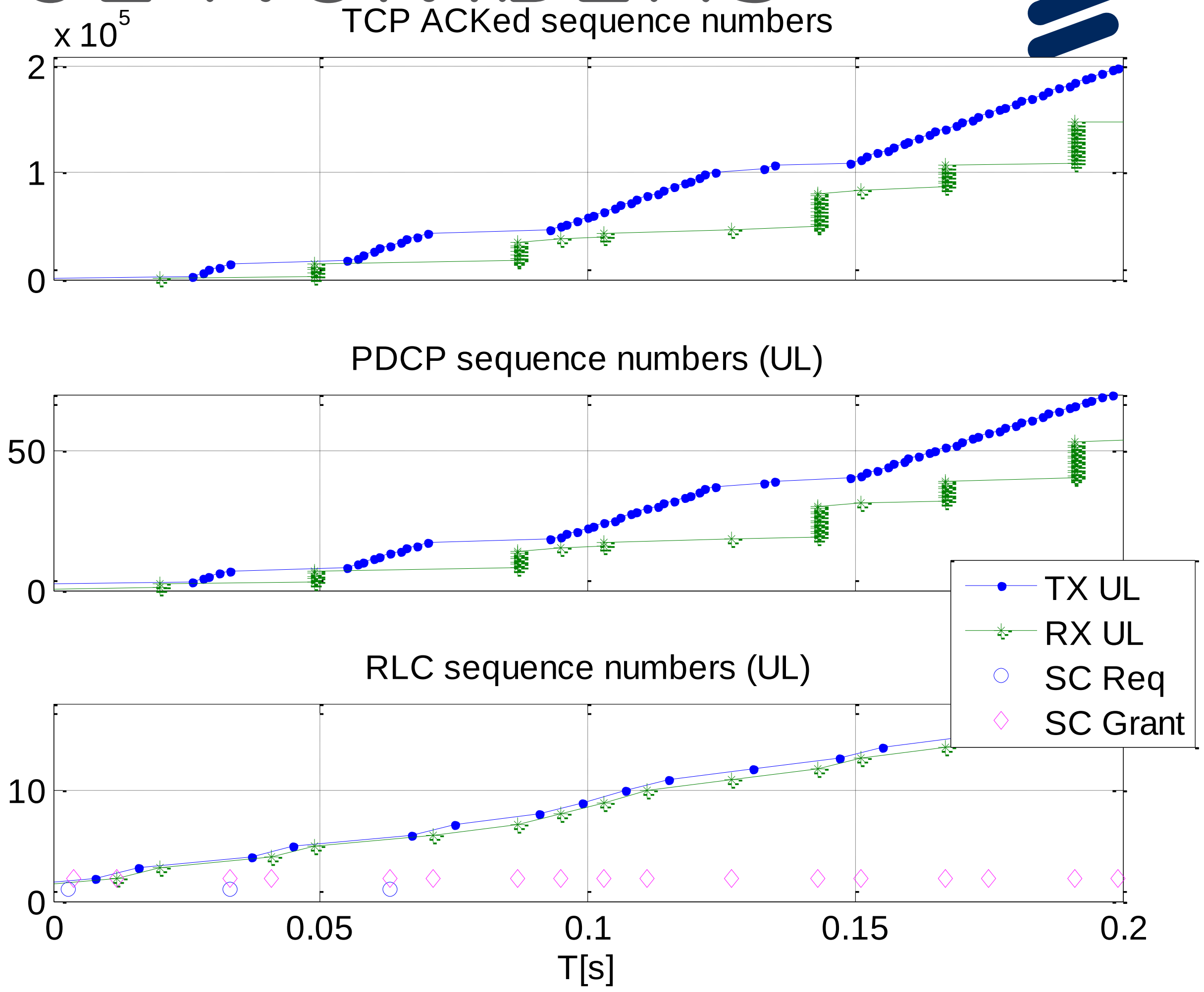
› Problem free packet transmission in downlink

› TCP bursts are transmitted as quickly as resource allocation allows



EXAMPLE 1, SEQUENCE NUMBERS UL

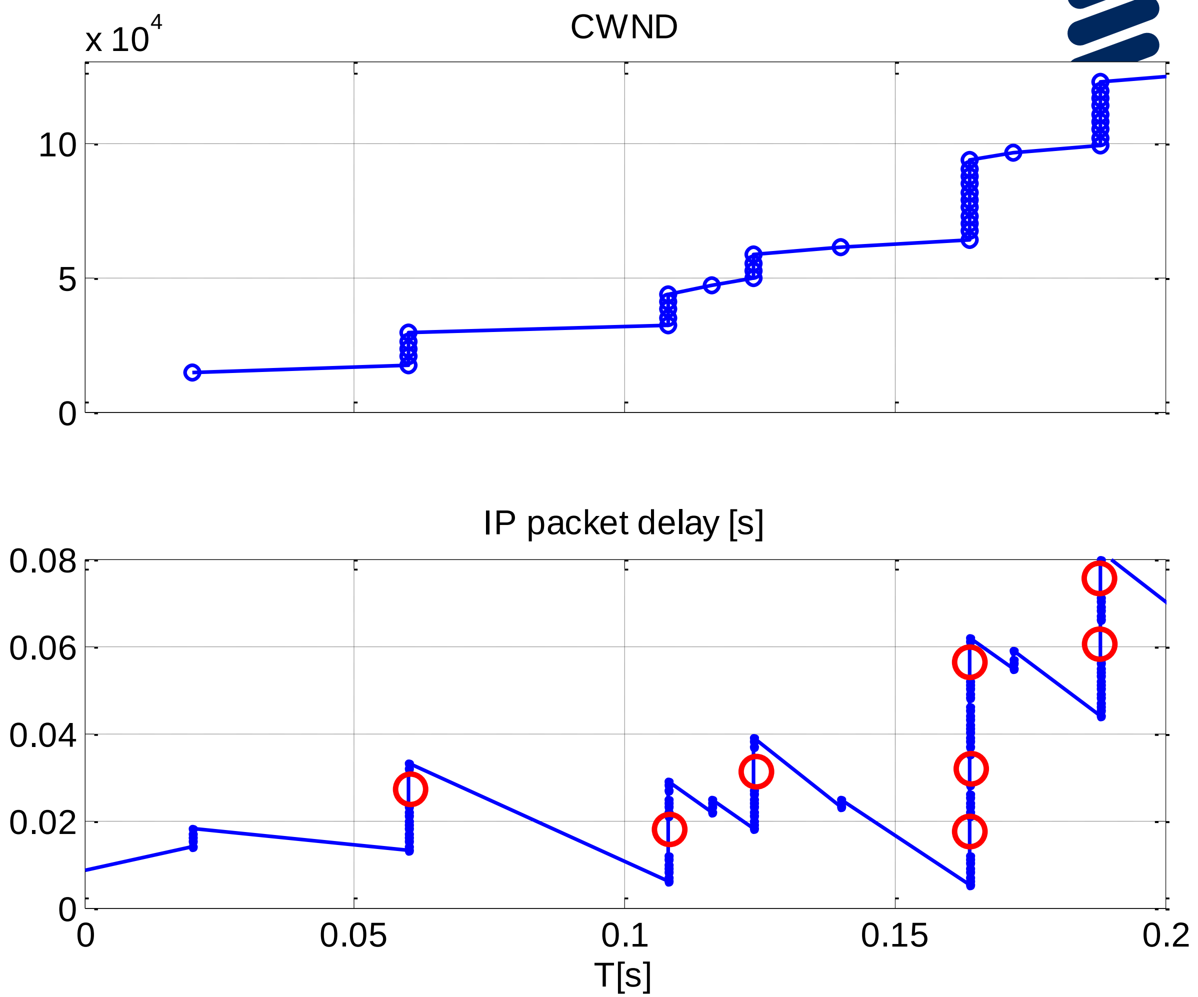
- Uplink ACKs are bundled → RTT affected by UL scheduling
- An uncongested downlink may thus be considered as congested by a too sensitive RTT based congestion trigger
  - Example : Cubic HyStart



