

**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]

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Outline

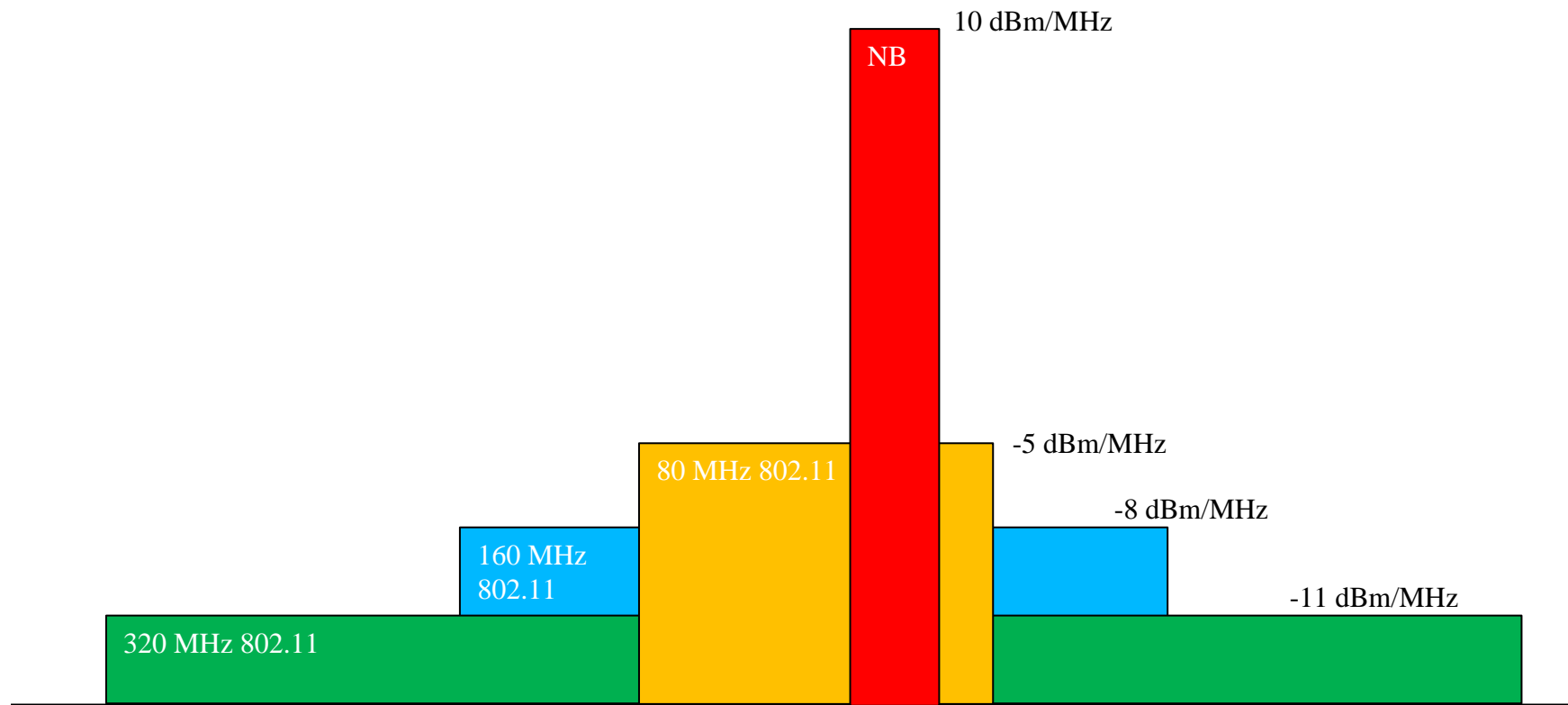
- Background
- Proposal
- Simulation Results
- Conclusions

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

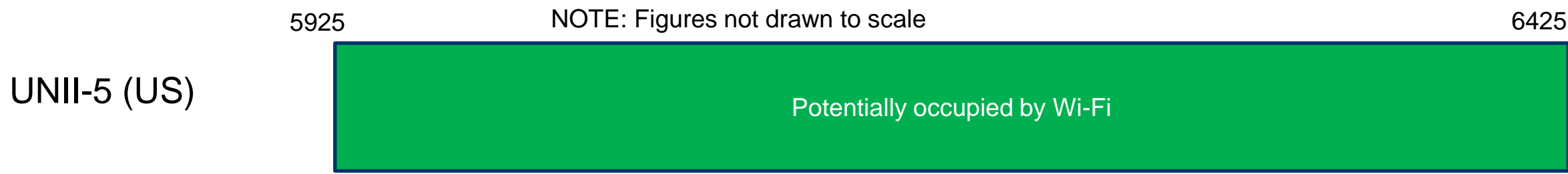
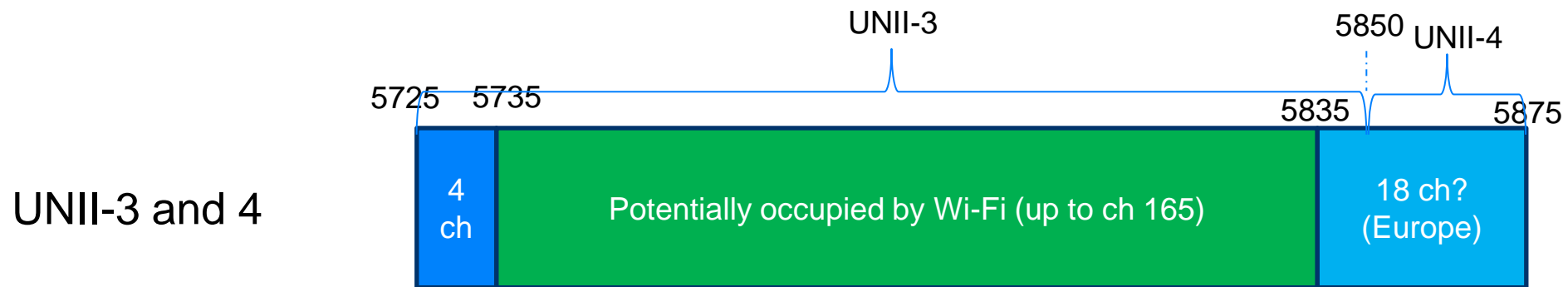
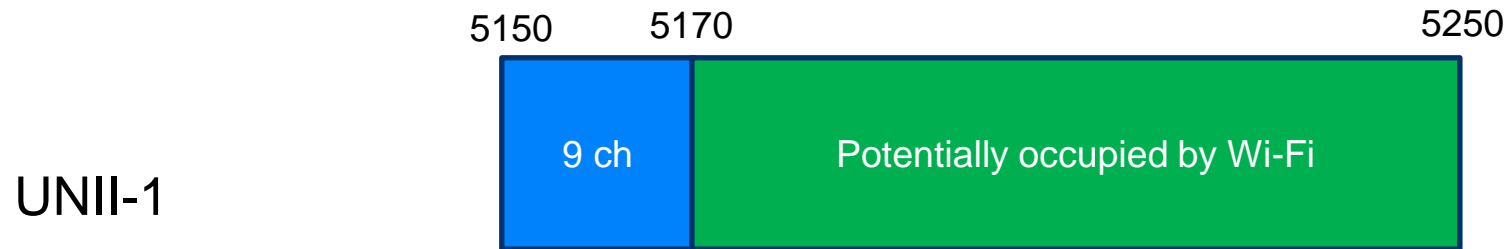
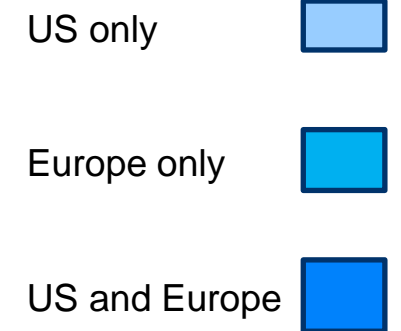
Background on Spectrum

- 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]

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

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



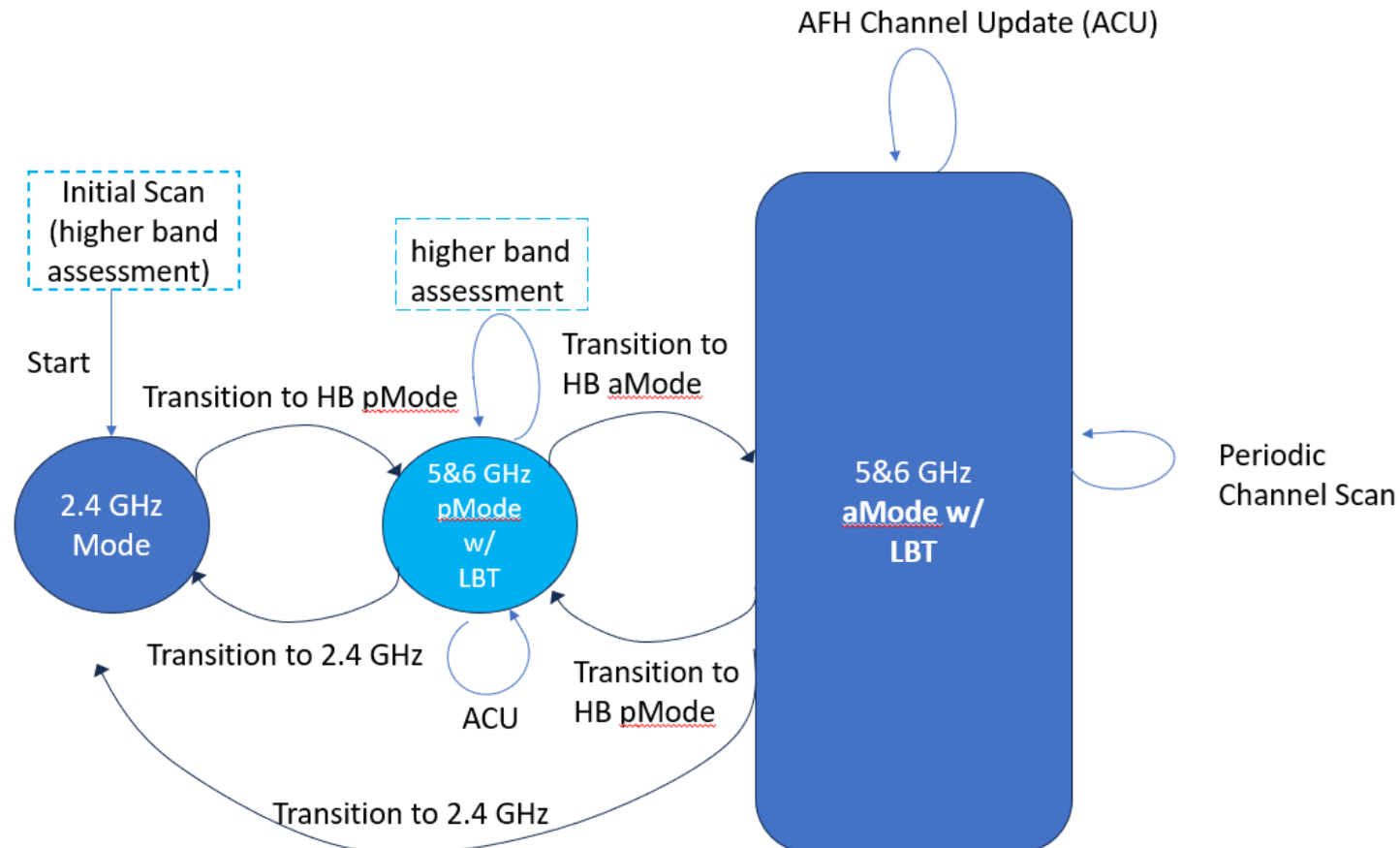
Key Aspects

- 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) $\geq 10\%$
- 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) \geq 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

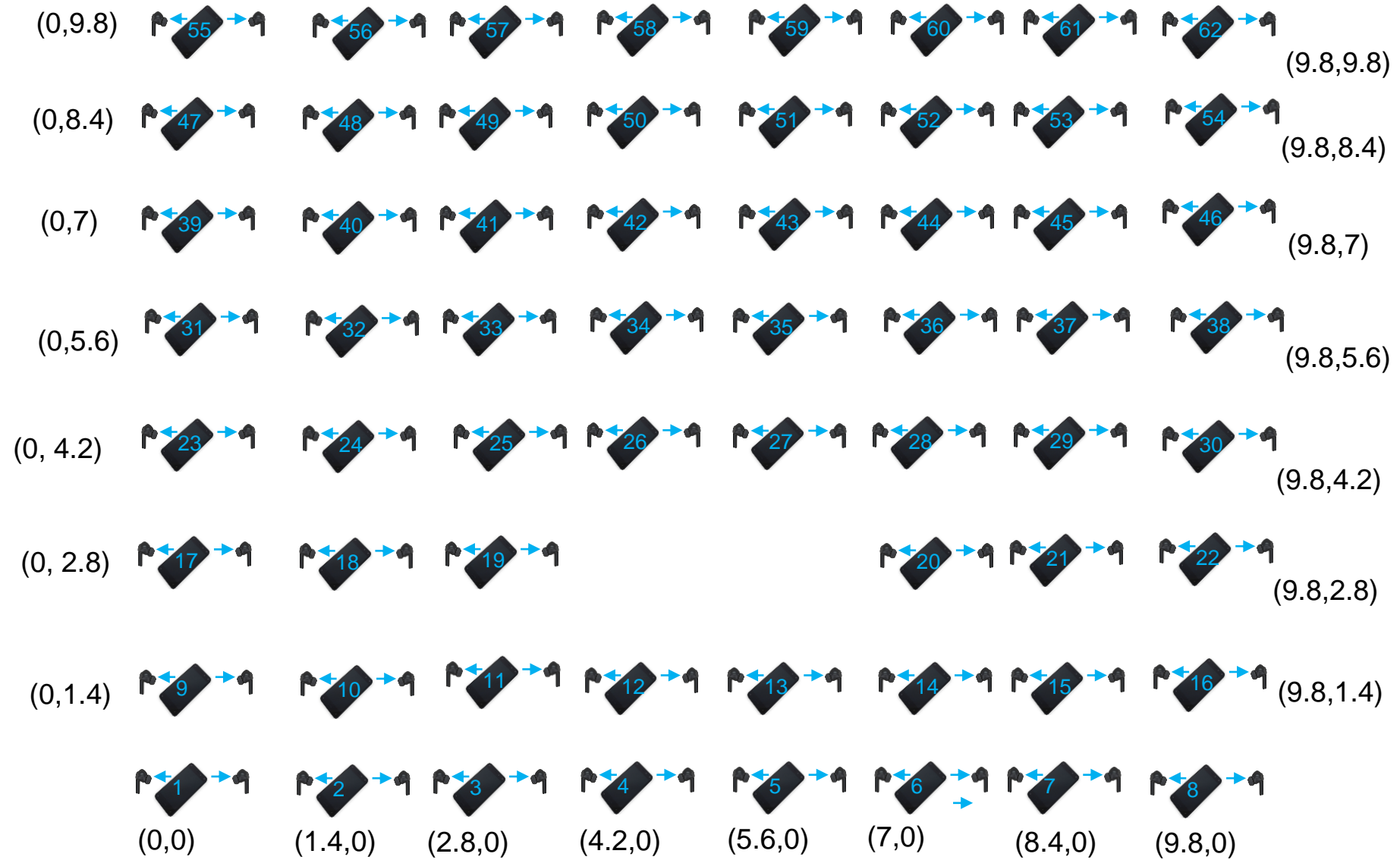
Wi-Fi Parameters

- 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 →



30 Channel BLE/BLE

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

Takeaways:

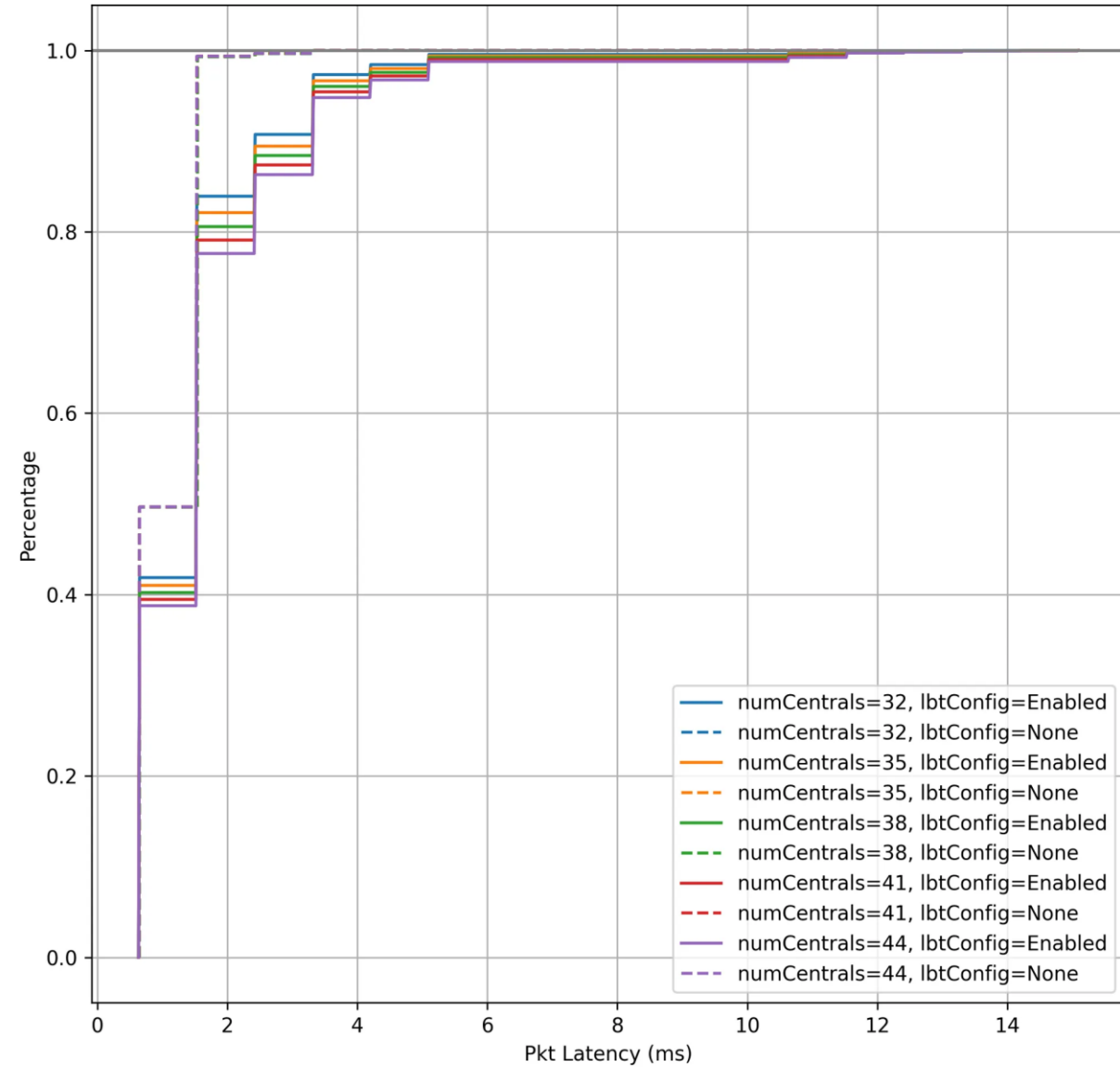
- LOS
 - No LBT slightly outperforms LBT
 - Most of the time both packets succeed, which is why no-LBT is better.
 - LBT can support ~ 30-40 centrals, depending on flush rate (e.g., ~39 centrals meet 0.01% flush rate)
- NLOS
 - LBT significantly outperforms no LBT
 - With LBT, when a collision happens,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

