ns-3 Recap : Open Source Wireless Network Simulator

- **National Science Foundation** (NSF) – original funding for ns-3 core simulator design and implementation (2006-15)

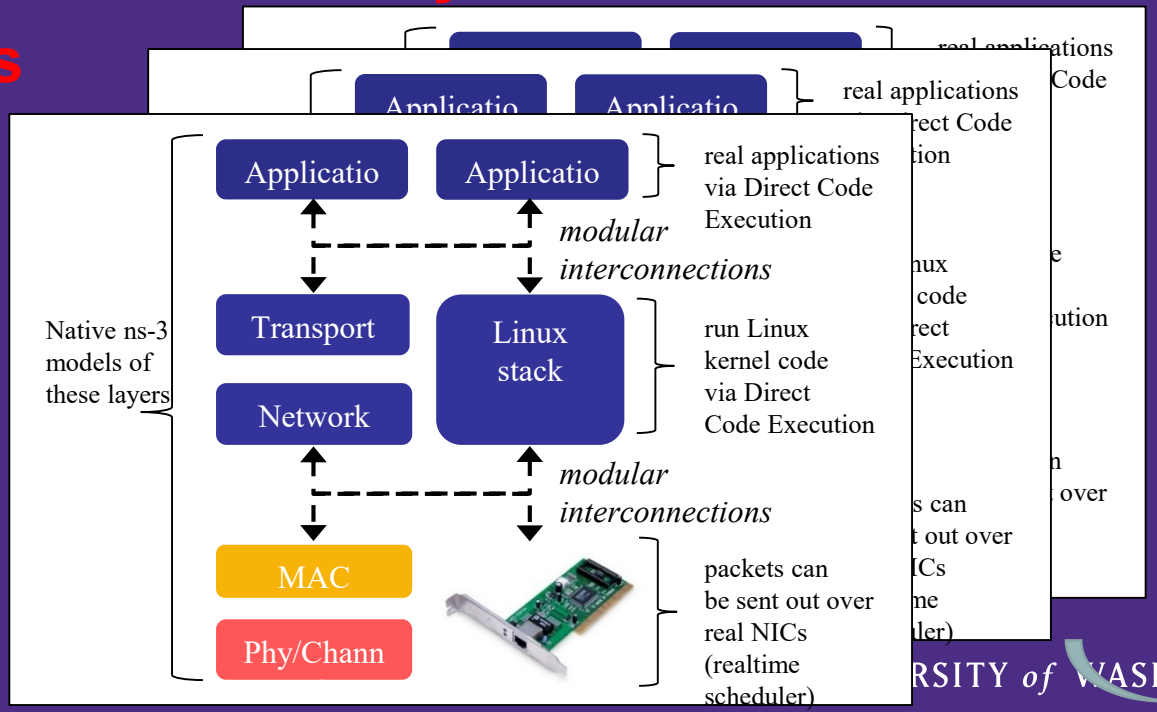
INDUSTRY/LABS SUPPORT

- **WiFi Alliance: LAA/WiFi Coexistence (2015)**
- **NIST: Public Safety Extensions to LTE (2017-19)**
- **Cisco, Intel 802.11ax MAC (2018-19)**

What is ns-3?

- Software environment as models of computer networks for performance evaluation studies
- Open source (GPLv2 license), **packet-level network simulator** featuring a **high-performance core** enabling **parallelization across a cluster**, **ability to run real code**, and **interact with testbeds**

