Effect of no-LBT NB on 802.11 devices

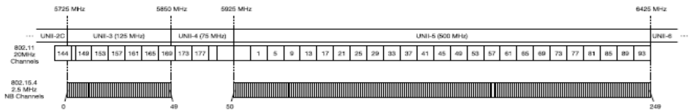
Authors:

Name	Affiliation	Address	Email
Carlos Aldana	Meta	1 Hacker Way, Menlo Park, CA 94025, USA	caldana at meta.com
Guoqing Li	Meta	1 Hacker Way, Menlo Park, CA 94025, USA	
Davide Magrin	Meta	1 Hacker Way, Menlo Park, CA 94025, USA	
Kumail Haider	Meta	1 Hacker Way, Menlo Park, CA 94025, USA	
Connor Kennedy	Meta	1 Hacker Way, Menlo Park, CA 94025, USA	
Claudio da Silva	Meta	1 Hacker Way, Menlo Park, CA 94025, USA	

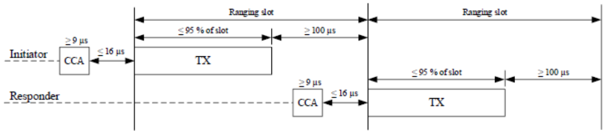
Background on 802.15.ab

802.15.4ab Narrowband is defined for 2 purposes: assist UWB ranging and Data Communications

- 2.5 MHz channel spacing, which is optimal for 10dBm/MHz and 14 dBm EIRP ETSI requirements
- 250 channels spanning UNII-3 and UNII-5 are defined



- In 15-22-381, LBT is an optional feature and is mandatory for 6 GHz subject to regulatory constraints with a TBD ED threshold



- In 15-23-243, due to limited available UWB channels, it is suggested to use NB for Data Communications to enable a gate entry use case. This is a potentially high duty cycle scenario. This may lead to NB Data communications in high device density scenarios (e.g., apartment buildings, malls, stadiums)
- In 15-22-261, various coex schemes were proposed: LBT, Adaptive Freq Hopping (AFH), and duty cycle limitation.
  - Although there currently is an AFH mechanism for an initiator to use a channel allowed list and for 20 MHz 802.11 channels to be blocked, it is an optional feature. The initiator is not mandated to use it.
- 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 (2 MHz BW), the SIR > 20 dB for 802.11 64QAM rate 5/6 PER to be < 10%.
- **<u>There is NO mandatory NB coexistence mechanism in either UNII-3 or UNI-5.</u>**

Overview

This work focuses on the effects of NB interference on 802.11 at the MAC level (experimental and simulation data)

This compares 2 scenarios:

1) effect of NB (without LBT) with various duty cycles on 802.11 link

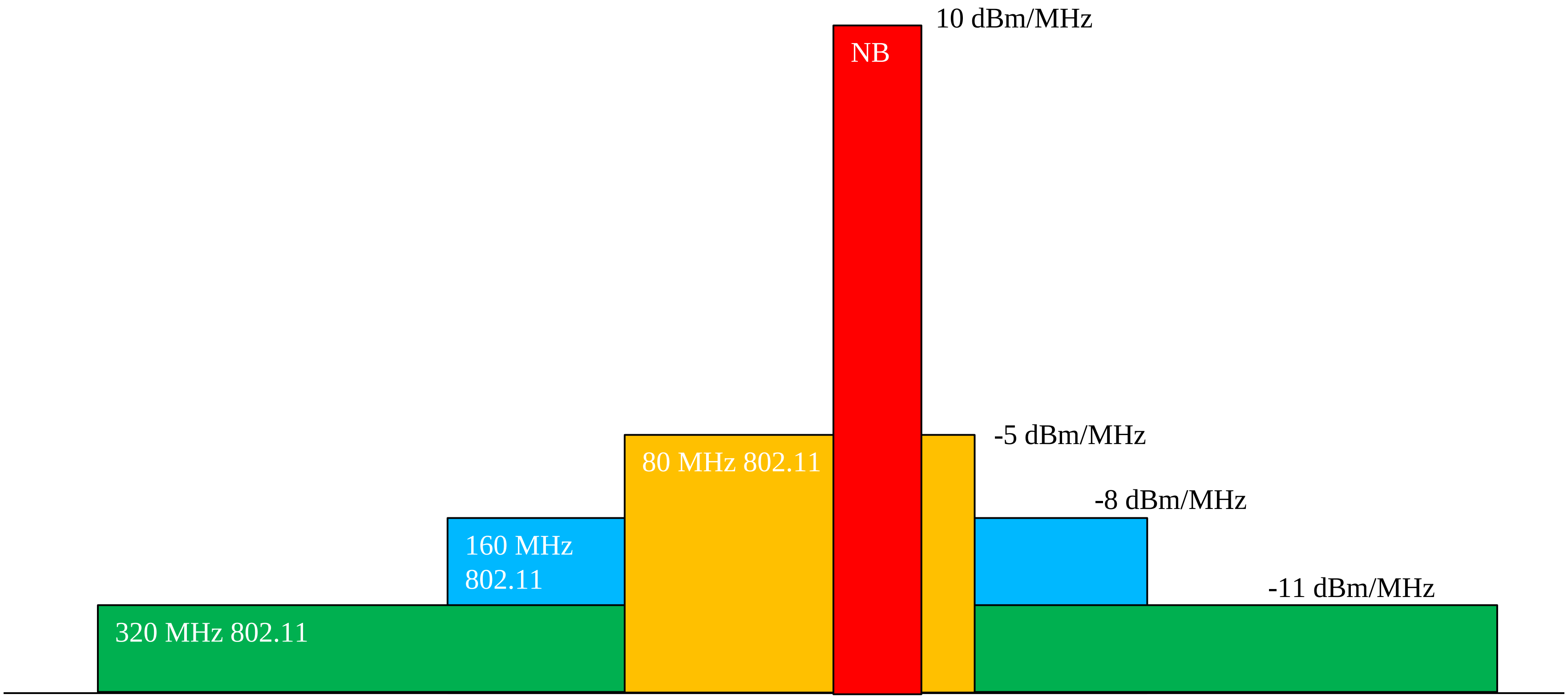
2) effect of 802.11 (with LBT) on 802.11 link

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?

Europe 6 GHz NB vs VLP 802.11 spectrum

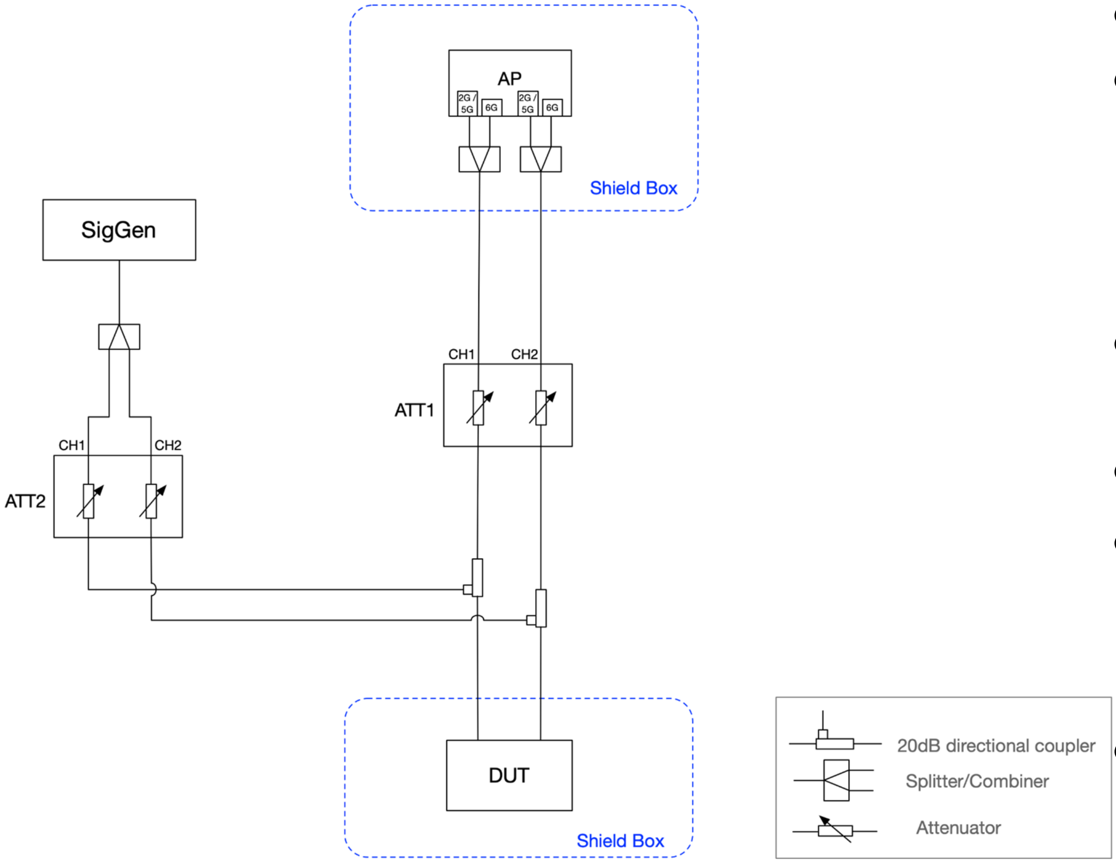
NB with 14 dBm EIRP is 15/18/21 dB stronger than VLP 802.11 with 80/160/320 MHz