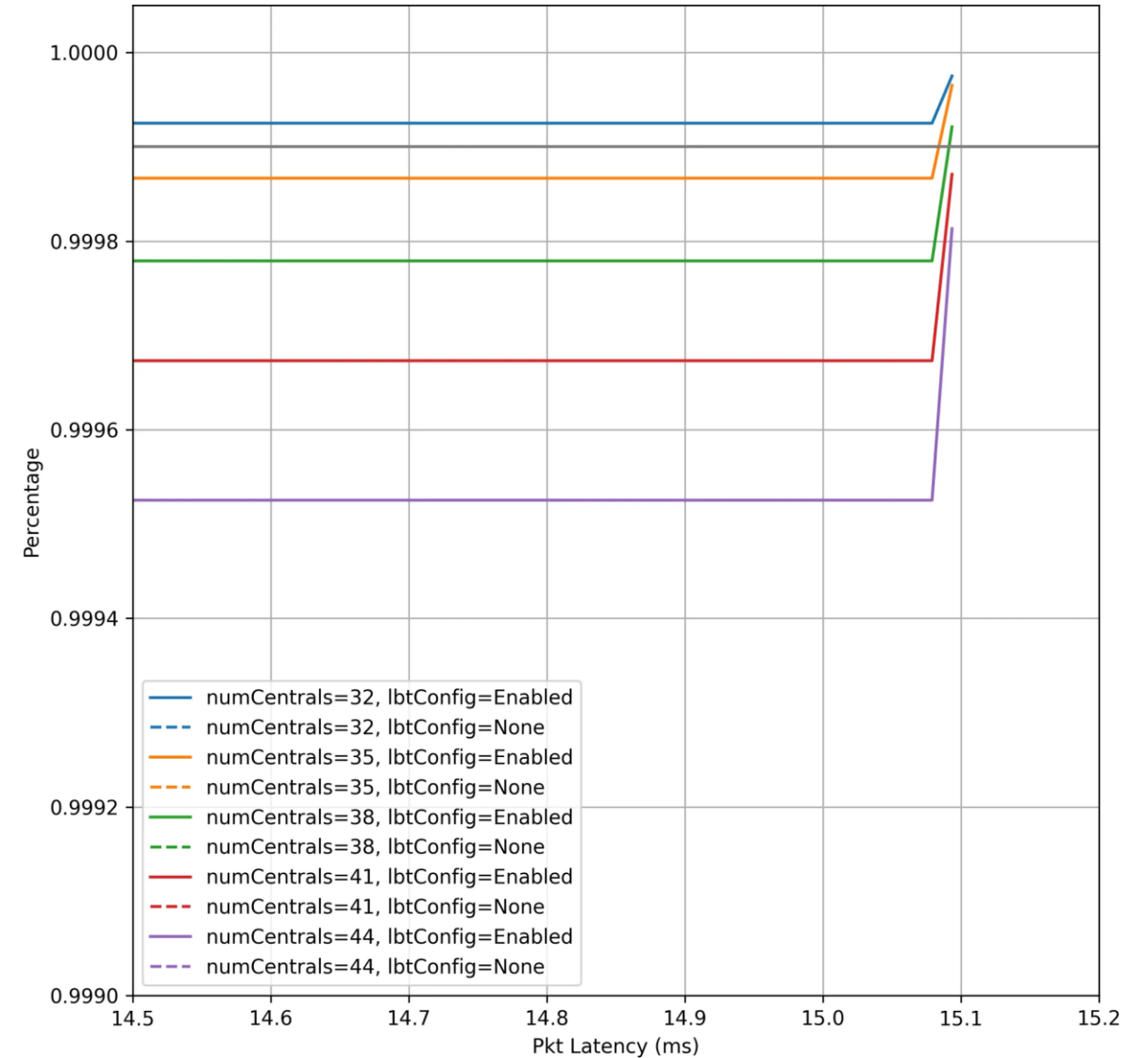
LBT is solid and no-LBT is dashed

*Zoomed-in version of graph on left

CDF bleLOS:1 TX DL



CDF bleLOS:1 TX DL



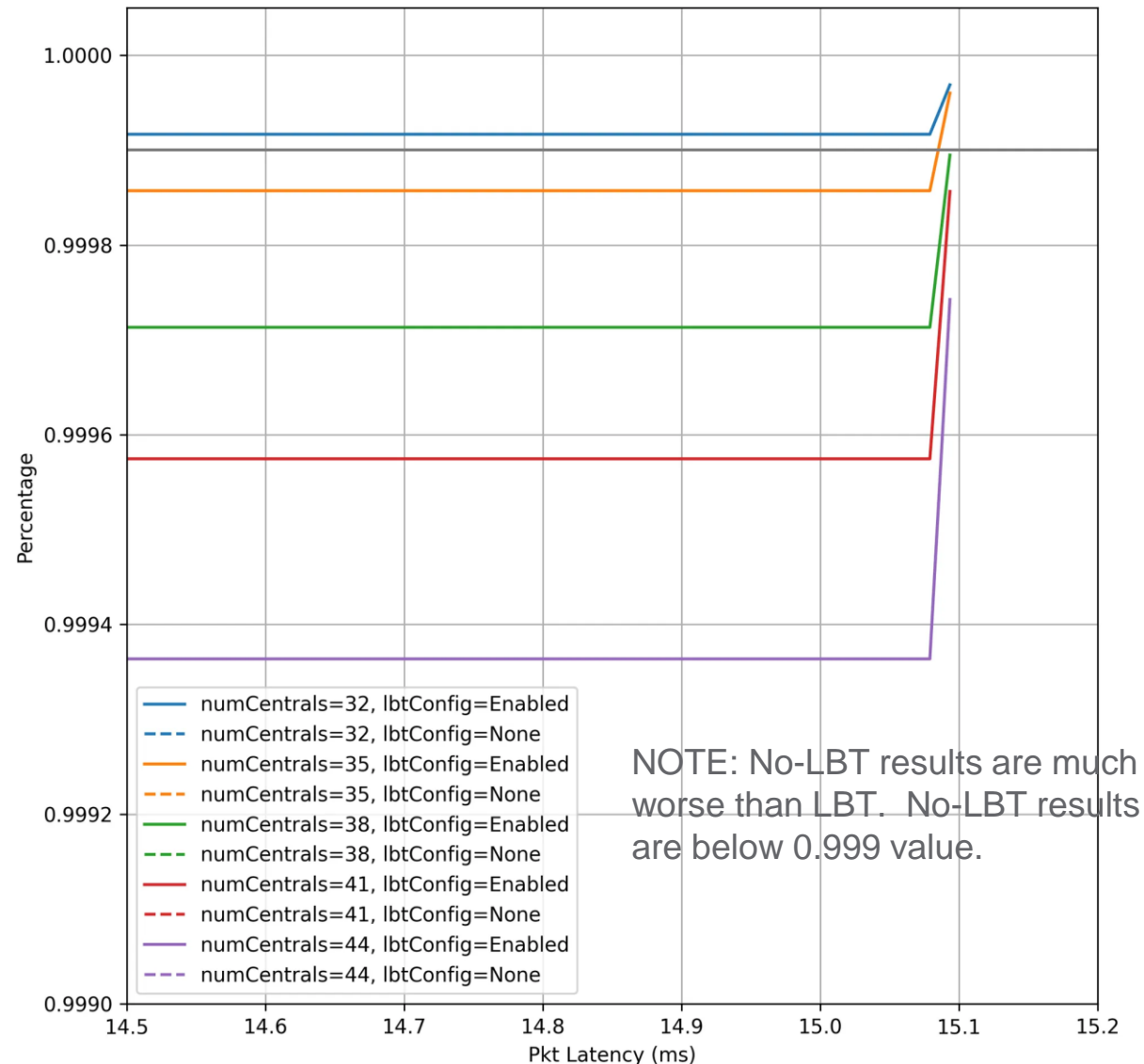
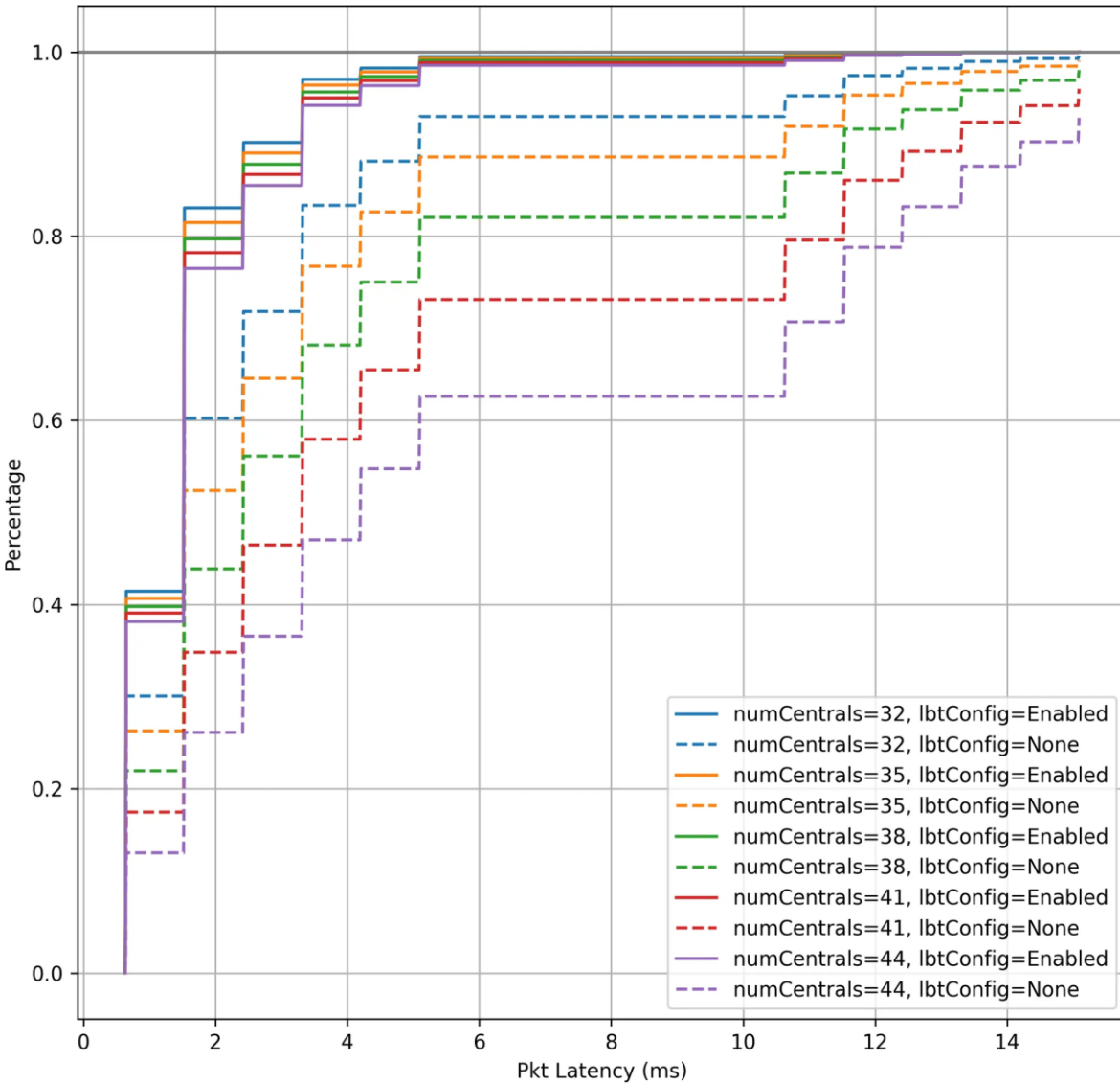
BLE/BLE NLOS Latency

LBT is solid and no-LBT is dashed

*Zoomed-in version of graph on left



CDF bleLOS:0 TX DL

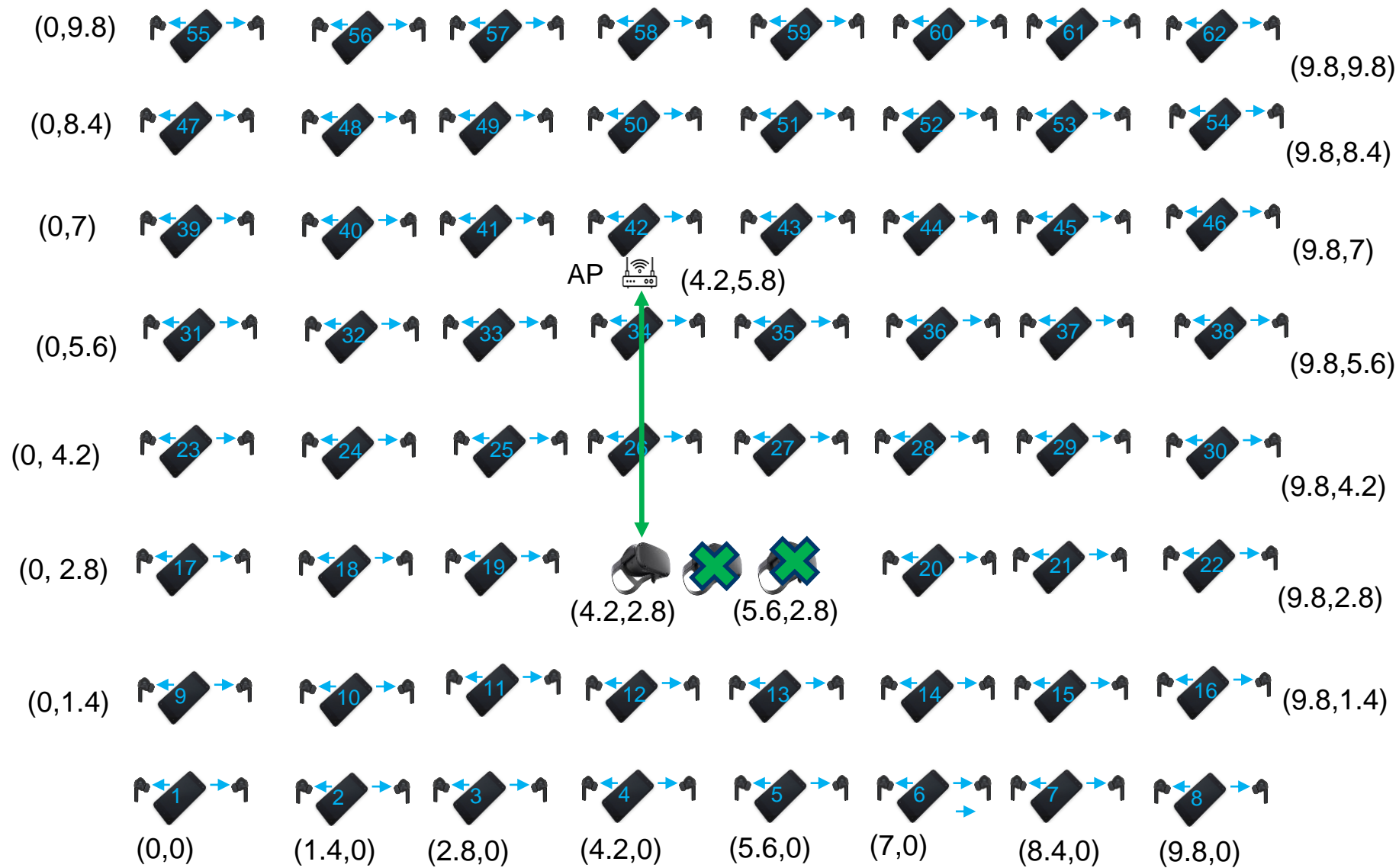
CDF bleLOS:0 TX DL



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

1 STA Scenario

UL/DL 802.11 
DL NB 



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

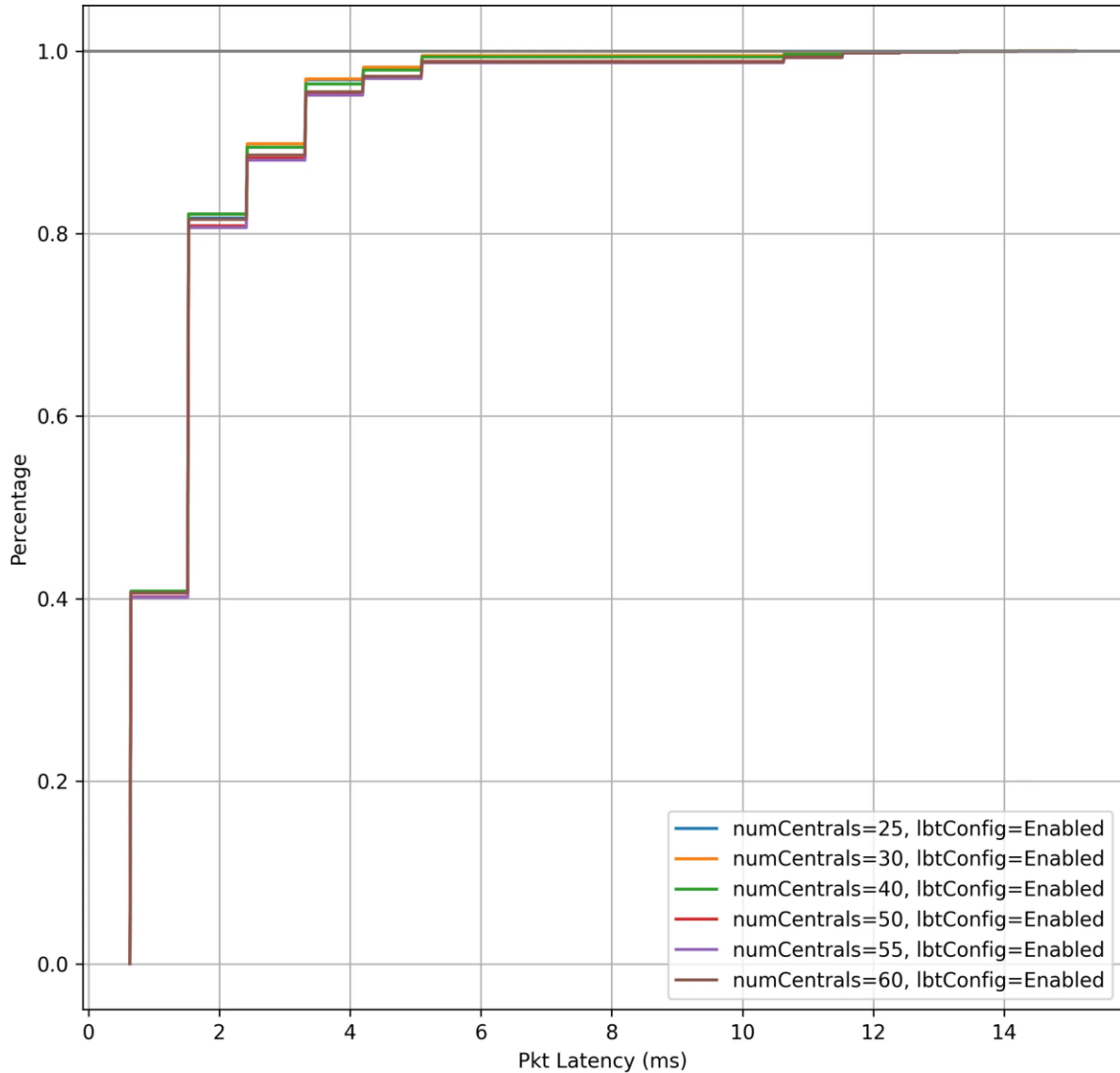
Takeaways:

- **~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**

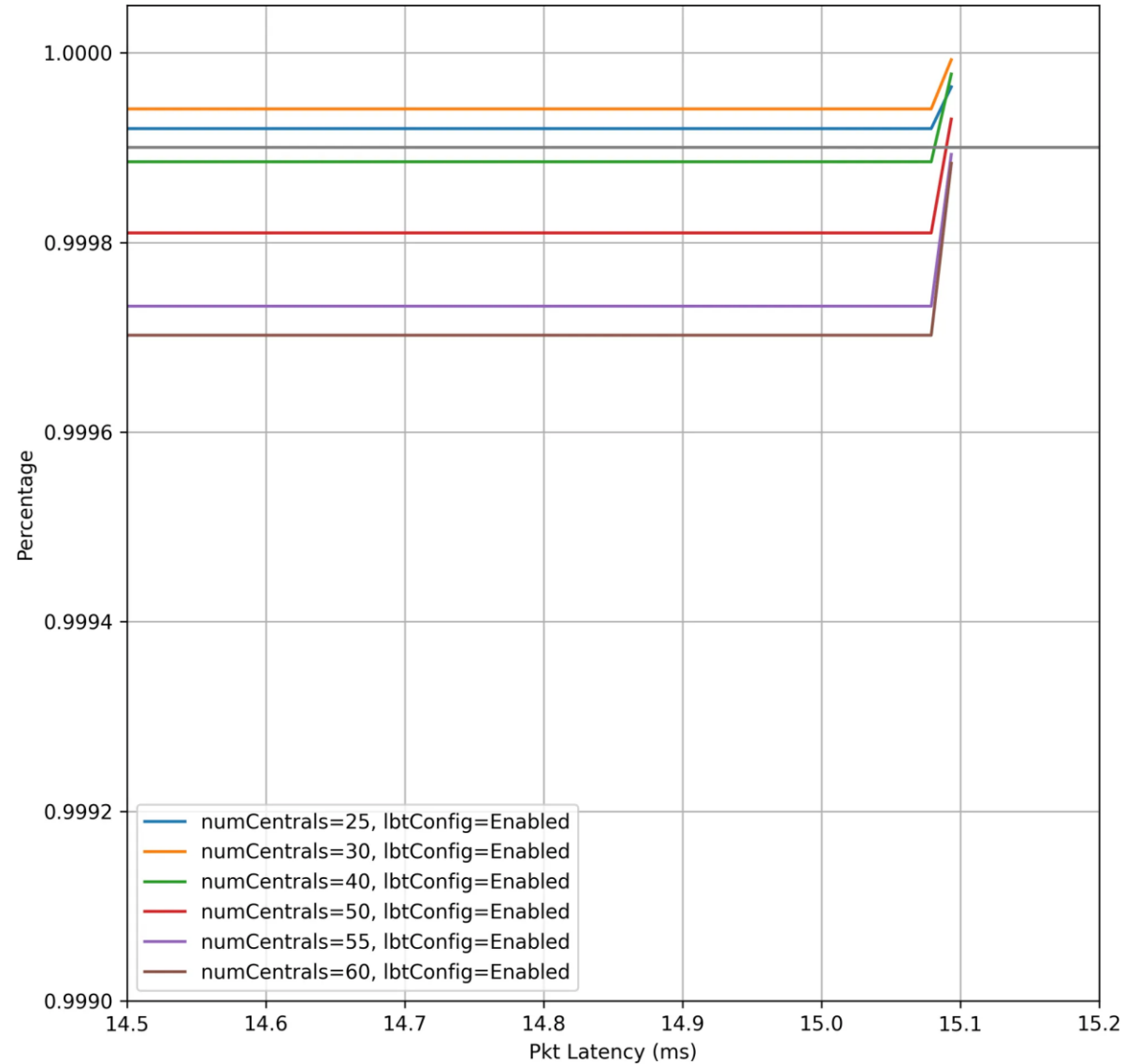
BLE/Wi-Fi 57% Overlap Even Time Split LOS BLE Latency

