DRX Measurements

PRESENTER: 郭瑋喆

2023.04.17

DRX
(Discontinuous Reception)

DRX (Discontinuous Reception)

- User Equipment (UE) has to keep listening to network

➢ But being “ON” all the time would drain the battery

=> Periodic repetition of "sleep mode and wake up mode"

- Trade-off between power saving and latency

- C-DRX (Connected Mode DRX) is DRX under RRC connected mode

LTE DRX

- UE wakes up periodically

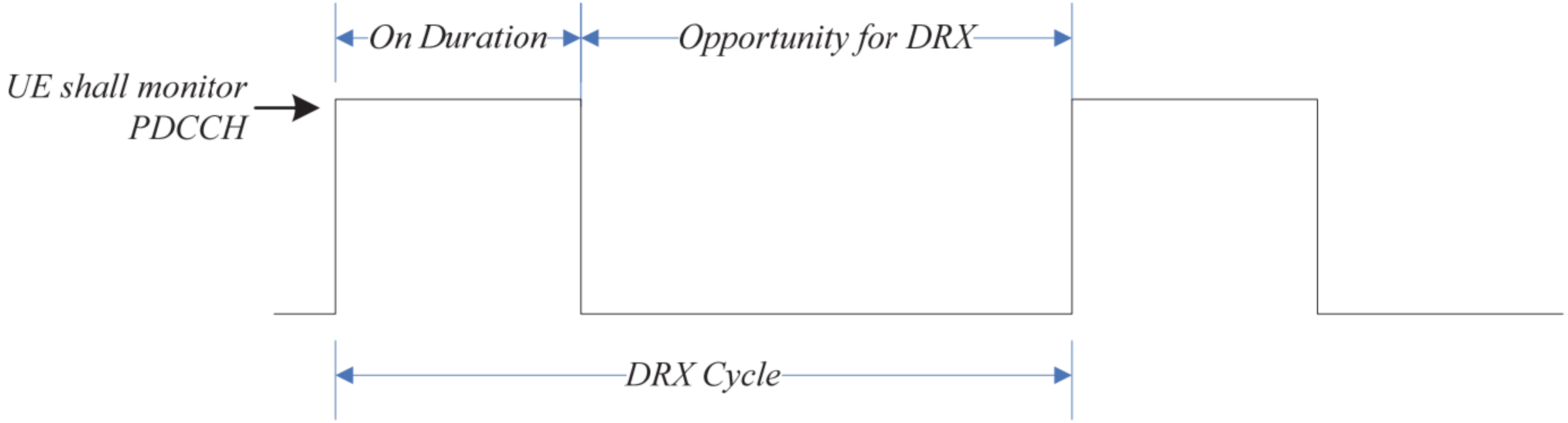
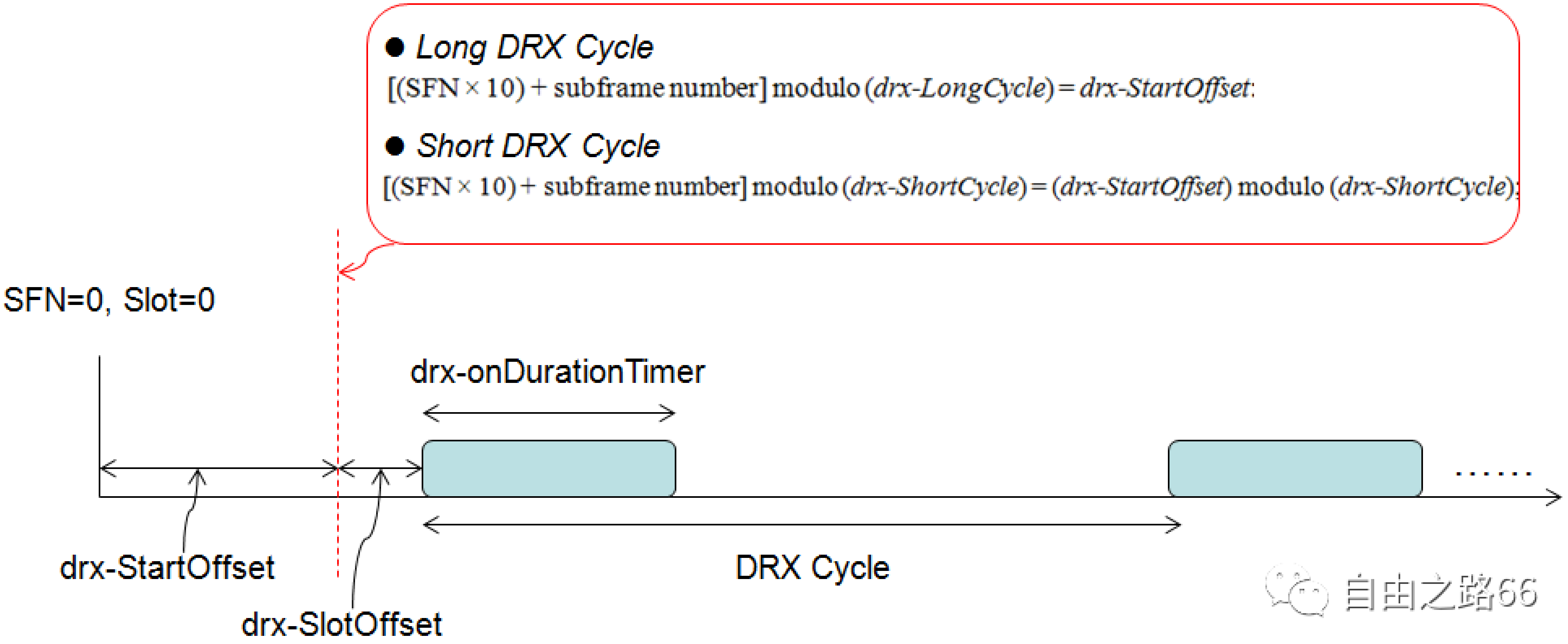


Figure 3.1-1: DRX Cycle

Reference: 3GPP TS 36.321

NR DRX



- *Long DRX Cycle*

[(SFN × 10) + subframe number] modulo (*drx-LongCycle*) = *drx-StartOffset*;

- *Short DRX Cycle*

[(SFN × 10) + subframe number] modulo (*drx-ShortCycle*) = (*drx-StartOffset*) modulo (*drx-ShortCycle*);

Reference: https://blog.csdn.net/kakamilan/article/details/105925178

DRX Parameters

LTE (3GPP TS 36.321)	NR5G (3GPP TS 138.321)
• DRX Inactivity Timer	• drx-InactivityTimer
• DRX Retransmission Timer	• drx-RetransmissionTimerDL/UL
• DRX Short Cycle Timer	• drx-ShortCycle (optional)
	• drx-ShortCycleTimer (optional)
• HARQ RTT Timer	• drx-HARQ-RTT-TimerDL/UL
• On Duration Timer	• drx-onDurationTimer
• RA-RNTI	• drx-SlotOffset
	• drx-LongCycleStartOffset

DRX Parameters

Parameters are configured by RRC.

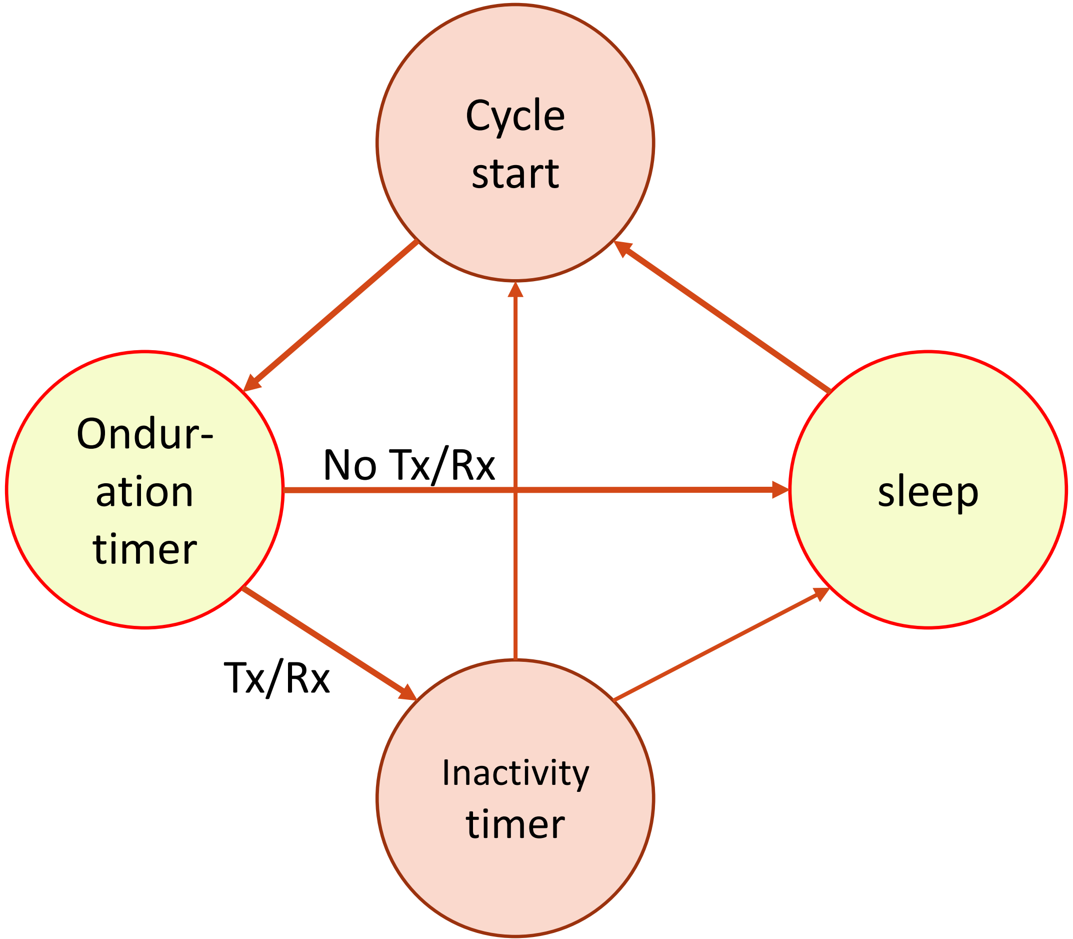
- *DRX-onDurationTimer:* How long to keep listening in a cycle
- *DRX-SlotOffset*: Time to wake up UE
- *DRX-InactivityTimer:* How long to keep listening after receiving
- *shortDRX-Cycle:* Cycle length (ms) of short DRX
- *DRX-ShortCycleTimer:* When to switch from short cycle to long cycle after a period without receiving

Long/Short DRX cycle

- UE would switch between short / long DRX cycle (if short cycle configured)

	Short DRX cycle (optional)	**Long DRX cycle**
cycle period	short	multiple of the shortDRX-Cycle value
power saving	less	more
delay	lower	higher

Signaling Sequences



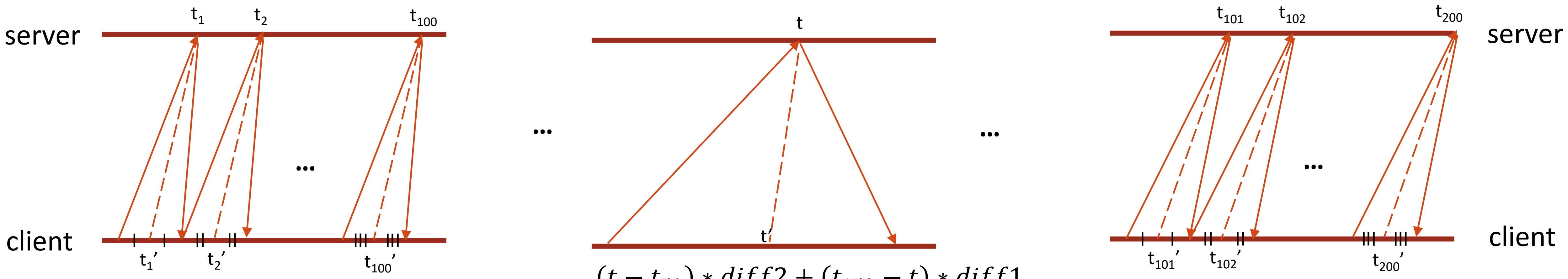
Time Synchronization

Time Synchronization

- Timestamps recorded by different traces are not synchronized
- There are 3~4 distinct clocks in this experiment:
  - Server (PC)
  - Client (Cellphone)
  - 4G/5G chipset (sync with base stations)
- Time Synchronization between devices is necessary for analysis
- But cross-device time synchronization is non-trivial in practice

Current Method: Server & Client

- Assumption: Clocks' speed is stable => clock misalignment is a linear function
- Send 100 bi-directional packets between server & client through intranet[1]
  - Do this before and after the experiment then calculate the average clock misalignment
  - Perform linear interpolation on each packet TX/RX timestamps



$$diff1 = avg(\Delta t_1, \dots, \Delta t_{100})$$

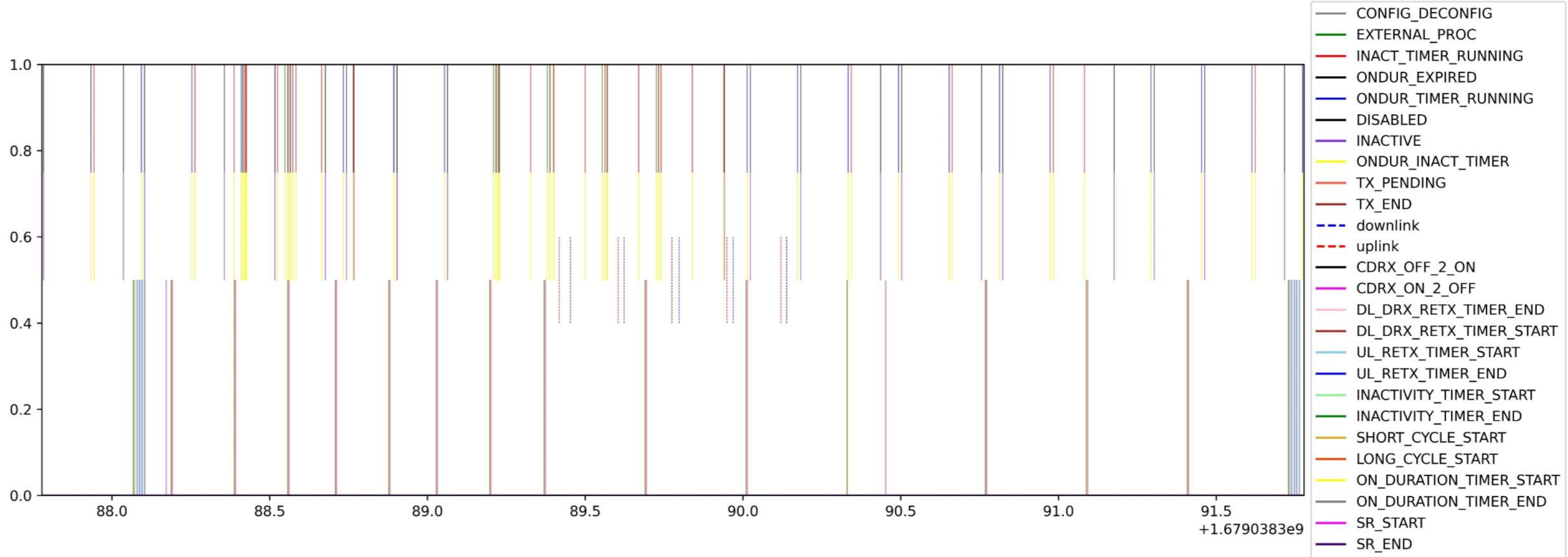
$$t' = t + \frac{(t - t_{50}) * diff2 + (t_{150} - t) * diff1}{t_{150} - t_{50}}$$

$$diff2 = avg(\Delta t_{101}, \dots, \Delta t_{200})$$

[1] RTT under this scenario is smaller than 3 ms; assume that DL and UL traffics have the same latency.

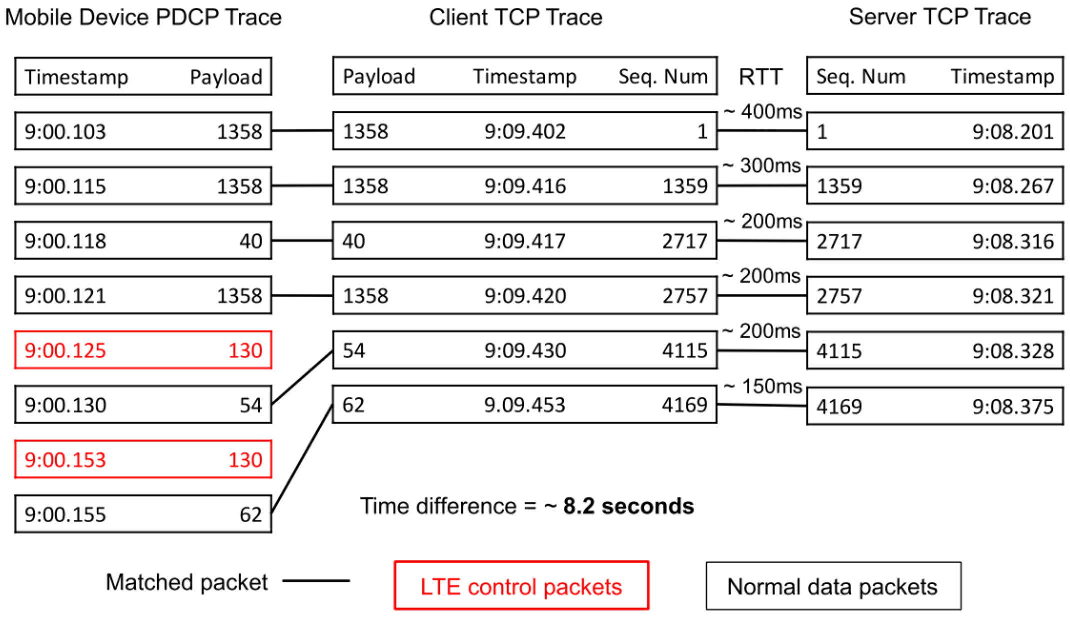
Current Method: Cellphone & Chipset

- There is also clock difference between cellphone (timestamp recorded at application layer) and the 4G/5G chipset (synchronizing with base stations)
- Looking for more information to resolve this problem currently



Other Possible Method

From *"A First Look at Disconnection-Centric TCP Performance on High-Speed Railways*[1]*"*:



Mobile Device PDCP Trace

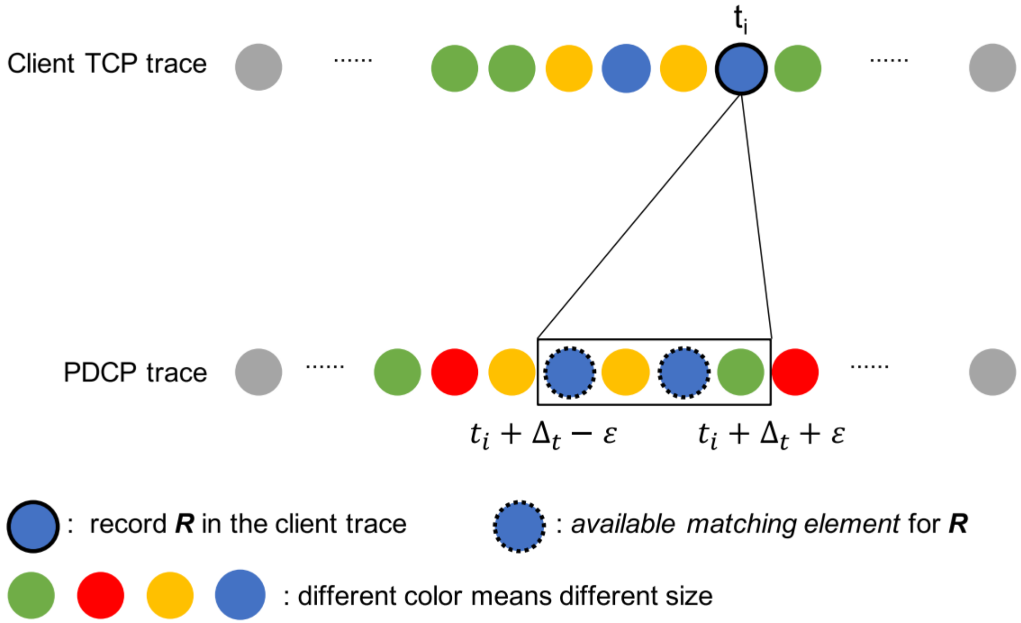
Timestamp	Payload
9:00.103	1358
9:00.115	1358
9:00.118	40
9:00.121	1358
9:00.125	130
9:00.130	54
9:00.153	130
9:00.155	62

Client TCP Trace / Server TCP Trace

Payload	Timestamp	Seq. Num	RTT	Seq. Num	Timestamp
1358	9:09.402	1	~ 400ms	1	9:08.201
1358	9:09.416	1359	~ 300ms	1359	9:08.267
40	9:09.417	2717	~ 200ms	2717	9:08.316
1358	9:09.420	2757	~ 200ms	2757	9:08.321
54	9:09.430	4115	~ 200ms	4115	9:08.328
62	9.09.453	4169	~ 150ms	4169	9:08.375

Time difference = ~ **8.2 seconds**

Fig. 10. Example of end-to-end alignment.



t$_i$
Client TCP trace
......
PDCP trace
$t_i + \Delta_t - \varepsilon$
$t_i + \Delta_t + \varepsilon$
: record ***R*** in the client trace
: *available matching element* for ***R***
: different color means different size

Fig. 11. TCP and PDCP trace alignment.

