Project: IEEE P802.15 Working Group for Wireless Personal Area Networks (WPANs)

Submission Title: Coex Proposal by Meta to BT-SIG

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Re: **Study Group 4ab: UWB Next Generation**

Abstract: [This provides the coex proposal made by Meta to BT-SIG]

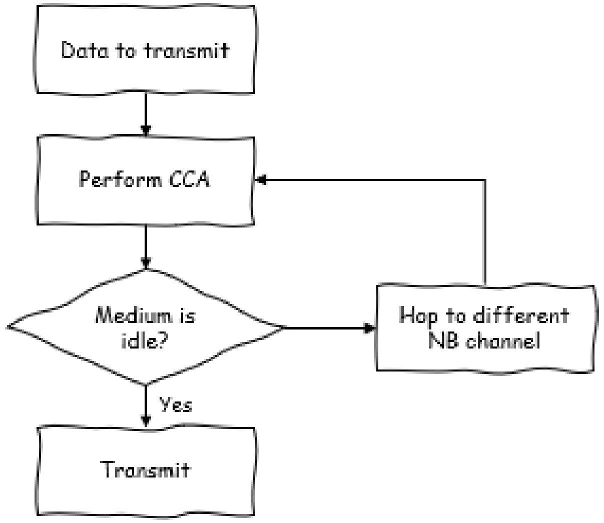
Purpose: [This shows effects of LBT to both Wi-Fi and NB devices]

Outline

- Background
- Proposal
- Simulation Results
- Conclusions

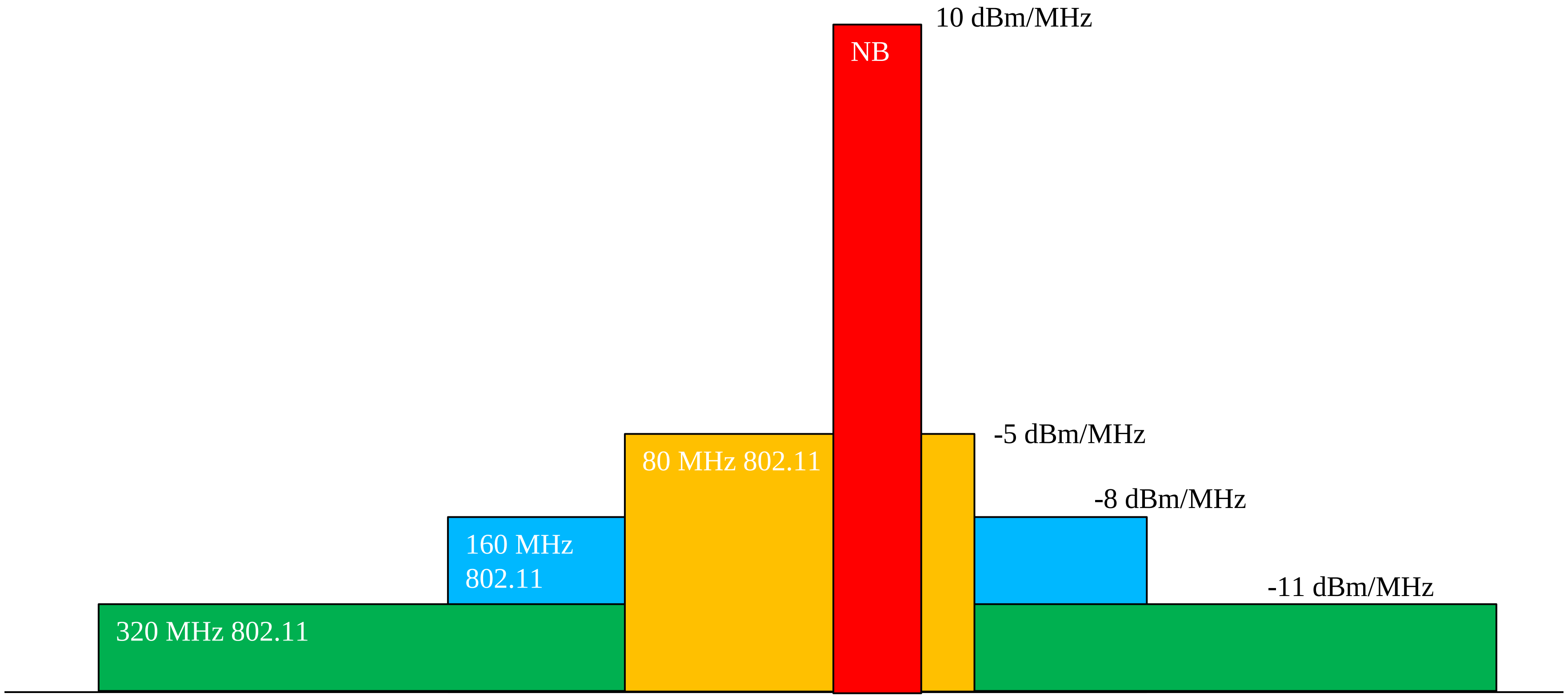
Background

- NB technology is currently allowed in Europe as specified in EN 303687 with a 10dBm/MHz PSD and 14 dBm TX Power.
  - Wi-Fi VLP has the same TX Power but much reduced PSD: -5/-8/-11 dBm (for 80/160/320 MHz) which means that NB has a 15/18/21 dB PSD advantage over Wi-Fi VLP using 80/160/320 MHz.
  - This implies that NB will significantly interfere with Wi-Fi VLP operations using 80/160/320 MHz, hence a coex scheme is required for NB technology in Higher Band.
- Bluetooth SIG made a channel access proposal to ETSI based on LBT in BRAN(24)123a003r1



Background: Europe 6 GHz NB vs 802.11 VLP spectrum

NB with 14 dBm EIRP is 15/18/21 dB stronger than 802.11 VLP with 80/160/320 MHz



Note that skirts associated with NB spectrum are not shown and affect many 802.11 sub-carriers

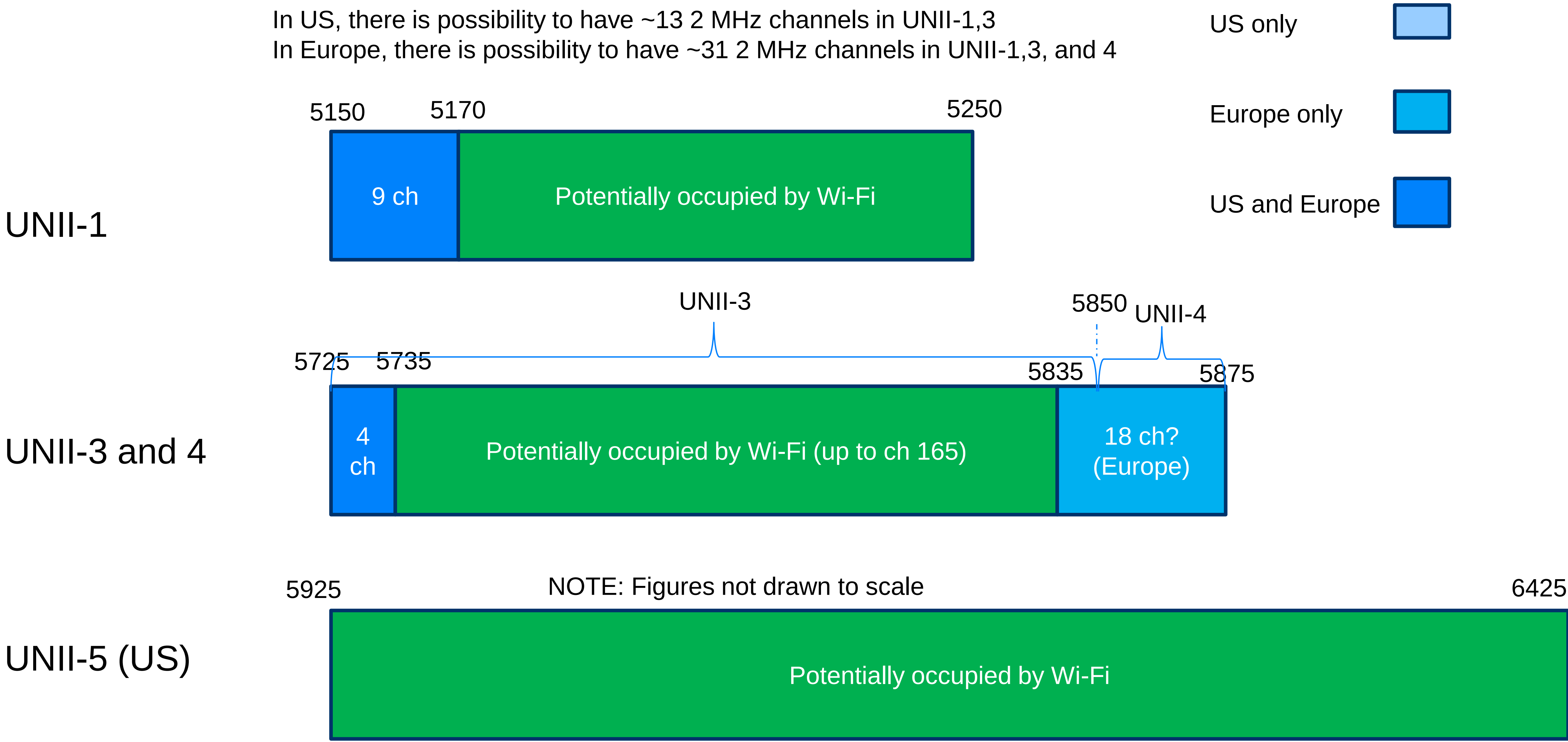
Background on Spectrum

Frequency Range (MHz)	Bandwidth (MHz)	U-NII name
5150-5250	100	U-NII-1
5250-5350	100	U-NII-2A
5350-5470	120	U-NII-2B
5470-5725	255	U-NII-2C
5725-5850	125	U-NII-3
5850-5925	75	U-NII-4
5925-6425	500	U-NII-5
6425-6525	100	U-NII-6
6525-6875	350	U-NII-7
6875-7125	250	U-NII-8

- BLE covers 5 GHz (UNII-1, UNII-3, UNII-4) and 6 GHz (UNII-5)
  - 800 MHz of additional spectrum in UNII-1,3,4 and 5
  - Not Considered UNII 6-8 band - additional 700 MHz
- Potential occupancy of Wi-Fi in HB? See ref here
  - UNII-1: 80 MHz [20 MHz non-overlapping]
  - UNII-3: 100/115 MHz (up to ch 165/169) [24/10 MHz non-overlapping]
  - UNII-4: 45 MHz in US (if ch 169-177 used) [0 MHz non-overlapping in US]
  - 0? In Europe [24 MHz non-overlapping in Europe?]
  - UNII-5 : 500 MHz [0 MHz non-overlapping]

Location of non-overlapping spectrum shown in blue

In US, there is possibility to have ~13 2 MHz channels in UNII-1,3
In Europe, there is possibility to have ~31 2 MHz channels in UNII-1,3, and 4



NOTE: Figures not drawn to scale

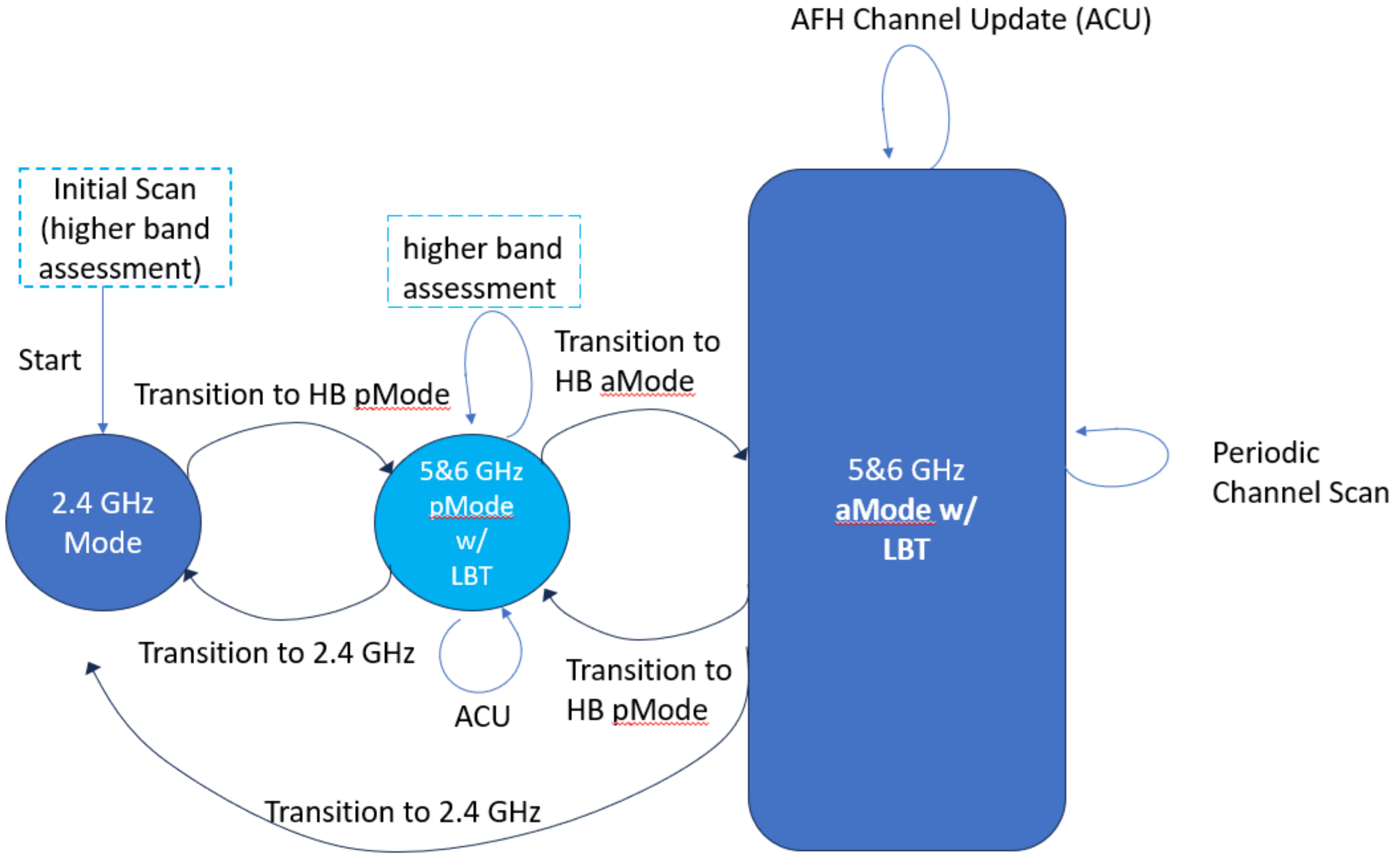
Key Aspects

- The proposed coex mechanism is based on 4 concepts:
  - **Primary mode, called pMode,** uses “non-overlapping” non-802.11 channels called “primary channels”. **All-Channel mode, called aMode,** uses both the “non-overlapping” and “overlapping” channels. When the device enter HB, it first enters pMode.
  - **Mandatory LBT**
  - **A device entering aMode shall perform the following**
    - **Initial scan** - reliable scan in HB that detects occupied channels (WB, or both NB and WB),
    - **Ongoing scan -** HB scanning during data transmission provides more detailed information about channel utilization (CU) and detecting any new interference
  - A device may stay in pMode without doing either the initial scan or ongoing scan
  - If all HB overlapping channels deemed “occupied” or link budget is not met, BLE can either go back to the non-overlapping channels, 2.4 GHz, or go to least occupied overlapping 20 MHz segment(s)

Meta’s Proposed Block Diagram

Two modes - pMode & aMode. pMode is primary mode - NB operation using “non-overlapping” channels. aMode uses all channels

CCA in Higher band allows for deferral in both aMode and pMode.



LBT Proposal

- Mandate LBT for Central device
- LBT by the Peripheral may not be needed if gap between central and peripheral transmissions is short enough (e.g. 25us)
- LBT with a CCA for a duration between 14-25us window before transmitting. If medium is sensed busy, defer; else transmit

Proposal of Initial Scan for devices planning to use aMode

- Initial scanning to detect WB interference
  - BLE Central may use 20 MHz scan to improve accuracy and/or duration
  - Mandate a maximum channel switch time for scanning (e.g. 25, 50, 75us)
    - 75us improves scan duration ~ 2x over 150us switch time (see Appendix)
- To improve scan/detection accuracy
  - Require 99% success probability at each channel to detect CU (Channel Utilization) > = 10%
- Testing of initial scan - test the DUT detects interference by confirming it does not transmit in “any” occupied 20 MHz channel

Proposal for Ongoing Scan

- Ongoing Scanning
  - Periodically every channel that the device may use should be scanned
  - Periodic scan time (e.g. 2ms in a 10ms connection interval, every X ms)
    - For example, if X= 40ms, the scan duty cycle is 5%
  - Compute CU (Channel Utilization) metric during the Ongoing Scan
- To reduce ongoing scanning time
  - Central could use a 20 MHz scan to speed up channel scan and/or improve accuracy
  - A smaller channel switch time (e.g. 25us/50us/75us) can also help speed up channel scan
- To improve scan/detection accuracy
  - Require at least 99% success probability at each channel to detect CU (Channel Utilization) > = 10% within TBD ms
- Power save option
  - Period of Ongoing Scan (value of X above) can be configured
  - Another possibility to avoid ongoing scan is to stay in pMode

Simulation Results

Simulations

Case 1: BLE/BLE in 30 channels (pMode), with no overlap with Wi-Fi

Case 2: BLE/Wi-Fi coex in 70 channels (57% overlap with Wi-Fi)

- 30 non-overlapping channels
- 40 channels overlapping 100% with an 80 MHz Wi-Fi with ~20% CU
- CU information not available to BLE

Case 3: BLE/Wi-Fi coex in 70 channels (57% overlap with Wi-Fi)

- identical to case 2 above but CU information is available to BLE

- Case 1 examines BLE LBT vs no LBT
- Figures examine line of sight (LOS) vs. non-line of sight (NLOS) between a central and its peripherals.
- LOS Channel model includes free space loss with a coefficient of 2 up to a breakpoint distance (d_BP), and 3.5 beyond d_BP.
  - d_BP = 10 to represent an indoor office scenario
- NLOS channel model adds an extra 30 dB of attenuation to LOS
- BLE throughput is normalized and Wi-Fi throughput,P50,P95 latency are shown.

BLE Parameters

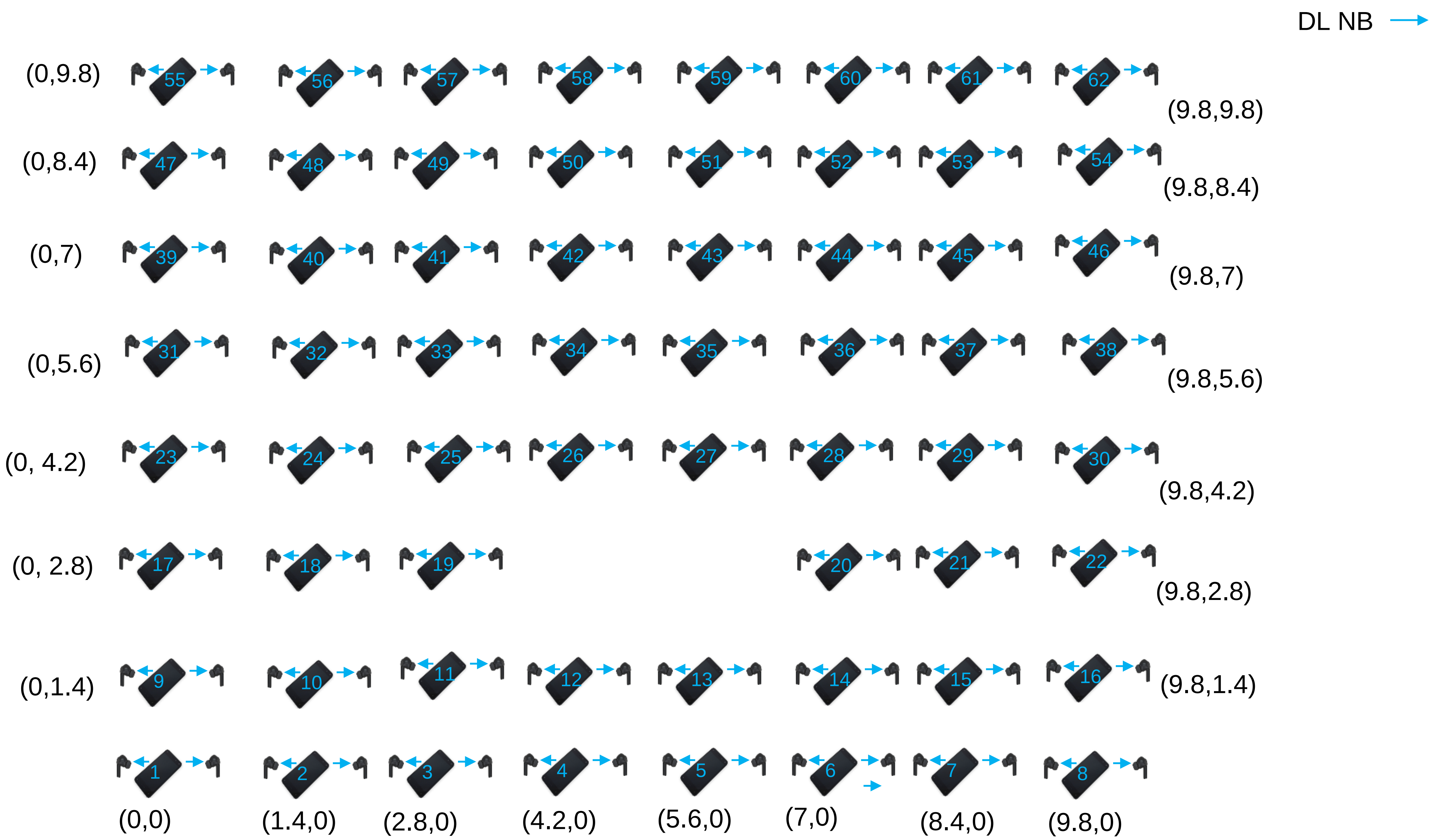
- 2 peripherals per central, 96 Kbps traffic to both, CIS traffic
- 10 ms ISO period
- 6 TX attempts over two ISO periods (NSE=3, FT=2)
- -75 dBm/MHz Energy Detection threshold
- Spectral mask with 35 dB drop in the adjacent 2 MHz channel and 50 dB drop in the next channel after that
- 14 dBm transmit power
- 25 us LBT before TX for both central and peripheral