A single simulation instance can run on a workstation or laptop



Alternatively, scenarios can be parallelized across a cluster

ICE-T Project: Performance Evaluation of Advanced Wireless Networks

Towards 5G NR-U/11ax Coexistence in ns-3

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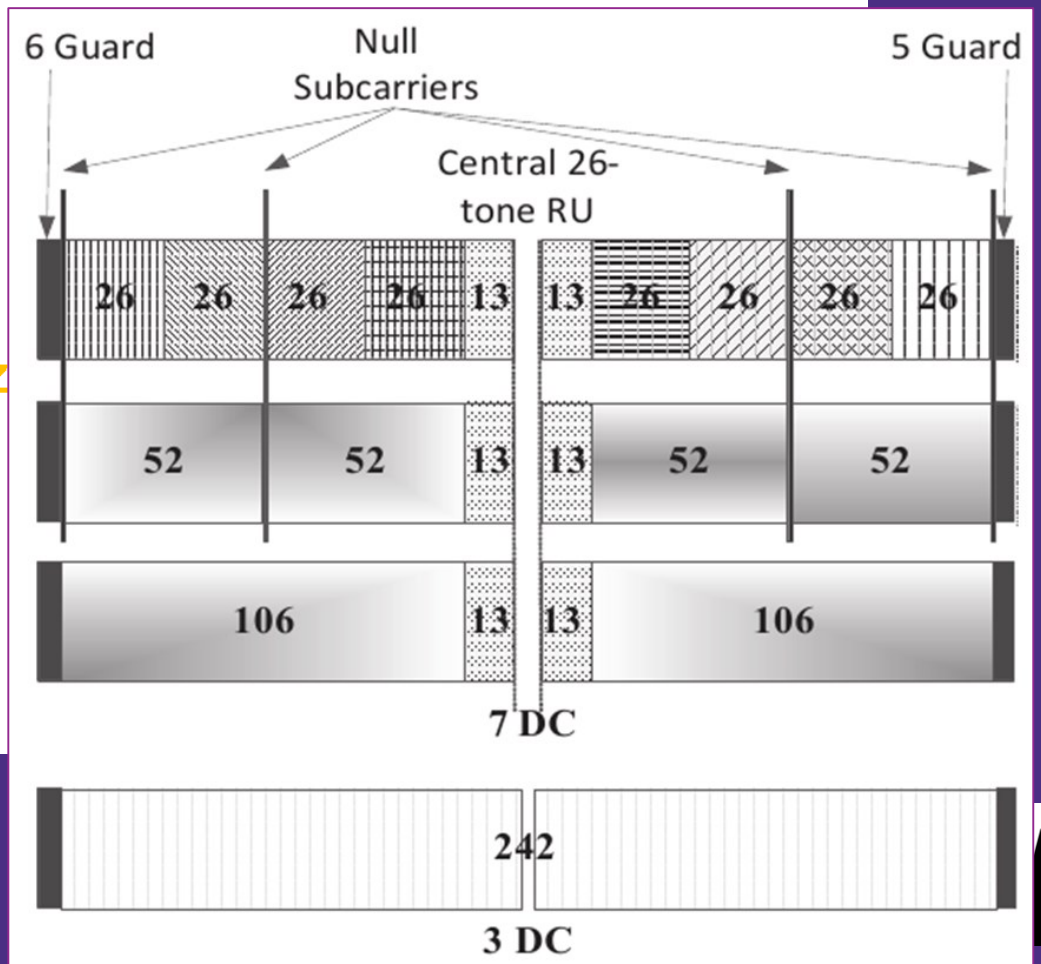
11ax PHY/MAC support in ns-3

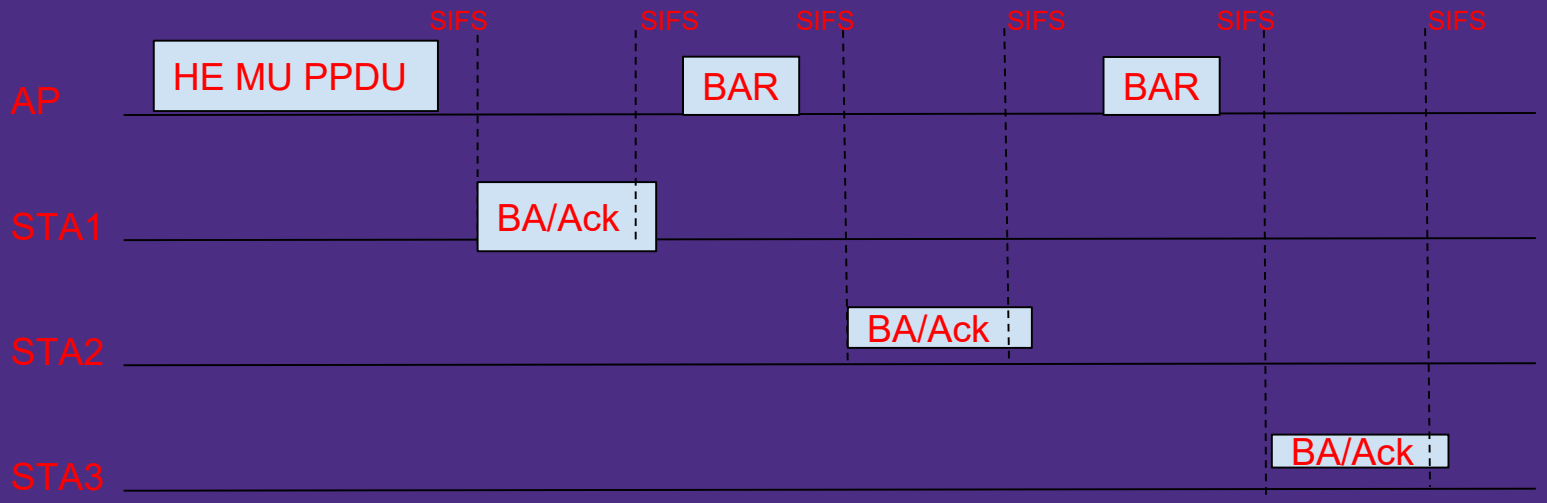
- **11ax OFDMA**
  - MAC: current status and next steps
  - PHY: current status and next steps
- **11ax OBSS-PD based spatial reuse**