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

Experimental Results focused on 802.11 Throughput

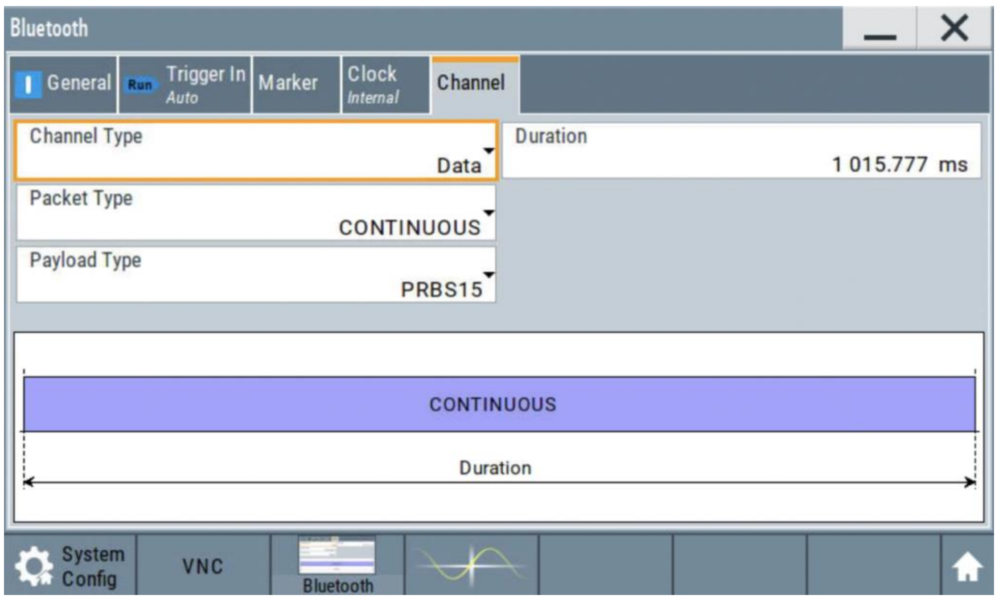
Setup – NB Interferer

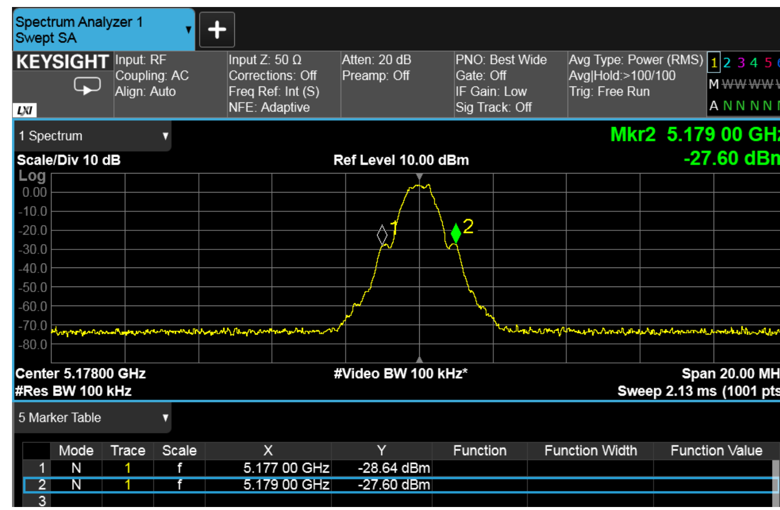


- SigGen: R&S SMBV100B
- 802.11 Channel: 5GHz CH36 (160MHz) centered at 5250 MHz (5170-5330 MHz)
  - Max PHY rate 2.0-2.4 Gbps (depends on guard interval)
- 802.11 does its own rate adaptation and AMPDU is enabled.
- Iperf udp traffic
- ATT2 is used to set the NB RX power to the desired level at the 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

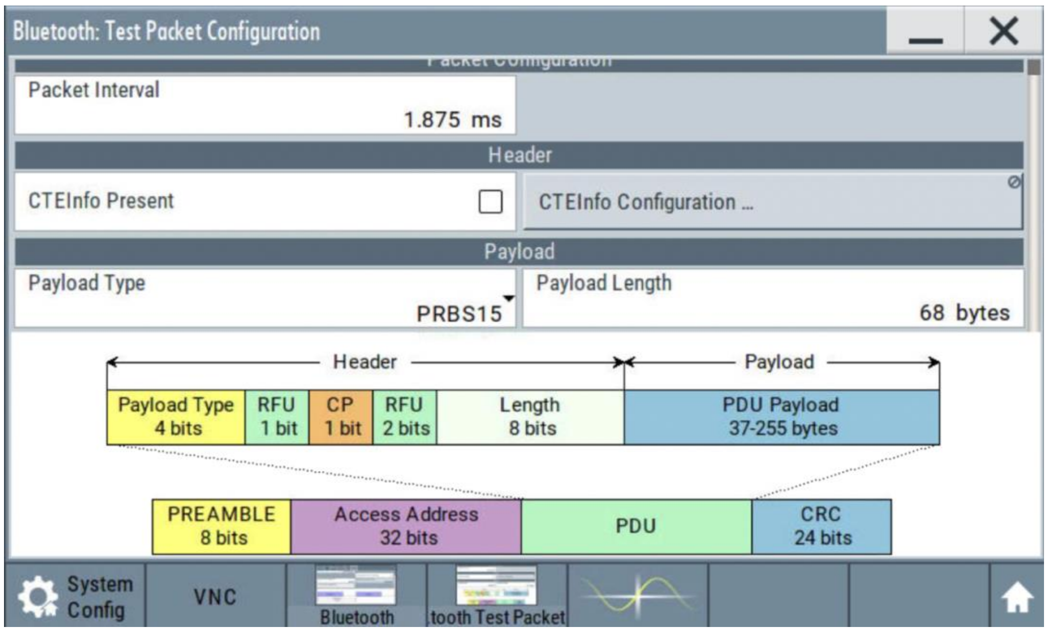


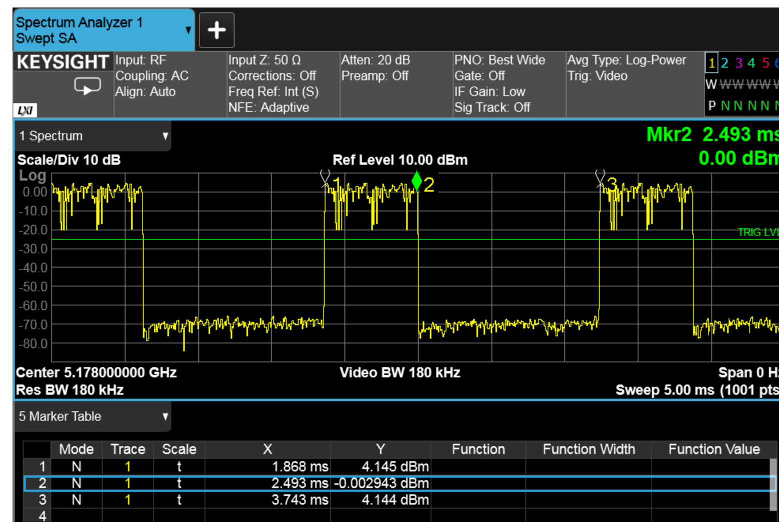


2 MHz BW

NB Profile 2 (68 bytes)

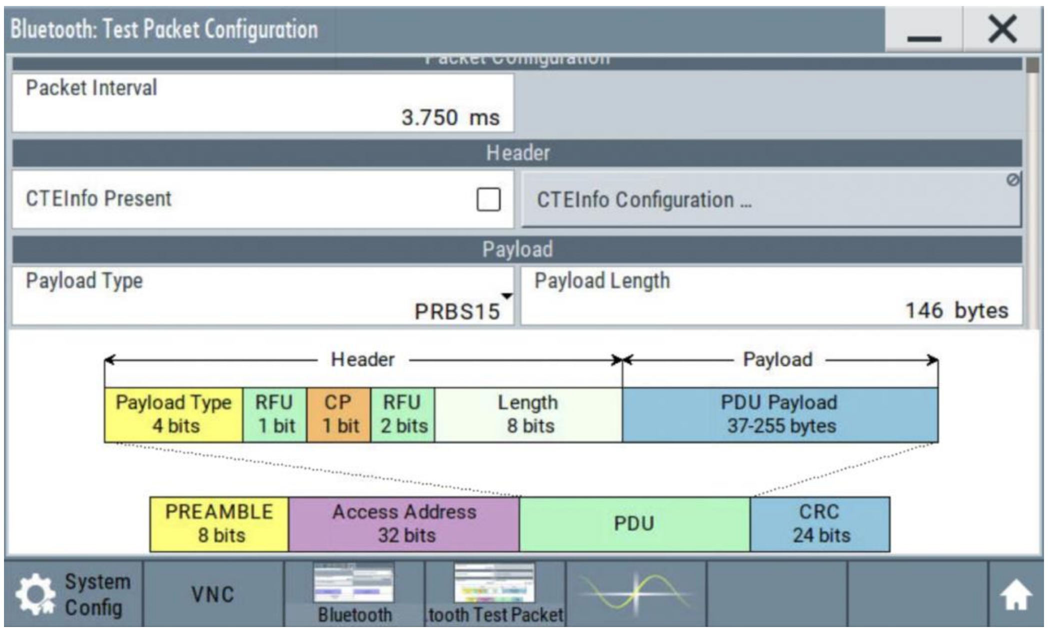
- BLE with dwell time 625us with a packet interval of 1.875ms, 33.3% duty cycle