Don't rely too much on RTT estimates

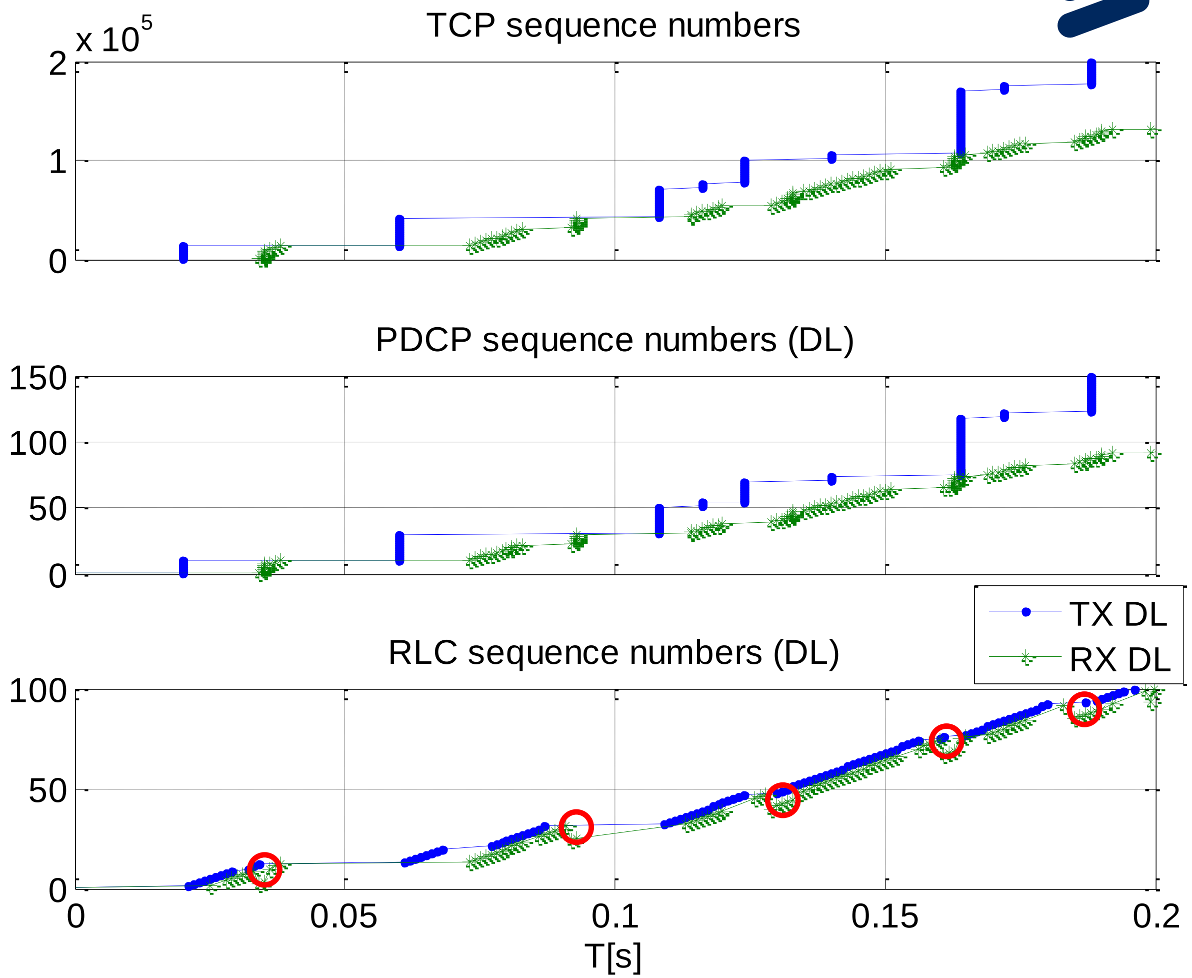
EXAMPLE 2

› Gaps in IP packet delay, why ?



EXAMPLE 2, SEQUENCE NUMBERS DL

- RLC AM bearer (in-sequence delivery)
- HARQ retransmissions delay packet forwarding to higher layers



Inter packet arrival measurements can become noisy

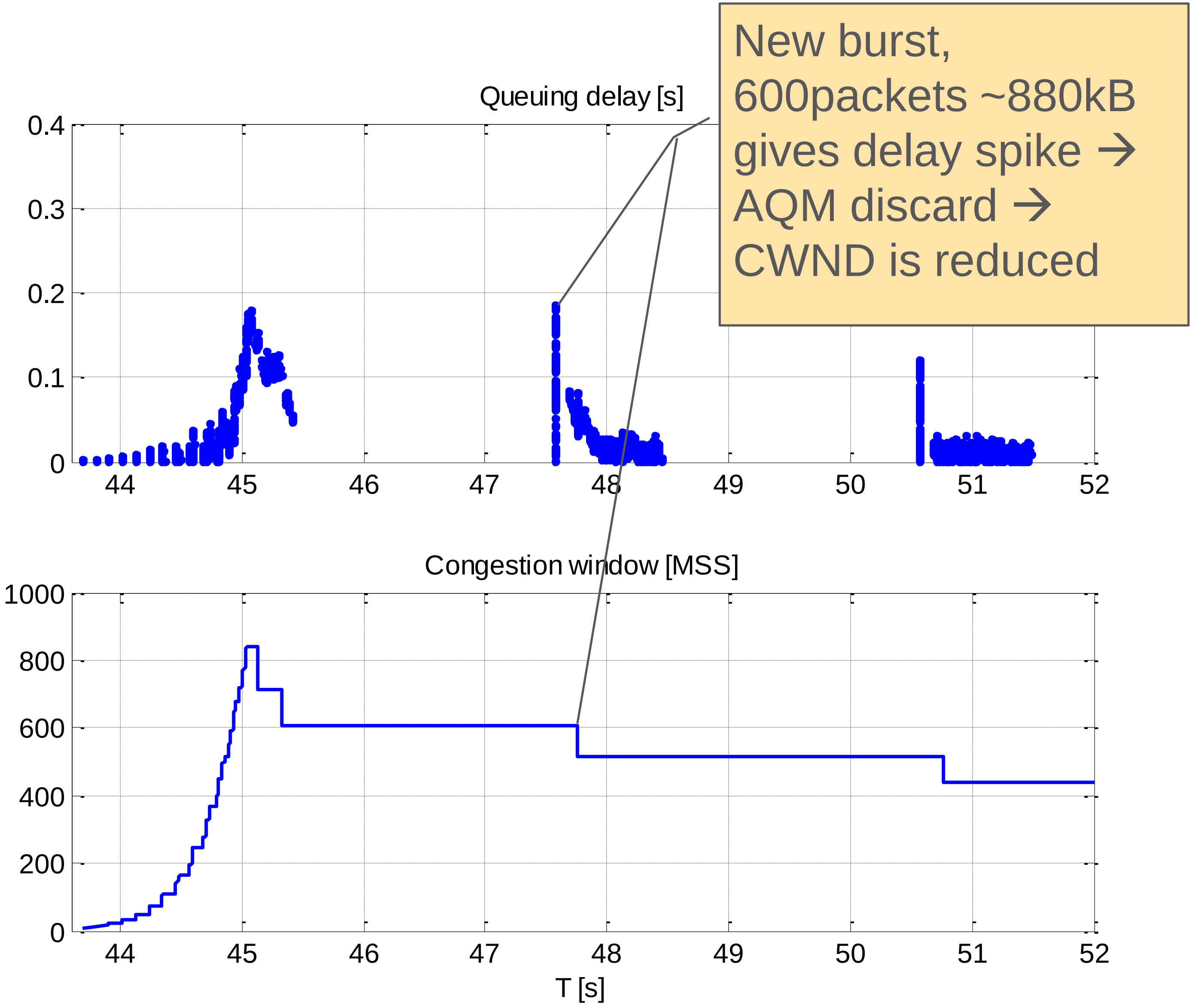
PACKET PACING

- LTE transport block sizes are limited
  - Example : 10MHz BW, max TB size ~36kByte
- Large bursts are queued up, queuing delay can trigger unnecessary AQM drops or ECN marks
- Lower AQM/ECN thresholds → Higher risk of false congestion indication
  - Consider L4S

