
NIST
National Institute of Standards and Technology
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# Implementation and Evaluation of a WLAN IEEE 802.11ay Model in Network Simulator ns-3

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Developing the Science of Networks

# Outline

- Introduction and Motivation
- Implementation of IEEE 802.11ay in ns-3
- Evaluation
- Conclusions and Future Work

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# Introduction to IEEE 802.11ay

- Increased interest for mmWave
  - 5G implementations
  - Consumer devices
  - Emerging wireless applications


mmWave distribution networks, wireless backhauling, FWA

- IEEE 802.11ay WLAN operation
  - Extension of IEEE 802.11ad
  - Data rates up to 100 Gbps and ultra low latency
  - Advanced PHY layer technologies: (MIMO, channel bonding/aggregation)
  - New beamforming techniques

Augmented Reality/ Virtual Reality

Data center inter-rack connectivity

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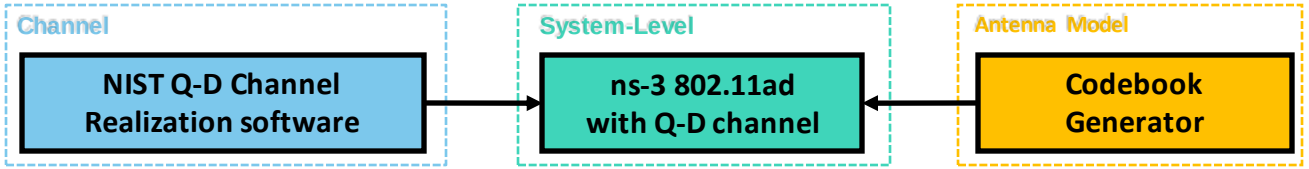
# Motivation

## Existing high-fidelity IEEE 802.11ad model




## Contribution

Extend the model to support the novel IEEE 802.11ay protocol

1. Basic IEEE 802.11ay support
2. New training field structure
3. MIMO operation support
    a) SU and MU MIMO BFT algorithms
    b) SU-MIMO channel access and data transmission

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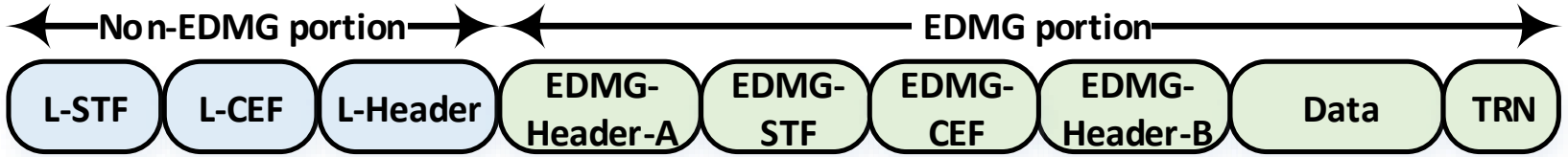
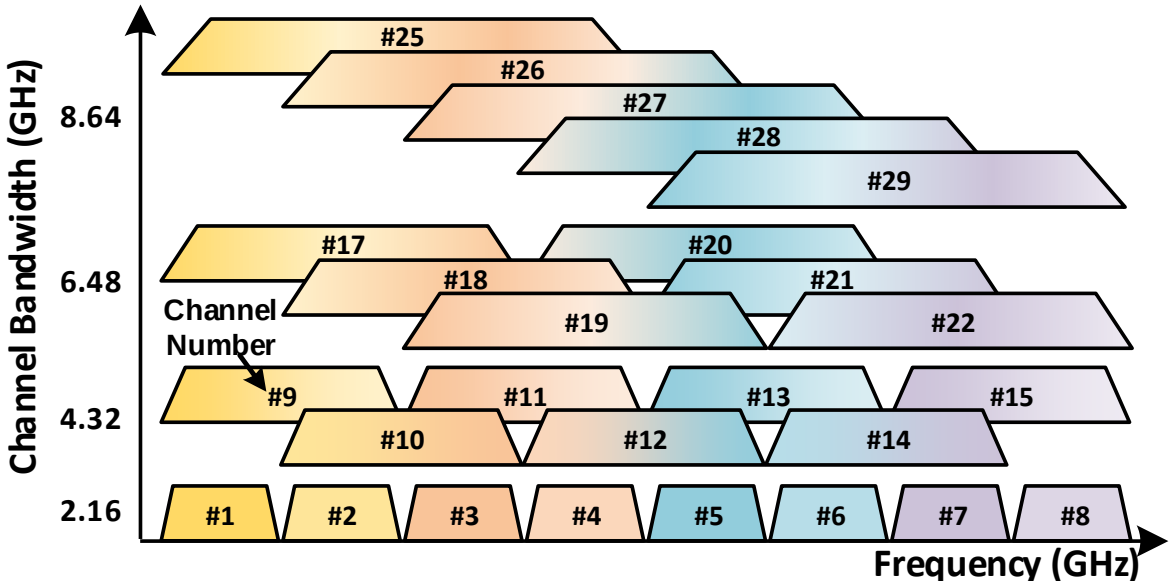
# IEEE 802.11ay basic support