[1] Chenren Xu et al., "A First Look at Disconnection-Centric TCP Performance on High-Speed Railways", IEEE Journal on Selected Areas in Communications , 2020

DRX Related Logs from QXDM

QXDM

- QXDM is a suite of the diagnostic tools set for DMSS, UE and AMSS. QXDM Pro was developed to provide a rapid prototyping platform for new diagnostic clients and diagnostic protocol packets

QXDM vs. MobileInsight

- In “*MobileInsight: Extracting and Analyzing Cellular Network Information on Smartphones* [2],” it is said that:
  - Debugging tools, such as QXDM [2], XCAL [3], MTK Catcher [4], xgoldmon [23], can collect cellular network messages and offer fine-grained information. However, they all work with PCs, and do not offer in-device collection or protocol analytics.
  - MobileInsight has access to the same cellular information as those tools.

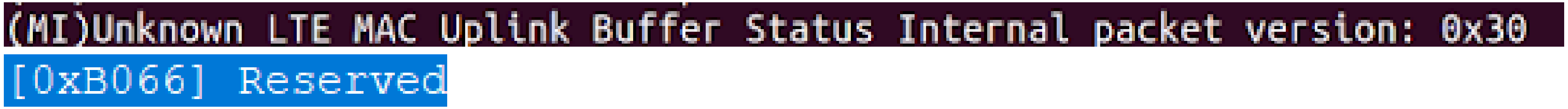
=> It seems that they collect data from the same resource, but MobileInsight provides a more convenient way

[2] Yuanjie Li et al., “Mobileinsight: extracting and analyzing cellular network information on smartphones,” MobiCom '16

QXDM vs. MobileInsight

- As my current understanding, packages not catchable or not resolvable in MobileInsight may be caused by two reasons:

1. The message is marked to be “reserved” in QXDM
   e.g. [0xB066] LTE MAC UL Buffer Status Internal

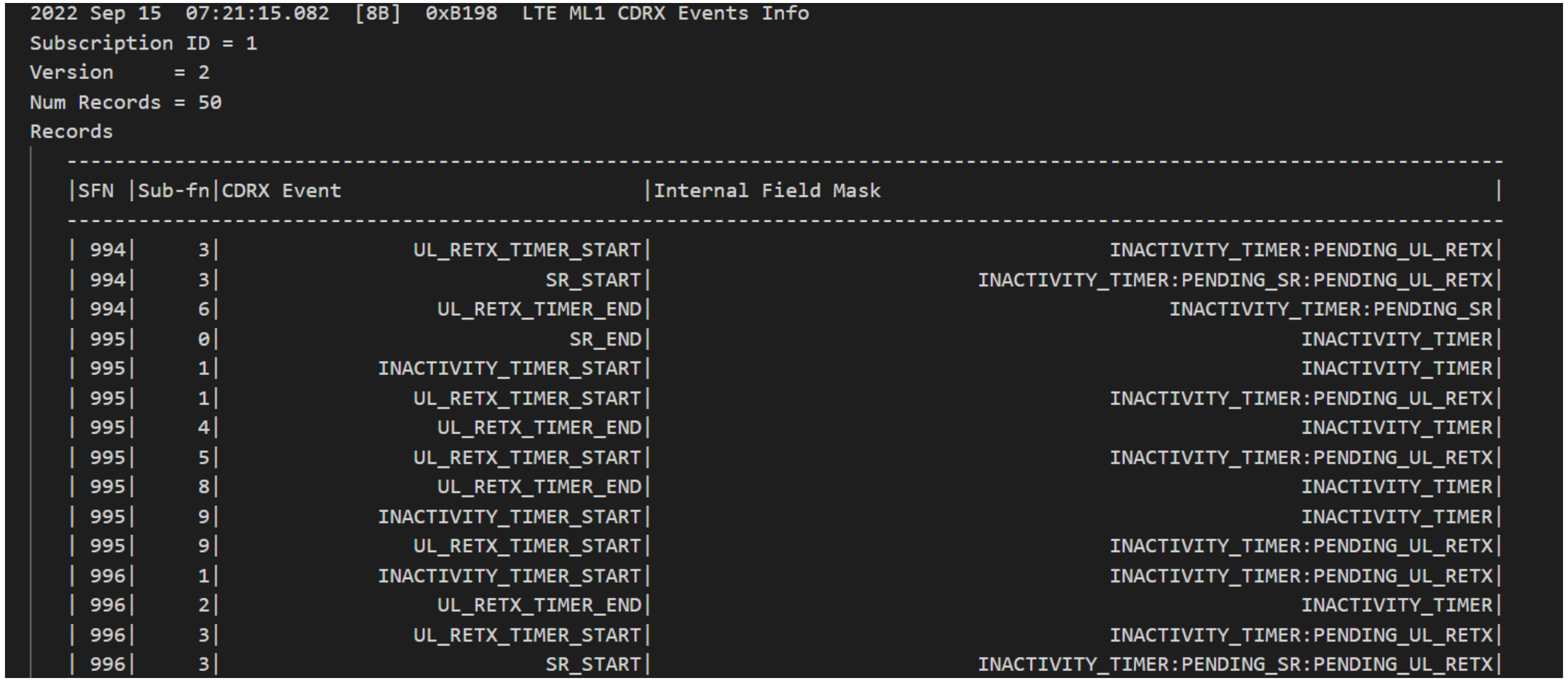


```
(MI)Unknown LTE MAC Uplink Buffer Status Internal packet version: 0x30
[0xB066] Reserved
```

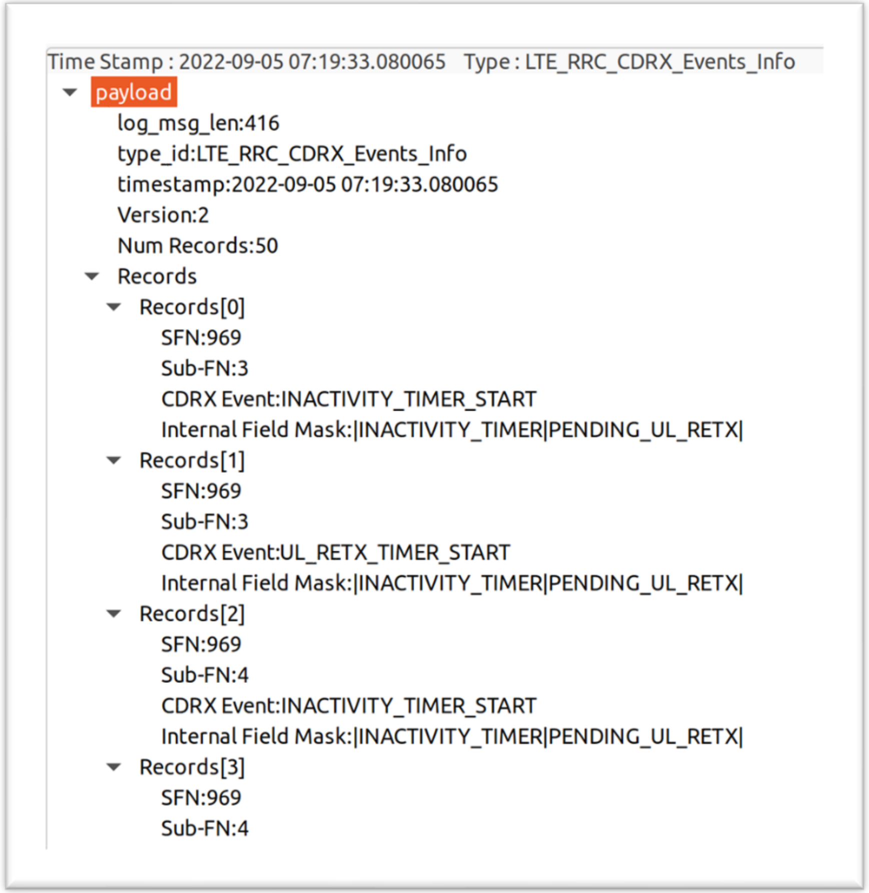
2. The message has not yet been supported by MobileInsight
   e.g. [0xB890] NR5G MAC CDRX Events Info

Same Package in QXDM and MI

- Take “LTE ML1 CDRX Events Info” in QXDM, and “LTE_RRC_CDRX_Events_Info” in MobileInsight for instance. They seem to be the same.



```
2022 Sep 15  07:21:15.082  [8B]  0xB198  LTE ML1 CDRX Events Info
Subscription ID = 1
Version      = 2
Num Records = 50
Records
   ------------------------------------------------------------------------------------------------------------------------
   |SFN |Sub-fn|CDRX Event                         |Internal Field Mask                                                   |
   ------------------------------------------------------------------------------------------------------------------------
   | 994|     3|                UL_RETX_TIMER_START|                                      INACTIVITY_TIMER:PENDING_UL_RETX|
   | 994|     3|                           SR_START|                           INACTIVITY_TIMER:PENDING_SR:PENDING_UL_RETX|
   | 994|     6|                  UL_RETX_TIMER_END|                                           INACTIVITY_TIMER:PENDING_SR|
   | 995|     0|                             SR_END|                                                      INACTIVITY_TIMER|
   | 995|     1|             INACTIVITY_TIMER_START|                                                      INACTIVITY_TIMER|
   | 995|     1|                UL_RETX_TIMER_START|                                      INACTIVITY_TIMER:PENDING_UL_RETX|
   | 995|     4|                  UL_RETX_TIMER_END|                                                      INACTIVITY_TIMER|
   | 995|     5|                UL_RETX_TIMER_START|                                      INACTIVITY_TIMER:PENDING_UL_RETX|
   | 995|     8|                  UL_RETX_TIMER_END|                                                      INACTIVITY_TIMER|
   | 995|     9|             INACTIVITY_TIMER_START|                                                      INACTIVITY_TIMER|
   | 995|     9|                UL_RETX_TIMER_START|                                      INACTIVITY_TIMER:PENDING_UL_RETX|
   | 996|     1|             INACTIVITY_TIMER_START|                                      INACTIVITY_TIMER:PENDING_UL_RETX|
   | 996|     2|                  UL_RETX_TIMER_END|                                                      INACTIVITY_TIMER|
   | 996|     3|                UL_RETX_TIMER_START|                                      INACTIVITY_TIMER:PENDING_UL_RETX|
   | 996|     3|                           SR_START|                           INACTIVITY_TIMER:PENDING_SR:PENDING_UL_RETX|
```



```
Time Stamp : 2022-09-05 07:19:33.080065   Type : LTE_RRC_CDRX_Events_Info
▾ payload
    log_msg_len:416
    type_id:LTE_RRC_CDRX_Events_Info
    timestamp:2022-09-05 07:19:33.080065
    Version:2
    Num Records:50
  ▾ Records
    ▾ Records[0]
        SFN:969
        Sub-FN:3
        CDRX Event:INACTIVITY_TIMER_START
        Internal Field Mask:|INACTIVITY_TIMER|PENDING_UL_RETX|
    ▾ Records[1]
        SFN:969
        Sub-FN:3
        CDRX Event:UL_RETX_TIMER_START
        Internal Field Mask:|INACTIVITY_TIMER|PENDING_UL_RETX|
    ▾ Records[2]
        SFN:969
        Sub-FN:4
        CDRX Event:INACTIVITY_TIMER_START
        Internal Field Mask:|INACTIVITY_TIMER|PENDING_UL_RETX|
    ▾ Records[3]
        SFN:969
        Sub-FN:4
```

DRX Related Logs

There are DRX info logs can be collected by QXDM:

- [0xB198] LTE ML1 CDRX Events Info
- [0xB890] NR5G MAC CDRX Events Info (with configuration information)

There are also some related logs:

- [0xB165] LTE Grant Manager Dedicated Configuration
- [0xB0C0] DL_DCCH / RRCConnectionReconfiguration

Which provides some information like LTE CDRX configuration.

DRX Parameters

LTE (3GPP TS 36.321)	NR5G (3GPP TS 138.321)
• DRX Inactivity Timer	• drx-InactivityTimer
• DRX Retransmission Timer	• drx-RetransmissionTimerDL/UL
• DRX Short Cycle Timer	• drx-ShortCycle (optional)
	• drx-ShortCycleTimer (optional)
• HARQ RTT Timer	• drx-HARQ-RTT-TimerDL/UL
• On Duration Timer	• drx-onDurationTimer
• RA-RNTI	• drx-SlotOffset
	• drx-LongCycleStartOffset

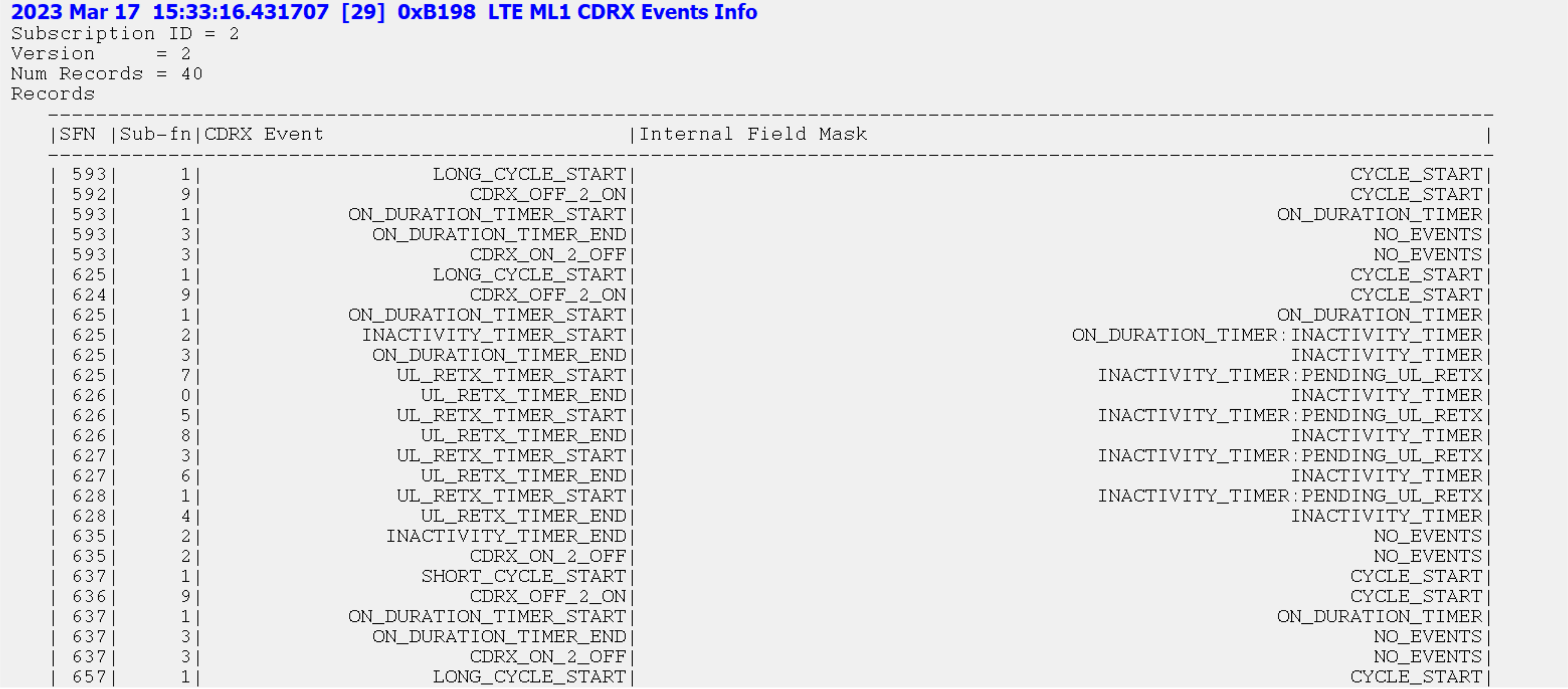
CDRX Configuration Comparison

- Two telecoms are using different settings. Not yet checked whether those configurations are fixed or not.
- LTE CDRX configurations may need to be checked under pure LTE mode.