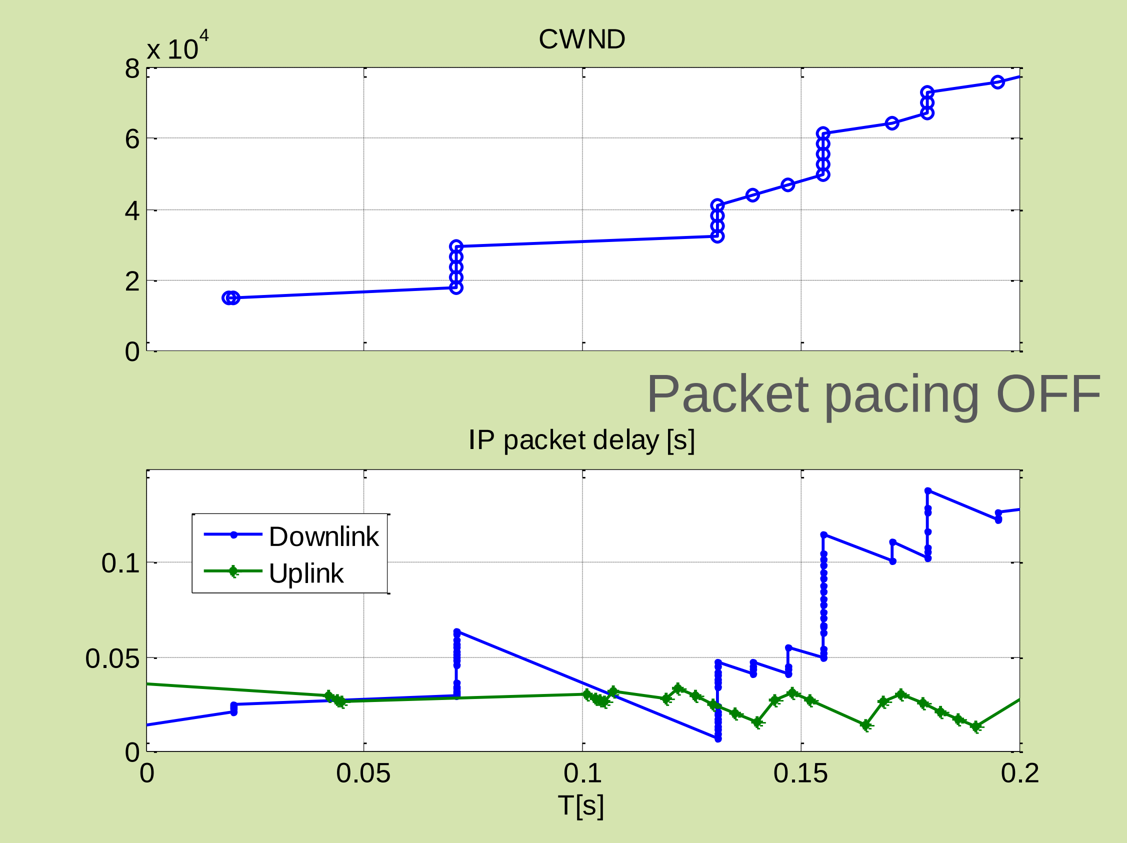
BURSTY TRAFFIC EXAMPLE

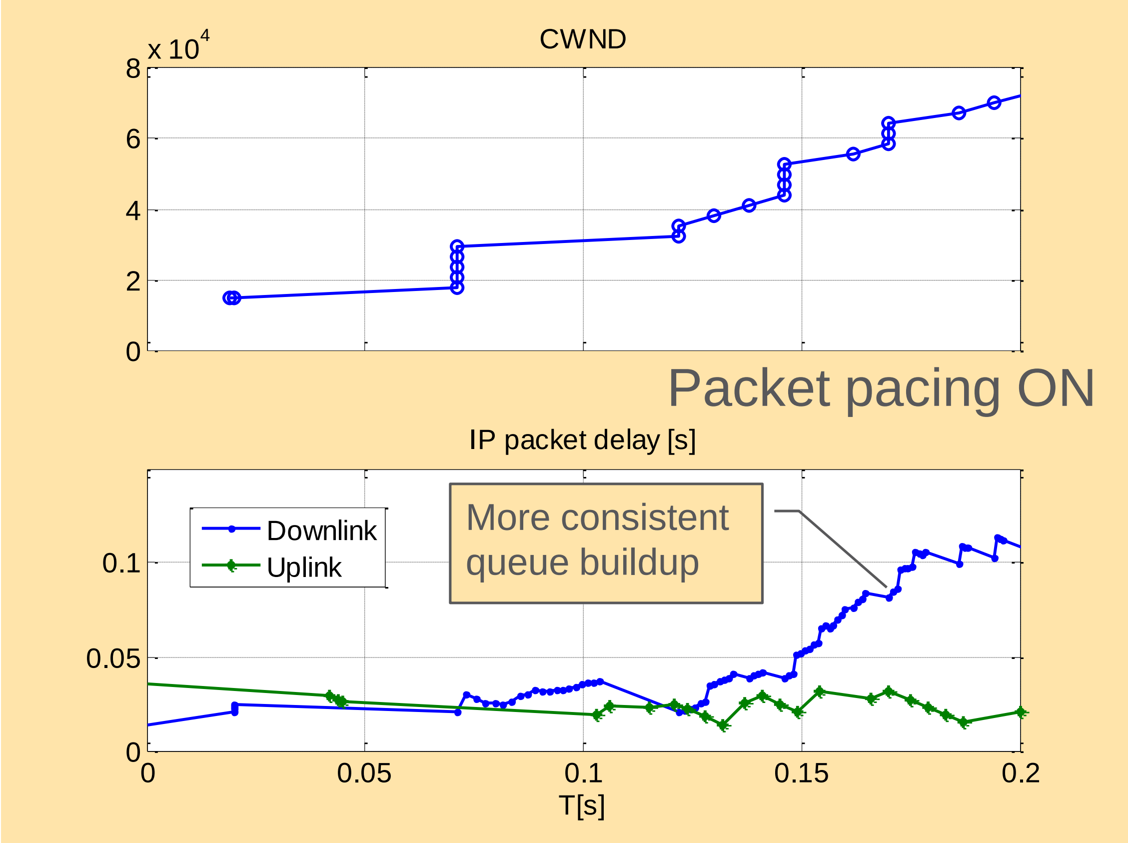
- Video streaming example
- Bursty on/off pattern generates large amounts of immediate data in RLC queue
- Leads to queuing delay spikes when new burst starts → AQM packet discard → Video rate reduction

