5G and Satellite Network Coexistence in FR3 Spectrum

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OUR TEAM

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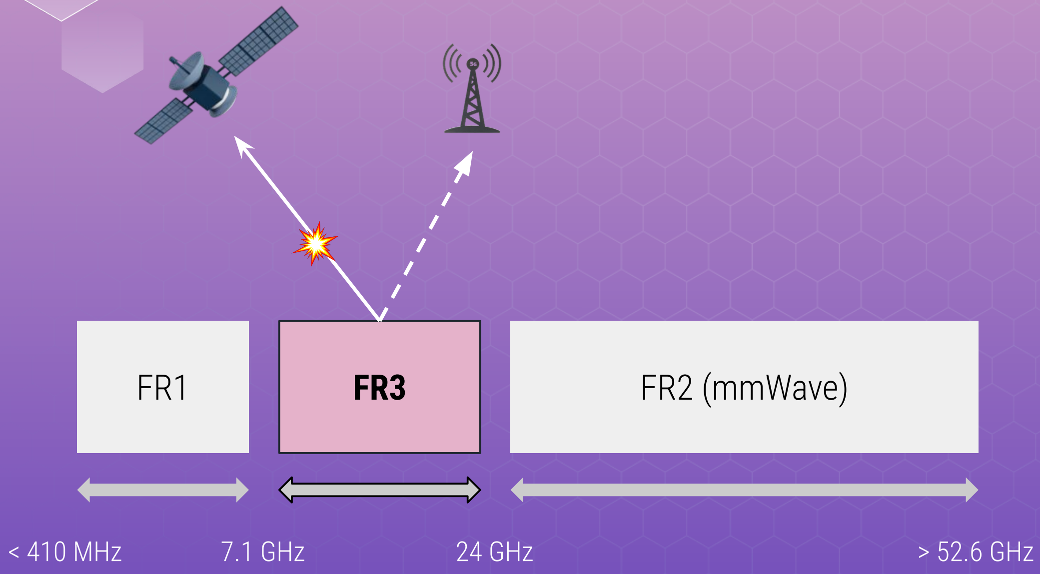
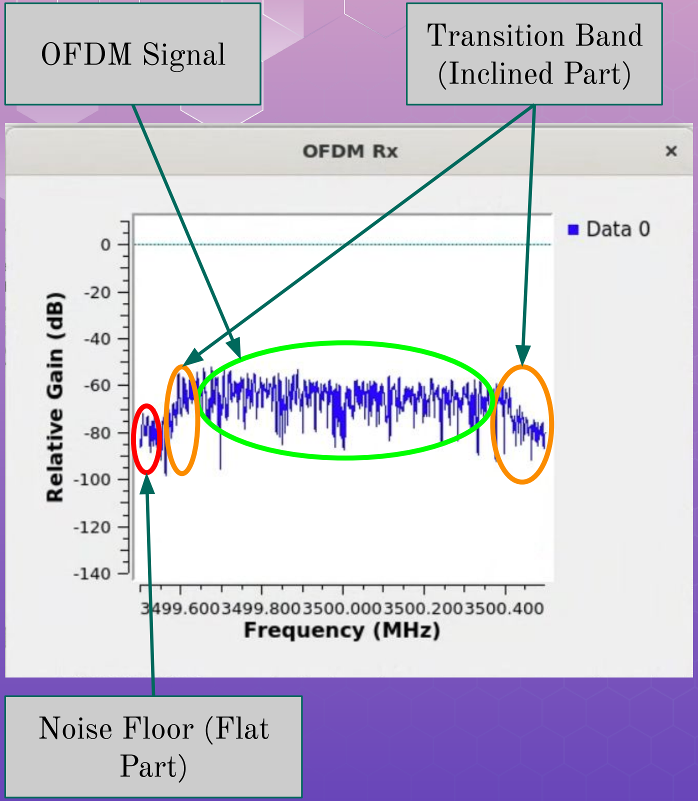
- Background in Python and ML

