# PREDICTIVE WI-FI BEHAVIOR IN NR-U ENVIRONMENTS

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## Description

Wi-Fi operation in unlicensed spectra will require to coexist with NR-U access technology in the 5/6 GHz bands.

While NR-U adopted a number of measures to coexist with 802.11ac/ax nodes, this coexistence may not be optimal. The implementation of a single ED threshold will drive to a more aggressive NR-U behavior towards Wi-Fi.

This solution addresses an adaptive Wi-Fi behavior implemented intended to increase the Wi-Fi air time access to 50% (or other ratios) when in the presence of coexistent NR-U traffic.

## Background

The under development 3GPP NR-U access technology (aiming to the unlicensed 5/6 GHz spectra) has the potential of being more aggressive than LTE LAA when coexisting with 802.11ac/ax systems, particularly due to the addition of the UL channels (PRACh, PUCCH) not supported by LTE LAA, to the unlicensed band.

While working in parallel in 3GPP NR-U to mitigate the impact of the NR-U upon WiFi, the actual solution proposes a proprietary implementation to adapt the behavior of WiFi nodes in order to learn the basic PHY parameters of the coexistent NR-U traffic and increase the WiFi traffic.

## Abstract

A Wi-Fi node detects a neighboring NR-U, based on the power/time signature of the received beams.

An AP could detect the NR-U DL DMRS signature, based on statistical symbol level measurements.

An AP could detect the NR-U DL PDCCh signature, based on statistical symbol level measurements.

A Wi-Fi node could adapt to this environment by not scheduling any transmissions during the detected Rx beam time durations, PDCCh and DMRS symbols (not harming the NR-U operation).

A Wi-Fi node could behave aggressively and block the NR SSB service by providing a suitable transmission pattern, starting with at least 9us before the detected beam pulses.

The AP builds the predictive TDD DL signature.

The AP schedules traffic outside the predictive TDD DL Signature for a duration of 7 symbols (every slot) in order to achieve 50% air time access.

Alternatively, a WiFi AP node could schedule traffic in aggressive way exceeding 50% of the air time.

# Adaptive Wi-Fi Operation in NR-U Environments

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**CableLabs**

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# The Challenge

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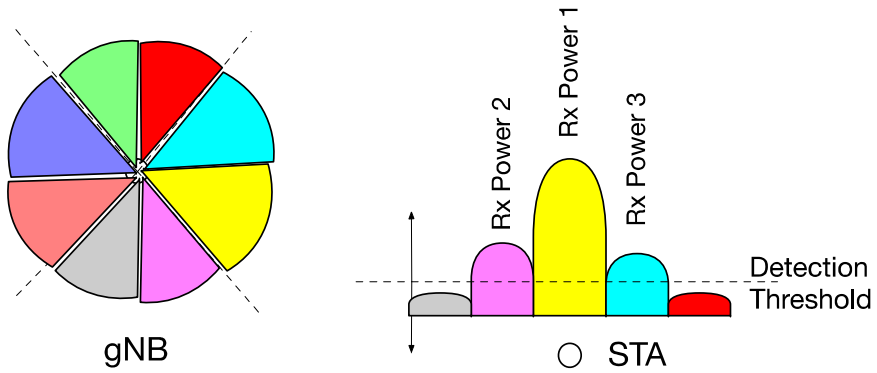
Wi-Fi operation in unlicensed spectra will require to coexist with NR-U access technology in the 5/6 GHz bands.

While NR-U adopted a number of measures to coexist with 802.11ac/ax nodes, this coexistence may not be optimal. The implementation of a single ED threshold will drive to a more aggressive NR-U behavior towards Wi-Fi.

This presentation addresses an adaptive Wi-Fi behavior implemented intended to increase the Wi-Fi air time access to 50% (or other ratios) when in the presence of coexistent Wi-Fi traffic.