Wi-Fi Parameters

- 100 Mbps 72 Hz DL, 3 Mbps 500 Hz UL
- 802.11ax: 80 MHz, MCS 11, NSS 2, 0.8us GI (~1.2 Gbps PHY) ~21% Channel Utilization (CU)
- Size 256 BA window
- RTS/CTS on
- A-MSDU aggregation off
- 14 dBm TX power
- Beacons are included

Case 1 30 channel BLE/BLE

BLE only


DL NB
(0,9.8)
55
56
57
58
59
60
61
62
(9.8,9.8)
(0,8.4)
47
48
49
50
51
52
53
54
(9.8,8.4)
(0,7)
39
40
41
42
43
44
45
46
(9.8,7)
(0,5.6)
31
32
33
34
35
36
37
38
(9.8,5.6)
(0, 4.2)
23
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30
(9.8,4.2)
(0, 2.8)
17
18
19
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21
22
(9.8,2.8)
(0,1.4)
9
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11
12
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16
(9.8,1.4)
1
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4
5
6
7
8
(0,0)
(1.4,0)
(2.8,0)
(4.2,0)
(5.6,0)
(7,0)
(8.4,0)
(9.8,0)

30 Channel BLE/BLE

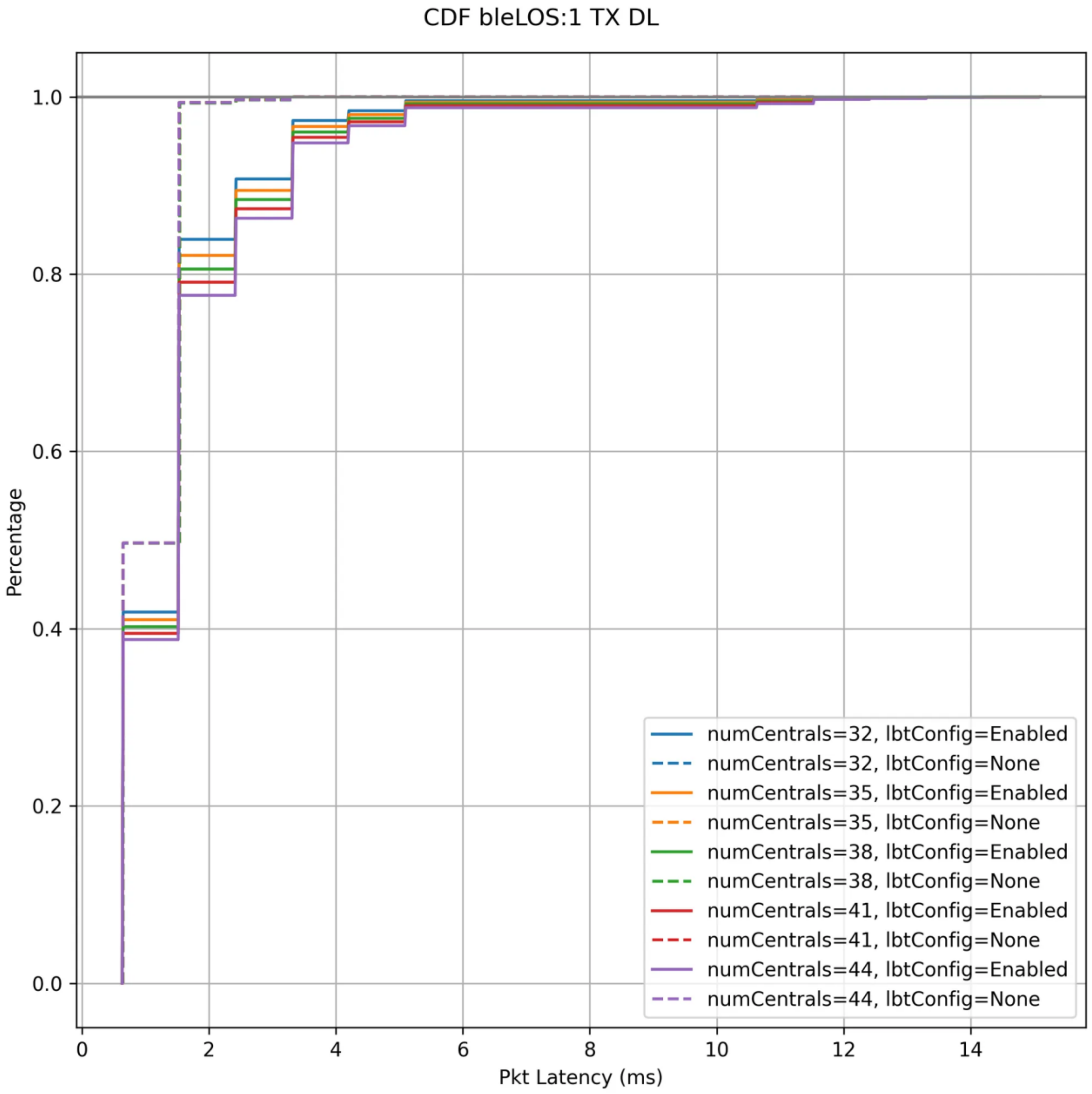
- Examines LBT and no LBT in both LOS and NLOS scenarios where only BLE devices are present

Takeaways:

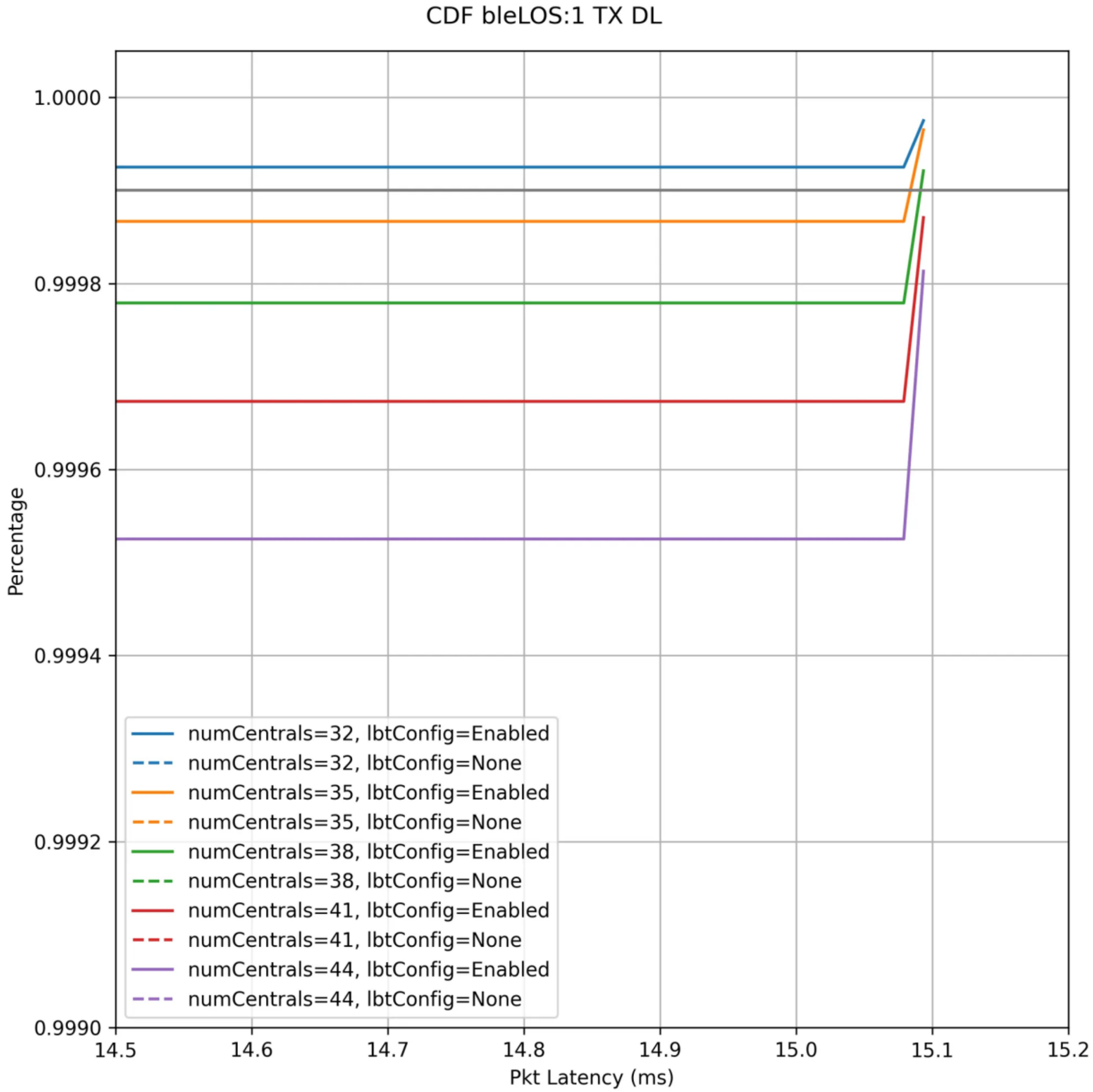
- LOS
  - No LBT slightly outperforms LBT
    - Most of the time both packets succeed, which is why no-LBT is better.
  - LBT can support ~ 30-40 centrals, depending on flush rate (e.g., ~39 centrals meet 0.01% flush rate)
- NLOS
  - LBT significantly outperforms no LBT
    - With LBT, when a collision happens, only 1 packet is “lost” whereas with no LBT both packets are “lost”.
  - LBT can support ~30-40 centrals, depending on flush rate (e.g., ~37 centrals meet 0.01% flush rate)

BLE/BLE LOS Latency

LBT is solid and no-LBT is dashed



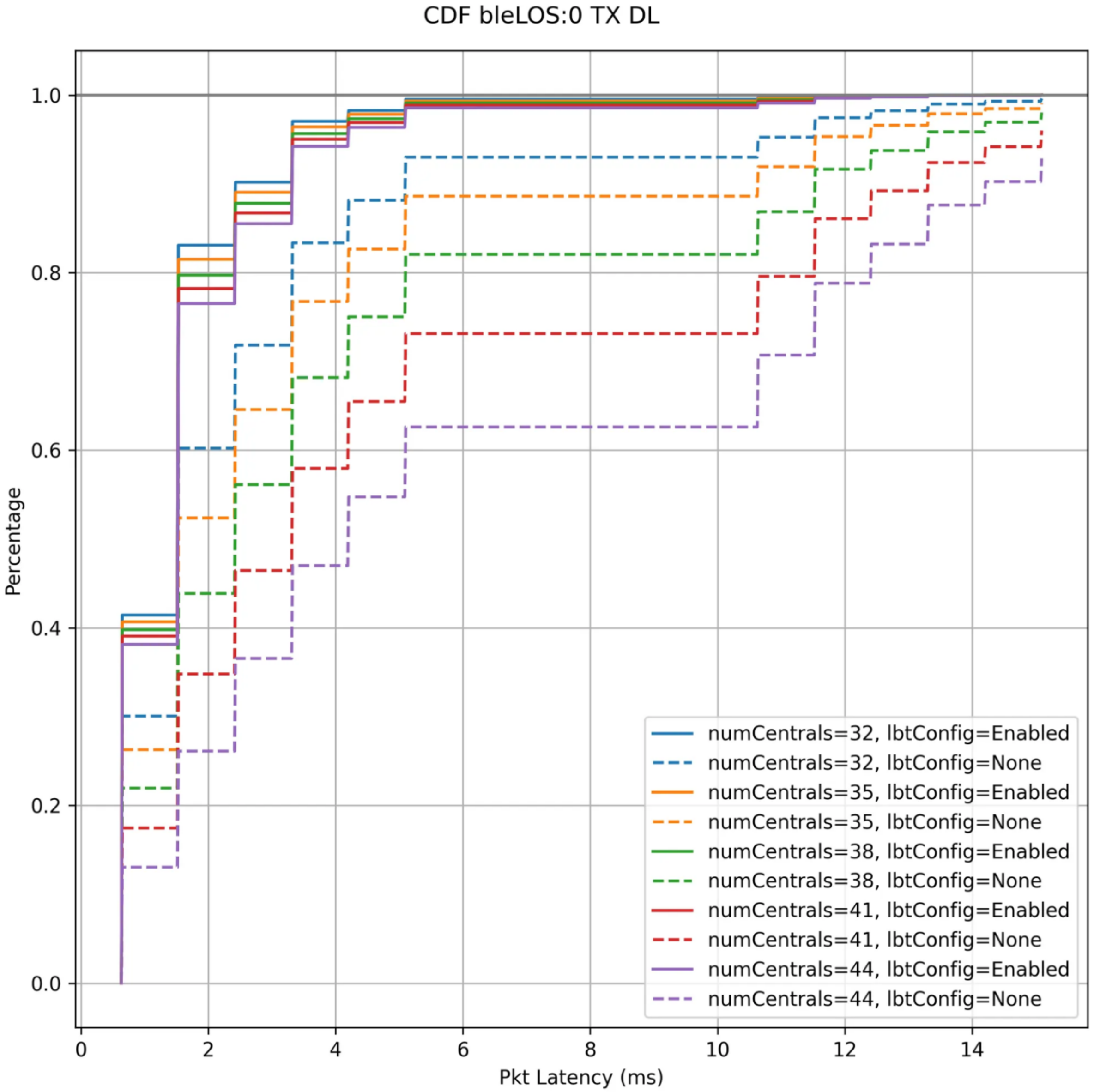
*Zoomed-in version of graph on left

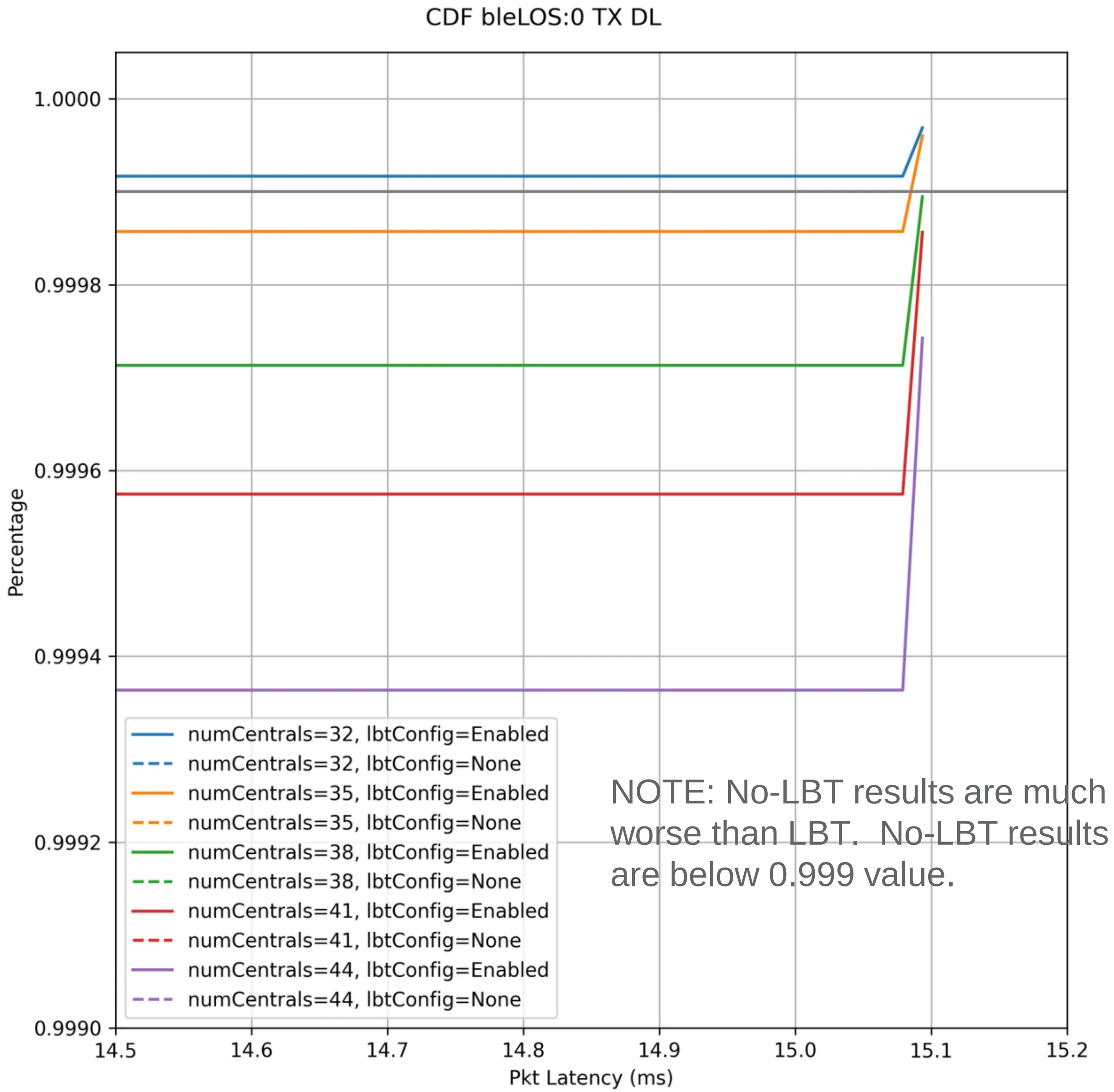


BLE/BLE NLOS Latency

LBT is solid and no-LBT is dashed

*Zoomed-in version of graph on left

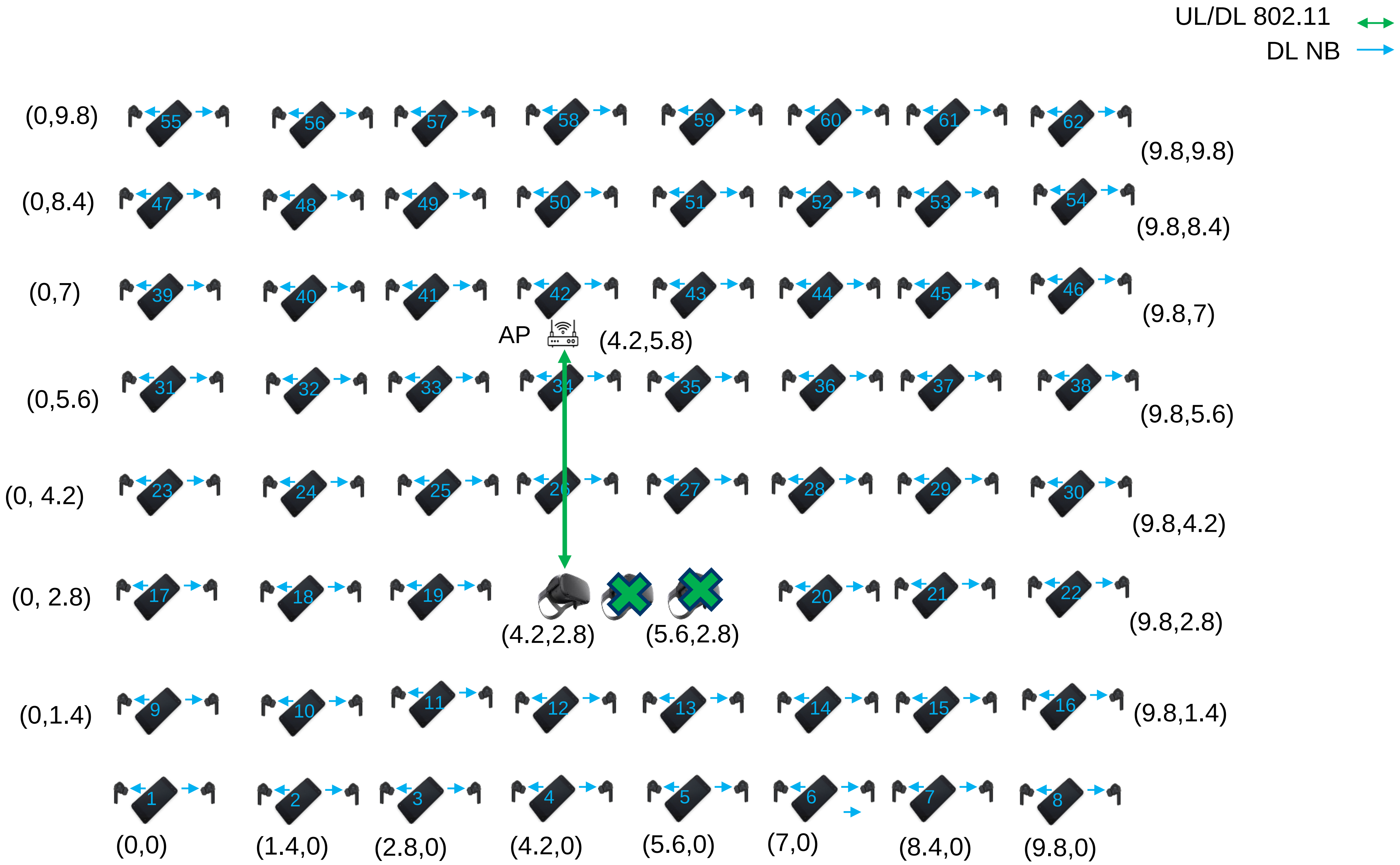




NOTE: No-LBT results are much worse than LBT. No-LBT results are below 0.999 value.