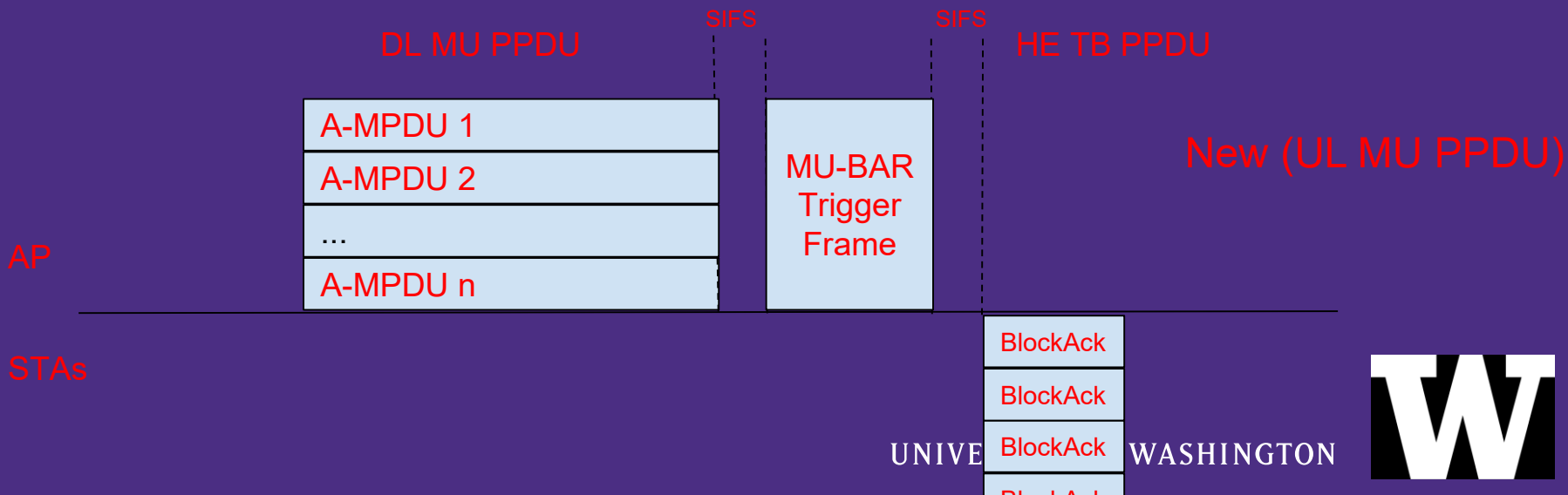
11ax OFDMA

- OFDM subcarriers can be grouped into sets of predefined size named **Resource Units** (RUs)
  - 26-tone RU (≅2 MHz)
  - 52-tone RU (≅4 MHz)
  - 106-tone RU (≅8 MHz)
  - 242-tone RU (≅20 MHz)
  - 484-tone RU (≅40 MHz)
  - 996-tone RU (≅80 MHz)
  - 2x996-tone RU (≅160 MHz