# The RF Power Signature of a gNB

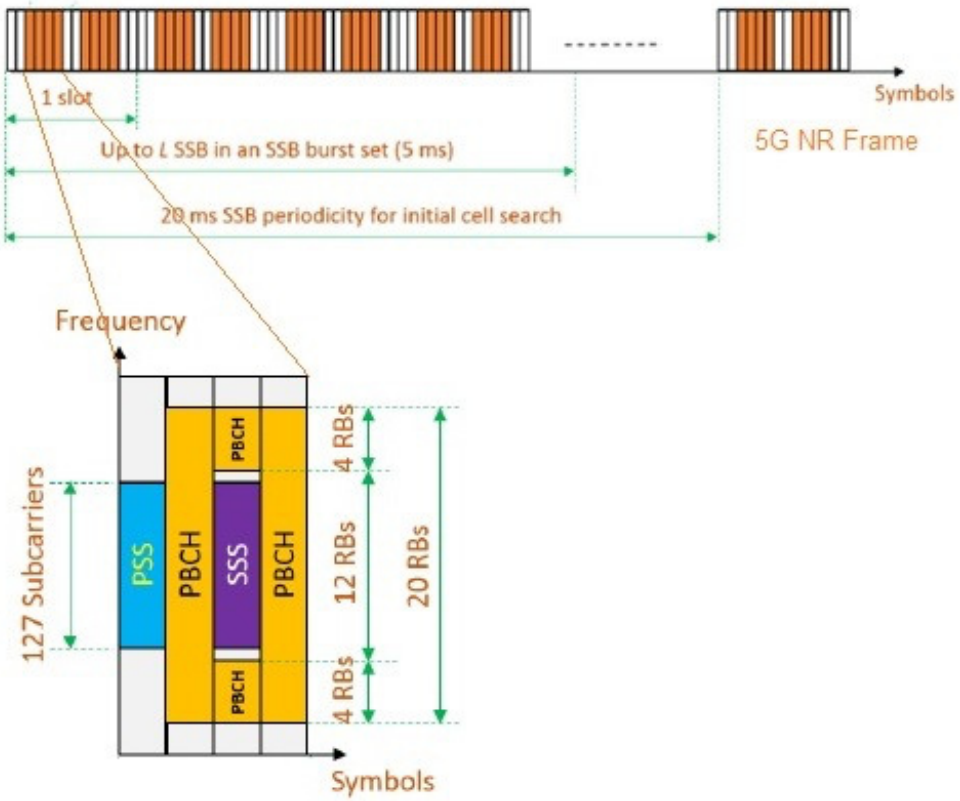



- An gNB NR-U (sub 7 GHz) will transmit usually 8 beams (360 deg coverage), each one of the them acting as a individual cell.
- A Wi-Fi node operating in the proximity of such a gNB, could decode (dependent on the path losses related to the gNB), if enabled to do so, the RF Rx Energy related to 1, 3 or 5 beams.
- The Rf Rx power of these beams is received at different timings and not simultaneously.
- This power/timing arrangement of the Rx Rf energy represents the Rf foot print of a gNB, operating in sub 7 GHz spectra.

Challenges:

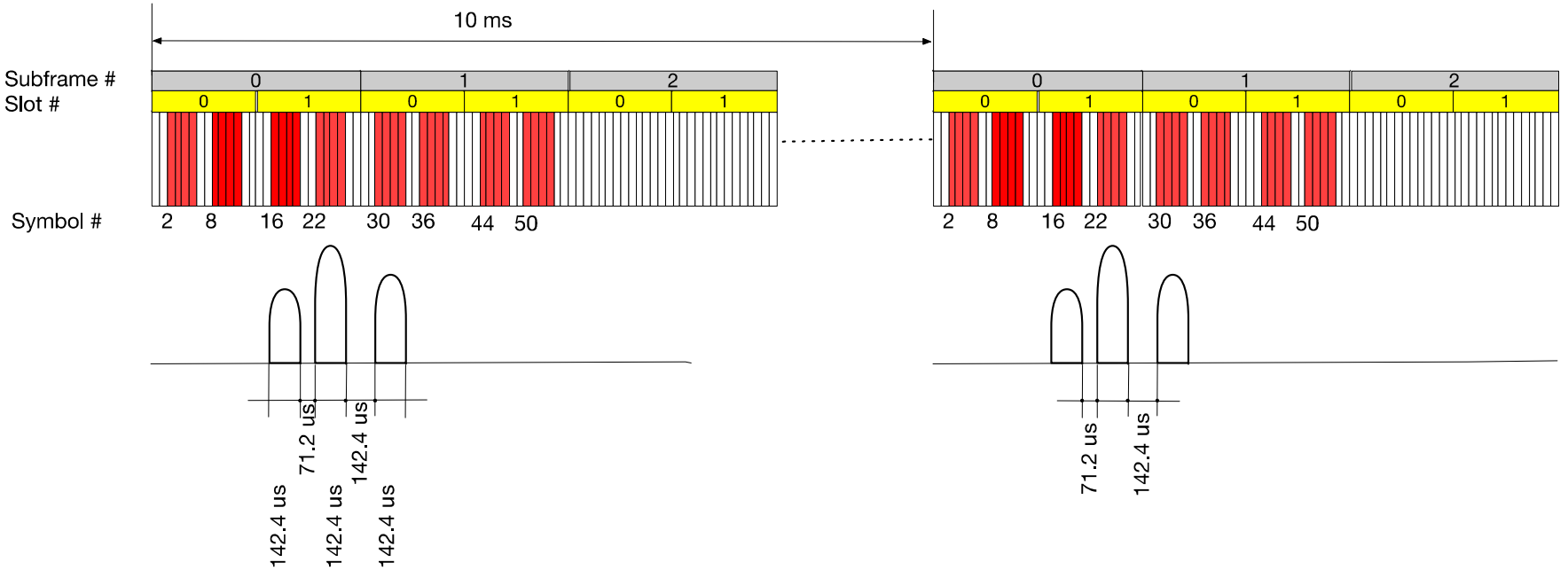
- The SSB channel/signal is not transmitted as a standalone signal but as part of the overall NR waveform.
- A Wi-Fi AP can't execute selective in-band power measurements. The only way to identify their position is by processing the traffic foot print of the SSB.

