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Implementation and Evaluation of a WLAN IEEE 802.11ad Model in ns-3

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Developing the Science of Networks

Outline

- Introduction to mmWave Communications.
- Background on IEEE 802.11ad Amendment.
- WLAN IEEE 802.11ad Model in ns-3.
- Evaluation.
- Conclusion.
- Future Work.

Introduction

- ➔ Existing mobile networks and WLAN technologies are becoming increasingly **congested** and **overloaded**.
- ➔ WiGig and the Wi-Fi Alliance took the initiative to leverage wide spectrum at the 60 GHz and provide multi-gigabit per second communication (WLAN IEEE 802.11ad amendment)

PROBLEM

- ➔ Experimental evaluation of networking in this band is extremely **costly** and available hardware has very **limited capabilities**.
- ➔ Current research studies deduce network performance from individual 60 GHz links but cannot evaluate the behavior of an entire network.

SOLUTION

Resort to network simulation which abstracts implementation details while providing a good grade of realism.

Background on IEEE 802.11ad

Pros

Provides very high throughput of up to 7 Gbps for short range communication for local area networks.

Cons

Transmission in this 60 GHz band has specific **signal propagation characteristics:**

1. Requires line of sight (Quasi optical propagation behavior).
2. Higher attenuation (High frequency).
3. Susceptible to blockage and human mobility.

Background on IEEE 802.11ad

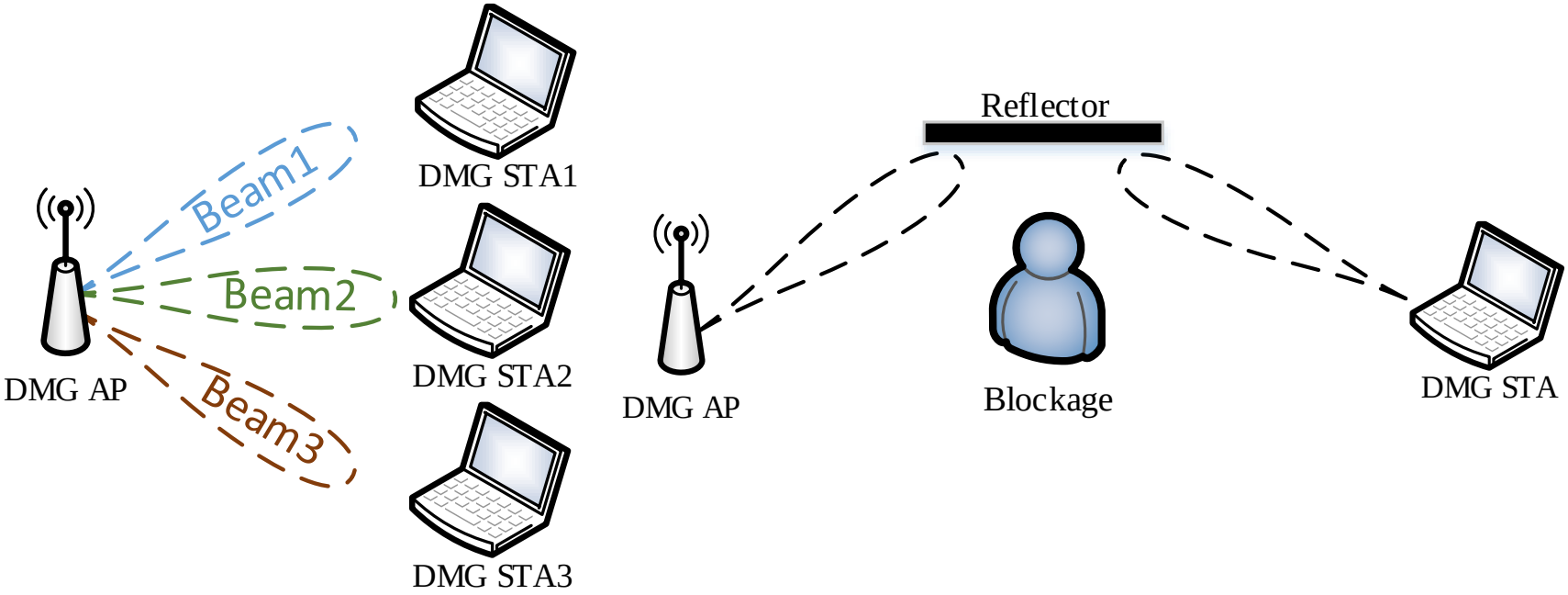
Physical Layer:

- Four different types of PHY layers:

1. **Control PHY:**
   - Dedicated to low SNR.
   - Mainly used for Beamforming.
2. **OFDM PHY:**
   - Provides the highest data rates of up to 6.76 Gbps.
   - Its implementation is complex so it targets devices with less stringent power and design constraints, such as docking stations and wireless streaming devices.
3. **SC PHY:**
   - Power limited and low complexity devices adopt this PHY.
   - Target mobile phones and tablet devices.
4. **LP-SC PHY:**
   - Allows for further power reduction by using low-density parity check (LDPC) codes instead of Reed-Solomon codes.