Motivation

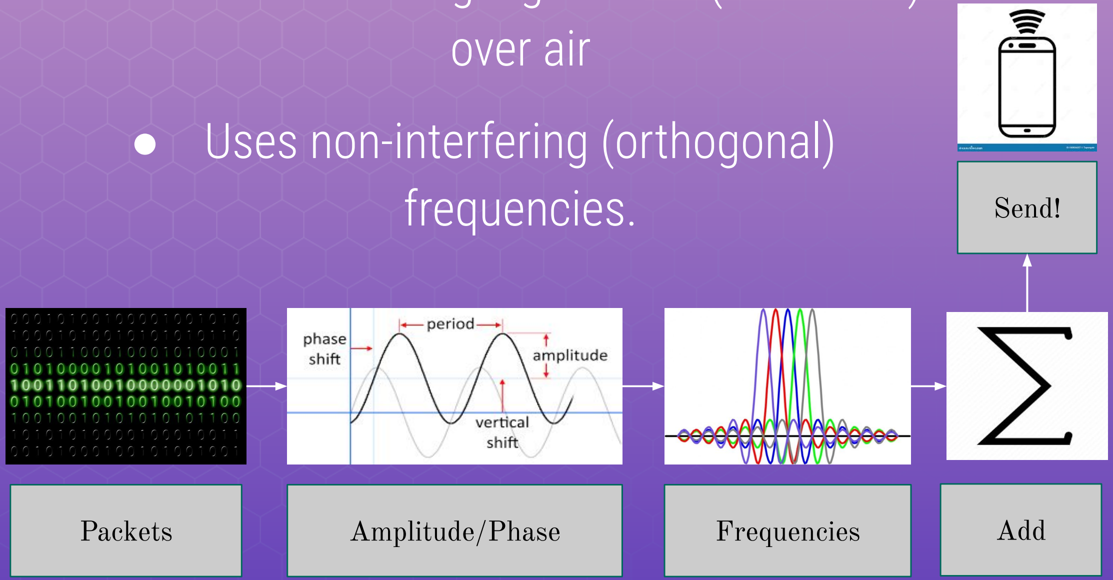


- Satellites (SAT) use the FR3 Spectrum to **transmit (Tx)** and **receive (Rx)** signals
- The band is considered a potential space for 5G.
- Existing mmWave trades off high speed for short range.