# The SSB time/power structure




- gNB transmits 8 beams (360 deg coverage) each one of them having their own synchronization and beam/cell broadcast information (Synchronization Signal Block – SSB)
- Symbols position: [(2:5)+14k, (8:11+14k], k=1:4
- SSB sequence repetition rate: 20ms

# SSB Time/Power Signature



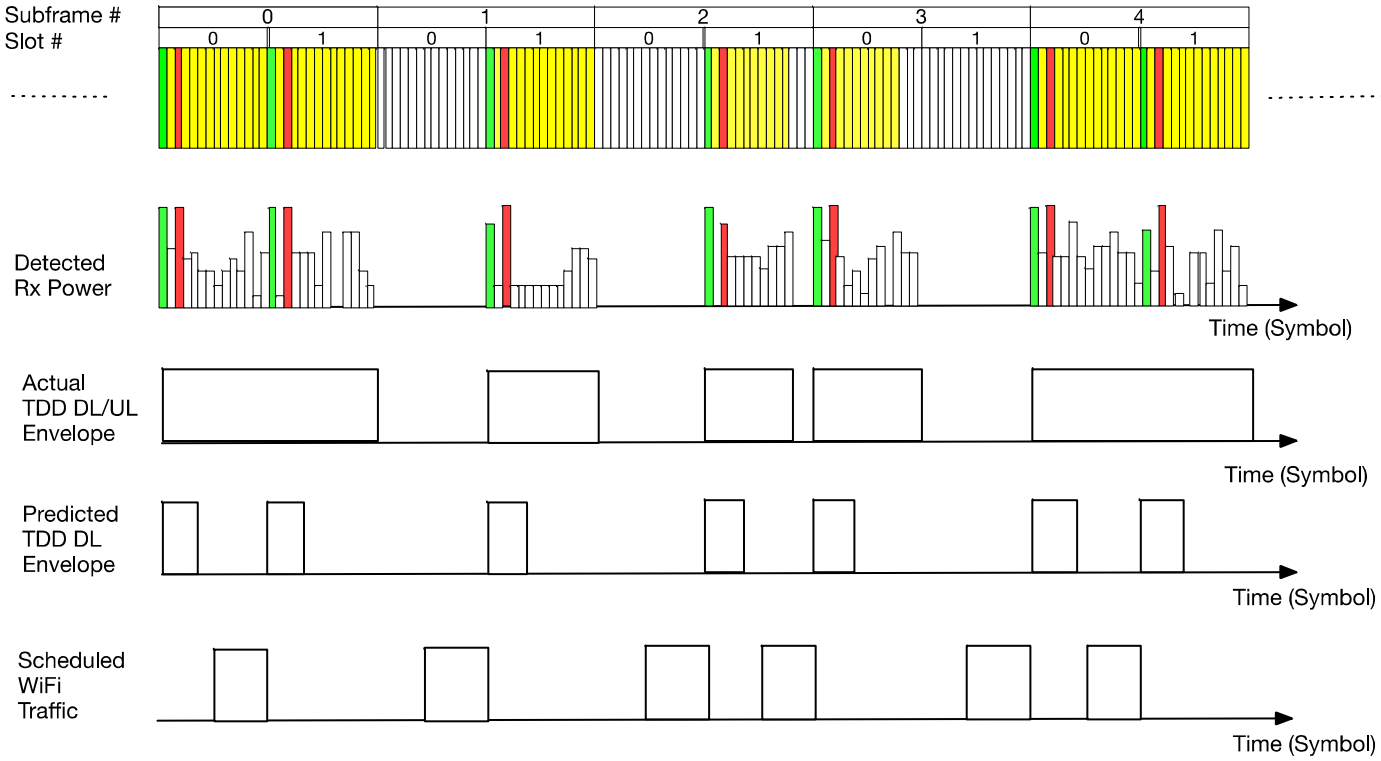

- The WiFi Node (positioned in a NR-U populated environment switches for 100ms (10 NR frames) to measurement mode.
- It executes Clear Channel Assessment (CCA) procedures with a cadence of 9us.
- It may detect a sequence of 1, 3* pulses for a total duration of 142us, 640 us with a repetition rate of 10ms. Due to the NR-U/WiFi coexistence, the measurements are statistical (some SSB may not be received).
- If this pattern is detected, the WiFi node decides that operates in the vicinity of a NR node.