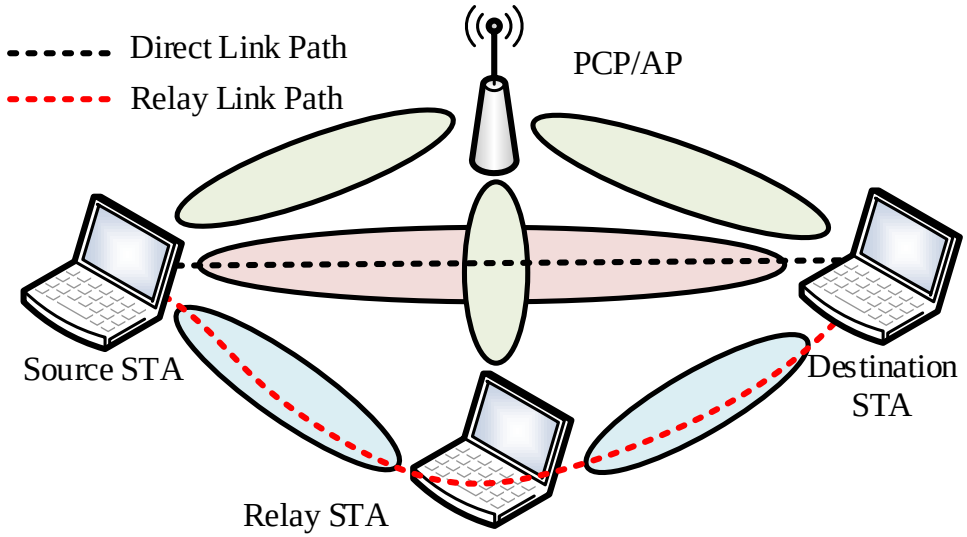
Background on IEEE 802.11ad

Beamforming Training:
IEEE 802.11ad provides a mechanism to establish a directional link through a beamforming training process to compensate for signal quality degradation.



Background on IEEE 802.11ad

Relay Operation:



- Coverage area extension.
- Improved link resilience against interruptions.
- Persistent multi-gigabit throughput.

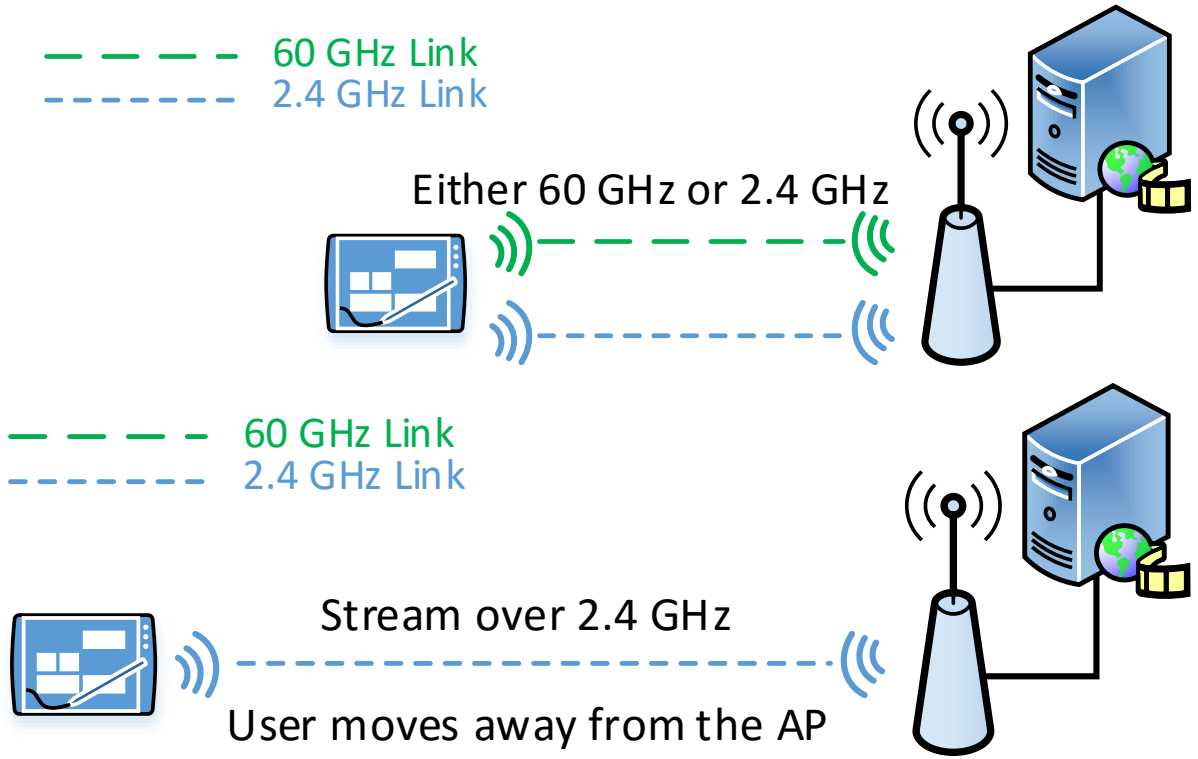
Two types of relay operation modes:

- **Link Switching Type:** The source STA uses either the direct link or the relay link. It can either work in Half Duplex Decode and Forward or Full Duplex Amplify and Forward.
- **Link Cooperating Type:** In this mode the source STA utilizes both direct link and relay link simultaneously to improve received signal quality at the destination STA.