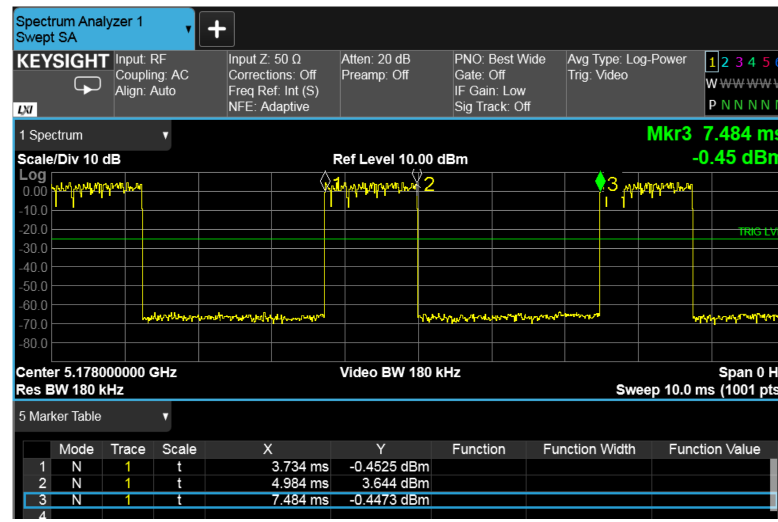




NB Profile 3 (146 bytes)

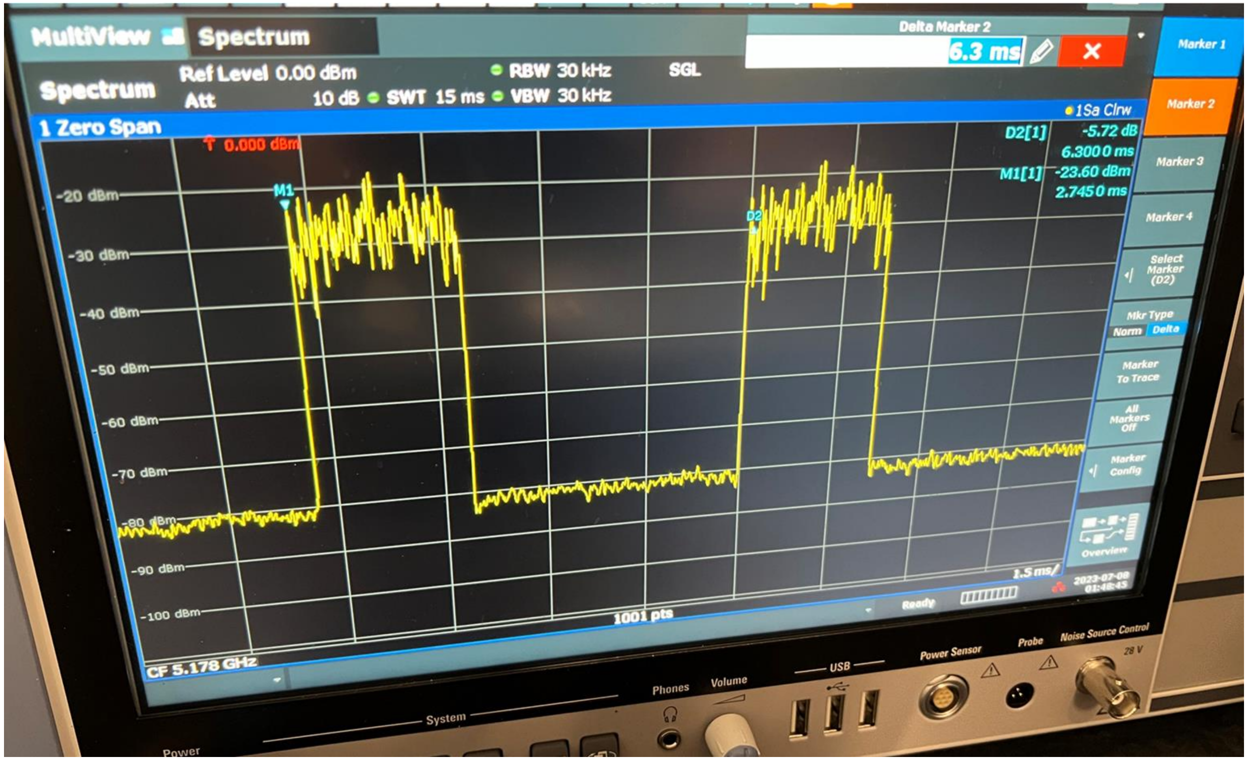
- BLE with dwell time 1.25ms with a packet interval of 3.75ms, 33.3% duty cycle





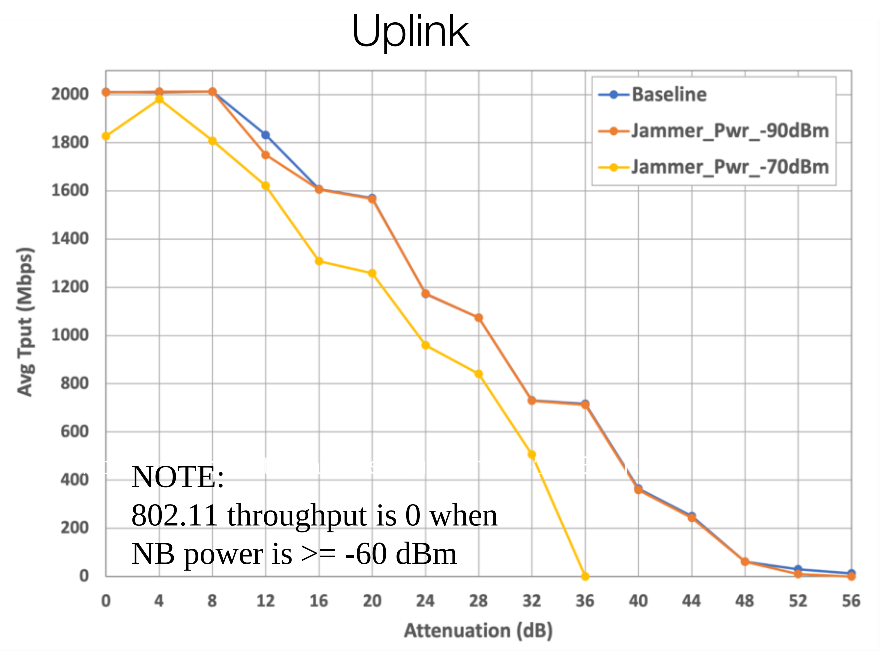
NB Profile 4 (255 bytes)