* 5 pulses may be detected but it complicates the detection algorithm

# Scheduled Wi-Fi Traffic




- The AP switches to silent/measurement mode
- It sends NAV messages to silence the attached STAs
- AP executes statistical measurements (peak power hold
- The PDCCh and DMRS sequences will be received with a higher level (the PDSCh symbols), being repetitive with a known cadence
- The AP assumes that the TDD DL lasts at least 2 more symbols (mini slot transmission), the DMRS sequence.
- The AP will schedule traffic outside the predicted TDD DL envelope, for 7 symbols, ending on the next PDCCH Symbol.
- If the NR-U TDD DL transmissions are scheduled with based on a slot step, the estimated Wi-Fi air time access Should be 50%.

- By detecting statistically the position of the NR-U DL PDCCh and DMRS symbols, the AP could schedule Wi-Fi traffic to provide target air interface access (e.g. 50%).
- This type of adaptive behavior corrects the sub-optimal WiFi air time access probability triggered by using an unique ED threshold.

# Repetitive NR Signals/Channels Time Signature. Principles

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<u>The SSB time/power signature (sub 7 GHz bands):</u>

- Spread across contiguous sequences of 4 symbols (2:5, 8:11, 16:19, 22:25, 30:33, 44:47, 50:53) repeated every frame (10ms).
- For NR-U 5/6 GHz, the preferred Single Carrier Spacing scheme is 30 or 60 KHz. We analyze the 30 kHz case.
  - The total number of subframe/slots per frame is 10/20,
  - Symbol duration: 35.6us,
  - Total number of symbols per frame: 280
  - Symbols 2, 16, 22, 30, 44 carries the NR pilot sequence (DMRS)
- In order to avoid the DMRS traffic impact, we try to identify the persistent power levels (guaranteed min power level) only on symbols 3:5, 9:11, 17:19, 23:25, 31:33, 45:47, 51:53
- In a low/mid traffic NR-U cell, there are no repetitive power/traffic patterns on all subframe symbol excluding:
  - A={3:5, 9:11, 17:19, 23:25, 31:33, 45:47, 51:53} *% these time positions identify the 8 SSB symbols, groups (except the 1st SSB symbol).*

<u>The PDCCH/DMRS time/power signature</u>

- B={0+14k} where k=1:8 (SCS=30 kHz) *% these time positions identify the 1st PDCCh symbol per slot*
- C={2+14k} where k=1:8 (SCS=30 kHz) *% these time positions identify the 1st DMRS symbol per slot*

- PDCCH and DMRS are transmitted repetitively with a constant power
  - The DMRS sequence is transmitted across the entire BW of the signal. The DMRS sequence structure may span across a few symbols across the slot, but it will always be present on symbol 2.
  - PDCCh may occupy up to the first two symbols of the slot, the PDCCh presence over the 1st symbol of the slot being guaranteed

The repetitive CCA measurements (all other STAs are muted*) target successive intervals of 999us (111 rows matrix)

- (1 subframe=1ms. 1 CCA=9us)