Case 2 BLE/Wi-Fi 57% Overlap with 21%CU, CU information not available to BLE

1 STA Scenario



70 Channel BLE/Wi-Fi 57% Overlap

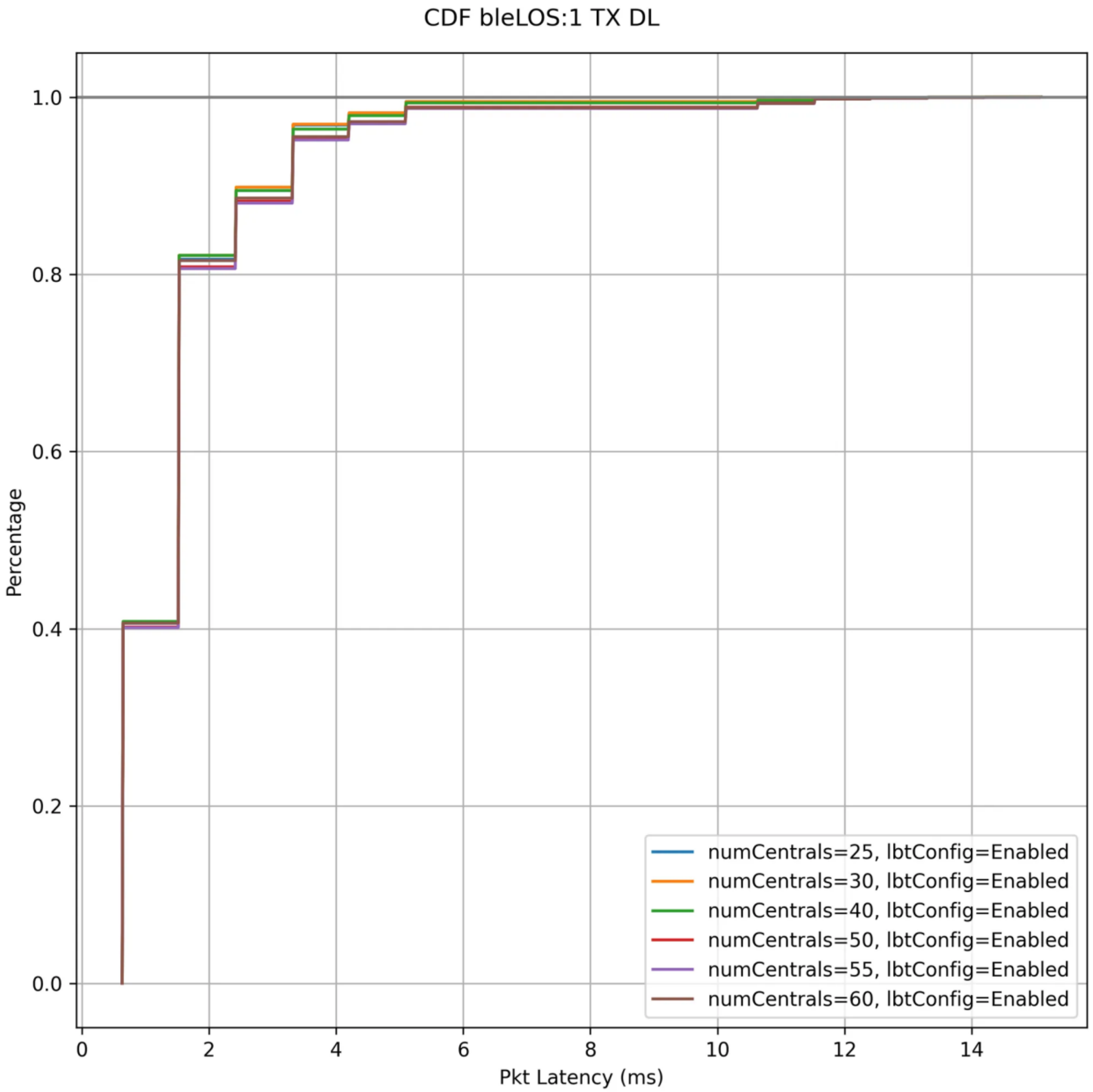
- Examines only LBT in both LOS and NLOS scenarios
- No LBT causes unacceptable Wi-Fi degradation
- Clear channels used at a ratio of 1:1 compared to overlapped Wi-Fi channels

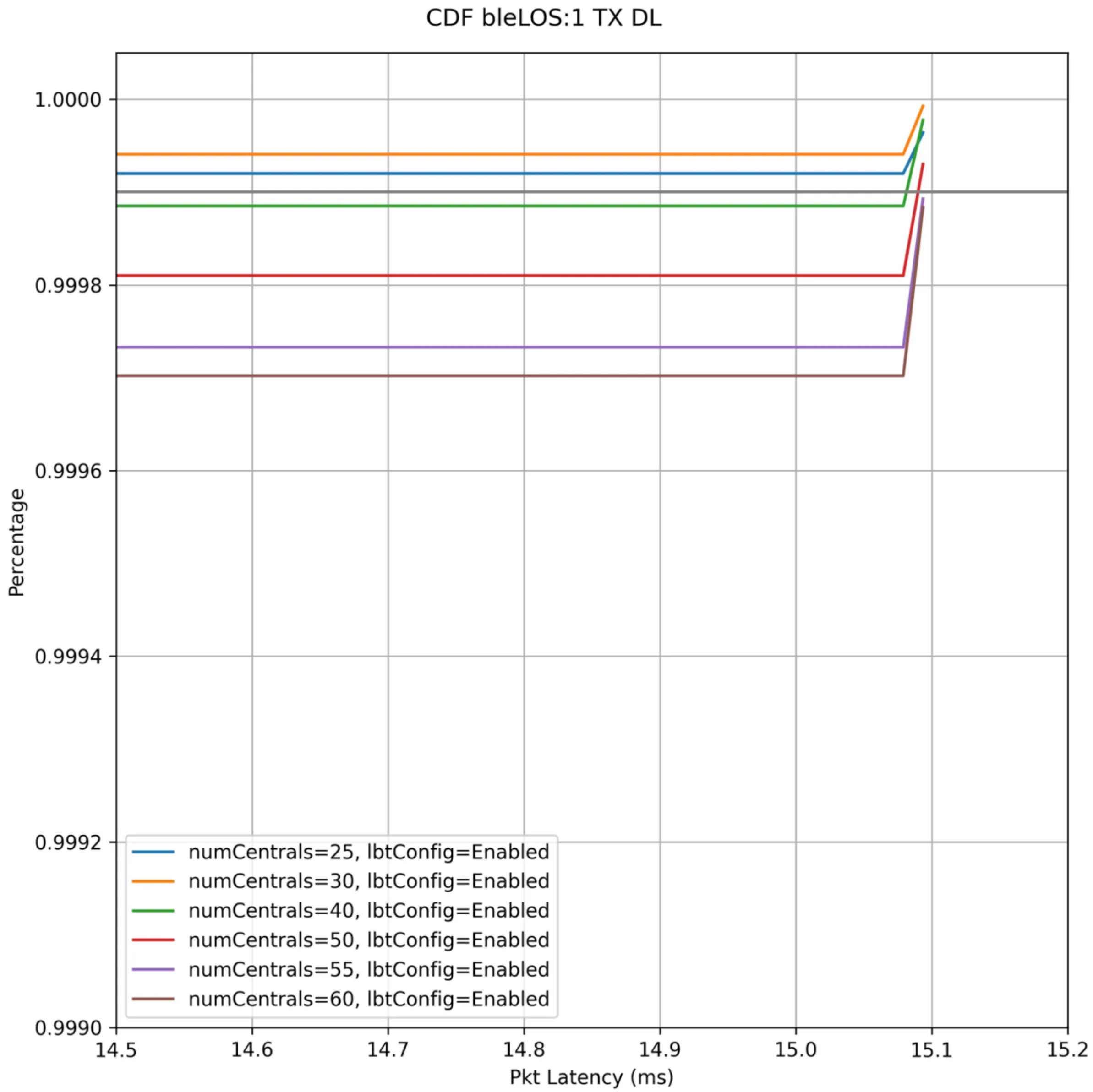
Takeaways:

- **~27 BLE centrals can be supported due to Wi-Fi P95 latency constraints, which is worse than BLE/BLE 30 channel case, which can support around 38 BLE centrals**
- **At 50 centrals, P95 Wi-Fi burst latency is ~75ms**

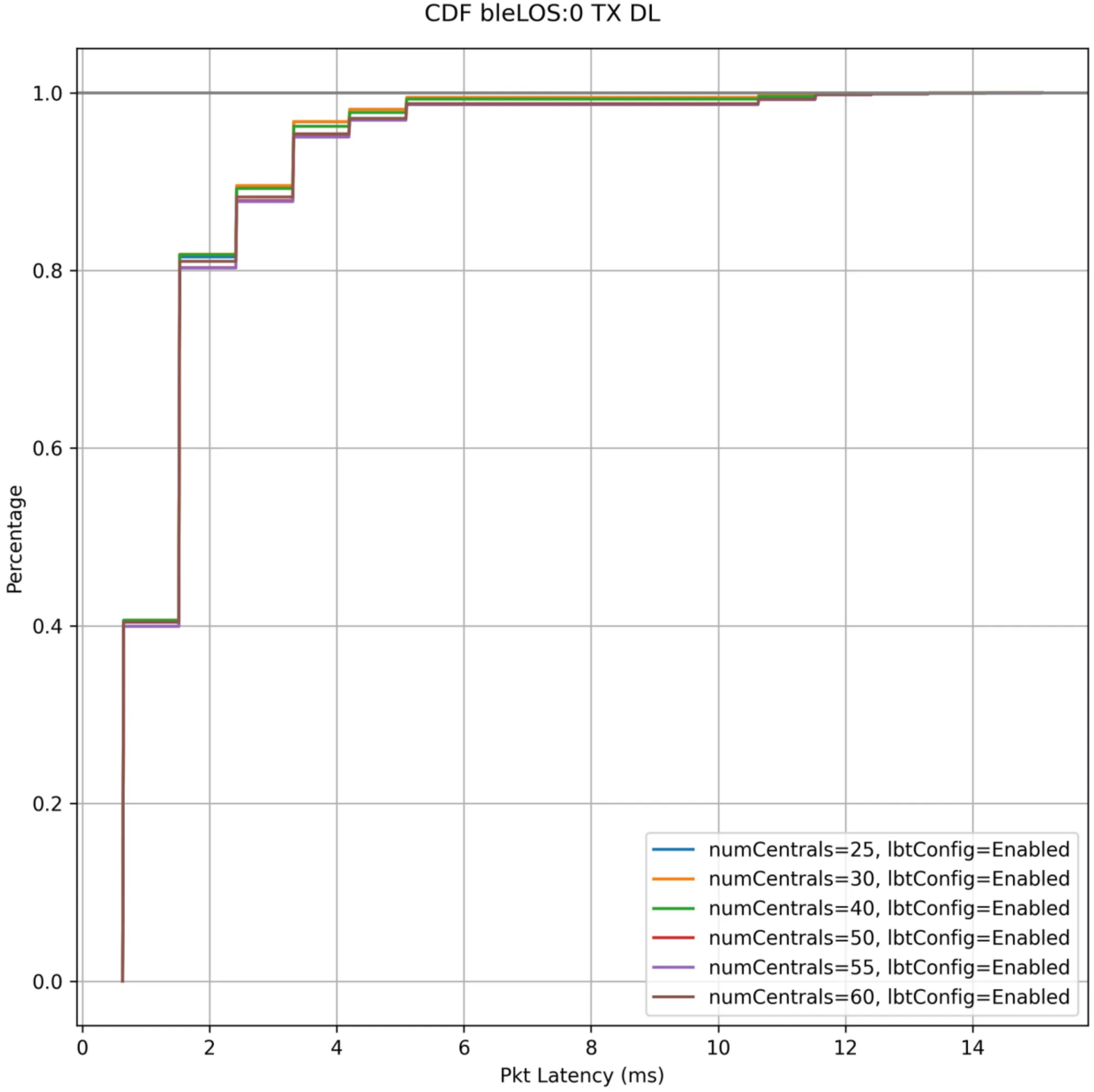
BLE/Wi-Fi 57% Overlap Even Time Split LOS BLE Latency

*Zoomed-in version of graph on left

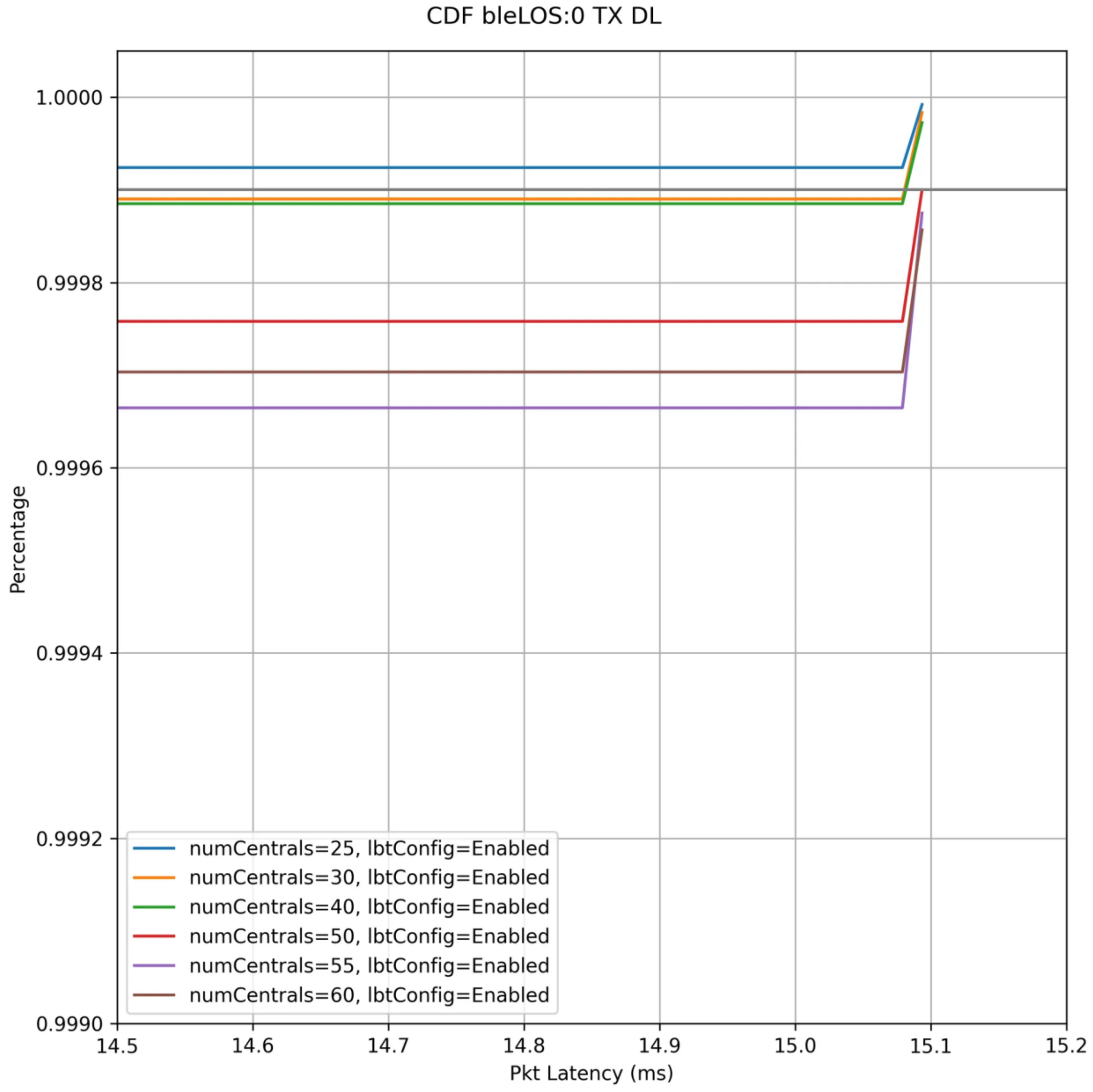




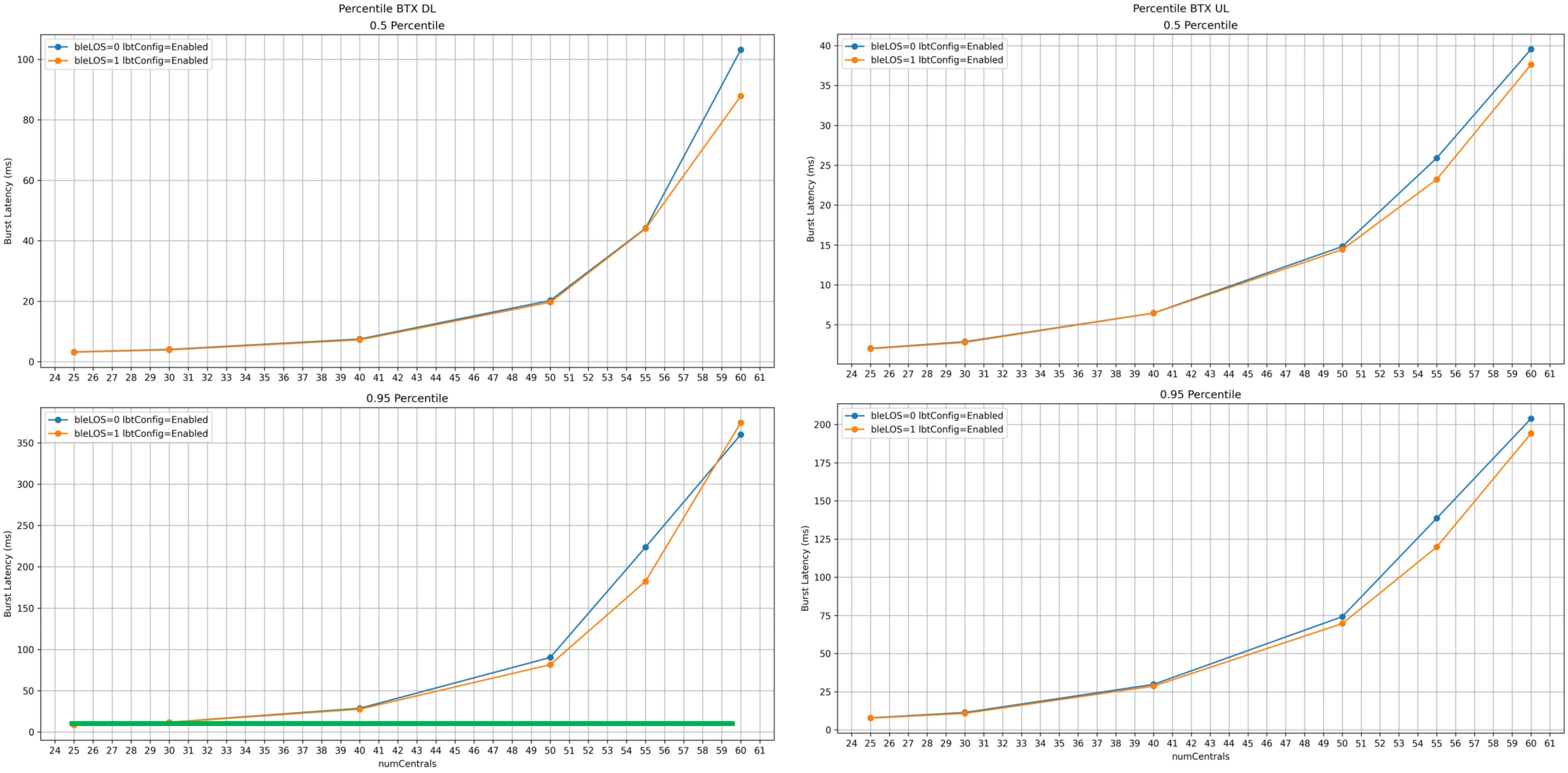
BLE/Wi-Fi 57% Overlap Even Time Split NLOS BLE Latency