- Solution : Enable packet pacing



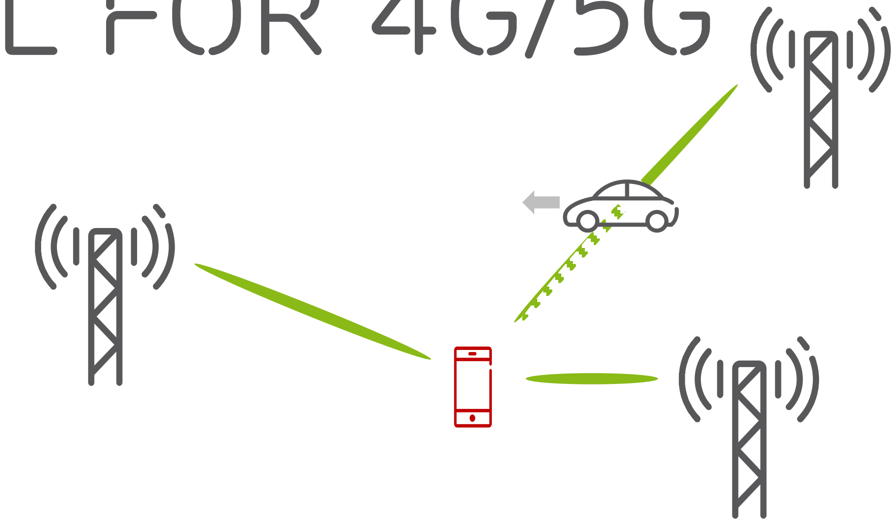
PACKET PACING EXAMPLE



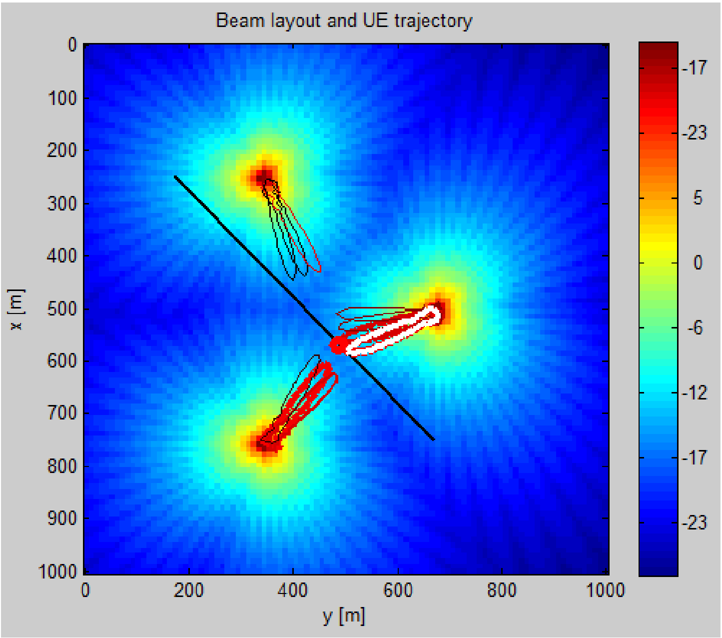


Smaller risk of unnecessary AQM discards or ECN marks with packet pacing

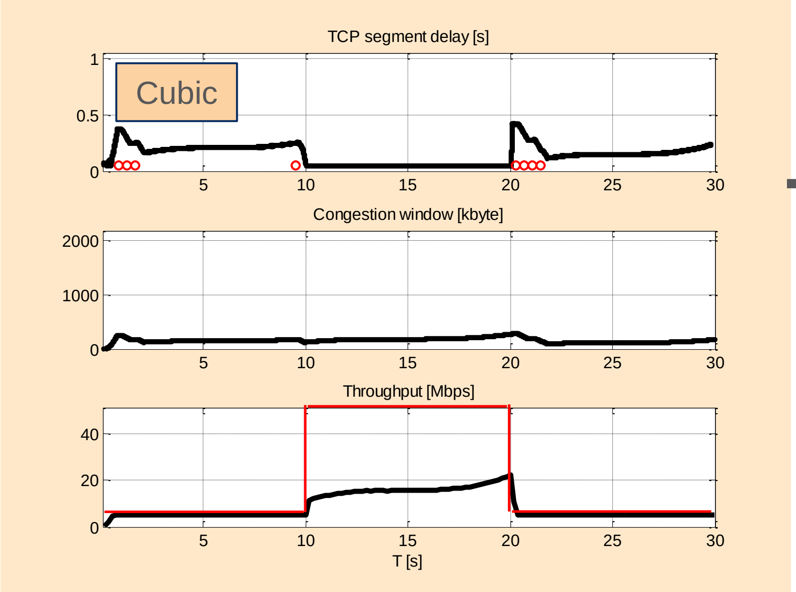
CONGESTION CONTROL FOR 4G/5G

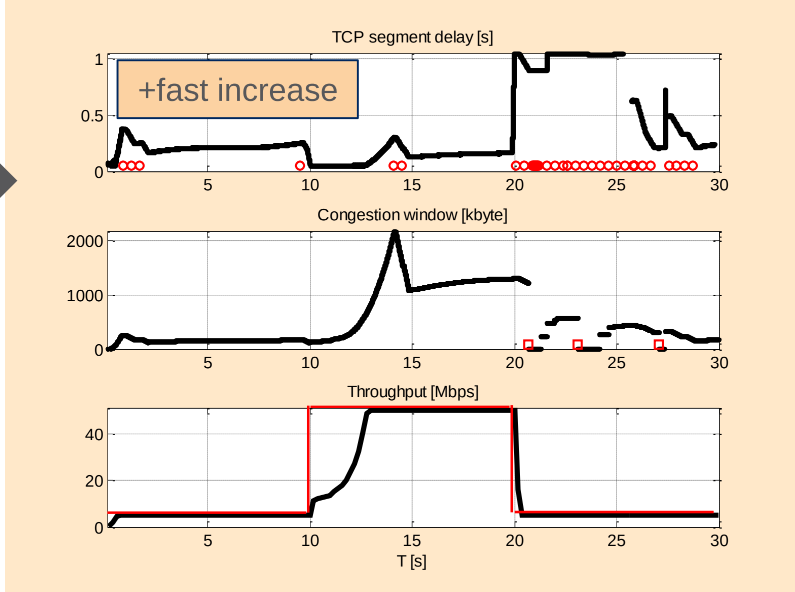


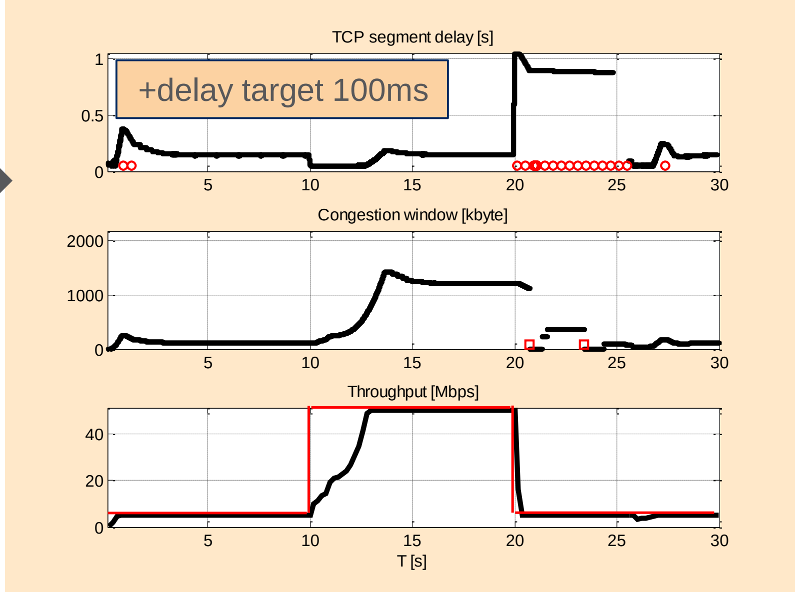
- Throughput variations
  - Larger variations expected
    - Carrier Aggregation
    - Dual Connectivity
    - Multi-beam technology
  - Solutions :
    - Fast increase options
      - SIAD
      - Cubic with fast increase option
    - Other : PCC, Verus ?
- Bufferbloat
  - Expected to be solved over time
    - AQM, ECN, L4S
  - But fallback to a delay/loss based CC good



EXAMPLE : CUBIC MODIFICATION
RTT_{MIN} = 100MS , VARIABLE BW = 5→50→5MBPS



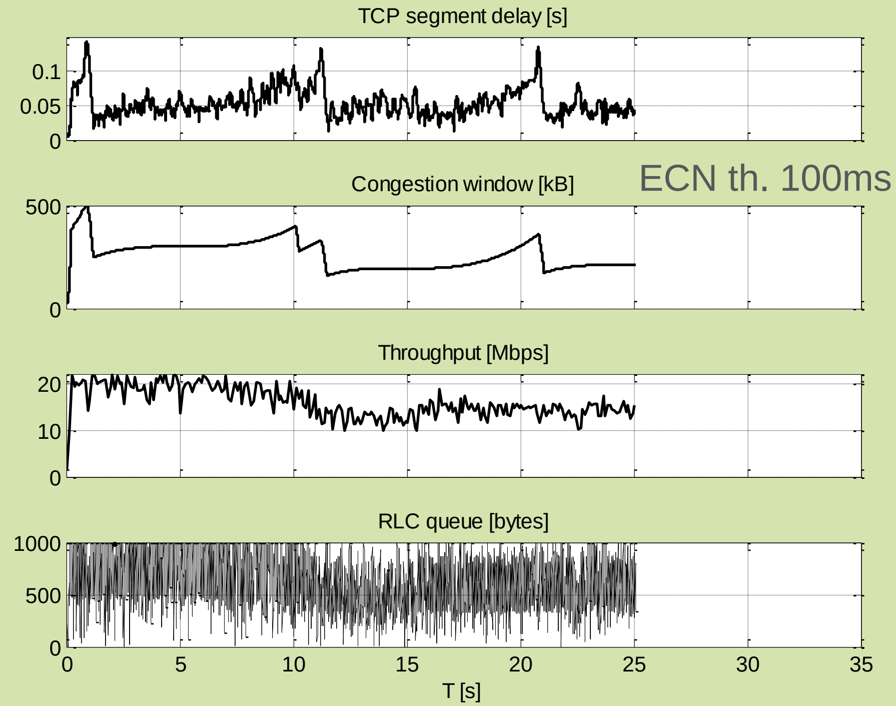


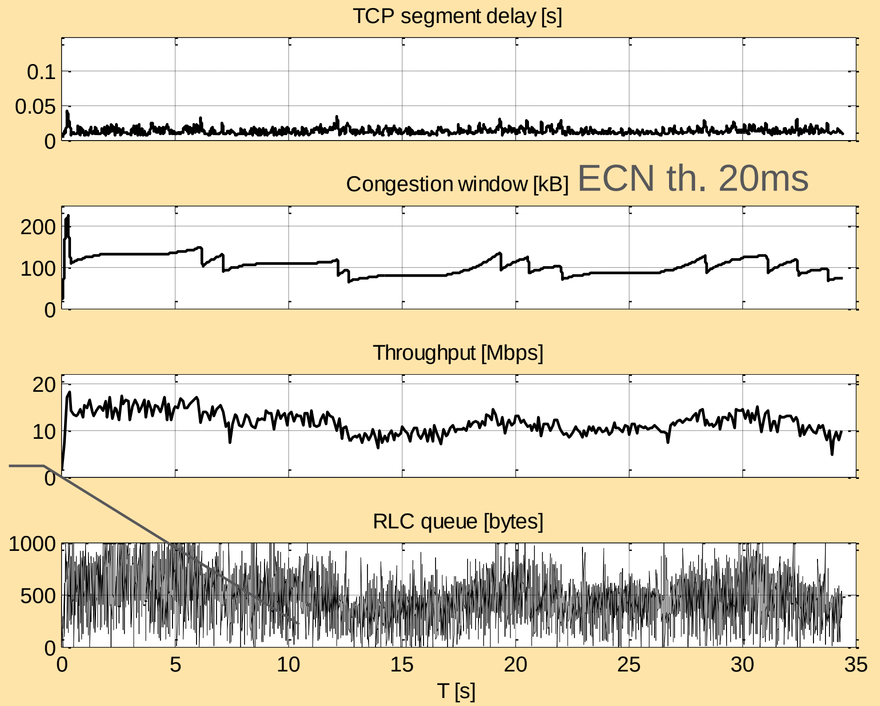


Modified congestion controls can improve performance in typical 4G/5G scenarios

PEAK THROUGHPUT vs LOW DELAY

10MB FILE TRANSFER





A too shallow RLC queue gives degraded resource utilization

A low target queue delay can give poor link utilization

Reason : Too little data in RLC queue

LATENCY IN 5G ?

- Numerology
  - Short subframe duration, 0.25-0.5 ms or less ➡ low latency (together with tighter UE/eNB processing)
    - HARQ RTT reduction from ~8ms to ~1ms possible
  - More robust HARQ
  - Multiple numerologies may be needed
    - Depending on deployment scenario, use case and frequency band
  - Many alternatives
- Option for contention based scheduling in UL

Increased bandwidth

Very high data rates

Increased subcarrier spacing

Phase-noise robustness, reduced CP overhead

Reduced subframe duration

Reduced latency

Questions/comments?