- New EDMG frame format

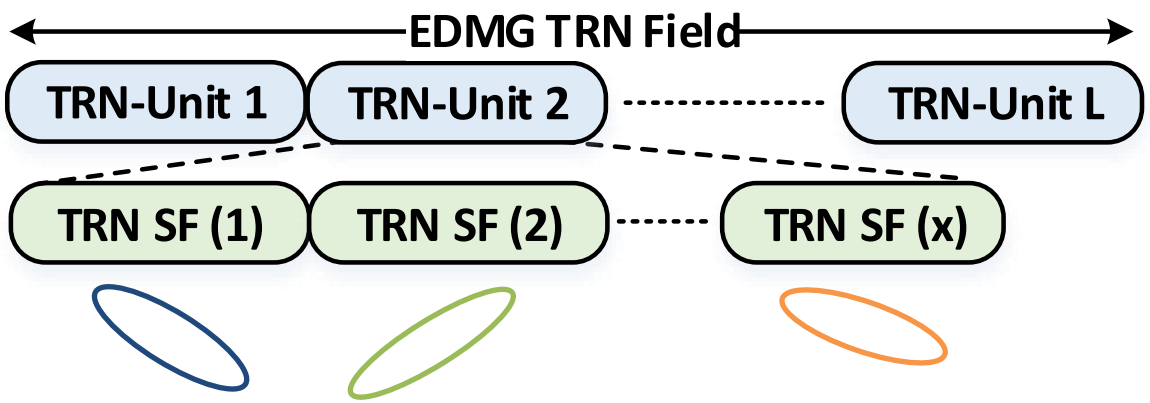


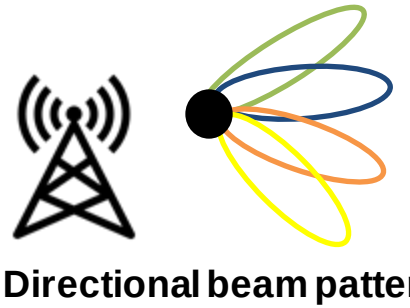

- Expanded set of MCSs for EDMG SC and EDMG OFDM PHY
  - New modulations and coding rates
  - New SNR to BER lookup tables for an accurate error model