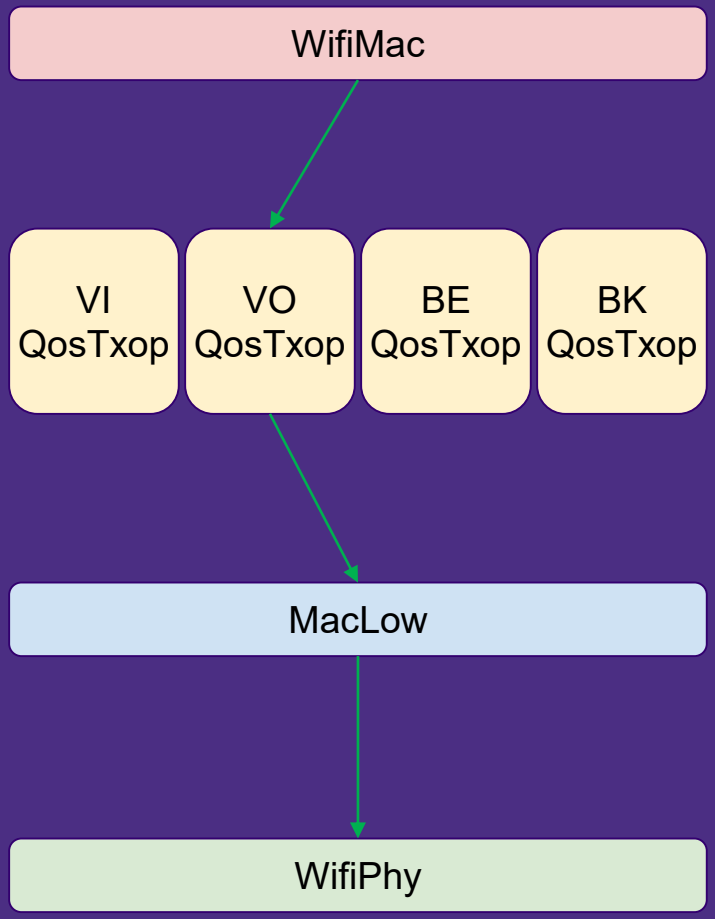


Block ACKs for DL MU PPDUs





ns-3 Current Wi-Fi stack

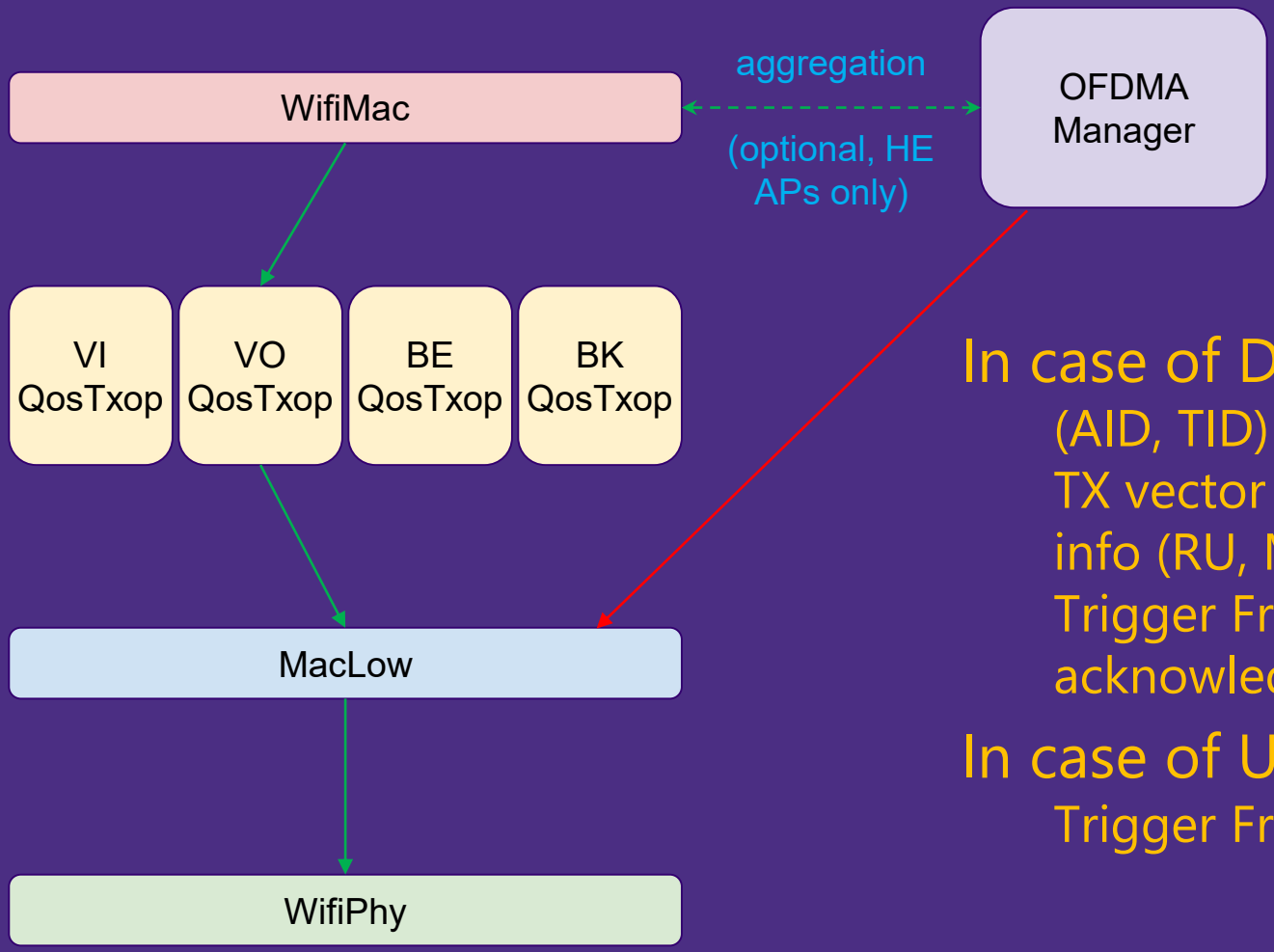


WifiMac enqueues MSDUs into EDCA queues

QosTxop selects the frame to be (re-)transmitted

MacLow performs aggregation and passes the resulting frame to the PHY layer

(New) Multi-user support in ns-3



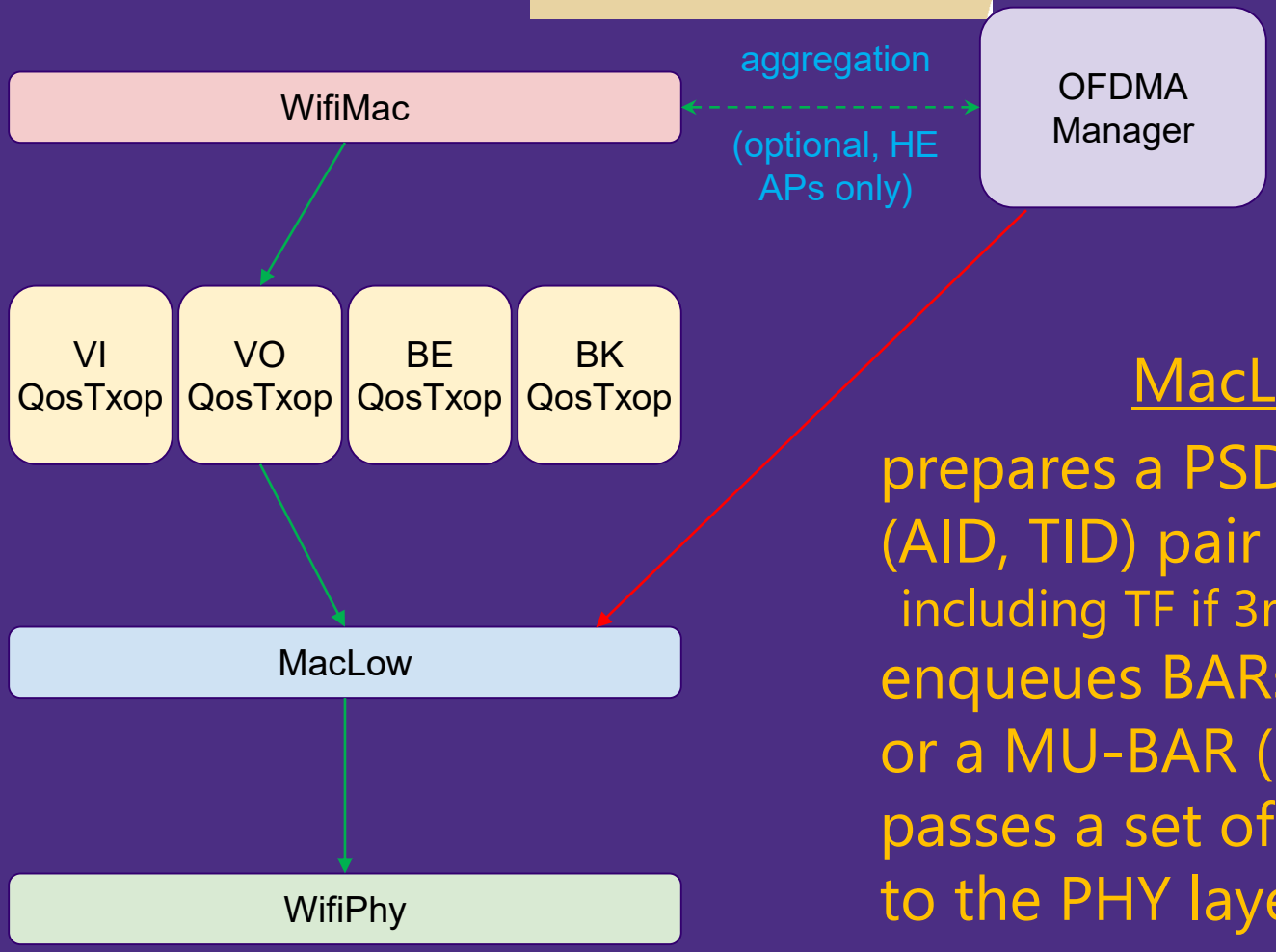
In case of DL OFDMA

- (AID, TID) pair for each receiver
- TX vector including per station info (RU, MCS, NSS)
- Trigger Frame payload (for MU acknowledgment only)

In case of UL OFDMA

- Trigger Frame payload

Multi-User support in ns-3



MacLow

prepares a PSDU for each (AID, TID) pair

including TF if 3rd ack seq

enqueues BARs (1st ack seq) or a MU-BAR (2nd ack seq)

passes a set of PSDUs down to the PHY layer

ns-3 support

Completed

- DL OFDMA with all ack sequences
  - Block Acks are not sent as UL MU
- UL OFDMA with Multi-STA Block Ack
- MU-RTS Trigger Frame

Next steps

- UORA (UL OFDMA-based Random Access

ns- 3 PHY changes for OFDMA

Current ns-3 implementation is not designed for OFDMA:

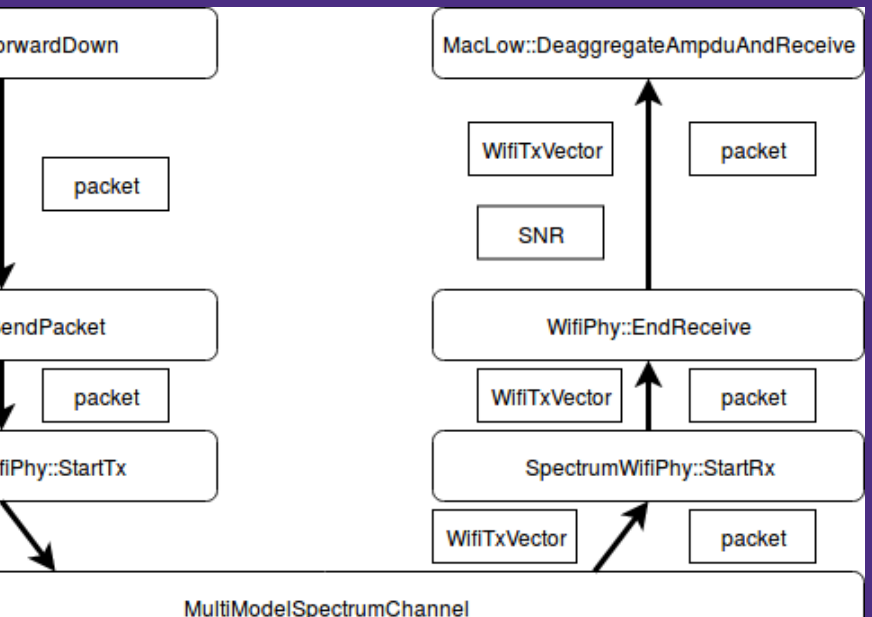
- PHY-MAC interface: packet + TXVECTOR
  ⇒ but… MU-PPDU contains multiple packets!
- Multiple RX events for each MPDU in A-MPDU
  ⇒ but … different A-MPDU size per user in MU-PPDU!

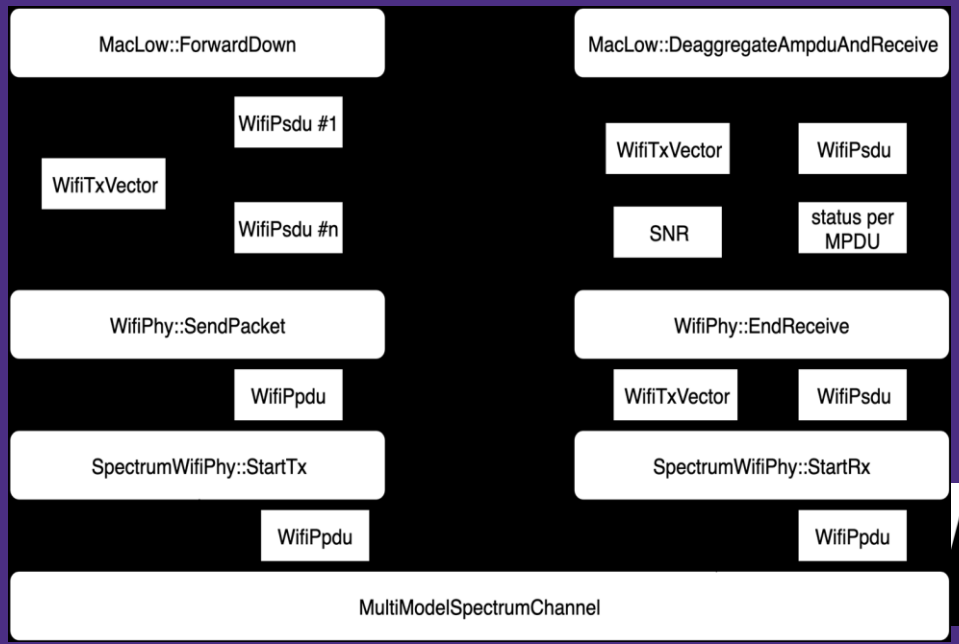
MAC/PHY interface extensions

- packet -> map of PSDUs (SU: single PSDU)
- A-MPDU simplified: single RX event, MPDUs hold by WifiPsdu, …