*Zoomed-in version of graph on left

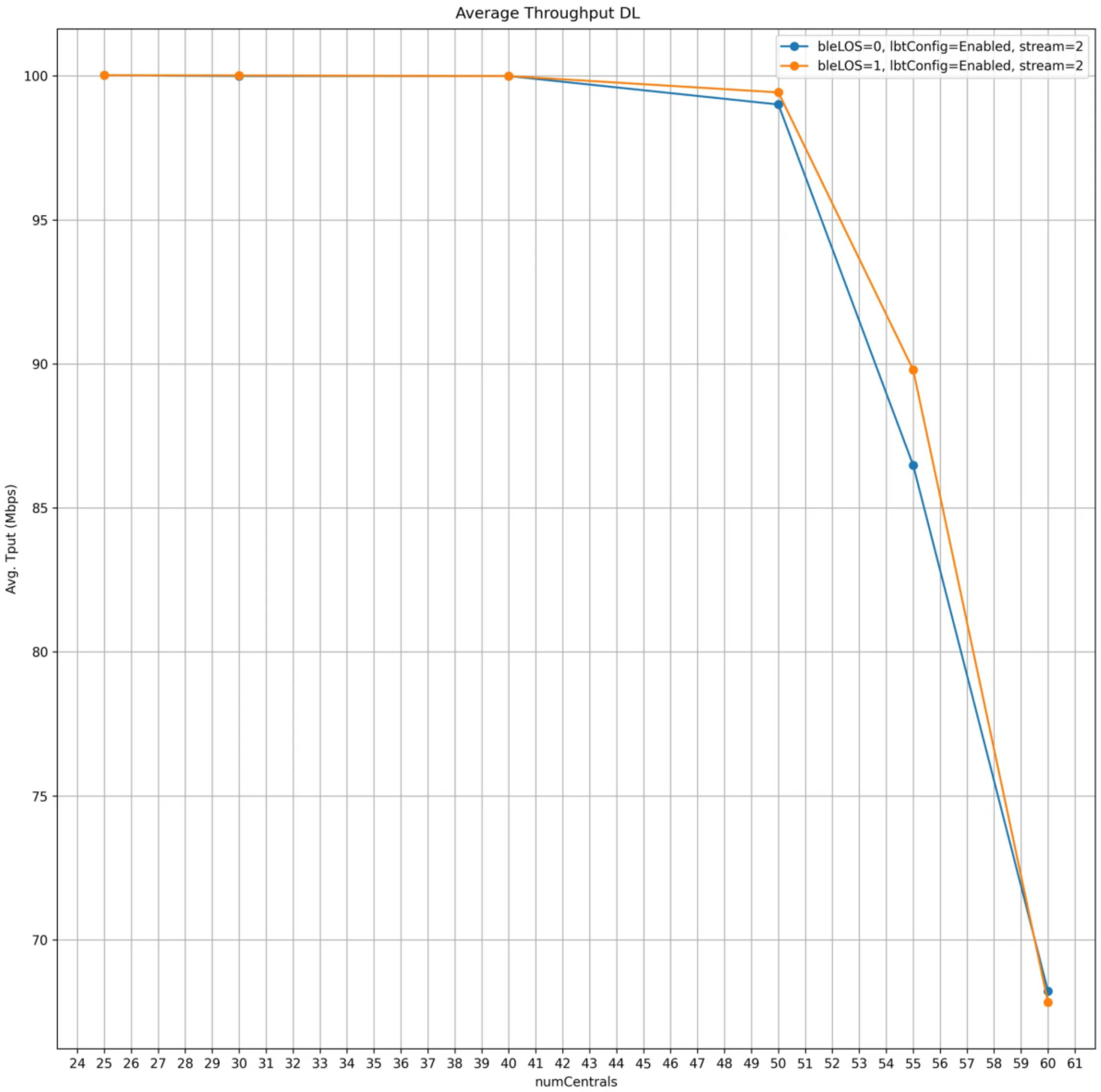


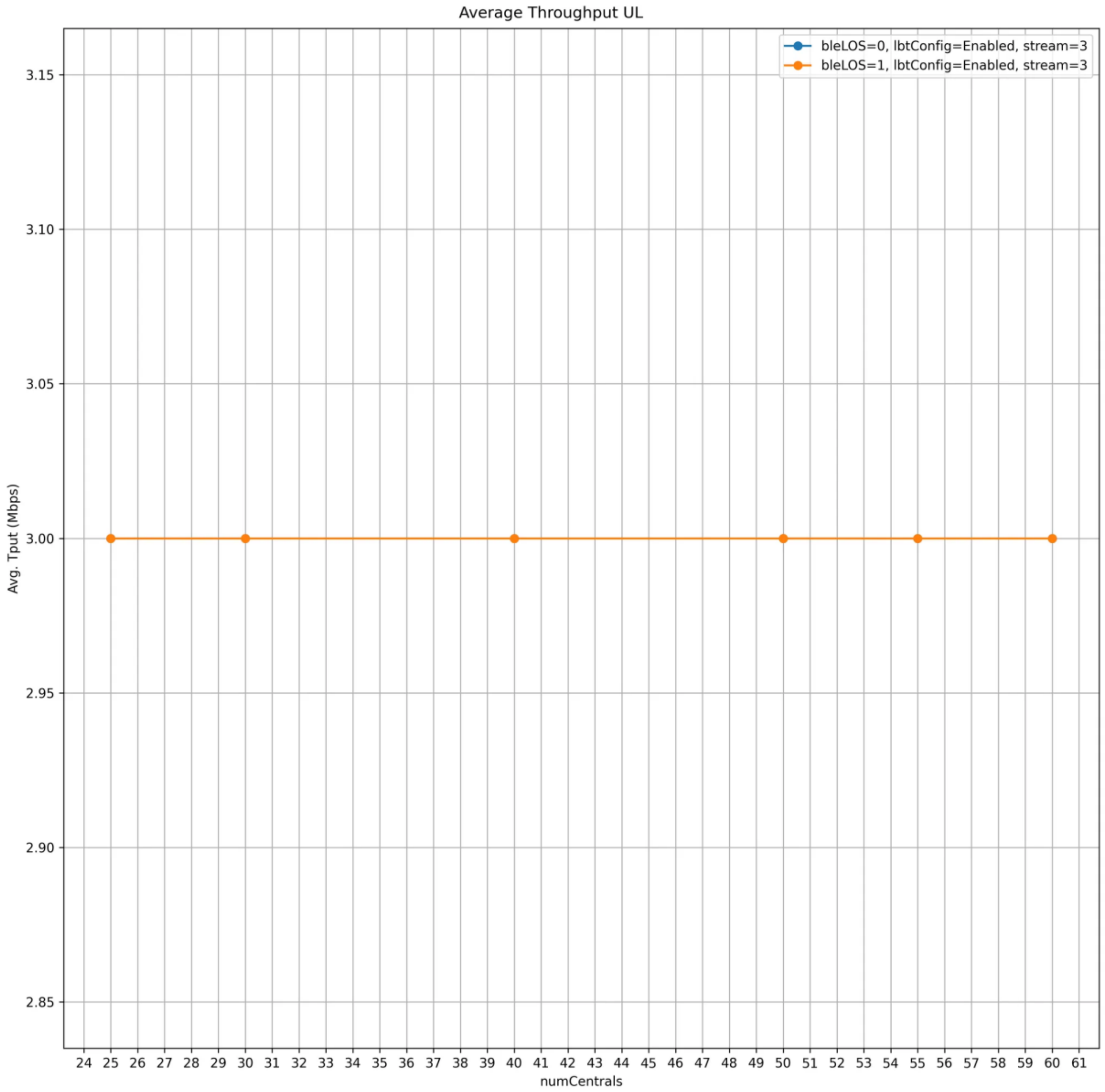
BLE/Wi-Fi 57% Even Time Split Overlap Wi-Fi Latency



BLE/Wi-Fi 57% Overlap Even Time Split Wi-Fi Throughput

Note that the y-axis is very small for both graphs





Case 3 BLE/Wi-Fi 57% Overlap with 21%CU, CU information available to BLE

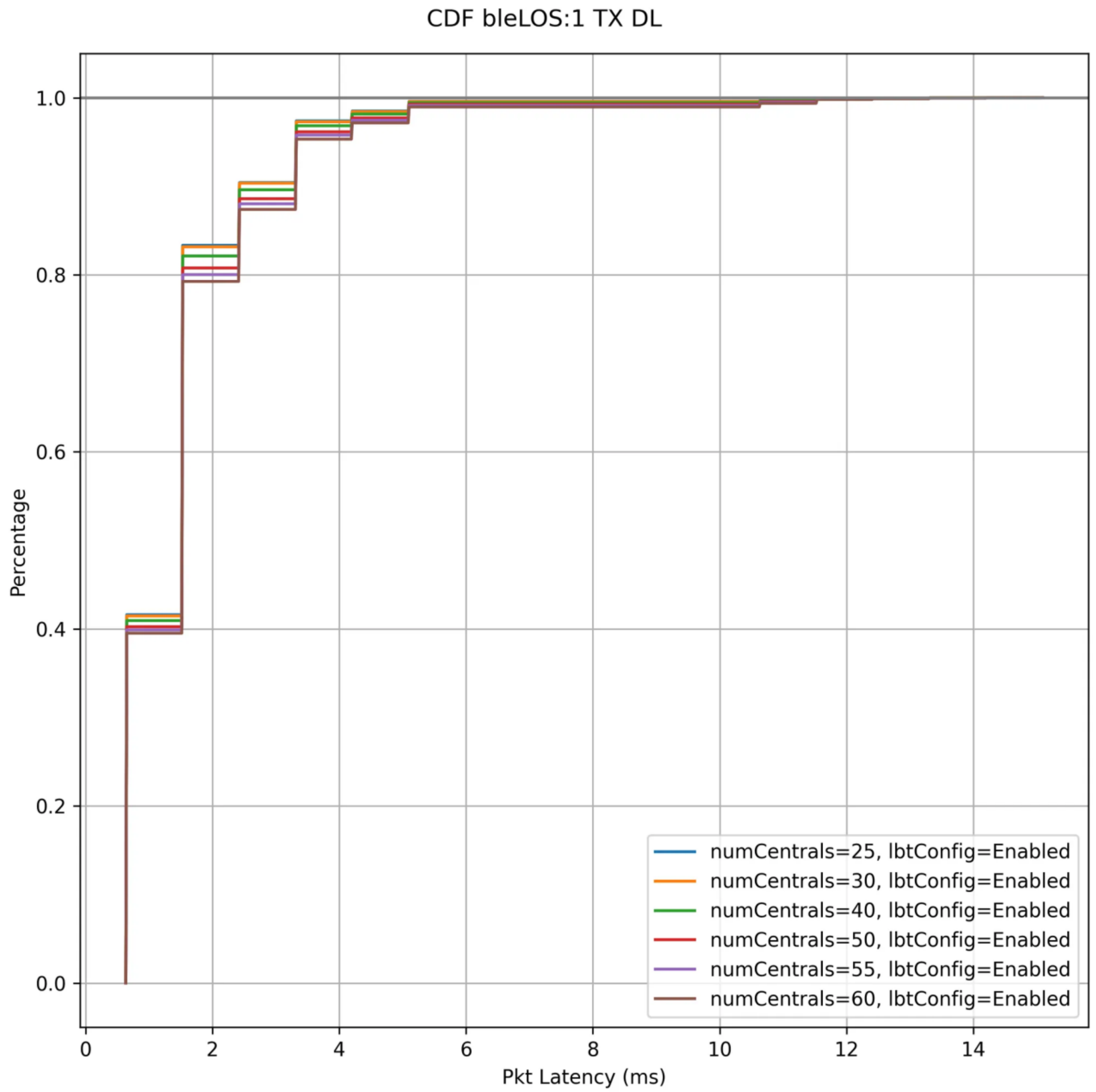
70 Channel BLE/Wi-Fi 57% Overlap

- Exact same as previous results but instead clear channels used at a ratio of 2:1 compared to Wi-Fi channels

Takeaways:

- **~30% improvement in BLE links** over BLE/BLE case in both LOS/NLOS cases
- Smooth Wi-Fi latency degradation as the number of centrals is increased
  - Even at 50 centrals, P95 burst latency is < 20 ms, which is ~4x better than the previous case.
- **Applying CU information allows for ~40% increase in BLE centrals as the supported number goes from 27 to 37.**

BLE/Wi-Fi 57% Overlap LOS BLE Latency



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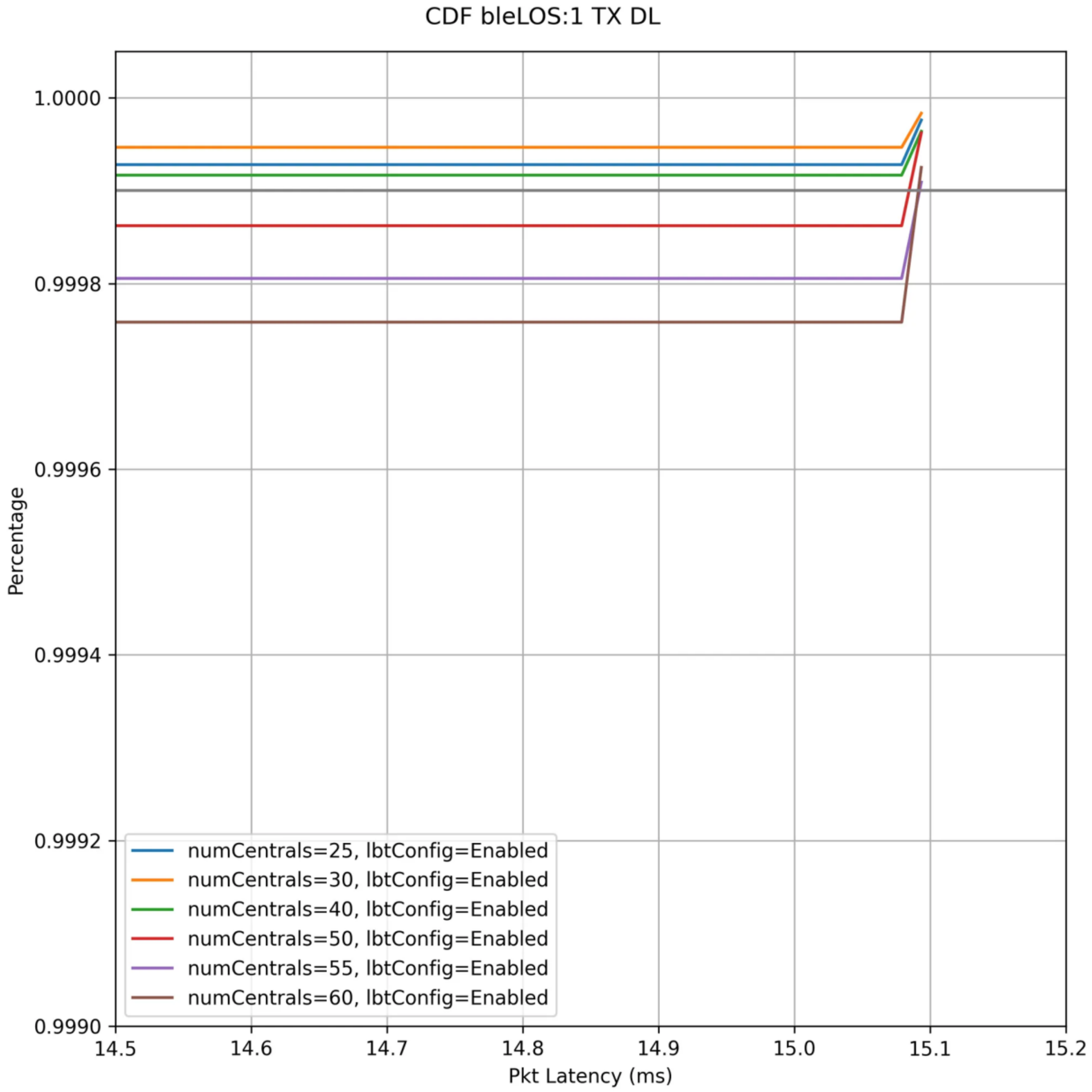
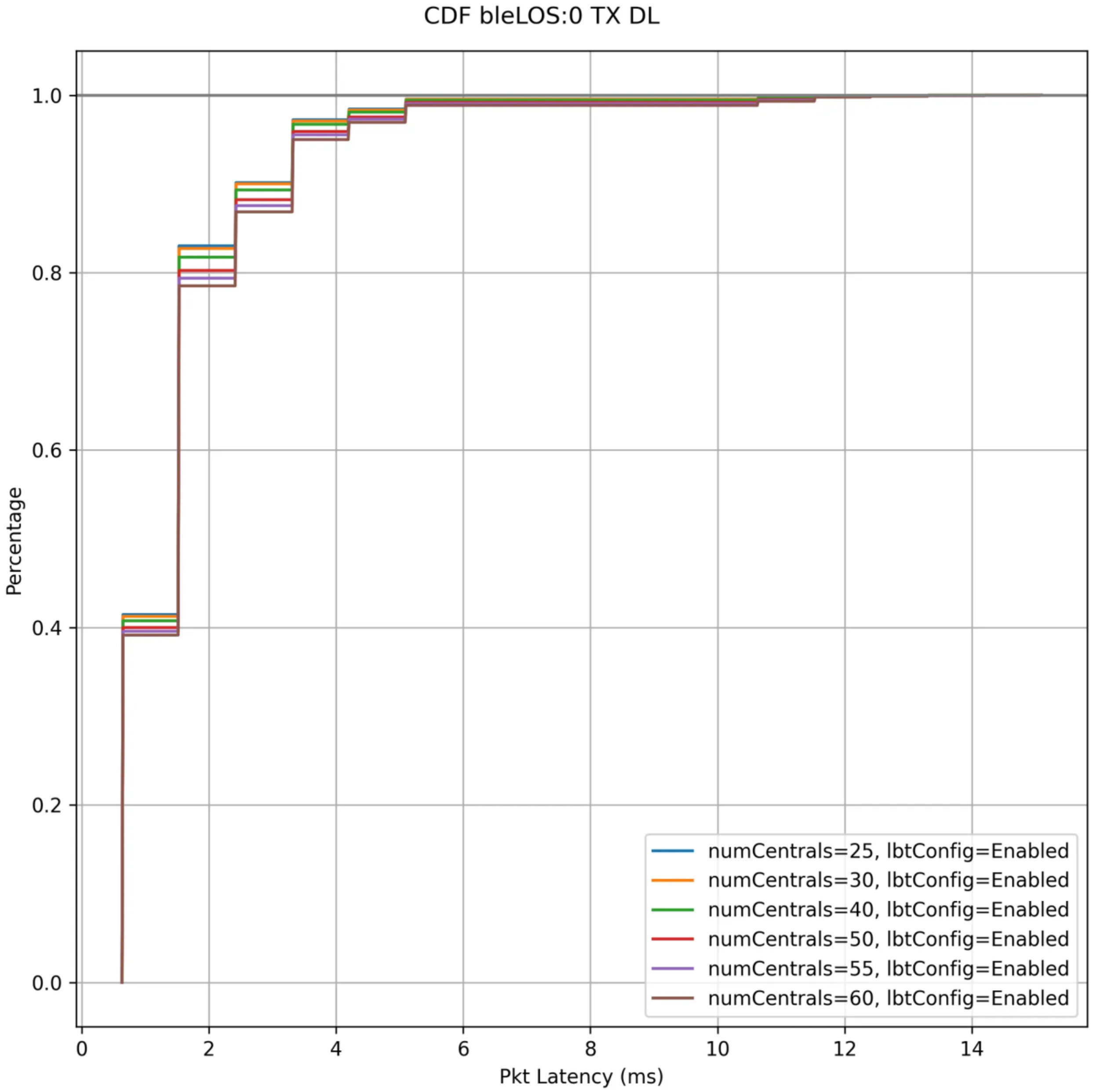