- Channel configurations
  - 4 new channels
  - Bonding of up to 4 channels

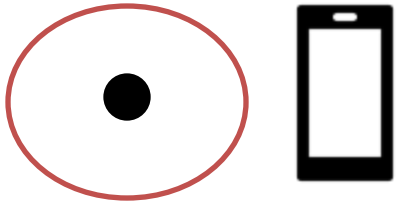


# EDMG TRN Field



Directional beam patterns

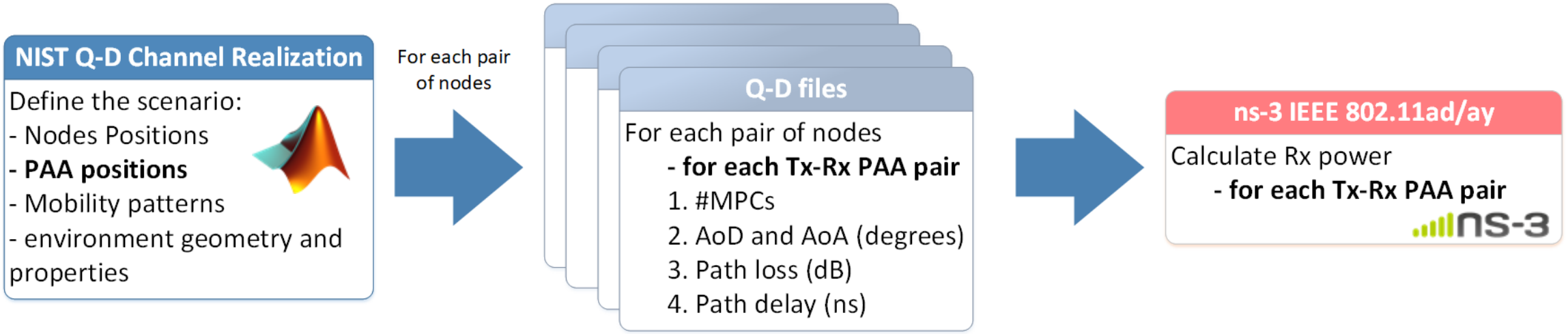


Quasi-omni beam pattern

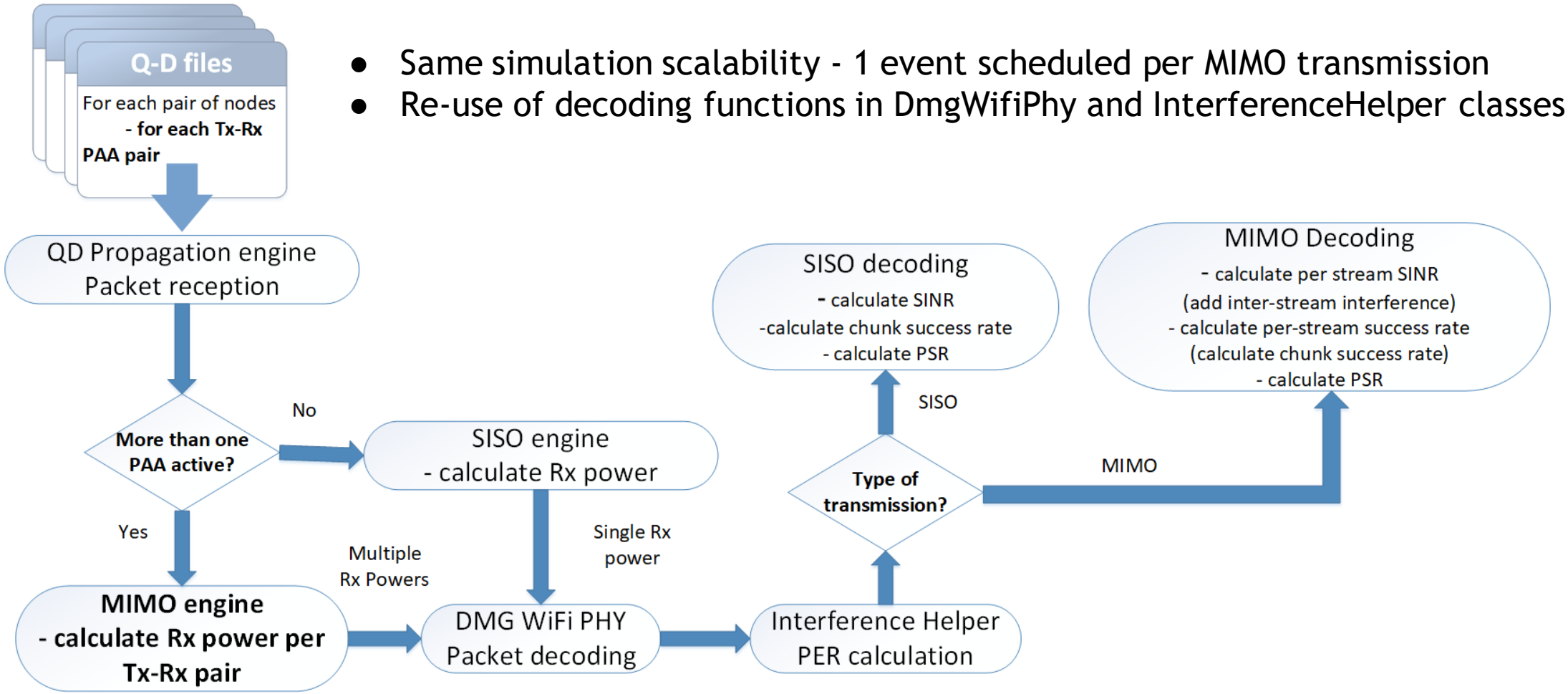
- Redesign and expanded use in IEEE 802.11ay
  - Flexibility of the format, size and switching requirements
  - New format for simultaneous transmit and receive training
  - Increased use (both for SISO and MIMO BFT)

# MIMO Implementation

- Extension of the NIST Q-D Channel Realization Software



# MIMO Implementation in ns-3




- Same simulation scalability - 1 event scheduled per MIMO transmission
- Re-use of decoding functions in DmgWifiPhy and InterferenceHelper classes