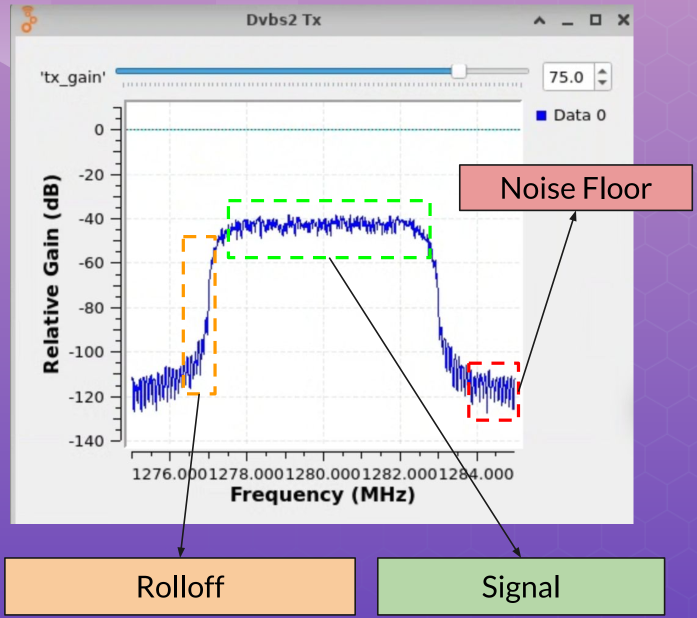
OFDM Transmission and Reception

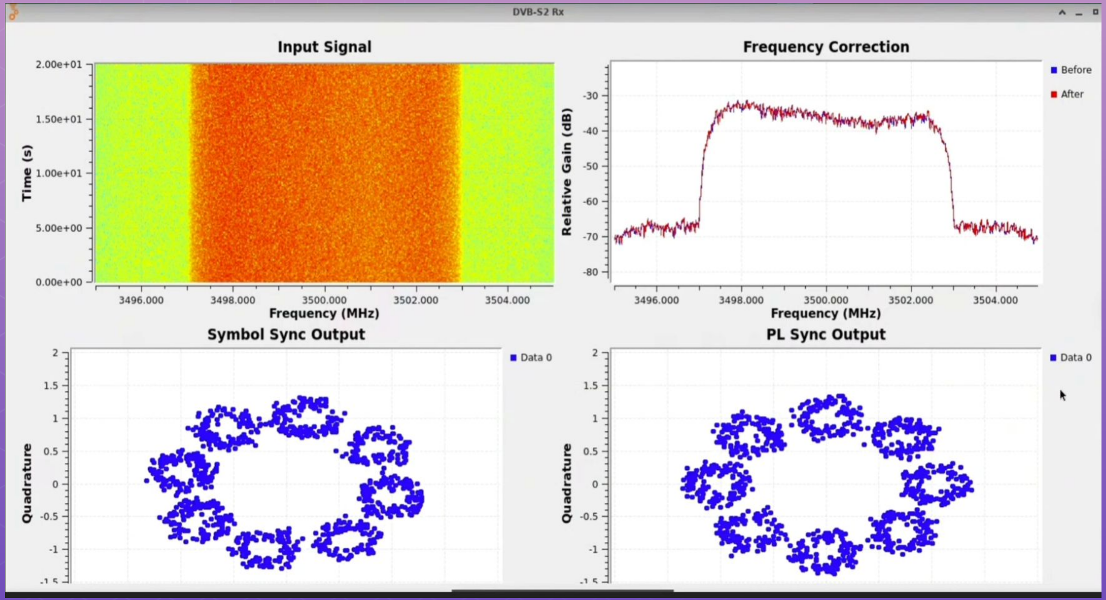


- Orthogonal Frequency Division Multiplexing for 5G
- Method of sending digital data (1s and 0s) over air
- Uses non-interfering (orthogonal) frequencies.



