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

Submission Title: Effect of no-LBT NB on 802.11 devices

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

Abstract: [This provides experimental and simulation results of how no-LBT NB affects 802.11 devices]

Purpose: [Suggests a way forward to improve coexistence]

Technical Guidance

PAR Objective	Proposed Solution (how addressed)
Safeguards so that the high throughput data use cases will not cause significant disruption to low duty-cycle ranging use cases.	
Interference mitigation techniques to support higher density and higher traffic use cases	
Other coexistence improvement	
Backward compatibility with enhanced ranging capable devices (ERDEVs).	
Improved link budget and/or reduced air-time	
Additional channels and operating frequencies	
Improvements to accuracy / precision / reliability and interoperability for high-integrity ranging;	
Reduce complexity and power consumption;	
Hybrid operation with narrowband signaling to assist UWB;	LBT should be employed by NB as a coexistence mechanism
Enhanced native discovery and connection setup mechanisms;	
Sensing capabilities to support presence detection and environment mapping;	
Low-power low-latency streaming	
higher data-rate streaming allowing at least 50 Mbit/s of throughput.	
Support for peer-to-peer, peer-to-multi-peer, and station-to-infrastructure protocols;	
Infrastructure synchronization mechanisms.	

Background

In 15-23-243, it is suggested to use NB for Data Communications for gate entry applications. We should also consider the effects on other technologies in high device density scenario (e.g., apartment buildings, malls)

In 15-23-119 the effect of NB interference on 802.11 at the PHY level was presented. It was shown that for 20 MHz 802.11 and a 31% duty cycle NB, the SIR > 20 dB for PER to be < 10%.

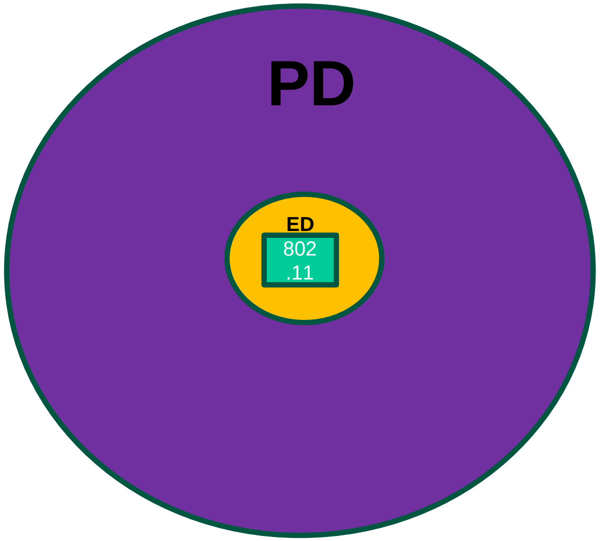
This work focuses on the effects of NB interference on 802.11 at the MAC level, from a lab measurement and simulation point of view.

We look to answer the following questions:

- Is NB (without LBT) a similar neighbor to 802.11 than another 802.11 neighbor?
- What NB duty cycle is not acceptable for a no-LBT NB solution?
- Would NB with LBT help 802.11?

Background on 802.11 ED and PD Threshold

Energy Detect (ED) Threshold set to -75 dBm/MHz (ETSI EN 303687 and IEEE 802.11 17.3.10.6) : shown by orange circle
Packet Detect (PD) Threshold set to -82 dBm (IEEE 802.11) : shown by purple circle

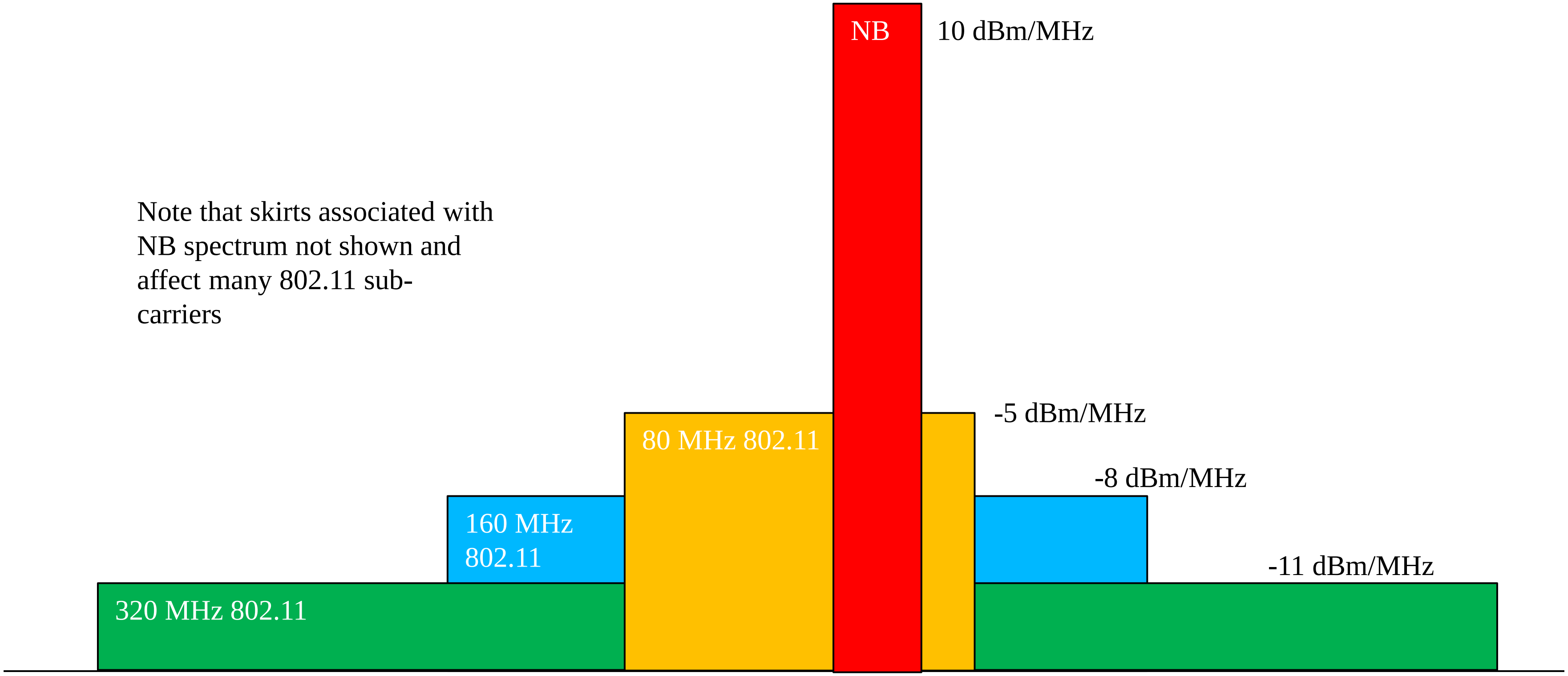


802.11ax
Rules for any signal
(802.11 or NB)
Present

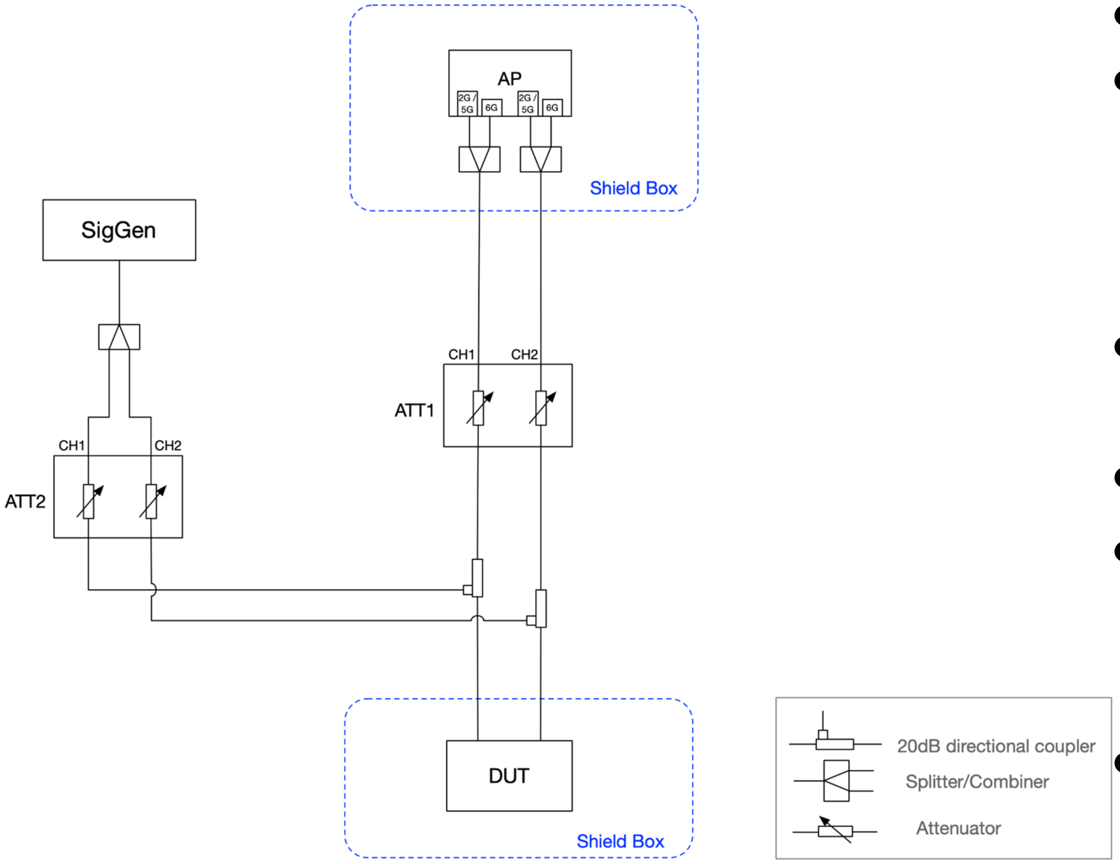
- ED threshold of -62 dBm for PRI20
- ED threshold of -62 dBm for SEC20
- ED threshold of -59 dBm for SEC40
- ED threshold of -56 dBm for SEC80