Transport PPDU instead of packet

- WifiPpdu: holds map of PSDUs, PHY headers, modulation class, preamble, …

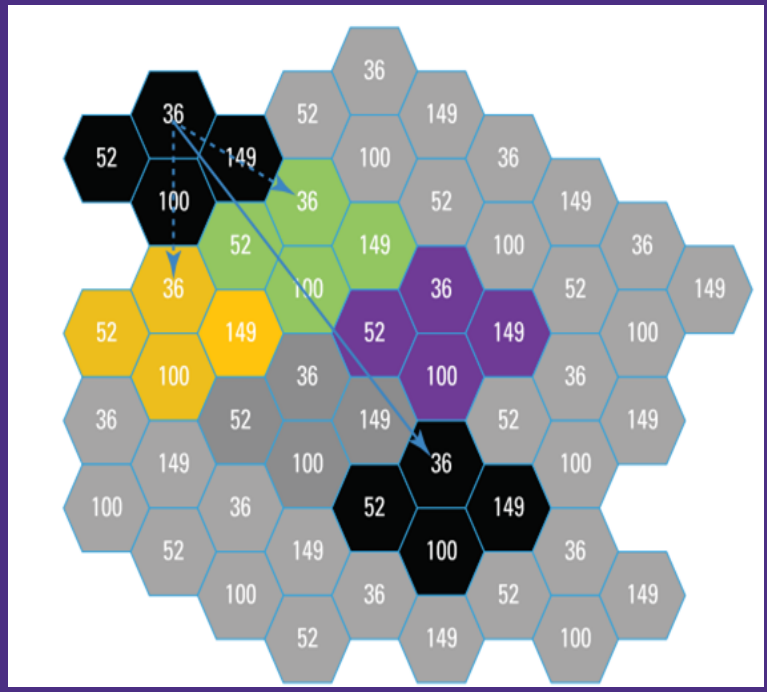




OBSS-PD based Spatial Reuse

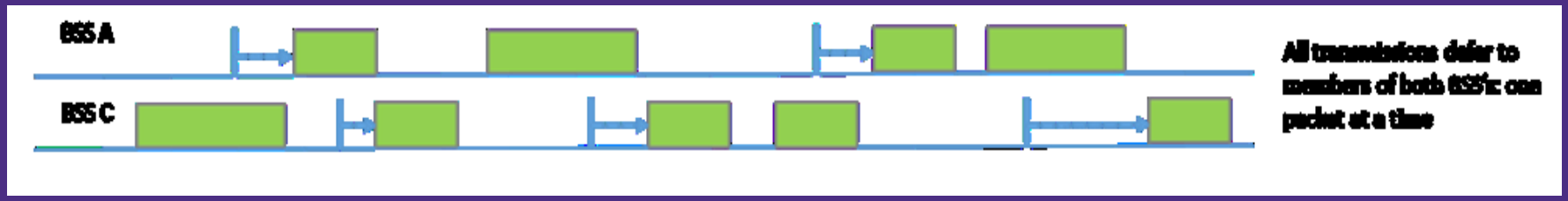
BSS coloring:

- BSS color = numerical identifier of the BSS.
- BSS color is transported in HE SIG-A
- 11ax STA able to differentiate between BSSs using BSS color identifier