SAT Transmission and Reception

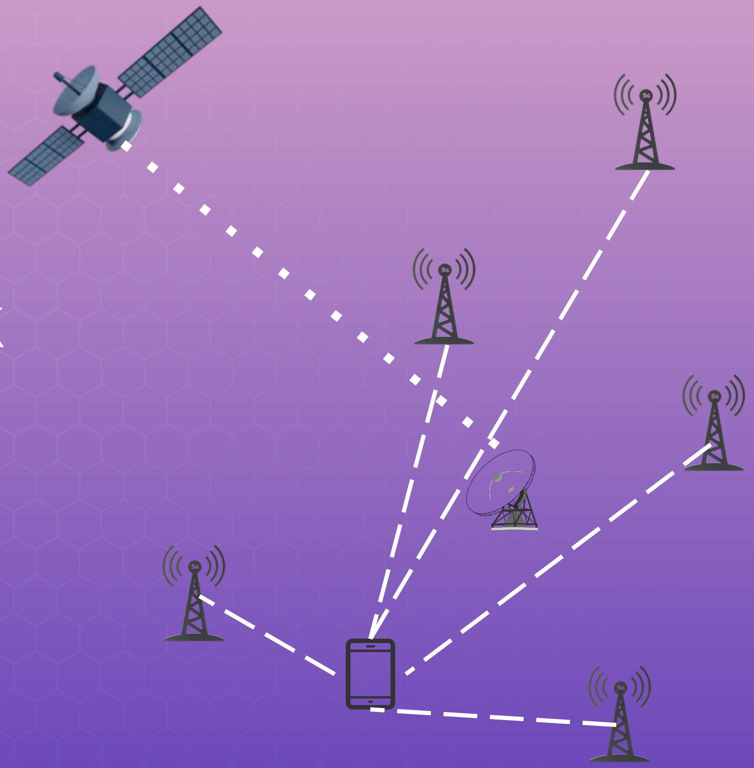




OFDM Tx and DVB-S2 Rx Simultaneously

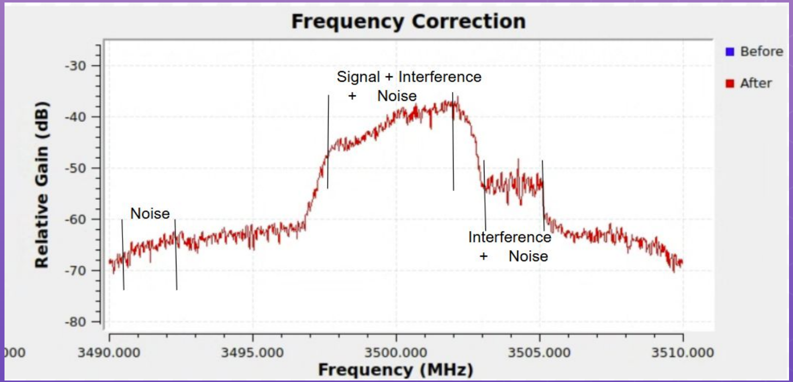
Overall Goal

- Develop a dynamic radio network on the ORBIT testbed that optimizes signal parameters
    - SINR, PER



S I N R

SIGNAL INTERFERENCE NOISE RATIO



$$SINR = \frac{Signal}{Interference + Noise}$$

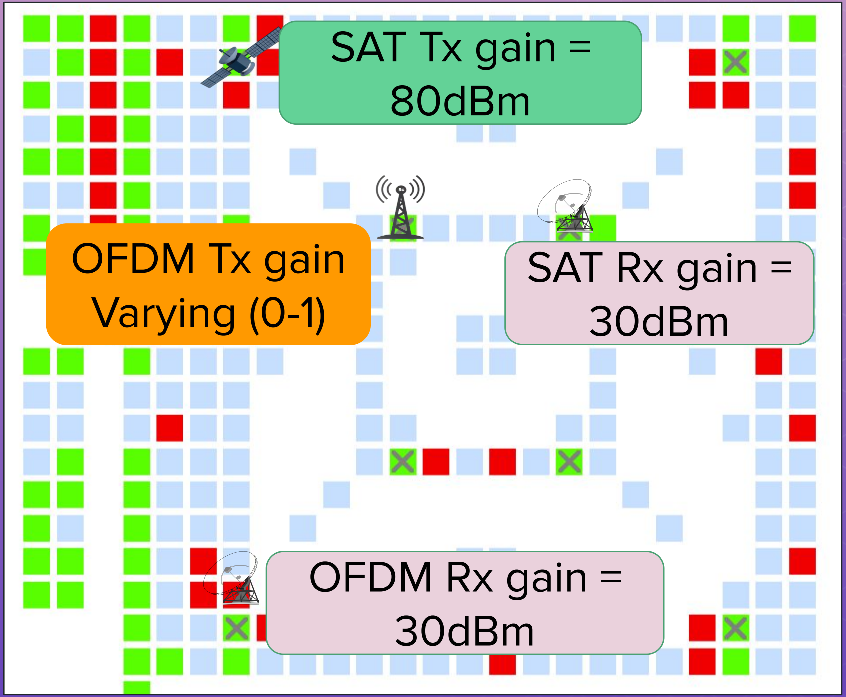
P E R

PACKET ERROR RATE

- Tells us how much of the packets didn’t get to the receiver safely
- Less than 5% is generally considered acceptable