Europe 6 GHz NB vs VLP 802.11 spectrum

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



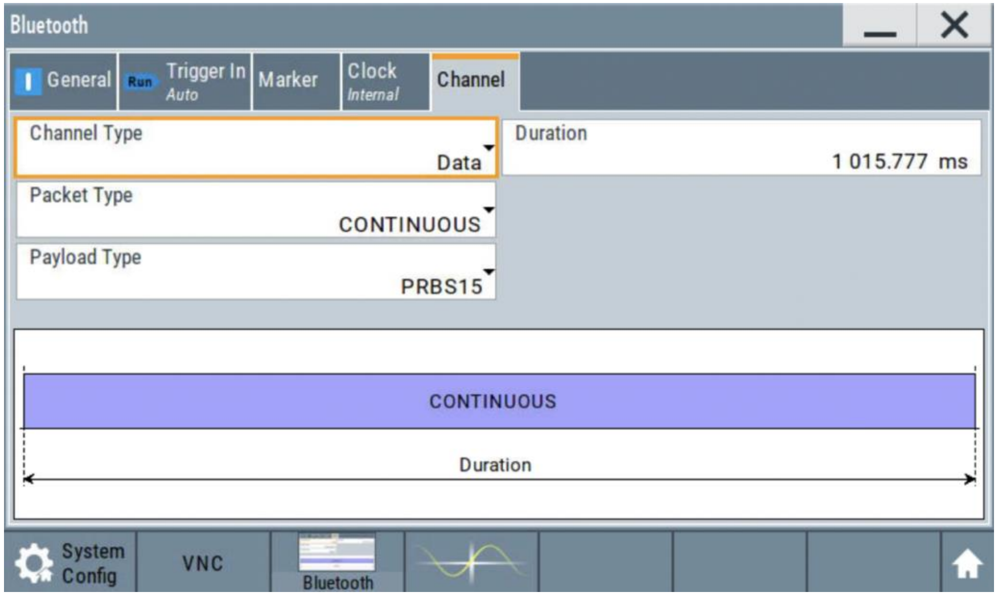
Setup – NB Interferer

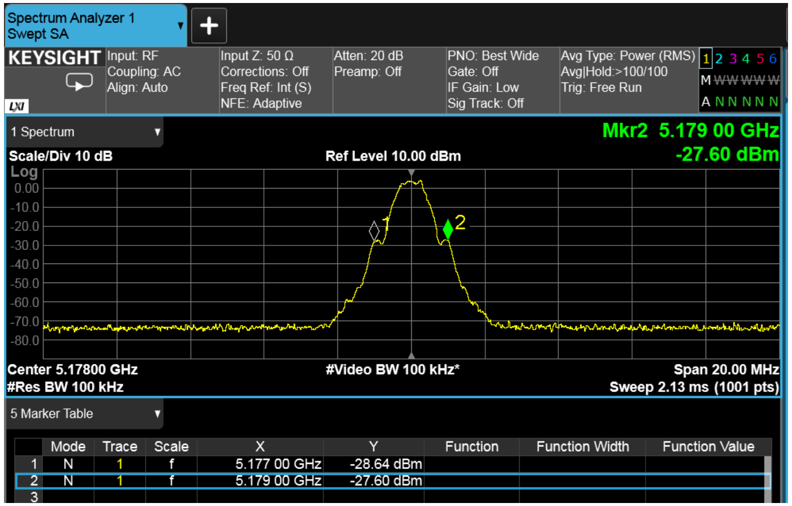


- SigGen: R&S SMBV100B
- 802.11 Channel: 5GHz CH36 (160MHz) centered at 5250 MHz (5170-5330 MHz)
  - Max PHY rate 2.0-2.4 Gbps (depends on guard interval)
- 802.11 does its own rate adaptation and AMPDU is enabled.
- Iperf udp traffic
- ATT2 is used to set the NB RX power to the desired level at the DUT and ATT1, called "Attenuation" in following plots is what is swept
- NB RX Power is swept from -50 to -90 dBm via ATT2

NB Profile 1

- Continuous BLE Signal, 2 MHz BW

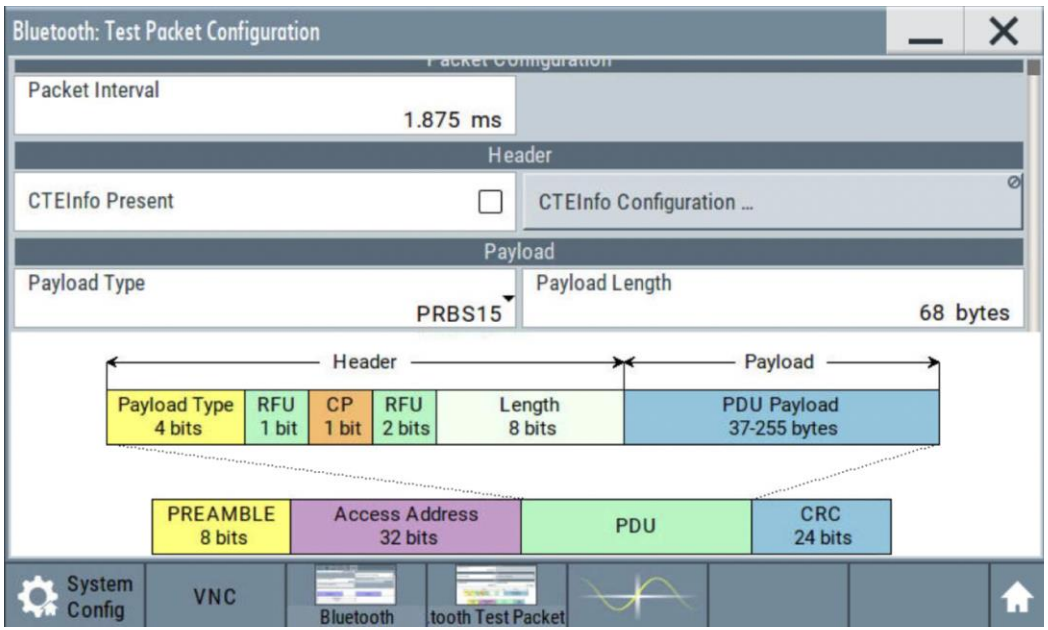


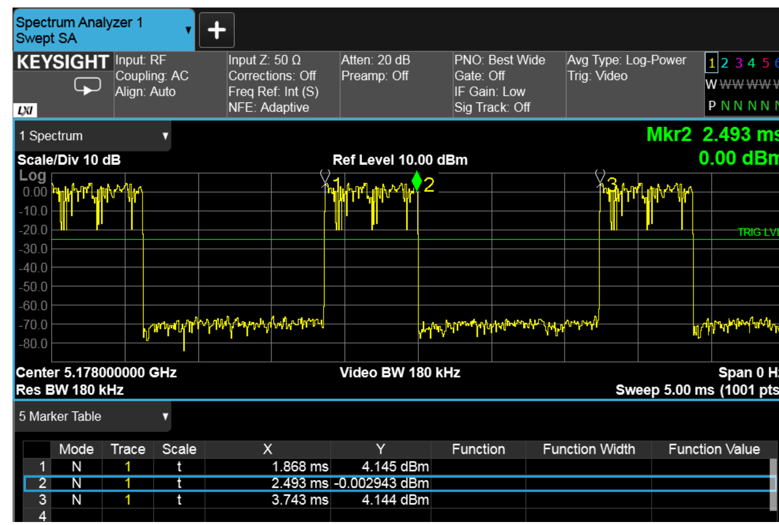


	Mode	Trace	Scale	X	Y	Function	Function Width	Function Value
1	N	1	f	5.177 00 GHz	-28.64 dBm			
2	N	1	f	5.179 00 GHz	-27.60 dBm			
3								