Background on IEEE 802.11ad

Fast Session Transfer Technique:

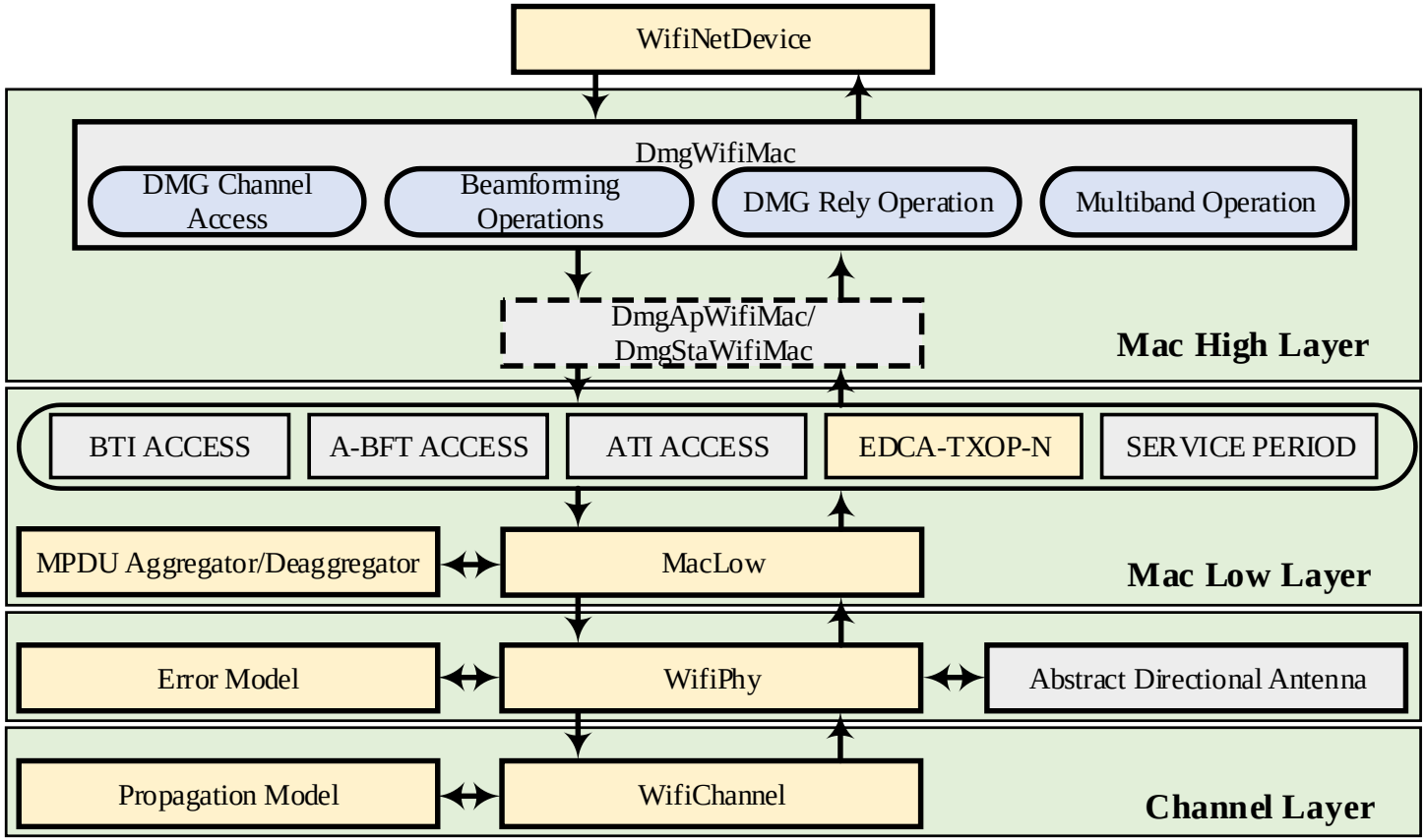
Communication in the 60 GHz band is limited in range and suffers from high penetration loss in case of obstacles.
Solution: IEEE 802.11ad included a fast session transfer (FST) technique. An IEEE 802.11 capable device can change its operational band seamlessly from 60 GHz to 2.4/5 GHz.



IEEE 802.11ad Implementation in ns-3

IEEE 802.11 Model in ns-3:

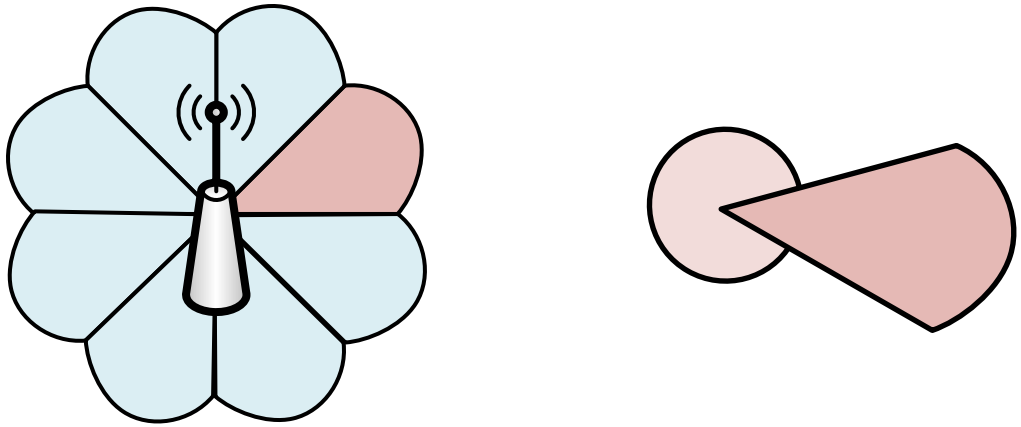
- The model is divided into four layers.
- Well suited for wireless technologies that use CSMA/CA scheme with omni-directional transmission and reception.