*Zoomed-in version of graph on left

CDF bleLOS:1 TX DL



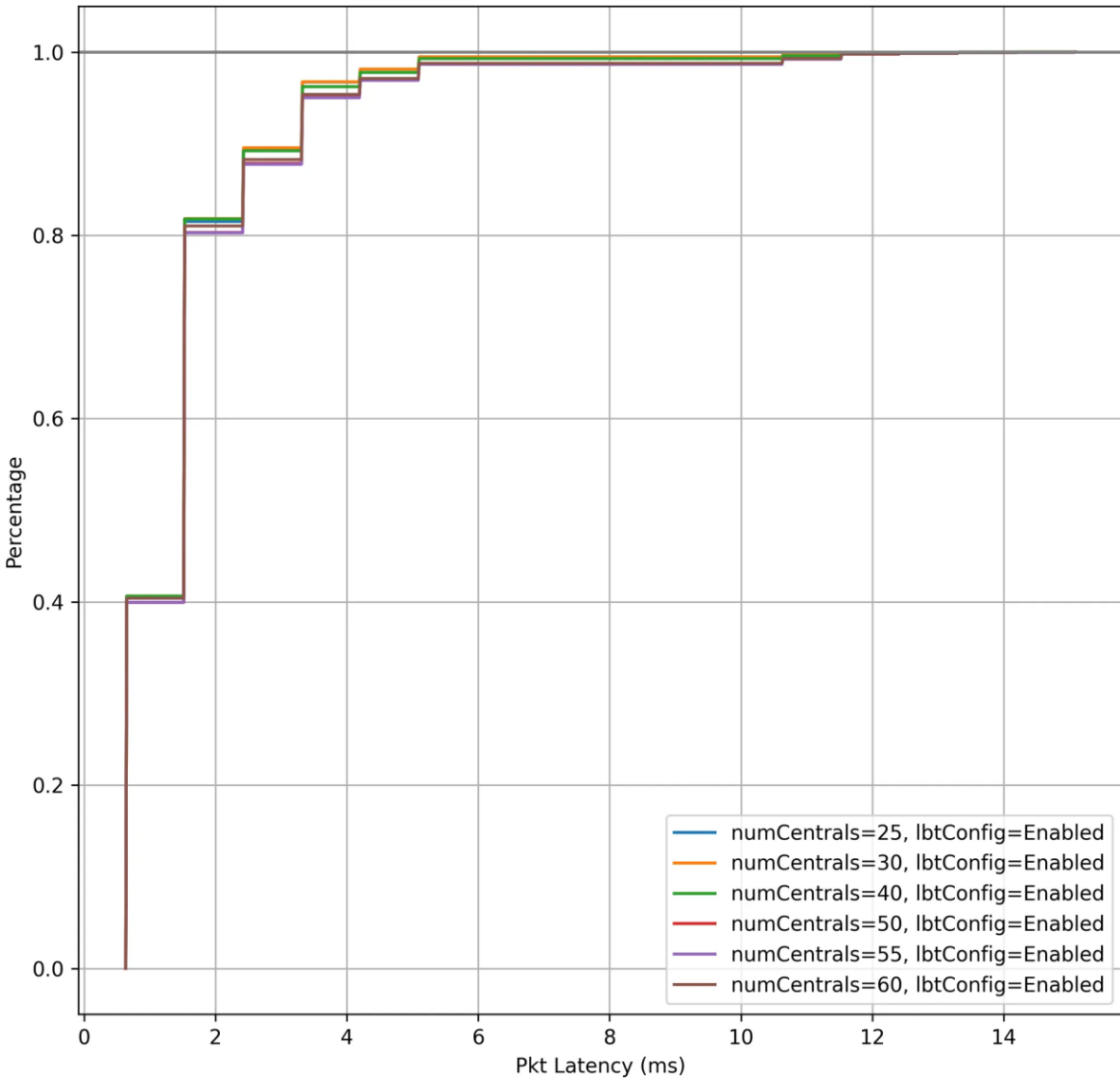
CDF bleLOS:1 TX DL



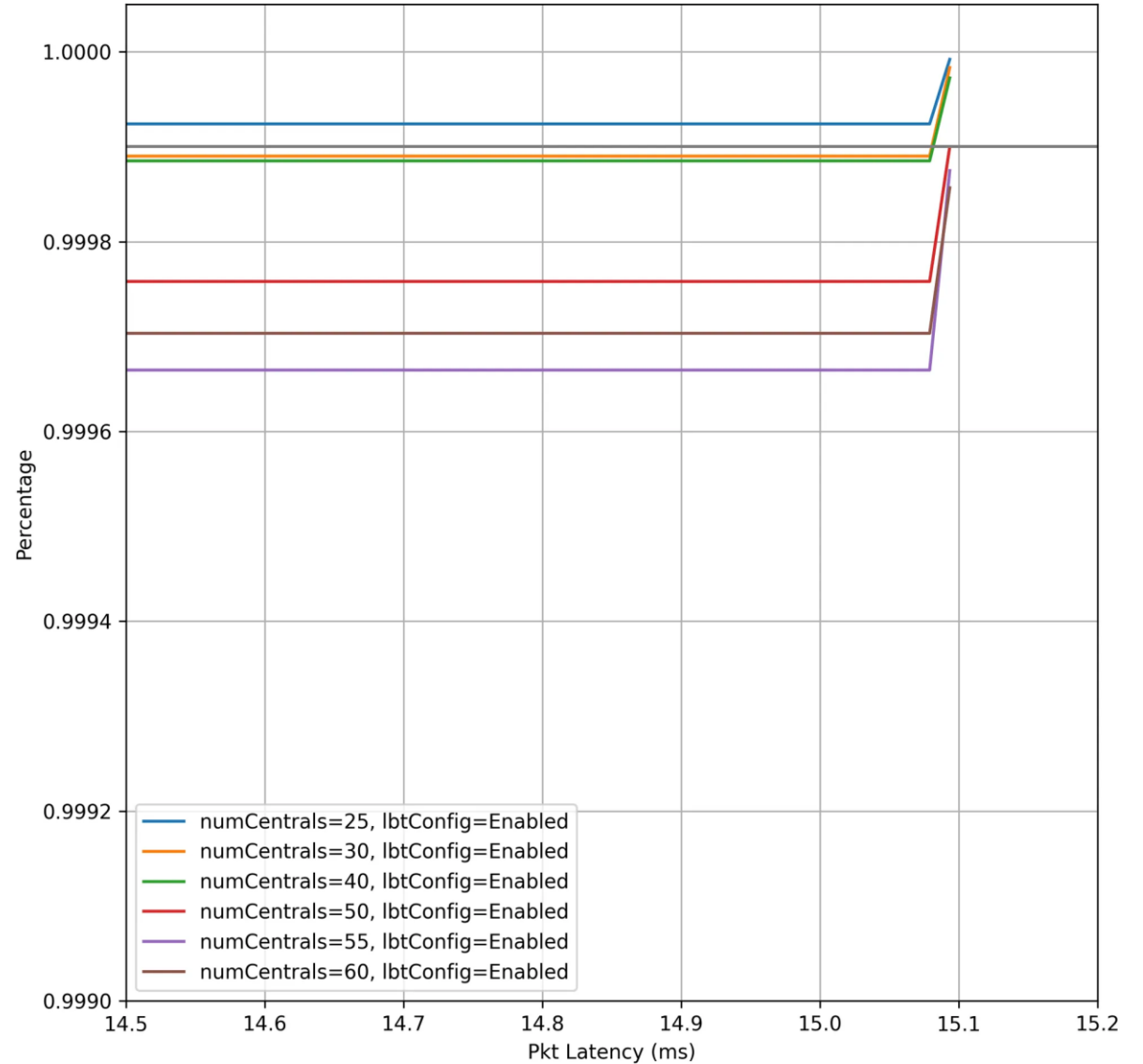
BLE/Wi-Fi 57% Overlap Even Time Split NLOS BLE Latency

*Zoomed-in version of graph on left

CDF bleLOS:0 TX DL

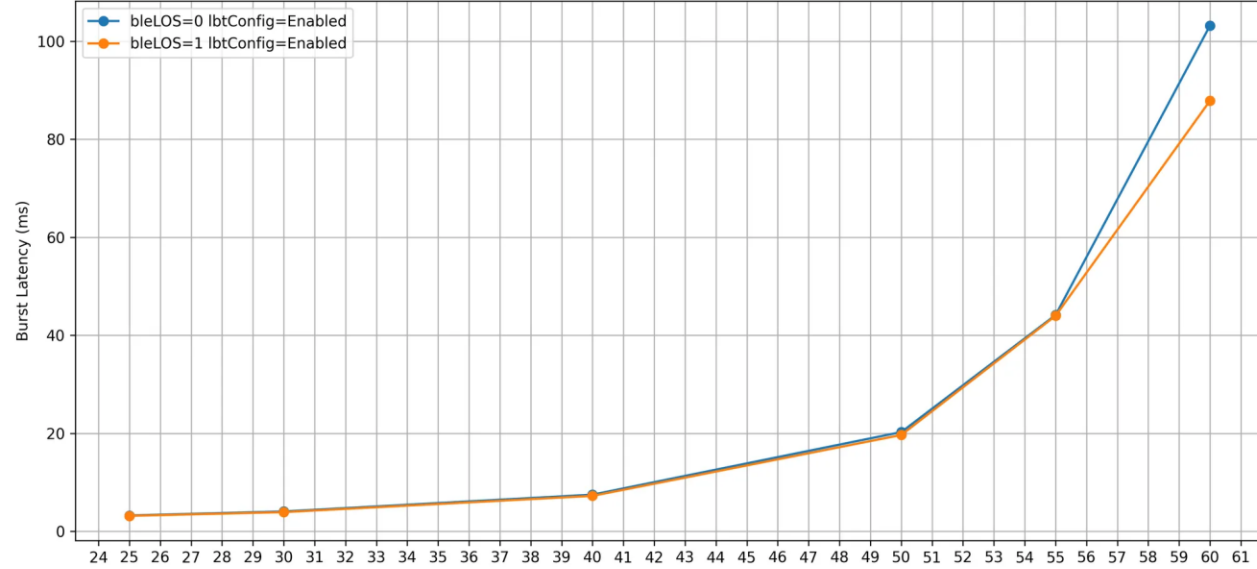


CDF bleLOS:0 TX DL

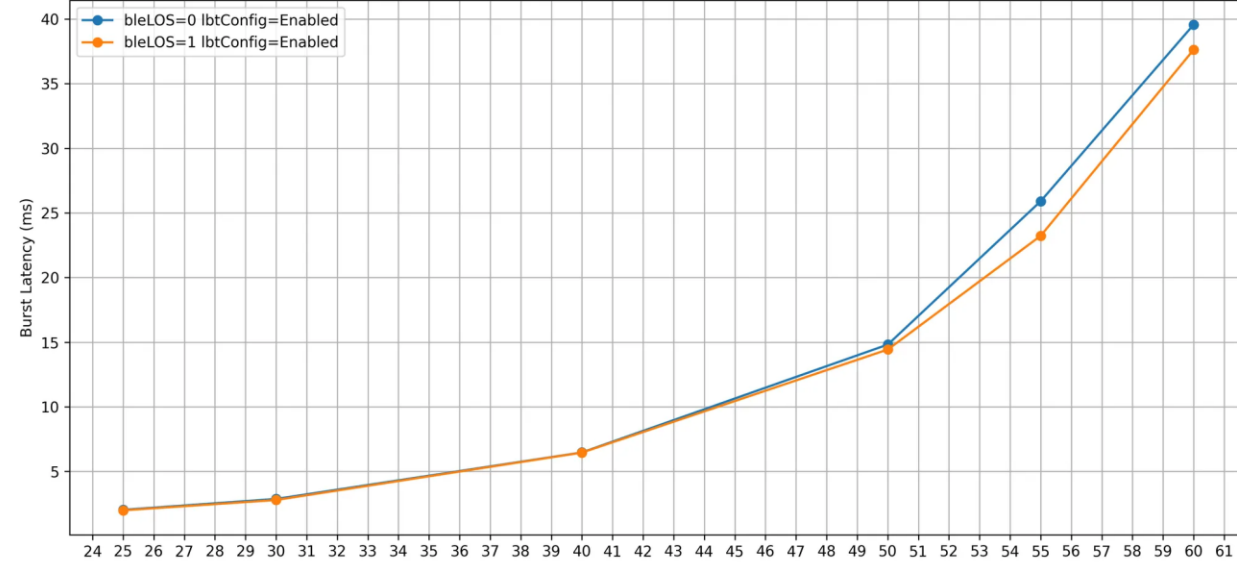


BLE/Wi-Fi 57% Even Time Split Overlap Wi-Fi Latency

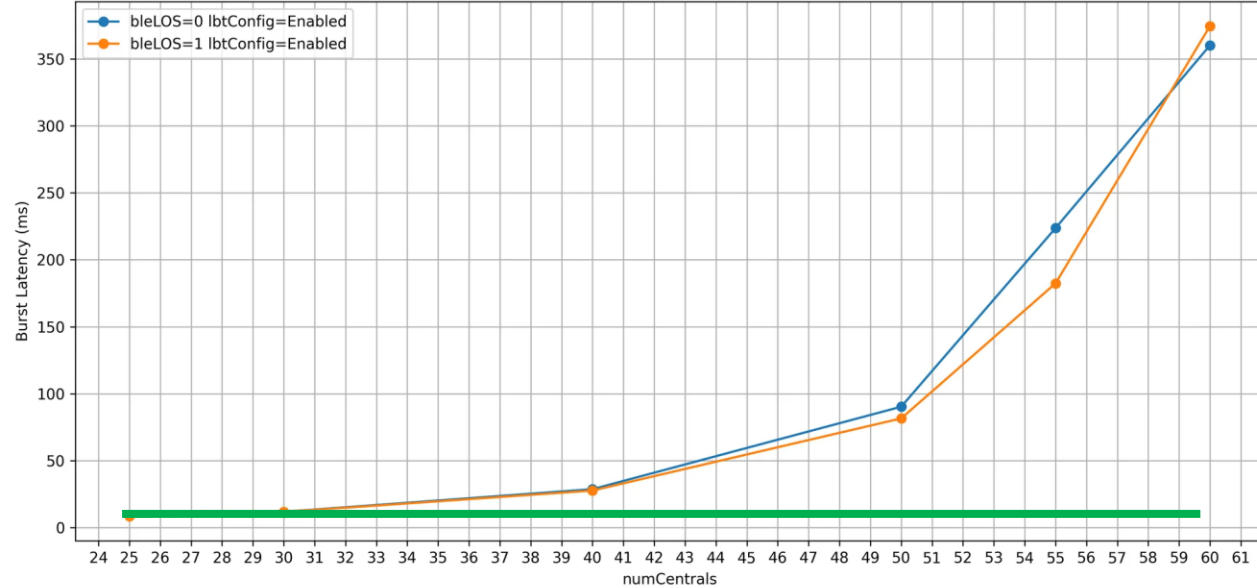
Percentile BTX DL
0.5 Percentile



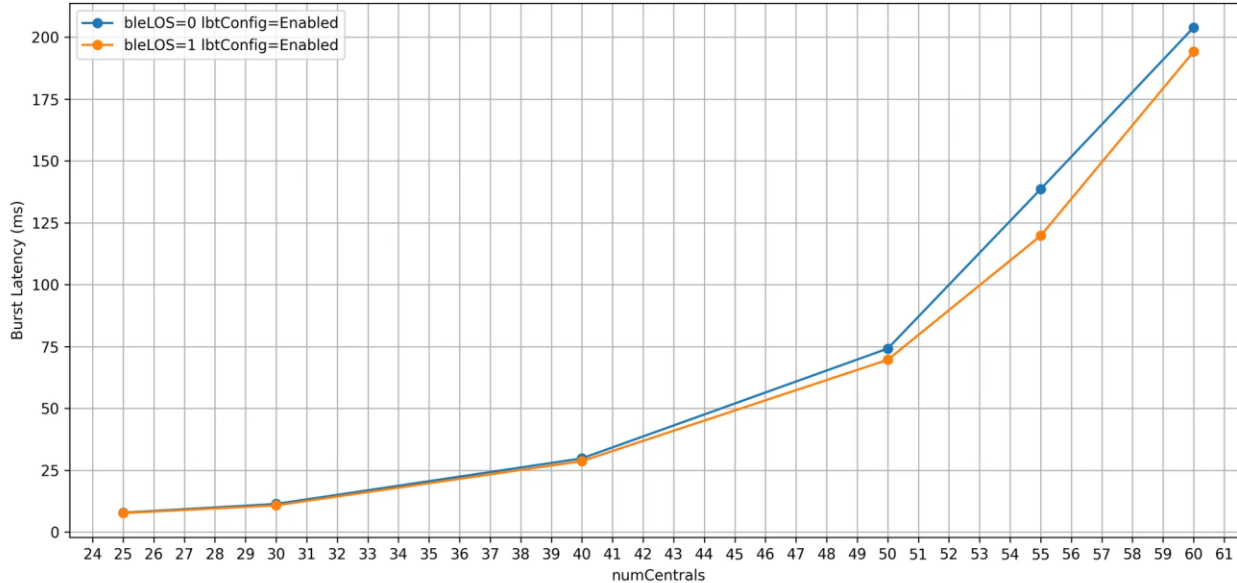
Percentile BTX UL
0.5 Percentile



0.95 Percentile



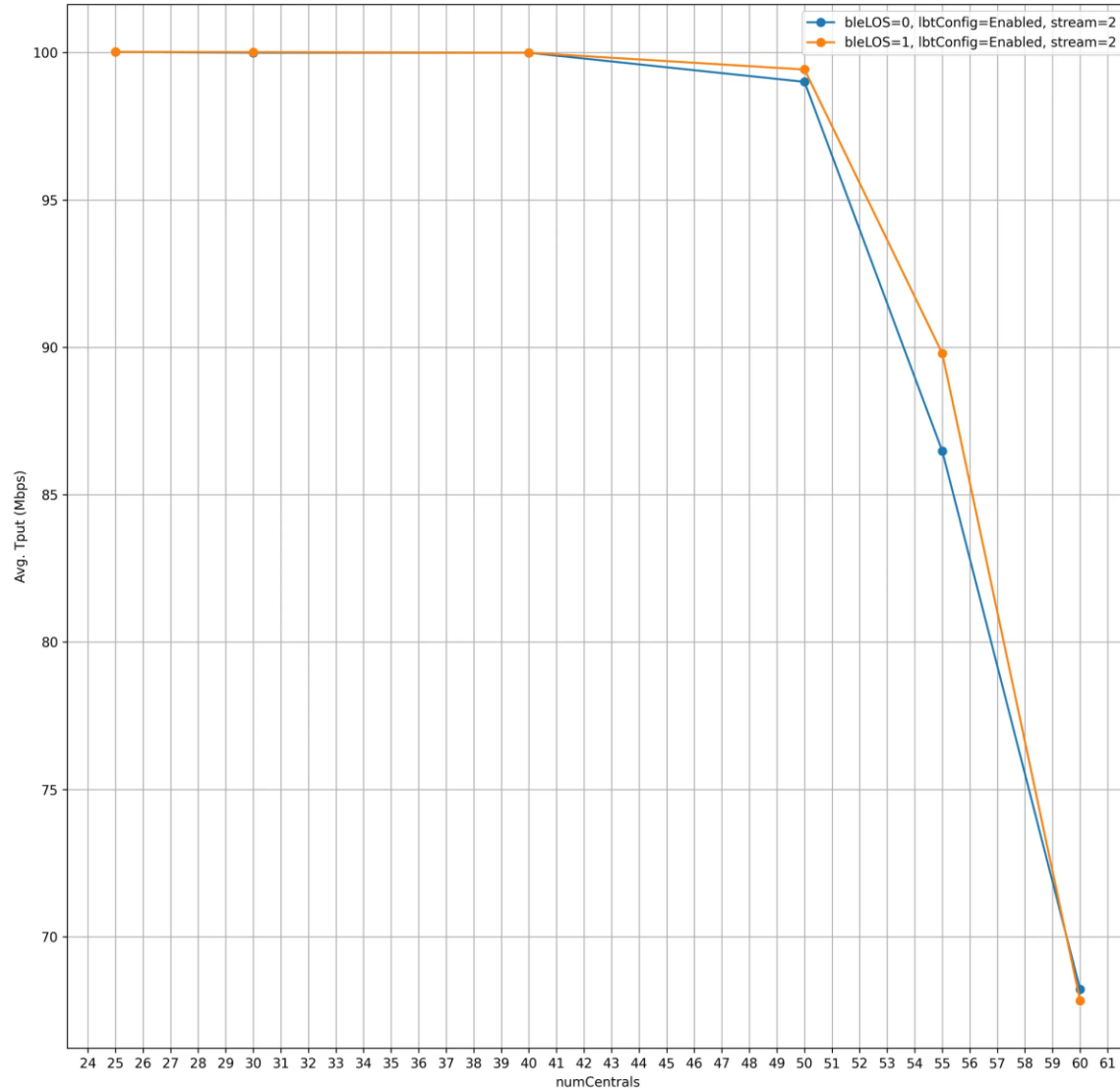
0.95 Percentile



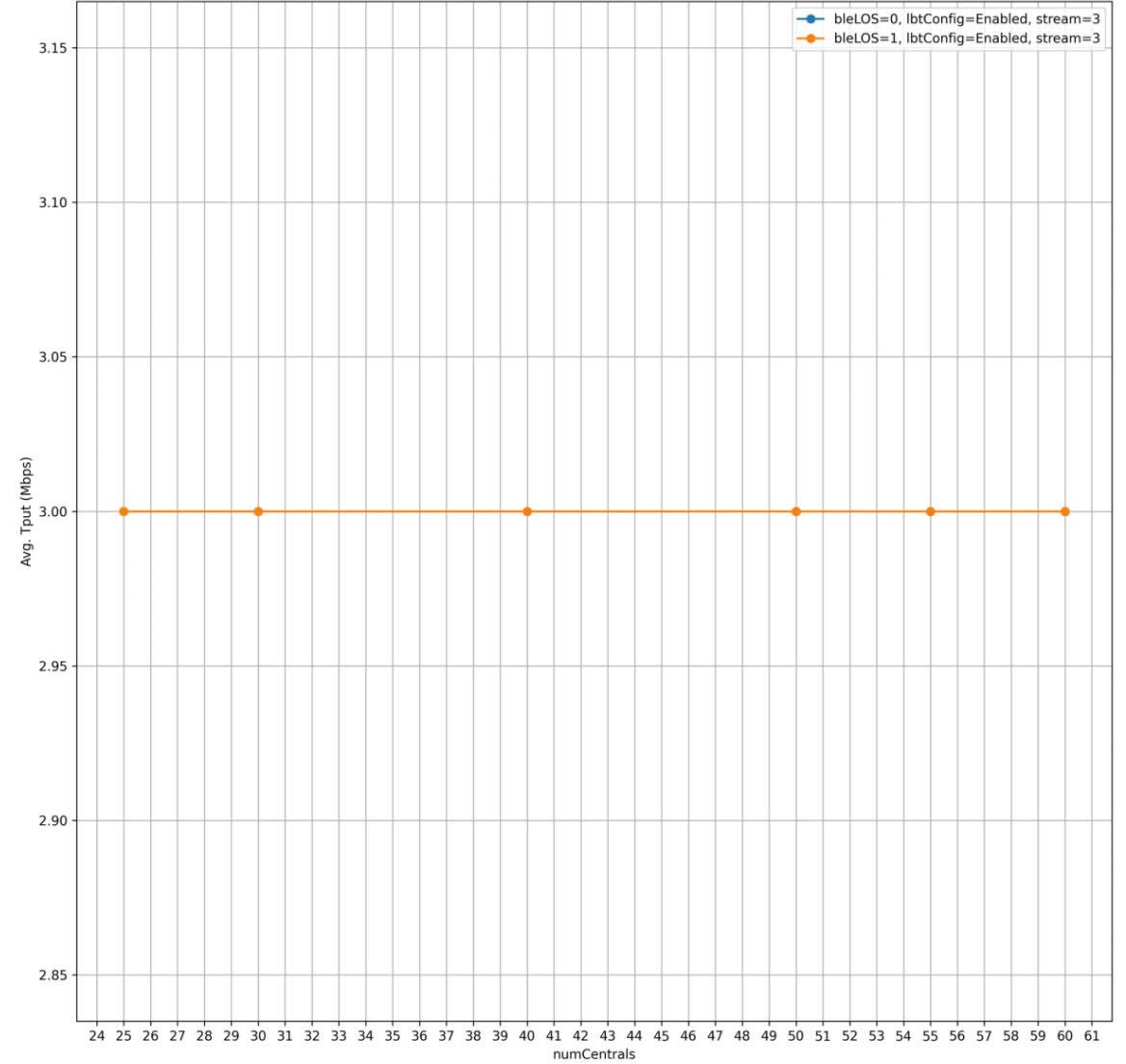
BLE/Wi-Fi 57% Overlap Even Time Split Wi-Fi Throughput