NB Profile 2

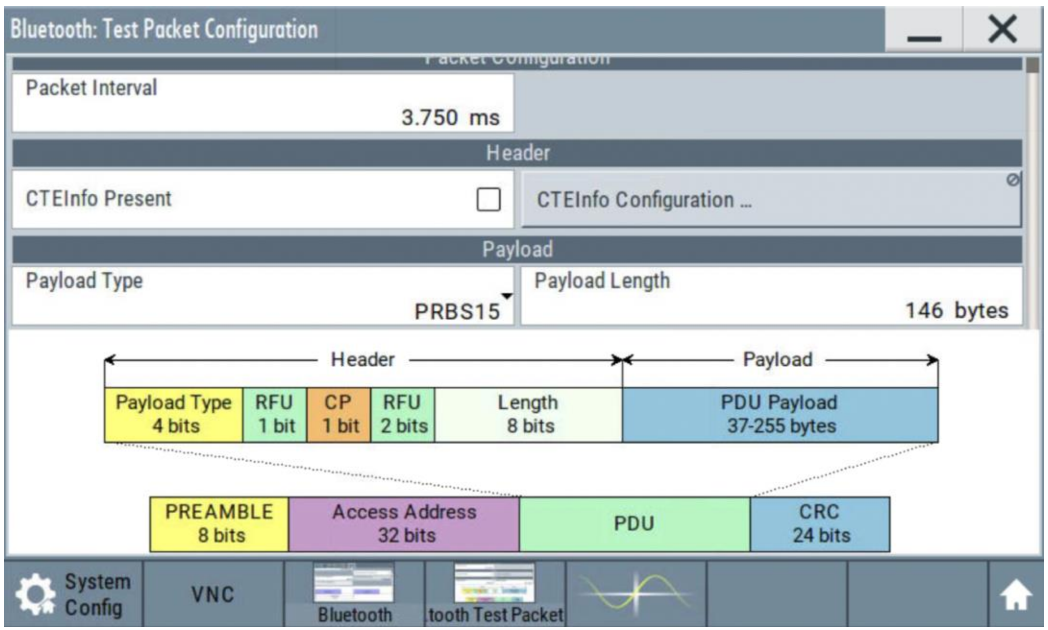
- BLE with dwell time 625us with a packet interval of 1.875ms, 33.3% duty cycle

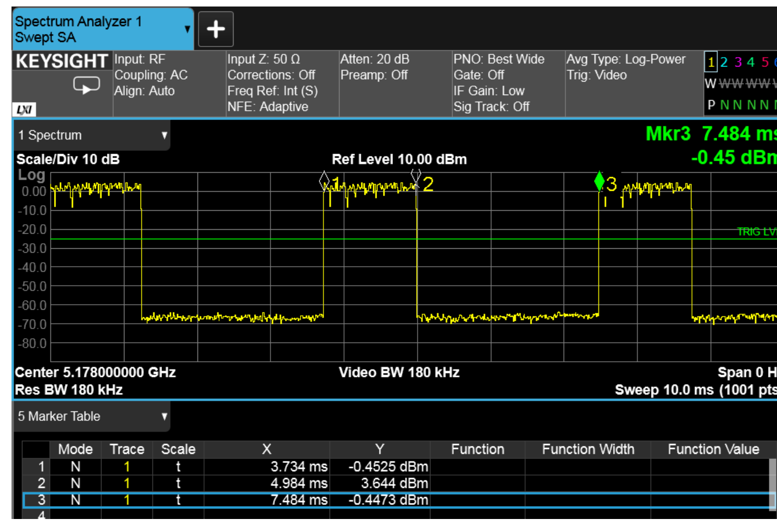




NB Profile 3

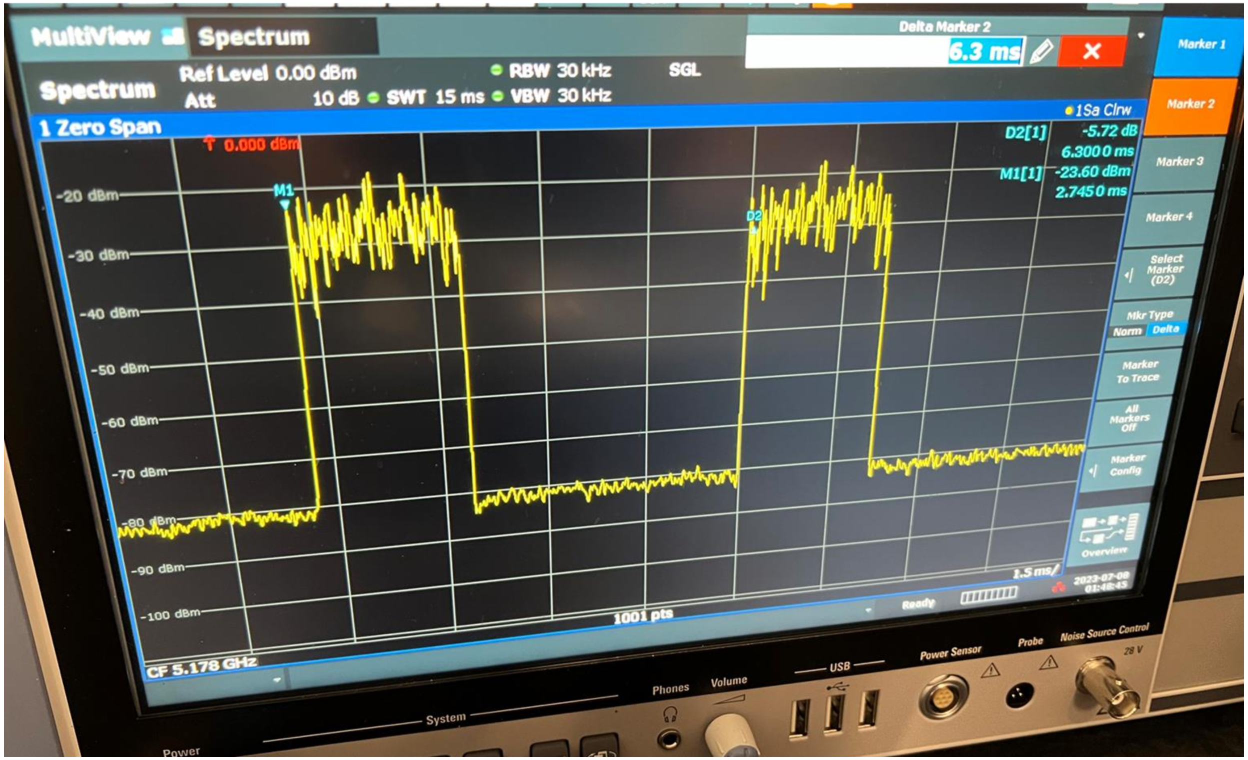
- BLE with dwell time 1.25ms with a packet interval of 3.75ms, 33.3% duty cycle





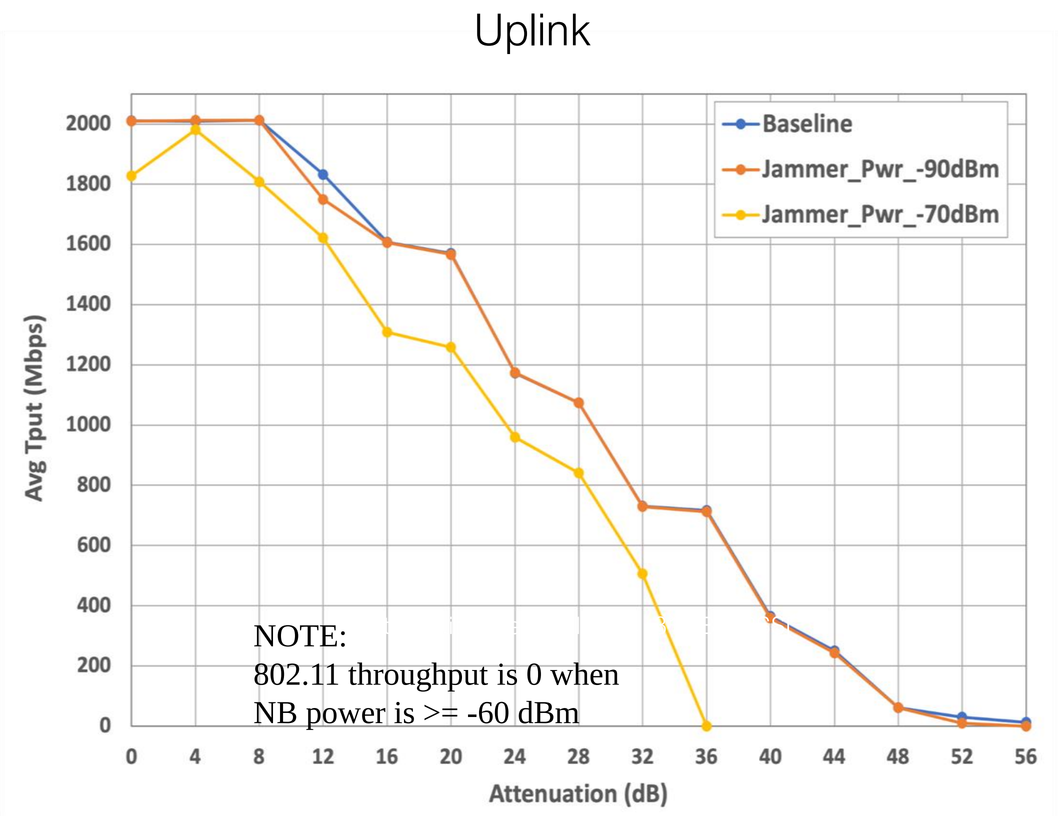
NB Profile 4 (255 bytes)