EXTRA SLIDES

MORE ON LATENCY IN LTE

LTE STATES

- Two ECM states
  - ECM-IDLE: No physical resources assigned
  - ECN-CONNECTED: Physical resources assigned
- UE goes into ECM-IDLE if inactive for a longer time
  - (vendor specific, 10s, 60s...)

Physical resource : Radio resource (SRB/DRB) and
Network Resource (S1 bearer/S1 signalling connection)

DRX
DISCONTINUOUS RECEPTION

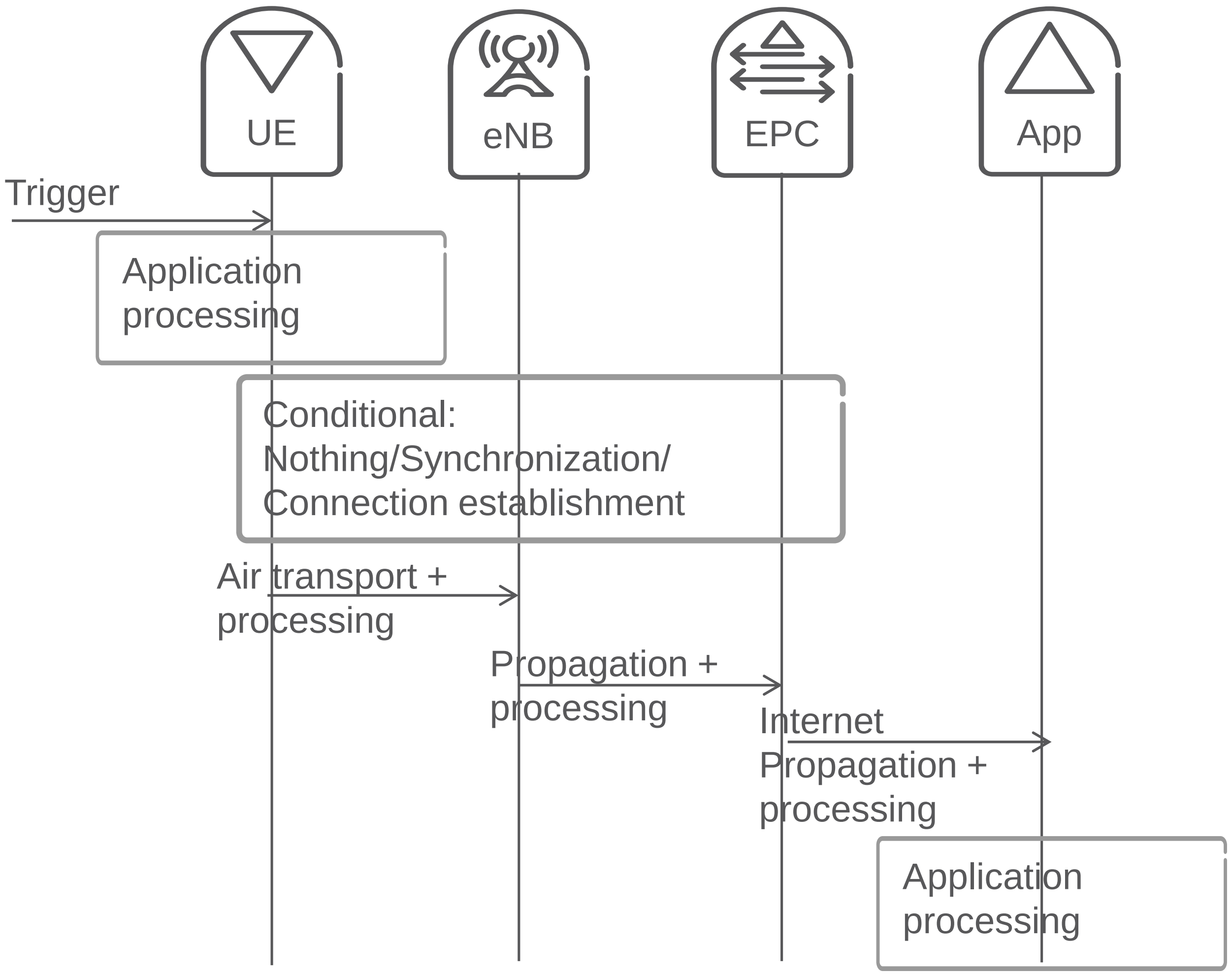
› C-DRX = Connected Mode DRX (ECM-CONNECTED)

› UE radio is turned off if nothing transmitted or received for an inactive timer period (e.g 10ms)
  - Radio turned on immediately if UL data available in UE
› UE wakes up and listens at intervals given by a short DRX timer (e.g 40ms)
› If no data transmitted or received for a given number of short DRX cycles, go into long DRX
  - UE wakes up and listens at intervals given by a long DRX timer (e.g 320ms)

› If UE inactive for a longer time (10s-60s) → go into idle state (ECM-IDLE)
  - UE wakes up and listens for paging at standardized intervals (e.g 1024ms)

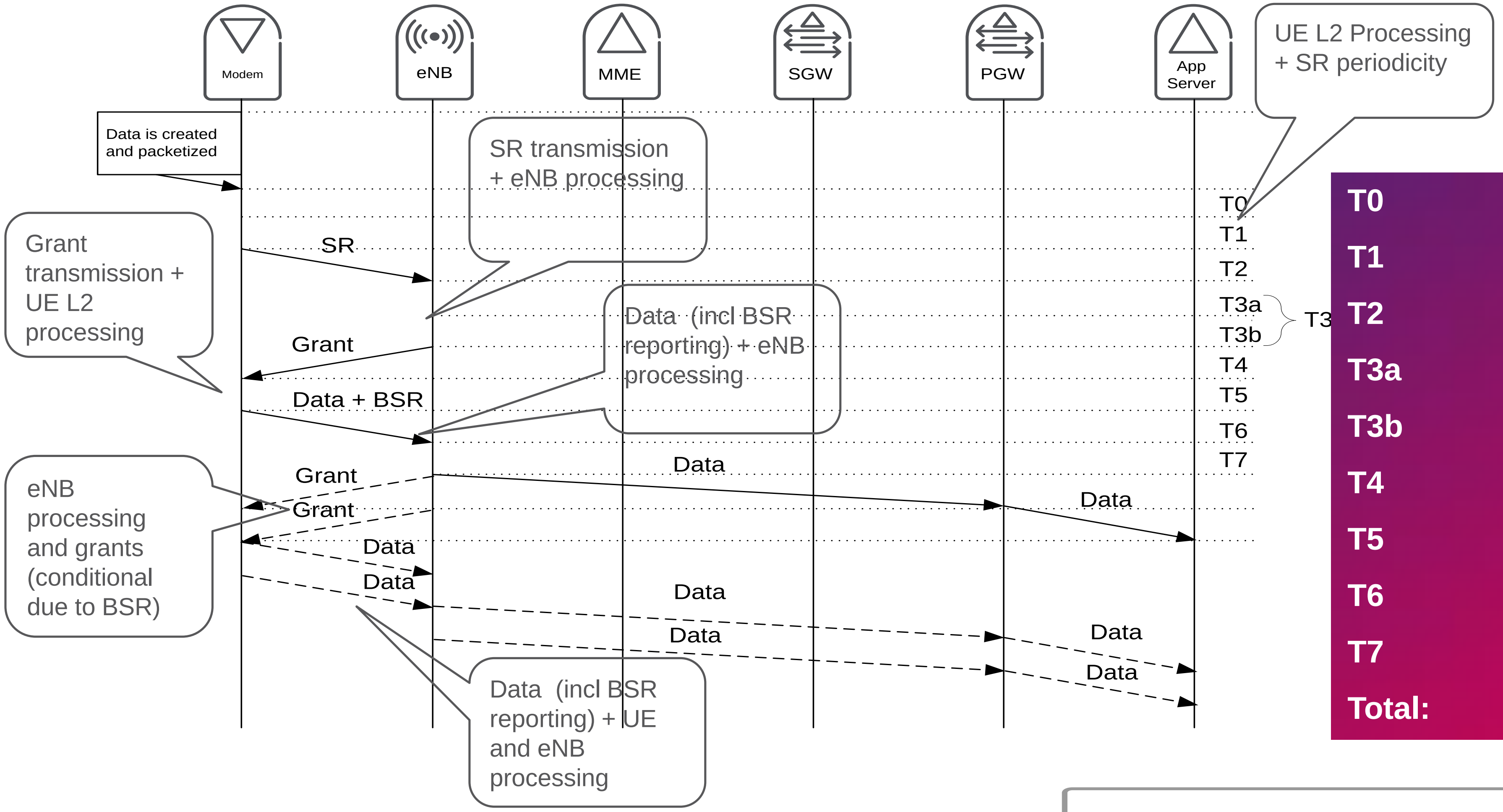
LTE LATENCY BREAKDOWN

- LTE
  - Connection establishment
  - Synchronization
  - **Air transport**
  - **Processing**
  - Paging/C-DRX (DL)
  - Handover/Mobility
- EPC
  - Connection establishment
  - Handover/Mobility
  - Packet processing (very small)
- Transport network
  - Propagation delay
  - Processing
- Application
  - Processing delay
- Internet transport
  - Propagation delay
  - Processing