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

Average Throughput DL



Average Throughput UL



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

70 Channel BLE/Wi-Fi 57% Overlap

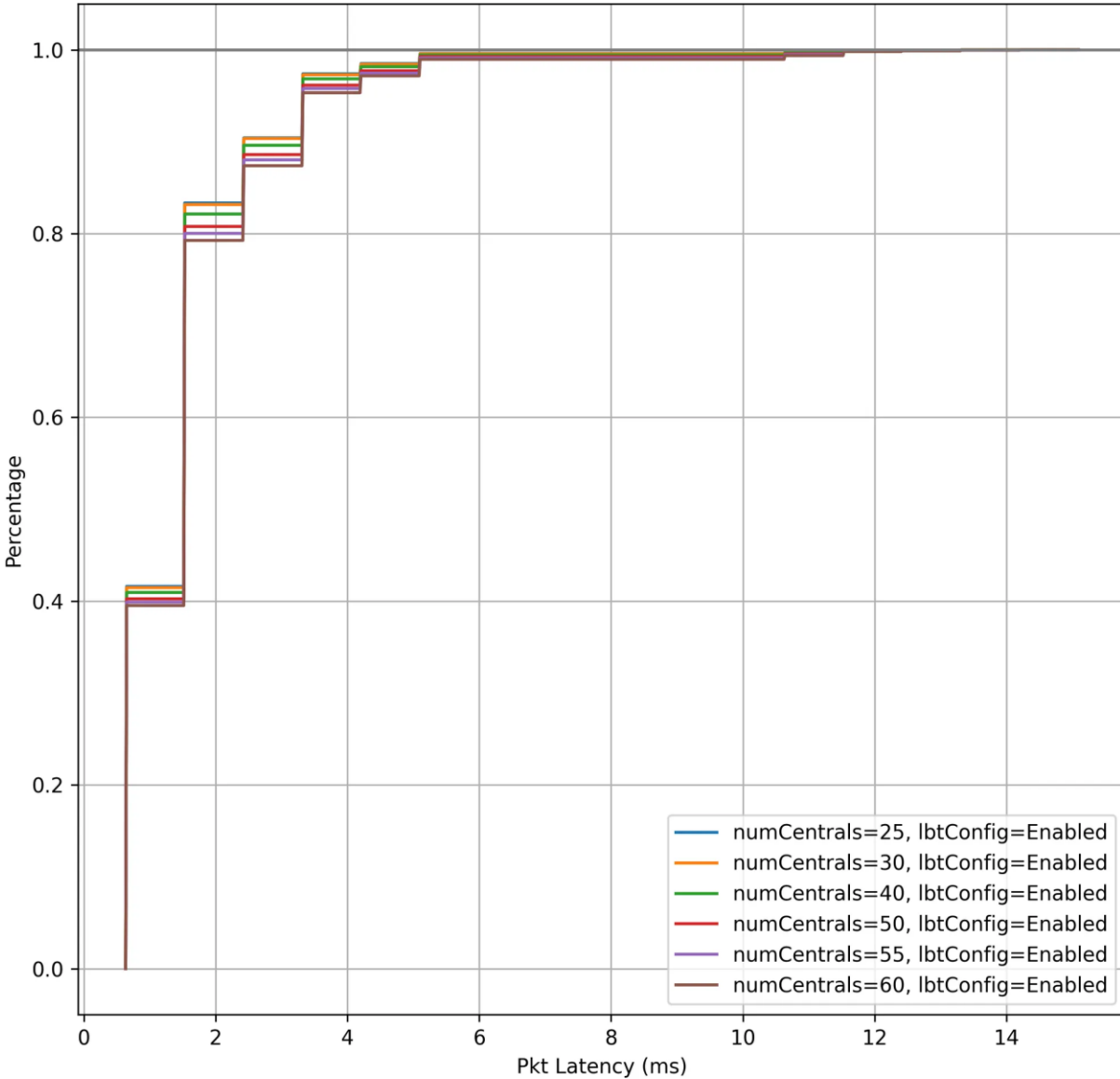
- Exact same as previous results but instead clear channels used at a ratio of 2:1 compared to Wi-Fi channels