- BLE with dwell time 2.1ms with a packet interval of 6.25ms, 34% duty cycle

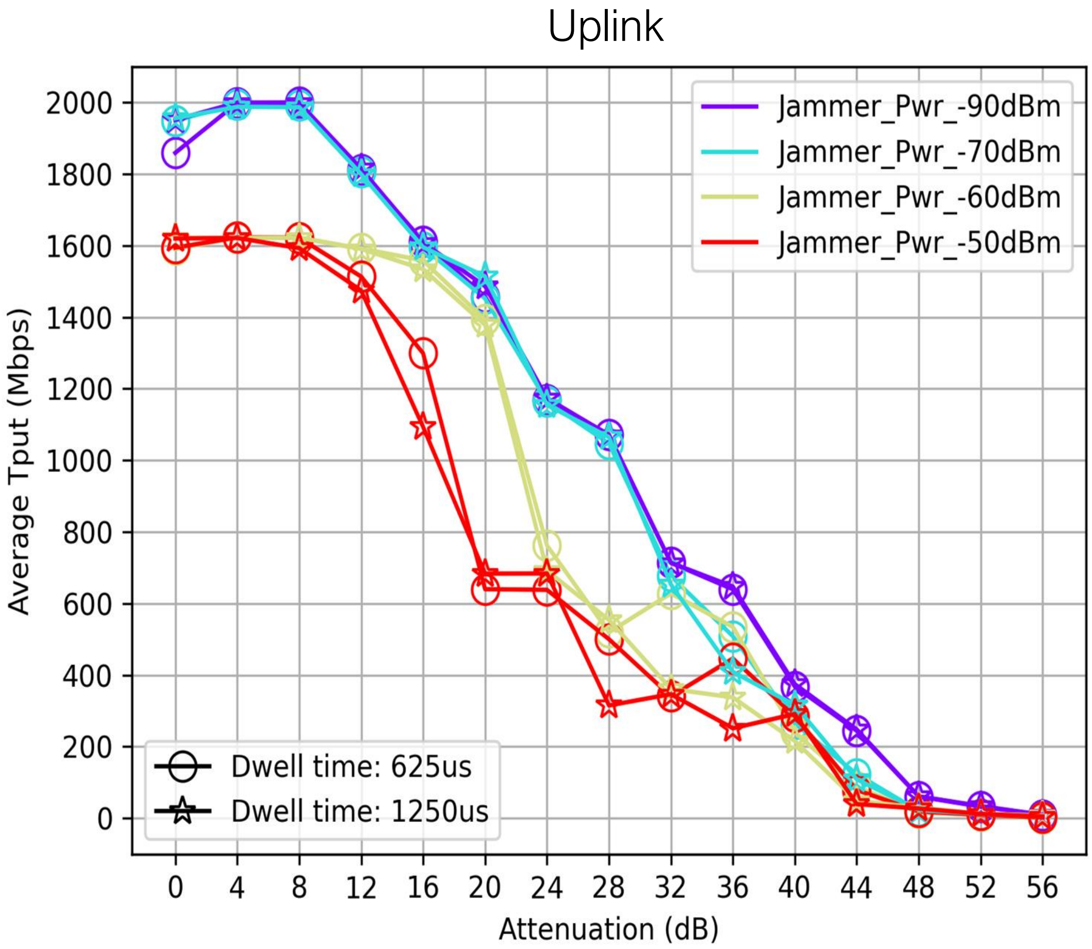


NB Profile 1 at 5178MHz

- 802.11 throughput is 0 when the NB power is -60dBm or -50dBm. At these interference levels, NB interferer completely prevents DUT from transmitting because 802.11 performs LBT.