IEEE 802.11ad Implementation in ns-3

Directional Antenna Pattern:

- Generic directional antenna model AbstractDirectionalAntenna
- Divides the 2D plane into a number of virtual sectors.
- Concrete antenna models are inherited from this base model.

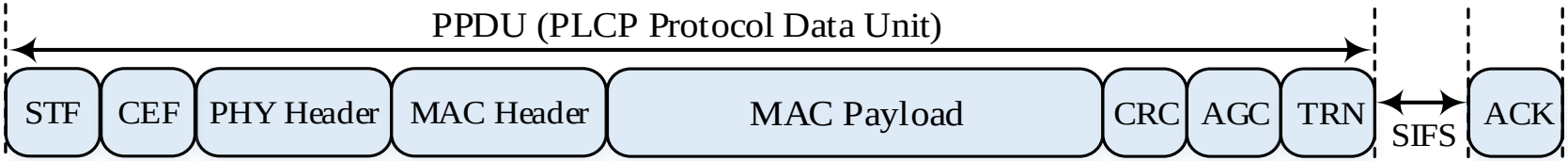


- Derived model: defines maximum gain and side lobe gain.

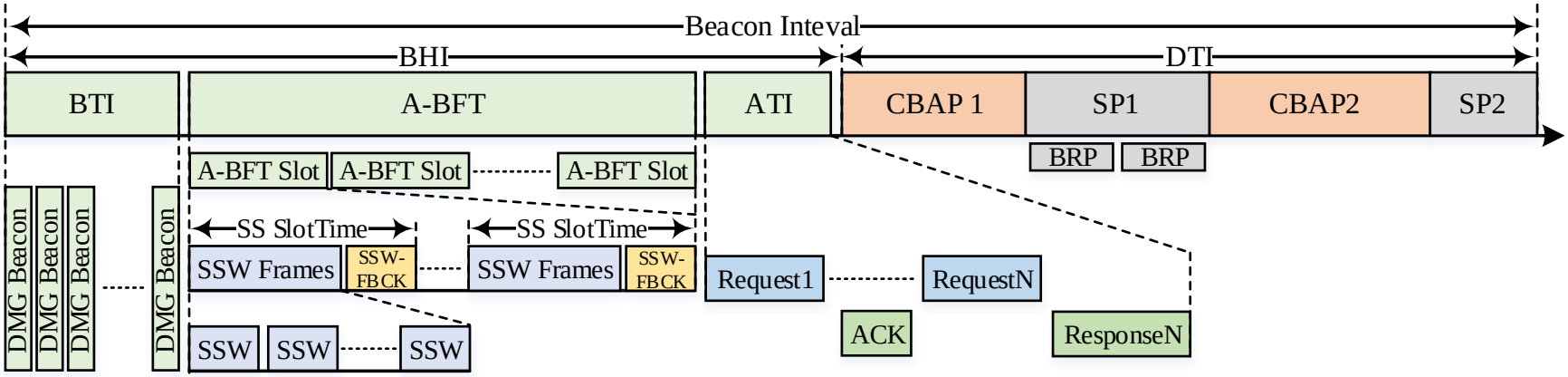
IEEE 802.11ad Implementation in ns-3

PHY Layer:

- Abstract PHY layer for the operation of IEEE 802.11.
- Transmission time for CTRL, SC, and OFDM PHYs.



Access Periods:

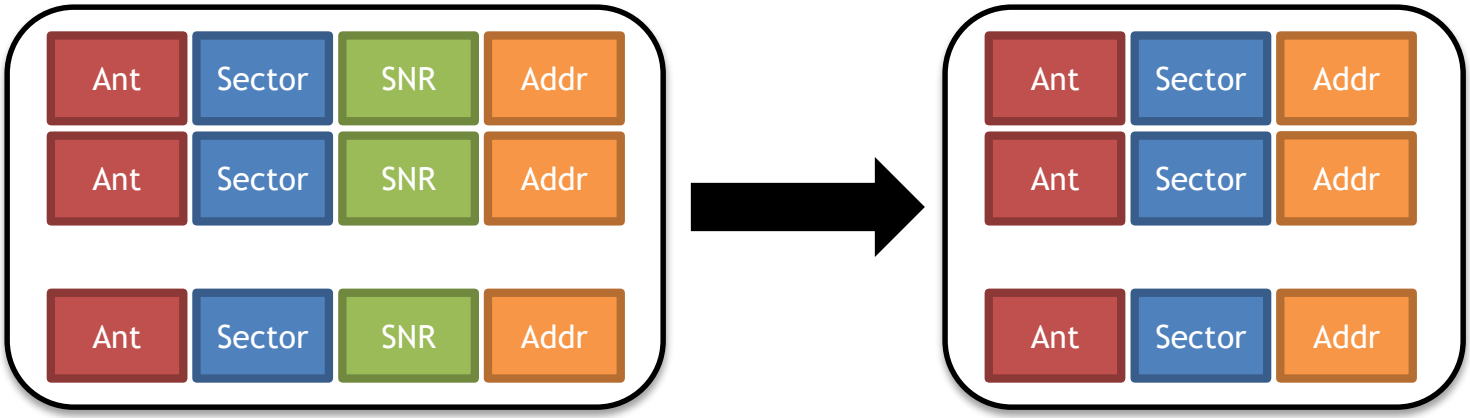


- DMG AP transmits DMG Beacons across its virtual sectors.
- DMG AP divides the A-BFT into Sector Sweep Slots.
- DMG STAs choose one of these slots randomly using a uniform distribution.
- ATI to perform the BRP setup phase and exchange BRP transactions.
- SP for Data Transmission or Beamforming Training.