* Multiple coexistent WiFi networks case is not addressed here

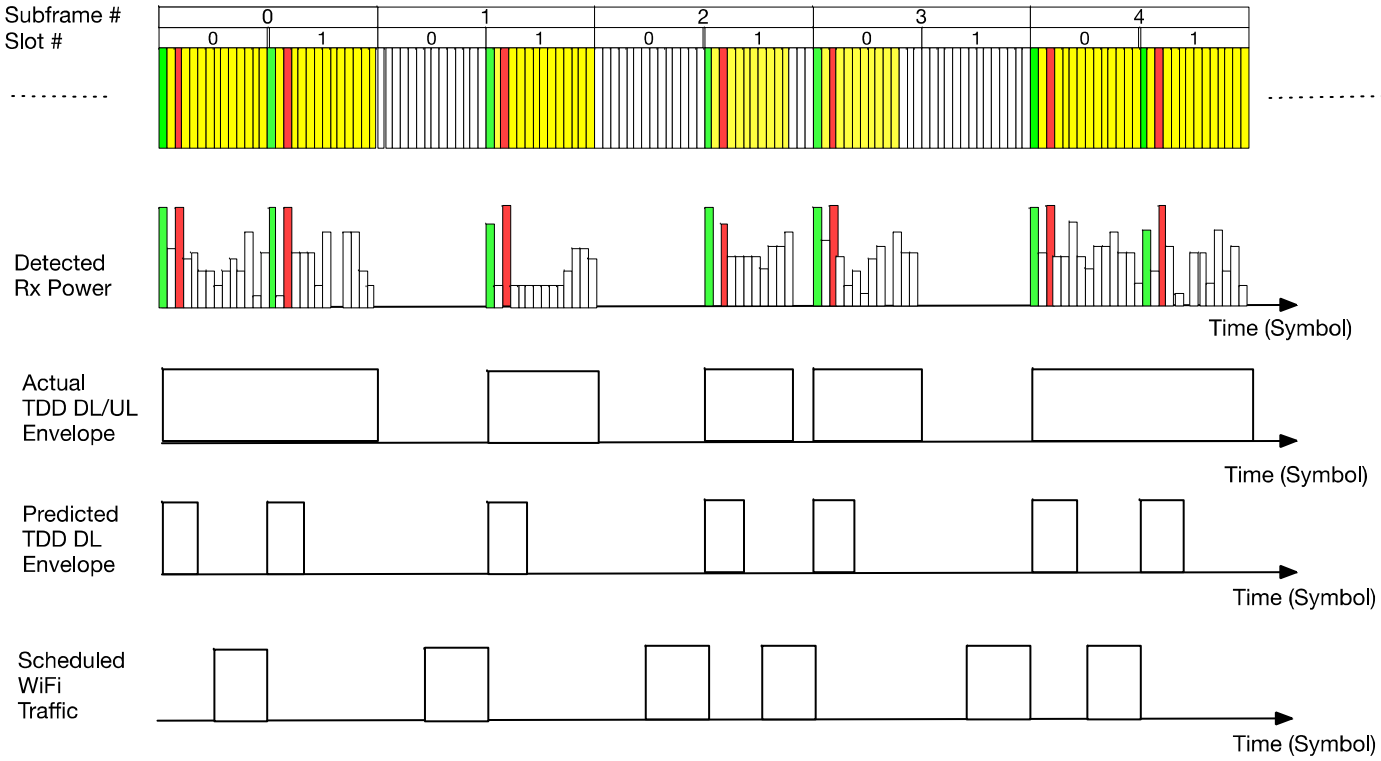
# Predictive Traffic Data Pattern. Example

Assumptions:

- DMRS: +3dB (vs. PDSCh), only on sym 2, 16, fixed signal sequence, full BW-->lowest Standard Deviation, highest Rx Power
- PDCCH: only on symbols 0, 14, variable control data, full BW, two symbols ahead of DRMS (-71.6 us)
- SBS: 8 beams, repetition rate: 20ms, min Rx power correspondent to 240 subcarriers; smaller Standard Deviation than user data (PDSCh)
- User Data (PDSCh) symbols: largest Standard Deviation
- Subframe start symbol already detected;
- Flat fading
- The WiFi chipset could alter the CCA duration down from 9us to 8.68us, in order to emulate the the timing duration of 1 NR-U symbol- 35.68 us