NR	CHT	TWM	FET
On Duration Timer	10 ms	10 ms	10 ms
Inactivity Timer	100 ms	80 ms	100 ms
UL Retransmission Timer	16	16	16
DL Retransmission Timer	16	16	16
Long DRX Cycle	160	160	160
Short DRX Cycle	Disabled	Disabled	Disabled

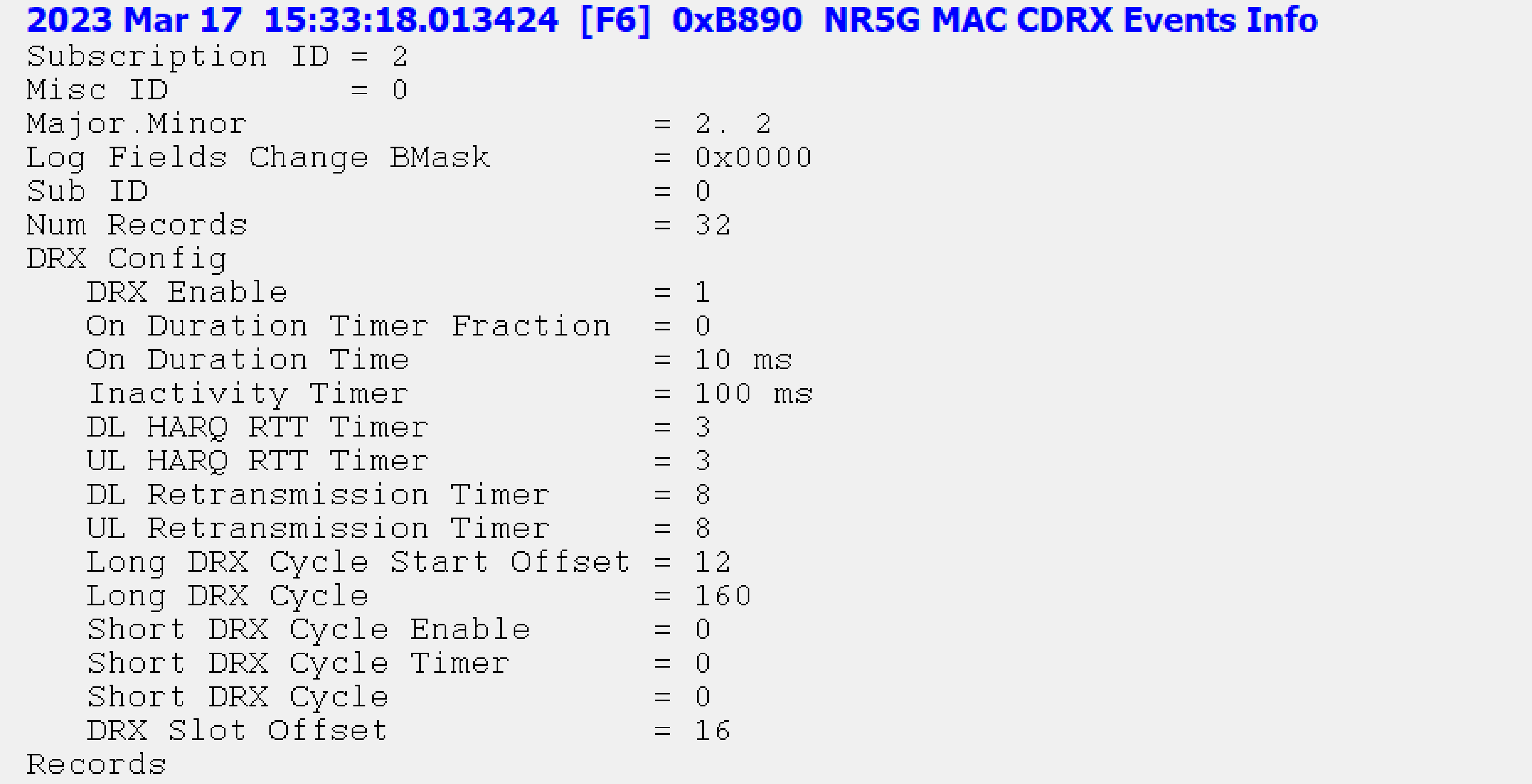
LTE	CHT	TWM	FET
On Duration Timer	2	10	
Inactivity Timer	100	100	
Retransmission Timer	4	8	
Long DRX Cycle	320		
Short DRX Cycle	20	80	
Short DRX Timer	1	2	

[0xB198] LTE ML1 CDRX Events Info



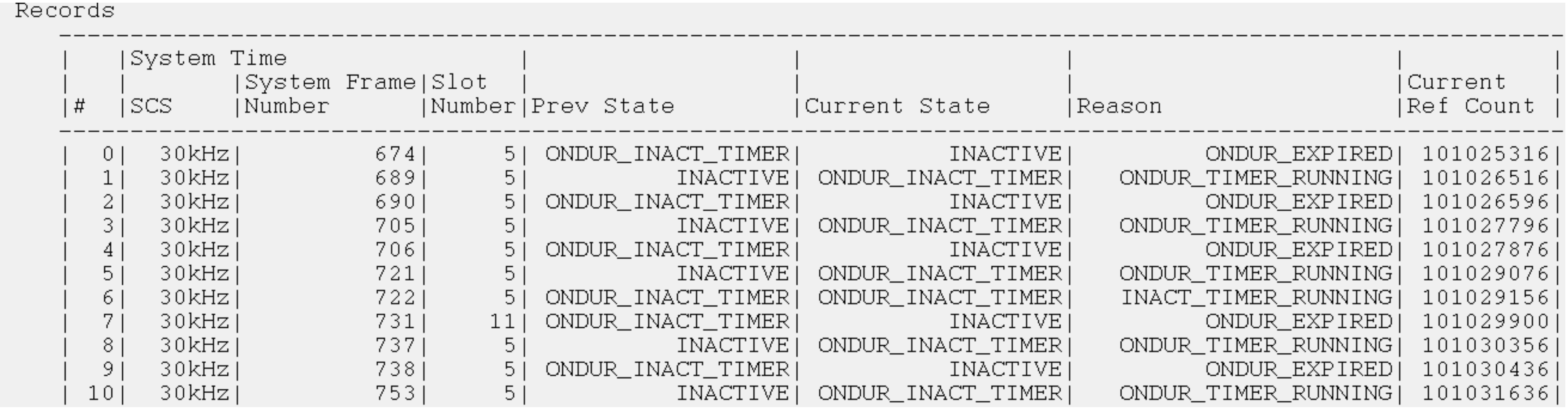
```
2023 Mar 17  15:33:16.431707  [29]  0xB198  LTE ML1 CDRX Events Info
Subscription ID = 2
Version     = 2
Num Records = 40
Records
   ------------------------------------------------------------------------------------------------------------------------
   |SFN |Sub-fn|CDRX Event                         |Internal Field Mask                                                   |
   ------------------------------------------------------------------------------------------------------------------------
   | 593|     1|                   LONG_CYCLE_START|                                                           CYCLE_START|
   | 592|     9|                      CDRX_OFF_2_ON|                                                           CYCLE_START|
   | 593|     1|            ON_DURATION_TIMER_START|                                                     ON_DURATION_TIMER|
   | 593|     3|              ON_DURATION_TIMER_END|                                                             NO_EVENTS|
   | 593|     3|                      CDRX_ON_2_OFF|                                                             NO_EVENTS|
   | 625|     1|                   LONG_CYCLE_START|                                                           CYCLE_START|
   | 624|     9|                      CDRX_OFF_2_ON|                                                           CYCLE_START|
   | 625|     1|            ON_DURATION_TIMER_START|                                                     ON_DURATION_TIMER|
   | 625|     2|             INACTIVITY_TIMER_START|                                    ON_DURATION_TIMER:INACTIVITY_TIMER|
   | 625|     3|              ON_DURATION_TIMER_END|                                                      INACTIVITY_TIMER|
   | 625|     7|                UL_RETX_TIMER_START|                                      INACTIVITY_TIMER:PENDING_UL_RETX|
   | 626|     0|                  UL_RETX_TIMER_END|                                                      INACTIVITY_TIMER|
   | 626|     5|                UL_RETX_TIMER_START|                                      INACTIVITY_TIMER:PENDING_UL_RETX|
   | 626|     8|                  UL_RETX_TIMER_END|                                                      INACTIVITY_TIMER|
   | 627|     3|                UL_RETX_TIMER_START|                                      INACTIVITY_TIMER:PENDING_UL_RETX|
   | 627|     6|                  UL_RETX_TIMER_END|                                                      INACTIVITY_TIMER|
   | 628|     1|                UL_RETX_TIMER_START|                                      INACTIVITY_TIMER:PENDING_UL_RETX|
   | 628|     4|                  UL_RETX_TIMER_END|                                                      INACTIVITY_TIMER|
   | 635|     2|               INACTIVITY_TIMER_END|                                                             NO_EVENTS|
   | 635|     2|                      CDRX_ON_2_OFF|                                                             NO_EVENTS|
   | 637|     1|                  SHORT_CYCLE_START|                                                           CYCLE_START|
   | 636|     9|                      CDRX_OFF_2_ON|                                                           CYCLE_START|
   | 637|     1|            ON_DURATION_TIMER_START|                                                     ON_DURATION_TIMER|
   | 637|     3|              ON_DURATION_TIMER_END|                                                             NO_EVENTS|
   | 637|     3|                      CDRX_ON_2_OFF|                                                             NO_EVENTS|
   | 657|     1|                   LONG_CYCLE_START|                                                           CYCLE_START|
```

[0xB890] NR5G MAC CDRX Events Info

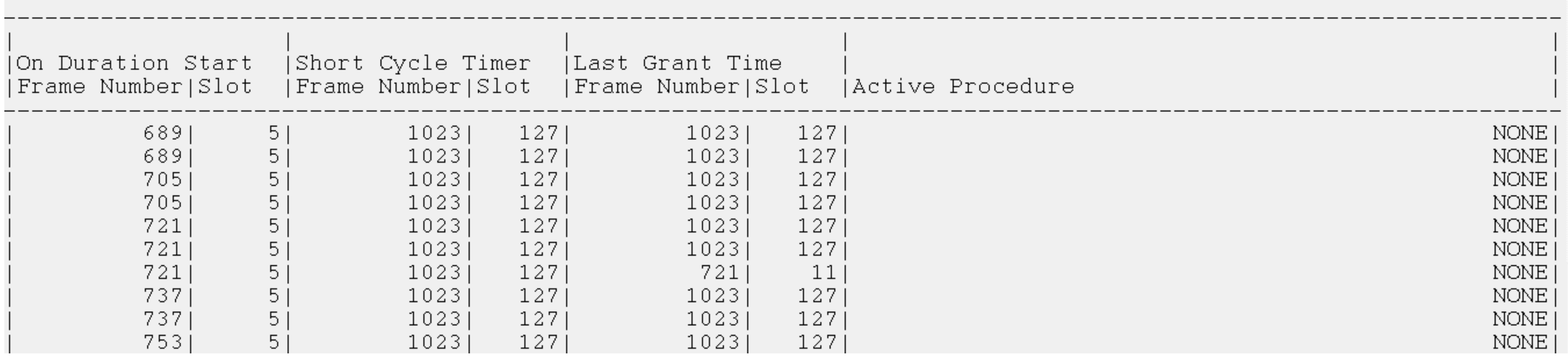


```
2023 Mar 17  15:33:18.013424  [F6]  0xB890  NR5G MAC CDRX Events Info
Subscription ID = 2
Misc ID         = 0
Major.Minor                    = 2. 2
Log Fields Change BMask        = 0x0000
Sub ID                         = 0
Num Records                    = 32
DRX Config
   DRX Enable                  = 1
   On Duration Timer Fraction  = 0
   On Duration Time            = 10 ms
   Inactivity Timer            = 100 ms
   DL HARQ RTT Timer           = 3
   UL HARQ RTT Timer           = 3
   DL Retransmission Timer     = 8
   UL Retransmission Timer     = 8
   Long DRX Cycle Start Offset = 12
   Long DRX Cycle              = 160
   Short DRX Cycle Enable      = 0
   Short DRX Cycle Timer       = 0
   Short DRX Cycle             = 0
   DRX Slot Offset             = 16
Records
```

[0xB890] NR5G MAC CDRX Events Info



```
Records
   ------------------------------------------------------------------------------------------------------------
   |   |System Time                |                  |                  |                      |          |
   |   |       |System Frame|Slot  |                  |                  |                      |Current   |
   |#  |SCS    |Number      |Number|Prev State        |Current State     |Reason                |Ref Count |
   ------------------------------------------------------------------------------------------------------------
   |  0|  30kHz|         674|     5| ONDUR_INACT_TIMER|          INACTIVE|         ONDUR_EXPIRED| 101025316|
   |  1|  30kHz|         689|     5|          INACTIVE| ONDUR_INACT_TIMER|   ONDUR_TIMER_RUNNING| 101026516|
   |  2|  30kHz|         690|     5| ONDUR_INACT_TIMER|          INACTIVE|         ONDUR_EXPIRED| 101026596|
   |  3|  30kHz|         705|     5|          INACTIVE| ONDUR_INACT_TIMER|   ONDUR_TIMER_RUNNING| 101027796|
   |  4|  30kHz|         706|     5| ONDUR_INACT_TIMER|          INACTIVE|         ONDUR_EXPIRED| 101027876|
   |  5|  30kHz|         721|     5|          INACTIVE| ONDUR_INACT_TIMER|   ONDUR_TIMER_RUNNING| 101029076|
   |  6|  30kHz|         722|     5| ONDUR_INACT_TIMER| ONDUR_INACT_TIMER|   INACT_TIMER_RUNNING| 101029156|
   |  7|  30kHz|         731|    11| ONDUR_INACT_TIMER|          INACTIVE|         ONDUR_EXPIRED| 101029900|
   |  8|  30kHz|         737|     5|          INACTIVE| ONDUR_INACT_TIMER|   ONDUR_TIMER_RUNNING| 101030356|
   |  9|  30kHz|         738|     5| ONDUR_INACT_TIMER|          INACTIVE|         ONDUR_EXPIRED| 101030436|
   | 10|  30kHz|         753|     5|          INACTIVE| ONDUR_INACT_TIMER|   ONDUR_TIMER_RUNNING| 101031636|
```



```
-----------------------------------------------------------------------------------------------------------
|                   |                   |                   |                                             |
|On Duration Start  |Short Cycle Timer  |Last Grant Time    |                                             |
|Frame Number|Slot  |Frame Number|Slot  |Frame Number|Slot  |Active Procedure                             |
-----------------------------------------------------------------------------------------------------------
|         689|     5|        1023|   127|        1023|   127|                                         NONE|
|         689|     5|        1023|   127|        1023|   127|                                         NONE|
|         705|     5|        1023|   127|        1023|   127|                                         NONE|
|         705|     5|        1023|   127|        1023|   127|                                         NONE|
|         721|     5|        1023|   127|        1023|   127|                                         NONE|
|         721|     5|        1023|   127|        1023|   127|                                         NONE|
|         721|     5|        1023|   127|         721|    11|                                         NONE|
|         737|     5|        1023|   127|        1023|   127|                                         NONE|
|         737|     5|        1023|   127|        1023|   127|                                         NONE|
|         753|     5|        1023|   127|        1023|   127|                                         NONE|
```

Experiments Based on Application Layer Records

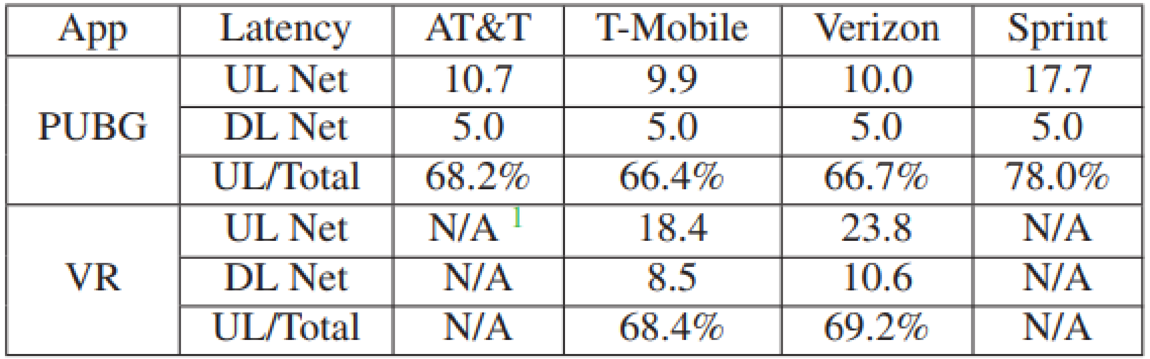
Tools

- Cellphones
  - Samsung A42 5G, Xiaomi 10T, Google Pixel 6a
- Sim cards
  - **C**hung**H**wa **T**elecom 5G, **T**ai**W**an **M**obile 5G, **F**ar**E**as**T**one Telecom 5G
- Qualcomm tools
  - QXDM (Qualcomm eXtensible Diagnostic Monitor 5)
  - QCAT (Qualcomm Commercial Analysis Toolkit)

Previous Work

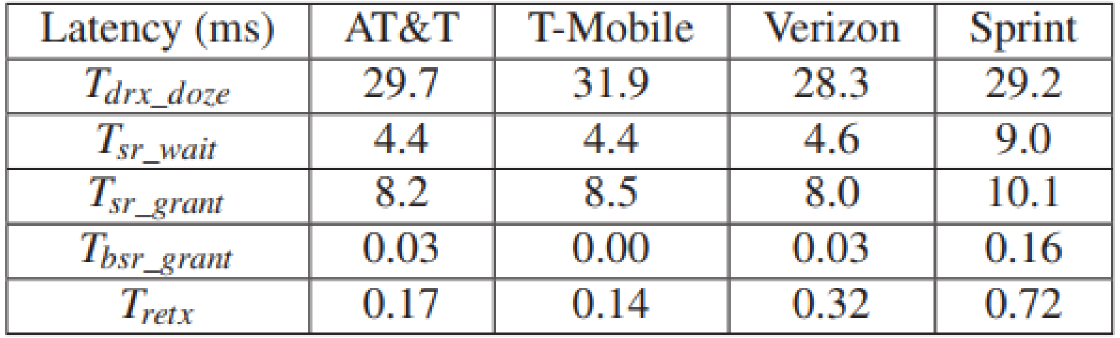
According to *“Device-Based LTE Latency Reduction at the Application Layer”* [3]:

- The uplink latency poses as a major component in overall latency (66.4-78.0%.)
- The latency of *DRX_doze* is significant in the overall uplink latency.



App	Latency	AT&T	T-Mobile	Verizon	Sprint
PUBG	UL Net	10.7	9.9	10.0	17.7
	DL Net	5.0	5.0	5.0	5.0
	UL/Total	68.2%	66.4%	66.7%	78.0%
VR	UL Net	N/A [1]	18.4	23.8	N/A
	DL Net	N/A	8.5	10.6	N/A
	UL/Total	N/A	68.4%	69.2%	N/A

Table 1: LTE latency (ms) for two mobile apps.



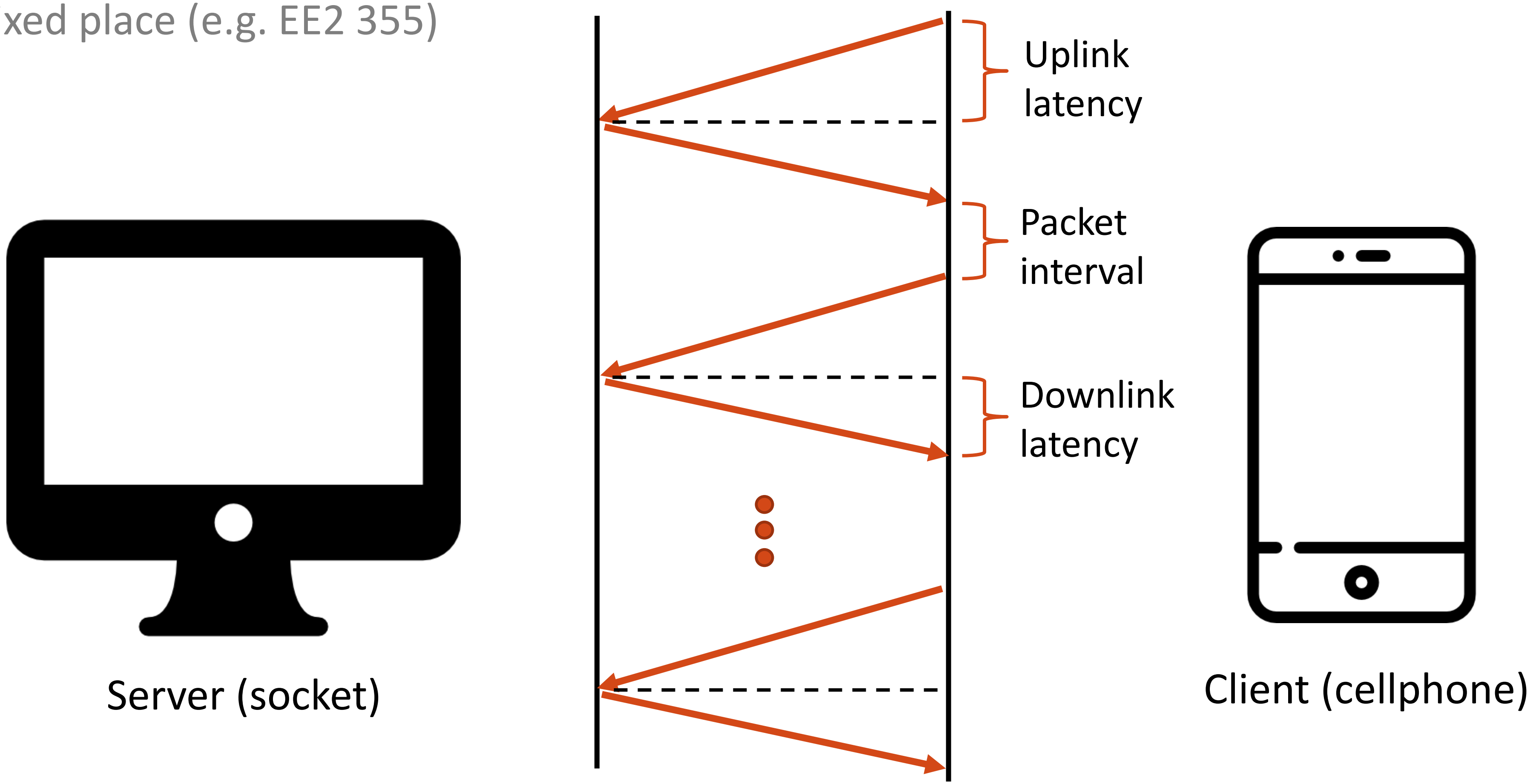
Latency (ms)	AT&T	T-Mobile	Verizon	Sprint
T_{drx_doze}	29.7	31.9	28.3	29.2
T_{sr_wait}	4.4	4.4	4.6	9.0
T_{sr_grant}	8.2	8.5	8.0	10.1
T_{bsr_grant}	0.03	0.00	0.03	0.16
T_{retx}	0.17	0.14	0.32	0.72

Table 2: Measured latency elements for VR application. T_{drx_doze} is the average value when present.