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

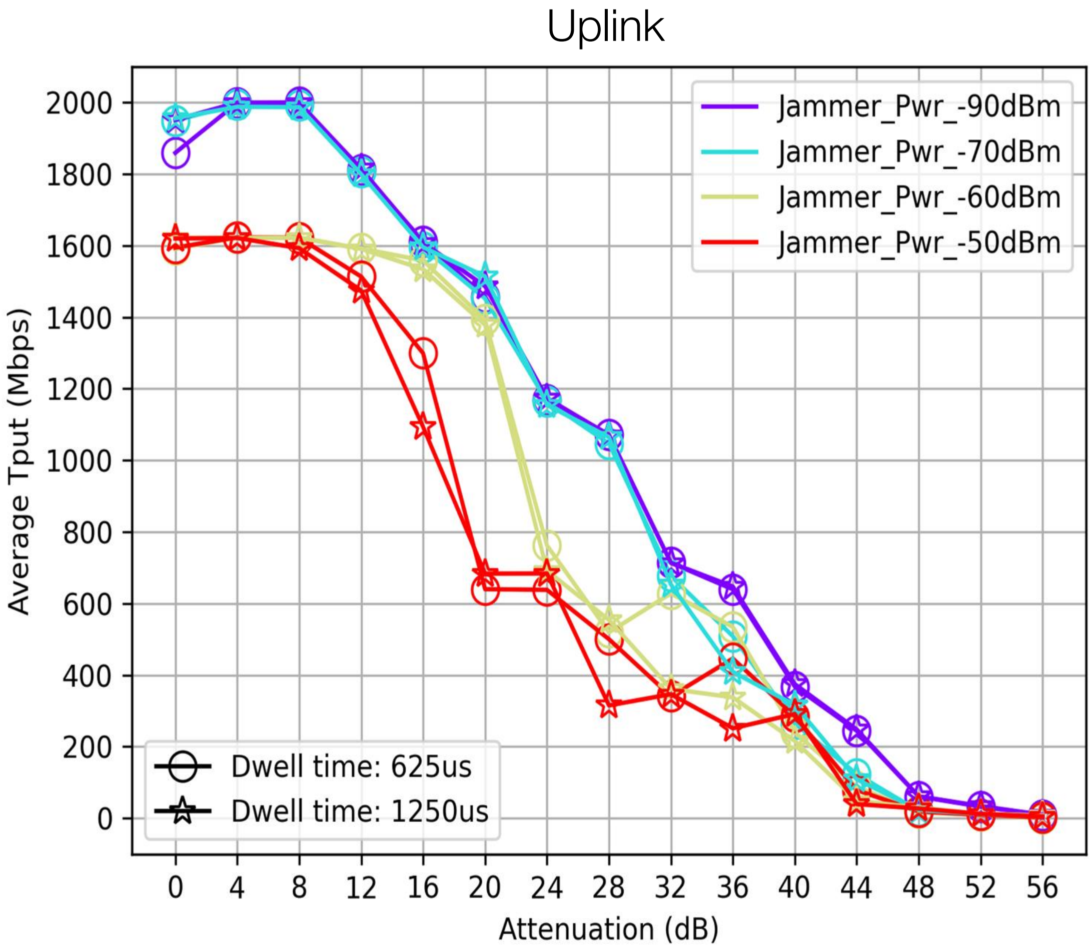


NB Profile 1 at 5178MHz

- 802.11 throughput is 0 when the NB power is -60dBm or -50dBm. At these interference levels, NB interferer completely prevents 802.11 DUT from transmitting because 802.11 performs LBT. Even at -70dBm NB power, 802.11 range becomes limited.

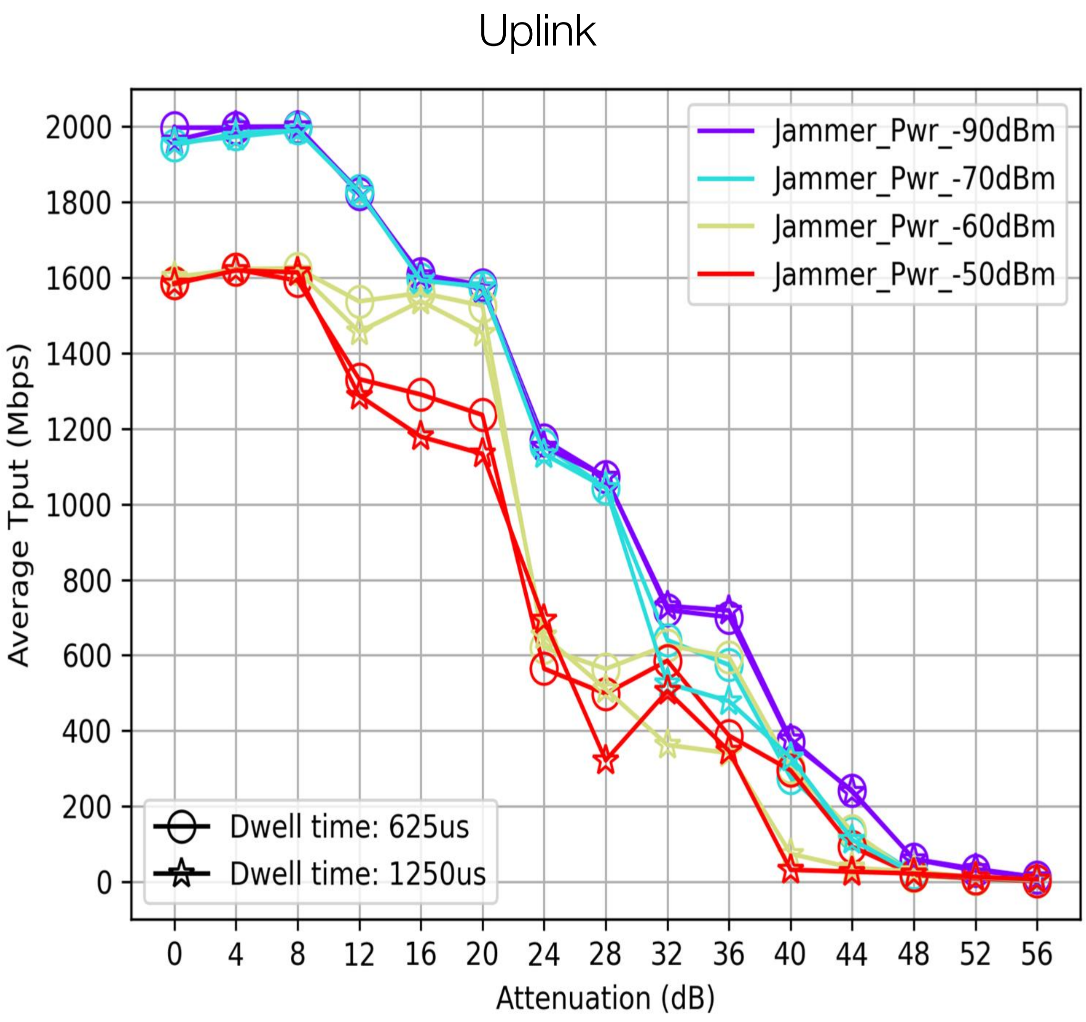


NB Profiles 2 and 3 at 5178MHz



NB Profiles 2 and 3 at 5258MHz

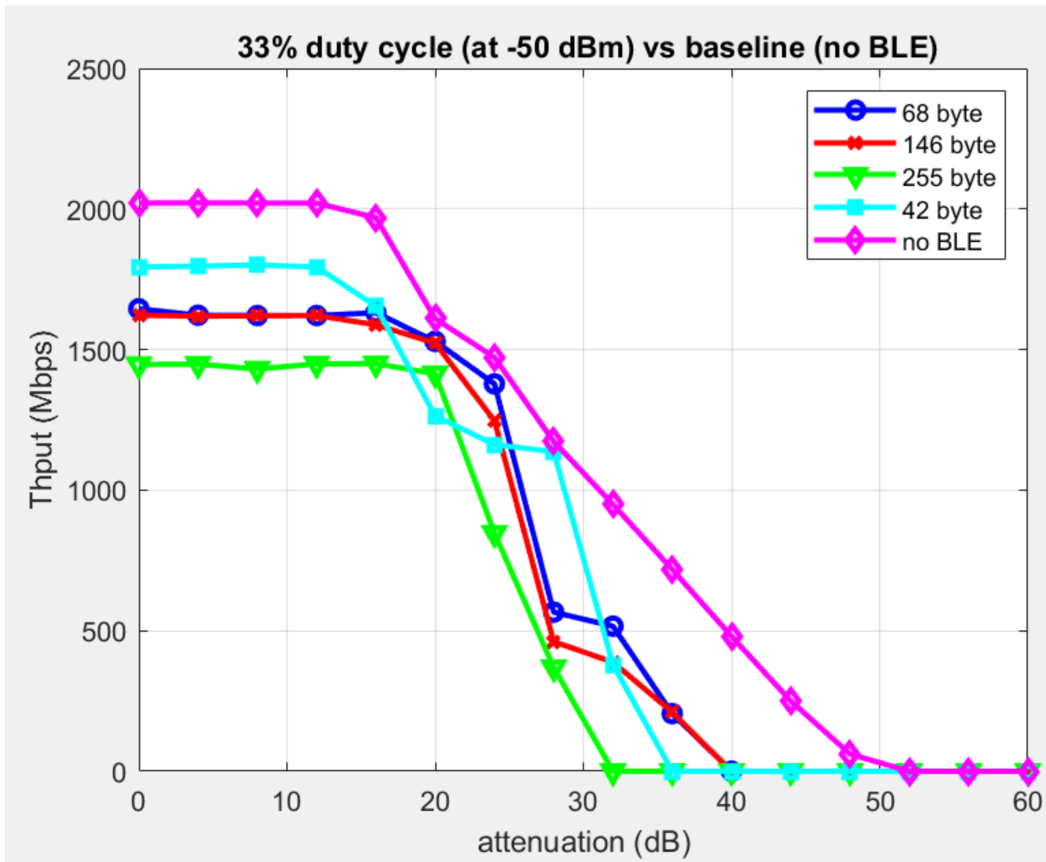
Location of NB interferer within the channel does not seem to matter



33% BLE Duty Cycle

255 byte BLE (NB Profile 4) transmissions causes the most degradation (in both peak rate and range)