| Row (Symbol) Number | Subframe Number | | | | | | | | | | Average Power | Min Power | Standard Deviation | STDEV<1.2 | 'DMRS: AveragePower>-60 | PDCCh: AND(STDEV<1.0,AveragePower<-60) | MIN Power>-72 | SBS: AND(P4=TRUE,R4=True) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | | | | | | | | |
| 0 | -65.679 | -65.816 | -66.526 | -66.537 | -67.542 | -67.571 | -66.252 | -65.357 | -66.237 | -65.133 | -66.265 | -67.571 | 0.836 | TRUE | FALSE | TRUE | TRUE | FALSE |
| 1 | -81.139 | -88.063 | -95.210 | -75.717 | -94.815 | -78.974 | -92.740 | -87.805 | -82.926 | -96.991 | -83.252 | -99.238 | 7.721 | FALSE | FALSE | FALSE | FALSE | FALSE |
| 2 | -58.087 | -58.868 | -59.491 | -58.871 | -58.708 | -57.846 | -59.001 | -59.311 | -59.461 | -58.858 | -58.850 | -59.491 | 0.523 | TRUE | TRUE | FALSE | TRUE | TRUE |
| 3 | -67.128 | -71.357 | -71.569 | -71.645 | -67.054 | -71.641 | -66.723 | -67.271 | -71.521 | -66.299 | -69.221 | -71.645 | 2.338 | FALSE | FALSE | FALSE | TRUE | TRUE |
| 4 | -70.936 | -66.284 | -69.182 | -69.697 | -70.027 | -71.456 | -66.389 | -67.515 | -66.419 | -67.600 | -68.550 | -71.456 | 1.956 | FALSE | FALSE | FALSE | TRUE | TRUE |
| 5 | -66.095 | -67.048 | -71.082 | -69.747 | -66.841 | -71.670 | -71.302 | -71.416 | -70.894 | -71.502 | -69.760 | -71.670 | 2.078 | FALSE | FALSE | FALSE | TRUE | TRUE |
| 6 | -79.027 | -79.020 | -77.774 | -99.804 | -79.529 | -93.433 | -96.665 | -90.119 | -91.936 | -87.960 | -87.527 | -99.804 | 8.187 | FALSE | FALSE | FALSE | FALSE | FALSE |
| 7 | -93.611 | -79.340 | -96.549 | -95.197 | -83.084 | -92.595 | -98.848 | -77.344 | -95.969 | -99.923 | -91.246 | -99.923 | 7.846 | FALSE | FALSE | FALSE | FALSE | FALSE |
| 8 | -69.718 | -67.565 | -67.556 | -68.091 | -70.482 | -69.060 | -67.686 | -66.451 | -70.428 | -71.599 | -66.931 | -70.303 | 1.660 | FALSE | FALSE | FALSE | TRUE | TRUE |
| 9 | -70.326 | -71.644 | -71.950 | -68.839 | -71.263 | -69.781 | -71.965 | -71.677 | -67.822 | -69.903 | -71.592 | -69.870 | 1.346 | FALSE | FALSE | FALSE | TRUE | TRUE |
| 10 | -68.109 | -68.935 | -66.411 | -70.113 | -67.183 | -71.099 | -66.428 | -67.755 | -70.001 | -69.181 | -67.756 | -66.129 | 1.619 | FALSE | FALSE | FALSE | TRUE | TRUE |
| 11 | -66.886 | -71.611 | -67.259 | -71.701 | -70.133 | -69.855 | -69.174 | -66.276 | -69.269 | -70.886 | -69.020 | -67.797 | 1.806 | FALSE | FALSE | FALSE | TRUE | TRUE |
| 12 | -96.993 | -95.587 | -79.811 | -79.594 | -83.402 | -98.553 | -75.388 | -94.135 | -99.412 | -95.977 | -89.885 | -99.412 | 8.774 | FALSE | FALSE | FALSE | FALSE | FALSE |
| 13 | -81.190 | -86.722 | -77.532 | -83.062 | -99.264 | -76.460 | -88.562 | -96.618 | -77.031 | -79.040 | -84.548 | -99.264 | 8.510 | FALSE | FALSE | FALSE | FALSE | FALSE |
| 14 | -66.081 | -67.274 | -65.586 | -67.861 | -65.649 | -65.017 | -65.214 | -66.360 | -66.363 | -67.247 | -66.729 | -66.831 | 0.881 | TRUE | FALSE | TRUE | TRUE | FALSE |
| 15 | -94.182 | -95.821 | -95.221 | -96.456 | -82.392 | -78.533 | -88.563 | -90.317 | -85.874 | -76.593 | -88.395 | -96.456 | 7.022 | FALSE | FALSE | FALSE | FALSE | FALSE |
| 16 | -59.616 | -57.813 | -57.655 | -57.663 | -58.794 | -58.491 | -59.767 | -58.521 | -57.873 | -57.319 | -59.088 | -58.005 | 0.800 | TRUE | TRUE | FALSE | TRUE | TRUE |
| 17 | -66.747 | -71.637 | -68.763 | -67.764 | -69.367 | -69.768 | -68.247 | -68.317 | -69.203 | -70.050 | -71.352 | -71.783 | 1.587 | FALSE | FALSE | FALSE | TRUE | TRUE |
| 18 | -70.409 | -67.719 | -69.509 | -66.235 | -71.782 | -71.654 | -70.158 | -71.480 | -68.330 | -71.129 | -69.936 | -70.224 | 1.702 | FALSE | FALSE | FALSE | TRUE | TRUE |
| 19 | -69.355 | -70.807 | -70.661 | -71.037 | -70.513 | -71.021 | -66.437 | -69.247 | -68.817 | -69.802 | -68.173 | -68.590 | 1.393 | FALSE | FALSE | FALSE | TRUE | TRUE |
| 20 | -69.114 | -83.342 | -89.307 | -87.495 | -91.796 | -81.199 | -87.700 | -90.140 | -82.660 | -86.335 | -84.909 | -91.796 | 6.215 | FALSE | FALSE | FALSE | FALSE | FALSE |
| 21 | -76.968 | -76.868 | -82.831 | -92.960 | -92.990 | -79.815 | -94.347 | -88.331 | -85.221 | -80.654 | -85.098 | -94.347 | 6.641 | FALSE | FALSE | FALSE | FALSE | FALSE |
| 22 | -70.937 | -67.873 | -68.054 | -67.809 | -66.012 | -69.803 | -66.095 | -66.801 | -69.161 | -67.413 | -69.856 | -68.427 | 1.533 | FALSE | FALSE | FALSE | TRUE | TRUE |
| 23 | -66.729 | -71.214 | -70.558 | -67.931 | -68.091 | -68.955 | -66.861 | -70.619 | -66.890 | -67.819 | -69.084 | -71.437 | 1.737 | FALSE | FALSE | FALSE | TRUE | TRUE |
| 24 | -68.755 | -68.031 | -70.616 | -71.802 | -71.515 | -68.629 | -66.570 | -69.195 | -66.093 | -68.394 | -69.496 | -68.628 | 1.734 | FALSE | FALSE | FALSE | TRUE | TRUE |
| 25 | -68.652 | -67.416 | -66.076 | -71.081 | -67.842 | -67.981 | -71.023 | -66.848 | -71.187 | -71.575 | -70.284 | -71.377 | 2.009 | FALSE | FALSE | FALSE | TRUE | TRUE |
| 26 | -79.472 | -94.887 | -88.684 | -91.840 | -82.911 | -97.985 | -76.784 | -75.111 | -84.422 | -87.078 | -85.917 | -97.985 | 7.726 | FALSE | FALSE | FALSE | FALSE | FALSE |
| 27 | -81.791 | -89.890 | -81.591 | -90.832 | -93.553 | -96.546 | -78.765 | -84.477 | -82.380 | -79.212 | -85.904 | -96.546 | 6.477 | FALSE | FALSE | FALSE | FALSE | FALSE |