BLE/Wi-Fi 57% Overlap NLOS BLE Latency



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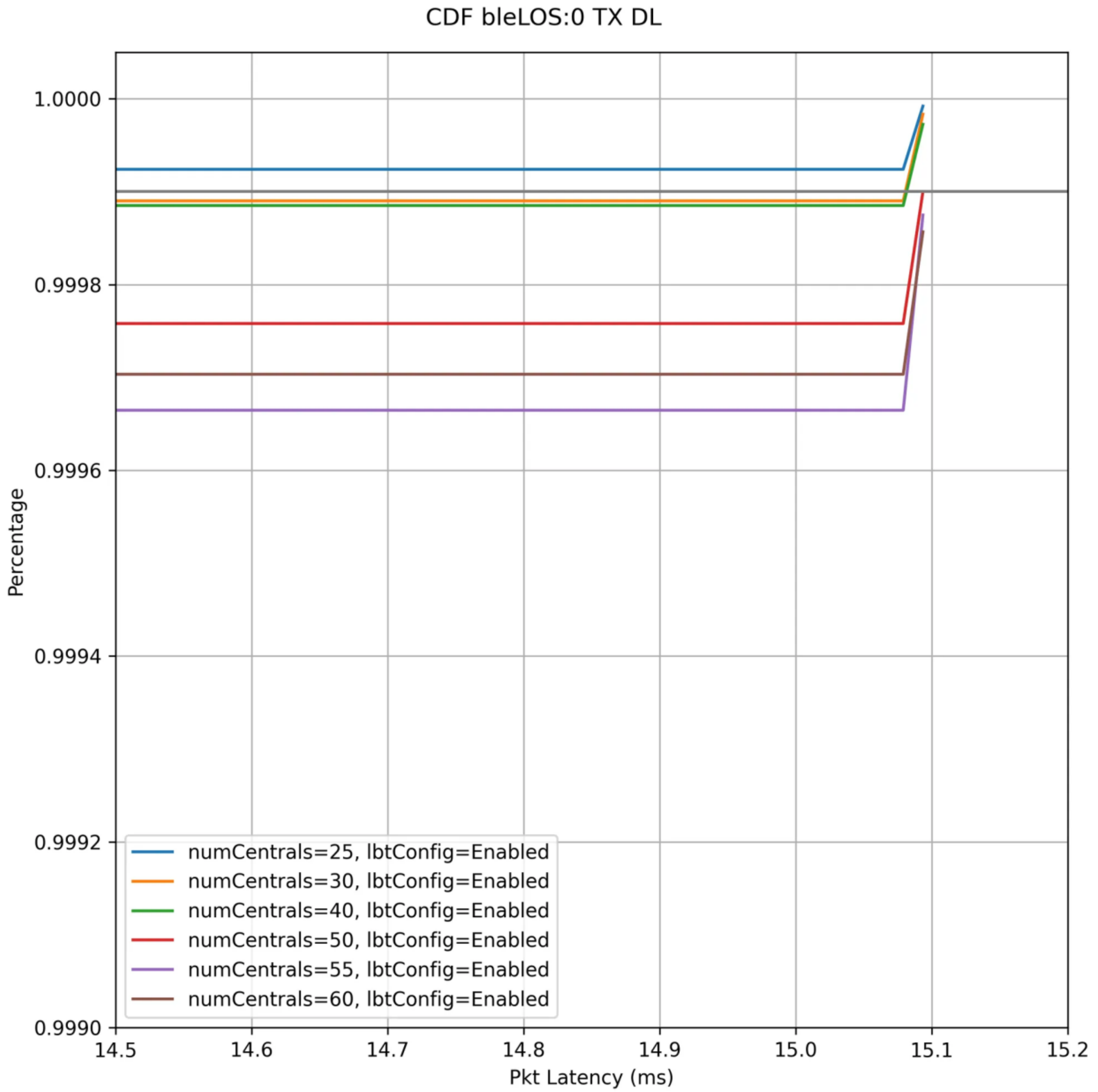
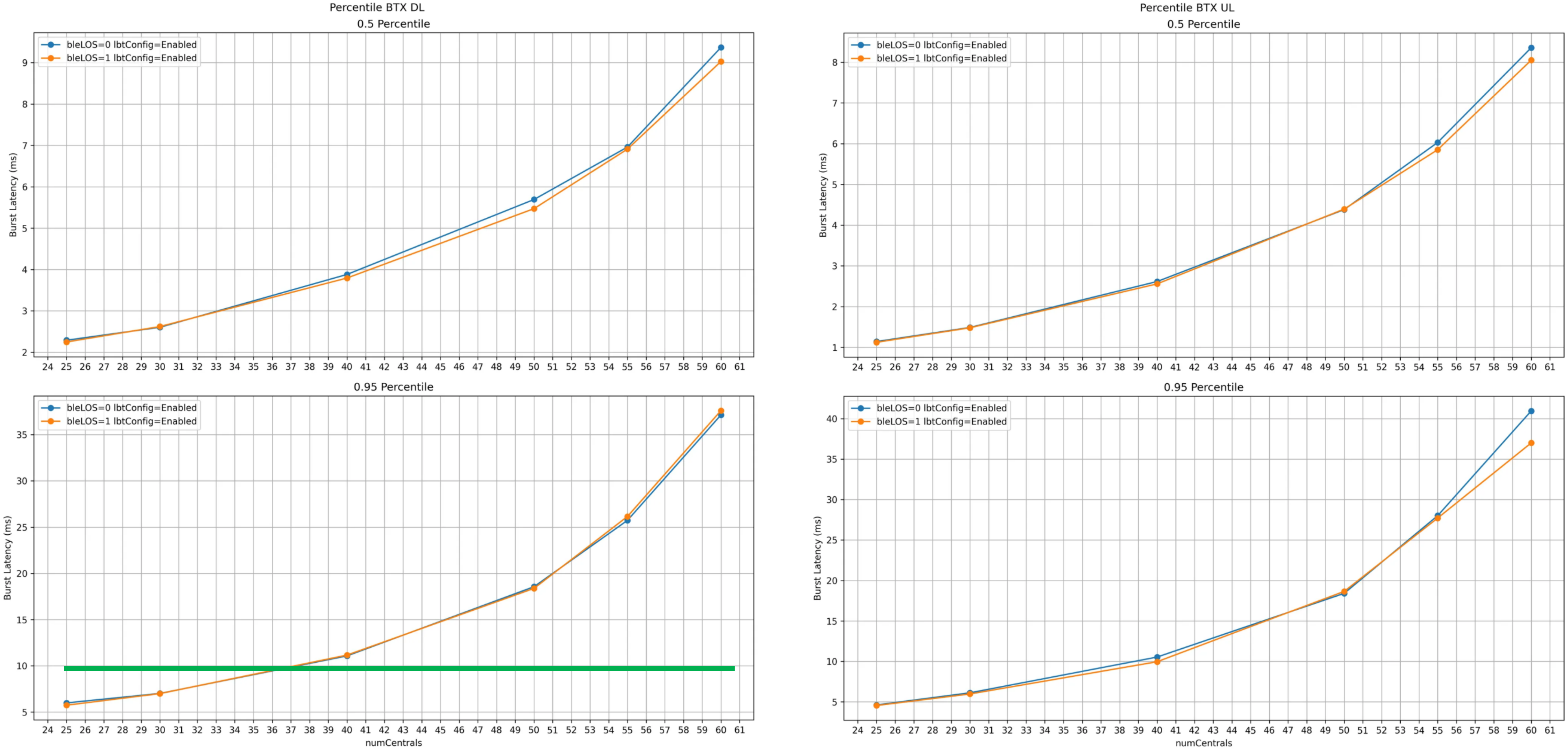
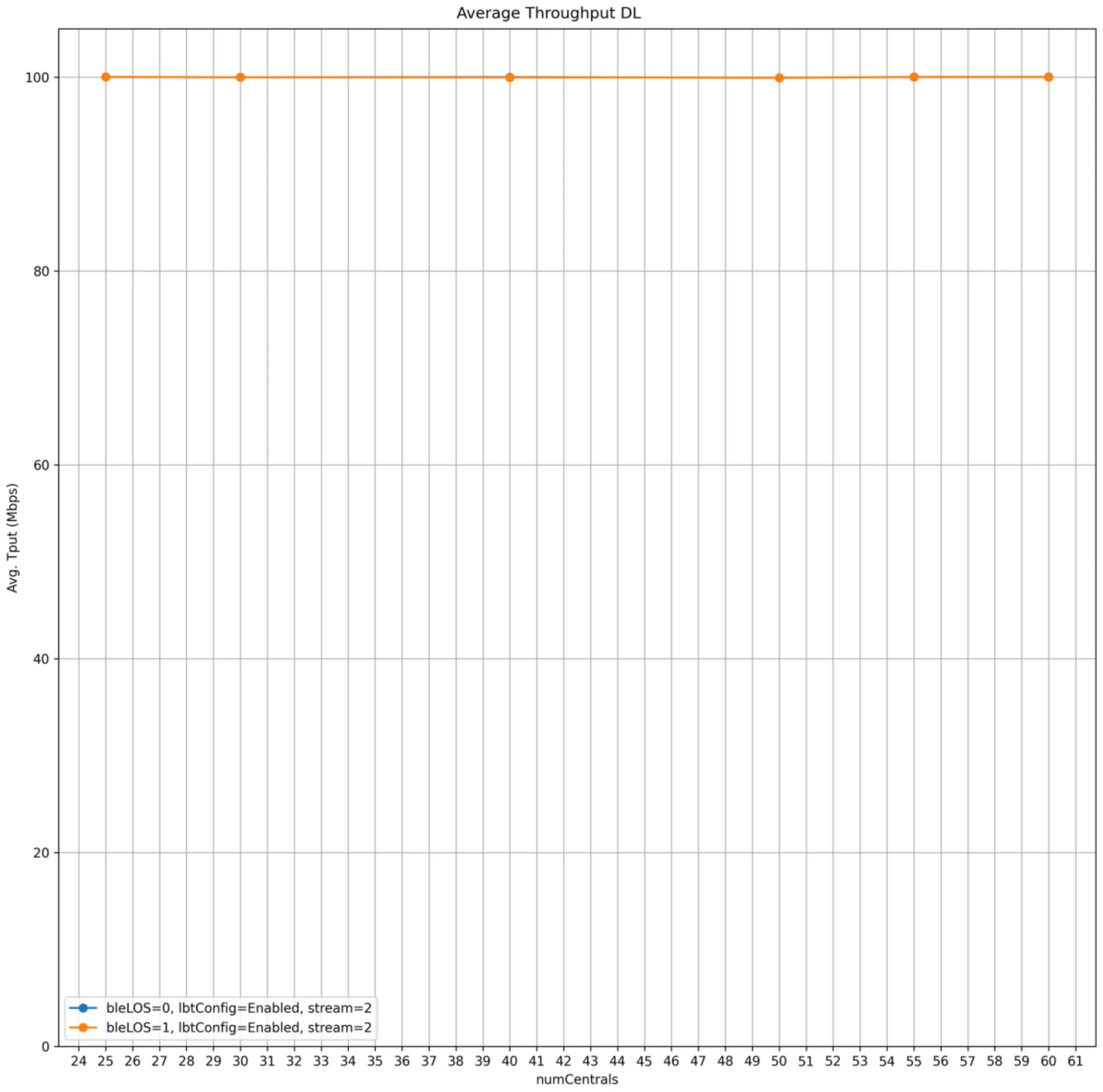
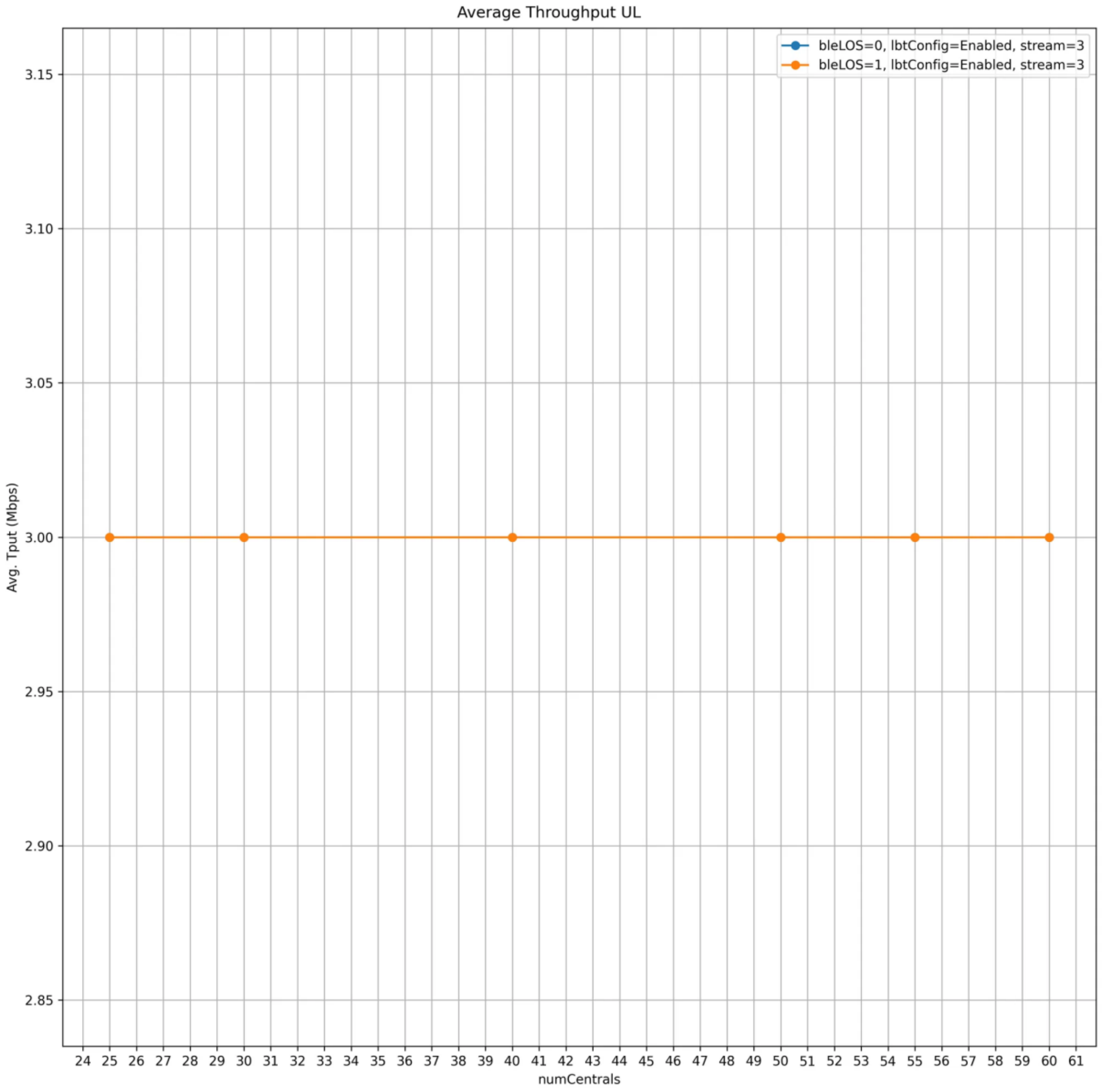


BLE/Wi-Fi 57% Overlap Wi-Fi Latency



BLE/Wi-Fi 57% Overlap Wi-Fi Throughput





Summary of 21% CU Results

- The table below shows the number of central devices supported for LOS/NLOS configurations

LOS/NLOS	30 channels (BLE only)	70 channels + CU unavailable	70 channels + CU available
BLE	39/37	53/50	>60/60
Wi-Fi (10ms DL P95 latency)		27/27	37/37

From a BLE only perspective, adding 40 channels with CU information gains ~60% capacity (over 30 channel case)

From a Wi-Fi perspective, adding CU information gains ~40% capacity

Conclusions

- LBT should be made mandatory to help BLE/BLE use case.
- Primary channels are used first and through appropriate offloading, the least occupied Wi-Fi channels should be used to minimize interference between the two technologies.
- An accurate scan allows the BLE device to distinguish between low-CU and high-CU Wi-Fi channels
- Low-CU Wi-Fi channels should not be completely avoided by BLE, but appropriately used instead
  - CU information from scans can be used to determine how often to visit the low-CU Wi-Fi channels. If properly used, a higher total number of BLE devices can be accommodated.
  - Not using the CU information appropriately makes performance worse for Wi-Fi.
- High-CU (e.g. ~60%) Wi-Fi channels should not be used by BLE (see appendix Cases 4 and 5) as it is detrimental for both BLE and Wi-Fi.

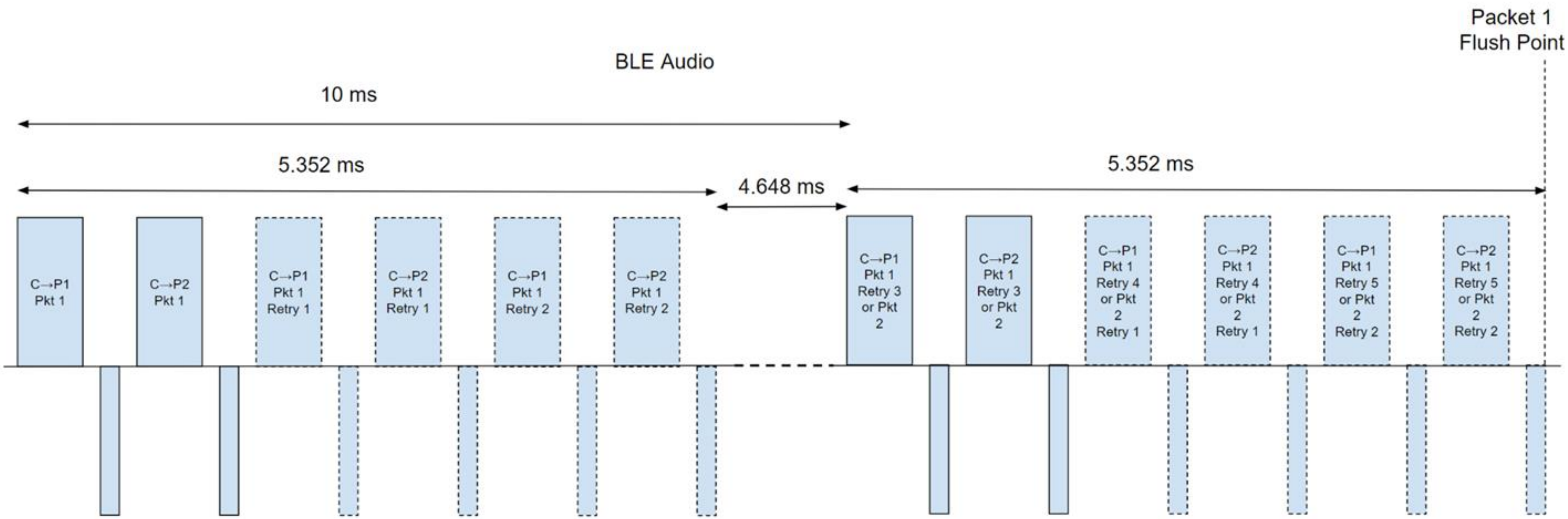
Appendix

Author(s):

Presentation Type:

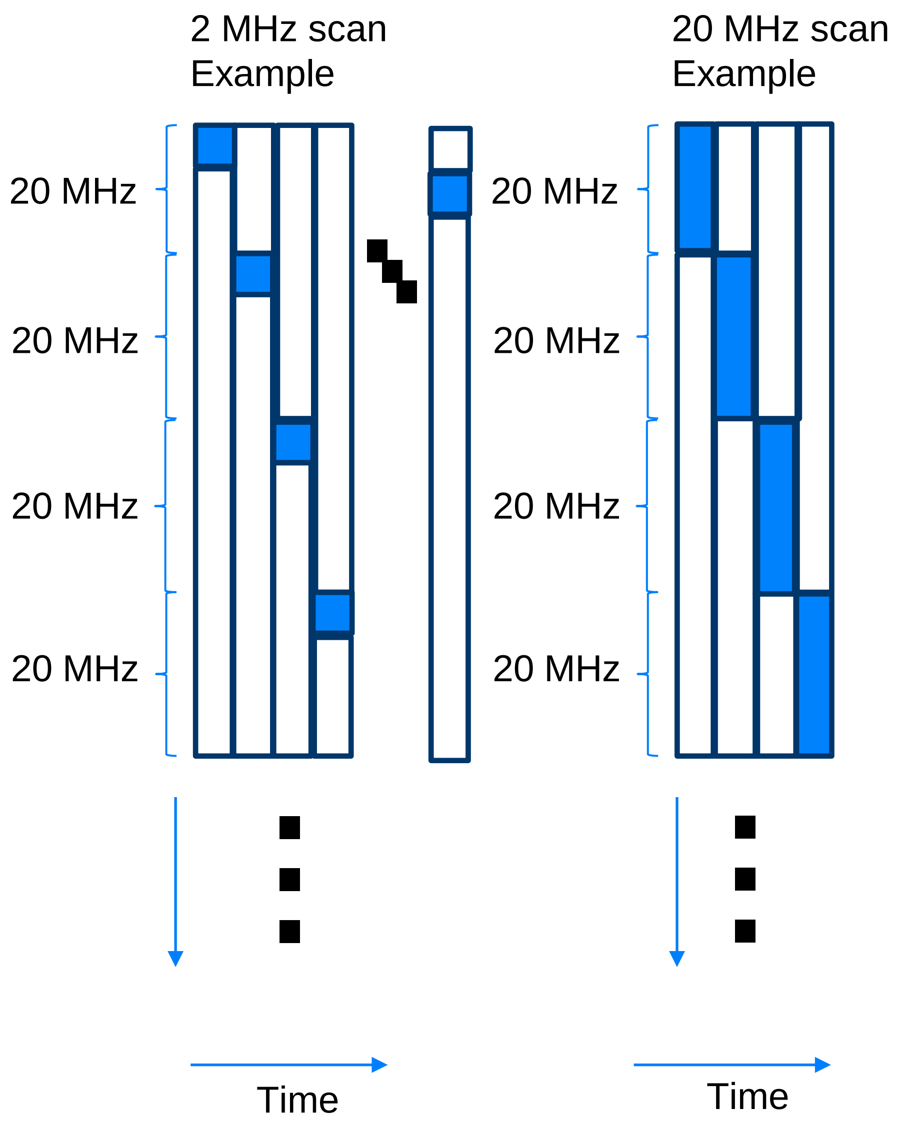
Date Submitted:

BLE Audio profile (channel switch happens after Ack)