IEEE 802.11ad Implementation in ns-3

Beamforming Training:

- Generic implementation for Beamforming Training.
- Usage in BTI period or as a scheduled SP between two DMG STAs.
- Two data structures:



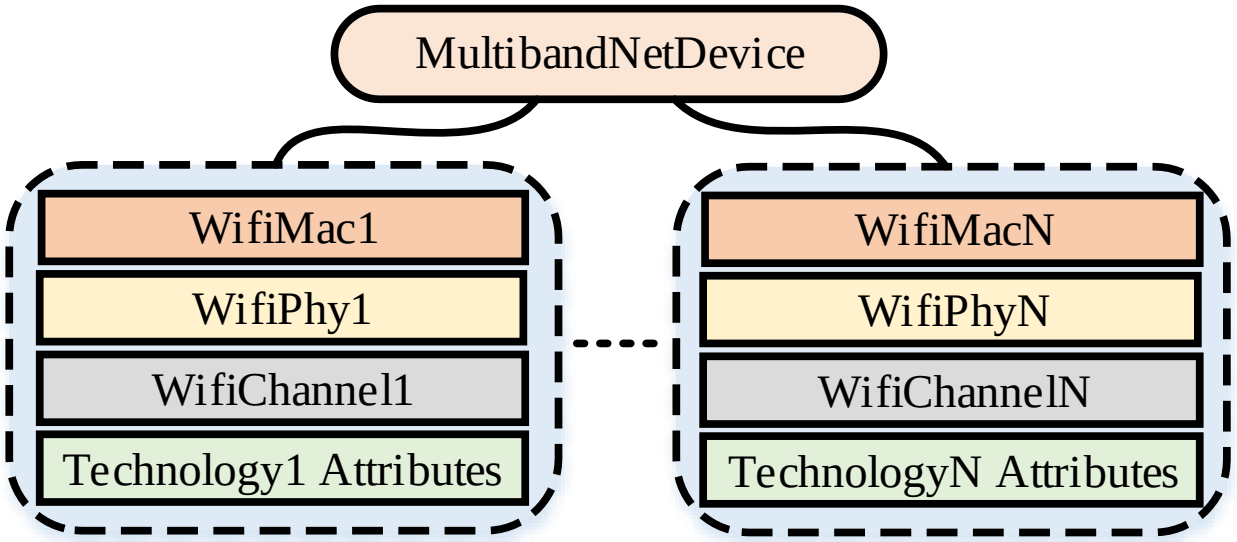
SNR Table **Antenna Configuration Table**

- Decisions are based on SNR measurements.

IEEE 802.11ad Implementation in ns-3

Fast Session Transfer:

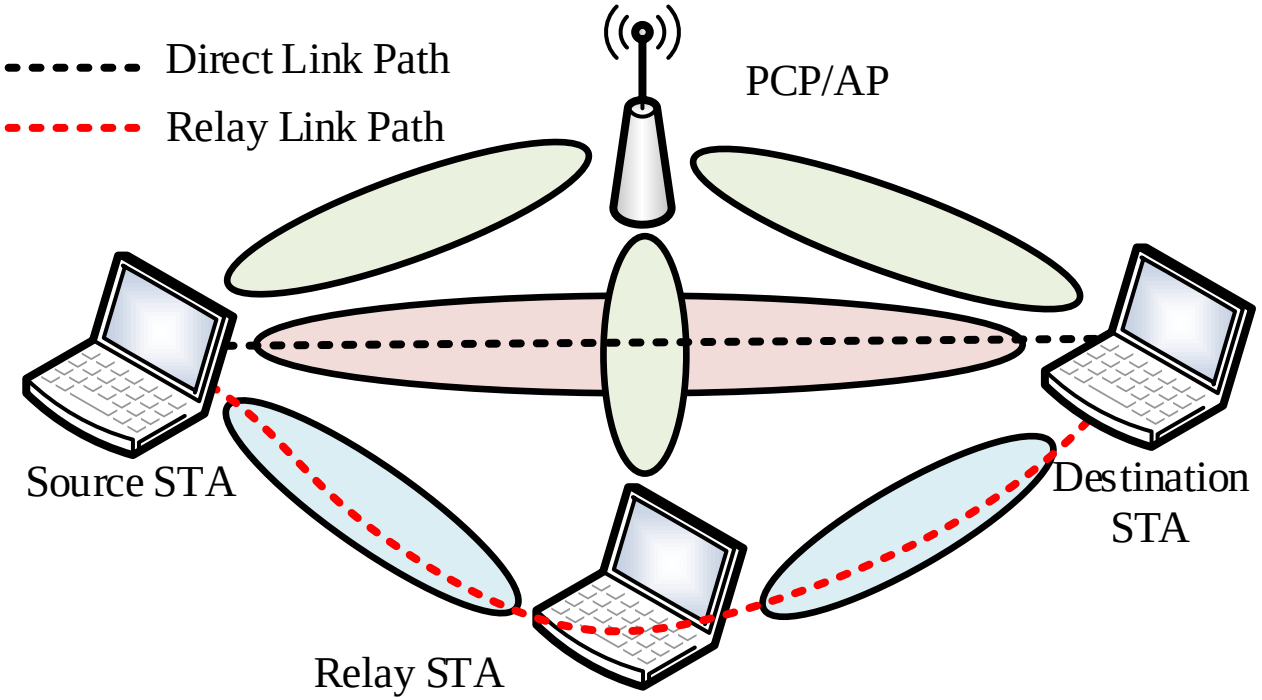
- New NetDevice (MutliBandNetDevice).
- Encapsulate different WiFi standards.
- Transparent mode, all MAC sub-layers in the STA expose a single MAC-Service Access Point (SAP) to the upper layers, i.e., a single MAC address.