# Scheduled Wi-Fi Traffic




- The AP switches to silent/measurement mode
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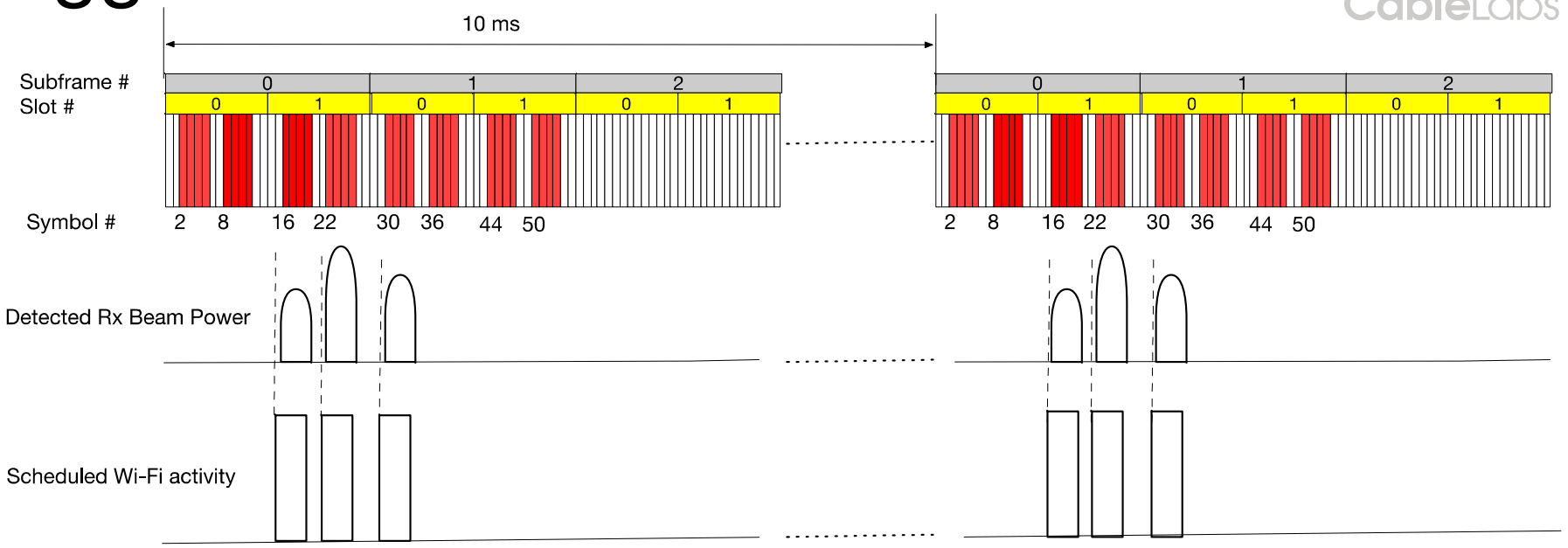
- AP executes statistical measurements (peak power hold
- The PDCCh and DMRS sequences will be received with a higher level (the PDSCh symbols), being repetitive with a known cadence
- The AP assumes that the TDD DL lasts at least 2 more symbols (mini slot transmission), the DMRS sequence.
- The AP will schedule traffic outside the predicted TDD DL envelope, for 7 symbols, ending on the next PDCCH Symbol.
- If the NR-U TDD DL transmissions are scheduled with based on a slot step, the estimated Wi-Fi air time access Should be 50%.

- By detecting statistically the position of the NR-U DL PDCCh and DMRS symbols, the AP could schedule Wi-Fi traffic to provide target air interface access (e.g. 50%).
- This type of adaptive behavior corrects the sub-optimal WiFi air time access probability triggered by using an unique ED threshold.