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.**

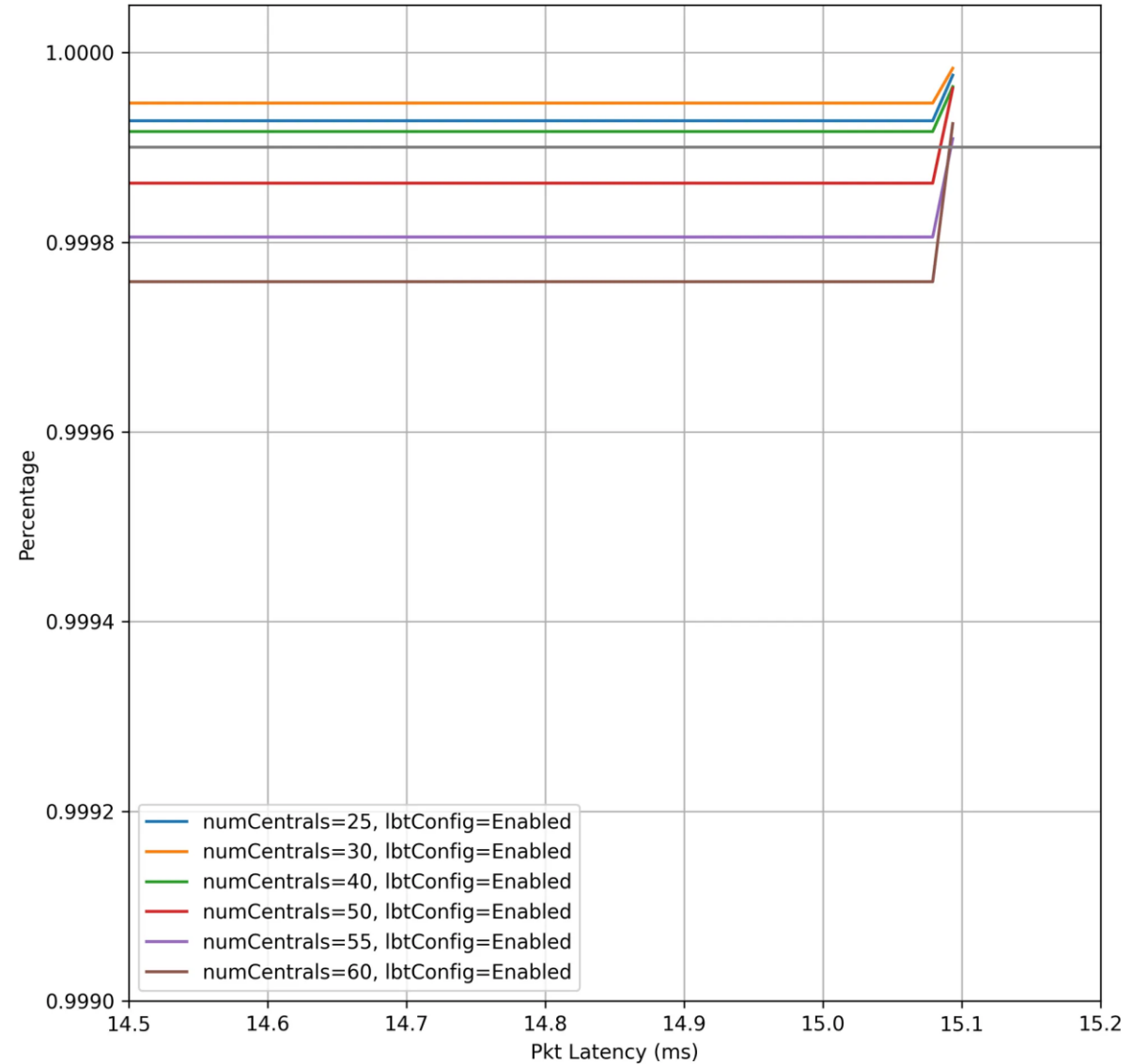
BLE/Wi-Fi 57% Overlap LOS BLE Latency

CDF bleLOS:1 TX DL



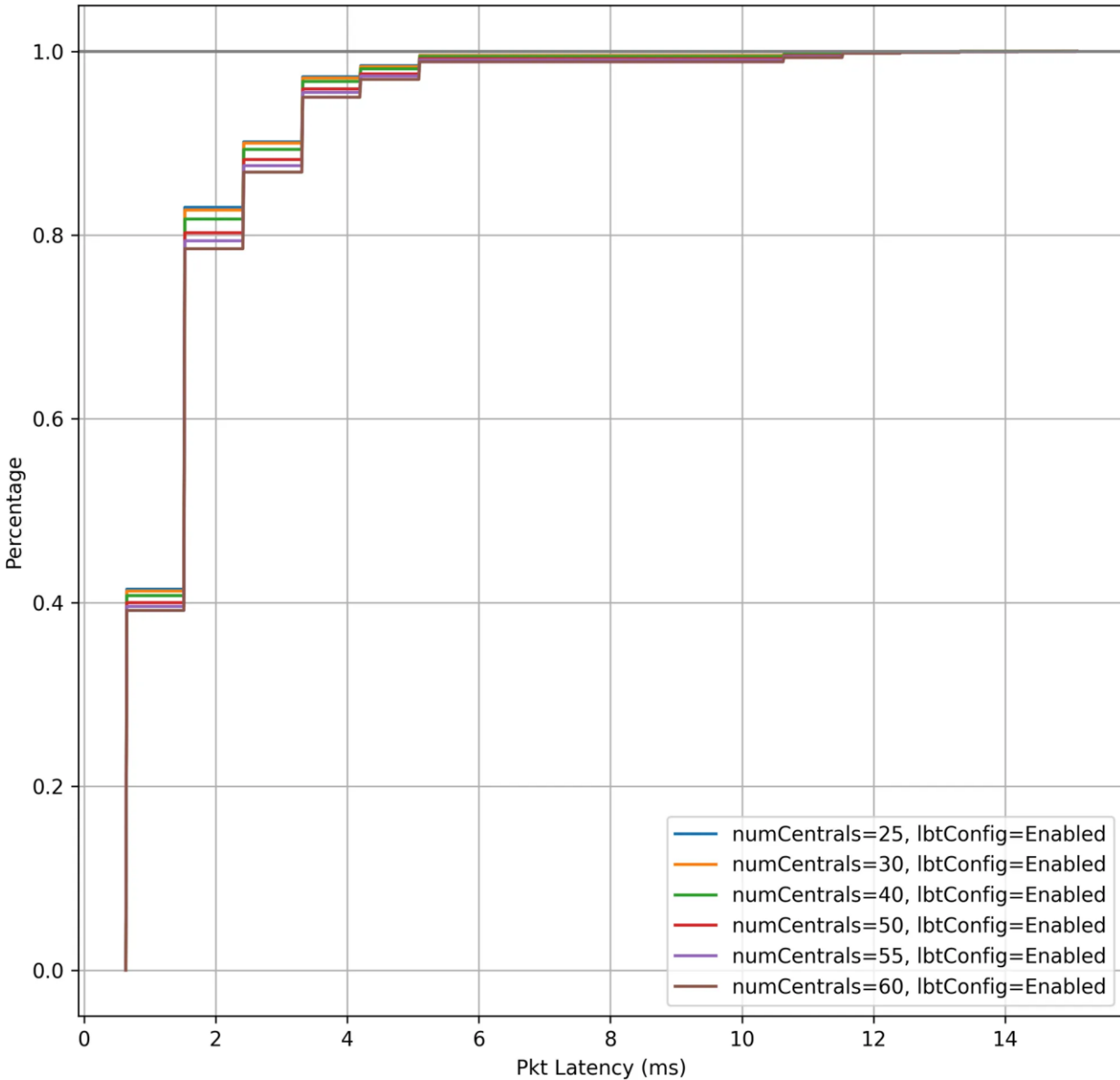
*Zoomed-in version of graph on left

CDF bleLOS:1 TX DL



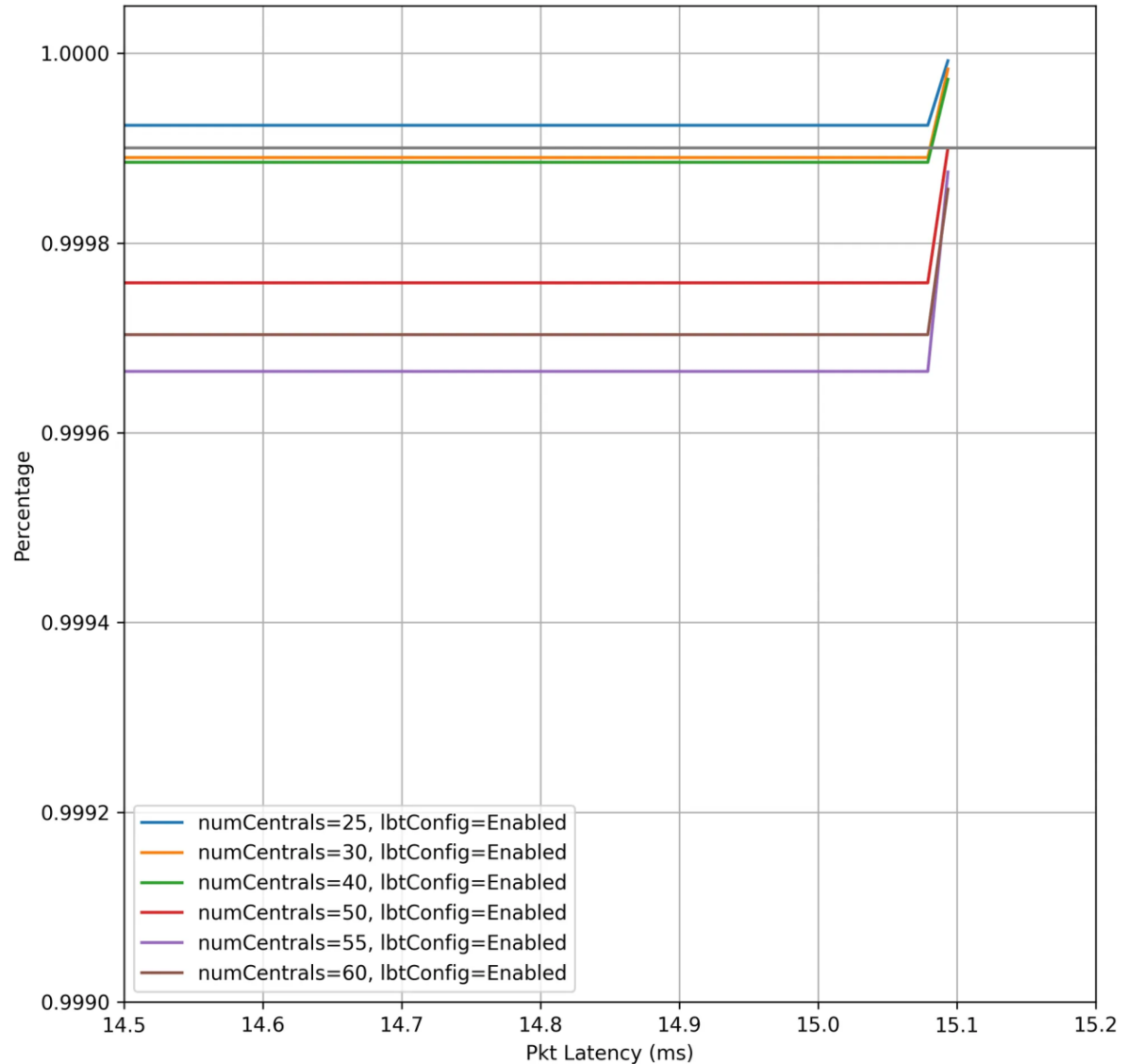
BLE/Wi-Fi 57% Overlap NLOS BLE Latency

CDF bleLOS:0 TX DL



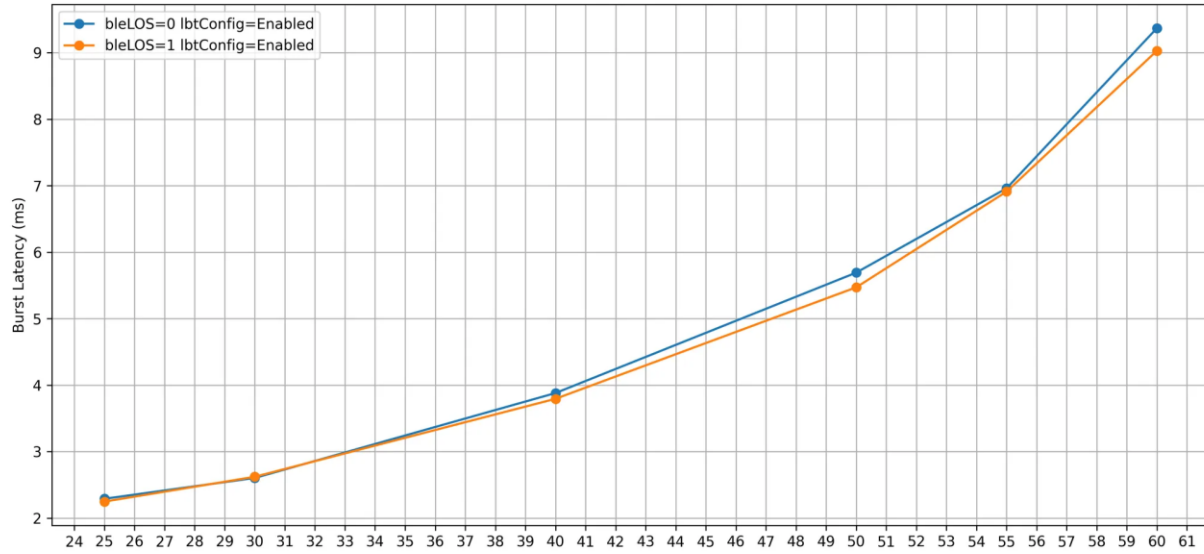
*Zoomed-in version of graph on left

CDF bleLOS:0 TX DL

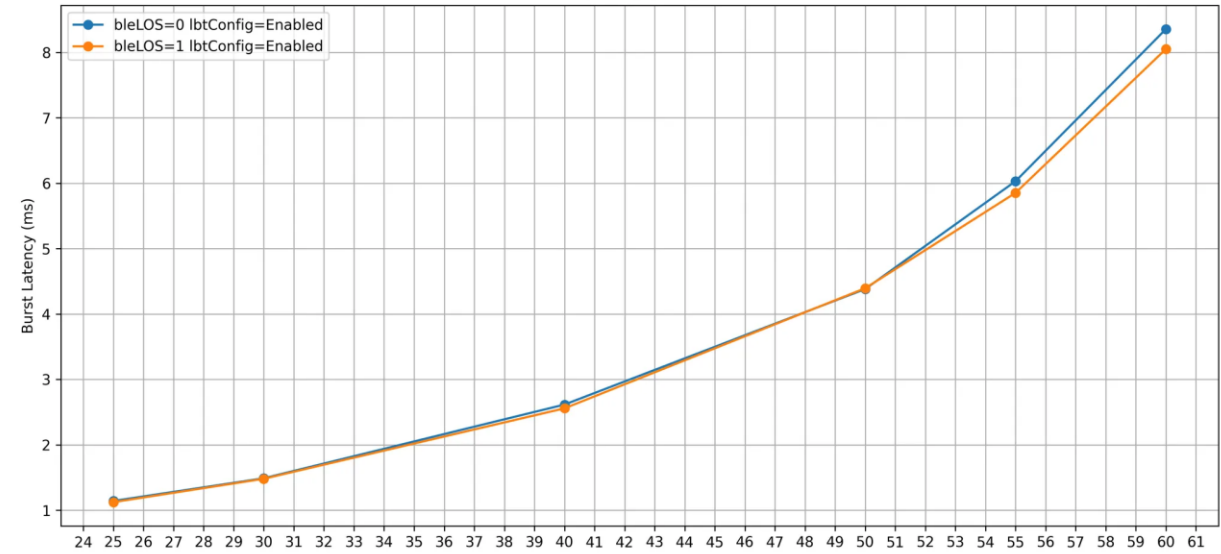


BLE/Wi-Fi 57% Overlap Wi-Fi Latency

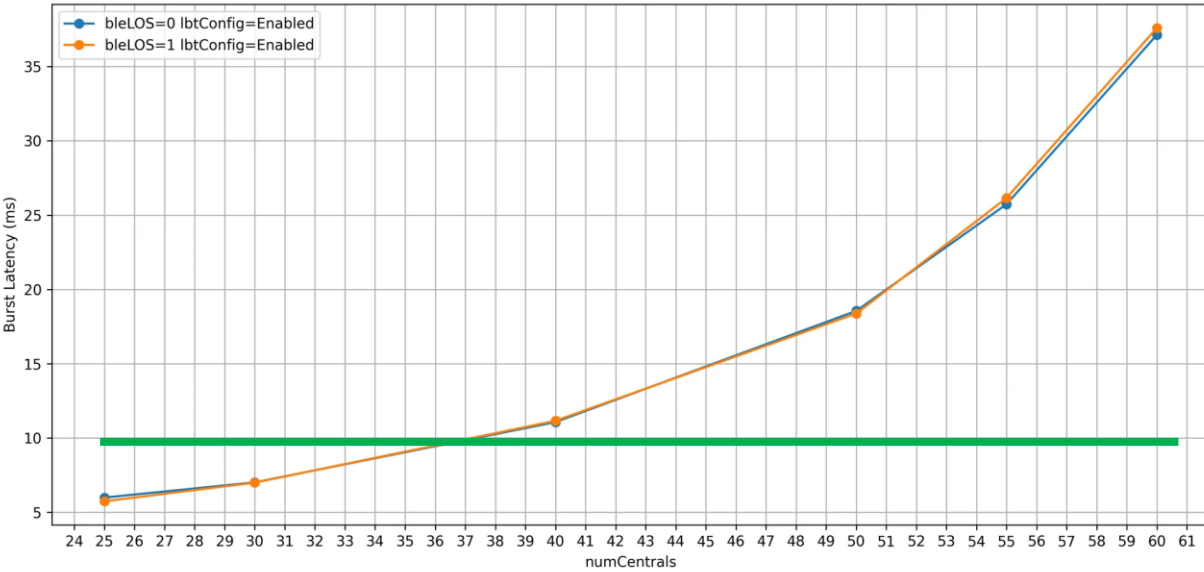
Percentile BTX DL
0.5 Percentile



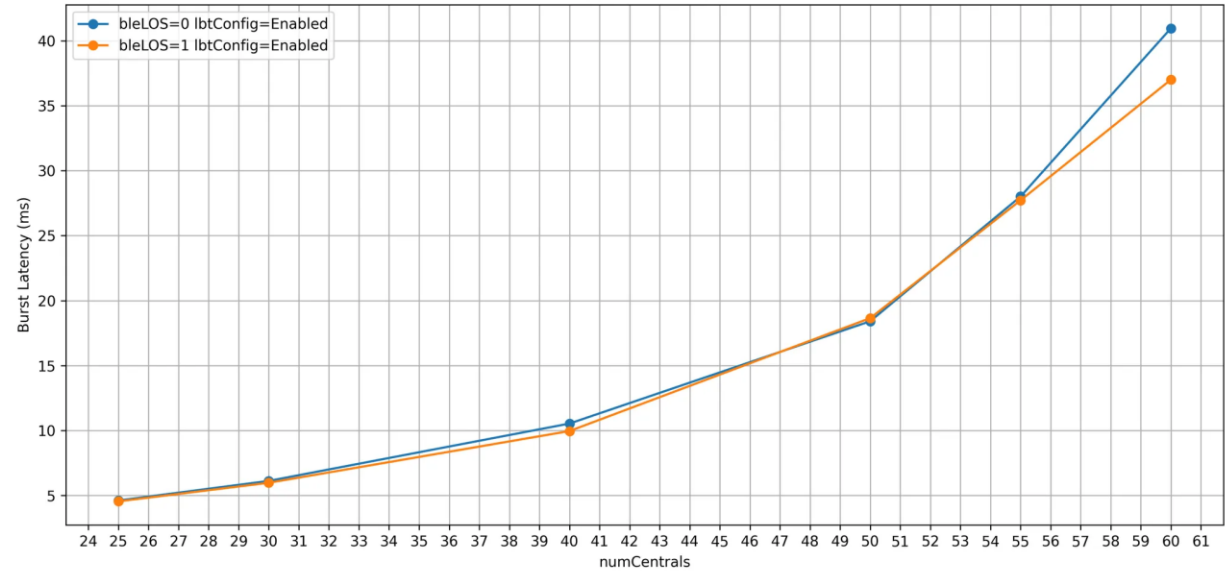
Percentile BTX UL
0.5 Percentile



0.95 Percentile

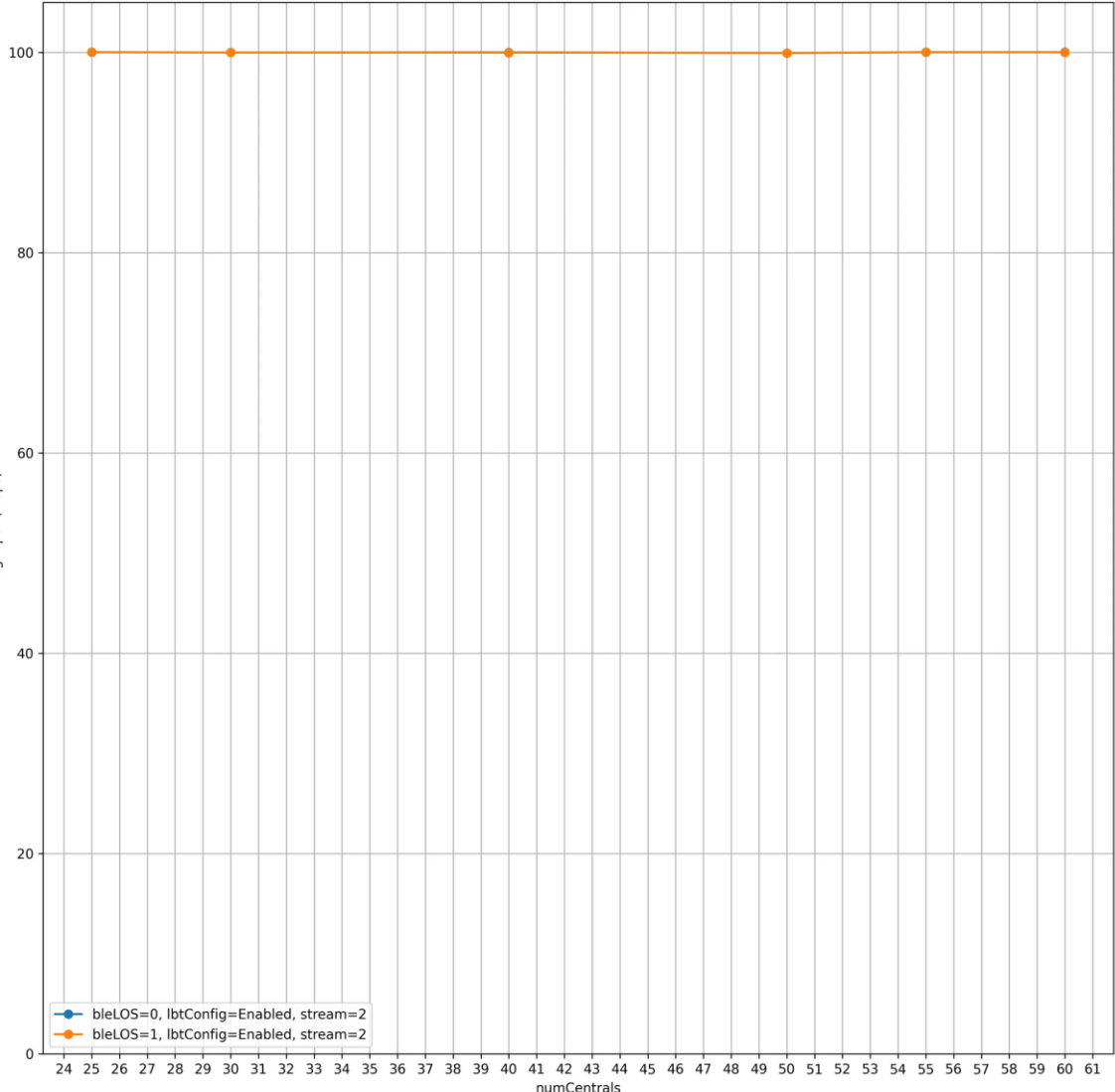


0.95 Percentile

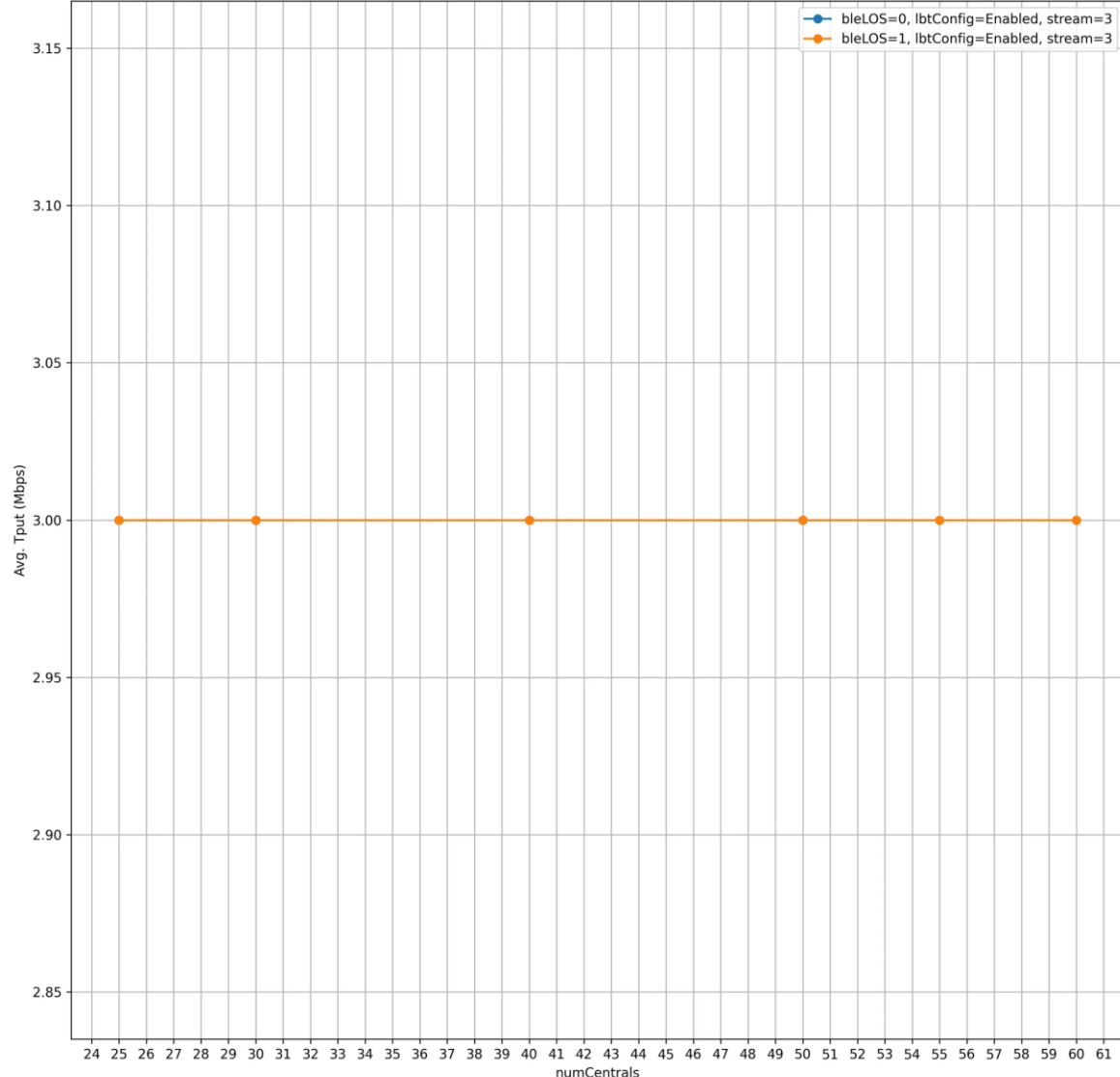


BLE/Wi-Fi 57% Overlap Wi-Fi Throughput

Average Throughput DL



Average Throughput UL



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.

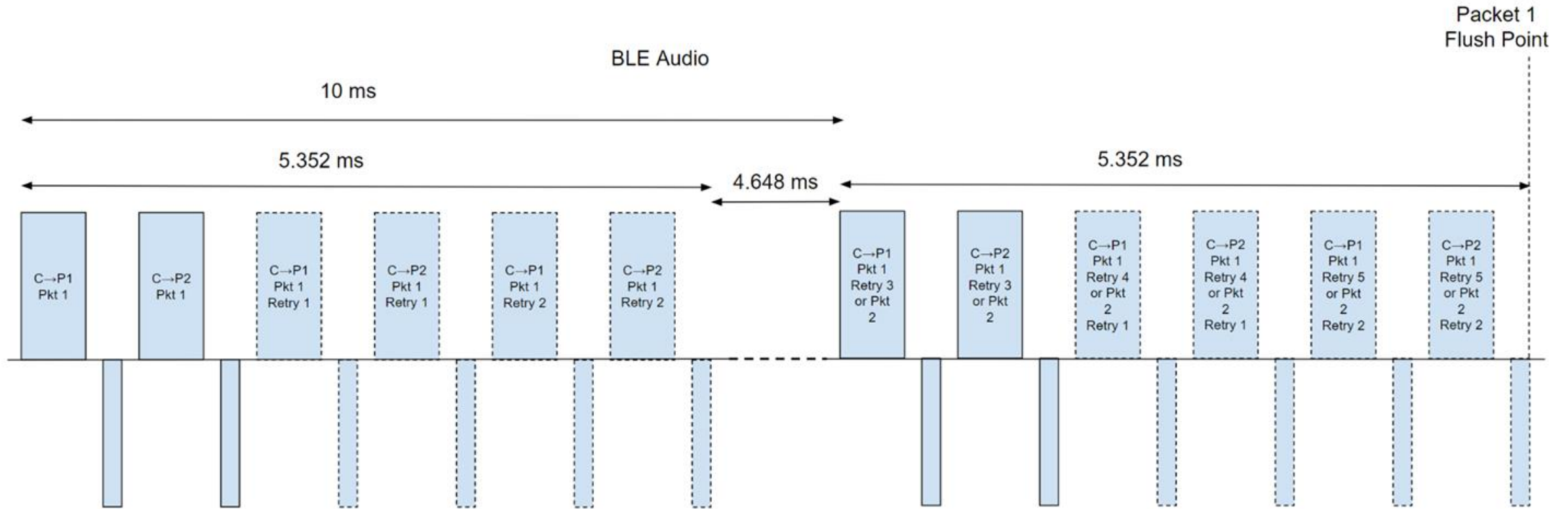
Appendix

Author(s):

Presentation Type:

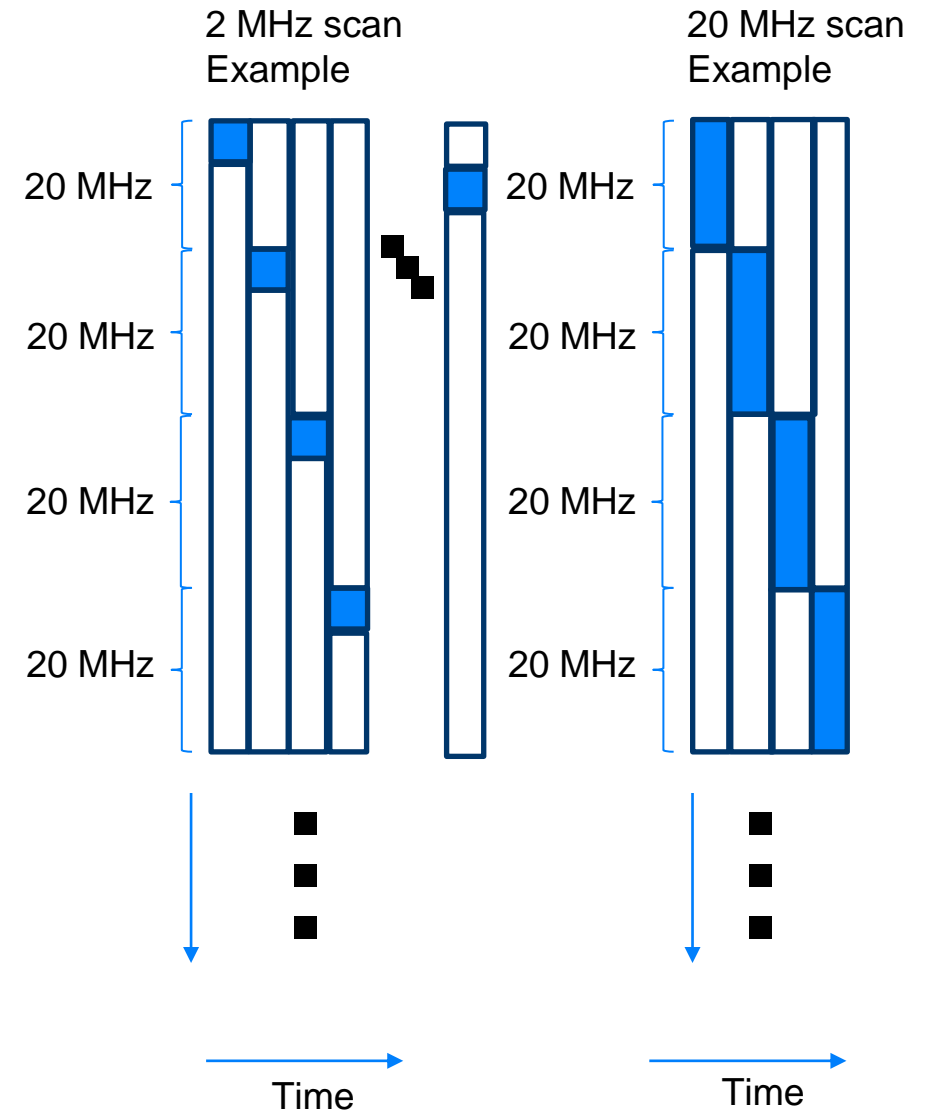
Date Submitted:

BLE Audio profile (channel switch happens after Ack)



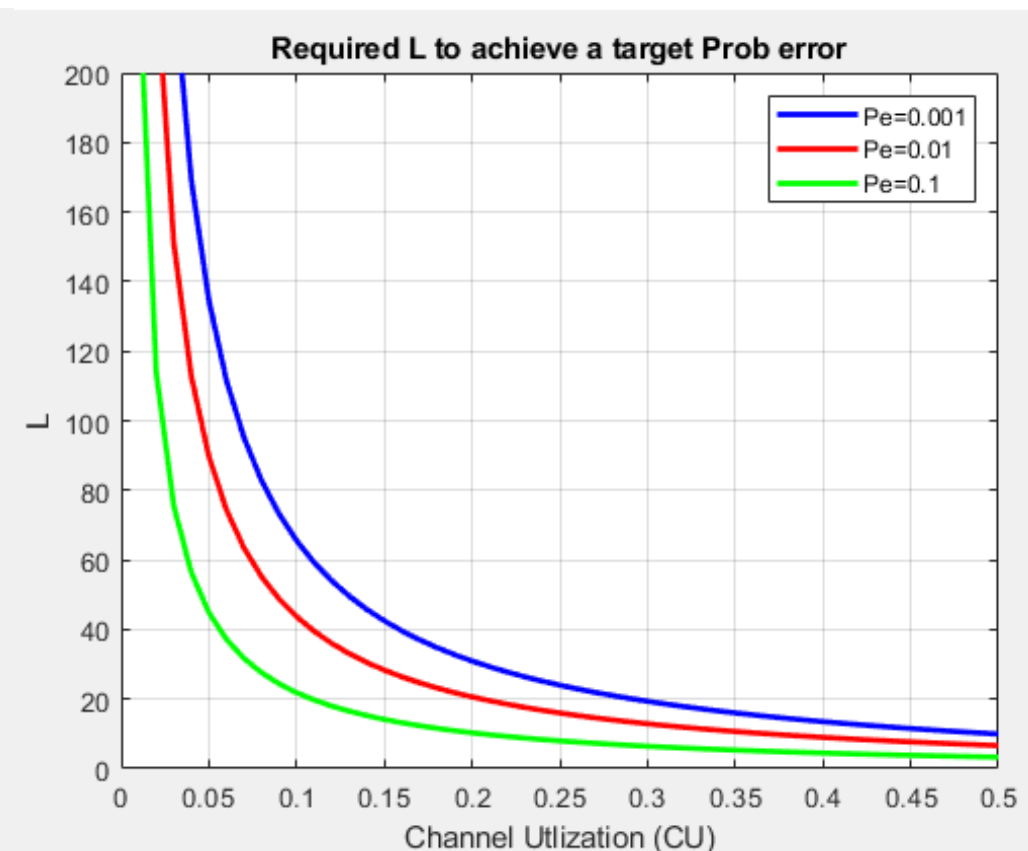
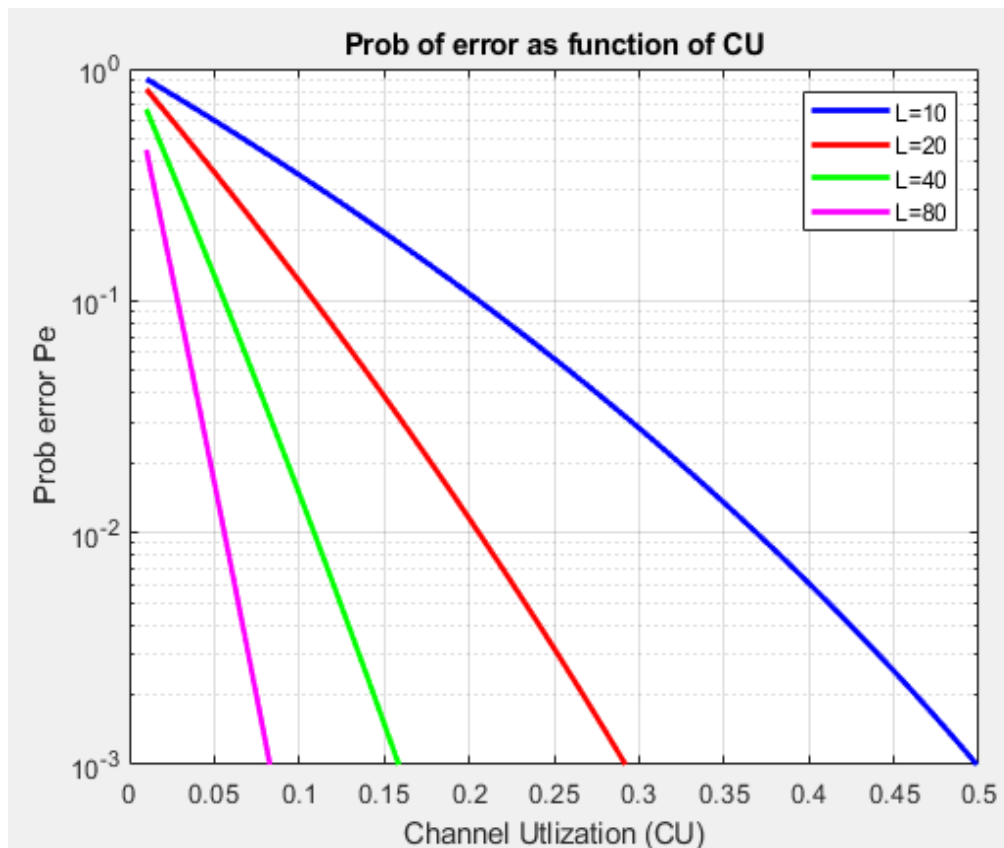
Initial Scan to detect Wi-Fi

- 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



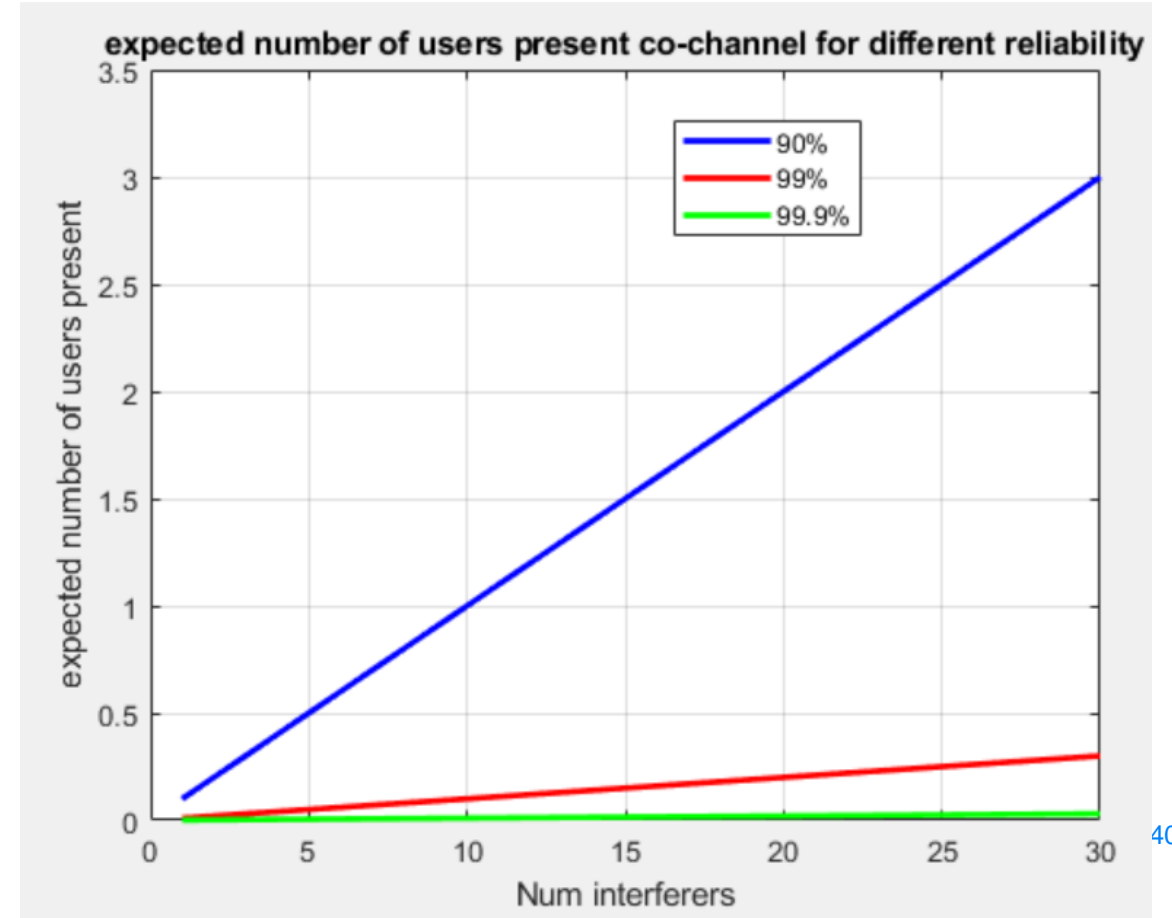
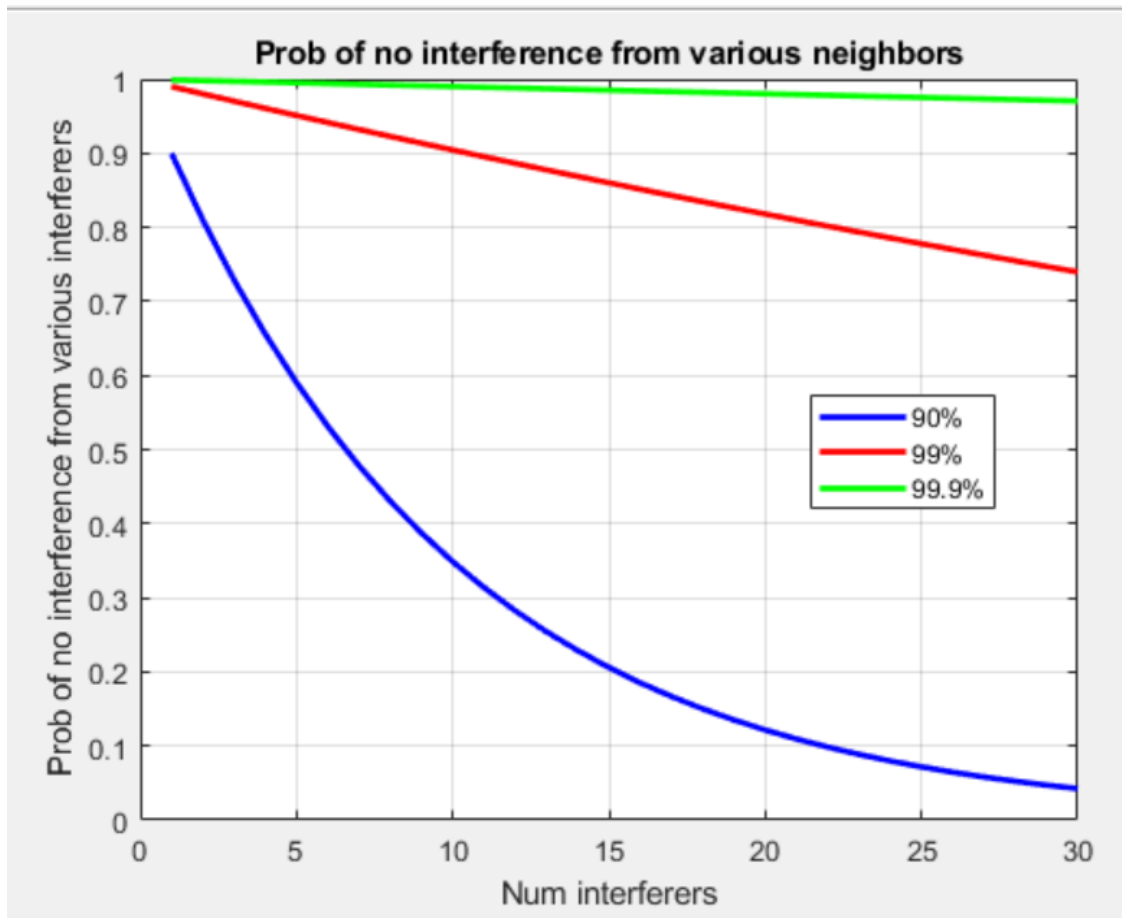
Prob of declaring channel is free when it is not