[3] Zhaowei Tan et al., "Device-Based LTE Latency Reduction at the Application Layer", NSDI '21

Overall Experiment Setting

Place: fixed place (e.g. EE2 355)



Uplink latency

Packet interval

Downlink latency

Server (socket)

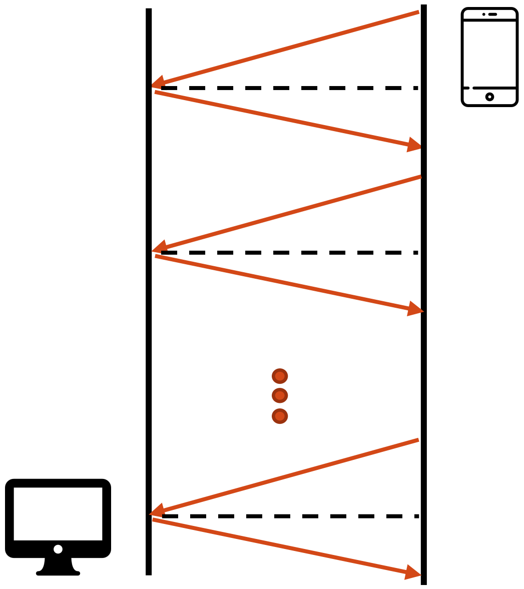
Client (cellphone)

Explanatory Variables - Tools

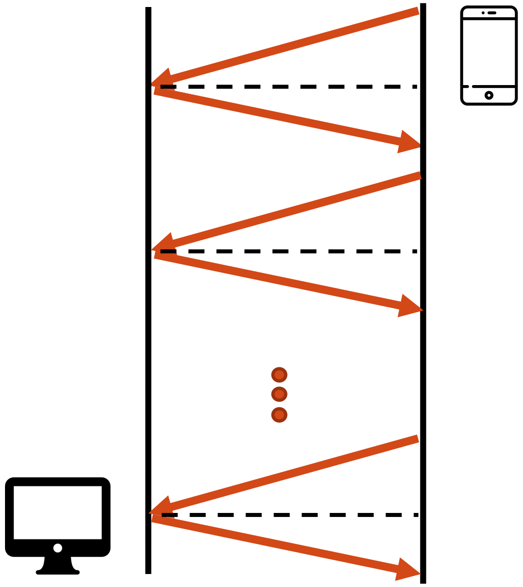
- Telecoms: CHT, TWM, FET
- Scenarios: 4G, 5G
- Cellphones:
  - Samsung A42 5G
  - Xiaomi 10T
  - Google Pixel 6a

Explanatory Variables - Parameters

- Packet size

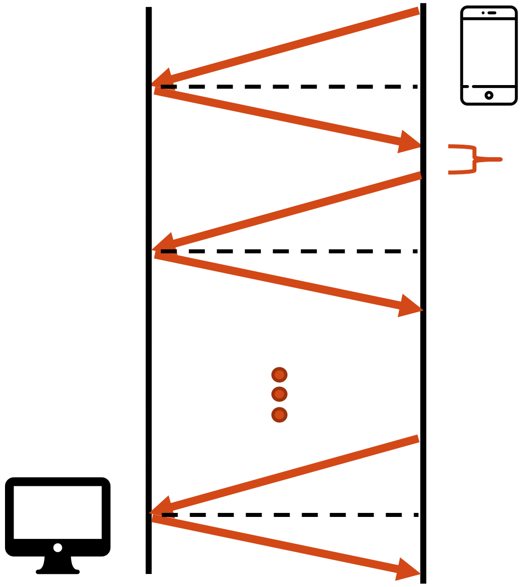


small packet

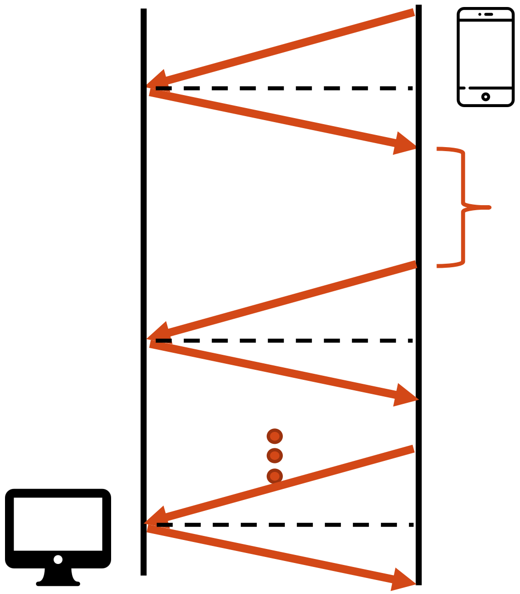


large packet

- Packet interval



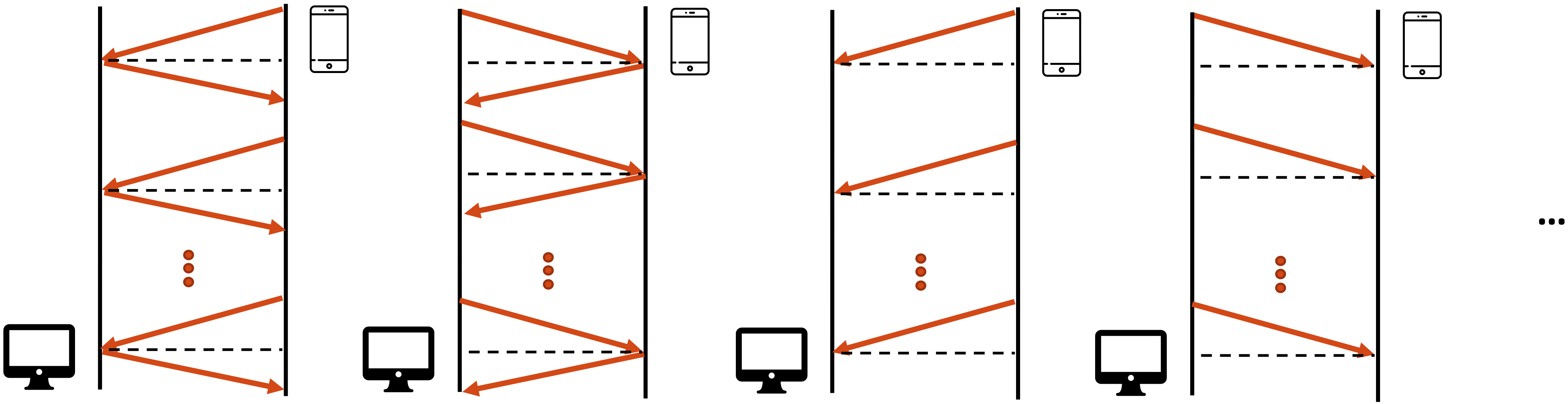
small interval



large interval

Explanatory Variables - Parameters

- Transmission sequence



UL then DL

DL then UL

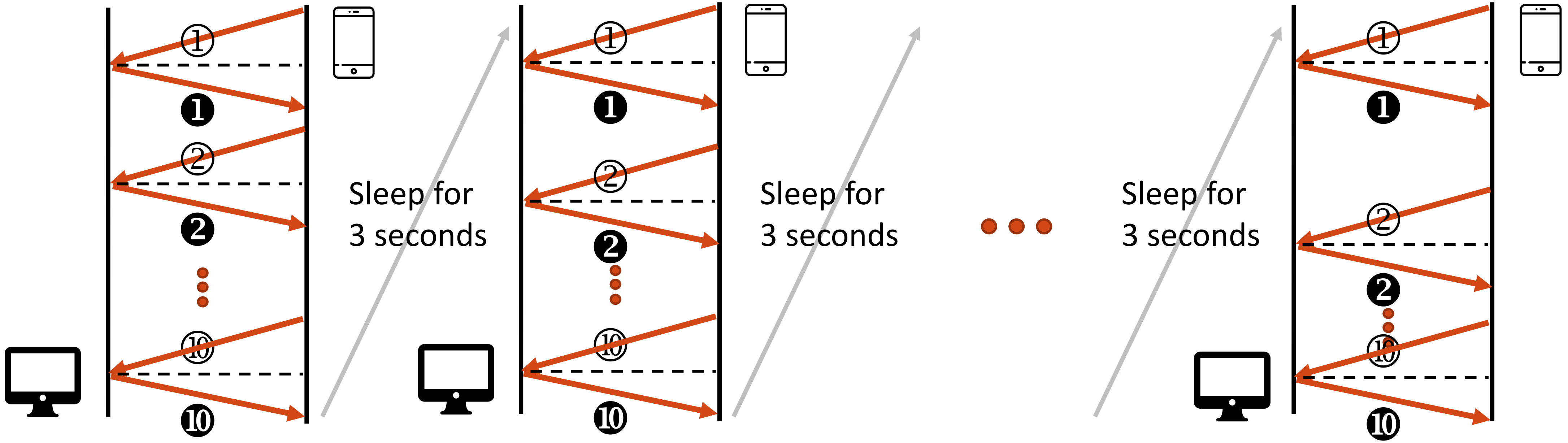
UL only

DL only

Experiment Results

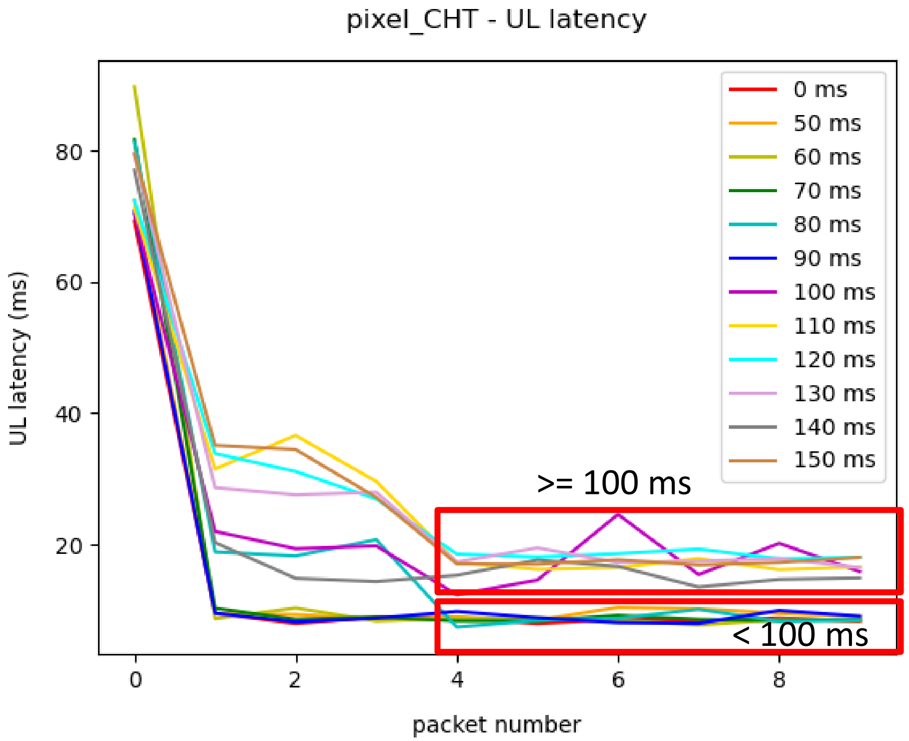
Experiment 1: UL First

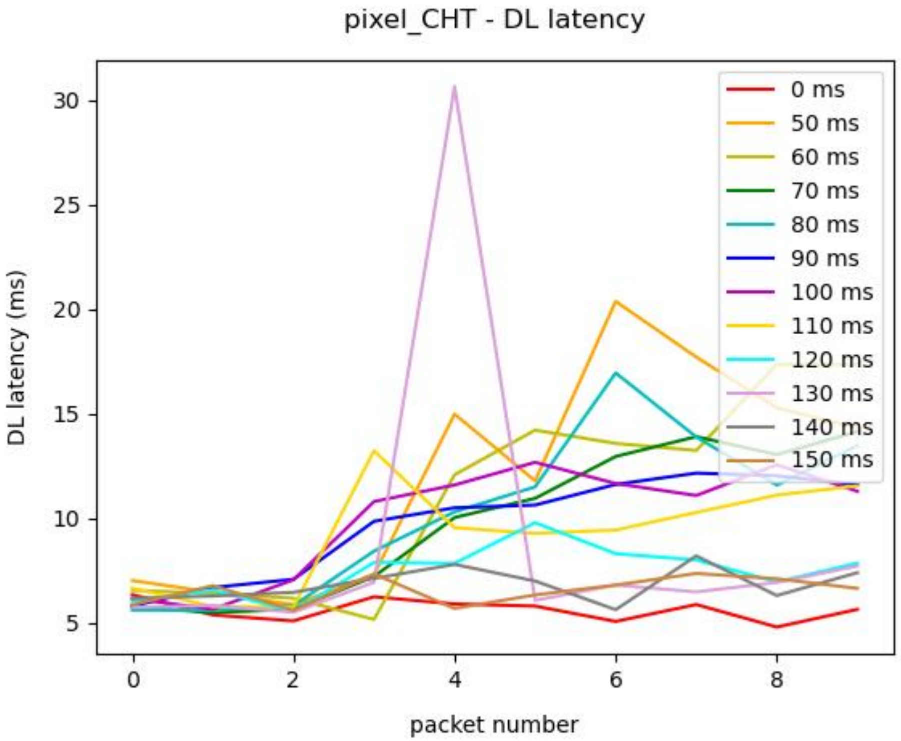
- Set *Packet_Interval* as 50~150 ms and send 10 packets each round. [4]
- After each round, sleep for 3 seconds.
- Measure the latency of each packet.



[4] NR5G CDRX inactivity timer: CHT=100ms, TWM=80ms, FET=100ms (from QXDM)

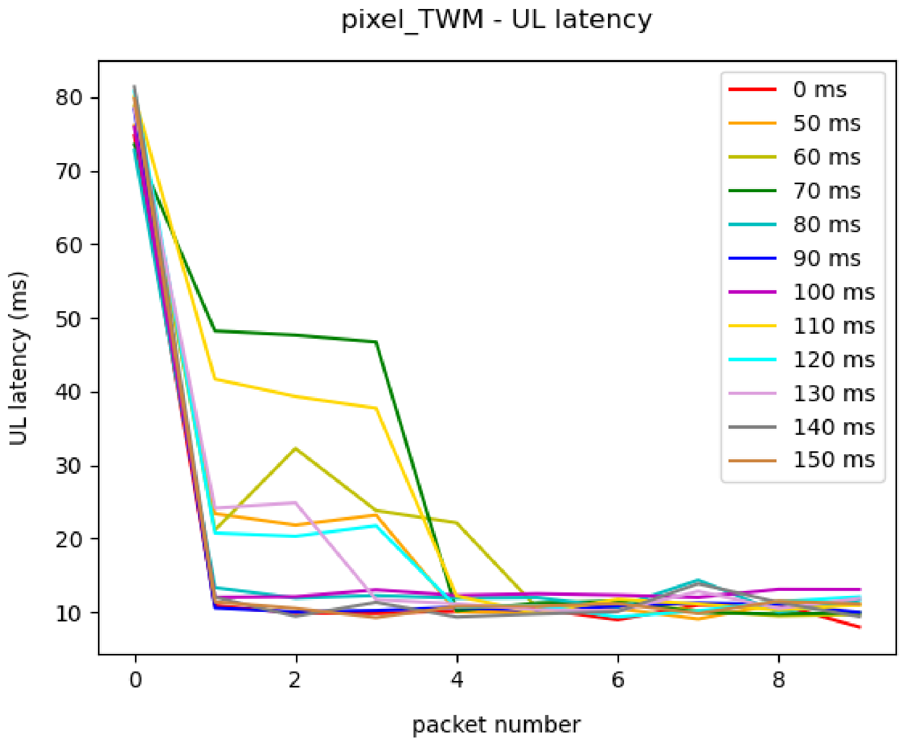
UL First: Result (Pixel_CHT)

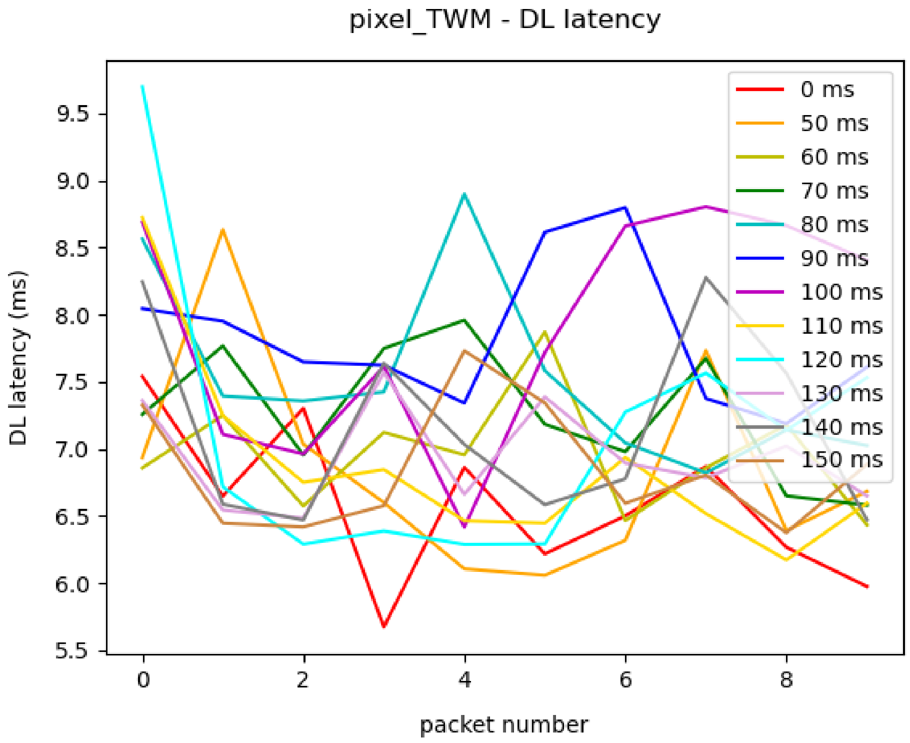




- UL: The first packet has large latency, and the next 2~3 packets may have some extra latency; clustering
- DL: No obvious tendency

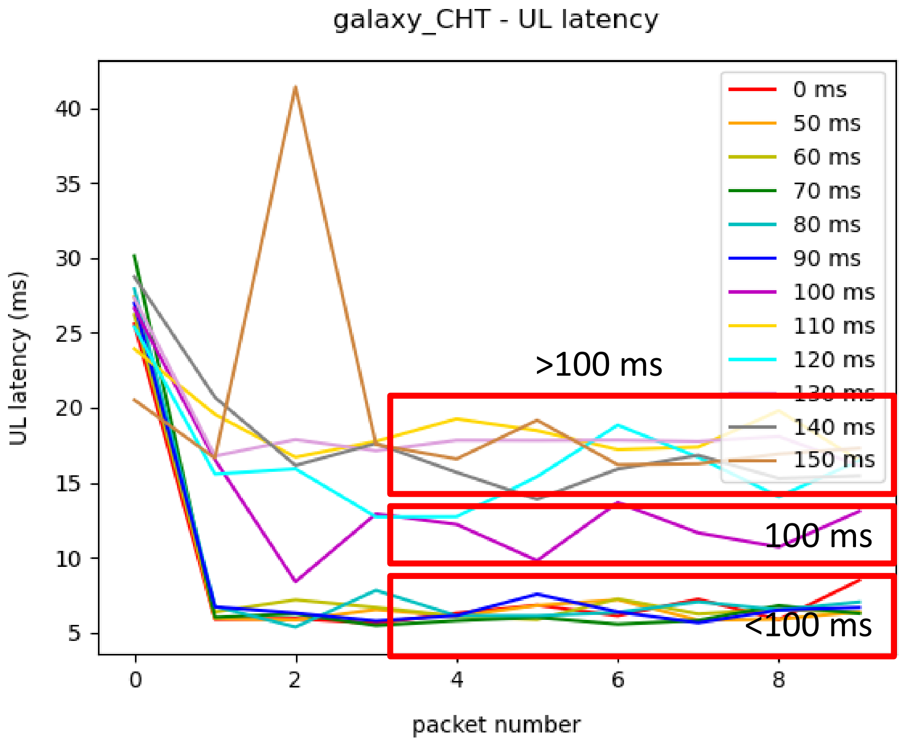
UL First: Result (Pixel_TWM)