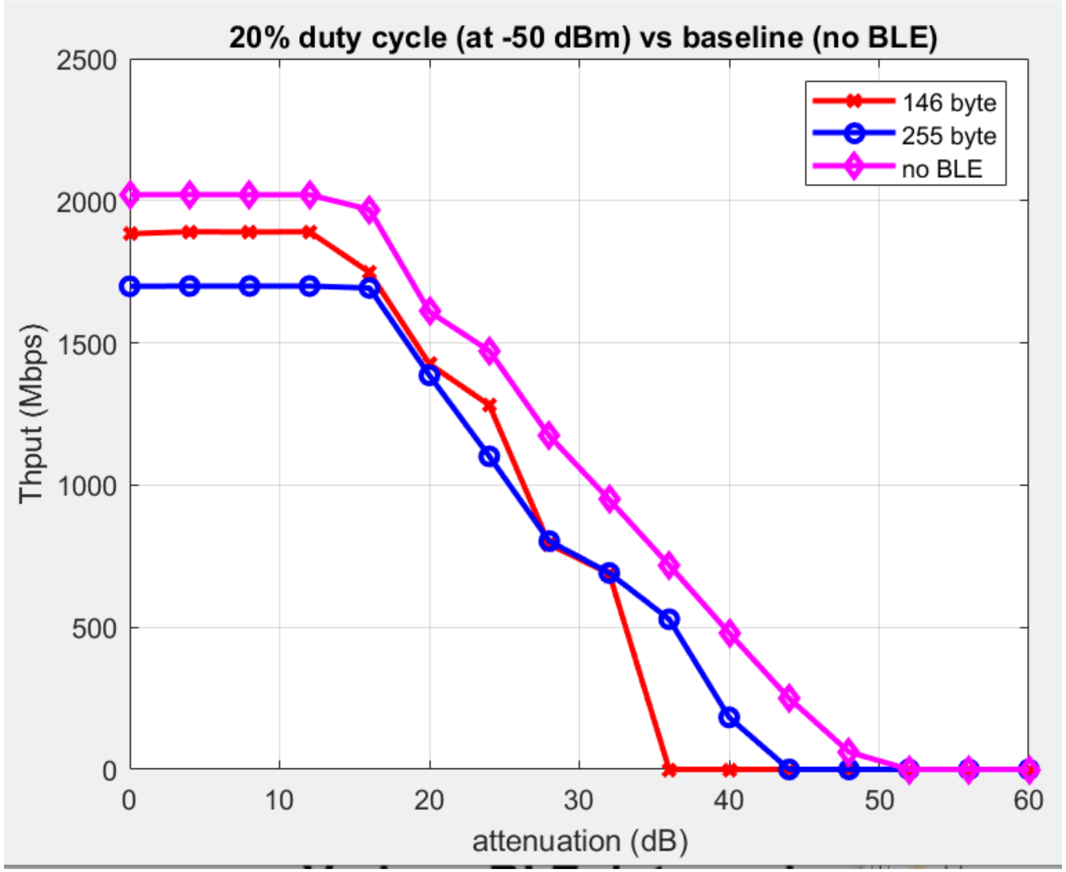
NB at 5178 MHz



20% BLE Duty Cycle

The 255 byte BLE transmissions again causes the most degradation in peak throughput

NB at 5178 MHz

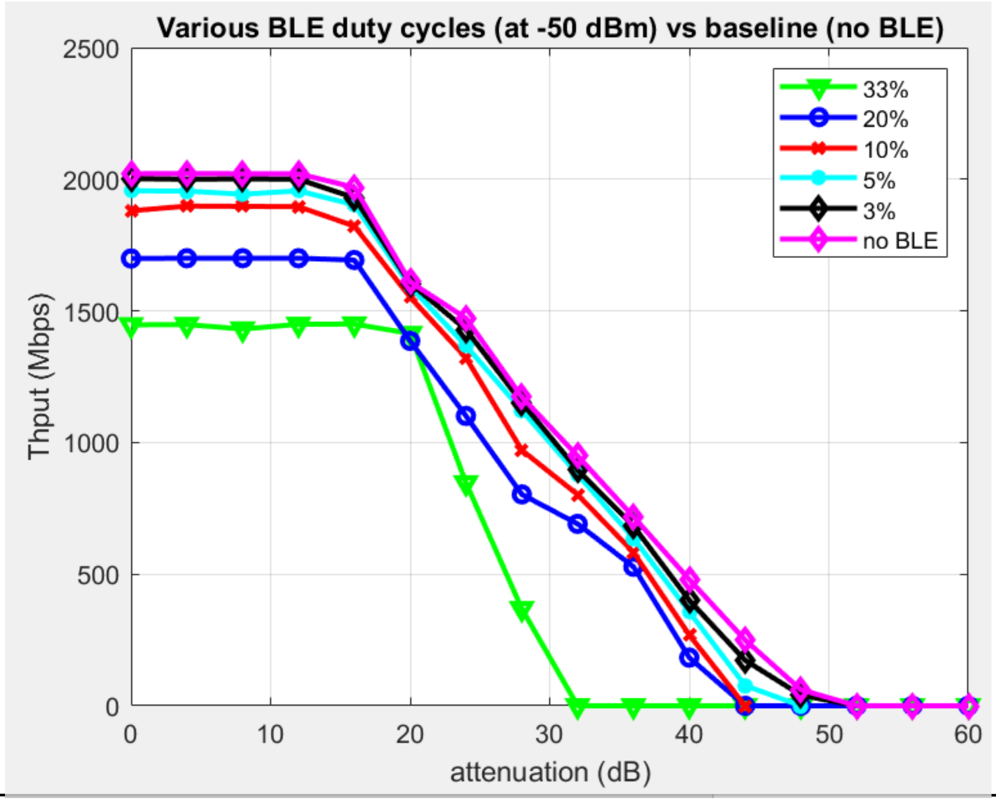


Various BLE Duty Cycles

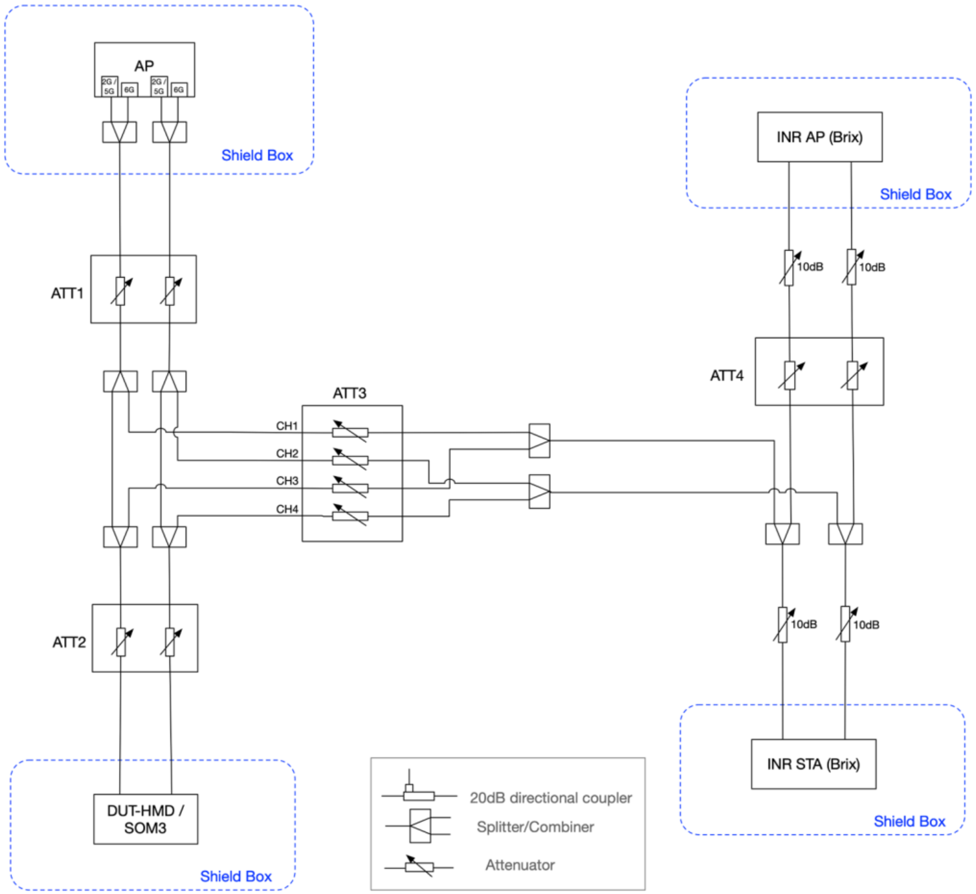
For 33% duty cycle, we see large reduction in peak throughput as well as in reach.