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



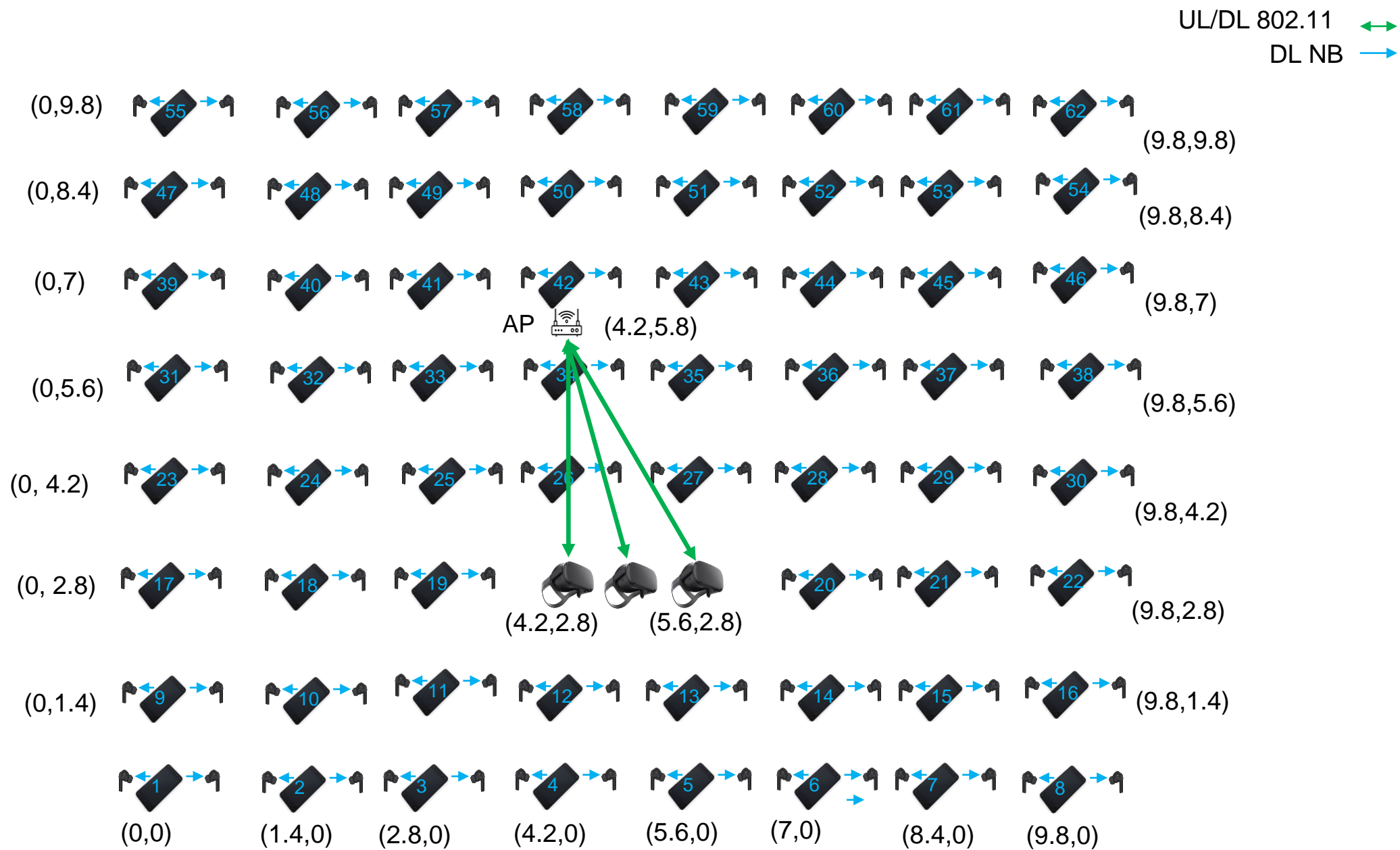
Target level of certainty for initial scan

- (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)

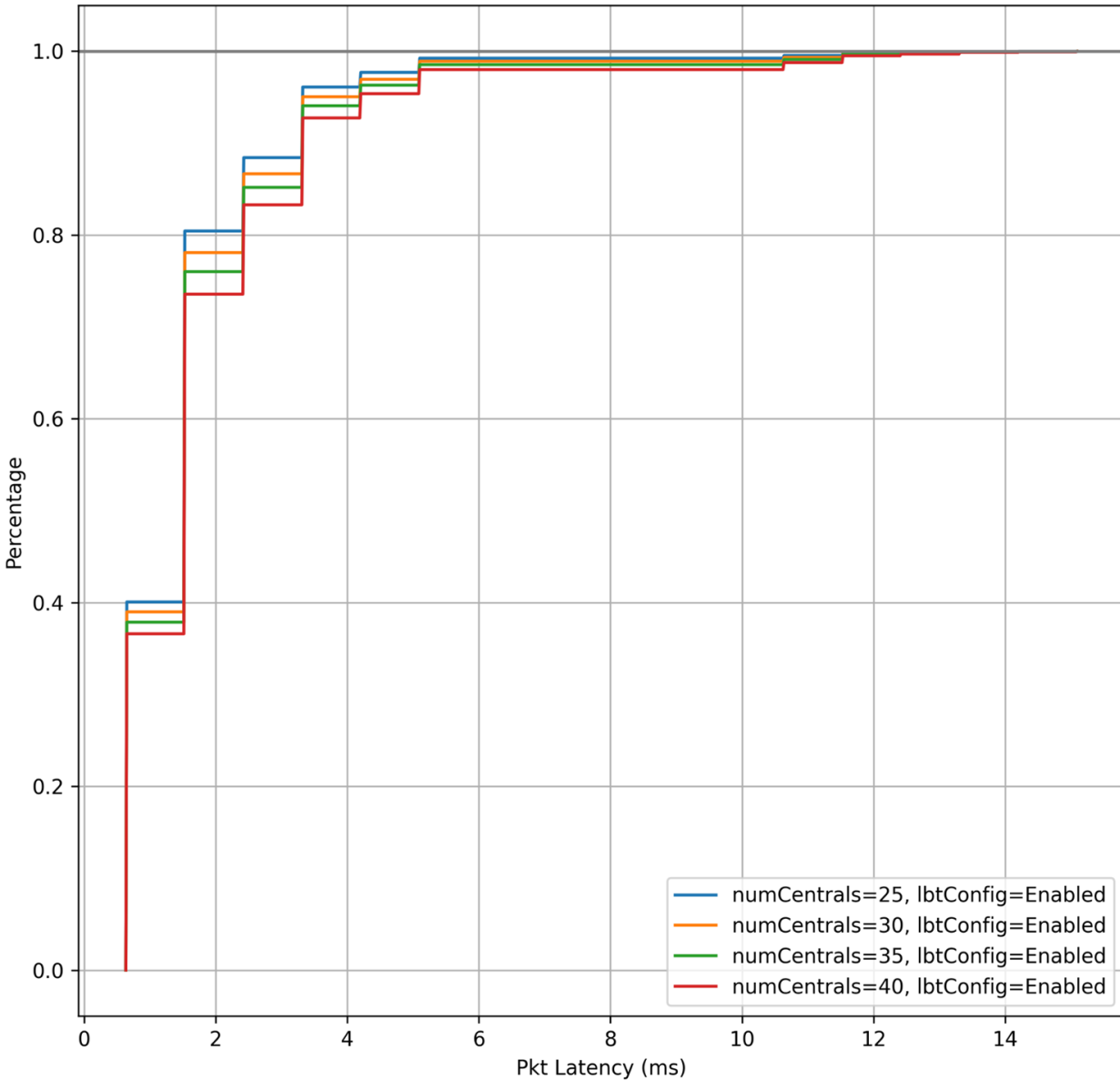
Examines only LBT in both LOS and NLOS scenarios

- No LBT causes unacceptable Wi-Fi degradation

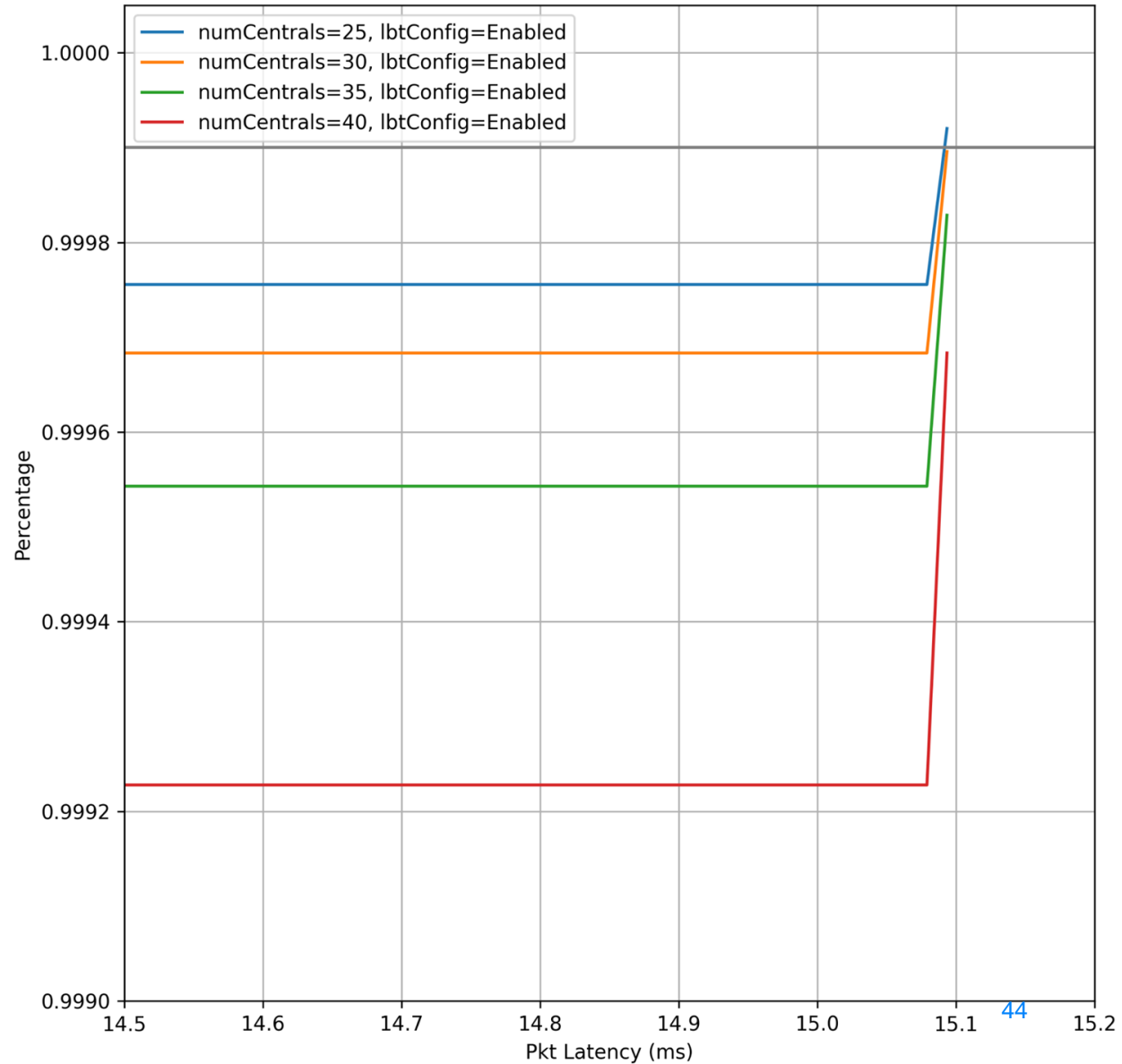
Clear channels used at a ratio of 37:1 compared to Wi-Fi channels