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# MIMO Beamforming Training

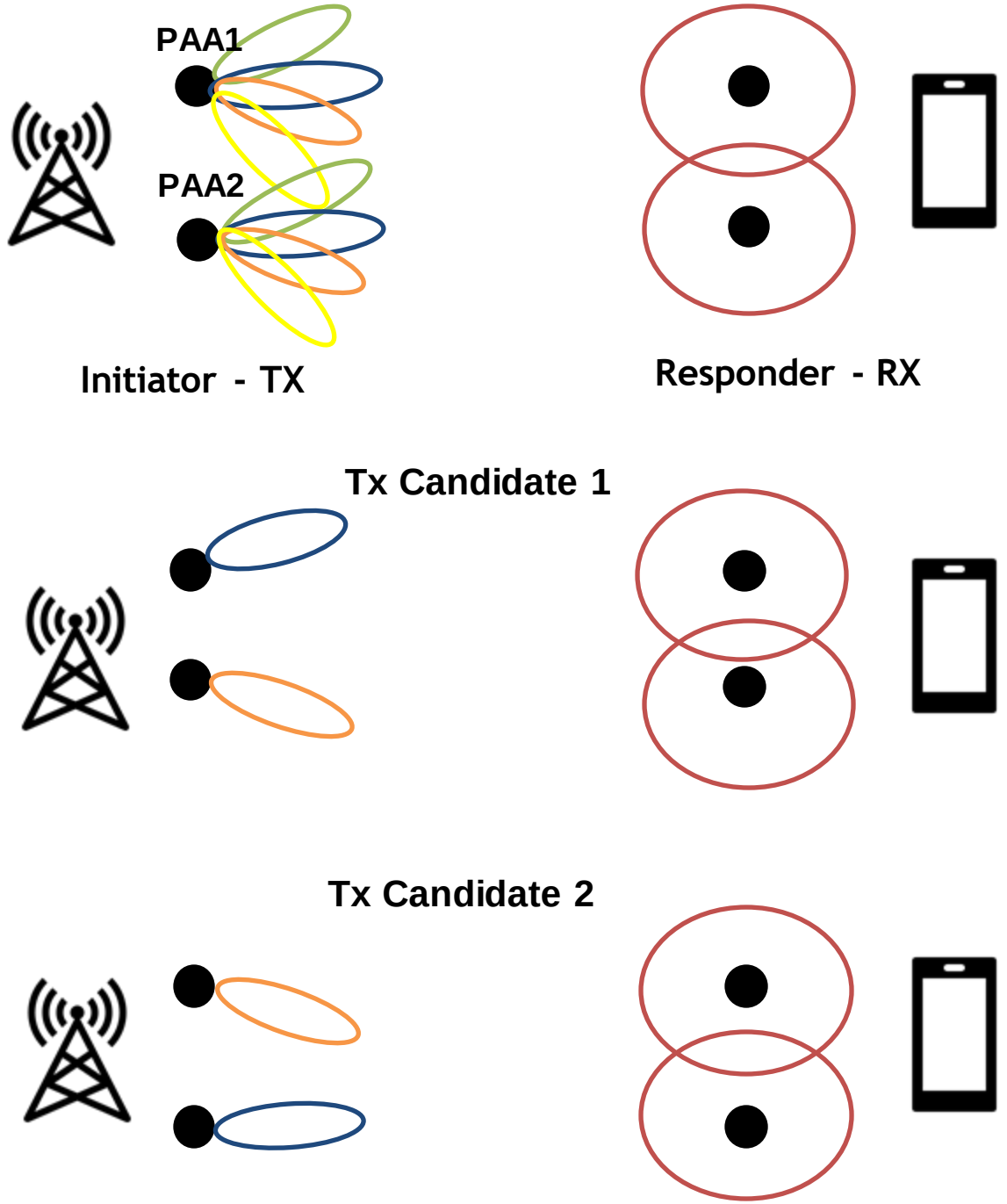
- Implement standard compliant SU/MU-MIMO BFT protocols
  - Training of transmit and receive antenna arrays
  - Exhaustive search is not possible - too many combinations

- Two main phases:
  - SISO phase - get the optimal SISO BFT configuration
  - Select MIMO combinations to test (based on SISO phase results)
  - MIMO phase - test specific MIMO combinations, get MIMO performance (including inter-stream interference)