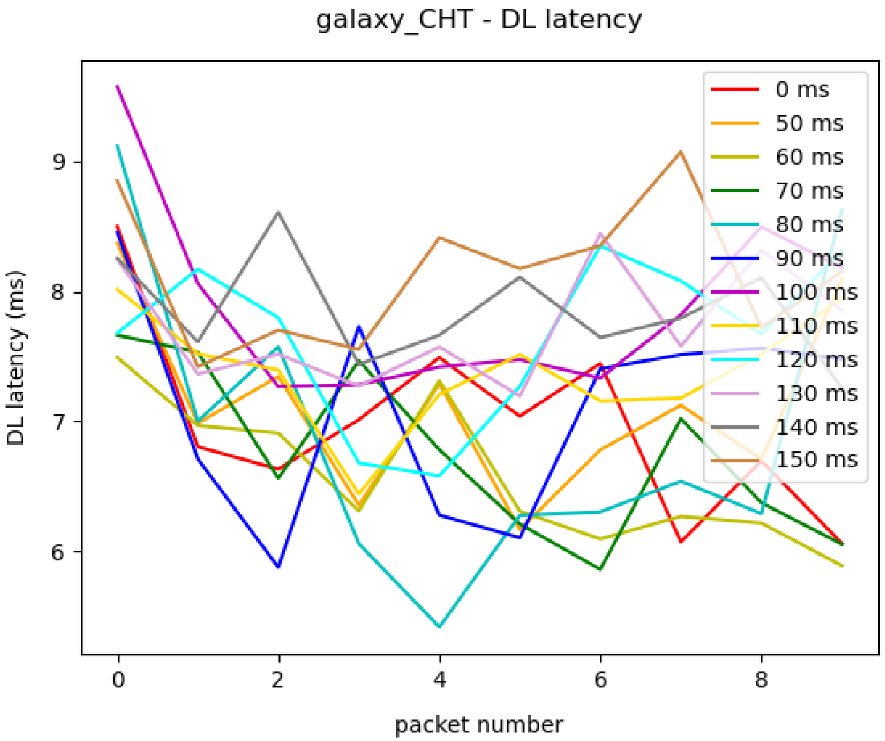




- UL: The first packet has large latency, and the next 2~3 packets may have some extra latency
- DL: No obvious tendency

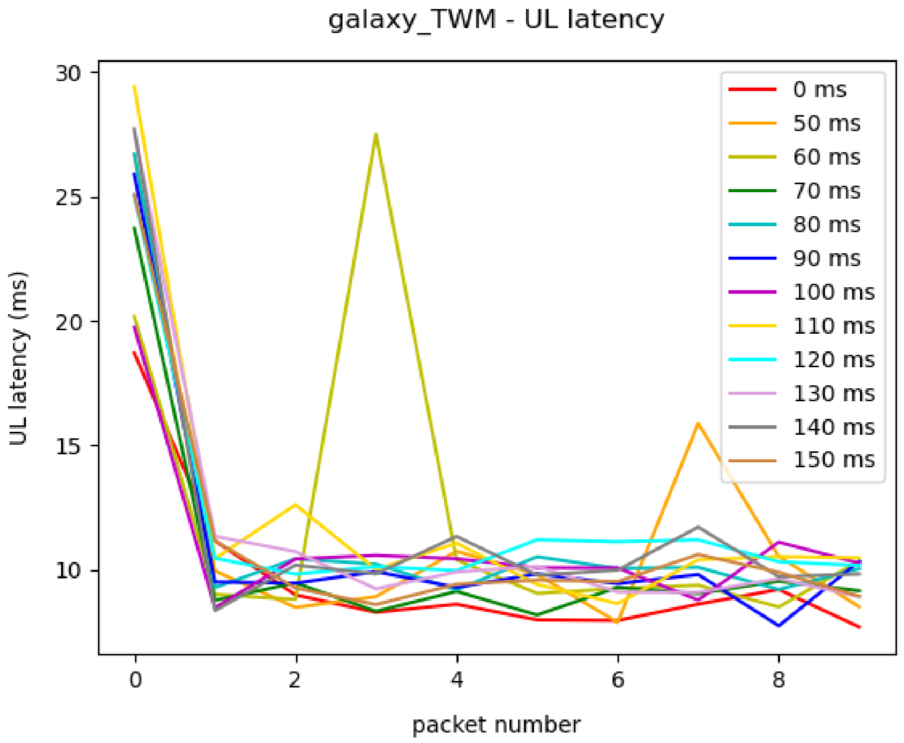
Experiment 1: Result (Galaxy_CHT)

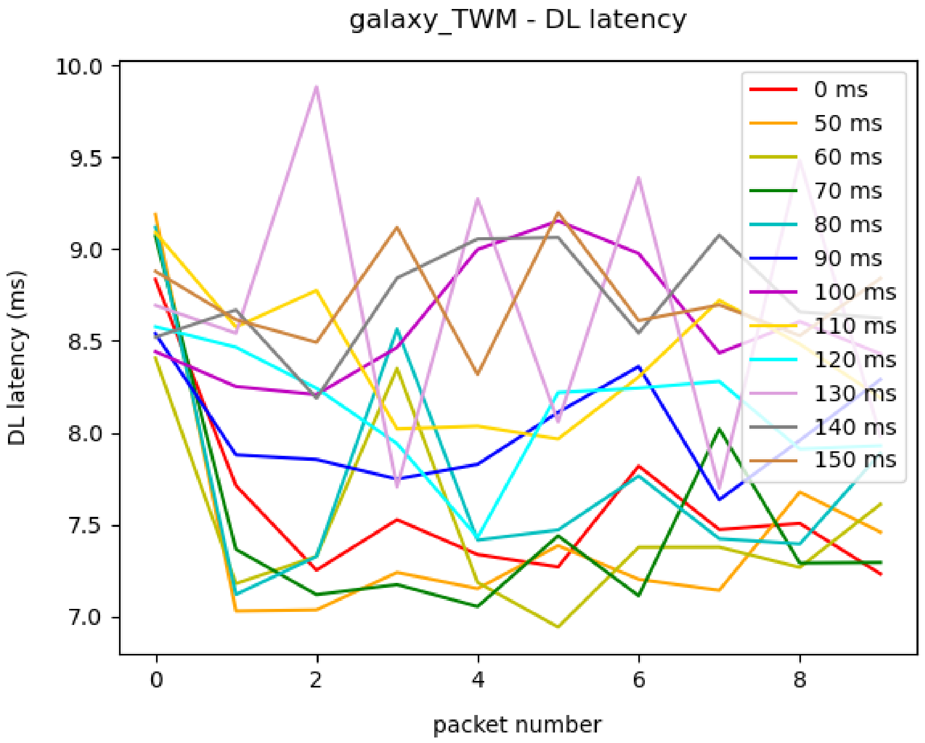




- UL: The first packet has large latency; **obviously clustering** (inactivity_timer = 100 ms)
- DL: The first packet tends to have larger latency

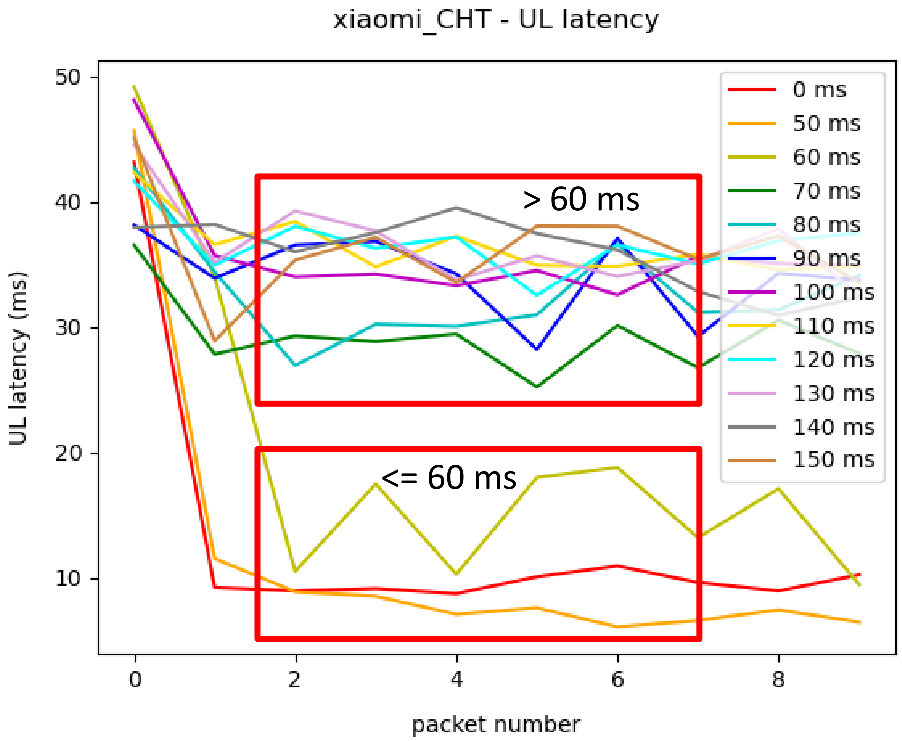
UL First: Result (Galaxy_TWM)

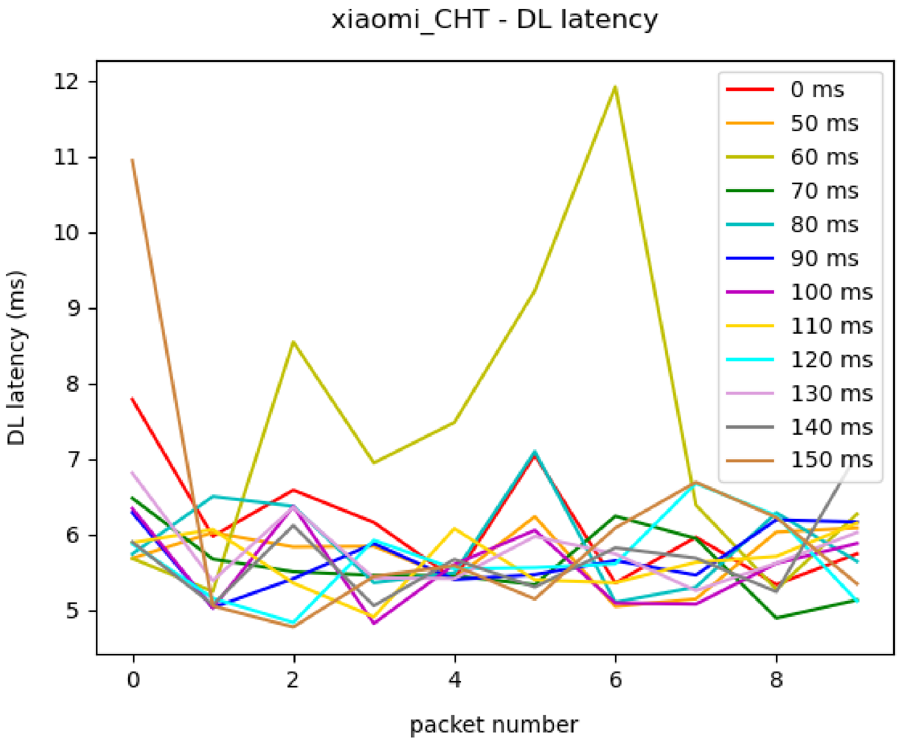




- UL: The first packet has large latency
- DL: The first packet tends to have larger latency

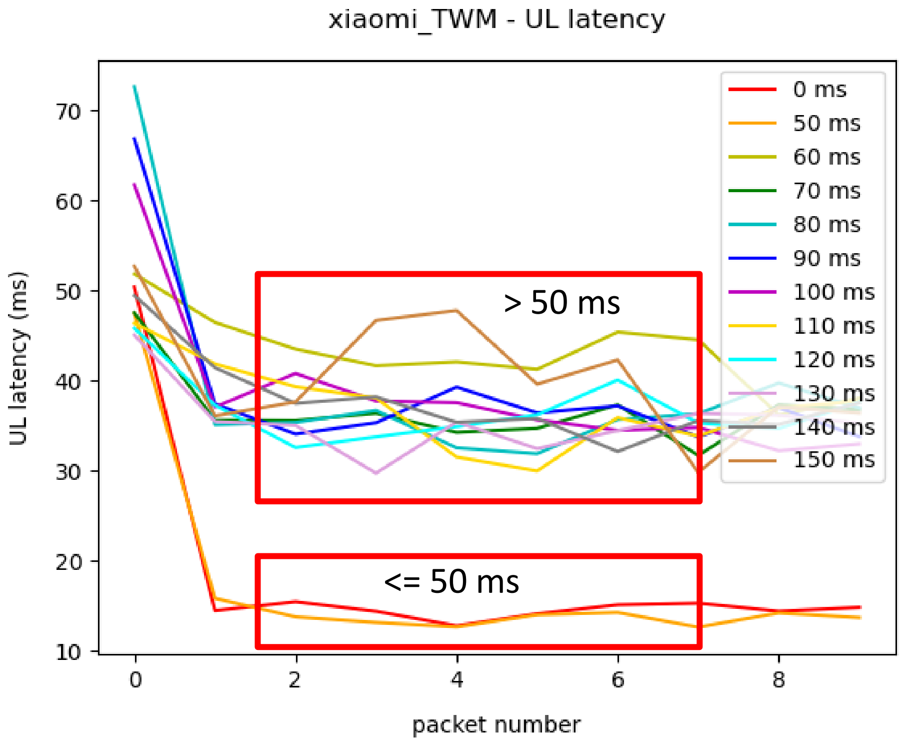
UL First: Result (Xiaomi_CHT)

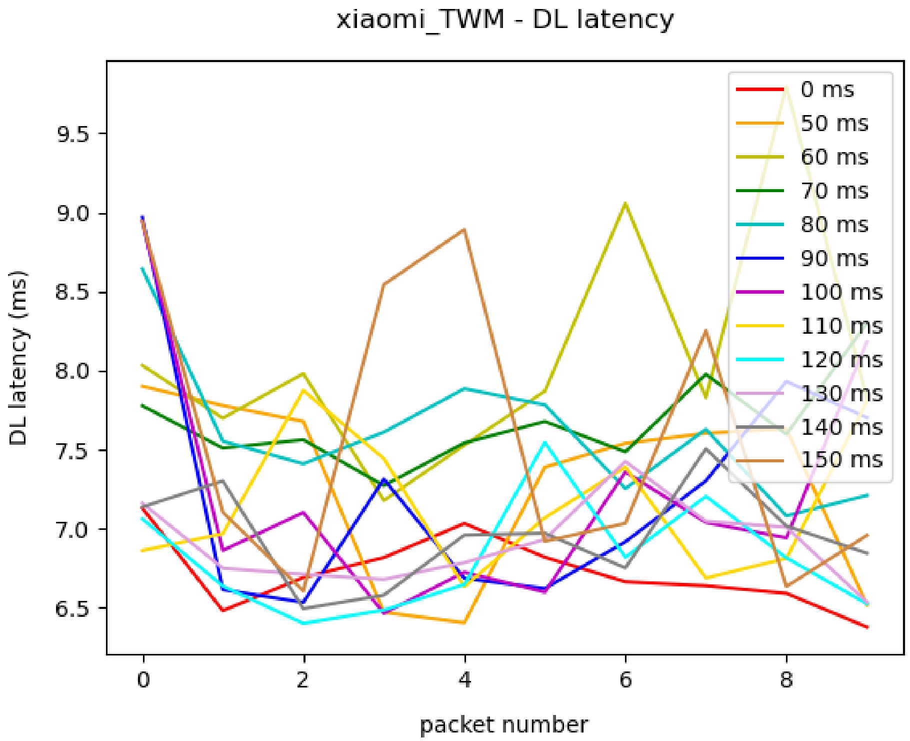




- UL: **obviously clustering** (threshold : 60-70 ms)
- DL: The first packet tends to have larger latency

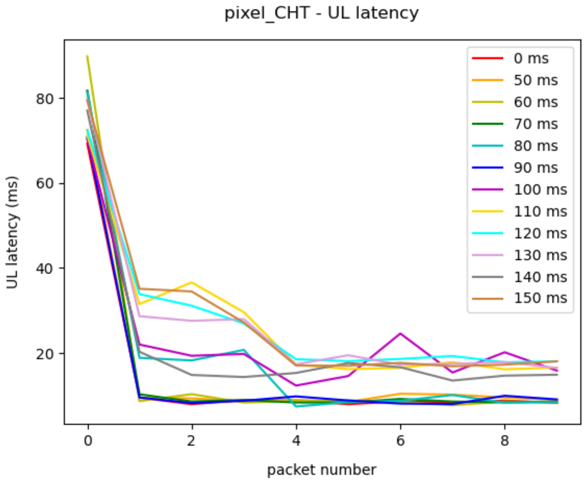
UL First: Result (Xiaomi_TWM)

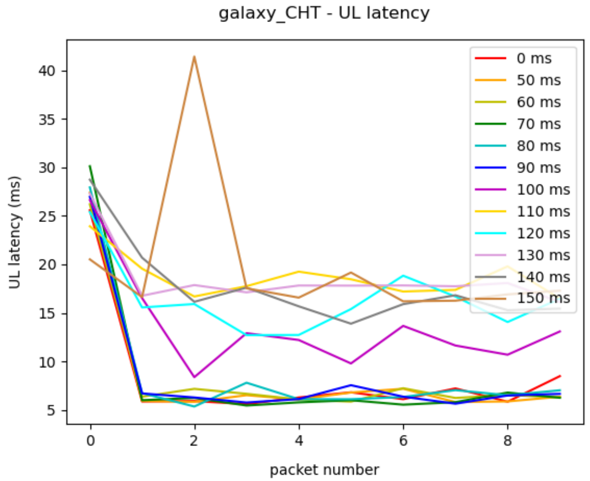


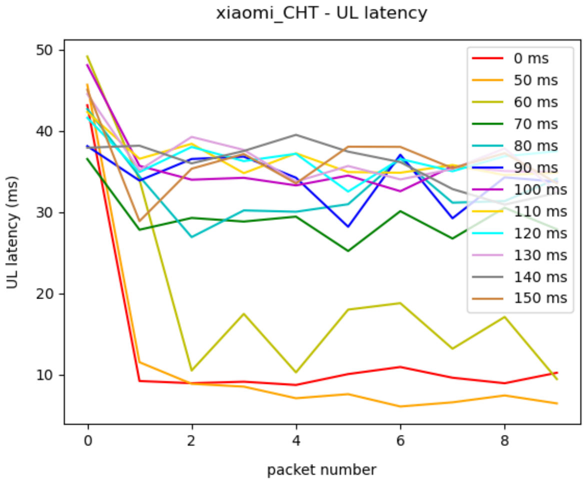


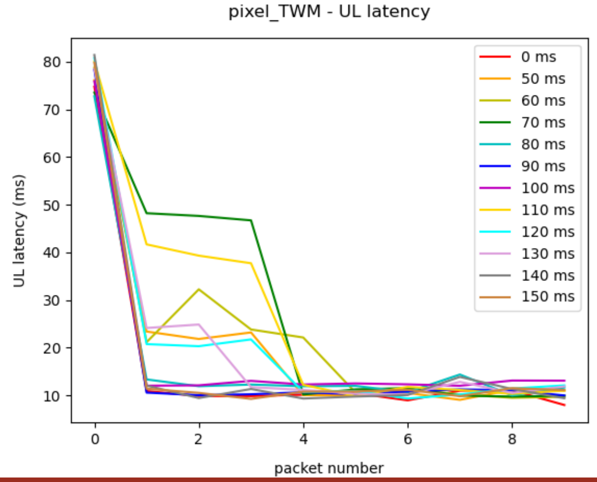
- UL: **obviously clustering** (threshold : 50-60 ms)
- DL: The first packet tends to have larger latency