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

CDF bleLOS:1 TX DL

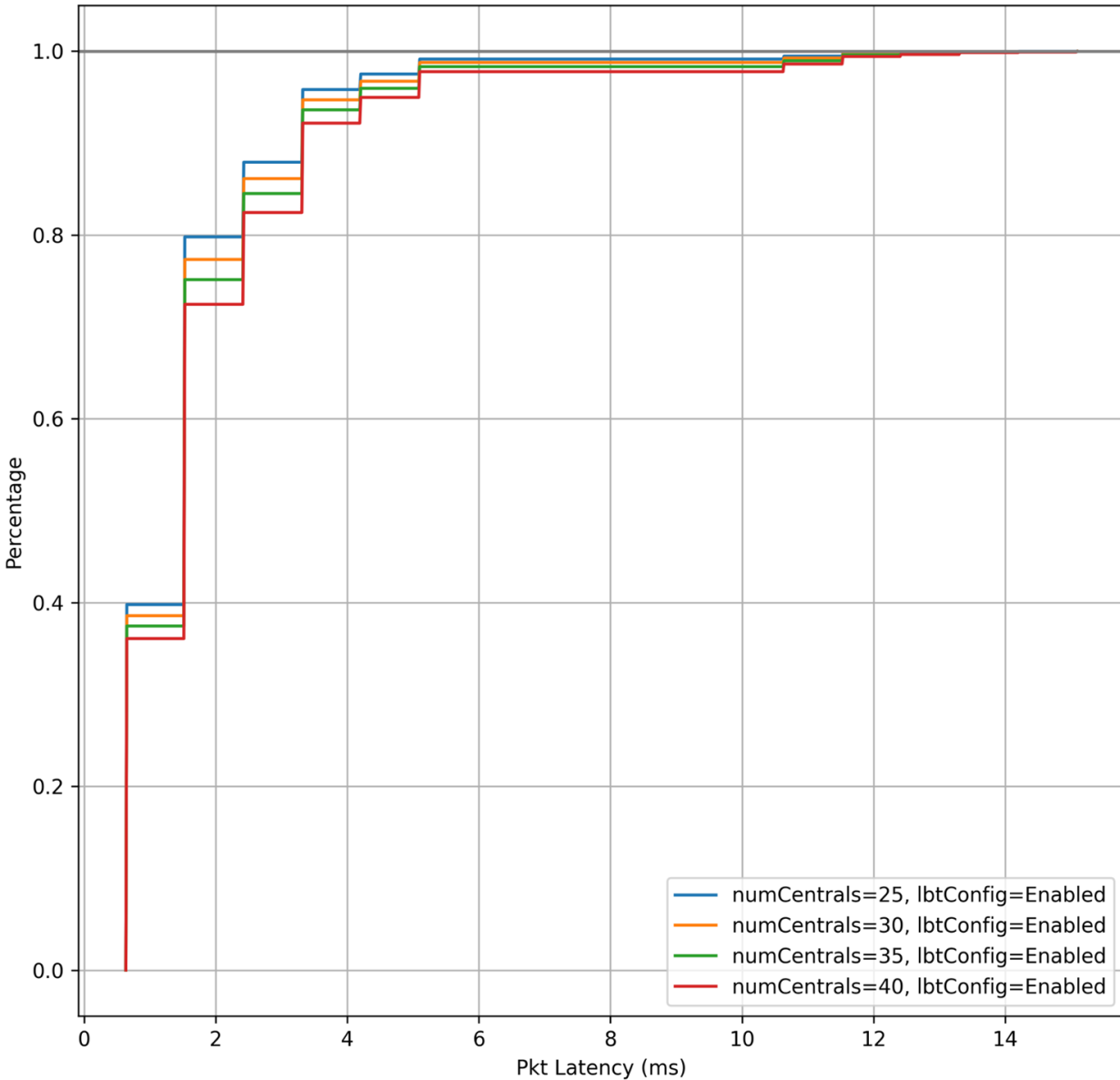


*Zoomed-in version of graph on left CDF bleLOS:1 TX DL

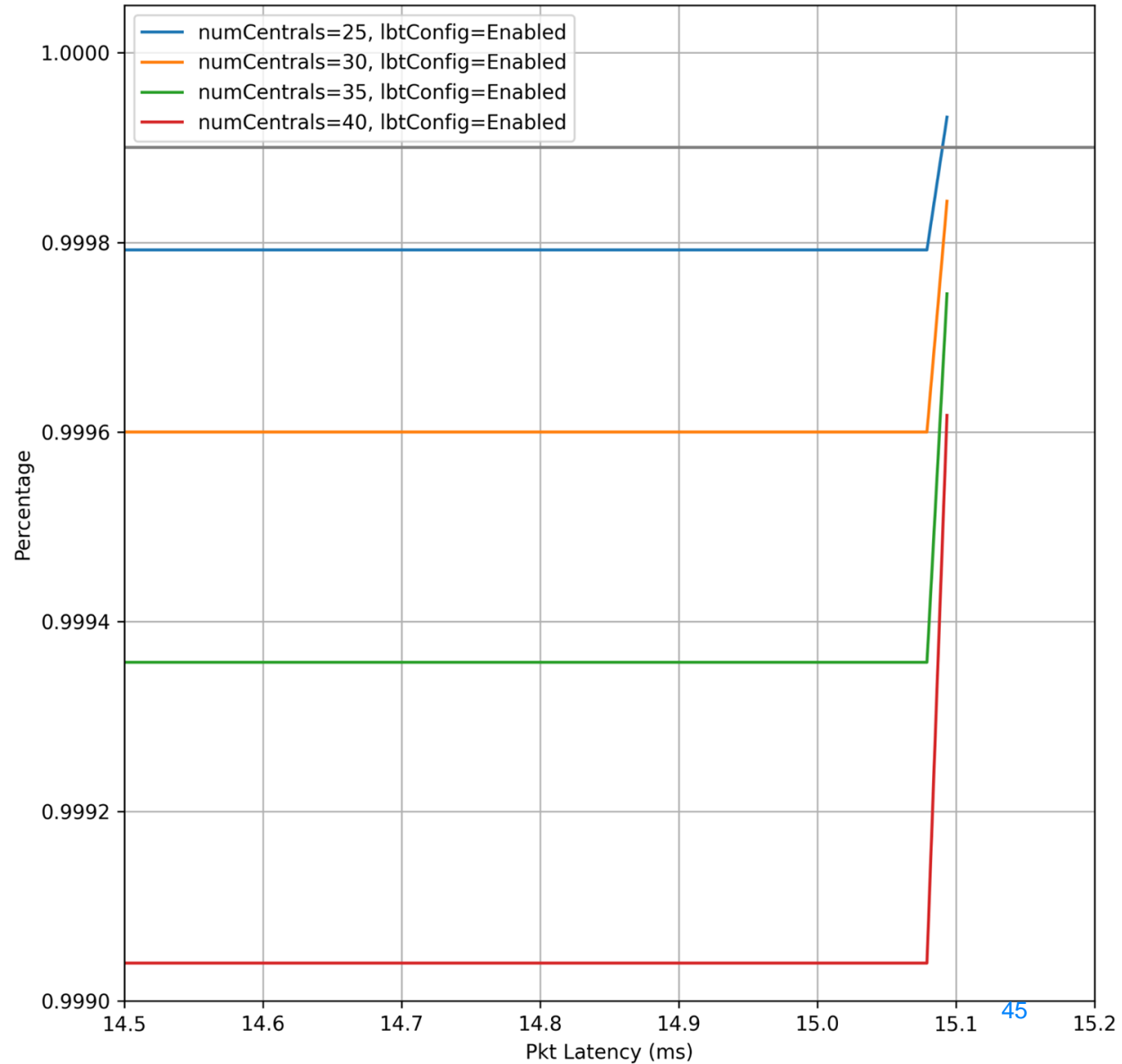


BLE/Wi-Fi 57% Overlap 63% CU NLOS BLE Latency

CDF bleLOS:0 TX DL

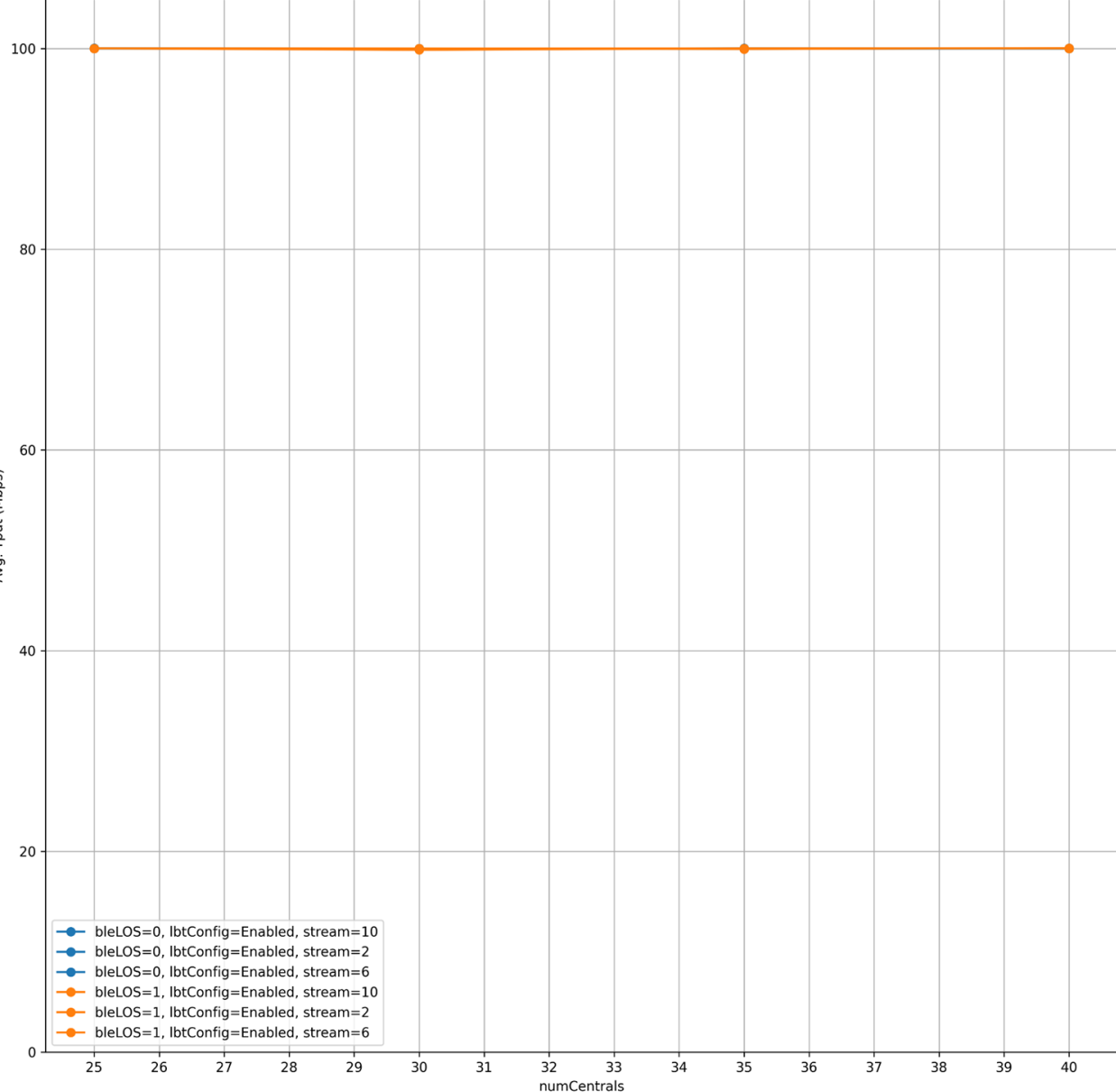


*Zoomed-in version of graph on left CDF bleLOS:0 TX DL

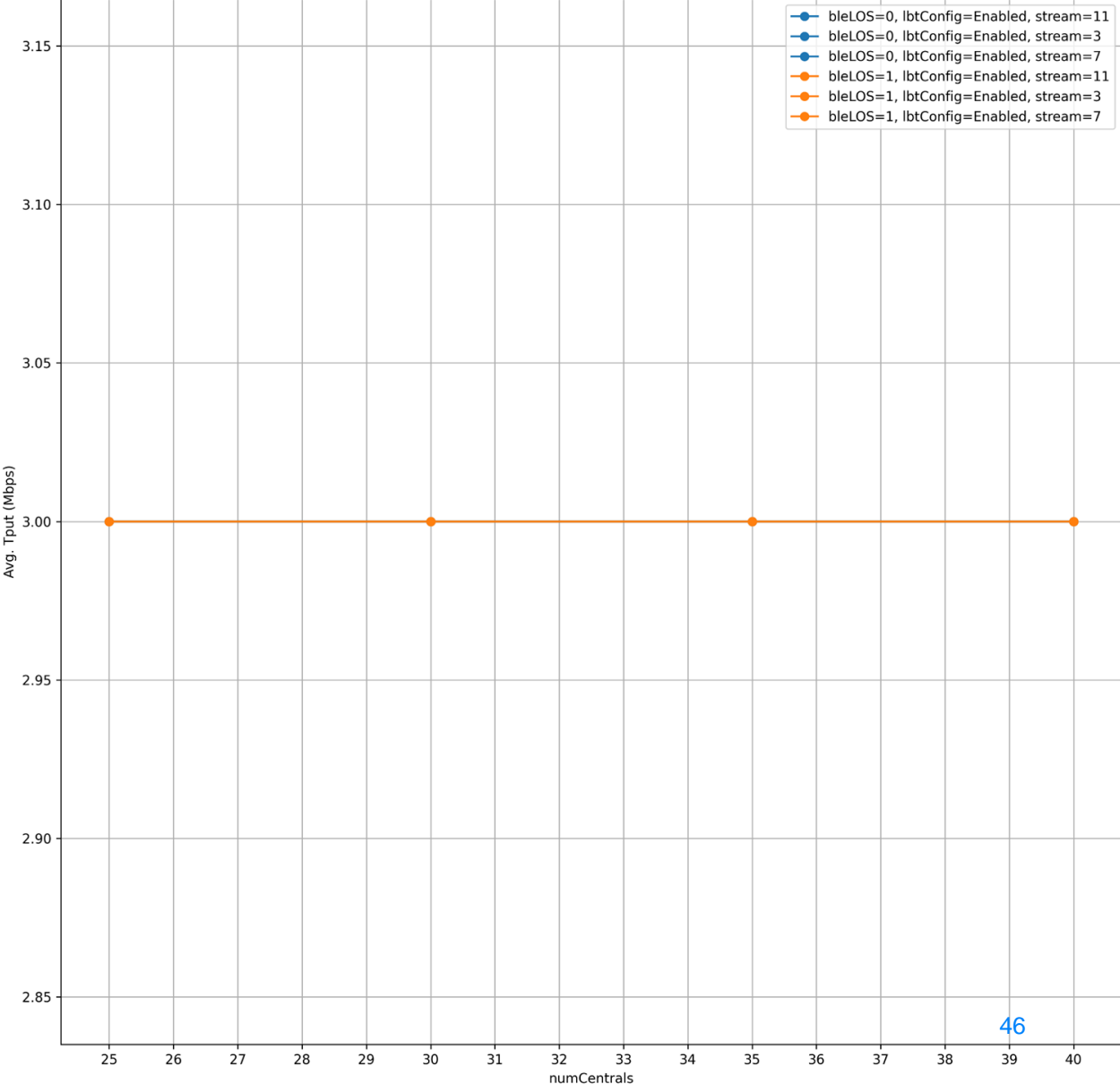


BLE/Wi-Fi 57% Overlap 63% CU Wi-Fi Throughput

Average Throughput DL



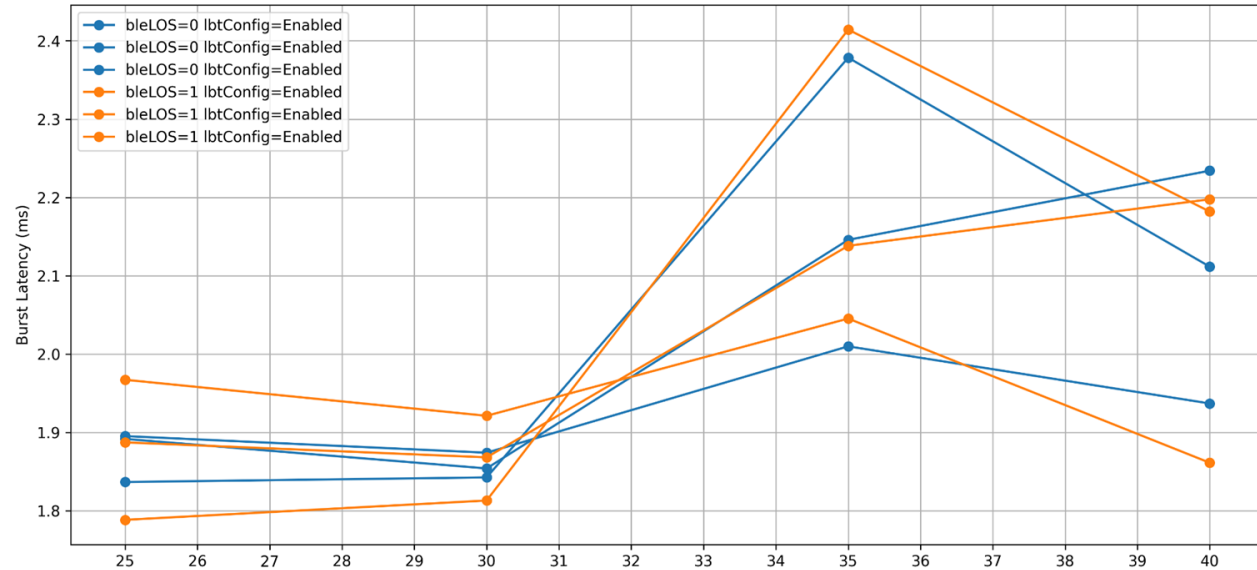
Average Throughput UL



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

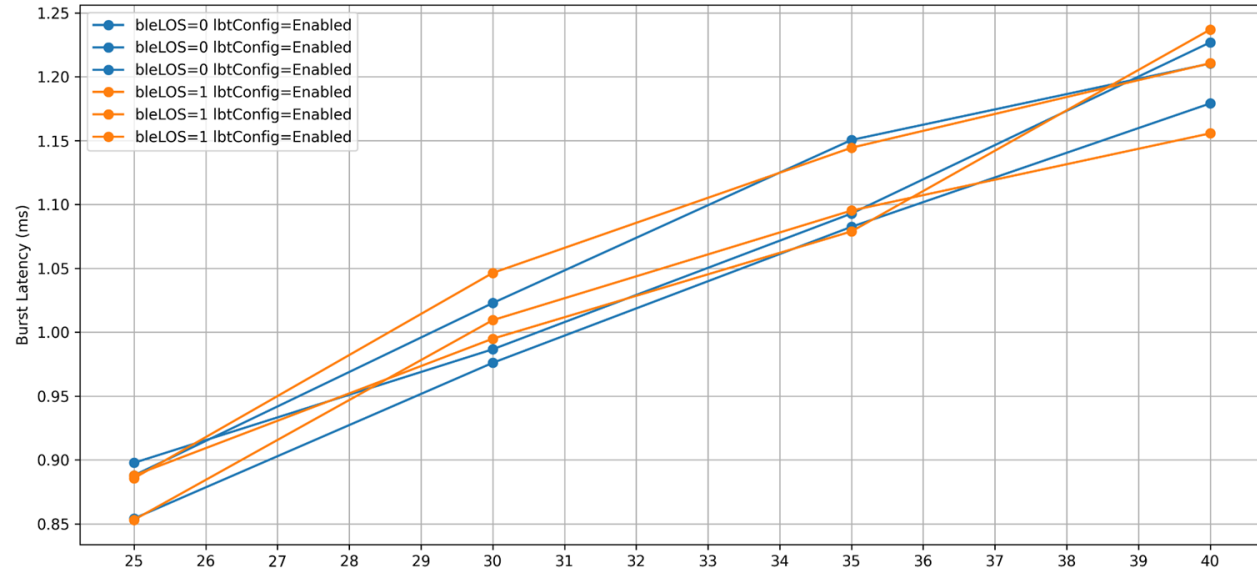
Percentile BTX DL

0.5 Percentile

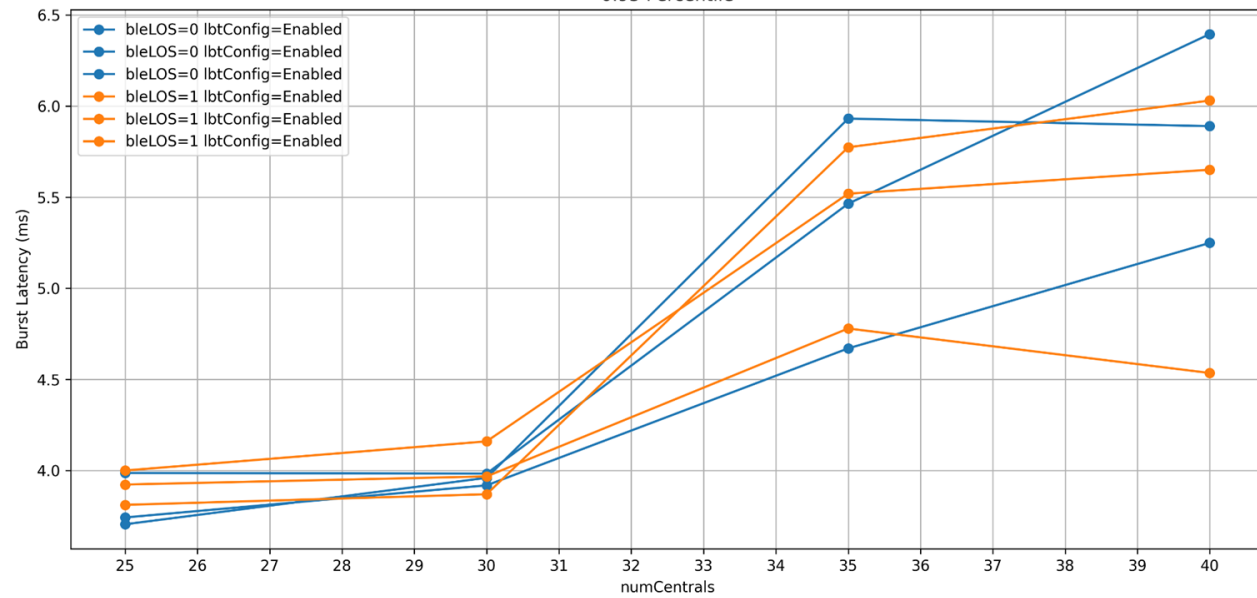


Percentile BTX UL

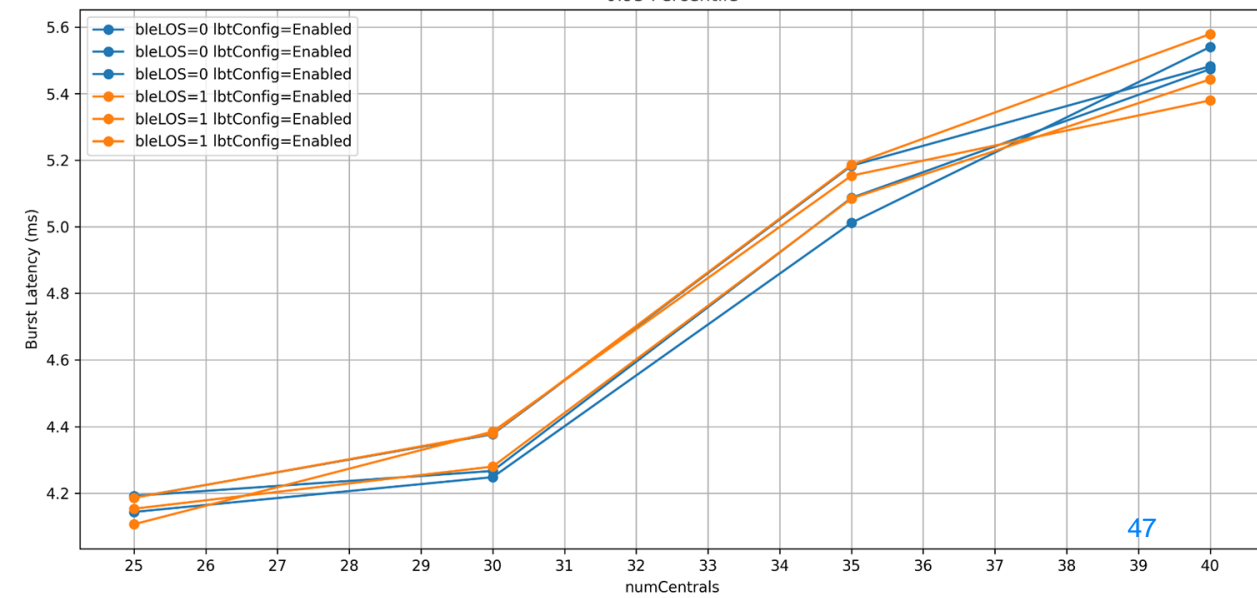
0.5 Percentile



0.95 Percentile



0.95 Percentile



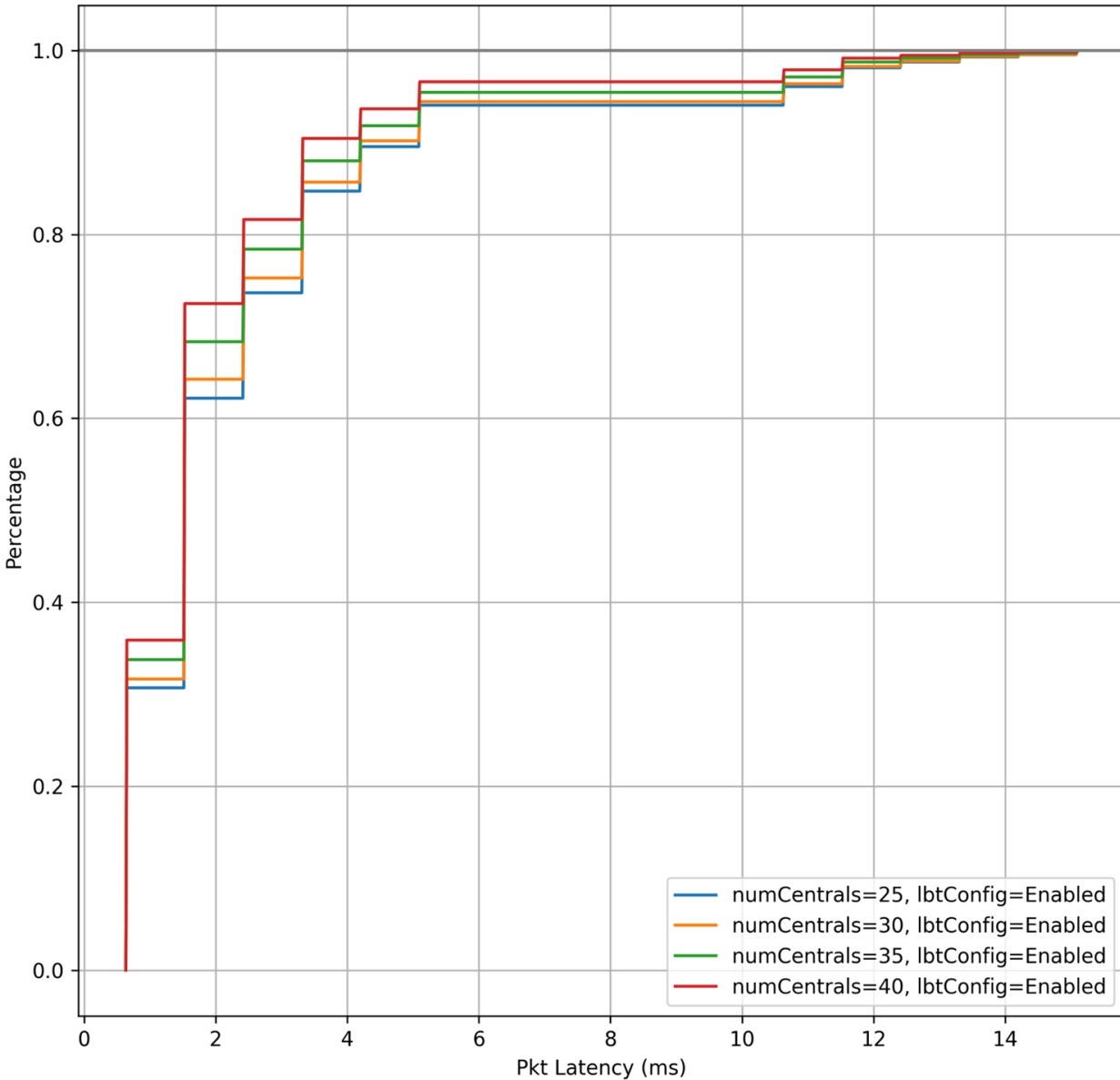
Case 5: BLE/Wi-Fi 57% Overlap with 63%
CU, CU information available to BLE

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

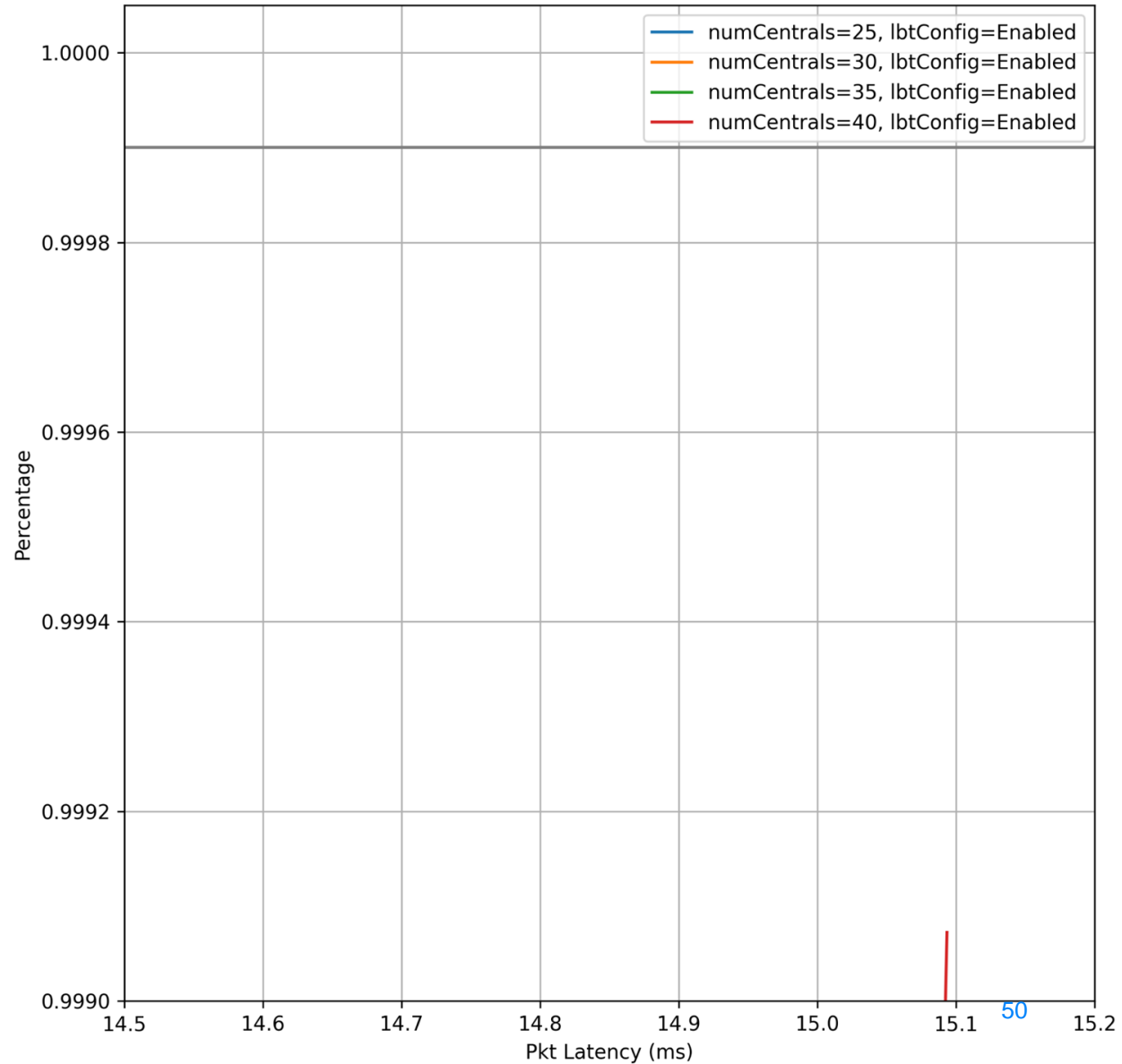
- Exact same as previous results but in these simulations, time is split evenly between all channels