# MIMO Beamforming Training

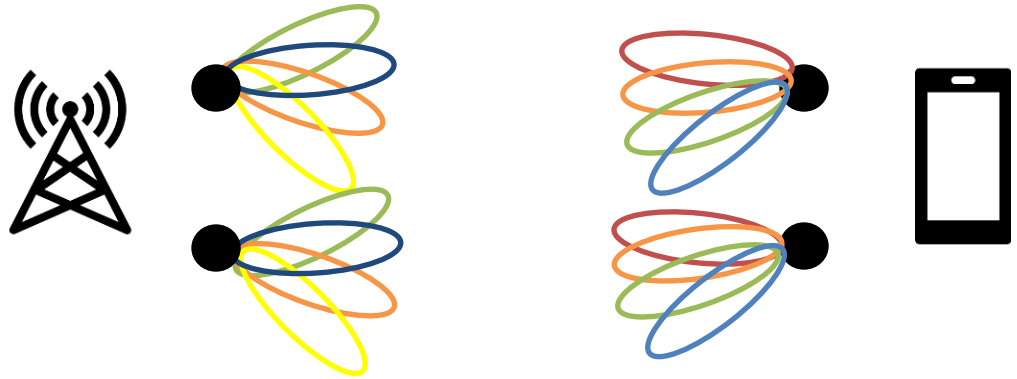
- SISO phase
  - Transmit training of initiator
  - Measure SISO performance
  - Get SNR of Tx beam patterns

- Choose MIMO transmit candidates
  - Candidate = antenna configuration for each antenna being trained
  - Selection algorithm

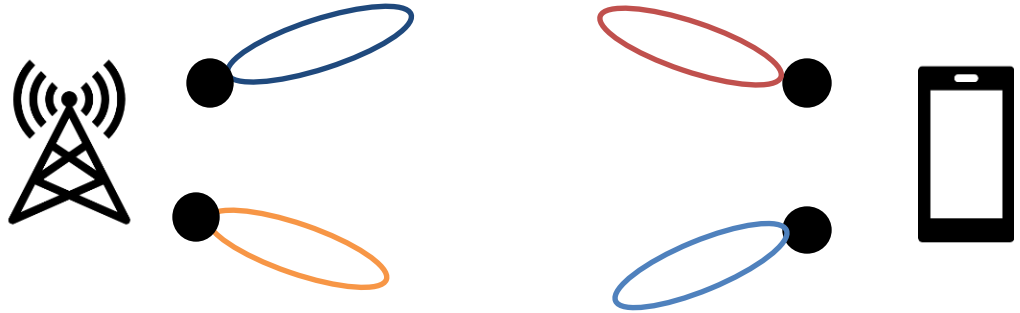


# MIMO Beamforming Training

- MIMO phase
  - Transmit and receive training of candidates
  - Measure MIMO performance
  - Get SINR of Tx-Rx MIMO combinations



- Choose optimal configuration
  - Maximize the minimum per stream SINR
  - Easily extended to other criteria



# MIMO Beamforming Training

- NxN MIMO (tested up to 4x4 MIMO)
- Beam refinement option in MIMO phase
  - Reduced scalability vs improved accuracy
- All Tx-Rx antenna pairs are tested to choose the optimal one
- Traces to get the full set of SISO and MIMO phase measurements and MIMO transmit candidates
- MIMO implementation is still being validated and extended for more complex scenarios
  - Full list of limitations in the WiKi page of the project