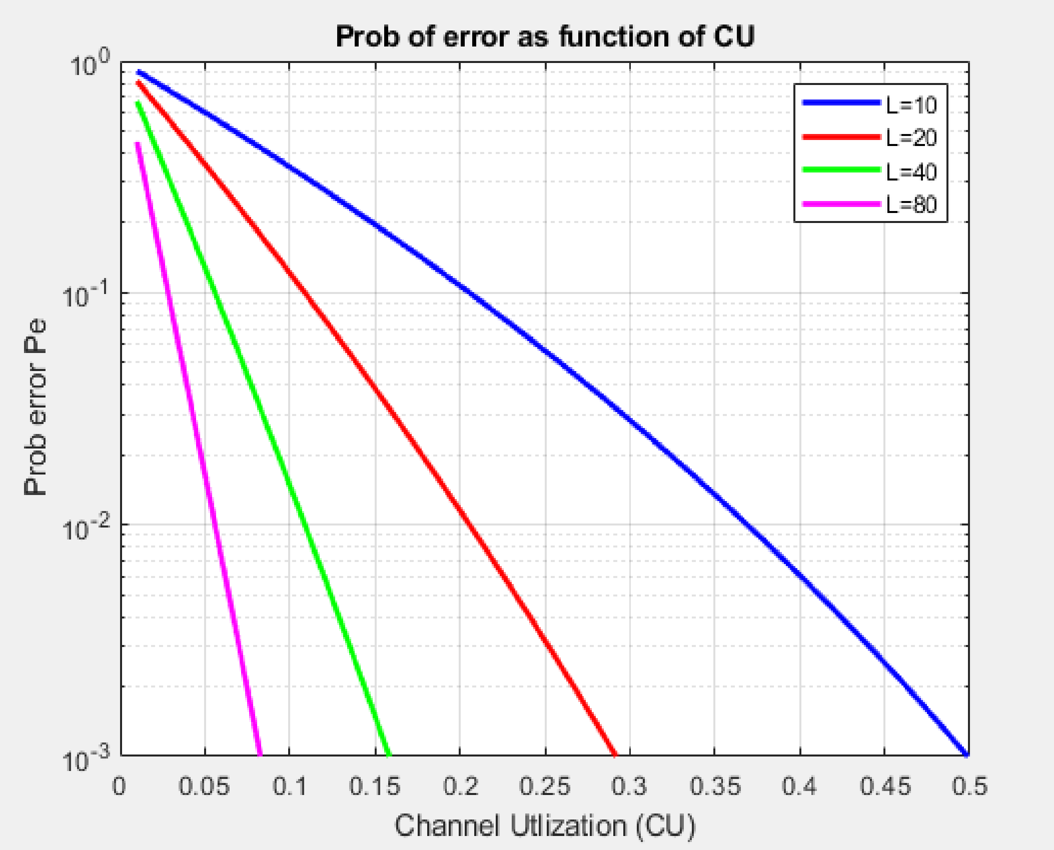
Initial Scan to detect Wi-Fi

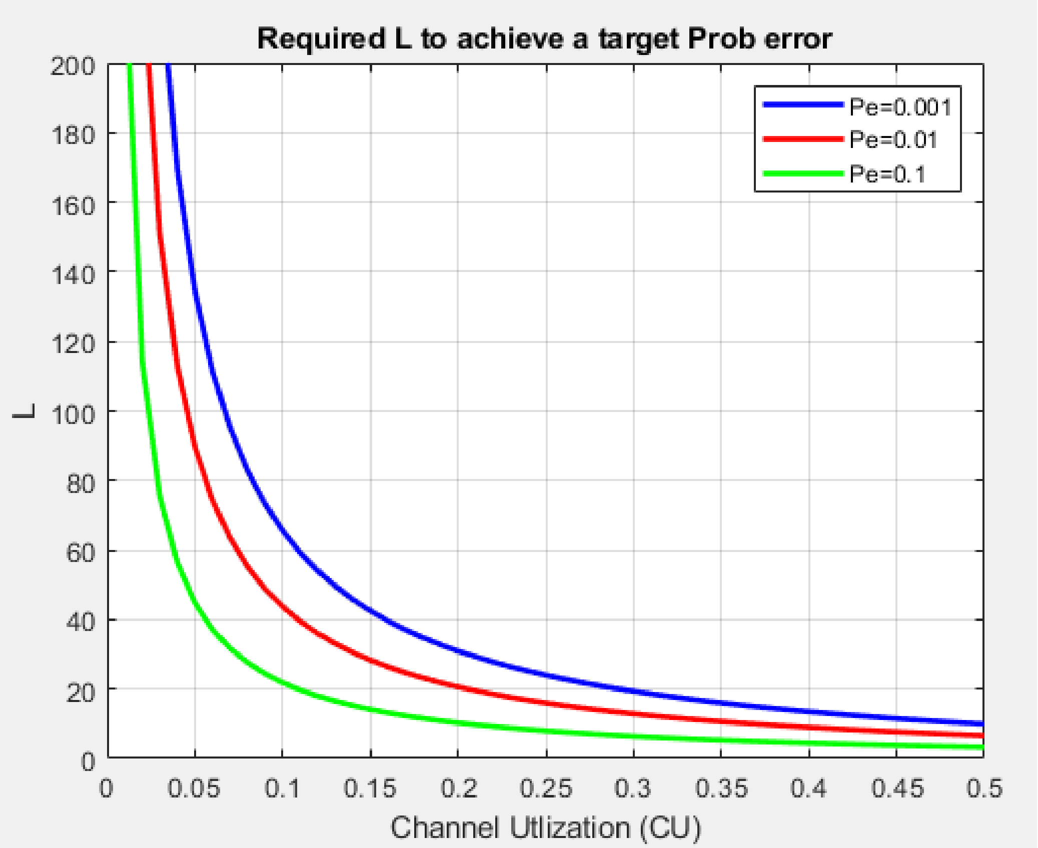
- UNII-1 (80 MHz), UNII-3 (100 MHz), and UNII-5 (480 MHz)
- Assume switching time is 150us and 25us scan on each channel
- 2 options: 2 MHz scan and 20 MHz scan
  - 2 MHz : 330 channels
    - 1 round scanning all channels takes 57.75ms
    - 44 rounds at each channel takes 2.541s
      - Reducing switching to 75/50/25us reduces this to 1452/1089/726 ms
  - 20 MHz : 33 20 MHz channels
    - 1 round scanning all channels takes 5.775ms
    - 44 rounds at each channel takes 254.1 ms
      - Reducing switching to 75/50/25us reduces this to 145.2/108.9/72.6 ms



Prob of declaring channel is free when it is not

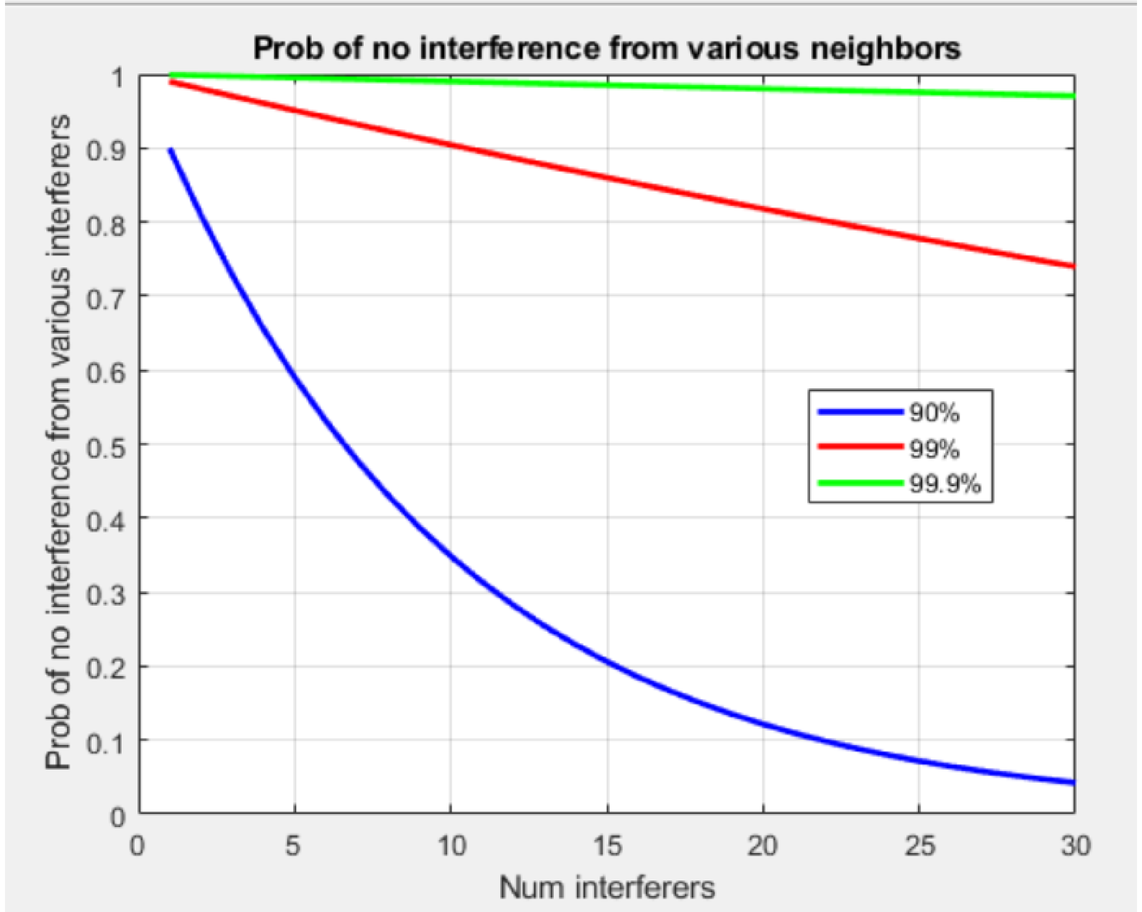
- Assume there are L rounds, each is independent
- Prob of missing traffic = $Pe=(1-CU)^L$ where CU = channel utilization and is between 0 and 1, or $L = \log_{(1-CU)} Pe$.

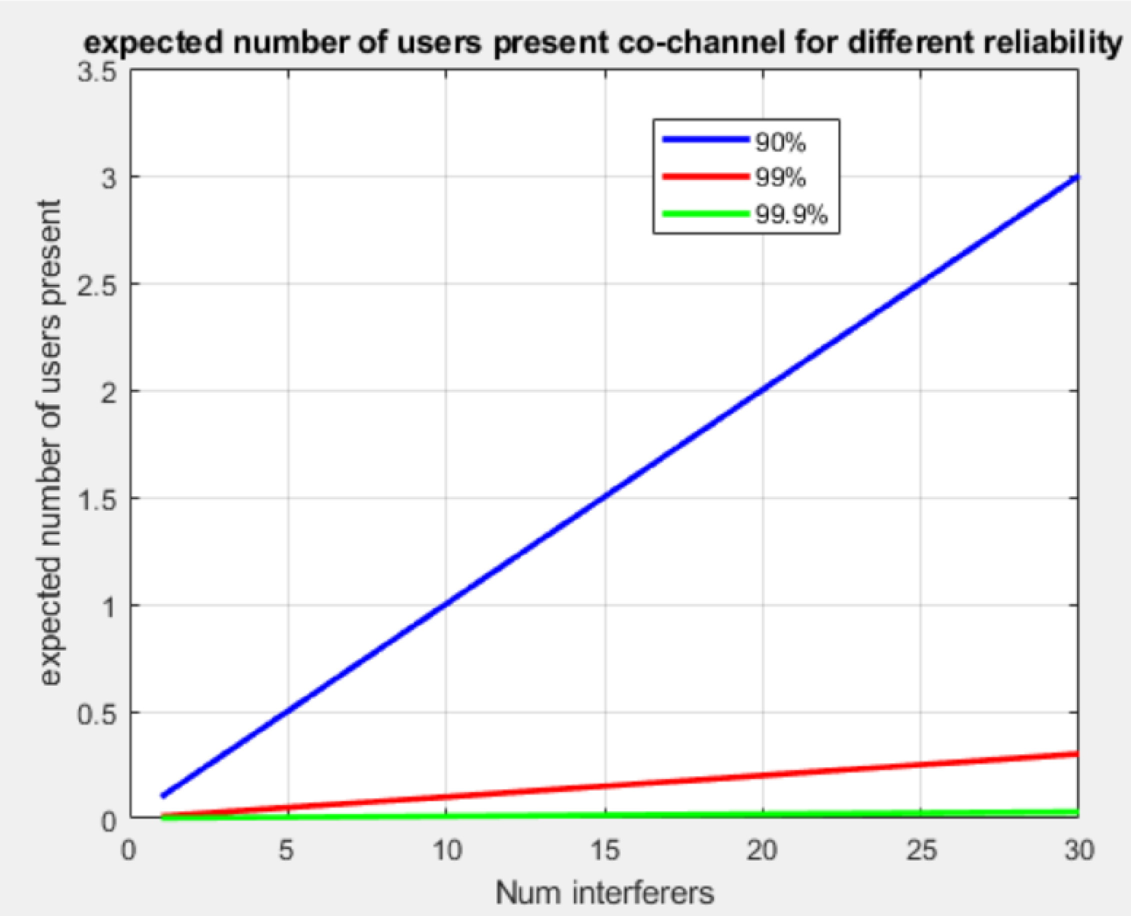




Target level of certainty for initial scan

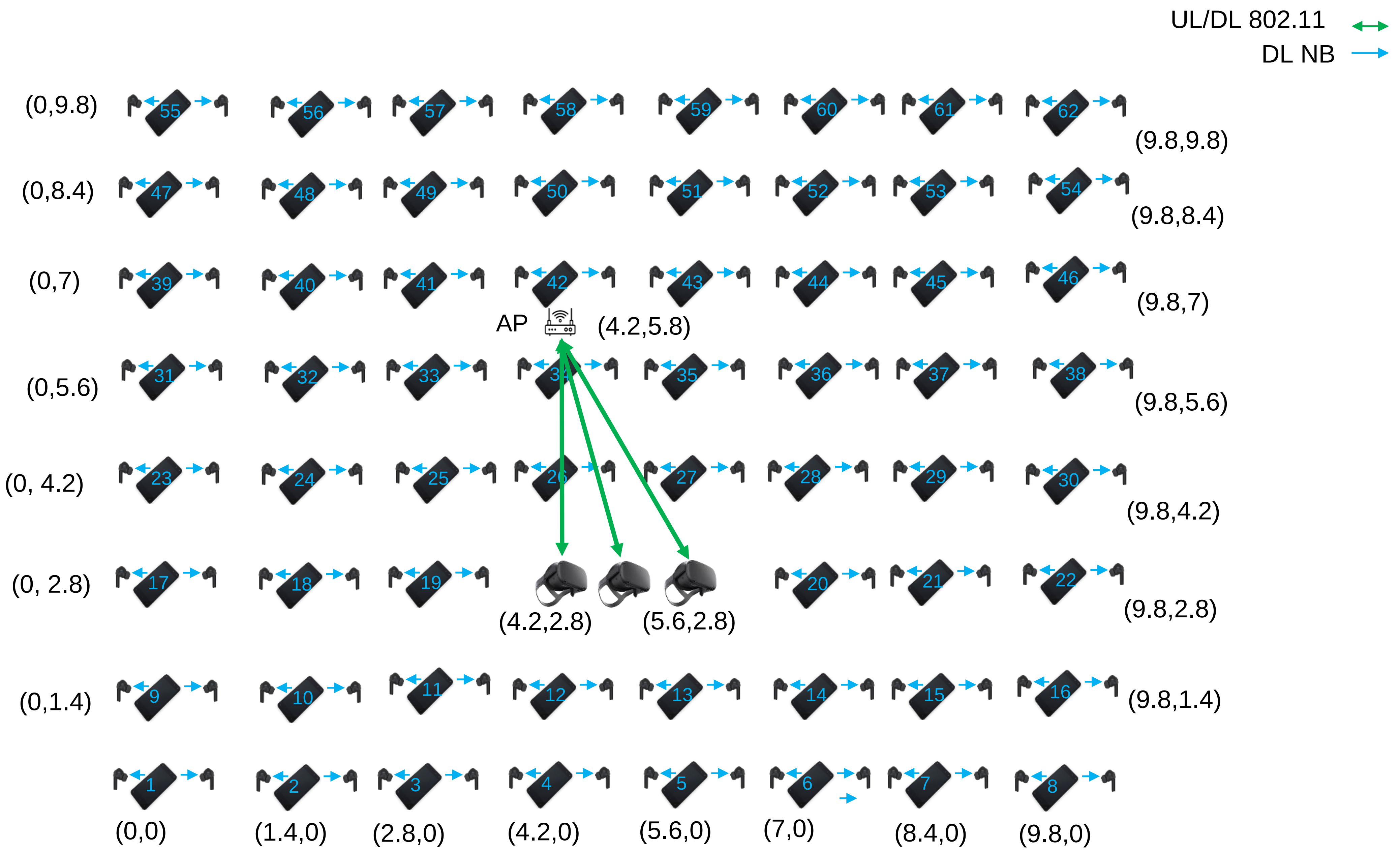
- (Left) Prob of no interference $= (1-p)^N$ $where\; p = 0.1, 0.01, 0.001$
- (Right) Expected Number of Interferers present = $\sum_{k=1}^{N} k\binom{N}{k}p^k(1-p)^{N-k}$





Case 4: BLE/Wi-Fi 57% Overlap with 63% CU,
CU information available to BLE

3 STA Scenario



70 Channel BLE/Wi-Fi 57% Overlap 63% CU

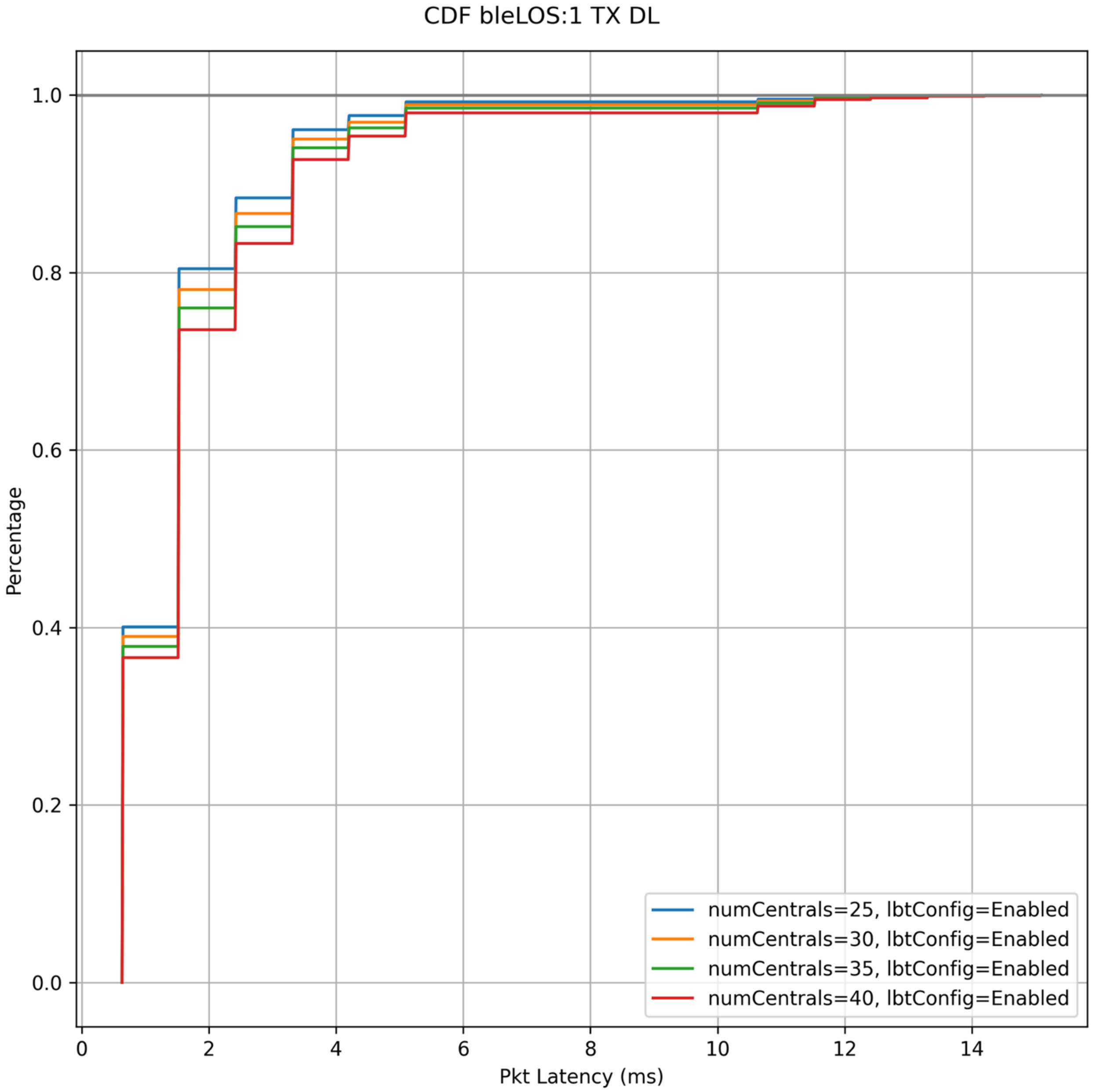
1 AP, 3 STAs, each running same 100 Mbps DL and 3 Mbps UL, resulting in ~63% channel utilization (CU)

Examines only LBT in both LOS and NLOS scenarios

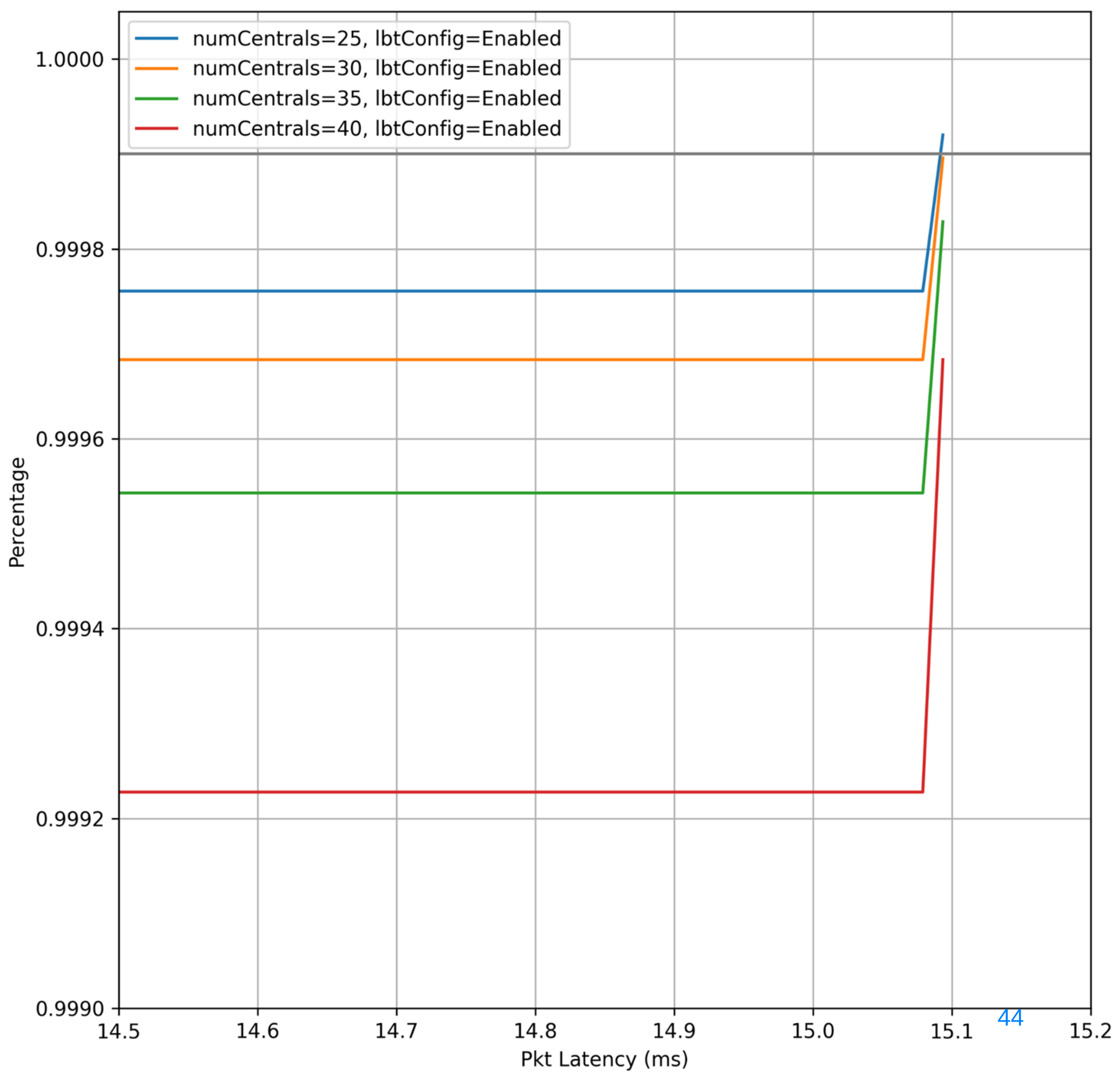
- No LBT causes unacceptable Wi-Fi degradation