OBSS_PD Spatial Reuse

Legacy case



11ax case

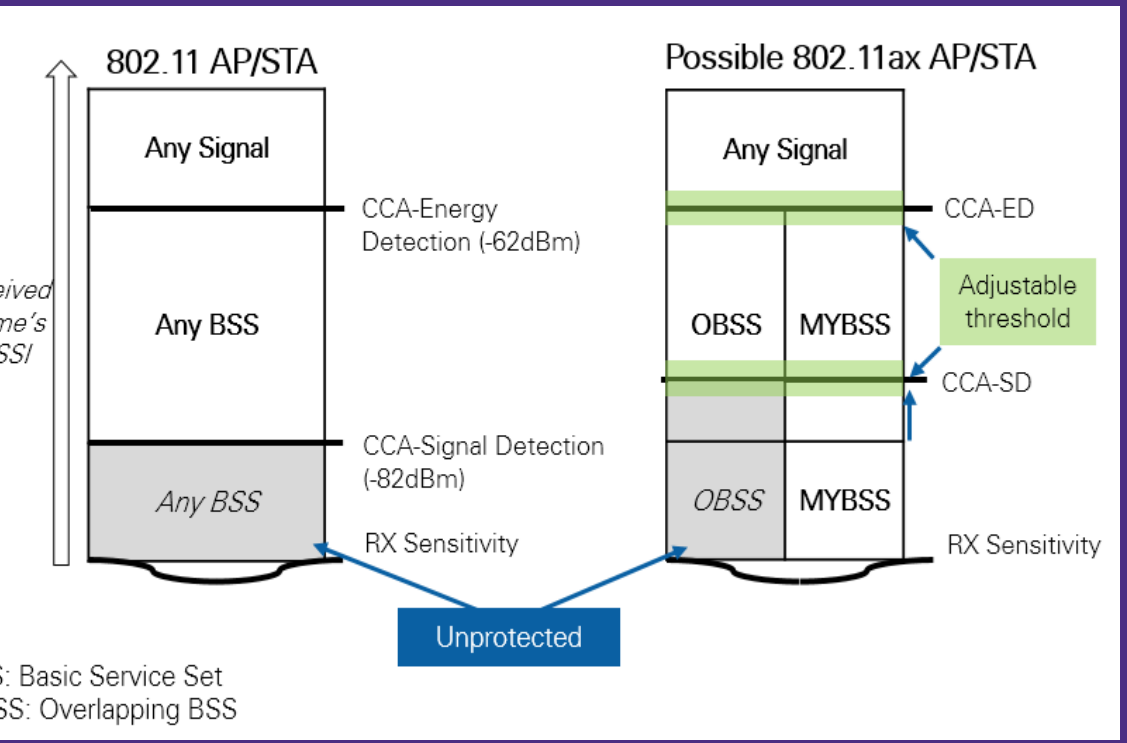
OBSS_PD Spatial Reuse

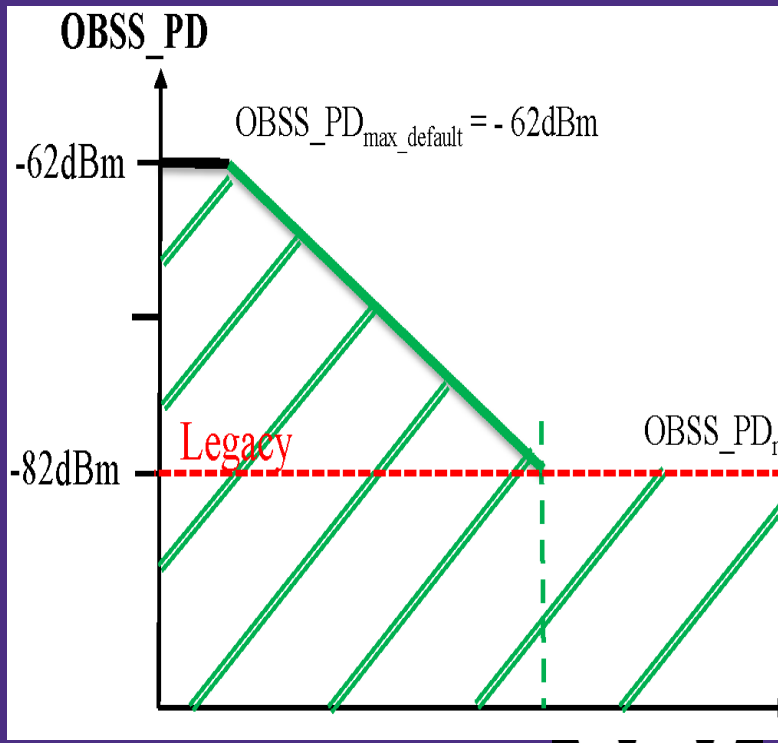
OBSS_PD algorithm

select appropriate threshold (between CCA-SD/PD and CCA-ED);
reset PHY to CCA-IDLE if OBSS below the OBSS_PD threshold.

TX power restriction:

If STA ignored inter-BSS PPDU, it shall start an OBSS_PD SR transmit power restriction period.





5G NR module

- Module initially released in Feb 2019 https://5g-lena.cttc.es/papers/

- The module contains currently the following features:
  - NSA architecture: 5G RAN and 4G EPC
  - Flexible and automatic configuration of the NR frame structure through multiple numerologies
  - OFDMA-based access with variable TTIs
  - Restructuring/redesign of MAC layer, including new flexible MAC schedulers that simultaneously consider time- and frequency-domain resources (resource blocks and symbols) both for Time-Division Multiple Access (TDMA) and OFDMA-based access schemes with variable TTI.
  - UpLink (UL) grant-based access scheme with scheduling request and 3GPP-compliant buffer status reporting
  - NR-compliant processing timings
  - New Bandwidth Part (BWP) managers and the architecture to support operation through multiple BWPs
  - PHY layer abstraction, considering LDPC codes (not released yet)

NR-U available development (60 GHz)

- NR-U/WiGig coexistence in 60 GHz bands with stand alone operation
  - Integration of 3GPP NR-U and WiGig (IEEE 802.11ad) codes to coexist
    - Migration of NR and WiGig to ns-3 spectrum module
    - Inclusion of 3GPP channel model and antenna array model to be used both by NR and WiGig
    - Enabling pathloss, channel, and interference generation among all the nodes
  - LBT-After-MAC processing based design is implemented
  - Different Channel Access Managers are available at gNB and UE
    - AlwaysON: NR uninterrupted behaviour
    - OnOff: Duty-cycled behaviour
    - LBT: with omnidirectional sensing at gNB, and directional sensing at UE
      - LBT Cat1, Cat2, Cat3 and Cat4 are available

Improvement plans for NR-U/802.11ax (sub 7 GHz bands)

- Improvements to NR module for NR-U/Wi-Fi coexistence
  - Send PDCCH directionally and schedule accordingly (currently, PDCCH is sent omnidirectionally, and PUCCh is sent directionally)
  - Develop realistic beam training (currently, it is ideal in NR/NR-U)

- NR-U/802.11ax coexistence in sub 7 GHz bands
  - Integration of NR-U and IEEE 802.11ax codes to coexist
    - Use of 3GPP channel model and antenna array model by IEEE 802.11ax
  - Preamble detection in NR-U
  - Implement directional LBT at gNB, and schedule UEs accordingly
    - Based on LBT-After-MAC implementation, a new interface from PHY to MAC is needed, to schedule on a beam-basis according to the directional sensing.
  - Carrier Aggregation and Dual Connectivity for NR-U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Thank you !!