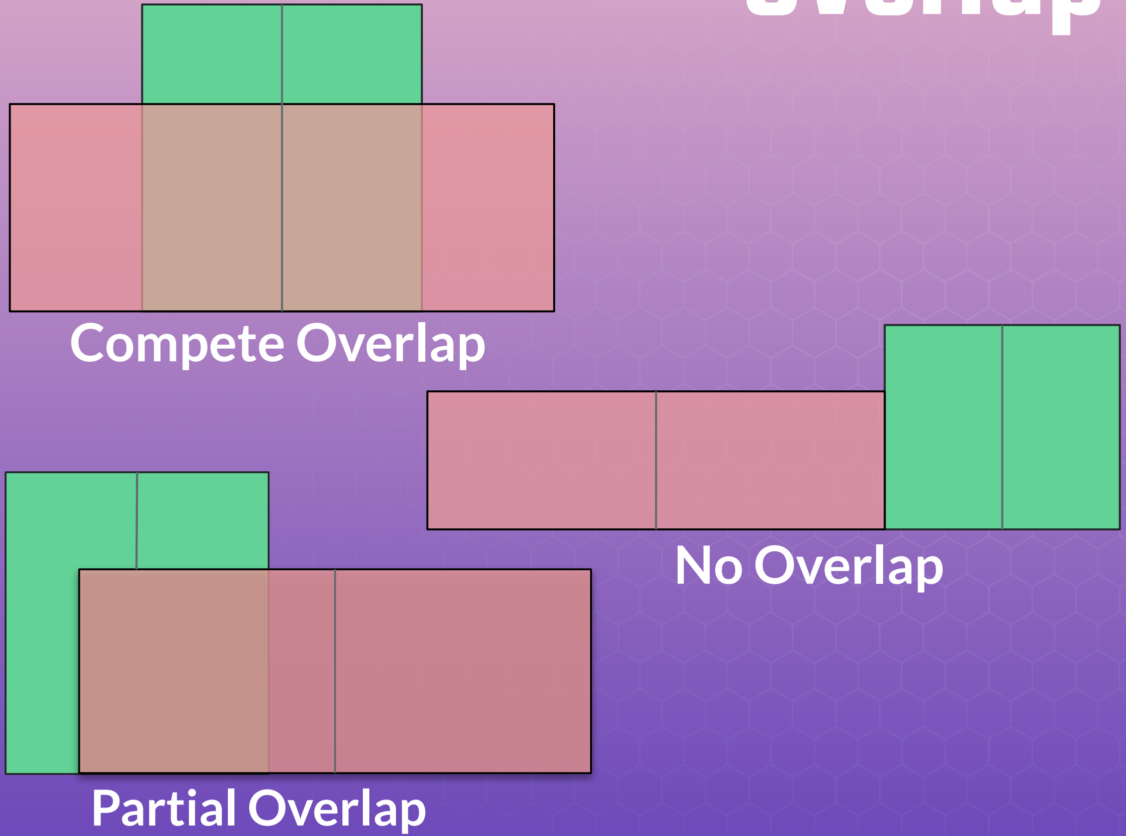
$$PER = 1 - \frac{Packets\ Received}{Total\ Packets\ Sent}$$

Data Collection



- Adjust normalised OFDM gains (amplification)
- Adjusted center frequencies from 3.49-3.51 GHz