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

CDF bleLOS:1 TX DL

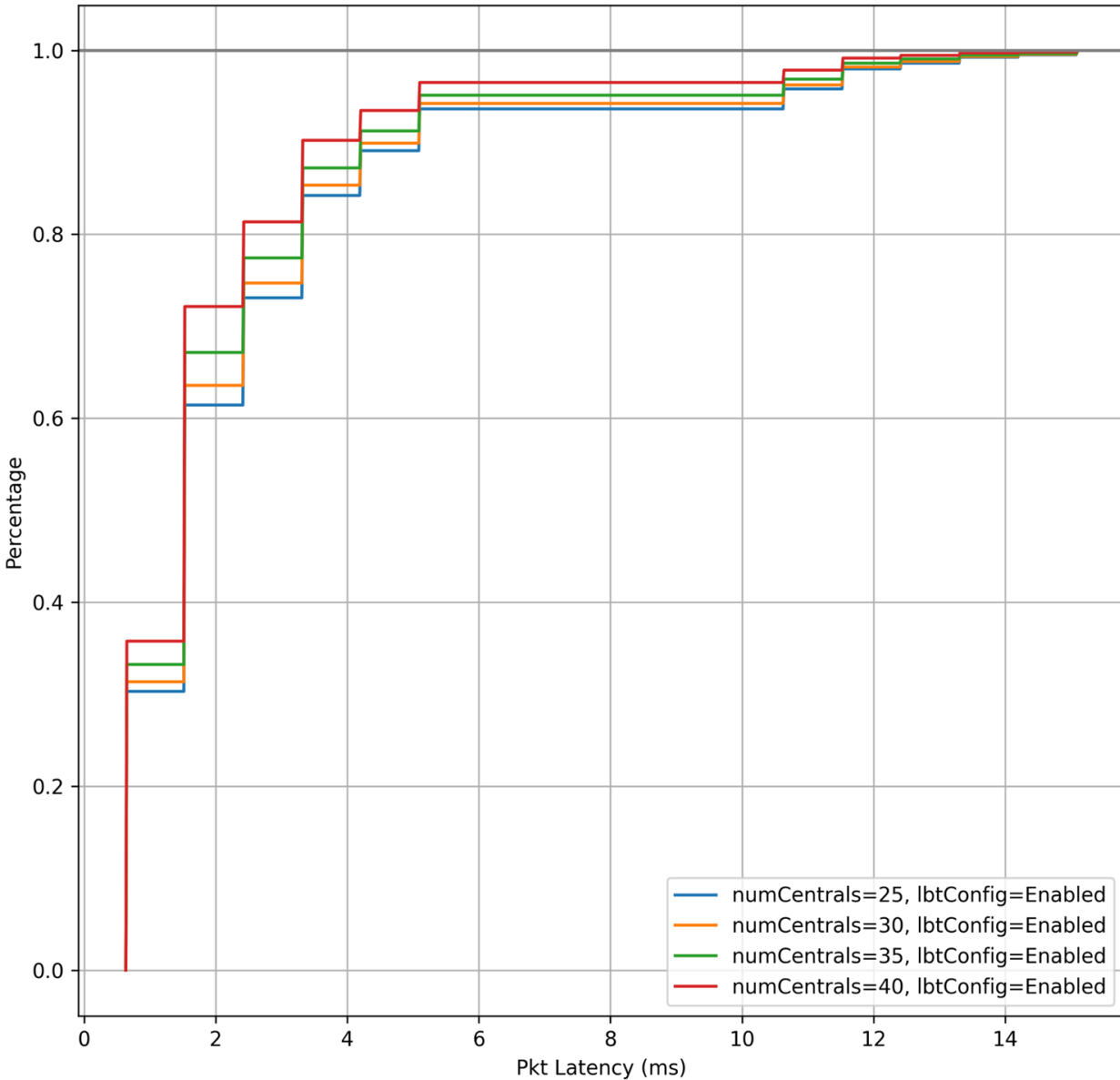


*Zoomed-in version of graph on left CDF bleLOS:1 TX DL

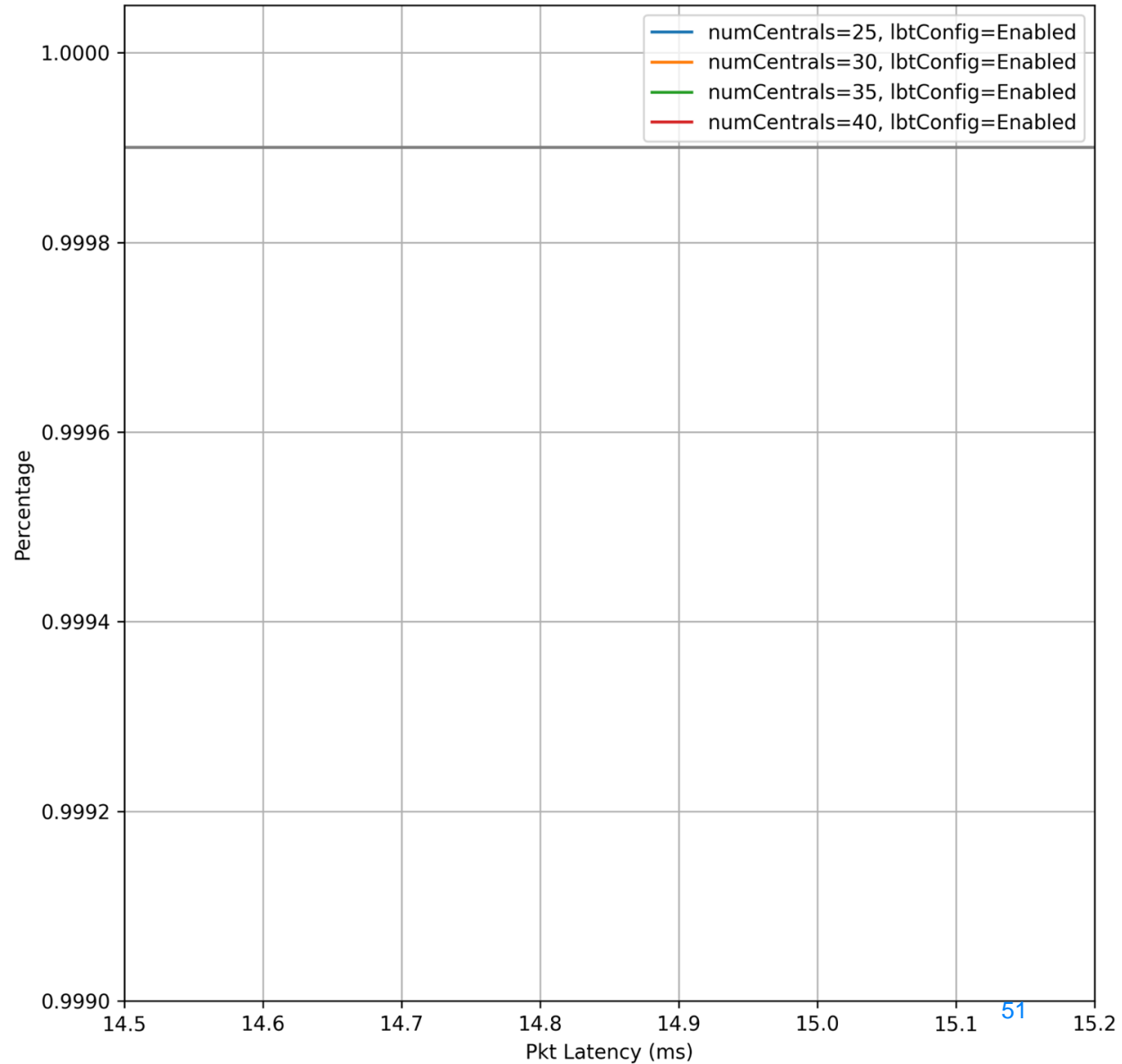


BLE/Wi-Fi 57% Overlap 63% CU Even Time Split NLOS BLE

CDF bleLOS:0 TX DL

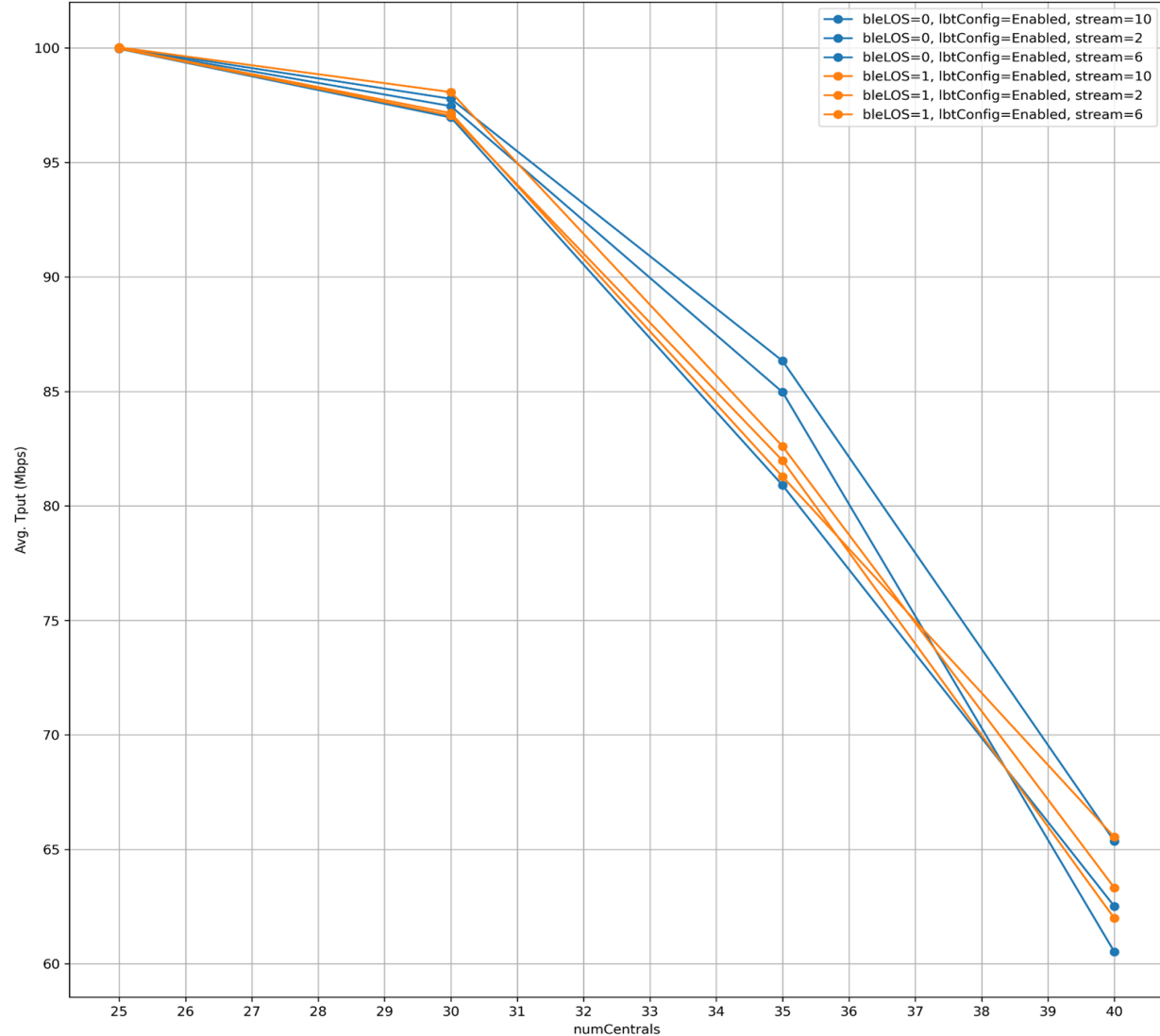


*Zoomed-in version of graph on left CDF bleLOS:0 TX DL

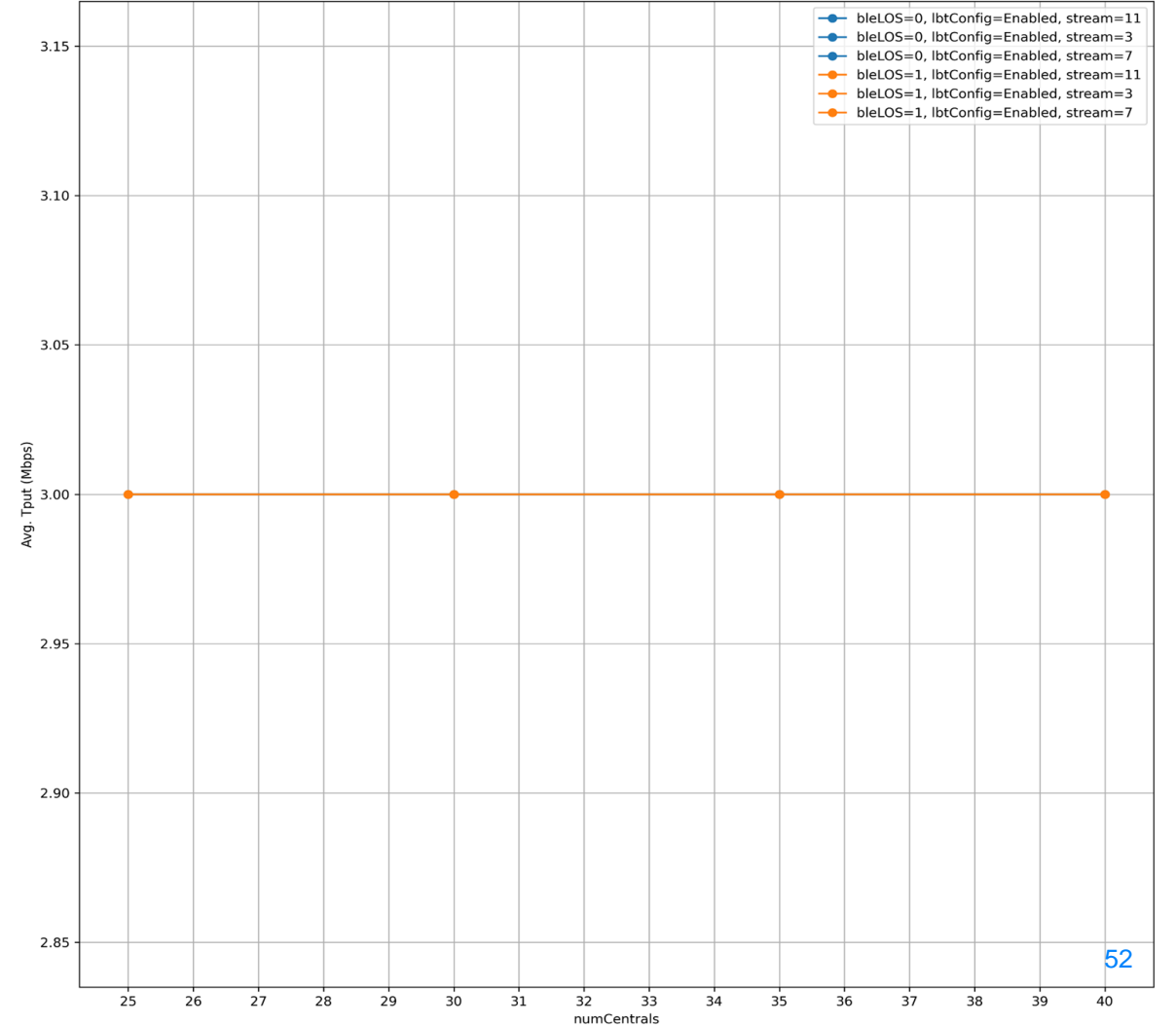


BLE/Wi-Fi 57% Overlap 63% CU Even Time Split Wi-Fi Throughput

Average Throughput DL

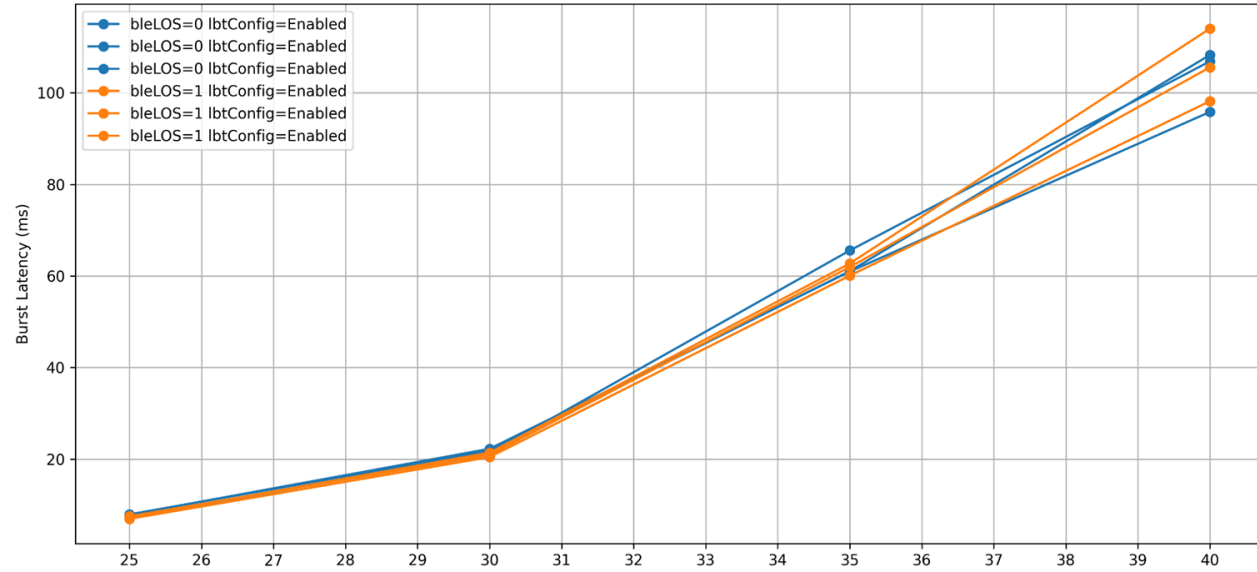


Average Throughput UL

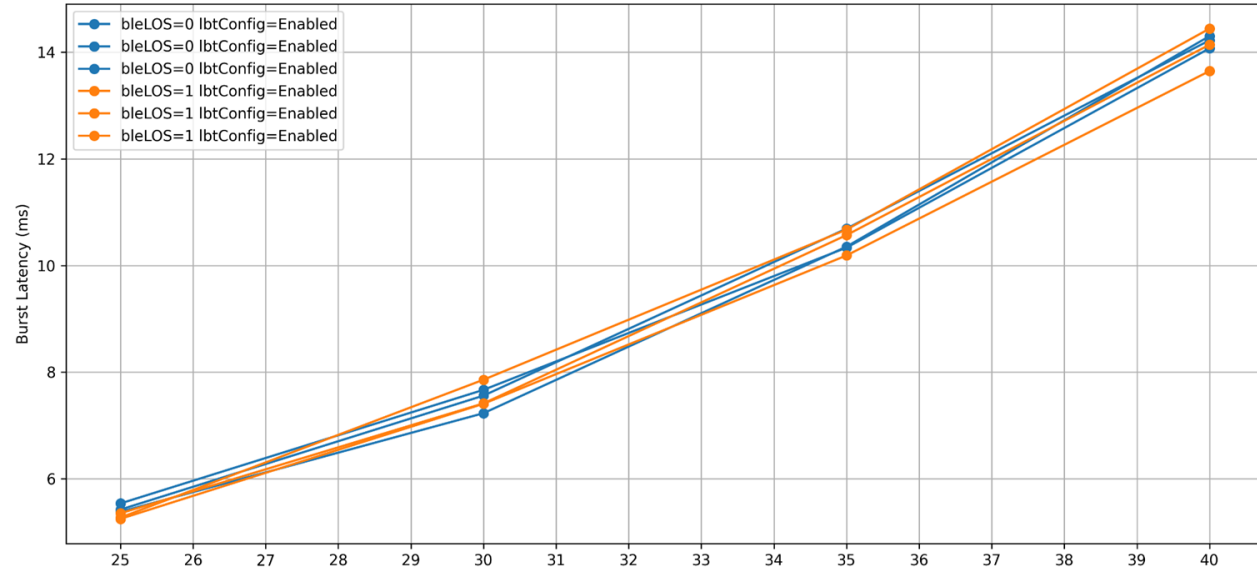


BLE/Wi-Fi 57% Overlap 63% CU Even Time Split Wi-Fi Latency

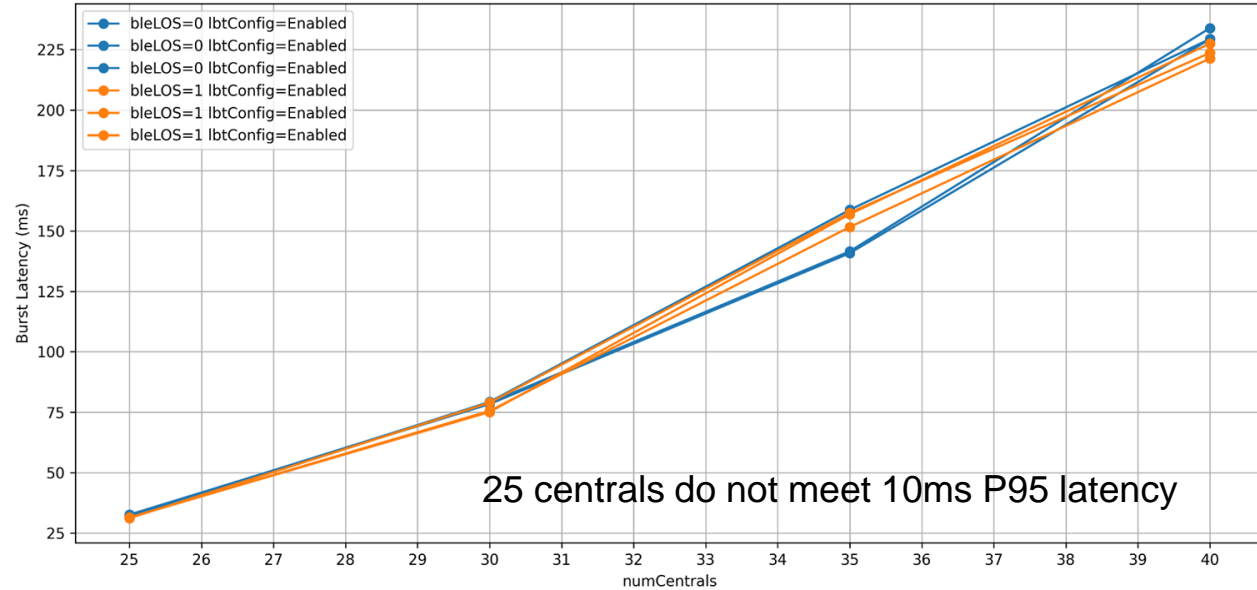
Percentile BTX DL
0.5 Percentile



Percentile BTX UL
0.5 Percentile



0.95 Percentile



0.95 Percentile