# Aggressive Behavior



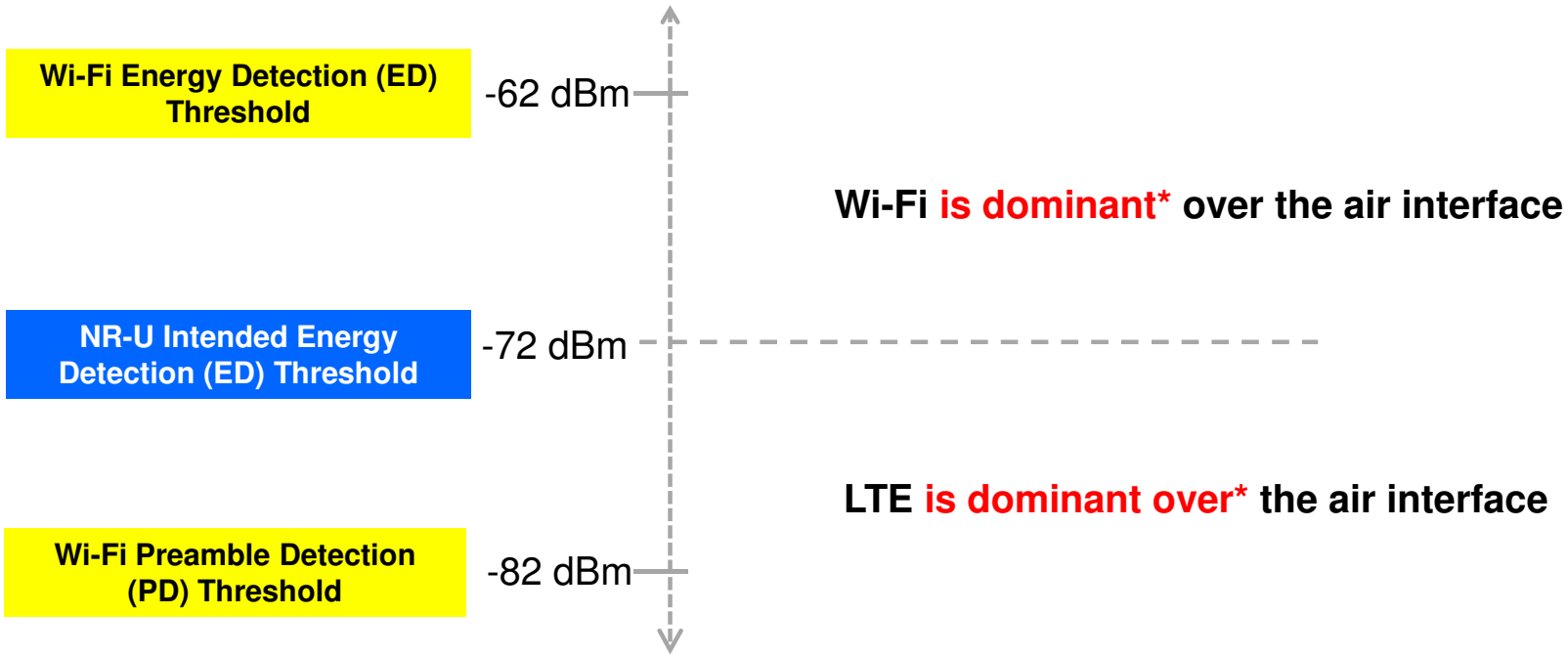

- Once the Wi-Fi node (either STA/AP) decided that operates in a NR-U environment, it will schedule transmissions with a duration of min 142us, starting with at least 9us before the detected Rx beam pulse.
- This behavior, if scheduled on a repetitive basis, knocks-off the gNB capability (no more synchronization provided) for the target coverage area.
  - The NR-U gNB executes a short LBT (LBT2) before transmitting the SSB sequence

# Claims

1. A Wi-Fi node detects a neighboring NR-U, based on the power/time signature of the received beams.
2. An AP could detect the NR-U DL DMRS signature, based on statistical symbol level measurements.
3. An AP could detect the NR-U DL PDCCh signature, based on statistical symbol level measurements.
4. A Wi-Fi node could adapt to this environment by not scheduling any transmissions during the detected Rx beam time durations, PDCCh and DMRS symbols (not harming the NR-U operation).
5. A Wi-Fi node could behave aggressively and block the NR SSB service by providing a suitable transmission pattern, starting with at least 9us before the detected beam pulses.
6. The AP builds the predictive TDD DL signature.
7. The AP schedules traffic outside the predictive TDD DL Signature for a duration of 7 symbols (every slot) in order to achieve 50% air time access.
8. Alternatively, a WiFi AP node could schedule traffic in aggressive way exceeding 50% of the air time.

# Appendix

# Unique ED Threshold



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