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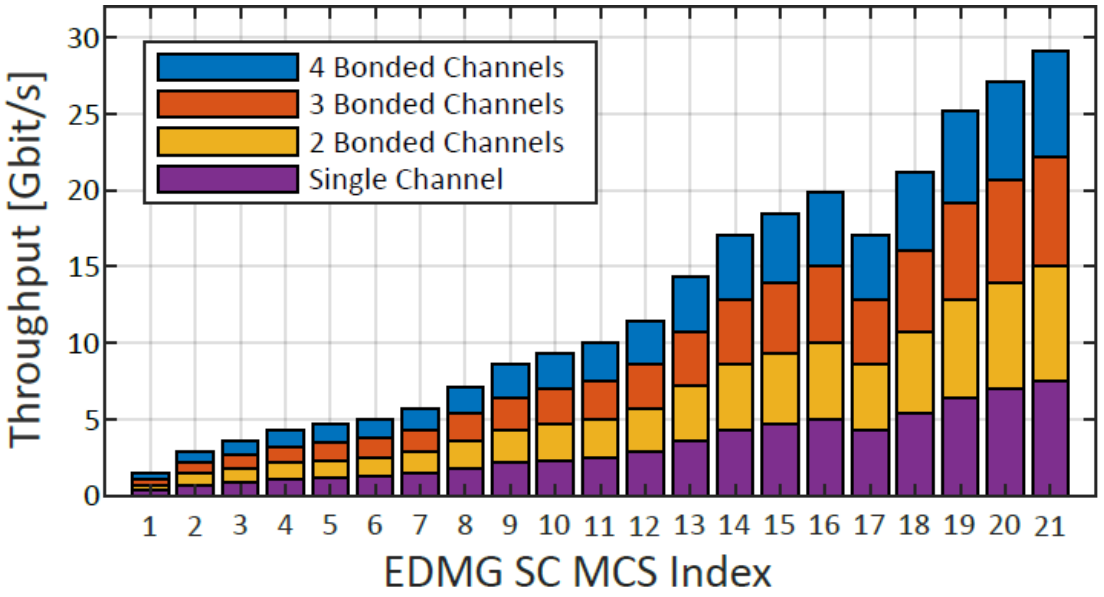
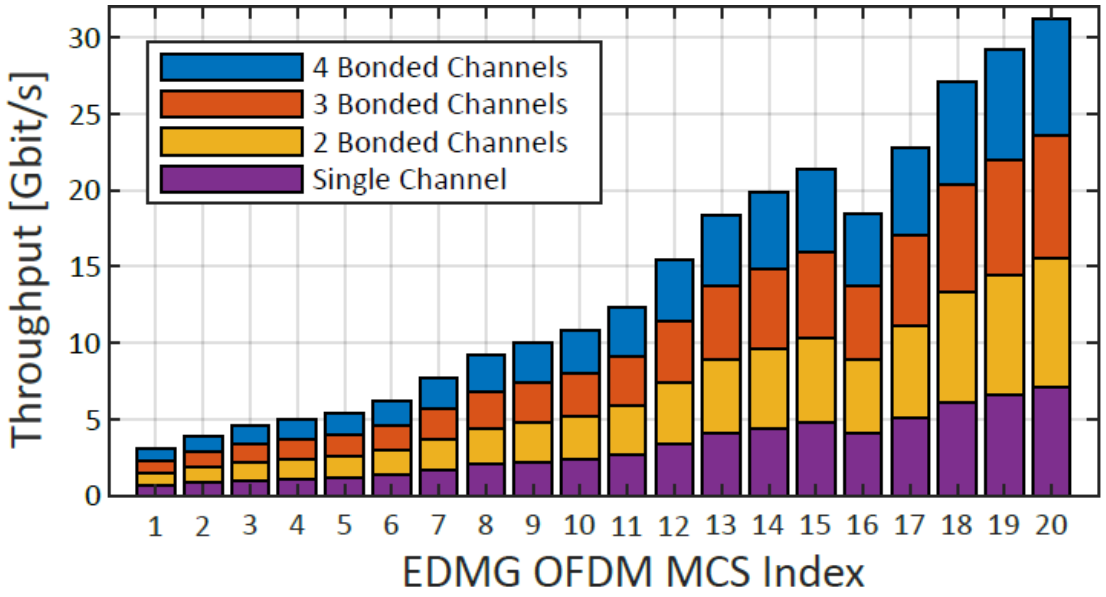
# Achievable Throughput