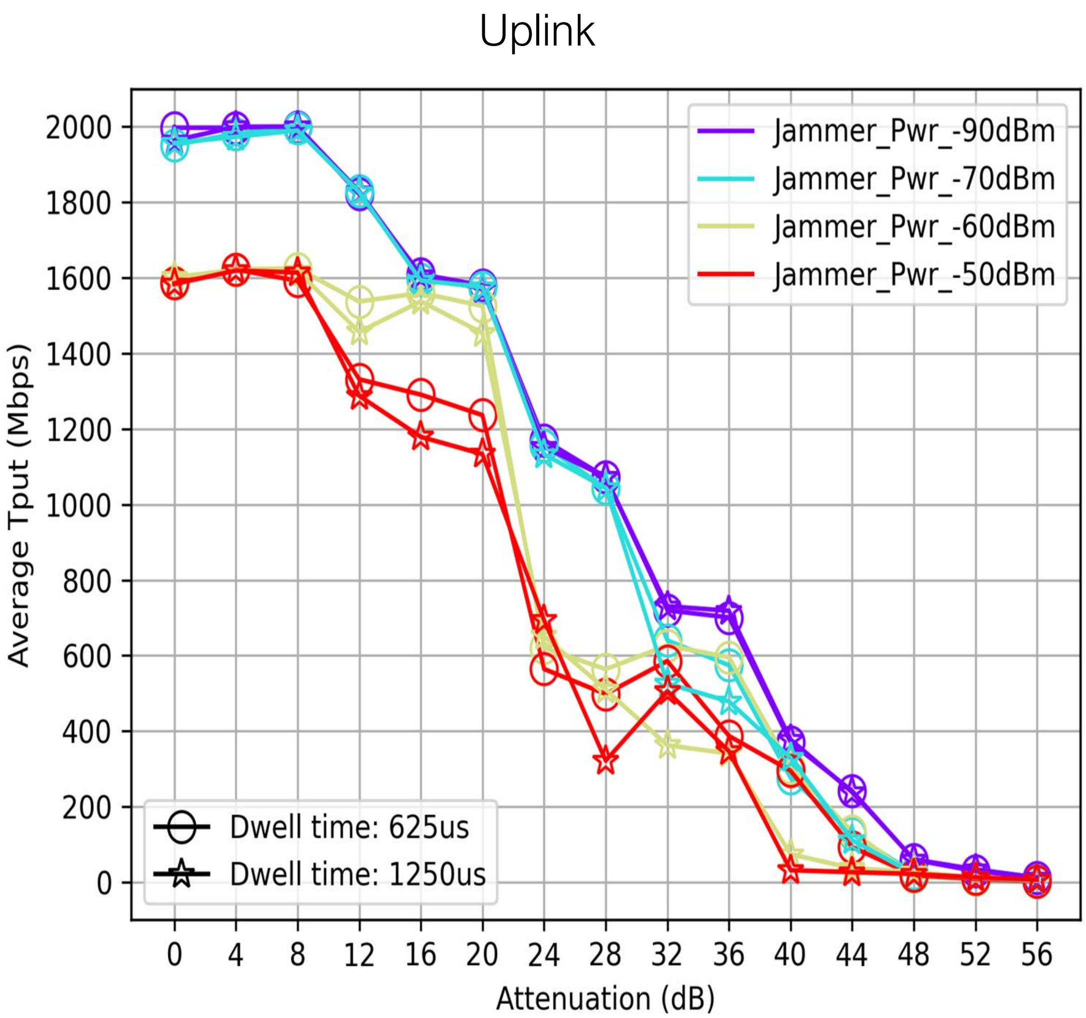


NB Profiles 2 and 3 at 5178MHz



NB Profiles 2 and 3 at 5258MHz

Location of NB interferer within the channel does not seem to matter

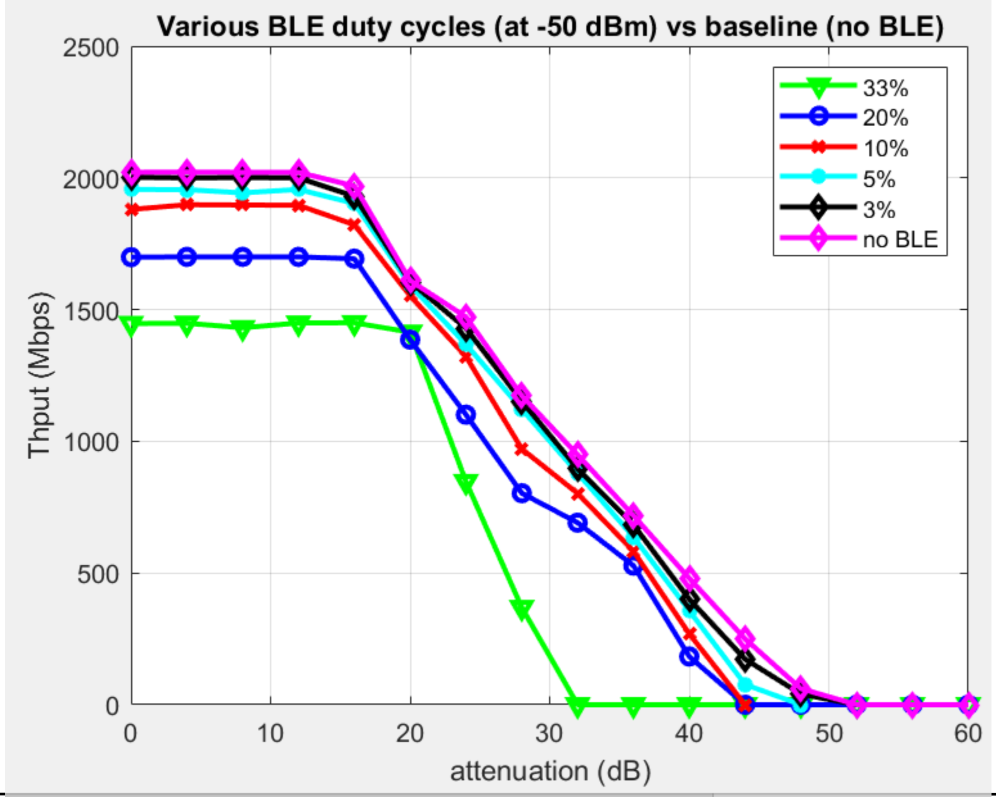


Various BLE Duty Cycles

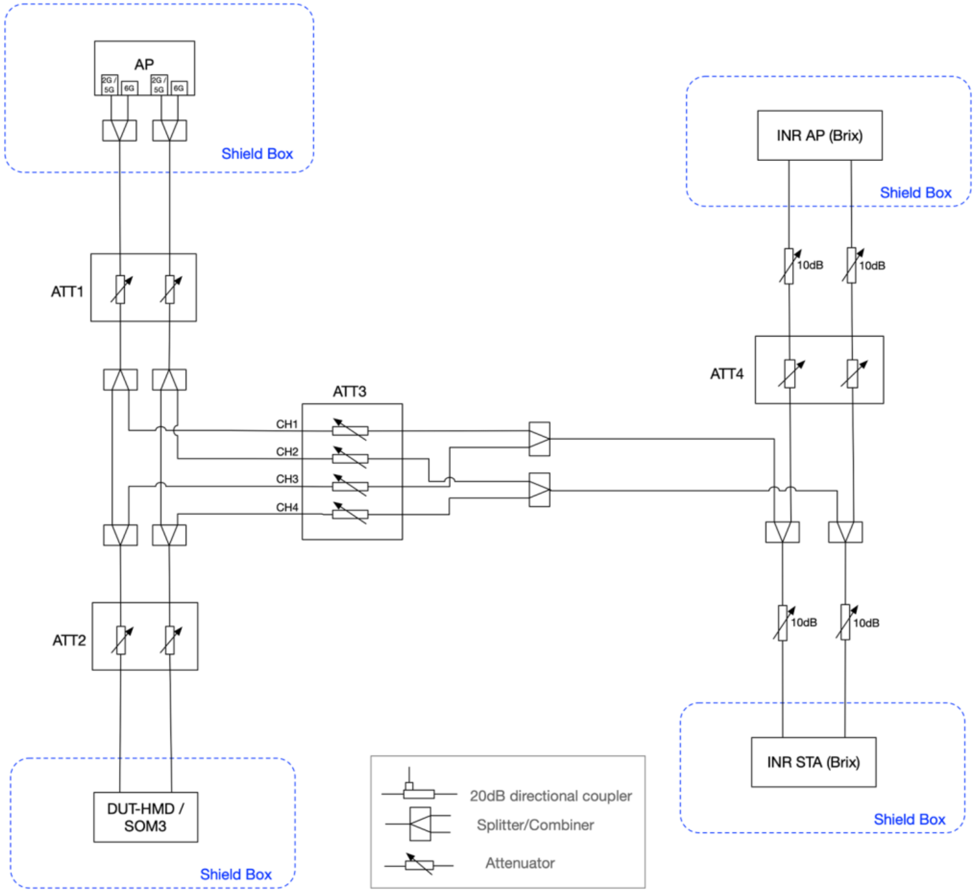
For 33% duty cycle, we see reduction in peak throughput as well as a large reduction in reach.

There is a small degradation of the peak rate even with 3% duty cycle and sensitivity degradation for 5% duty cycle

NB at 5178 MHz

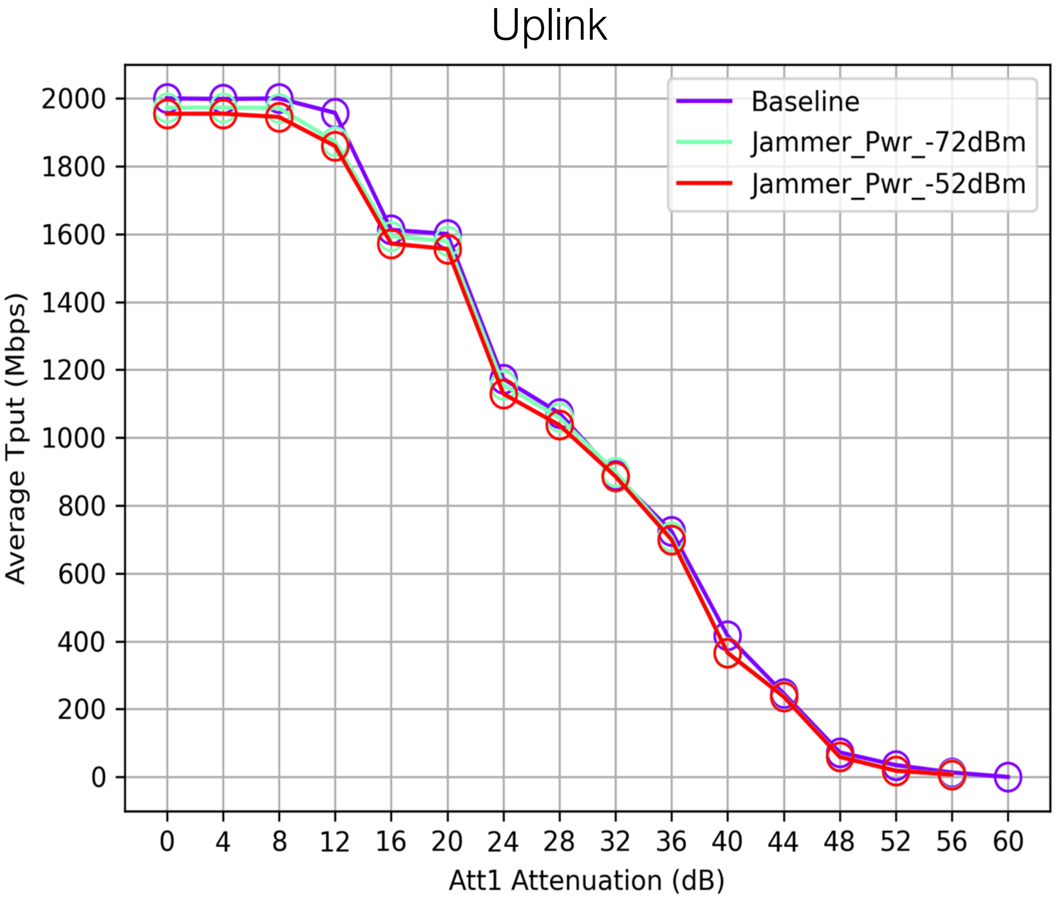


Setup - WiFi Interferer



- Desired Link:
  - 802.11 Channel: 5GHz CH36/160MHz
- Interference Link:
  - AP/STA:
  - 802.11 Channel: 5GHz CH36/160MHz
  - iperf UDP UL **3Mbps**
- ATT1 is swept for the main link, as before
- ATT2 is set to 0
- ATT3 controls the interference level