LTE UL AIR INTERFACE LATENCIES

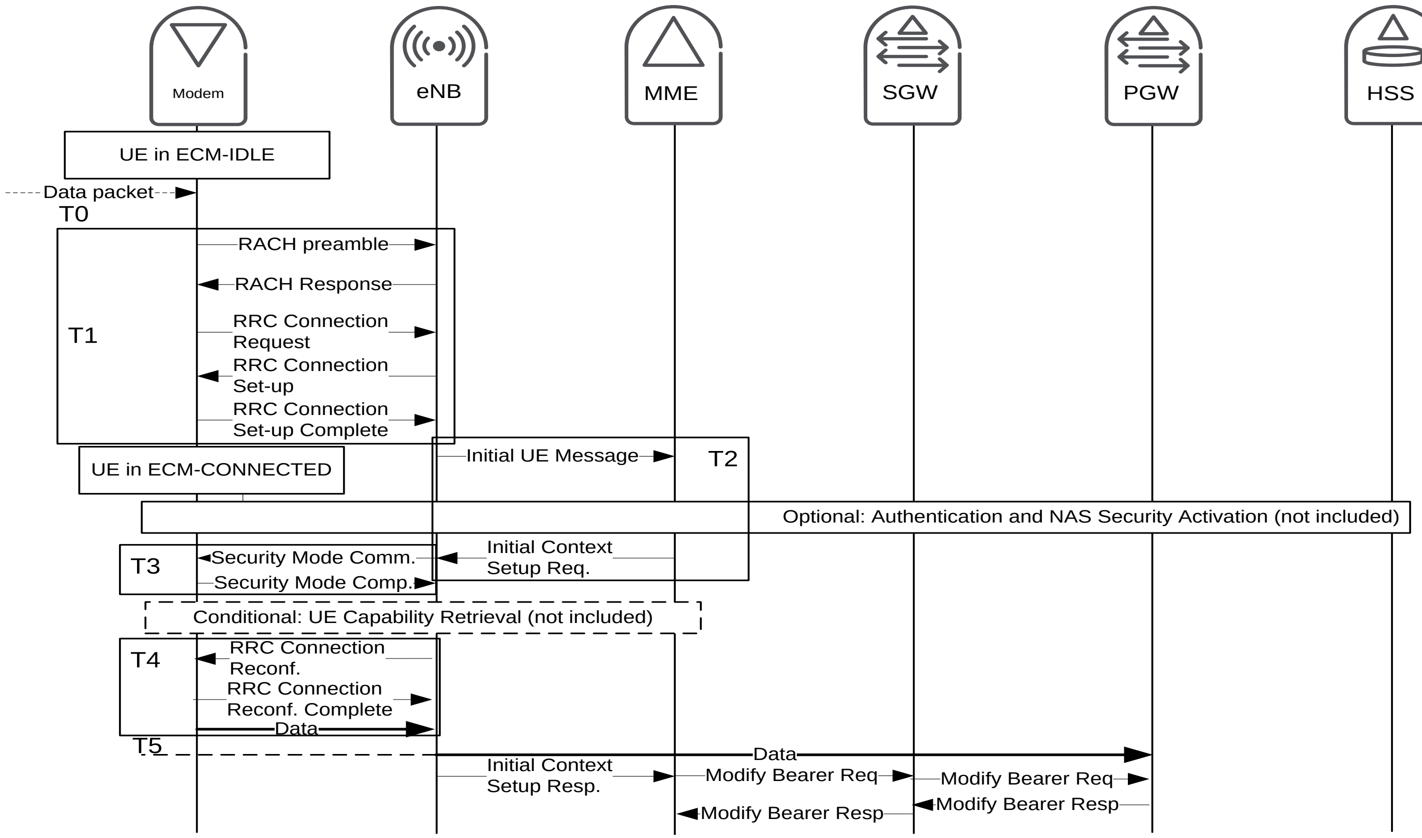
EXAMPLE 1



T0	
T1	**0.5-5 ms**
T2	**1 ms**
T3a	**2 ms**
T3b	**0 ms**
T4	**1 ms**
T5	**3 ms**
T6	**1 ms**
T7	**2 ms**
Total:	**10.5-15 ms**

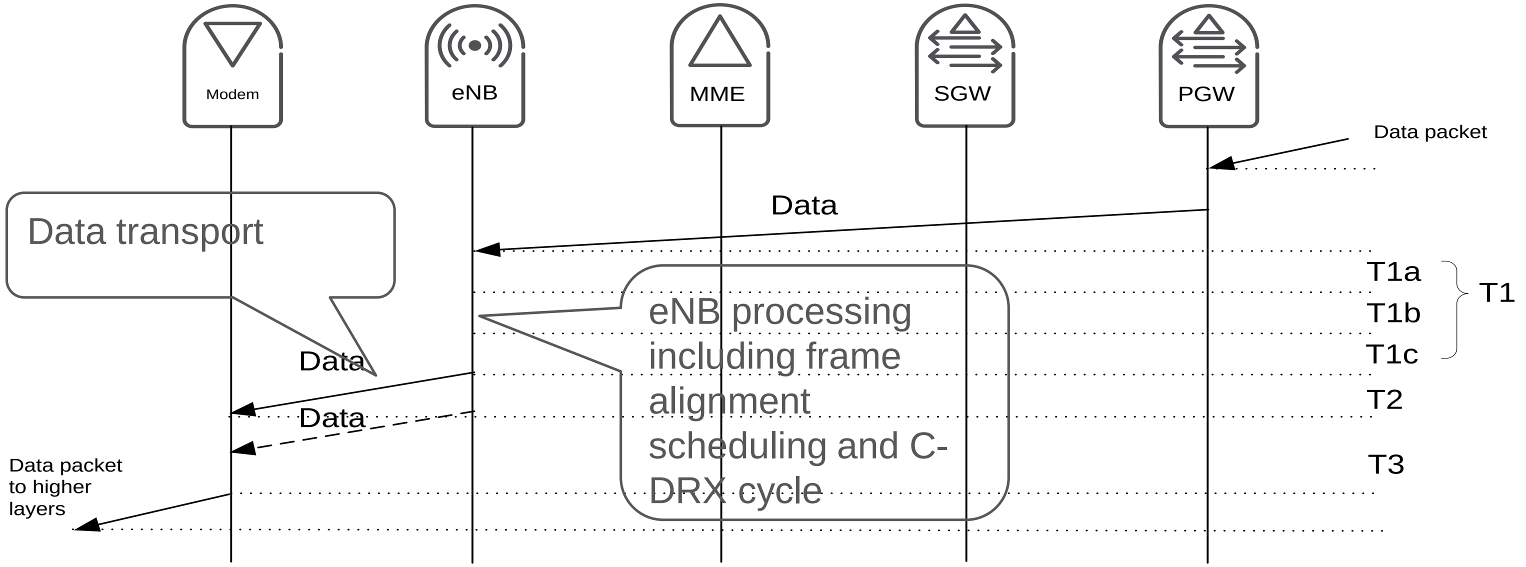
From ECM-CONNECTED

LTE UL AIR INTERFACE LATENCIES
EXAMPLE 2



From ECM-IDLE: 130 ms – Don't mix states in testing

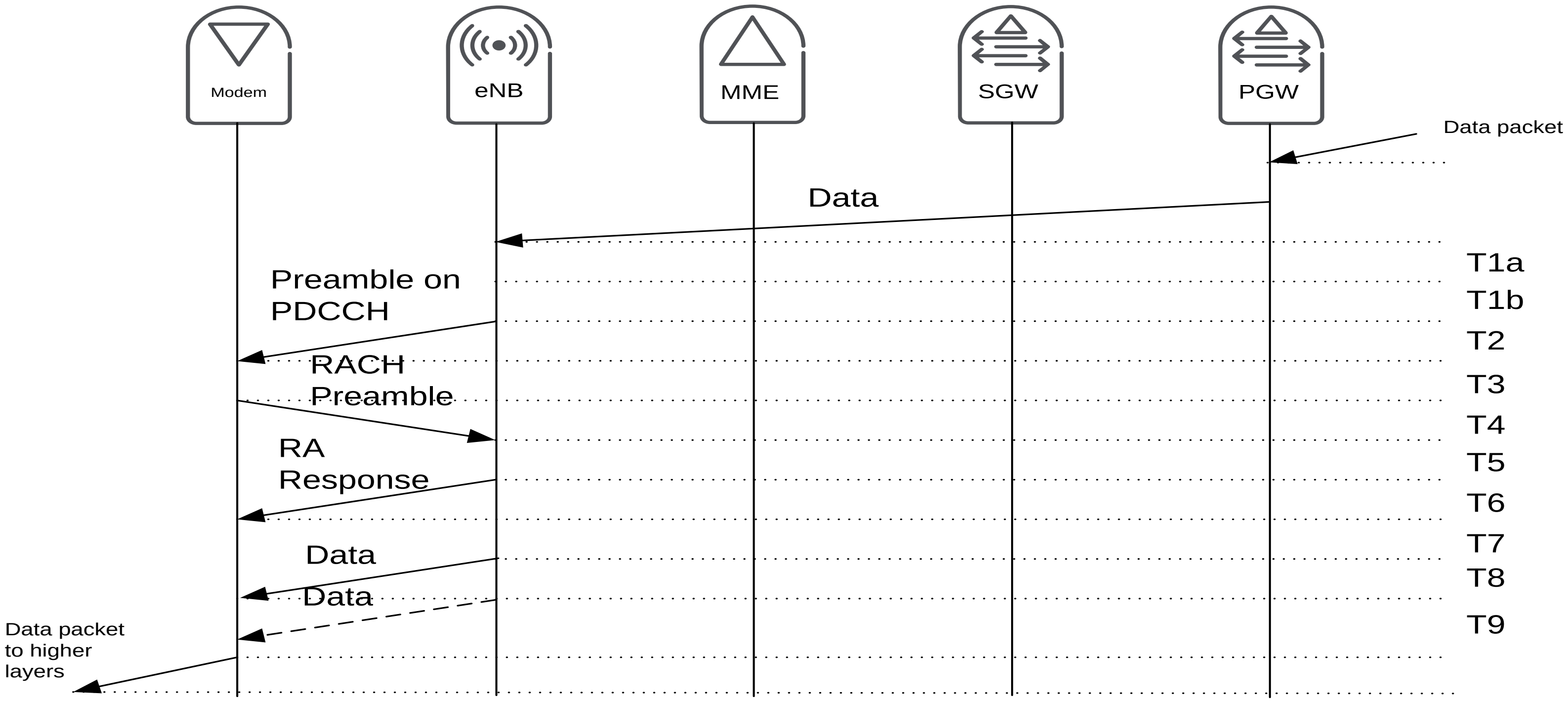
LTE DL AIR INTERFACE LATENCIES
EXAMPLE 1