Clear channels used at a ratio of 37:1 compared to Wi-Fi channels

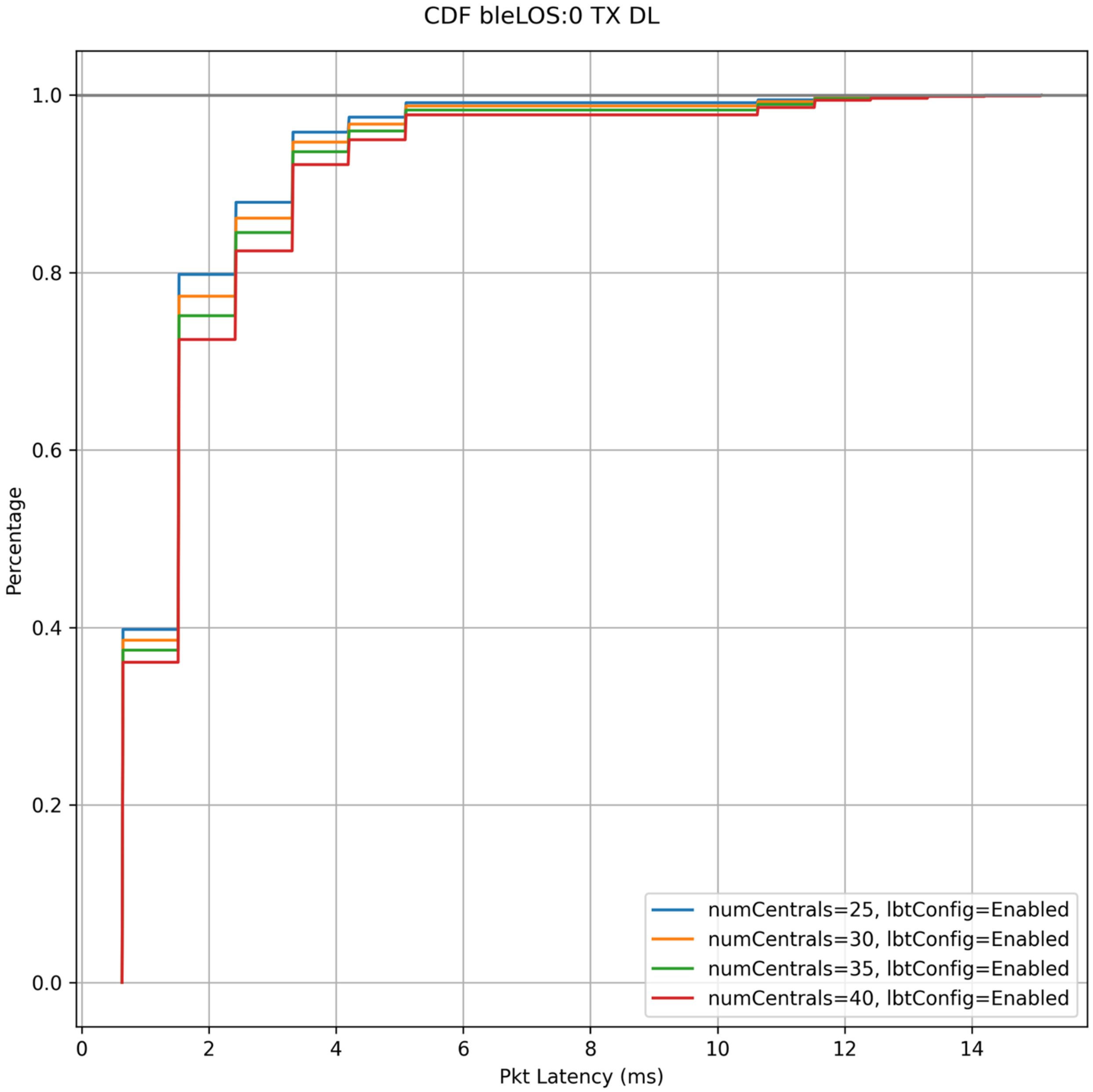
BLE/Wi-Fi 57% Overlap 63% CU LOS BLE Latency



*Zoomed-in version of graph on left



BLE/Wi-Fi 57% Overlap 63% CU NLOS BLE Latency



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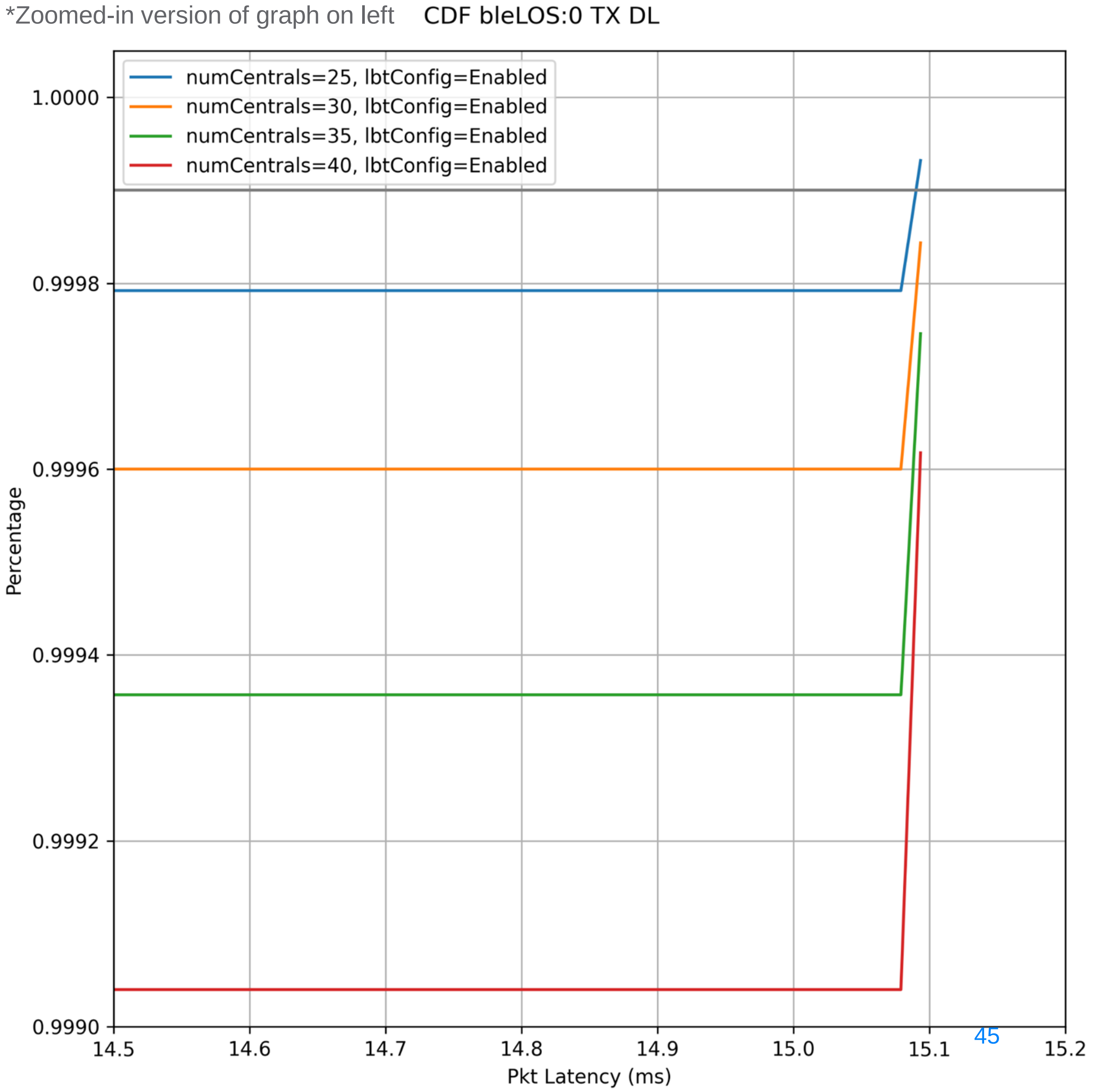
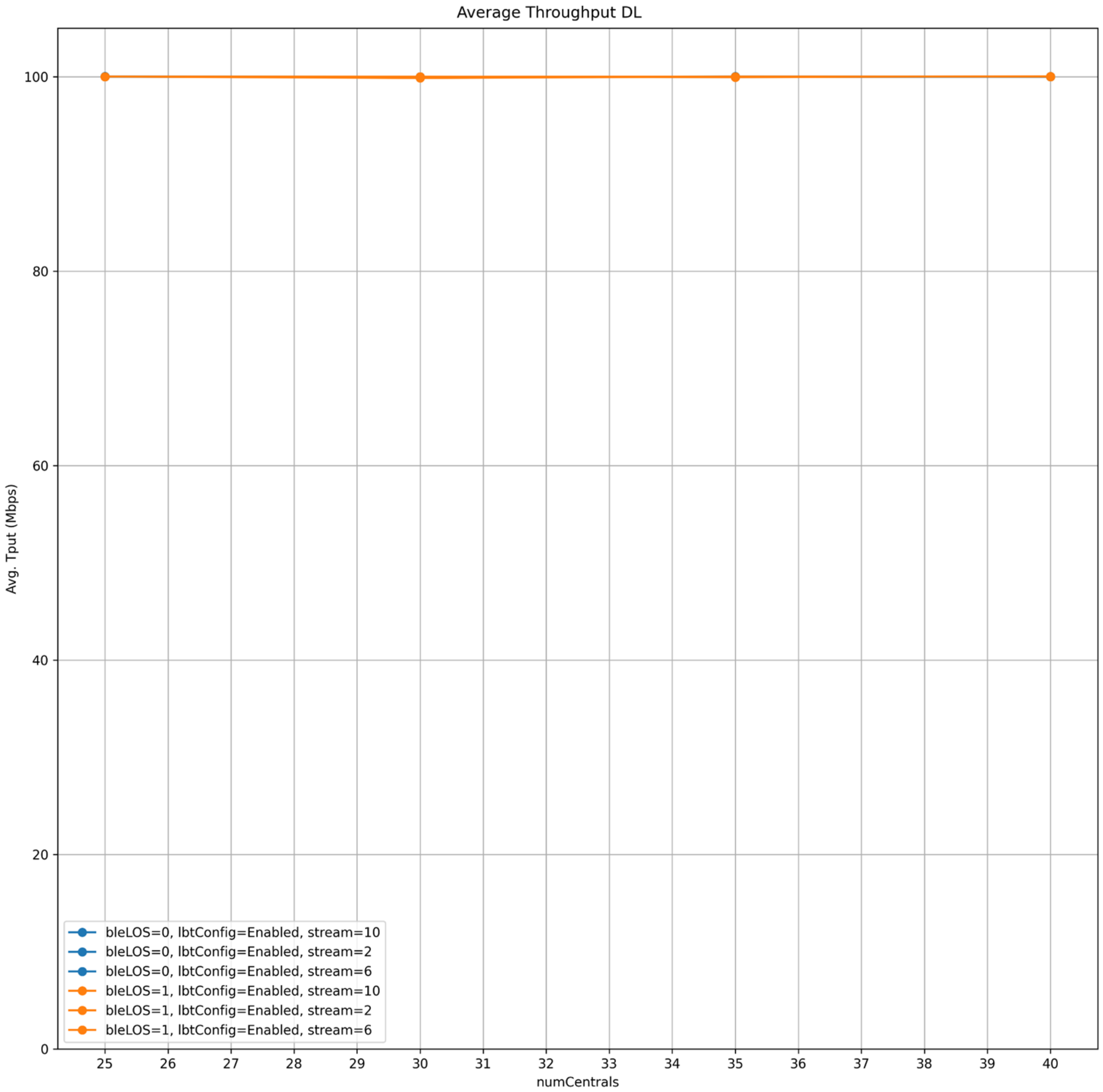
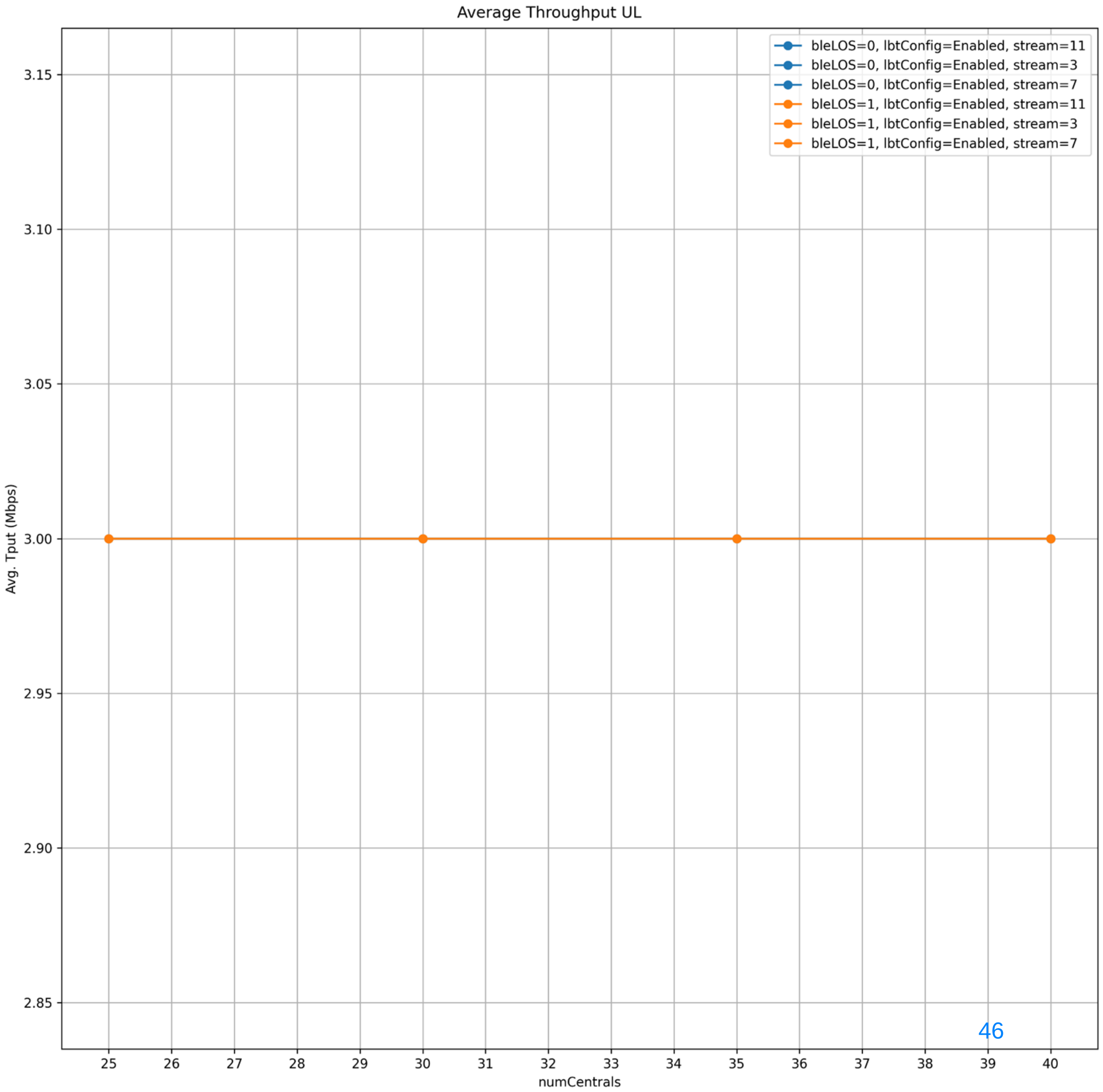
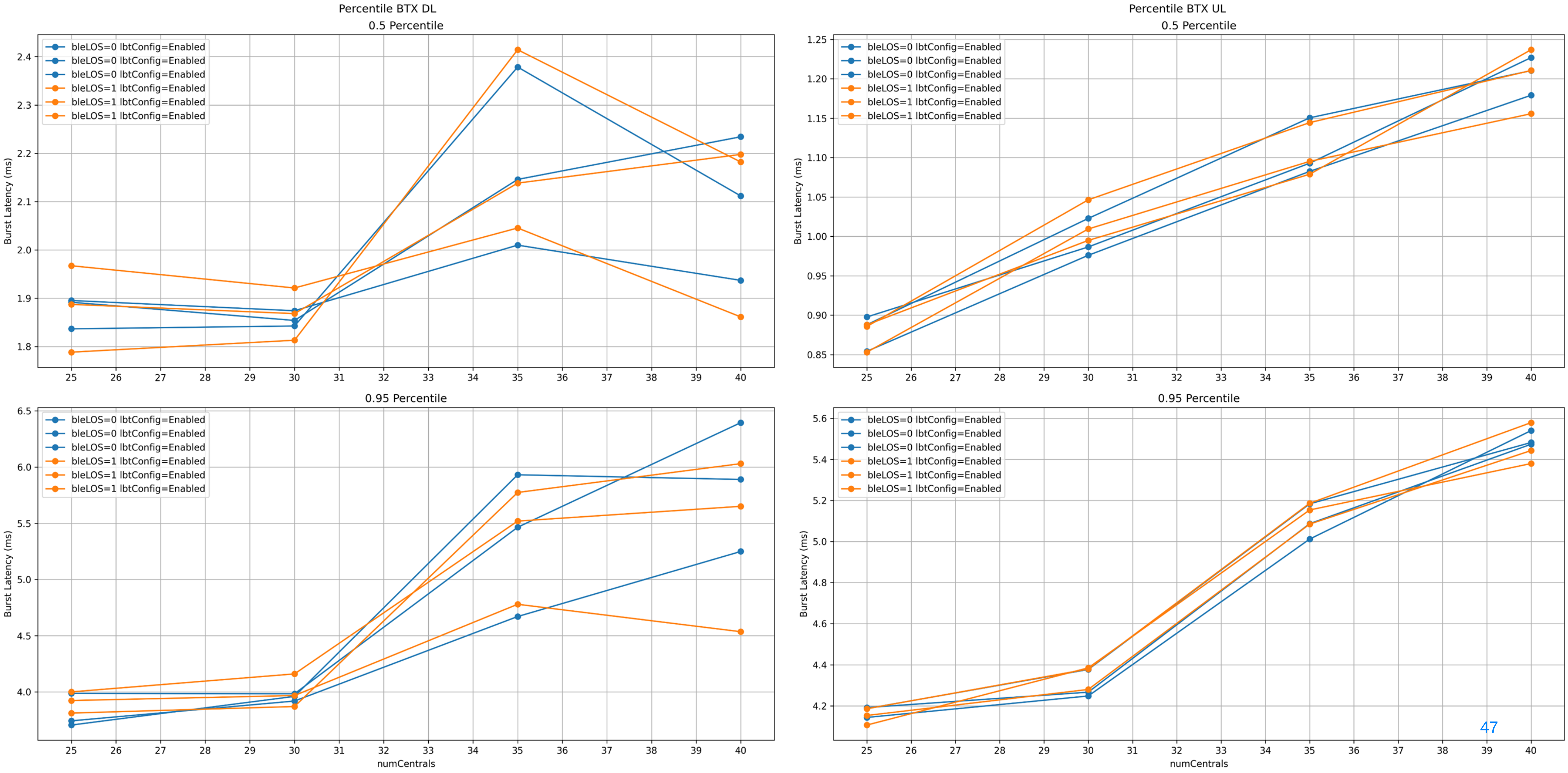