Result - WiFi Interferer

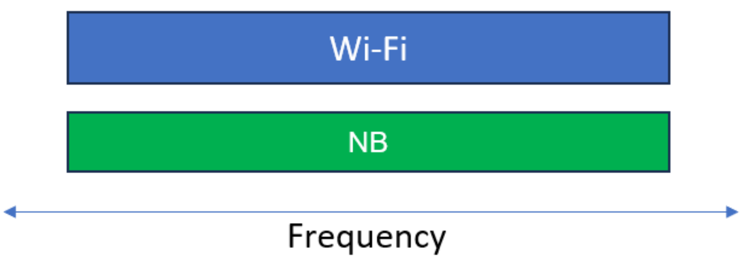


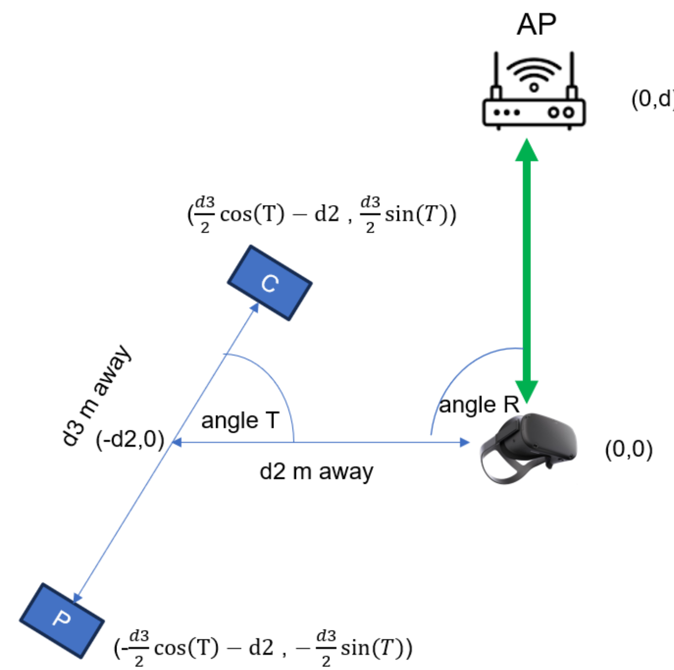
Simulation Results for both Throughput and per-packet Latency

Simple Scenario

802.11 AP and STA d meters away and another set of NB devices, separated by d3 meters, has centroid that is d2 meters away from STA.

C and P are NB devices transmitting in same frequency as 802.11 devices

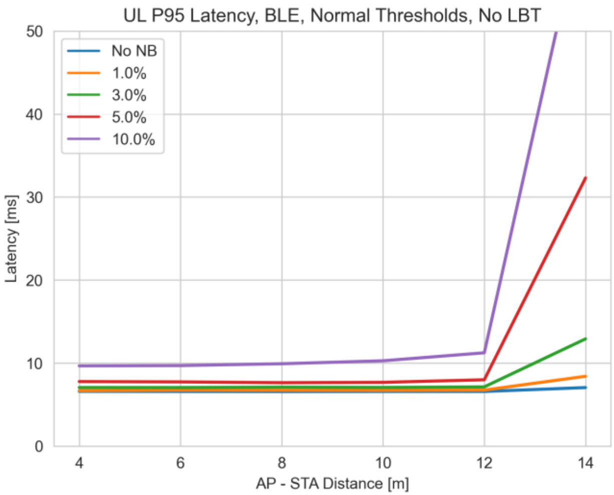




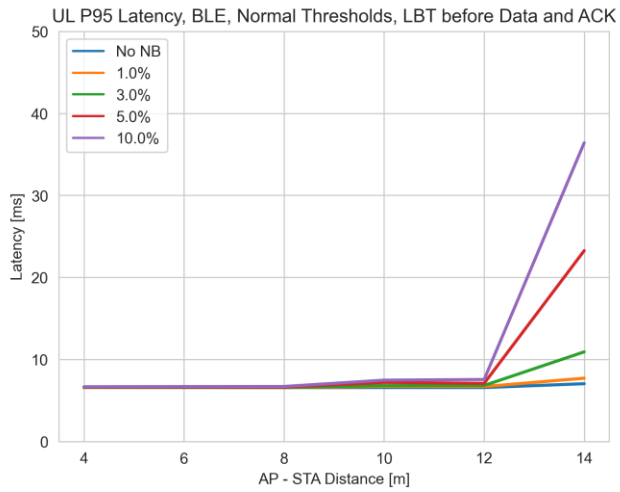
Assumptions

- Sweep over d while keeping d2=2m, T=R=pi/2 and d3=1m.
- 802.11
  - 14 dBm at both AP and STA
  - XR Traffic : 100 Mbps DL @72 Hz and 3 Mbps UL @ 500 Hz
  - MCS2 with ~55% duty cycle
  - BW=80 MHz
  - Traffic type : UDP, AC_BE
  - 0.8s GI, 2x HE-LTF, AMSDU Agg, RTS/CTS off
  - -62 dBm ED threshold at primary 20 (per 802.11 spec)
    - Note that -62 dBm in primary 20 is equivalent to -75 dBm/MHz ETSI threshold
- NB
  - 14 dBm at both C and P
  - fc at 802.11 primary channel
  - -75 dBm/MHz Max ED Threshold value
  - Fixed duty cycle with 42 byte (416us) NB packet
    - For 10,5,3,1% duty cycle, data packet size remains fixed but packet interval increases
    - Enable/Disable NB 80us/416us Ack with 150us/584us IFS
- 802.11 AWGN Channel model with dbp=5, fc @6.425 GHz
- Distances are shown in which 802.11 target throughputs are met
- Reduced ED threshold mode : -65 dBm on 802.11 primary 20 (to allow AP/STA to defer to each other at d=14m) and -85 dBm/MHz on NB

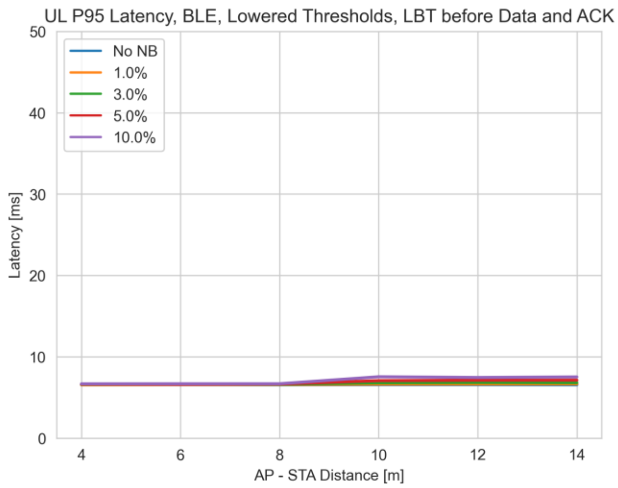
UL Results with MCS=2 (150us IFS), 80 MHz (no LBT vs LBT)



No LBT



Max ED Threshold

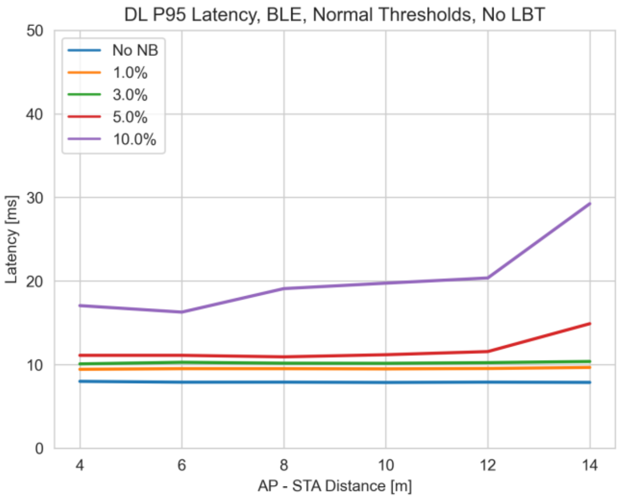


Reduced ED Threshold

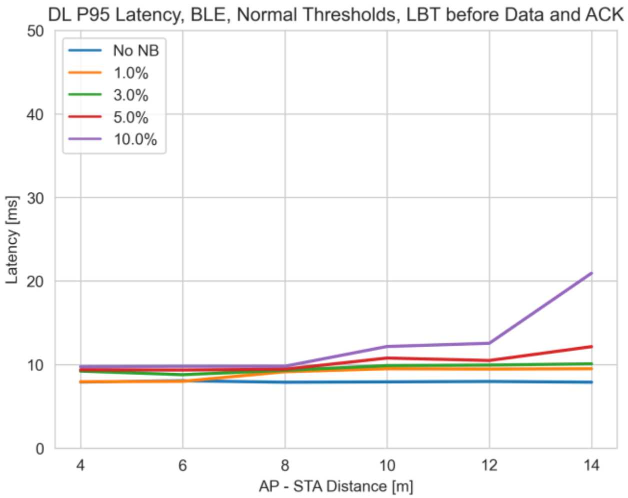
At 14m, AP does not defer to NB C or P nodes, since NB power < -62 dBm

For No LBT, a 3% duty cycle causes ~50% increase in P95 latency
For No LBT, a 10% duty cycle causes unacceptable P95 latency