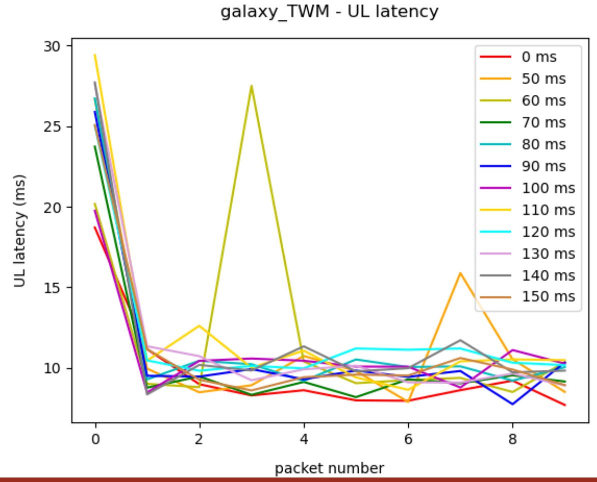
UL First: Result - Comparison

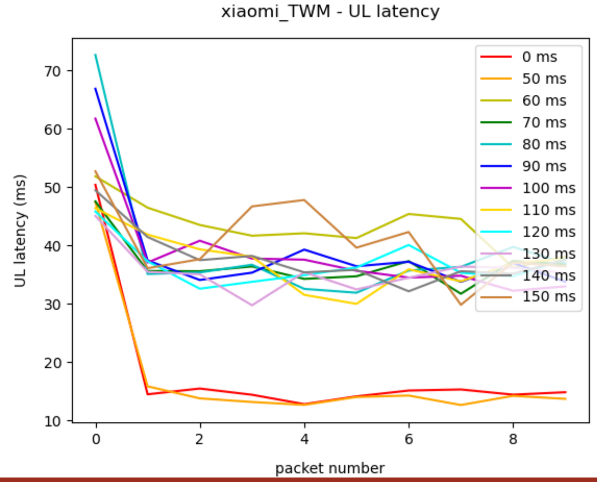












UL First: Result - Table

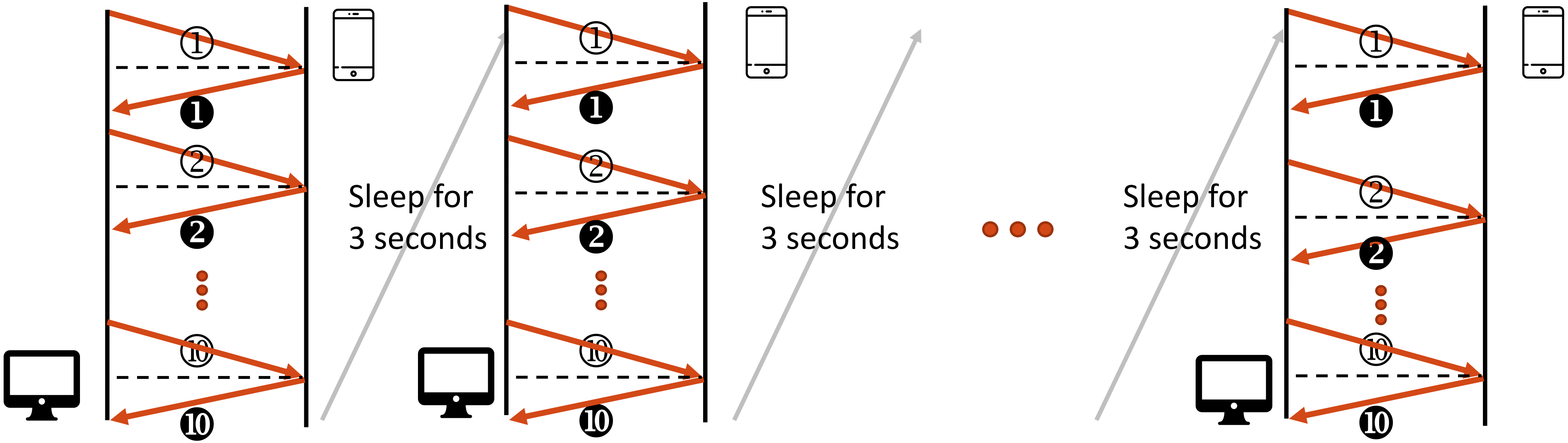
- Galaxy A42’s behavior is roughly as expected, but others are not.

Combination		**Pixel 6a**				**Galaxy A42**				**Xiaomi 10T**			
		All packets		Without first		All packets		Without first		All packets		Without first	
		avg.	std.	avg.	std.	avg.	std.	avg.	std.	avg.	std.	avg.	std.
CHT	UL latency (ms)	21.02	22.39	11.4	3.4	12.94	11.15	12.2	7.73	29.81	13.92	26.72	12.11
	DL latency (ms)	8.99	8.3	9.0	4.12	7.34	1.96	7.3	1.96	5.91	2.64	5.82	2.65
	UL%	70.1%		55.9%		63.8%		62.6%		83.5%		82.1%	
TWM	UL latency (ms)	20.48	24.32	17.21	25.1	11.4	7.45	9.31	2.17	42.39	17.07	42.02	10.16
	DL latency (ms)	7.15	2.61	6.7	1.09	8.09	1.14	8.14	1.14	35.0	16.33	35.36	10.1
	UL%	74.1%		72.0%		58.5%		53.4%		82.8%		84.4%	

Table 2: average UL/DL latency of experiment 2.

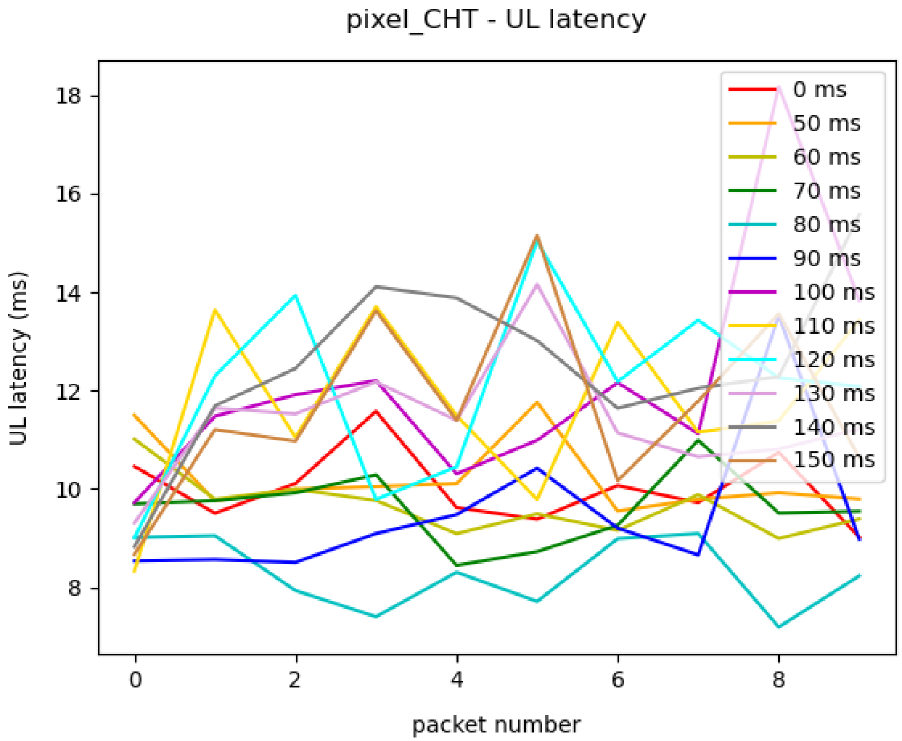
Experiment 2: DL First

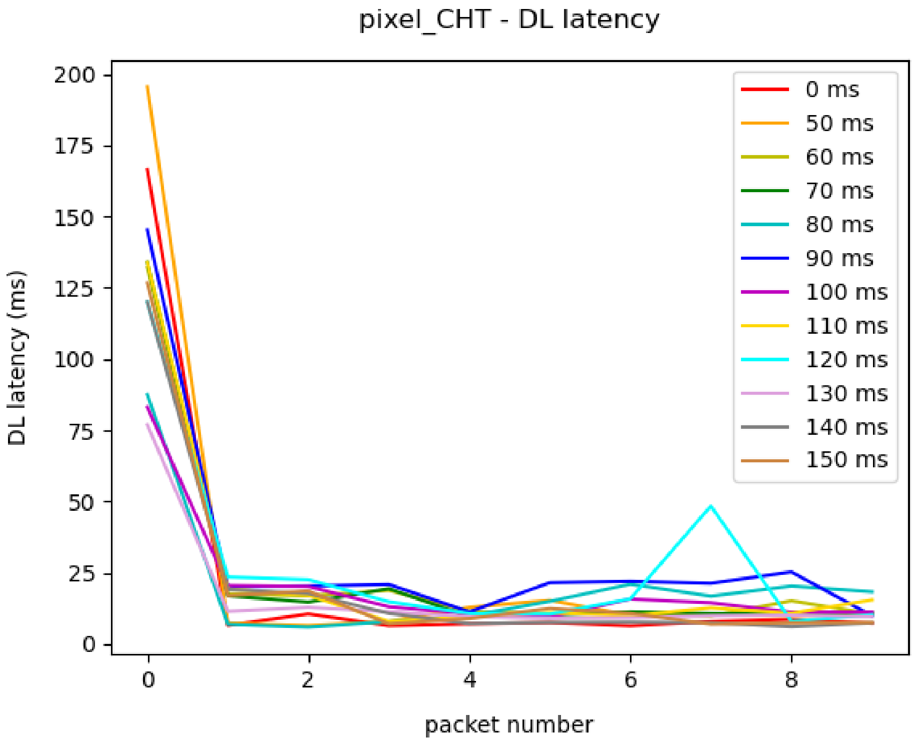
- Set *Packet_Interval* as 50~150 ms and send 10 packets each round. [2]
- After each round, sleep for 3 seconds.
- Measure the latency of each packet.



[2] NR5G CDRX inactivity timer: CHT=100ms, TWM=80ms (from QXDM)

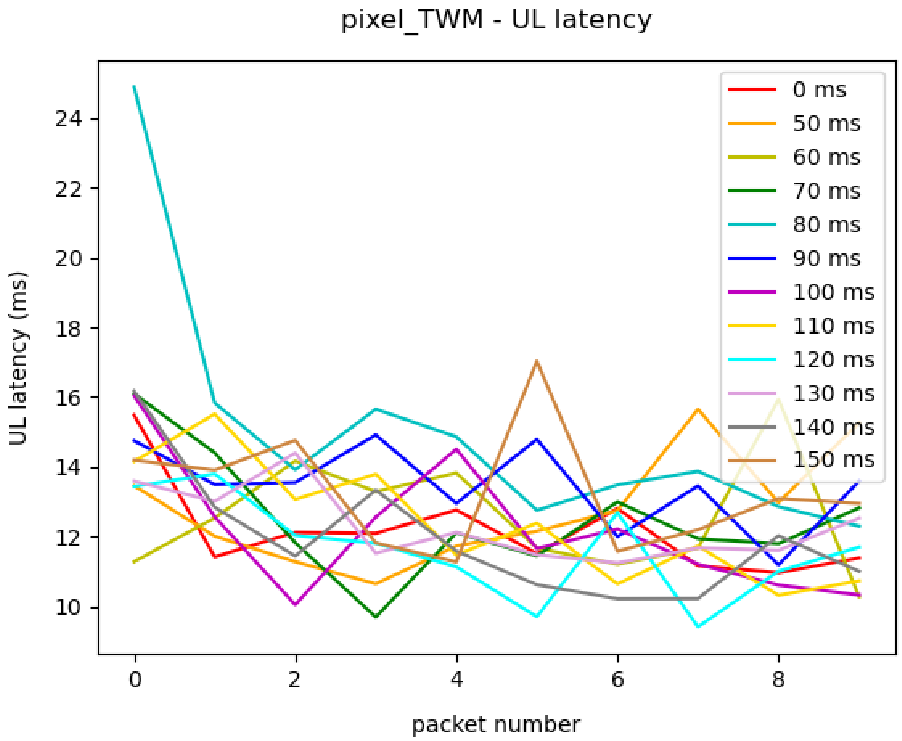
DL First: Result (Pixel_CHT)

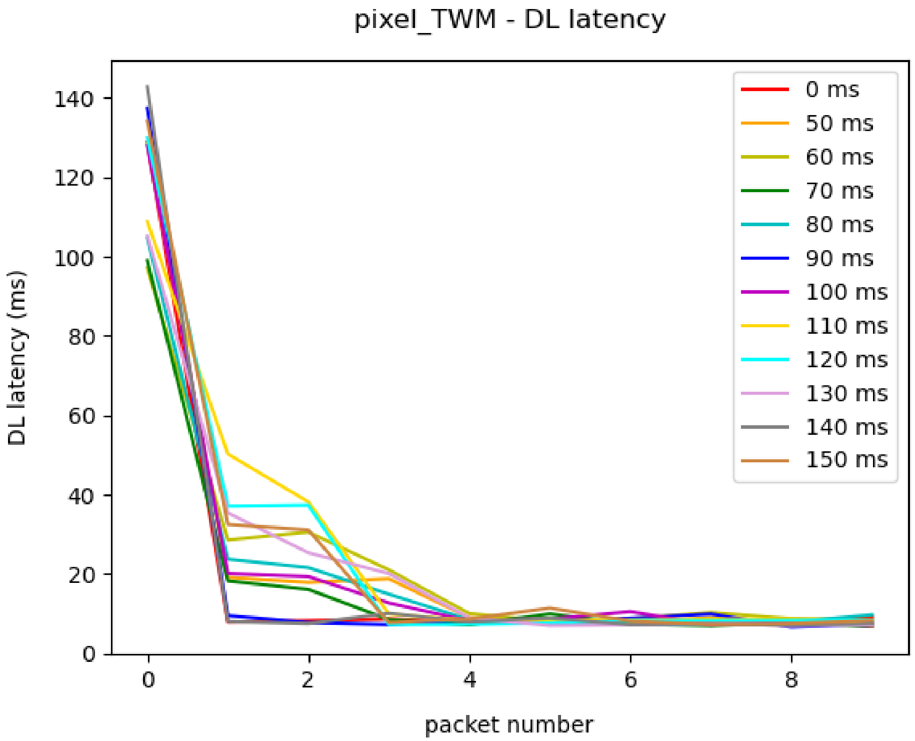




- UL: No obvious tendency
- DL: The first packet has large latency

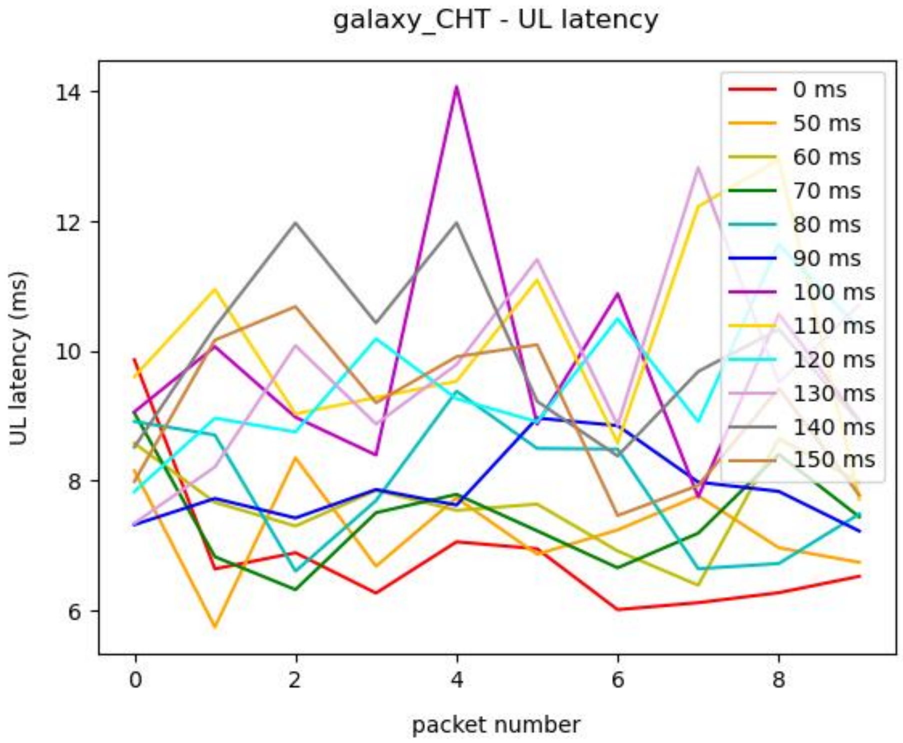
DL First: Result (Pixel_TWM)

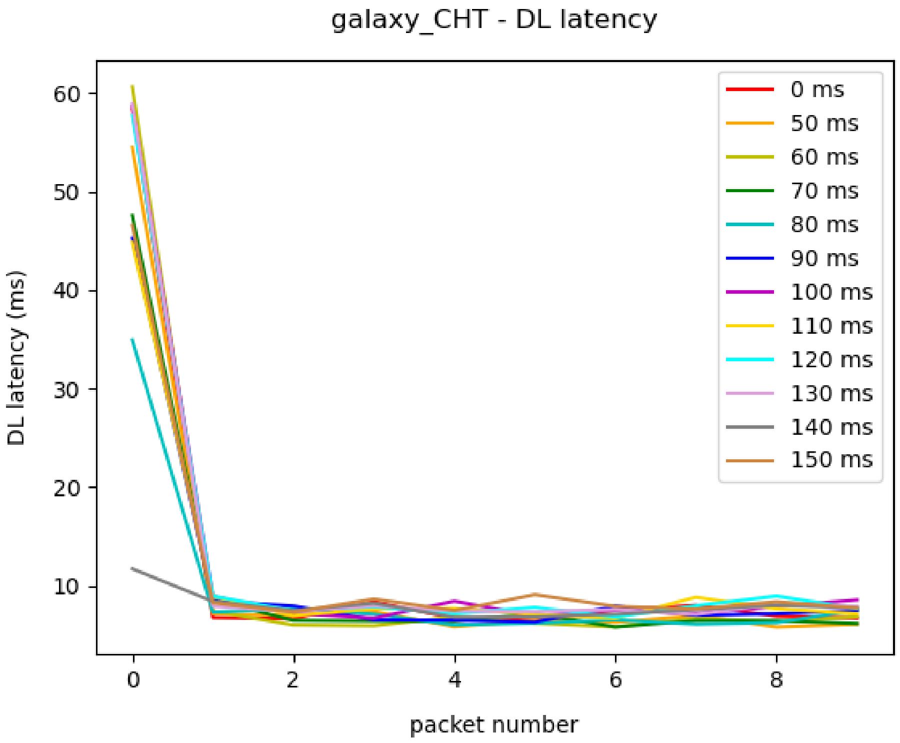




- UL: No obvious tendency
- DL: The first packet has large latency, and the next 2~3 packets may have some extra latency