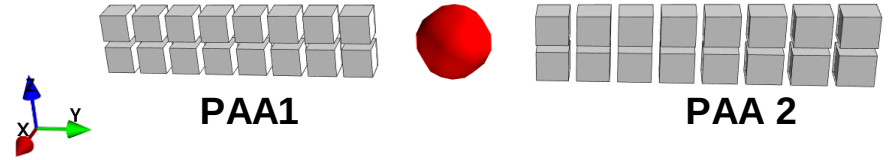


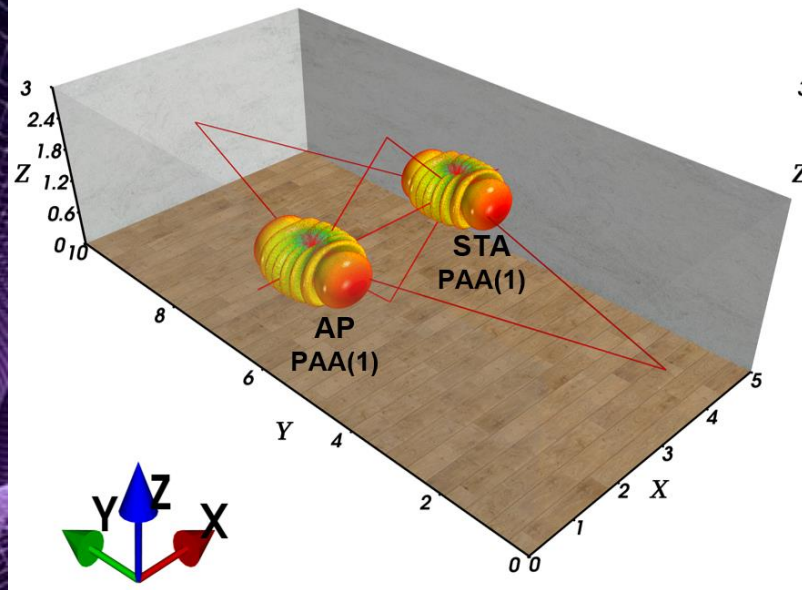



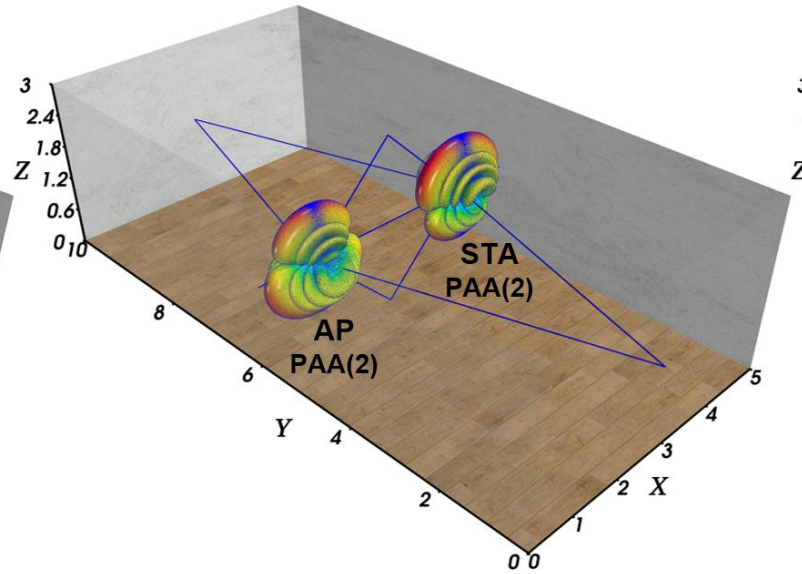

- Validation of our implementation in terms of application throughput
  - Closely matches the data rates from the standard
  - Up to 30 Gbit/s single stream throughput per device