T1a	2 ms
T1b	0 ms
T1c	0.5 ms
T2	1 ms
T3	
Total:	3.5 ms

From ECM-CONNECTED

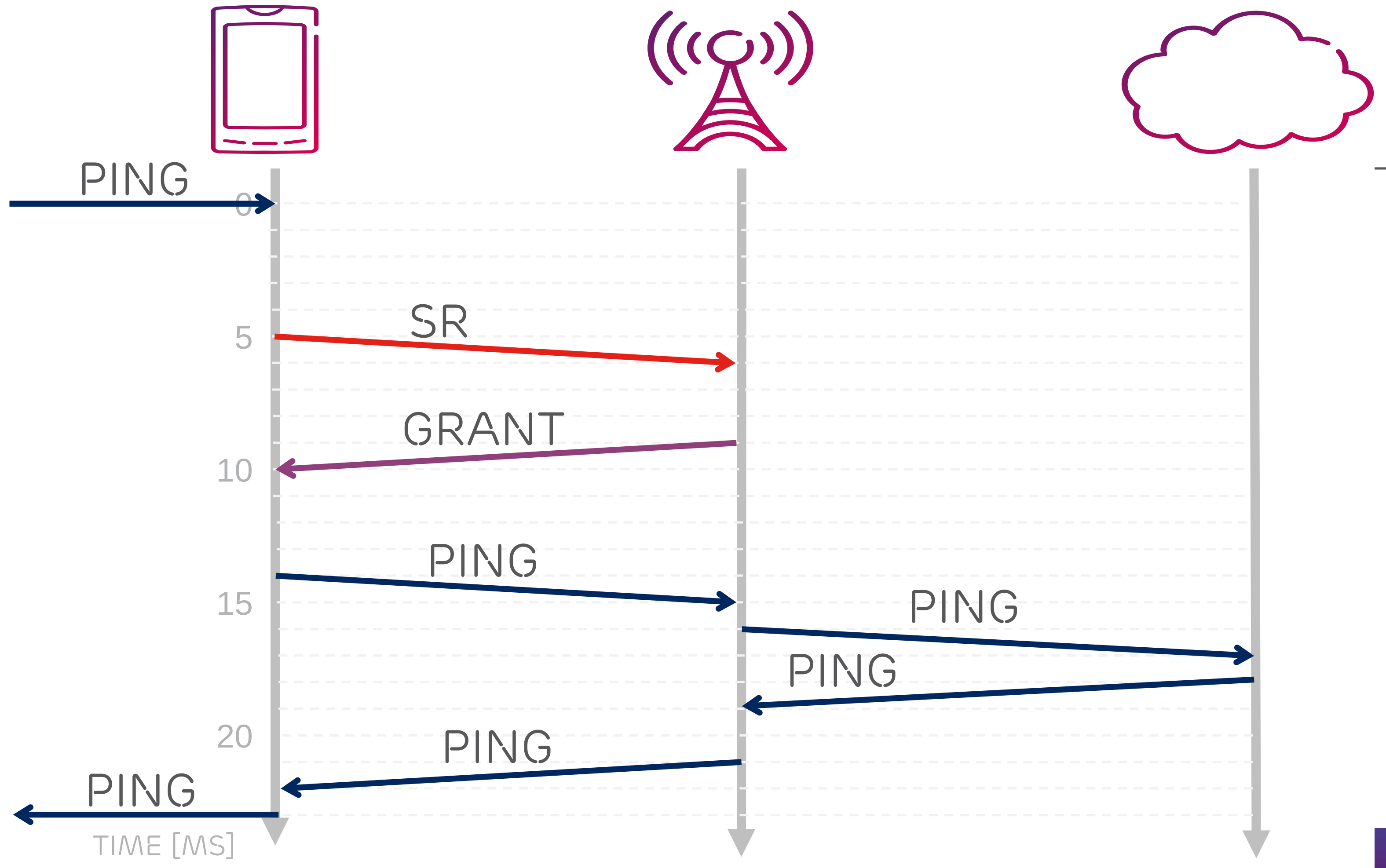
LTE DL AIR INTERFACE LATENCIES
EXAMPLE 2



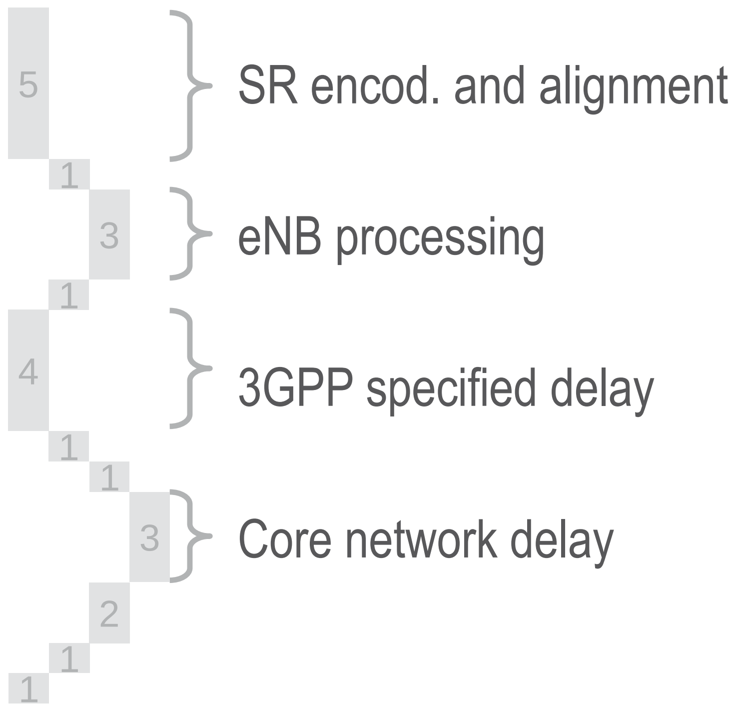
From ECM-CONNECTED but out of synch: 23 ms – Don’t mix states in testing