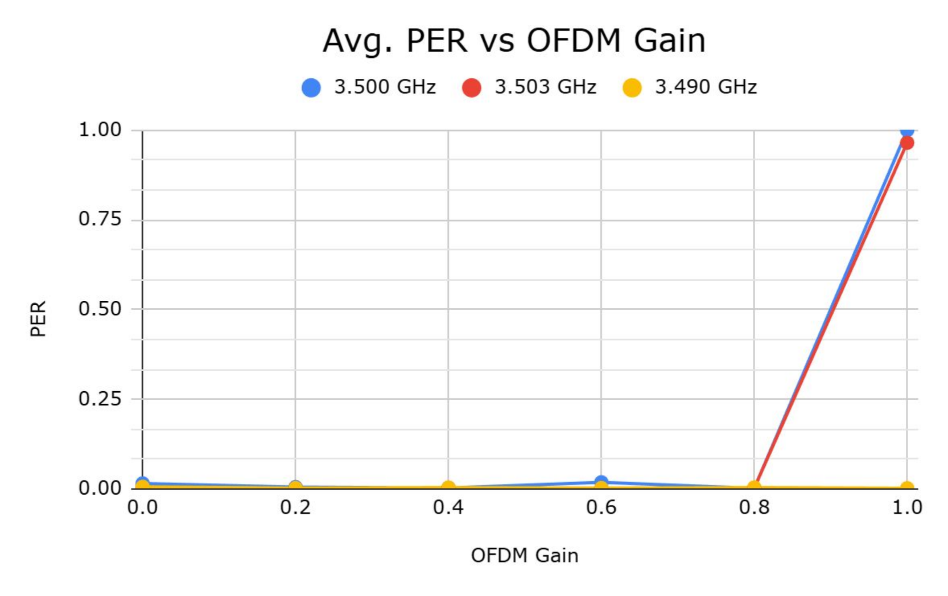
Overlap

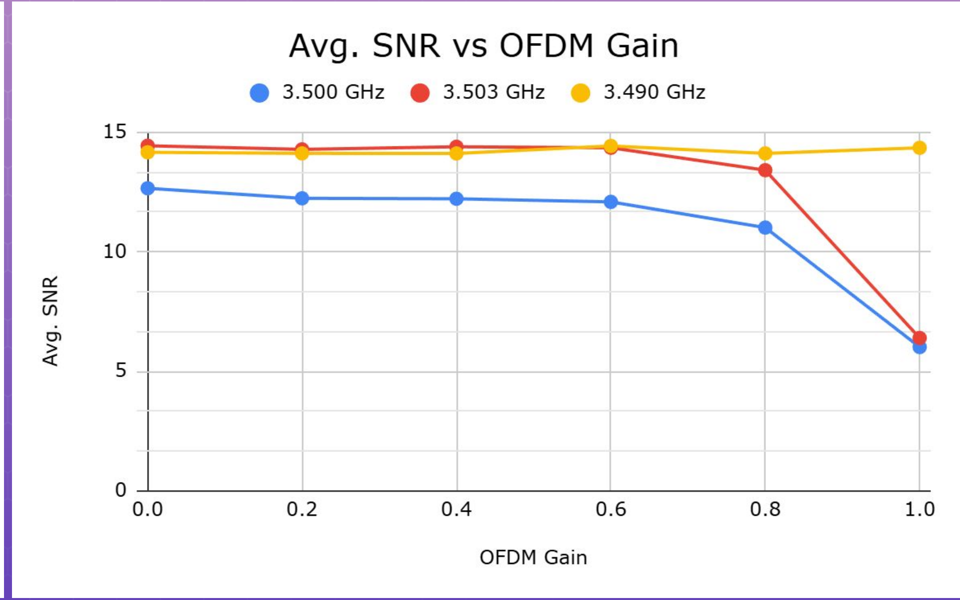


- SAT (green) Bandwidth of 6 MHz
- OFDM (red) Bandwidth of 10 MHz

Observed PER and SNR for Varying Overlaps

Complete Overlap   Partial Overlap   No Overlap

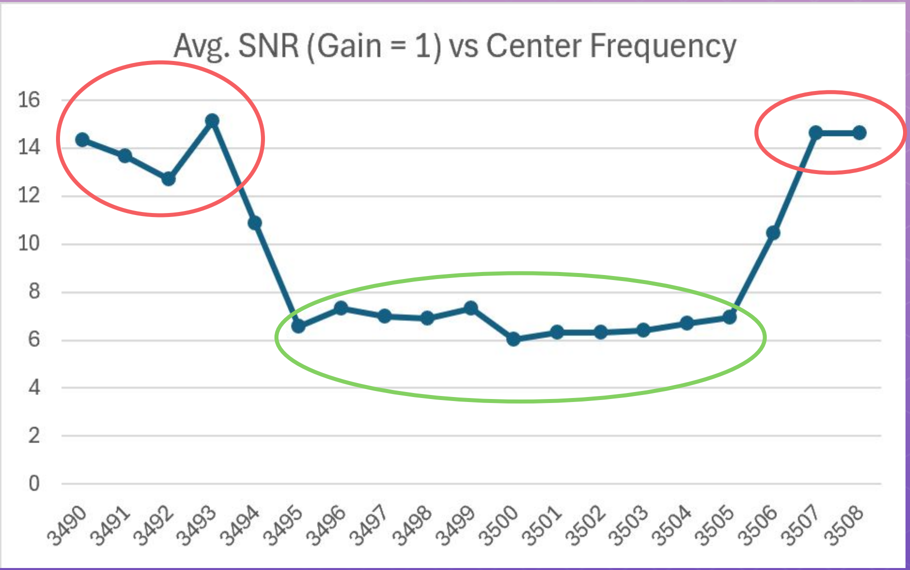




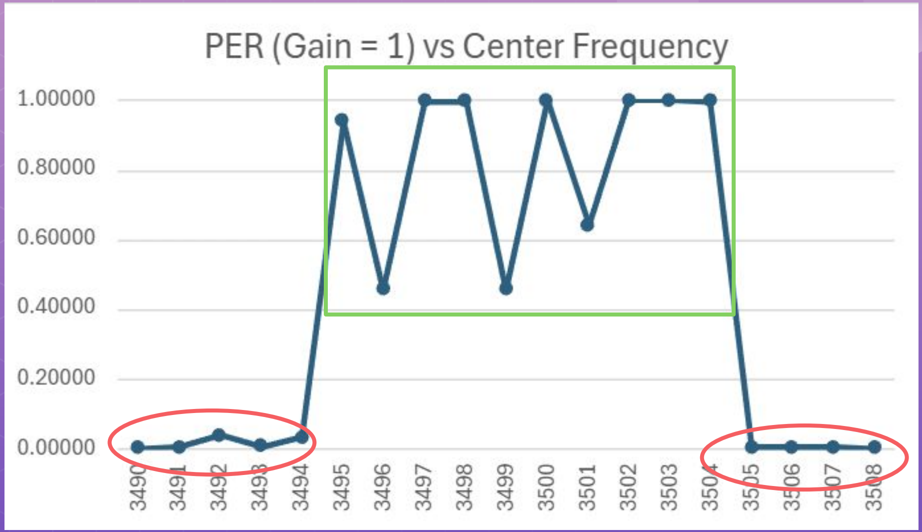
Analysis

No Overlap

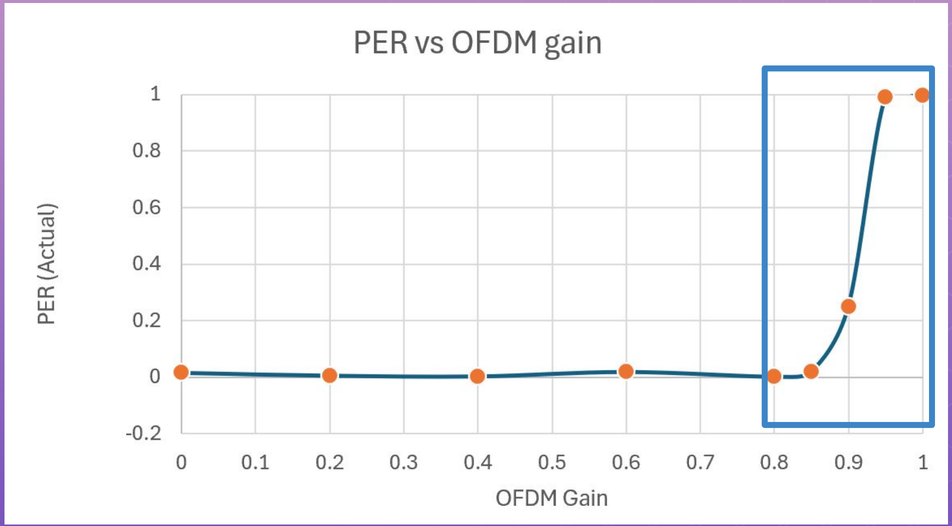
No Overlap



Complete/Partial Overlap



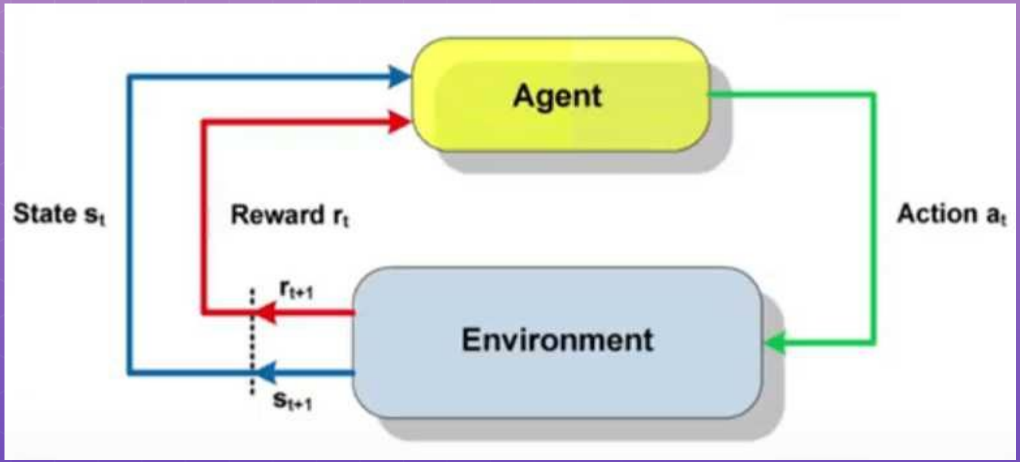
Model Justification



- A generally acceptable PER is below 5%.
- High PER during full-power 5G suggests interference with satellites.
- Therefore, dynamic spectrum sharing is warranted.

What is Reinforcement Learning (RL)?