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

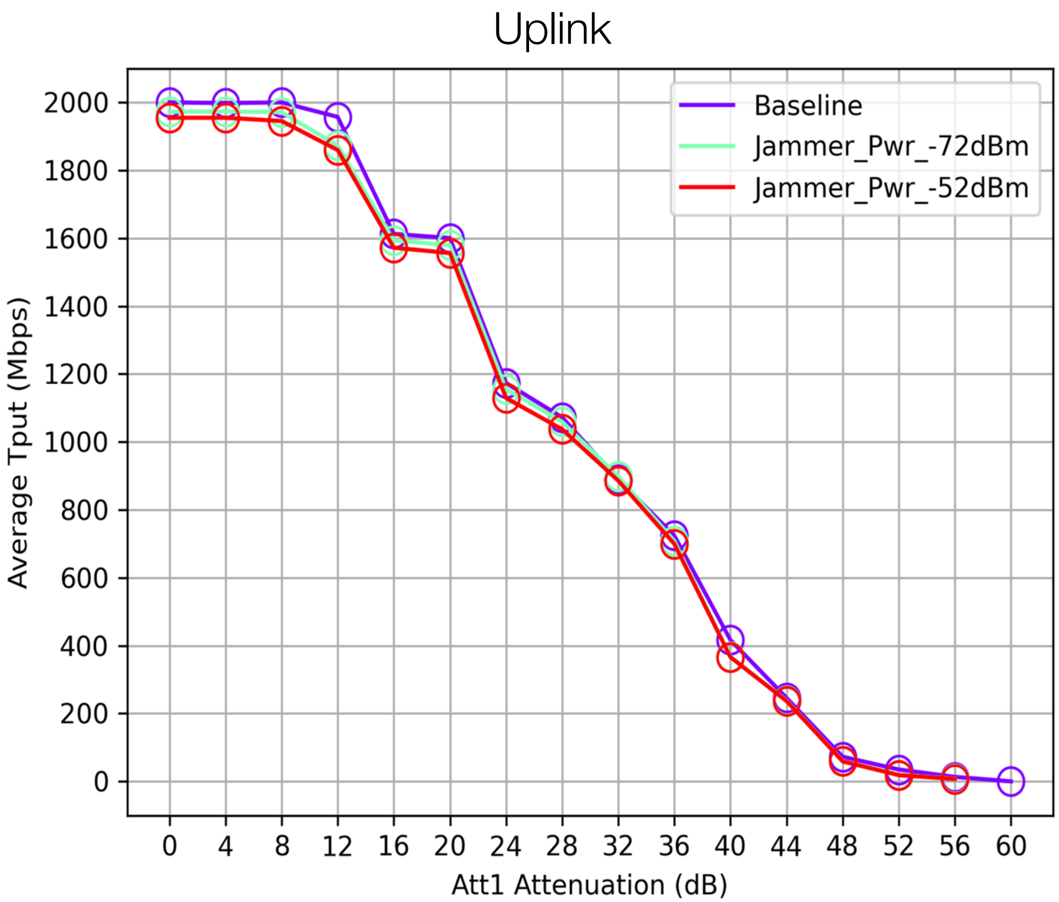


Setup - WiFi Interferer



- 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

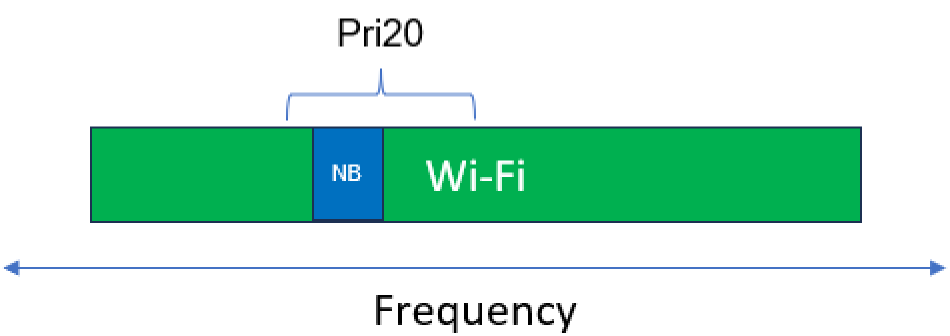


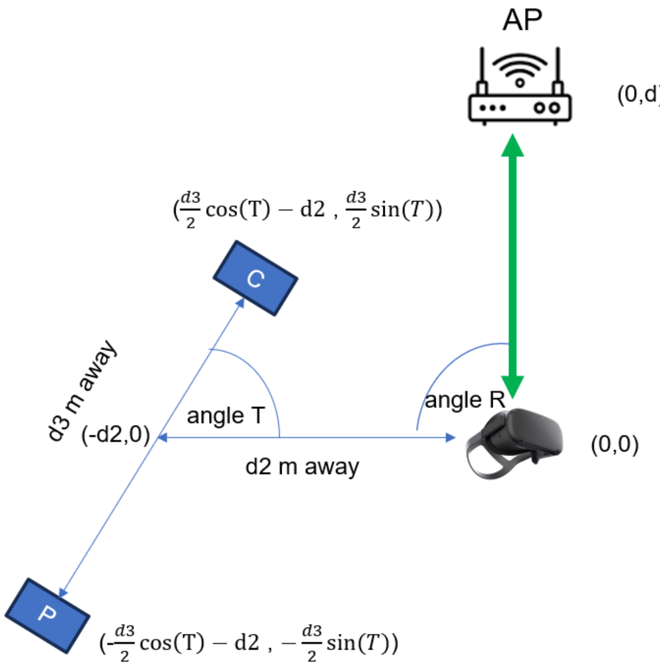
Simulation Results for both Throughput and per-packet Latency

Simple Scenario

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 only in Pri20 of 802.11 devices

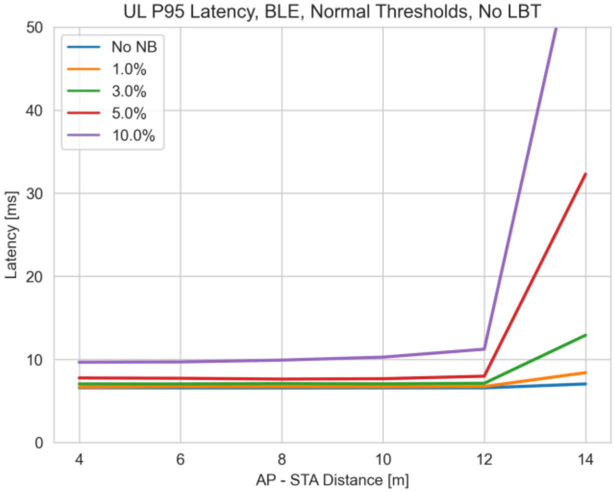


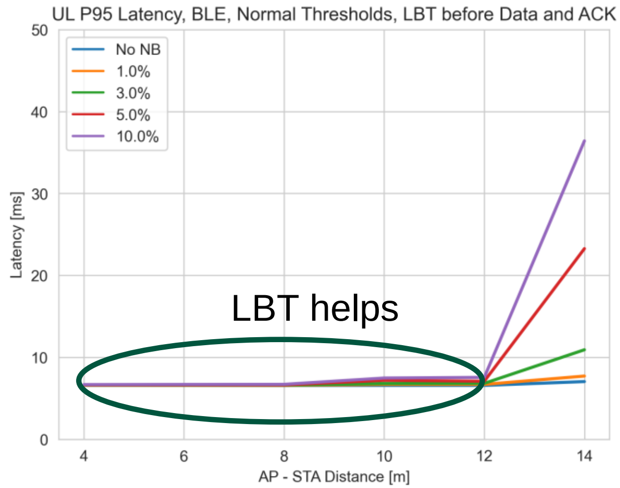


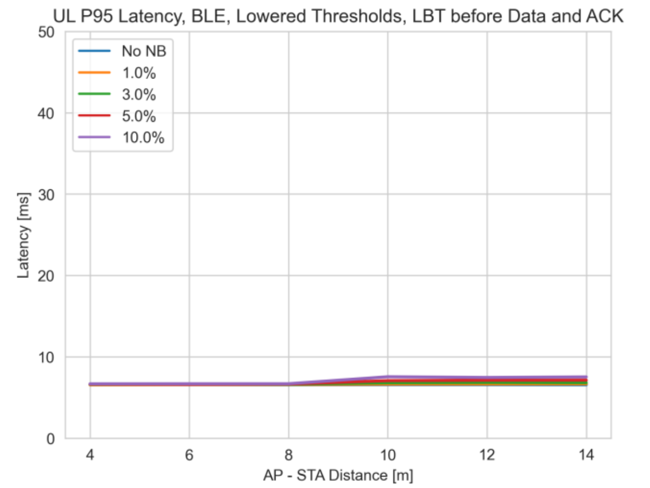
Assumptions

- 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)
- NB
  - 14 dBm at both C and P
  - -75 dBm/MHz Max ED Threshold value
  - Fixed duty cycle with 42 byte (416us) NB packet
    - For 33,20,10,5,3,1% 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 d 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

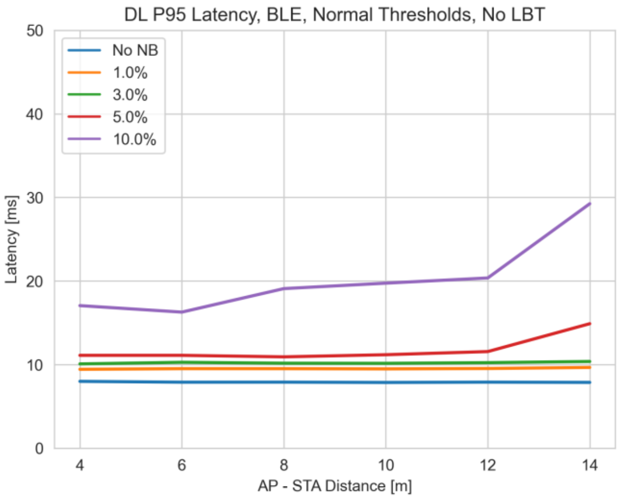
At 14m, AP does not defer to NB C or P nodes, since NB power < -62 dBm