PRE-SCHEDULING

PRE-SCHEDULING OFF



DELAY BREAKDOWN

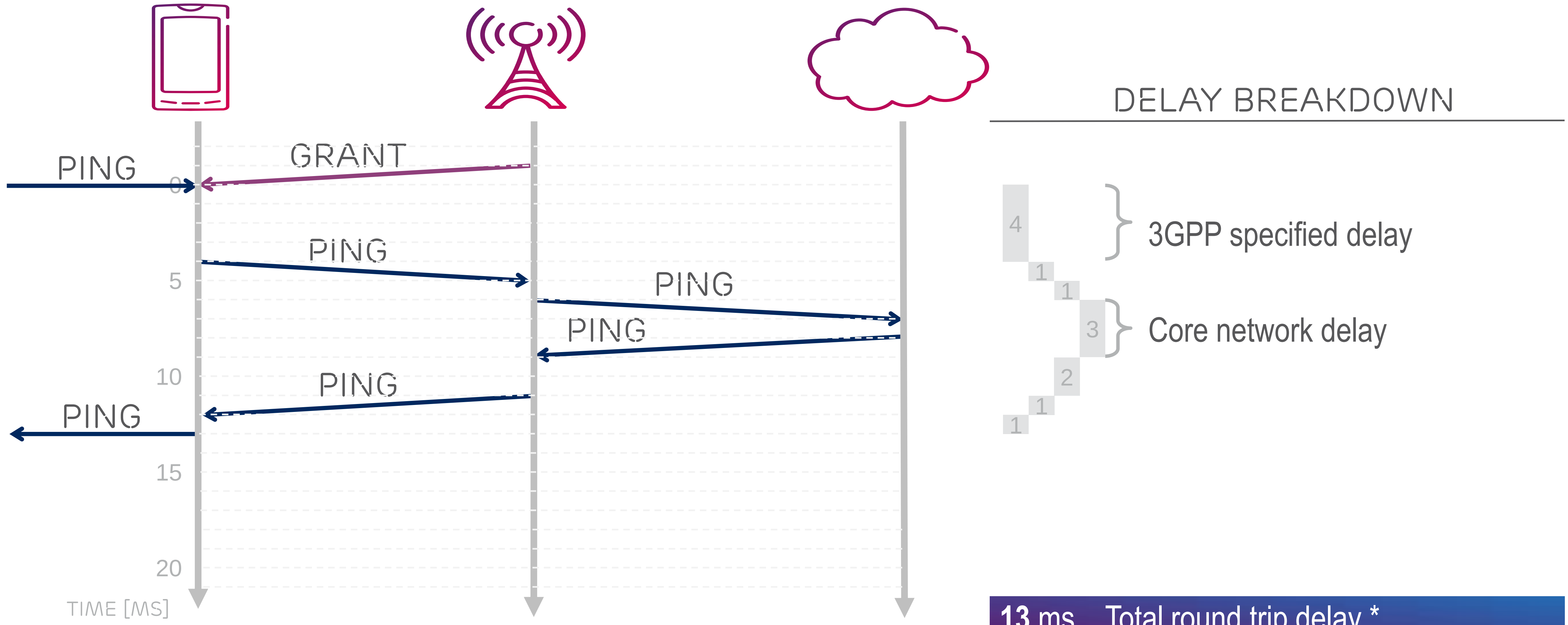


23 ms Total round trip delay *

*Note: Numbers are example only

PRE-SCHEDULING

PRE-SCHEDULING ON

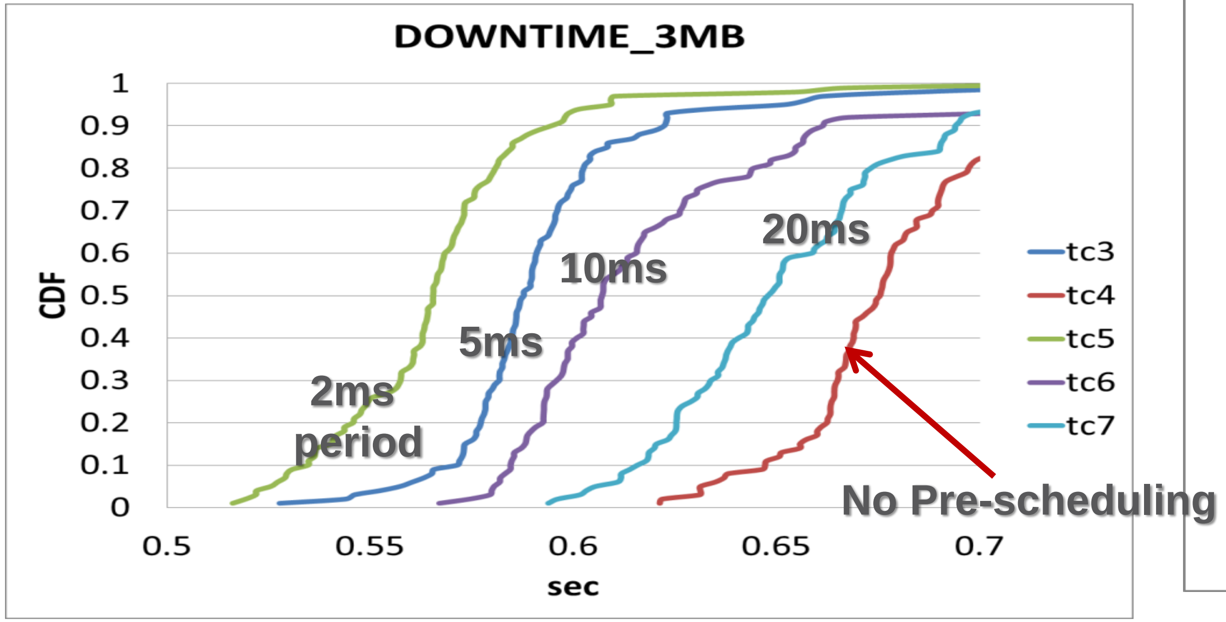


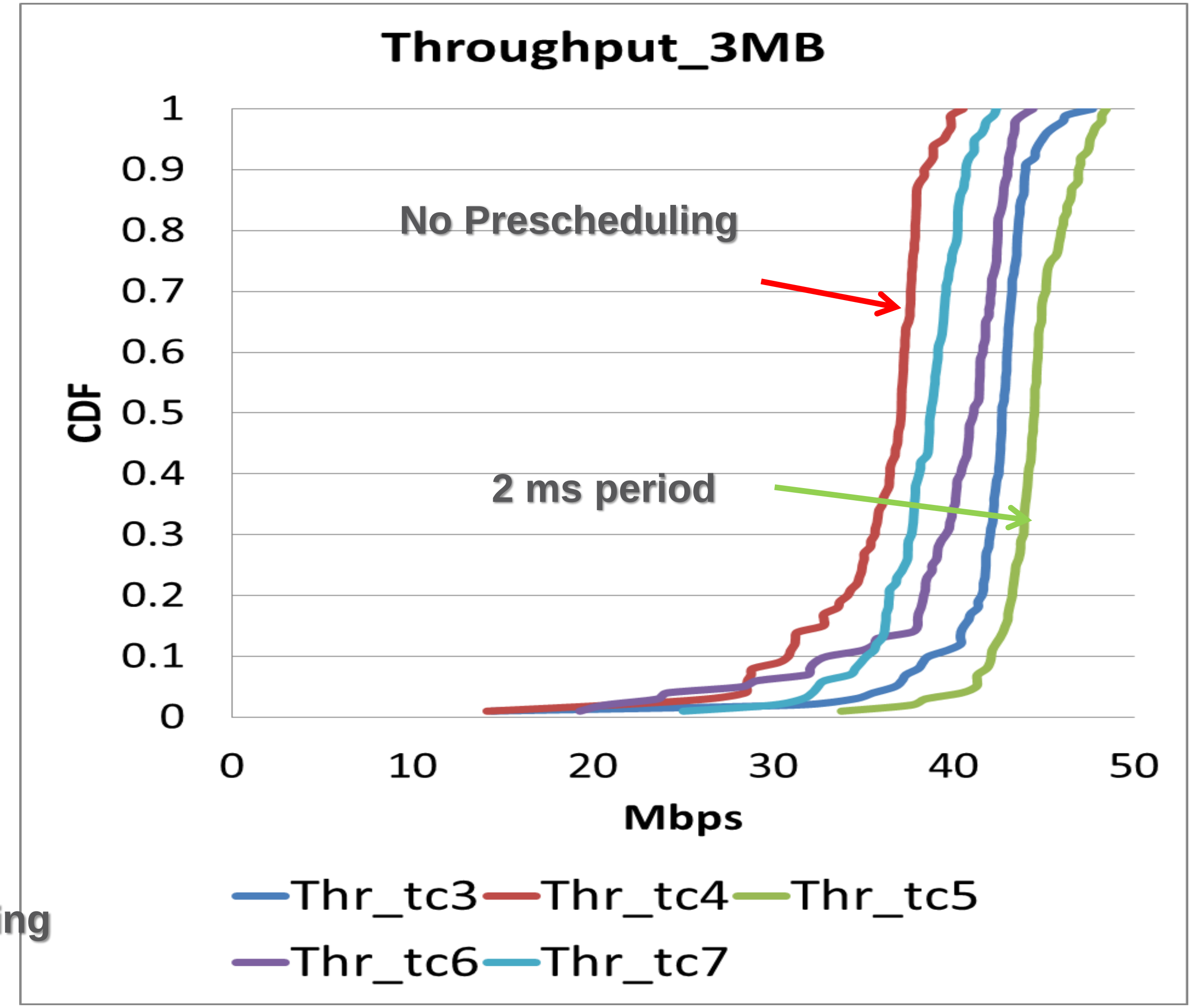
13 ms Total round trip delay *

*Note: Numbers are example only

PRE-SCHEDULING
SHORT FILE DOWNLOAD

- The gain of the prescheduling on short file transfers is clear and directly proportional to the period of the prescheduling.
- The delta between best and worst case scenario gains is around 100 ms
- Cost : More interference and resource usage





GLOSSARY

- EPS : Evolved Packet System
- EPC : Evolved Packet Core
- EMM : EPS Mobility Management
- ESM : EPS Session Management
- ECM : EPC Connection Management
- SRB : Serving Radio Bearer
- DRB : Data Radio Bearer
- DRX : Discontinuous Reception
- UE : User Equipment ~ Terminal

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