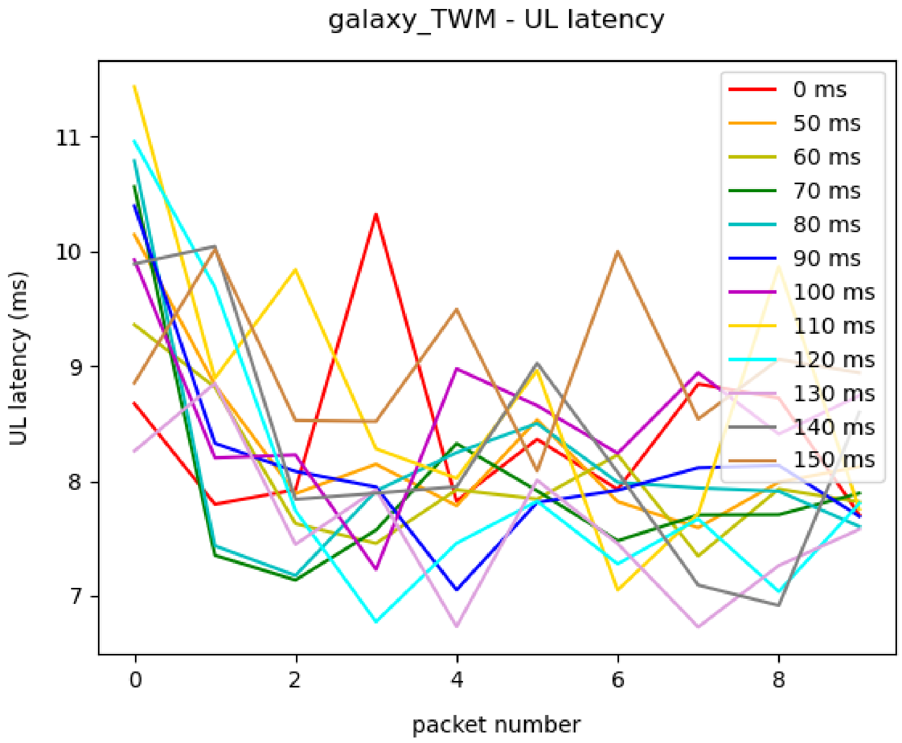
DL First: Result (Galaxy_CHT)

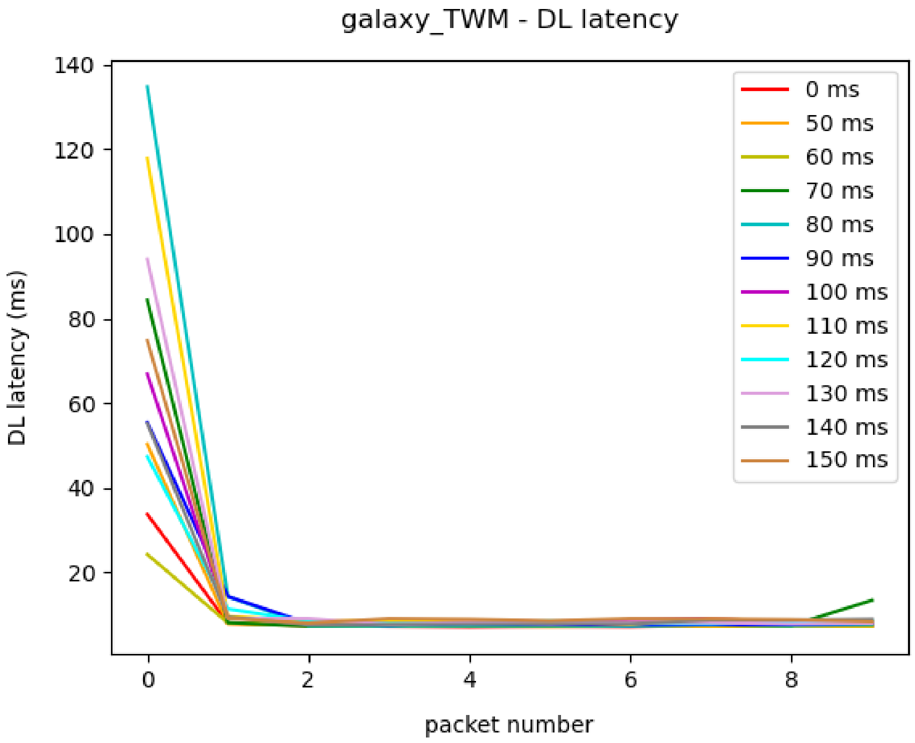




- UL: No obvious tendency
- DL: The first packet has large latency

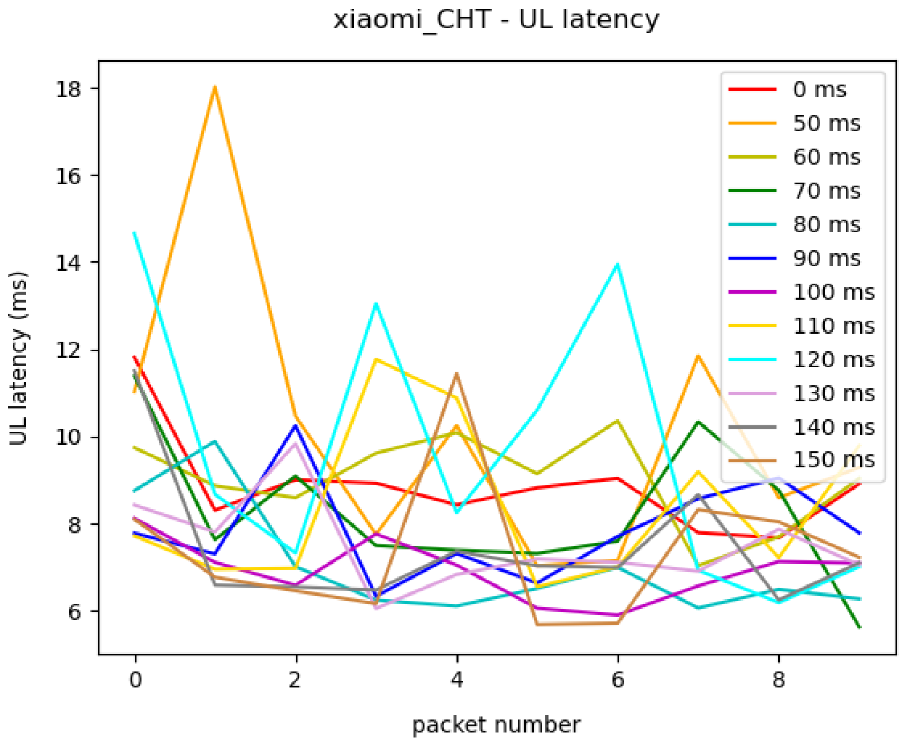
DL First: Result (Galaxy_TWM)

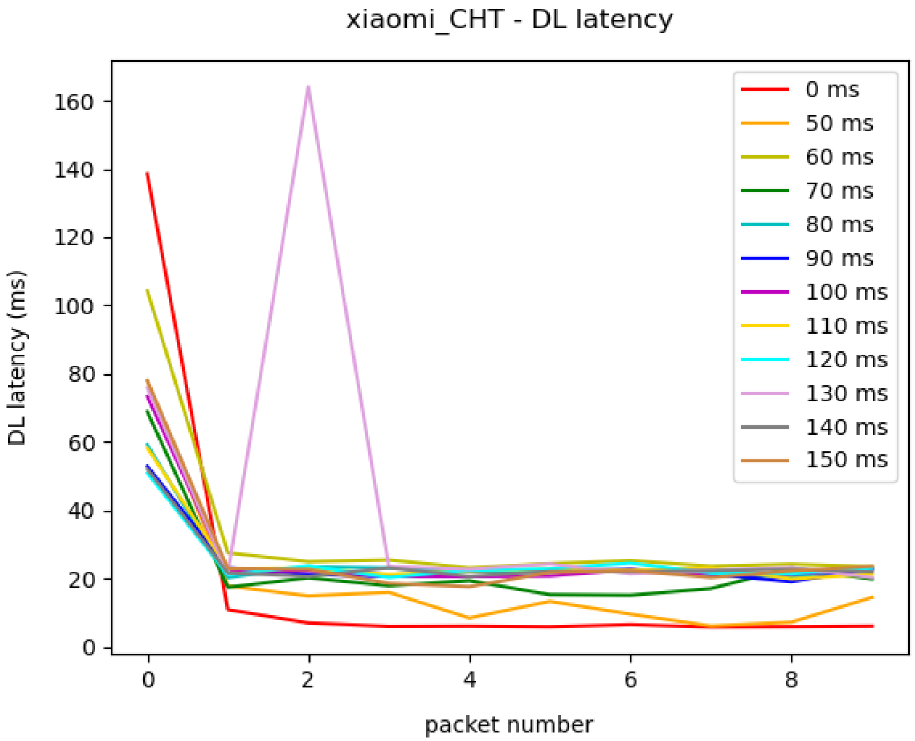




- UL: No obvious tendency
- DL: The first packet has large latency

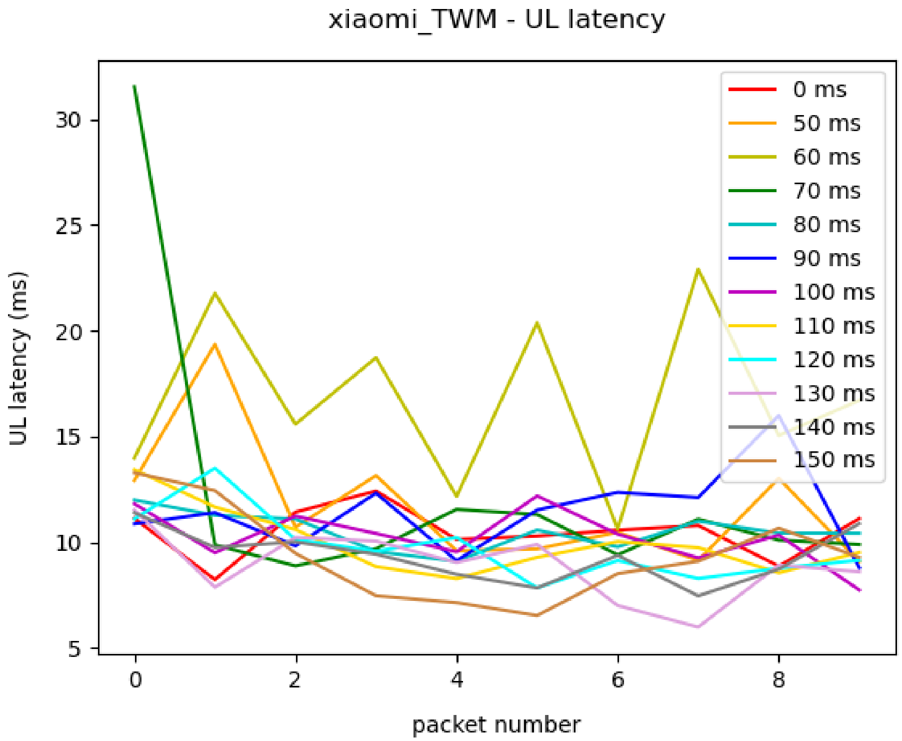
DL First: Result (Xiaomi_CHT)

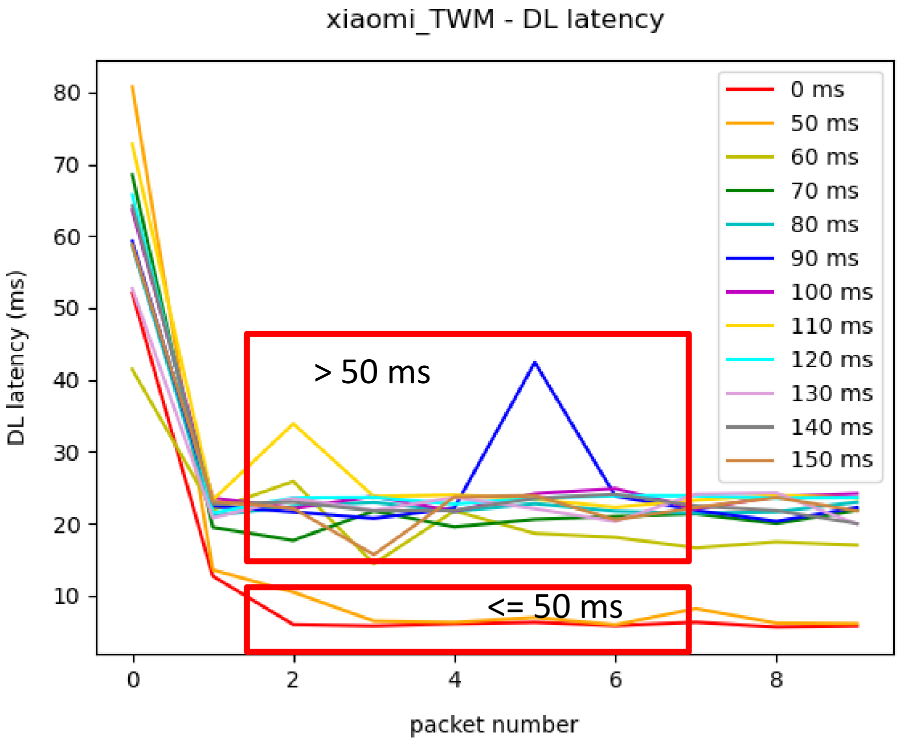




- UL: No obvious tendency
- DL: The first packet has large latency; **some clustering** (threshold : 50-60 ms)

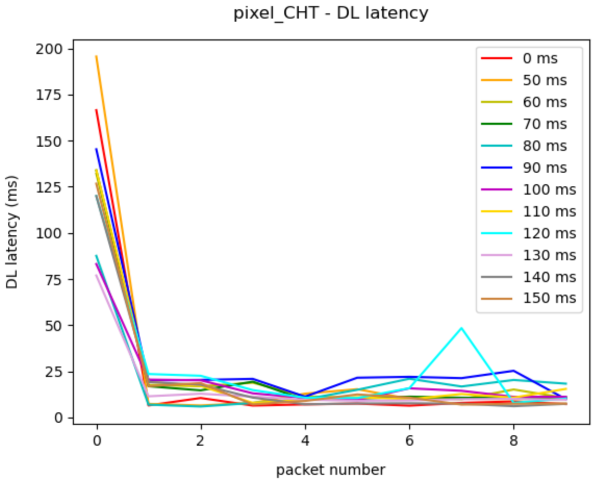
DL First: Result (Xiaomi_TWM)

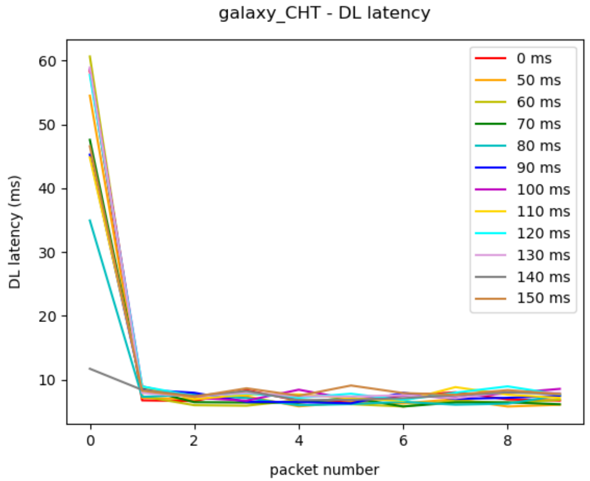


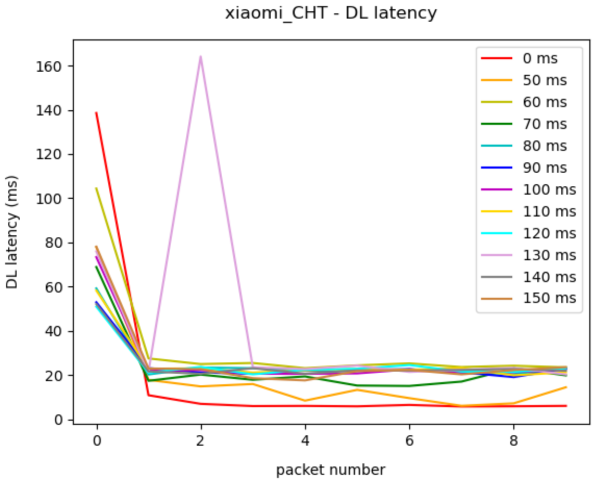


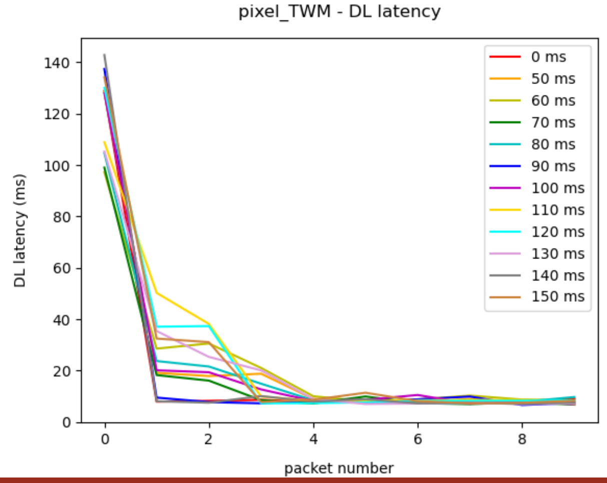
- UL: No obvious tendency
- DL: The first packet has large latency; **obvious clustering** (threshold : 50-60 ms)

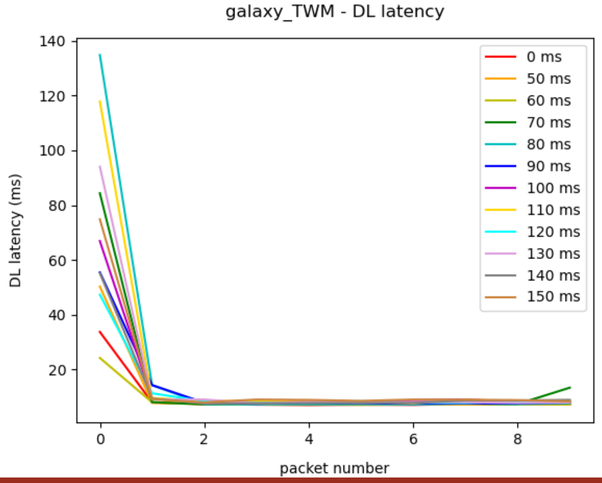
DL First: Result - Comparison

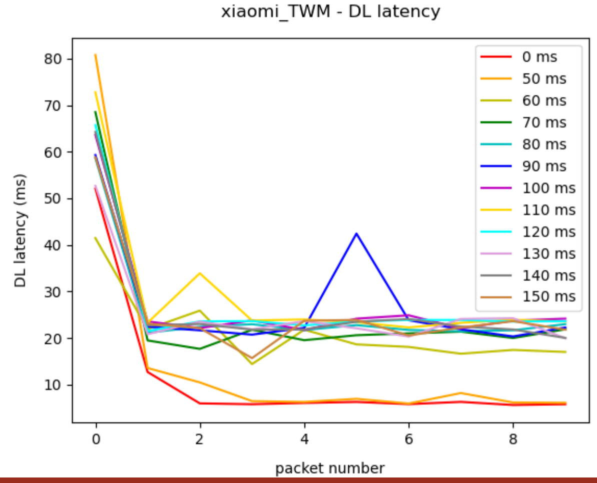












DL First: Result - Table

- Galaxy A42’s behavior seems to be more reasonable

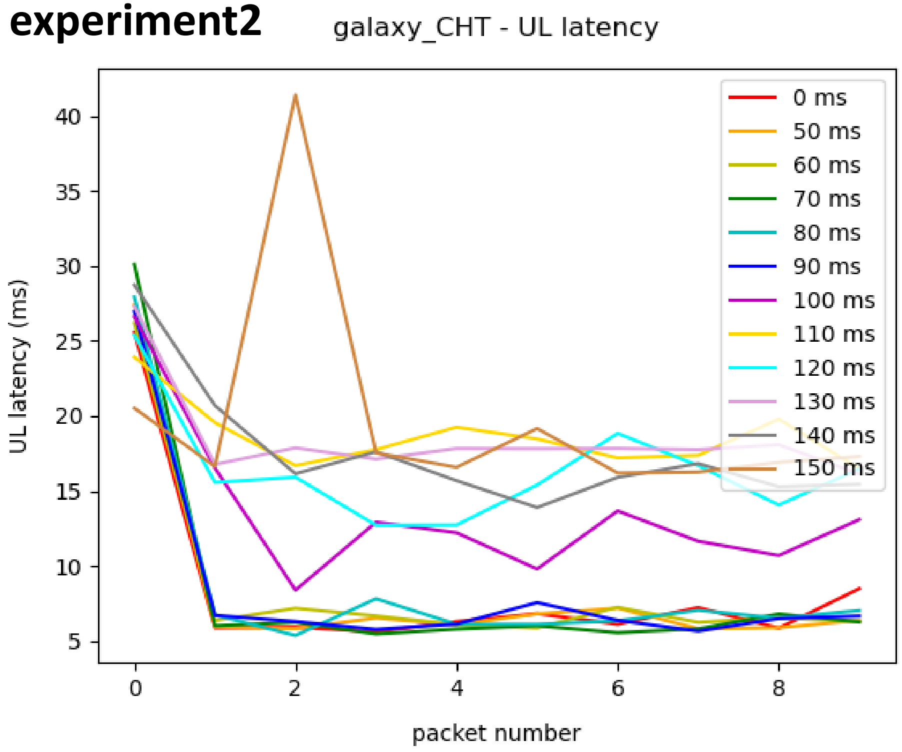
Combination		**Pixel 6a**				**Galaxy A42**				**Xiaomi 10T**			
		All packets		Without first		All packets		Without first		All packets		Without first	
		avg.	std.	avg.	std.	avg.	std.	avg.	std.	avg.	std.	avg.	std.
CHT	UL latency (ms)	10.74	4.65	12.66	7.36	8.6	3.36	8.44	3.07	8.22	5.68	8.3	4.35
	DL latency (ms)	24.18	45.3	14.08	21.01	11.37	18.26	7.18	1.87	26.32	48.91	20.49	8.86
	UL%	30.8%		47.3%		43.1%		54.0%		23.8%		28.8%	
TWM	UL latency (ms)	12.69	6.11	9.41	2.4	8.28	2.18	8.1	2.01	10.91	8.0	12.41	7.75
	DL latency (ms)	22.7	40.42	16.15	26.9	14.38	23.75	8.11	1.08	24.02	22.16	19.0	7.8
	UL%	35.9%		36.8%		36.5%		50.0%		31.2%		39.5%	

Table 3: average UL/DL latency of experiment 3.