Max ED threshold

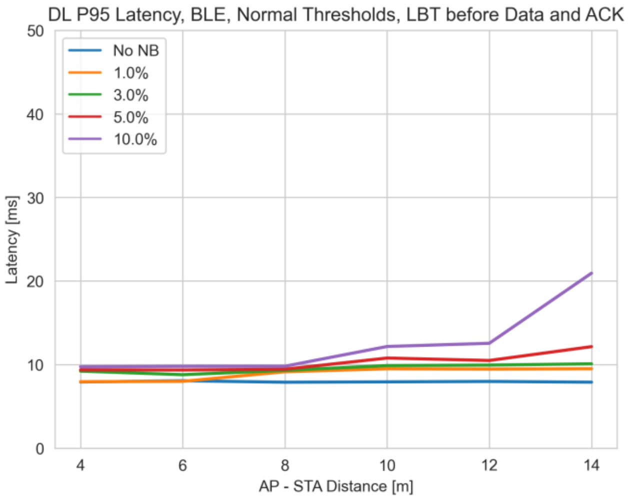
Reduced ED threshold

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

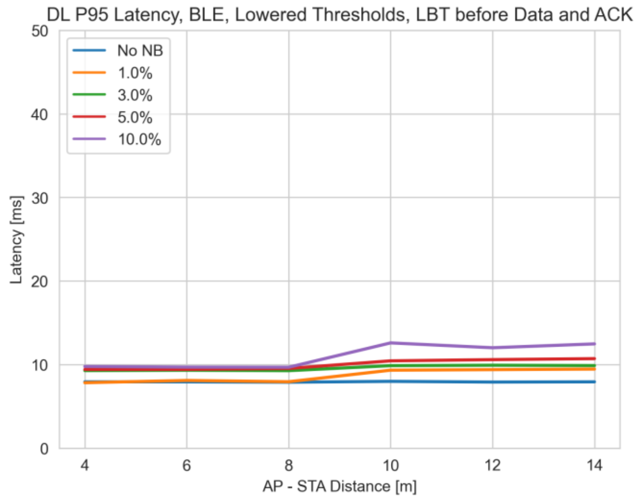
DL Results with MCS=2 (150us IFS), 80 MHz (no LBT vs LBT)



No LBT



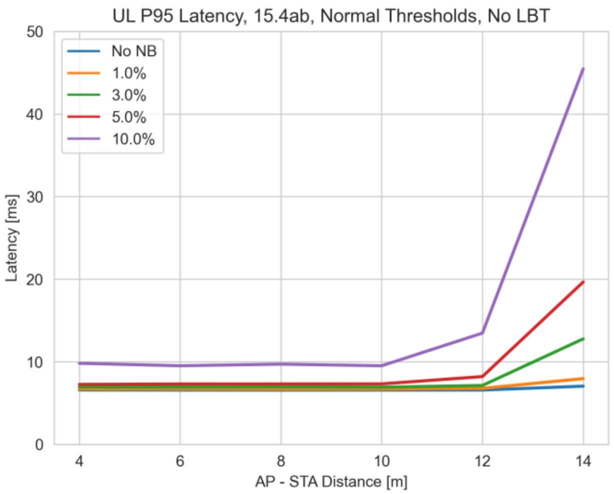
Max ED threshold



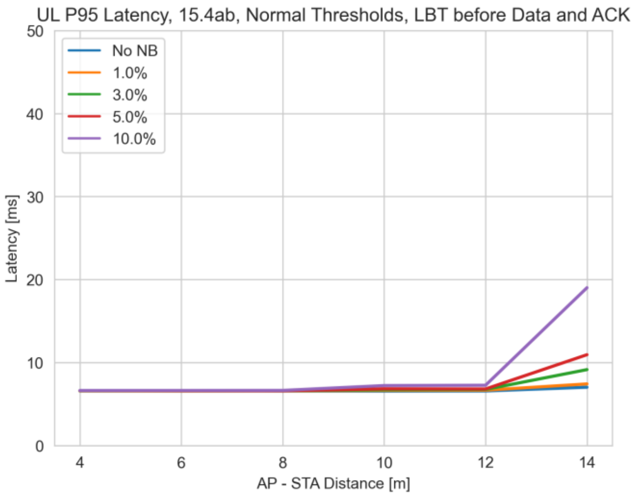
Reduced ED threshold

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

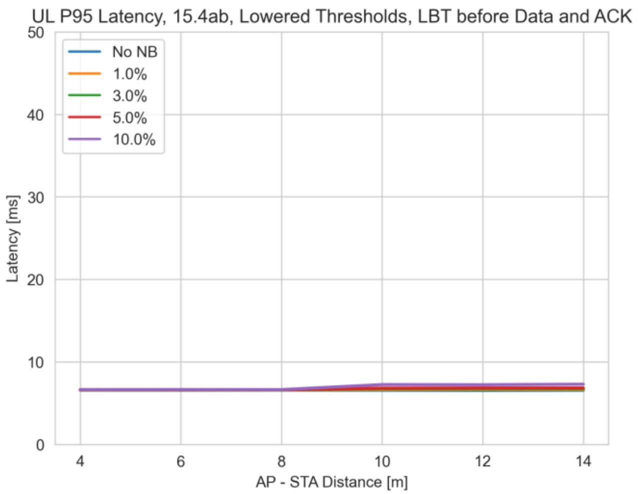
UL Results with MCS=2 (584us IFS), 80 MHz (no LBT vs LBT)



No LBT



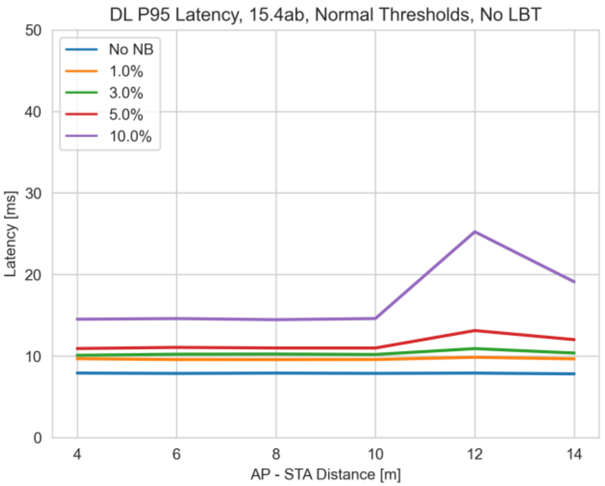
Max ED threshold

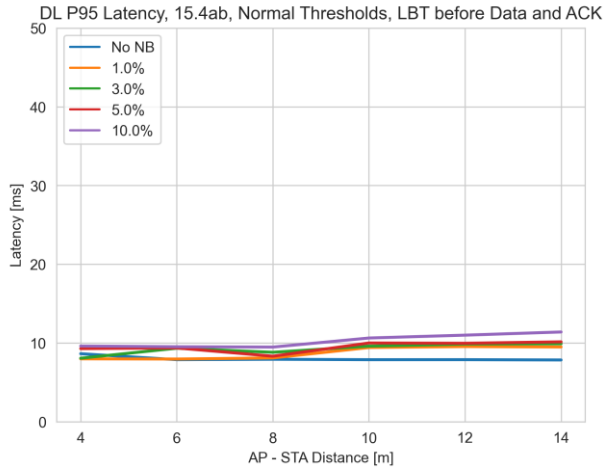


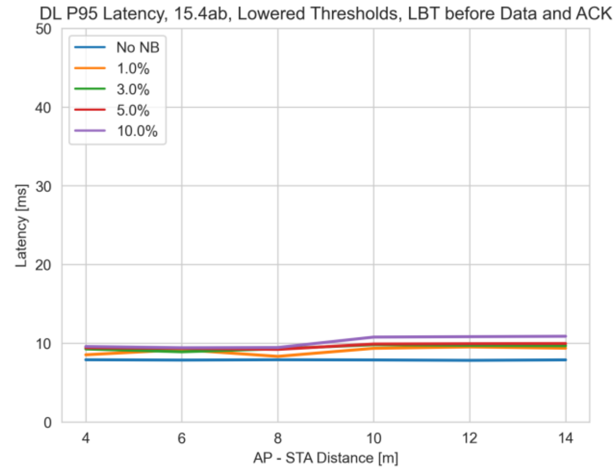
Reduced ED threshold

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

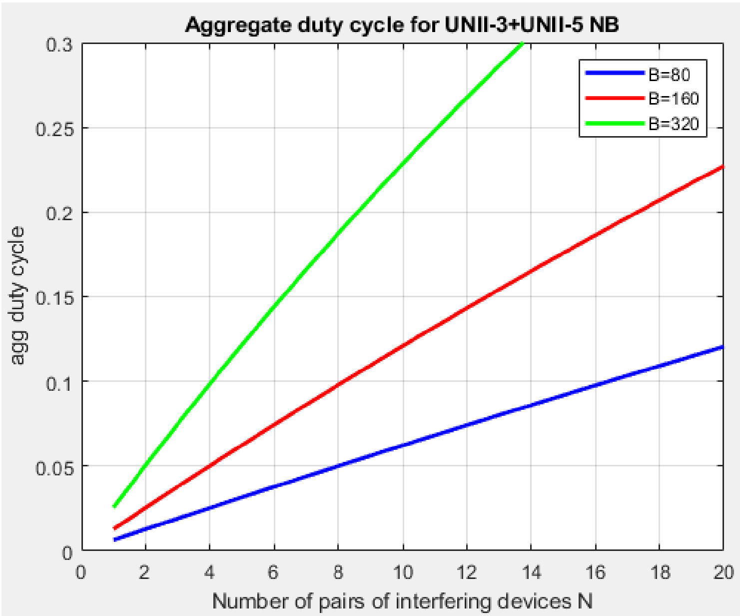
At 12m, AP does not defer to NB P node, since NB power < -62 dBm