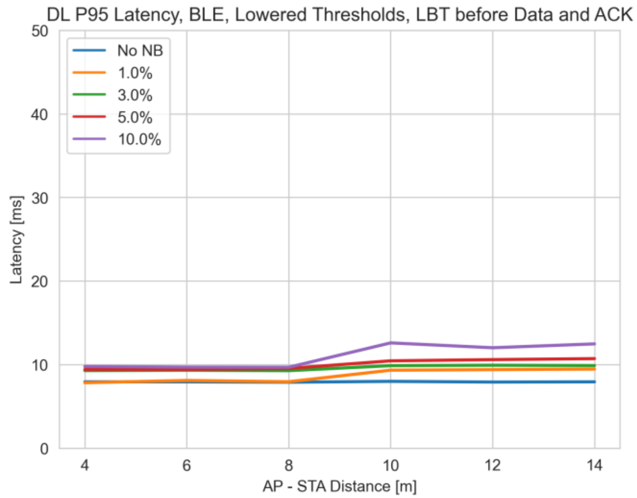
DL Results with MCS=2 (150us IFS), 80 MHz (no LBT vs LBT)



No LBT



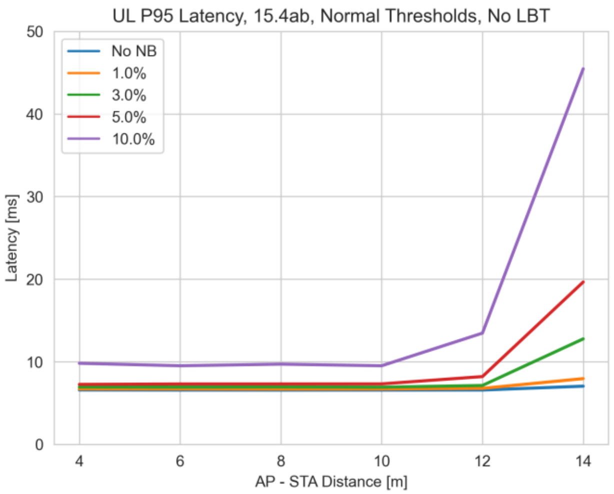
Max ED Threshold



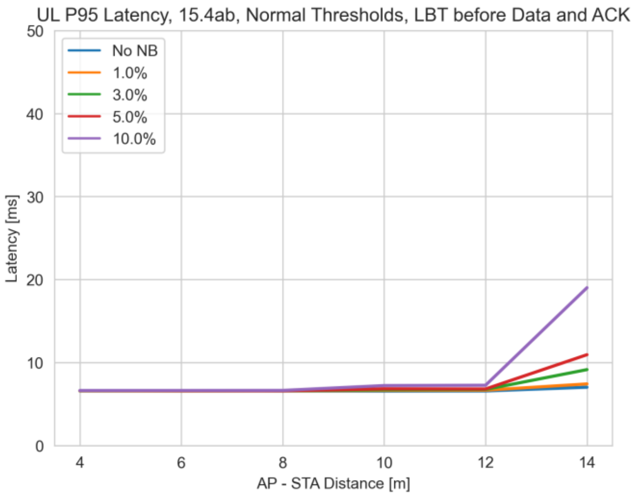
Reduced ED Threshold

For No-LBT, P95 latency for 10% duty cycle is ~3.6x no NB case

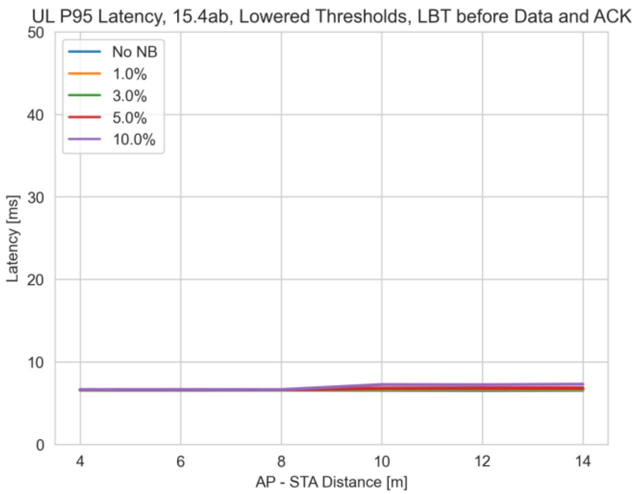
UL Results with MCS=2 (584us IFS), 80 MHz (no LBT vs LBT)



No LBT



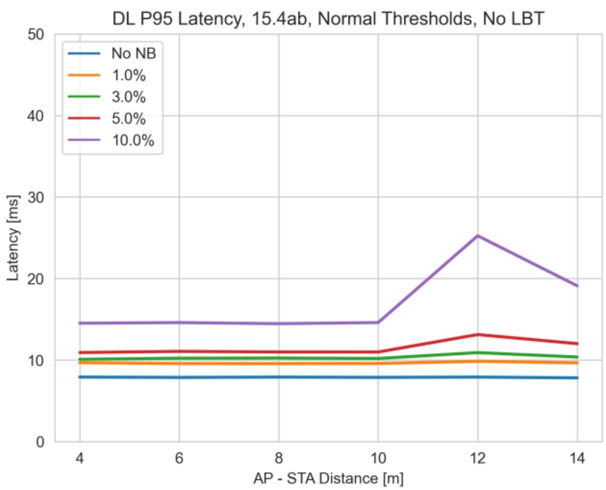
Max ED Threshold



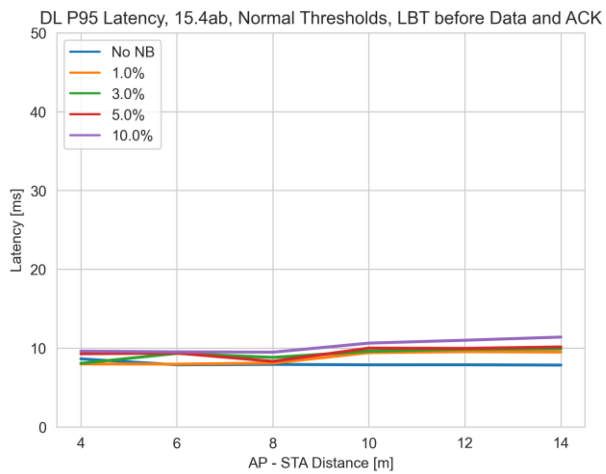
Reduced ED Threshold

For no-LBT, a 3% duty cycle causes ~50% increase in P95 latency
For no-LBT, a 10% duty cycle causes unacceptable P95 latency

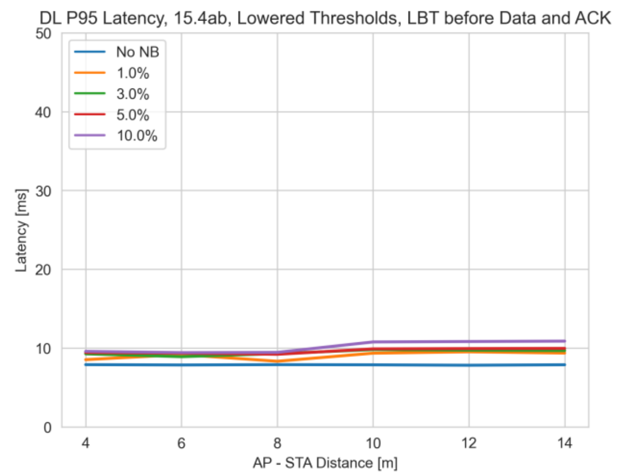
DL Results with MCS=2 (584us IFS), 80 MHz (no LBT vs LBT)