IEEE 802.11ad Implementation in ns-3

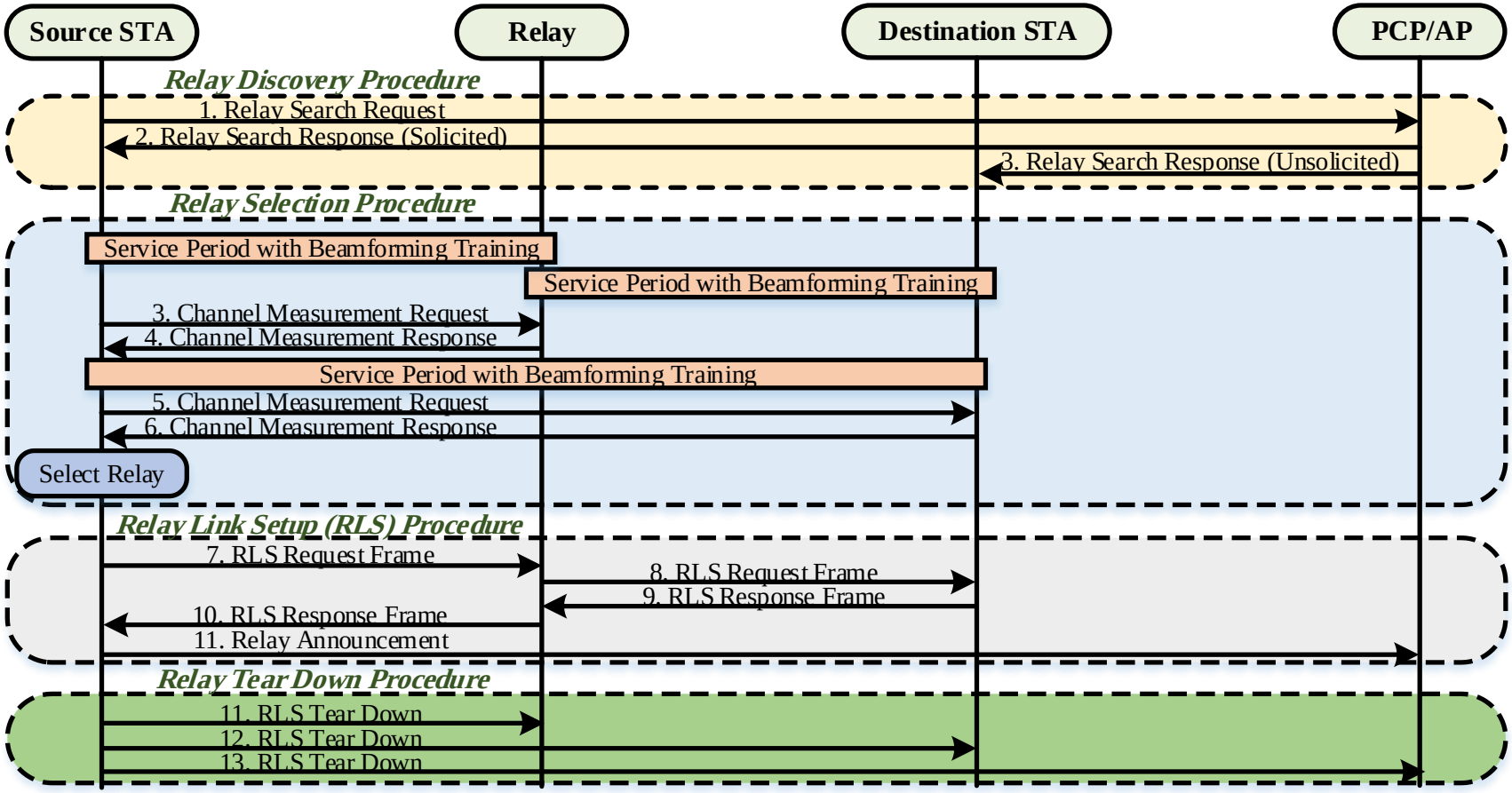
Relay Operation:

- Link Switching Type.
- Full duplex amplify and Forward (FD-AF).
- Relay selection procedure based on SNR.



IEEE 802.11ad Implementation in ns-3

Relay Operation:



Model Evaluation

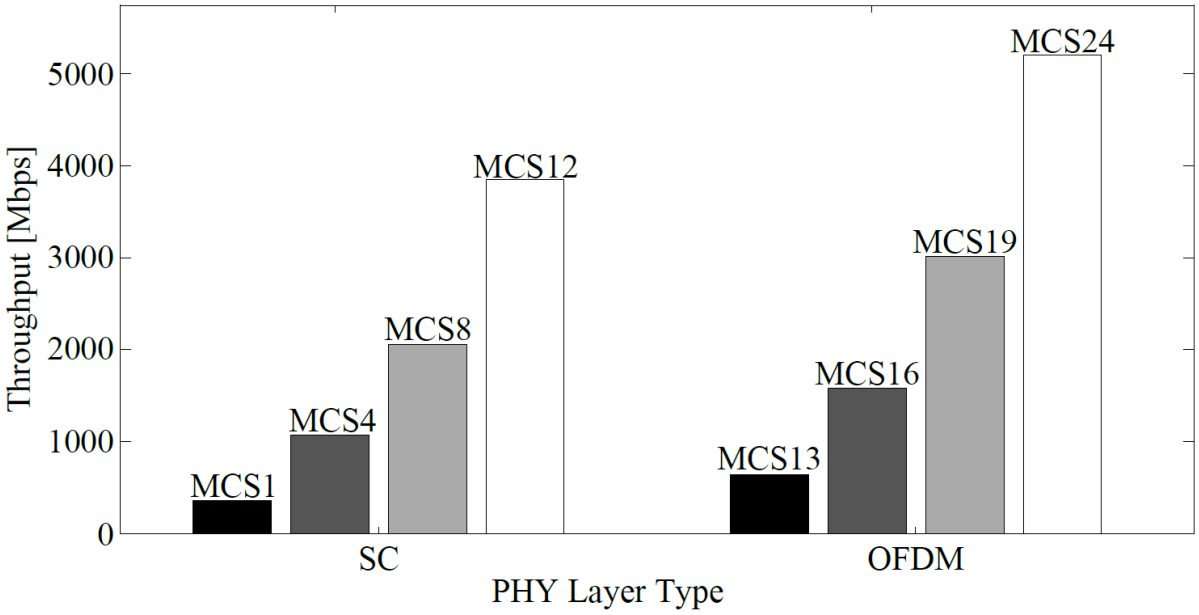
802.11ad Throughput:

Demonstrate the obtained throughput for different MCSs for both Single Carrier (SC) and OFDM PHY layers.

Scenario:

- Two nodes: one DMG AP and one DMG STA spaced.
- UDP as transport layer with CBR application.
- One antenna array with 8 virtual sectors.
- Two Level Aggregation (A-MSDU + A-MPDU).

Results:



Model Evaluation

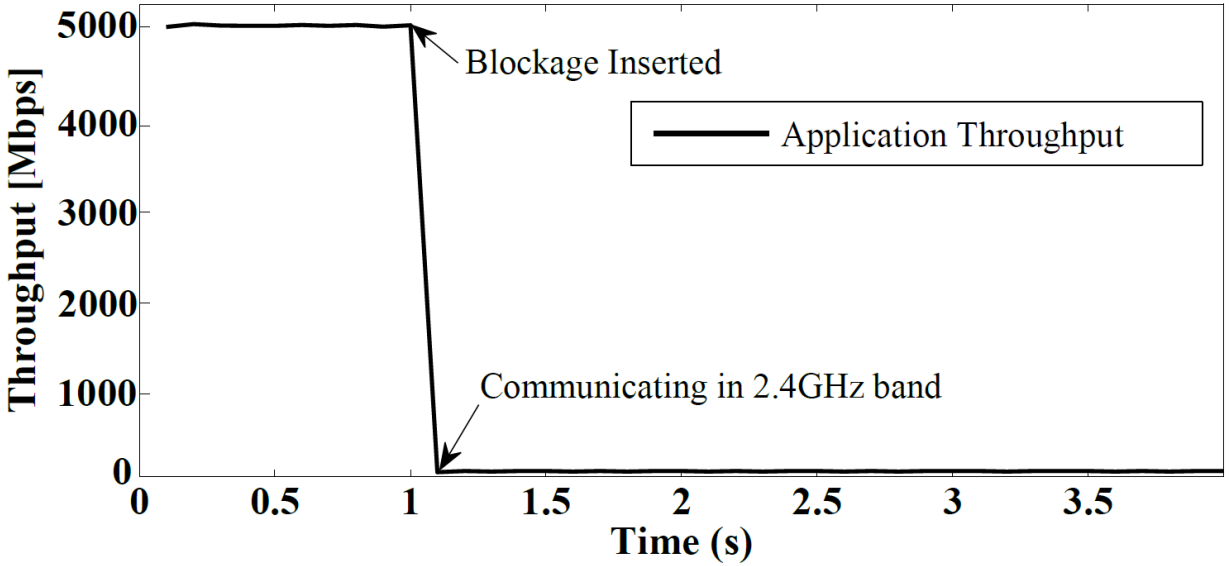
Evaluating Fast Session Transfer:

- Demonstrate the capability of transferring an on-going data session smoothly from the 60 GHz band to the 2.4 GHz band.

Scenario:

- Set the value of LLT to 1000 which corresponds to a link loss countdown value of 32ms.
- After one second, we introduce a blockage in the link of -45 dBm. This blockage breaks the link so the nodes starts a link loss countdown.

Results:

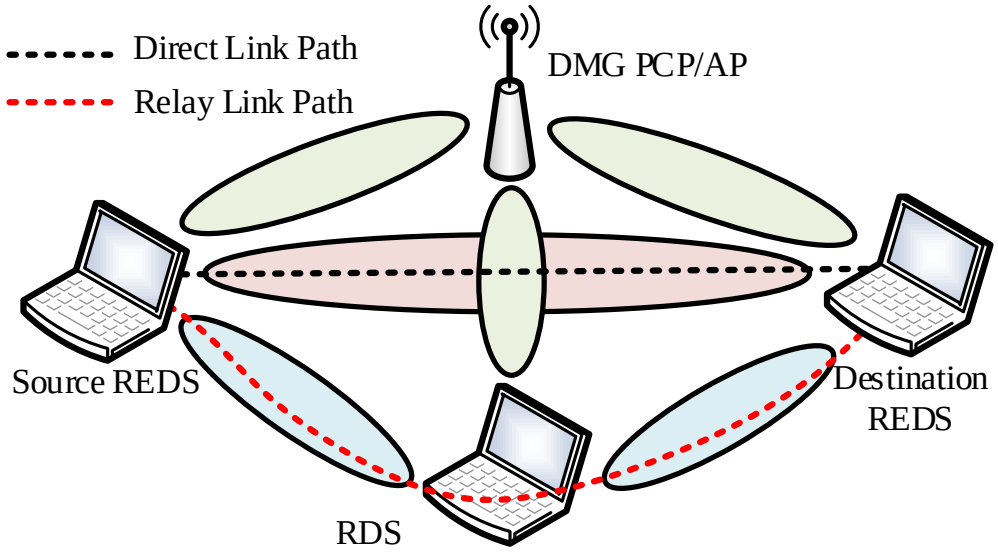


Model Evaluation

Evaluating DMG Relay Operation:

- Calculate throughput gain we obtain by using this alternative path compared to the case where we do not have any available relay (RDS).

Scenario:

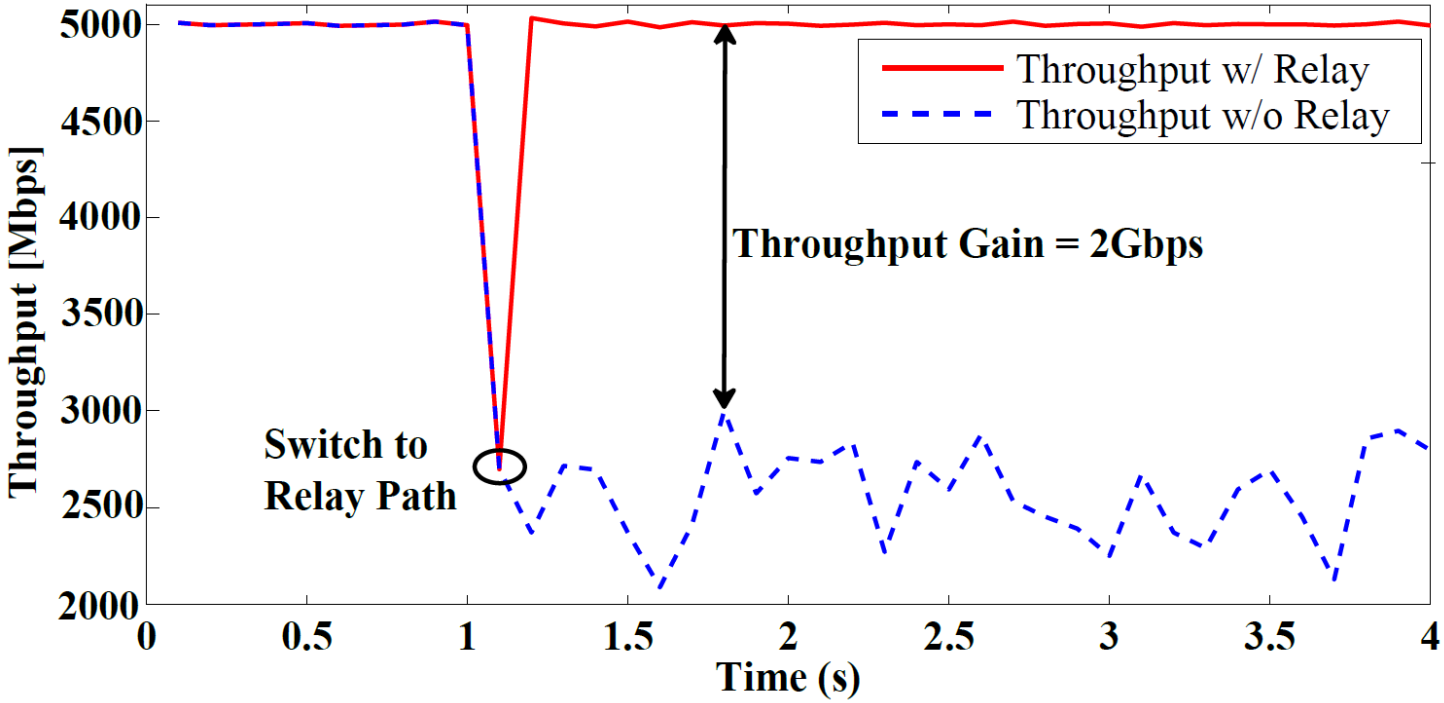


Model Evaluation

Evaluating DMG Relay Operation:

Results:

- Link switching takes around 117 μs
- Using the relay link results in a throughput gain of 2.5 Gbps.



Conclusions

- We provide an architecture for modeling WLAN IEEE 802.11ad with its various enhancements in ns-3.
- We implement beamforming training and steering, relay operation, and fast session transfer.
- We rely on simple channel and error models.
- Finally, we evaluate the previous mechanisms for different scenarios and shows their benefits.
- The source code of our implementation is publicly available at GitHub on the following URL:

https://github.com/hanyassasa87/ns3-802.11ad

Future Work

We are planning to extend the model and support the following features and mechanisms:

- Half Duplex DMG Relay Support.
- Fast Link Adaptation.
- Dynamic Channel Allocation (Polling).
- Reverse Direction Protocol (RDP).
- More accurate channel model and propagation model.
- Handover support.
- Merge the model with ns-3 mainline.

Acknowledgements

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