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

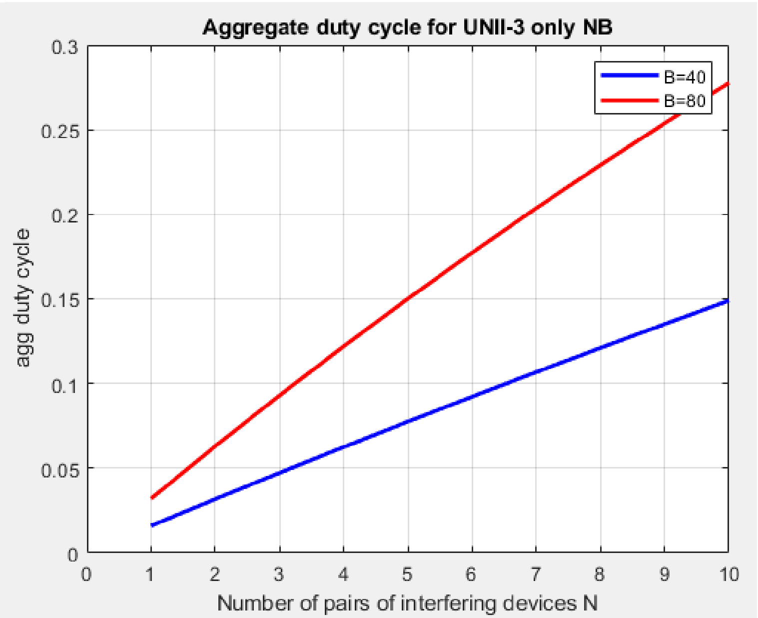
Number of NB Devices and Aggregate Duty cycle

When N pairs of narrowband transmitting UWB devices are freely hopping using total bandwidth of W MHz (no longer confined to be in Pri20 of 802.11, as before), each pair with duty cycle x, the aggregate duty cycle on any B MHz channel is given by $1-(1-x*B/W)^N$

W=625 MHz



W=125 MHz



~10% aggregate duty cycle is reached on a single 320/160/80 MHz 802.11 channel when x=5% duty cycle with 4/8/16 (UNII-3 + UNII-5) NB pairs of interfering devices

~10% aggregate duty cycle is reached on a single 80/40 MHz 802.11 channel when x=5% duty cycle with 3/6 (UNII-3 only) NB pairs of interfering devices

Observations

- For this scenario and the IFS values tested, 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 NB to adopt a mandatory coexistence mechanism to ensure adequate performance for both 802.11 and NB.
- The mandatory coexistence mechanism can consist of a combination of LBT or other techniques.

Appendix

Background

In Europe, Narrowband transmissions with high PSD are allowed in the lower 6 GHz band.

In ETSI BRAN(21) 111033r3, the following VLP requirements for Narrowband (NB) devices were added into the 6GHz item:

1) Mean EIRP density of 10dBm/MHz if 15 hops are used and 1 dBm/MHz if less than 15 hops are used
2) BW restriction <= 20 MHz
3) frequency hopping mechanism

Table 2: Very Low Power (VLP) Category A devices

Parameter	Technical conditions
Permissible operation	Indoors and outdoors Use on drones is prohibited
Category of device	The VLP device is a portable device
Frequency band	5945-6425 MHz
Channel access and occupation rules	An adequate spectrum sharing mechanism shall be implemented.
Maximum mean e.i.r.p. for in-band emissions (note 3)	14 dBm
Maximum mean e.i.r.p. density for in-band emissions (note 3) (note 5)	1 dBm/MHz
Narrow Band Usage maximum mean e.i.r.p. density for in-band emissions (note 3)	10 dBm/MHz (note 4)
Maximum mean e.i.r.p. density for out-of-band emissions below 5935 MHz (note 3)	-45 dBm/MHz

Note 3: The "mean e.i.r.p." refers to the e.i.r.p. during the transmission burst, which corresponds to the highest power, if power control is implemented.

Note 4: Narrow Band (NB) devices are devices that operate in channels bandwidths below 20 MHz. Narrow Band only devices also require a frequency hopping mechanism based on at least 15 hop channels to operate at a PSD value above 1 dBm/MHz.

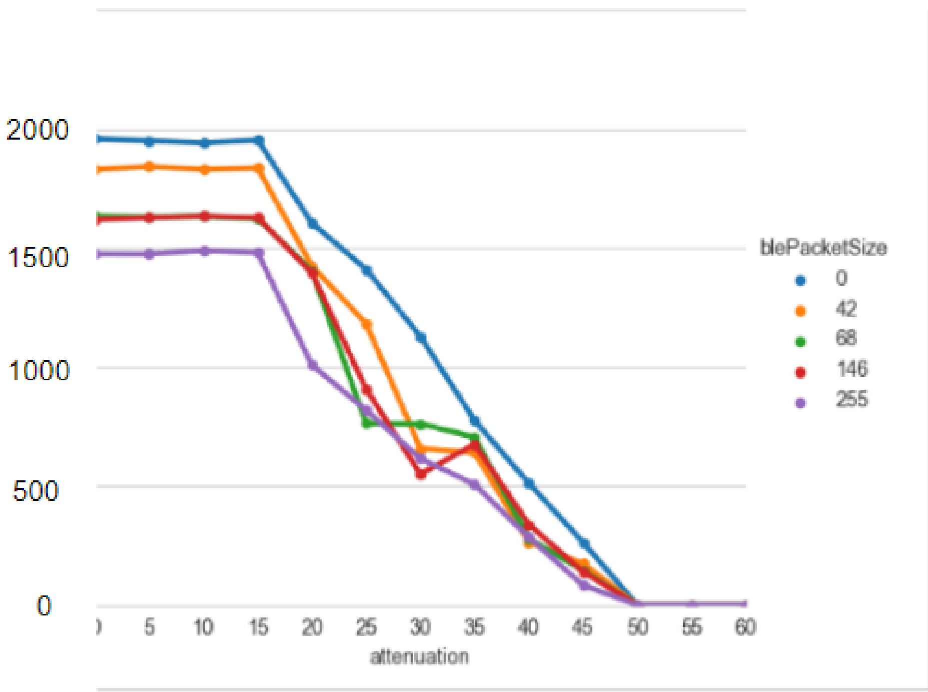
Note 5: This applies to channel sizes of >= 20 MHz, recognising the overall maximum in-band e.i.r.p. always applies.

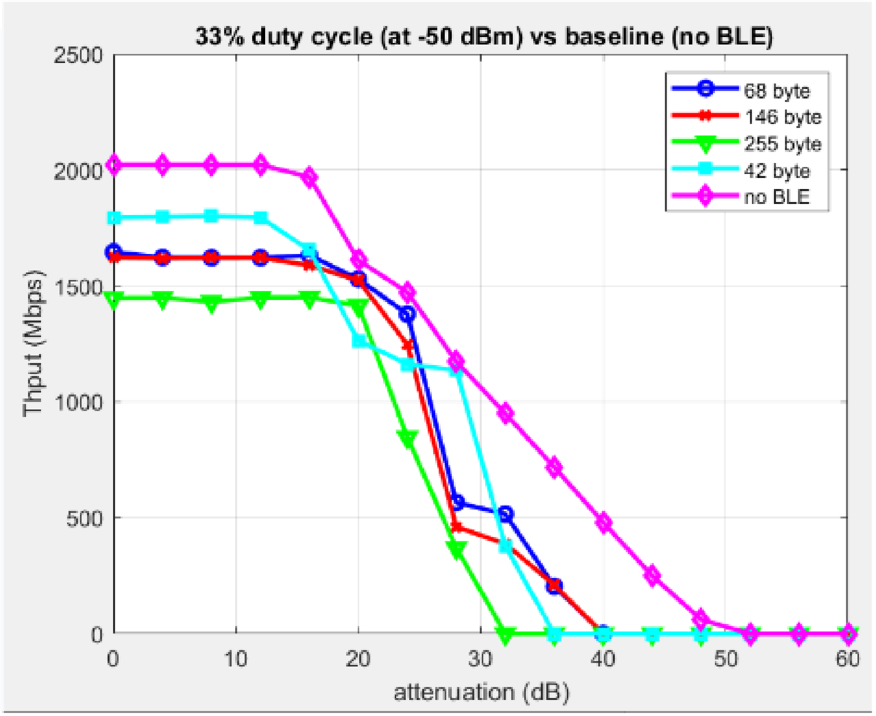
Frequency range (MHz)	Level (dBm)		
	LPI usage	VLP usage	NB Usage
5 925 to 6 425	23	14	14

Frequency range (MHz)	Level (dBm/MHz)		
	LPI usage	VLP usage	NB Usage
5 925 to 6 425	10	1	10 (Note 1)
NOTE : For NB systems with <15 hopping channels the limit shall be 1dBm/MHz			

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

Europe 6 GHz NB vs LPI 802.11 spectrum

NB with 14 dBm EIRP is 6/9/12 dB stronger than LPI (23 dBm) 802.11 with 80/160/320 MHz