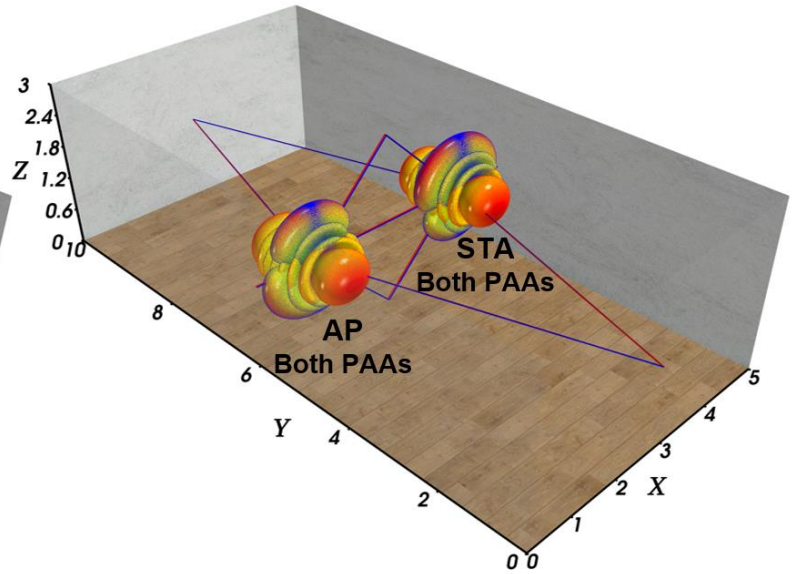
# SU-MIMO evaluation

- Antenna Configuration
  - AP/STA: 2 PAAs. Each PAA is 2*8



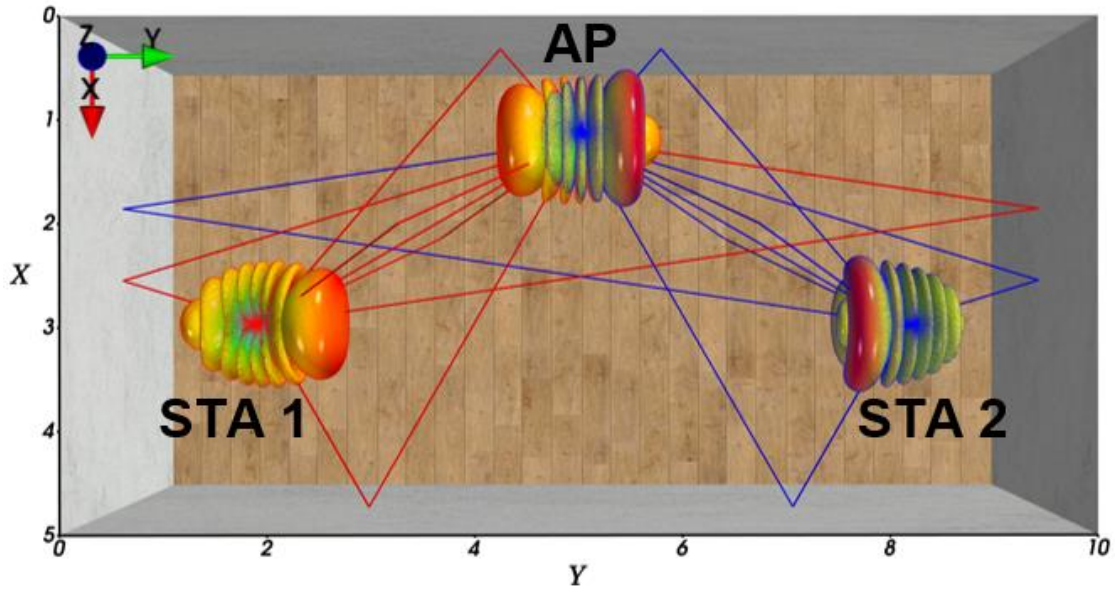



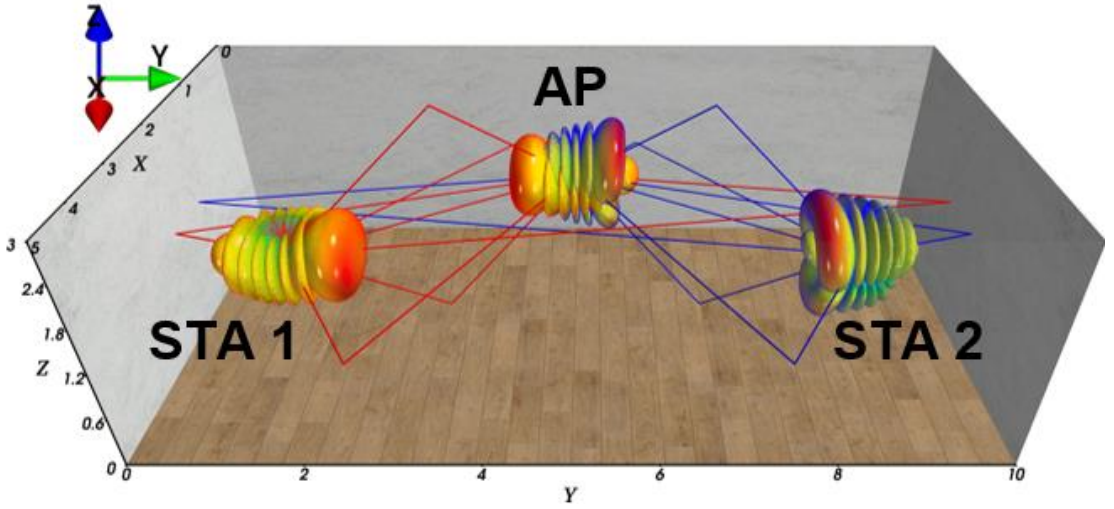




- Visualization of the best SU-MIMO configuration
- Very high spatial separation of the streams, despite small PAA separation
  - Very high SINRs of 23.53 dB for Stream 1 and 39.25 dB for Stream 2
- Use of EDMG SC MCS-21 achieves aggregate throughput of 14 Gbit/s

# MU-MIMO Evaluation

- Antenna configuration
  - AP: 2 PAAs of 2*8
  - STA: 1 PAA of 2*8
- Visualization of the best MU-MIMO configuration
- Very good spatial separation of the stations
  - SINRs of 33.8 dB and 33.3 dB



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# Conclusions and Future Work

Conclusions:

- Implementation of the novel IEEE 802.11ay protocol
- Evaluation of new technologies introduced, including mmWave MIMO operation

Future Work:

- Multi-channel scheduling
- MU-MIMO channel access procedure and data transmission
- Antenna polarization support
- TDD protocol for Fixed Wireless Access (FWA)

# Contact Information

Framework Repositories:
https://github.com/wigig-tools

Project maintainers email addresses:

1. ns-3 IEEE 802.11ad/ay Module and Codebook Generator:
   - Hany Assasa (hany.assasa@gmail.com)
   - Nina Grosheva (nina.grosheva@imdea.org)

2. NIST Q-D Channel Realization + Q-D Interpreter
   - Tanguy Ropitault (tanguy.ropitault@nist.gov)

# Questions