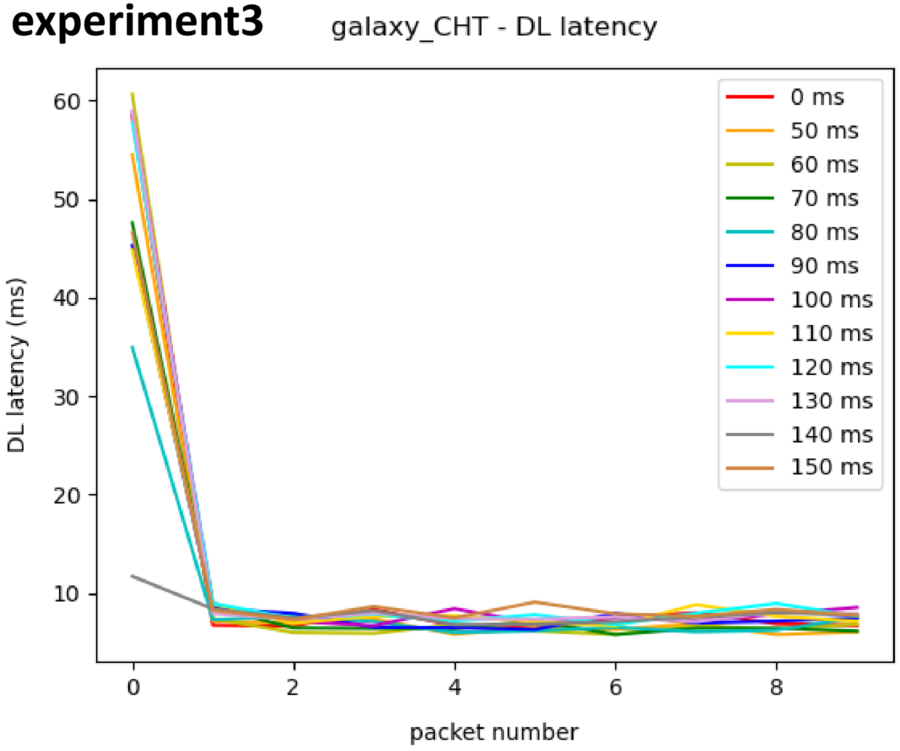
Experiments Comparison: Galaxy_CHT

- Here we use Galaxy A42 (the only phone can run QXDM) as example.

experiment2



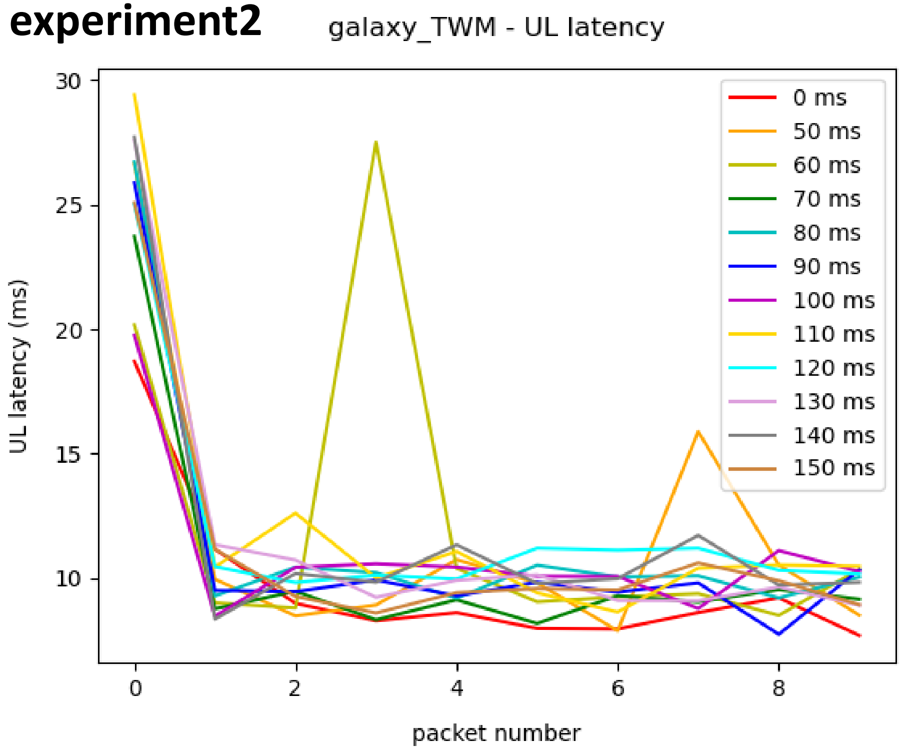
experiment3



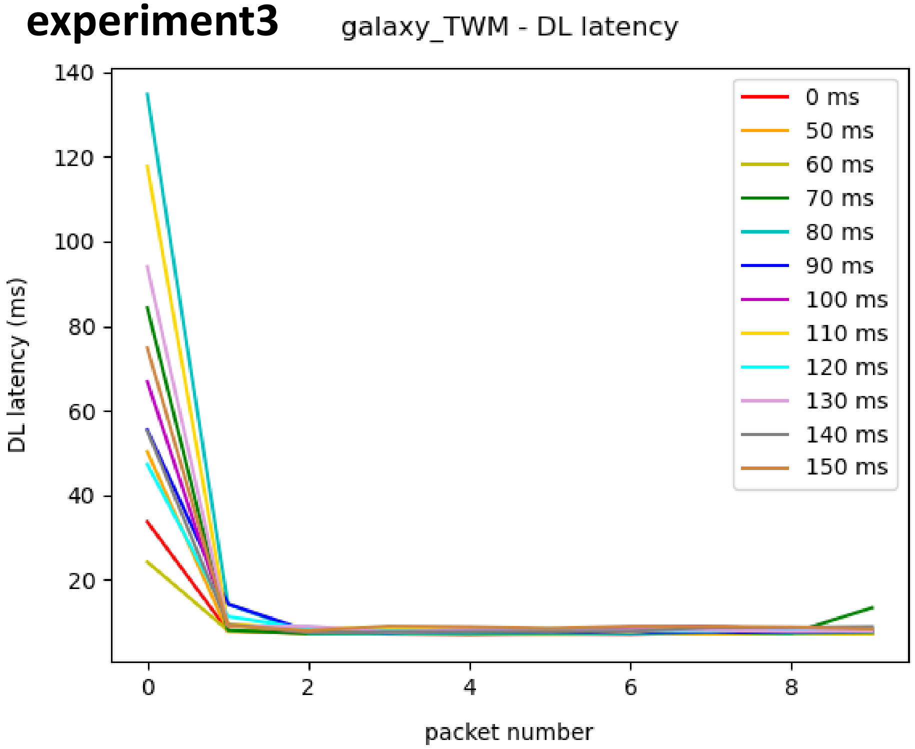
Experiments Comparison: Galaxy_TWM

- Here we use Galaxy A42 (the only phone can run QXDM) as example.

experiment2



experiment3



Experiments Comparison: Table

- The latency of the first UL packet after sleep has lower latency than DL
- Also, the latency of the first UL packet has smaller standard deviation than DL
- DL usually has a smaller latency than UL

Combination		**Pixel 6a**				**Galaxy A42**				**Xiaomi 10T**			
		UL first (experiment 2)		DL first (experiment 3)		UL first (experiment 2)		DL first (experiment 3)		UL first (experiment 2)		DL first (experiment 3)	
		avg.	std.	avg.	std.	avg.	std.	avg.	std.	avg.	std.	avg.	std.
CHT	latency (ms)	76.23 (11.4)	15.19	126.82 (14.08)	73.17	26.39 (12.2)	8.49	48.31 (7.18)	42.24	42.88 (26.72)	12.47	74.17 (20.49)	60.45
TWM	latency (ms)	77.56 (17.21)	10.31	120.4 (16.15)	55.34	24.7 (9.31)	6.65	69.91 (8.11)	46.08	53.17 (42.02)	27.52	61.55 (19.0)	48.81

Table 4: comparison of experiment 2 & 3. (): the average latency without first packet)

DRX Event Logs Analysis

DRX Parameters

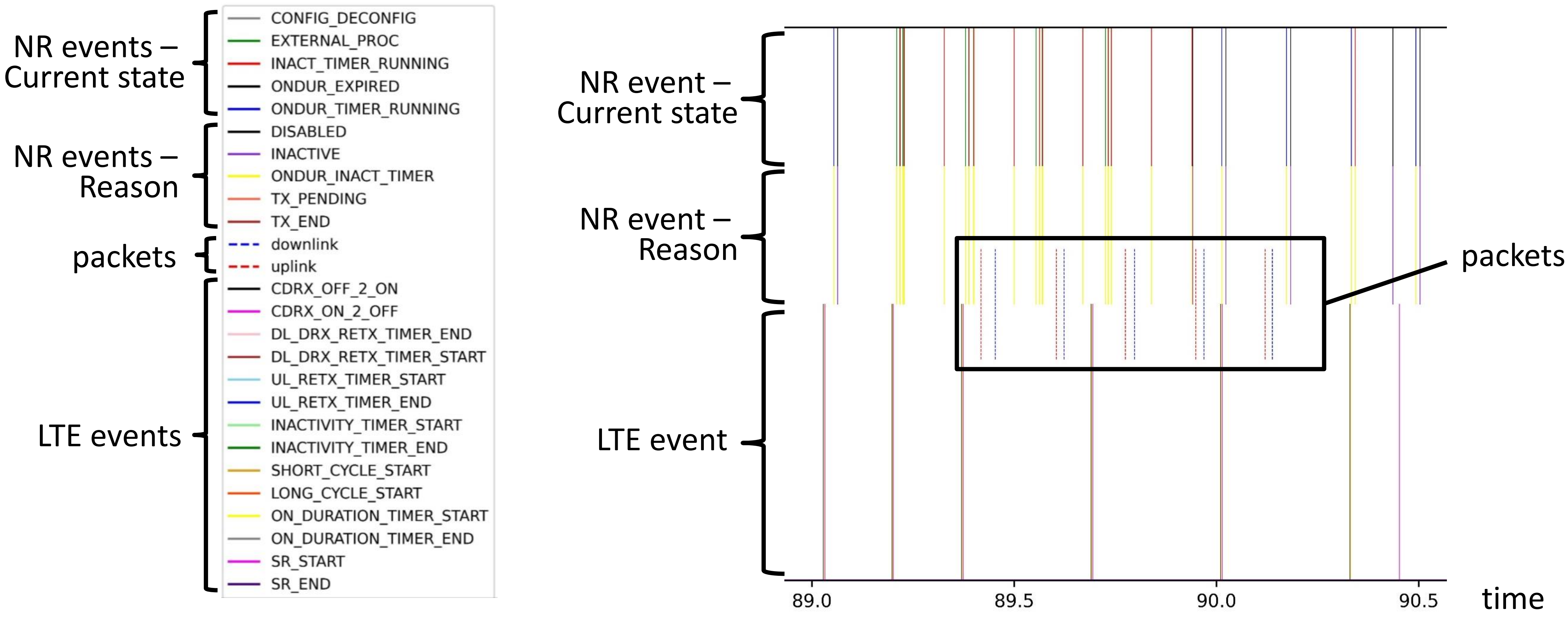
LTE (3GPP TS 36.321)	NR5G (3GPP TS 138.321)
• DRX Inactivity Timer	• drx-InactivityTimer
• DRX Retransmission Timer	• drx-RetransmissionTimerDL/UL
• DRX Short Cycle Timer	• drx-ShortCycle (optional)
	• drx-ShortCycleTimer (optional)
• HARQ RTT Timer	• drx-HARQ-RTT-TimerDL/UL
• On Duration Timer	• drx-onDurationTimer
• RA-RNTI	• drx-SlotOffset
	• drx-LongCycleStartOffset

DRX Parameters

Parameters are configured by RRC.

- *DRX-onDurationTimer:* How long to keep listening in a cycle
- *DRX-SlotOffset*: Time to wake up UE
- *DRX-InactivityTimer:* How long to keep listening after receiving
- *shortDRX-Cycle:* Cycle length (ms) of short DRX
- *DRX-ShortCycleTimer:* When to switch from short cycle to long cycle after a period without receiving

Figure Illustration



NR events – Current state

NR events – Reason

packets

LTE events

NR event – Current state

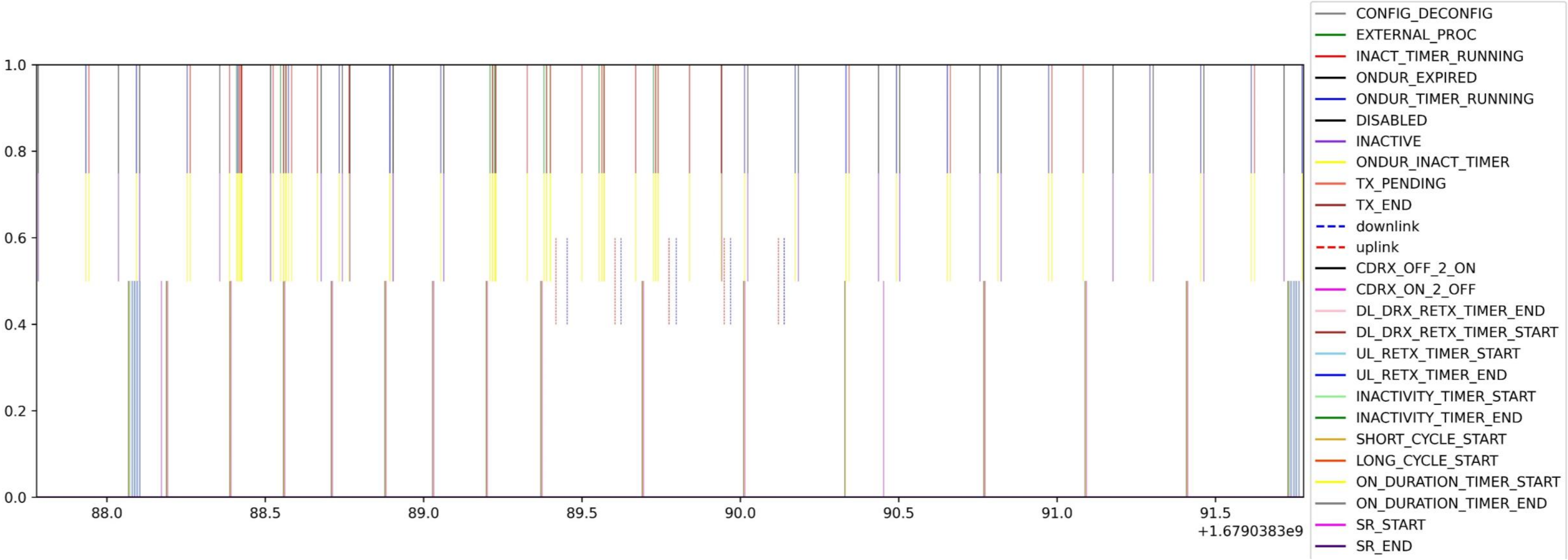
NR event – Reason

packets

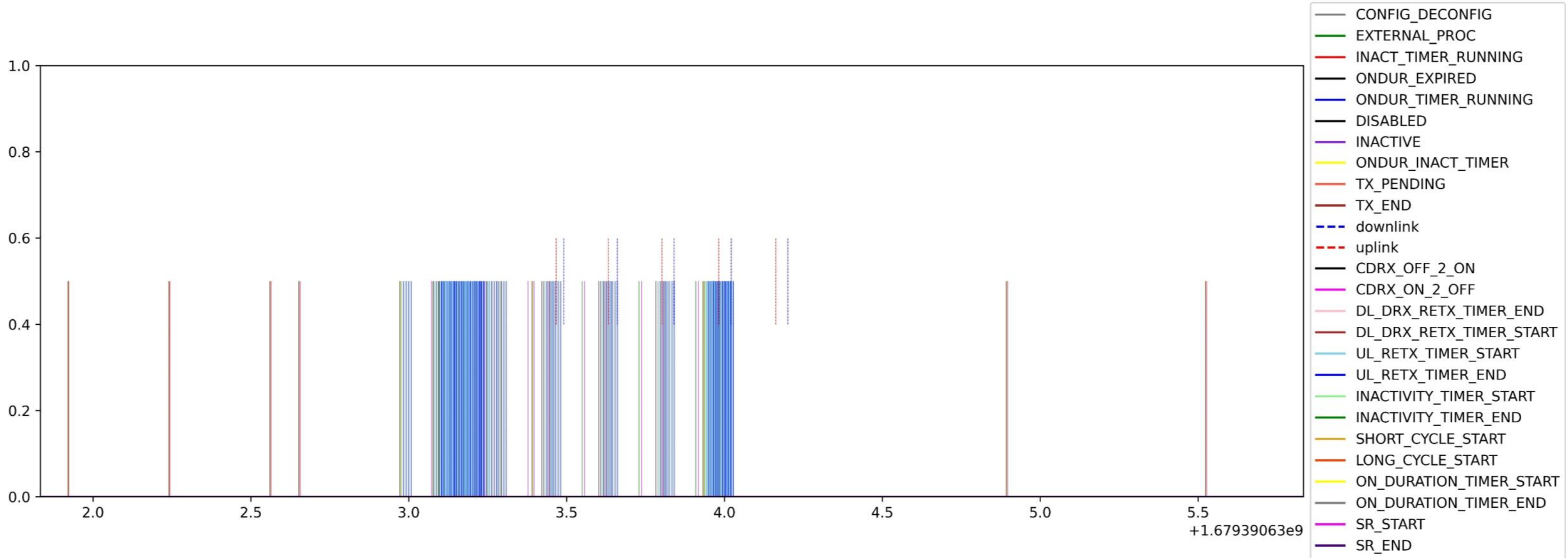
LTE event

time

Figuration - NSA



Figuration - LTE Only


+1.67939063e9
CONFIG_DECONFIG
EXTERNAL_PROC
INACT_TIMER_RUNNING
ONDUR_EXPIRED
ONDUR_TIMER_RUNNING
DISABLED
INACTIVE
ONDUR_INACT_TIMER
TX_PENDING
TX_END
downlink
uplink
CDRX_OFF_2_ON
CDRX_ON_2_OFF
DL_DRX_RETX_TIMER_END
DL_DRX_RETX_TIMER_START
UL_RETX_TIMER_START
UL_RETX_TIMER_END
INACTIVITY_TIMER_START
INACTIVITY_TIMER_END
SHORT_CYCLE_START
LONG_CYCLE_START
ON_DURATION_TIMER_START
ON_DURATION_TIMER_END
SR_START
SR_END