No LBT



Max ED Threshold



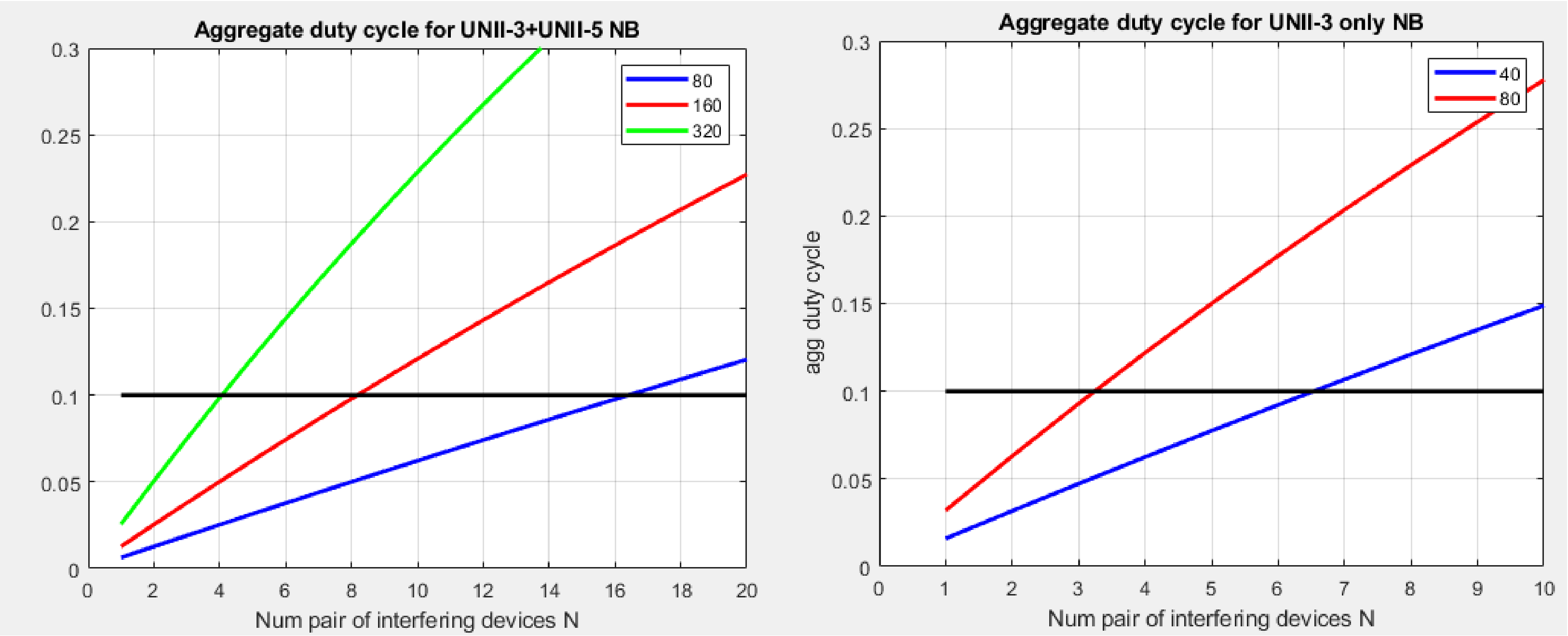
Reduced ED Threshold

At 12m, AP does not defer to NB P node, since NB power < -62 dBm

For No-LBT, P95 latency for 10% duty cycle is ~3x no NB case

Number of NB Devices and Aggregate Duty cycle

When N pairs of narrowband transmitting UWB devices are using total bandwidth of W MHz, each pair with duty cycle x, the aggregate duty cycle on any B MHz channel is given by $1-(1-x*B/W)^N$



We can reach ~10% aggregate duty cycle with x=5% duty cycle with 4/8/16 (UNII-3 + UNII-5) NB pair of interfering devices on a single 320/160/80 MHz 802.11 channel.

We can reach ~10% aggregate duty cycle with x=5% duty cycle with 3/6 (UNII-3 only) NB pair of interfering devices on a single 80/40 MHz 802.11 channel.

Observations

- For this scenario, 802.11 latency is more sensitive than 802.11 throughput and smaller IFS value is more detrimental than the larger one.
- NB Tx Power control could help improve coexistence
- The 802.11 interferer with similar data rates as NB can coexist with 802.11 without significant degradation.
- 10% aggregate duty cycle can be easily reached with multiple NB interferers
- Low NB duty cycle exhibits better coexistence with 802.11 technologies
    - For the considered scenario, even 3% NB duty cycle causes a ~50% increase in P95 packet latency. A 10% duty cycle causes unacceptable P95 latency.
- The use of NB LBT improves 802.11 performance
    - Effect of NB LBT (or other proposed coex mechanism) on NB performance (throughput and latency) still needs to be assessed

Recommendations

- To ensure better co-existence with 802.11, recommendation is for 802.15.4ab to adopt a mandatory coexistence mechanism to ensure adequate performance for both 802.11 and 802.15.4ab.
- The mandatory coexistence mechanism can consist of a combination of LBT or other techniques.

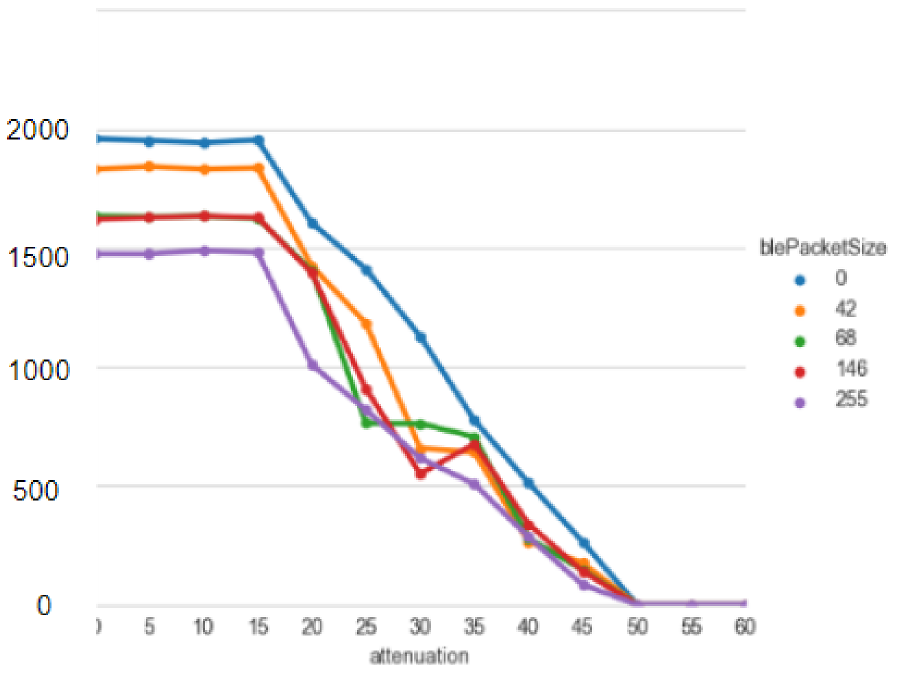
Proposed text Change

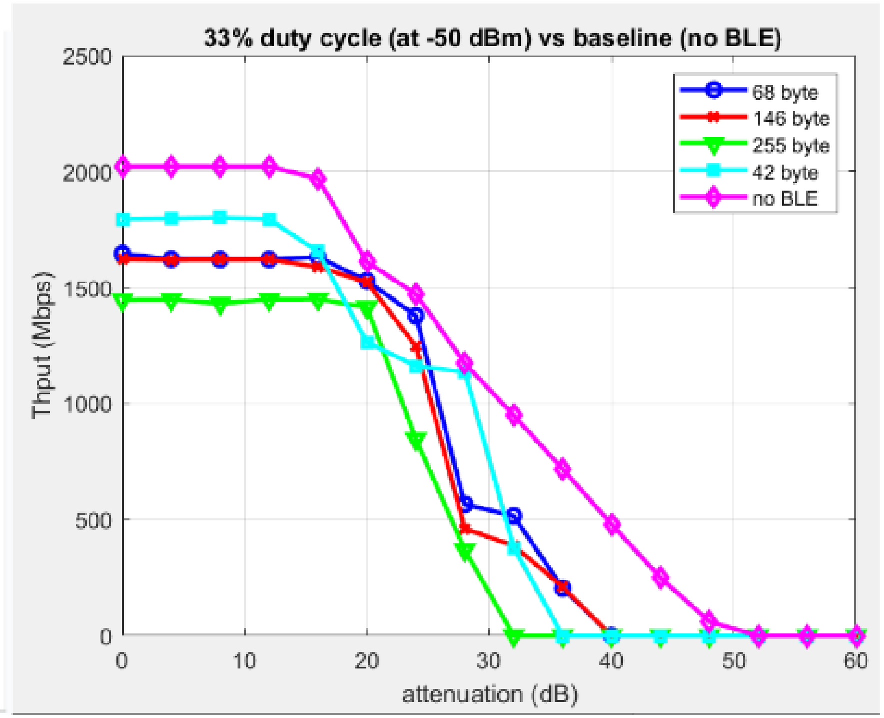
- Current NB text is :
  - LBT shall be applied to NB channels 50-249 according to regulatory constraints. LBT may be applied to all NB channels 0-249 in the absence of regulatory constraints, for example, to improve QoS and coexistence with other shared spectrum radio, like IEEE 802.11.
- Proposed NB text is :
  - For duty cycle < TBD%, LBT may be applied to all channels 0-249 to improve QoS and coexistence with other shared spectrum radio, like IEEE 802.11. For duty cycle >= TBD%, LBT shall be applied to all channels 0-249.

Appendix

Simulation Calibration

- ns-3 on the left vs measurements on the right





Derivation of Aggregate Duty Cycle

Prob(one channel is occupied) = 1- prob (one channel is free)

=1 – prob (all N devices are not transmitting in that one channel)

=1- (a single device is not transmitting in that one channel)^N

= 1- (1-prob(a single device is transmitting on that one channel))^N

=1 – (1-x *B/W)^N where x is the duty cycle, B is the channel bandwidth and W is the total bandwidth that may be occupied by NB.

Packet configurations for some duty cycle experiments

Duty cycle	Bytes	Packet Interval (ms)
33	255	6.25
20	255	10.625
10	146	12.5
5	68	12.5
3	37	12.5