BLE/Wi-Fi 57% Overlap 63% CU Wi-Fi Throughput





BLE/Wi-Fi 57% Overlap 63% CU Wi-Fi Latency

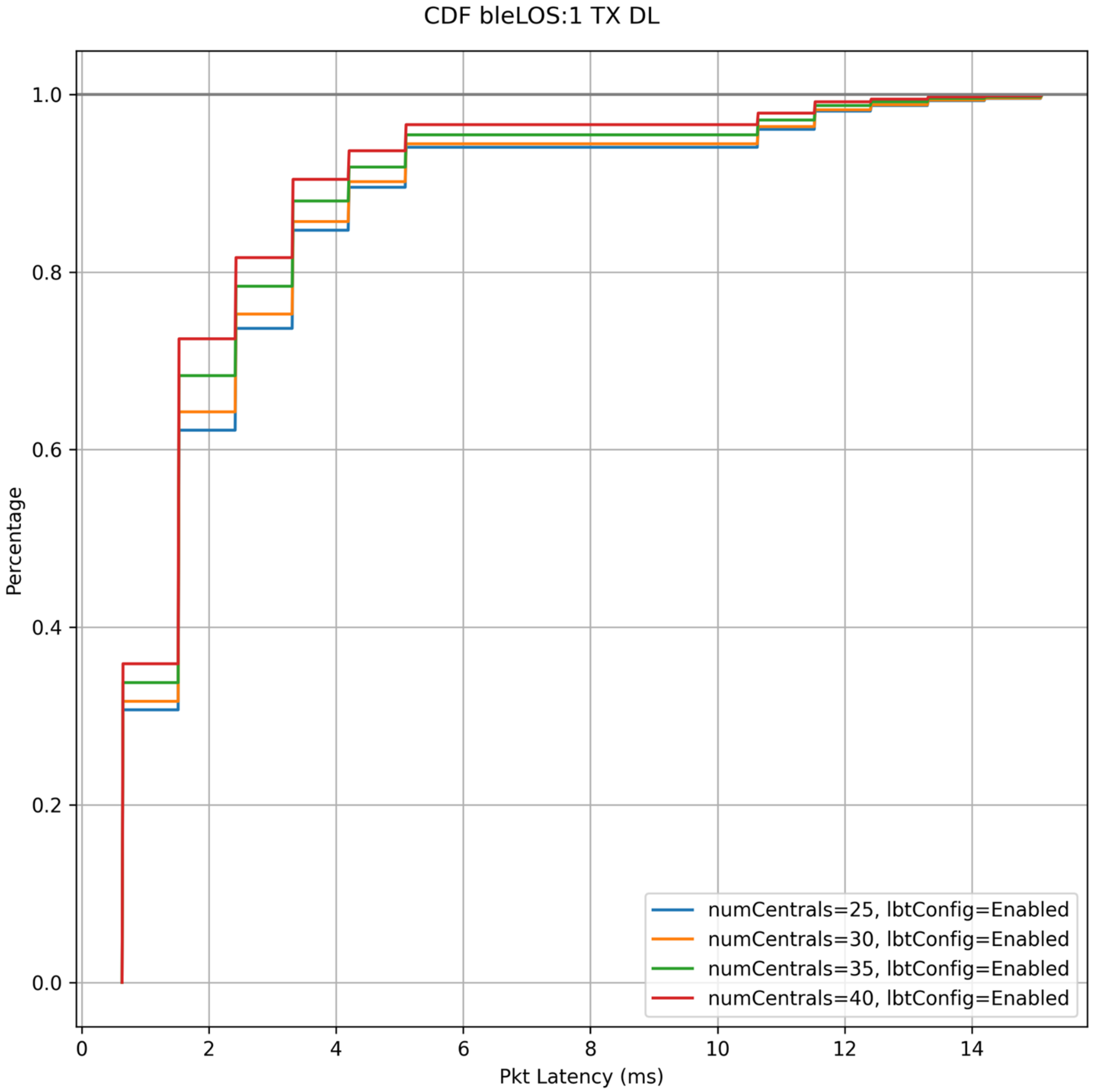


Case 5: BLE/Wi-Fi 57% Overlap with 63% CU, CU information available to BLE

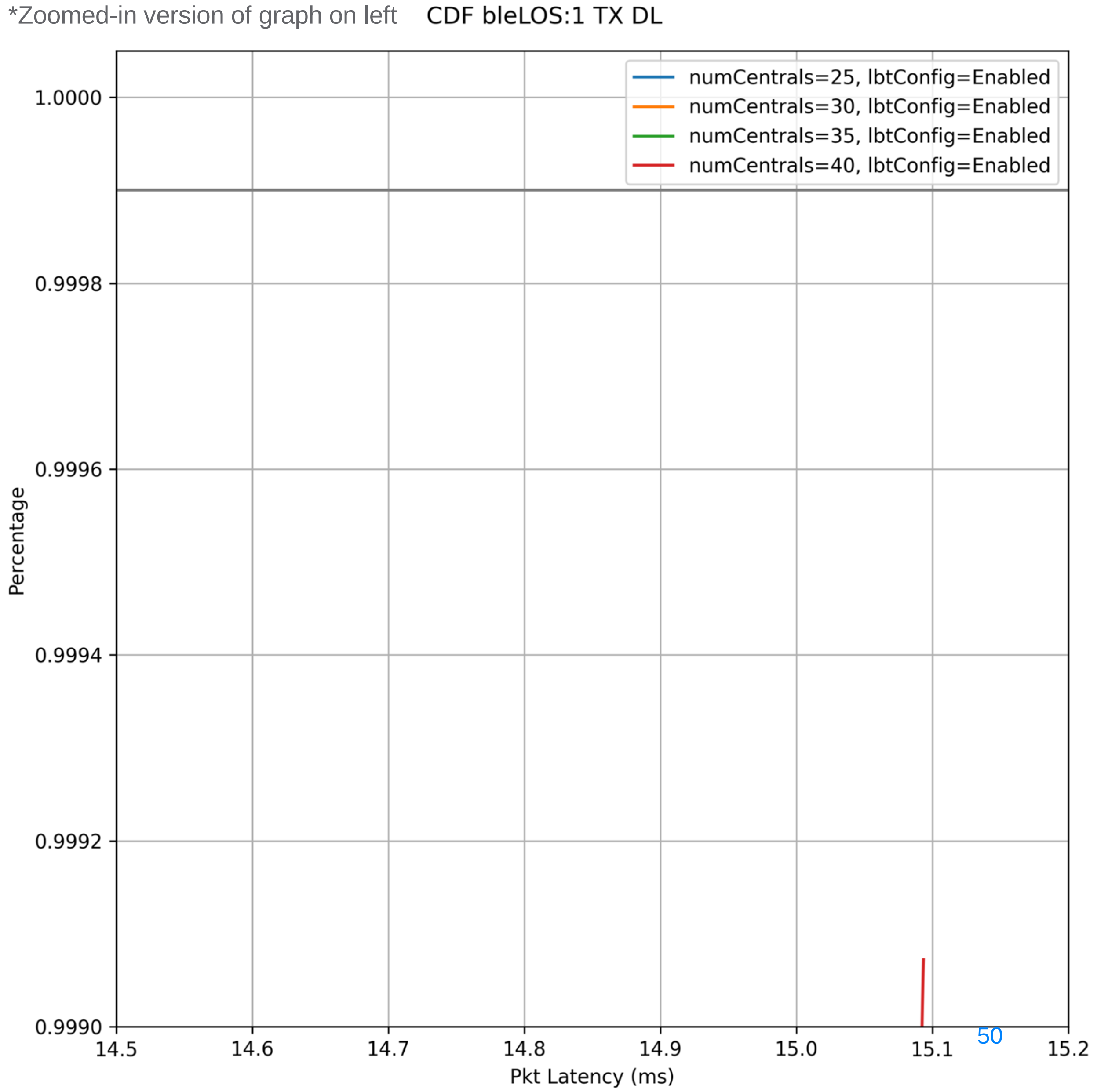
70 Channel BLE/Wi-Fi, 57% Overlap, 63% CU

- Exact same as previous results but in these simulations, time is split evenly between all channels

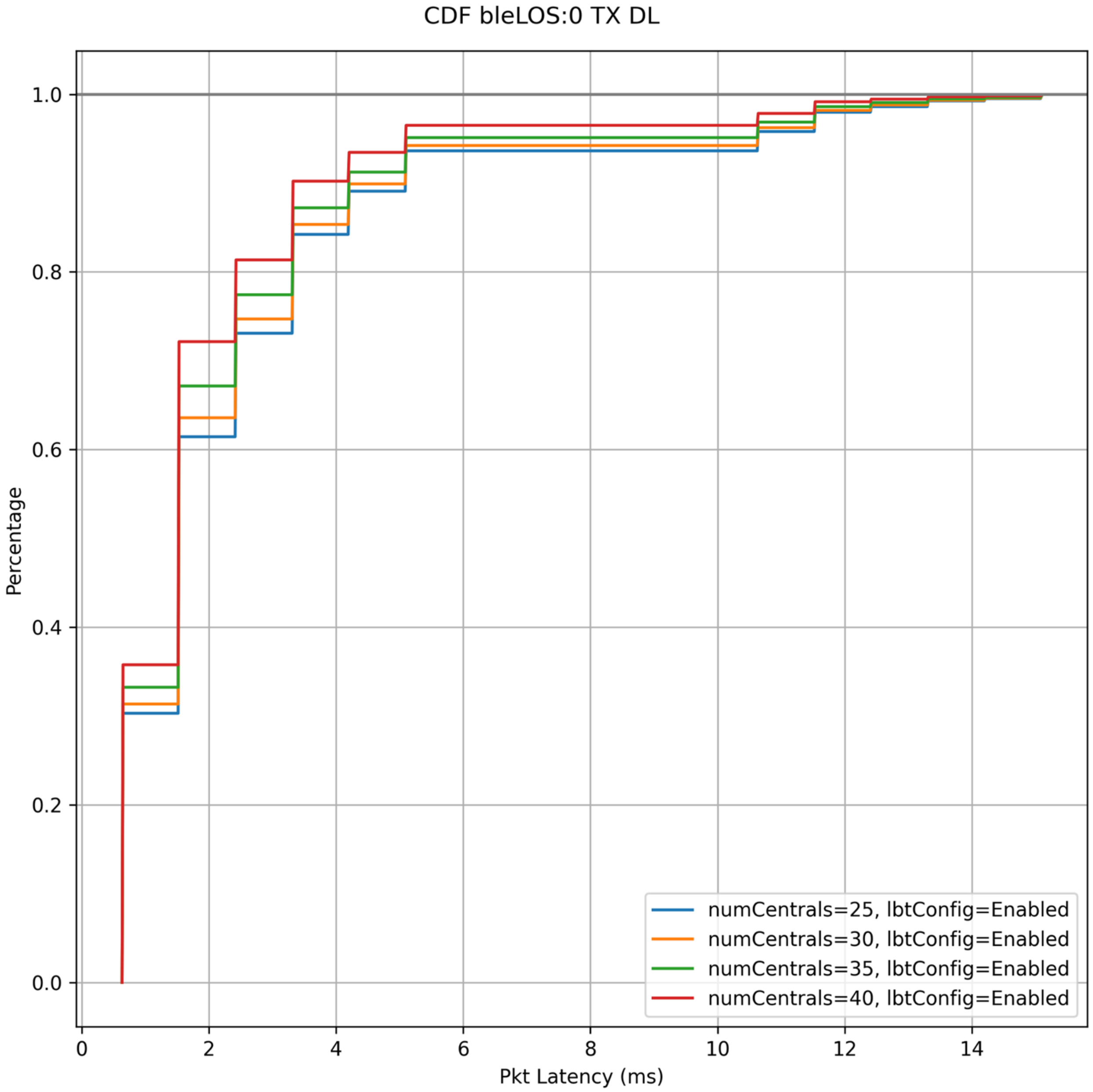
BLE/Wi-Fi 57% Overlap 63% CU Even Time Split LOS BLE



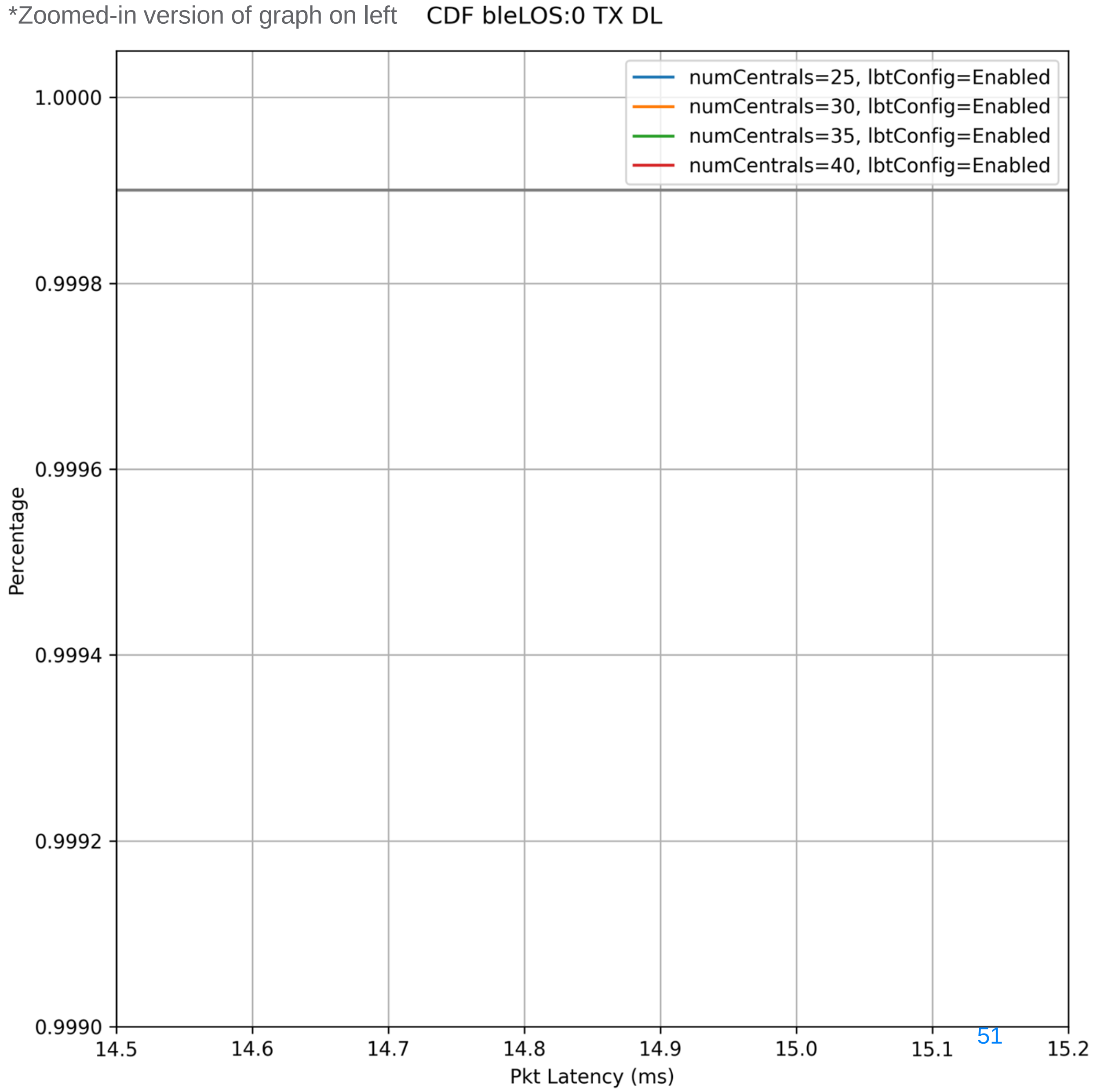
*Zoomed-in version of graph on left



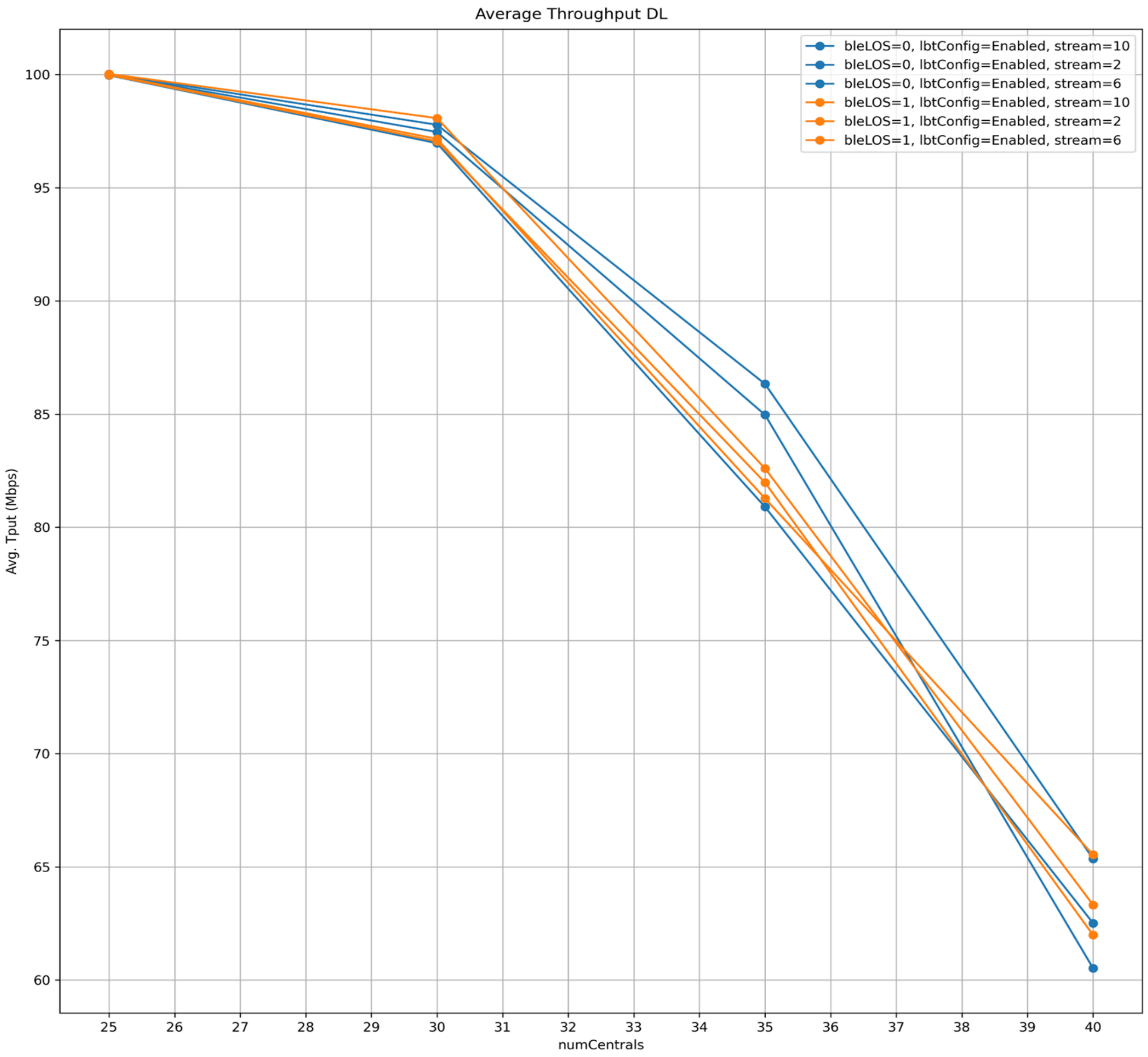
BLE/Wi-Fi 57% Overlap 63% CU Even Time Split NLOS BLE

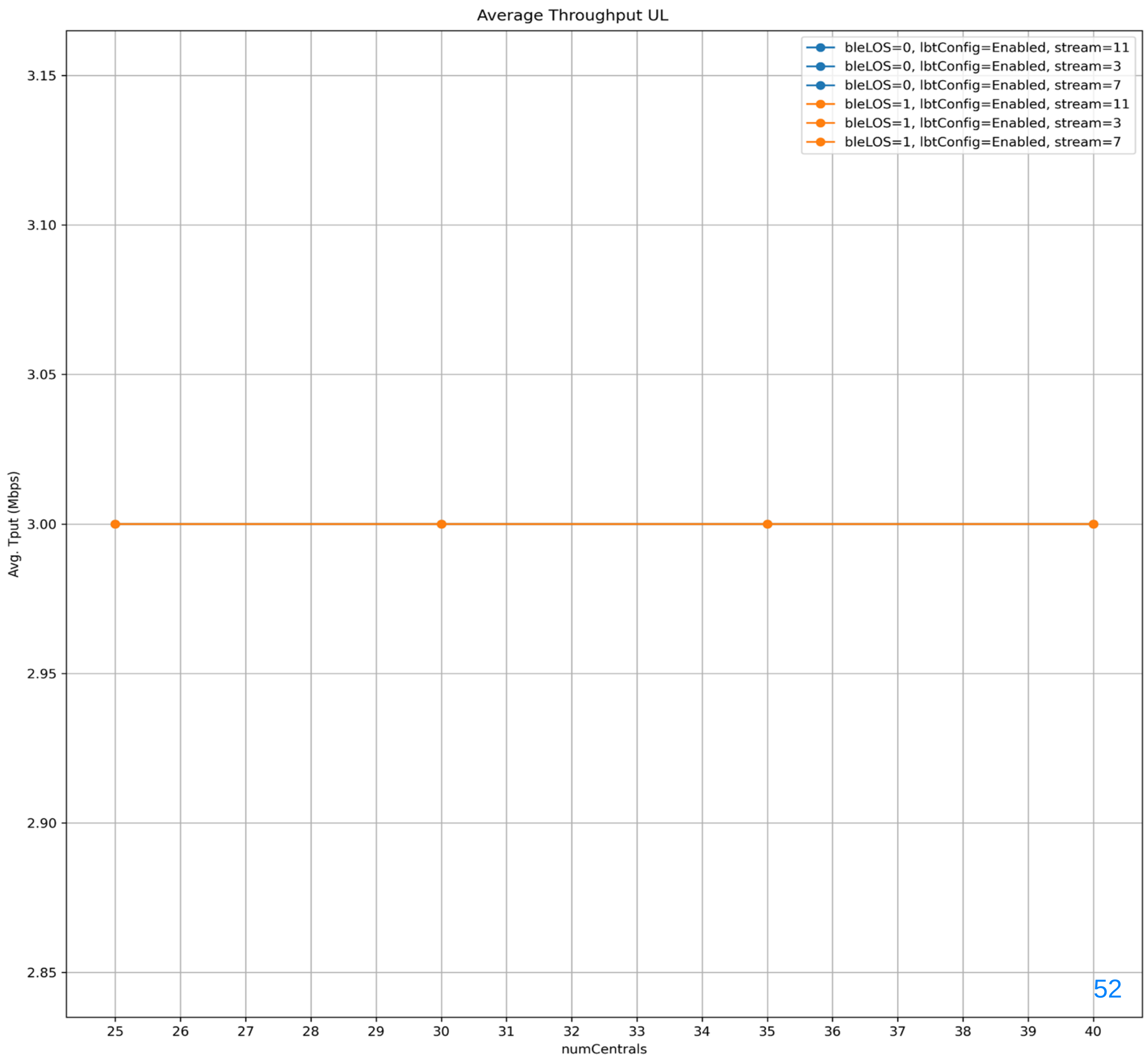


*Zoomed-in version of graph on left



BLE/Wi-Fi 57% Overlap 63% CU Even Time Split Wi-Fi Throughput





BLE/Wi-Fi 57% Overlap 63% CU Even Time Split Wi-Fi Latency