- ML where Agent learns to make optimal decisions by interacting with an Environment
- Agent is guided by a system of rewards and penalties



Coexistence in FR3 Spectrum

Environment

Orbit Testbed

State

SINR at FFT sensors

PER at DVB-S2 RX

SINR at OFDM RX

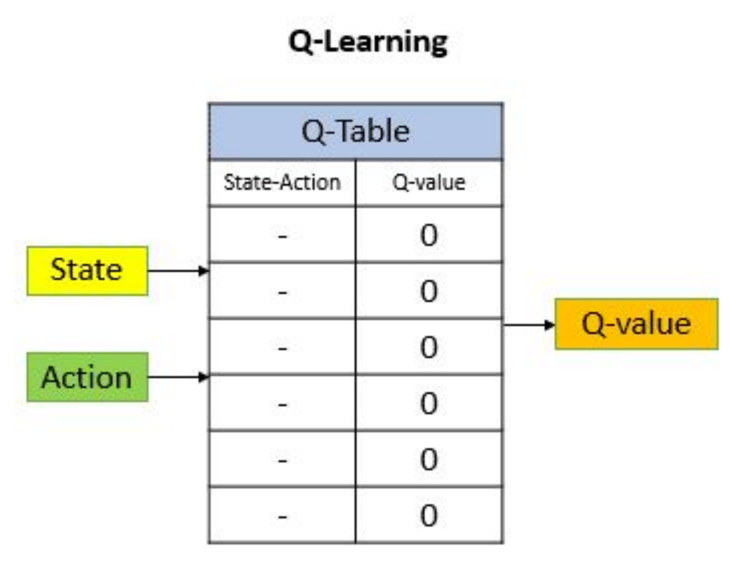
Action

Change OFDM Gain/CF

Reward

Feedback on Action

Tabular Q-Learning



- **States:** SINR/PER values are discretized into bins
- **Actions:** A set of discrete (Gain, Frequency) pairs.
- **Q-value:** the predicted long-term reward for taking an Action in a given State.

Learning Process

Old Q Value   Reward   Discount Rate (0 ~ 1)

$$Q(s,a) \leftarrow Q(s,a) + \alpha\big(\underbrace{r + \gamma \underset{\text{Maximum Q value of transition destination state}}{\underline{\max_{a'} Q(s',a')}} - Q(s,a)}_{\text{TD error}}\big)$$

New Q Value   Learning Rate (0 ~ 1)

Bellman Equation

- Value of a decision is the immediate reward you get, plus the value of the best decision you can make next

Reward Function

Rewards high SNR

$$\text{fft\_score} = \frac{\text{fft\_sinr} - 5}{5}$$

$$\text{ofdm\_score} = \begin{cases} \frac{\text{ofdm\_snr} - 3}{3}, & \text{if ofdm\_snr} < 3 \\ -0.01, & \text{otherwise} \end{cases}$$

Penalizes high SAT PER

$$\text{per\_score} = -2 \cdot \left(\frac{\text{dvb\_per}}{100} \right)$$

Rewards being closer to 3500 MHz (SAT center frequency)

$$\text{cf\_score} = 1 - \frac{|\text{cf\_mhz} - 3500|}{8}$$

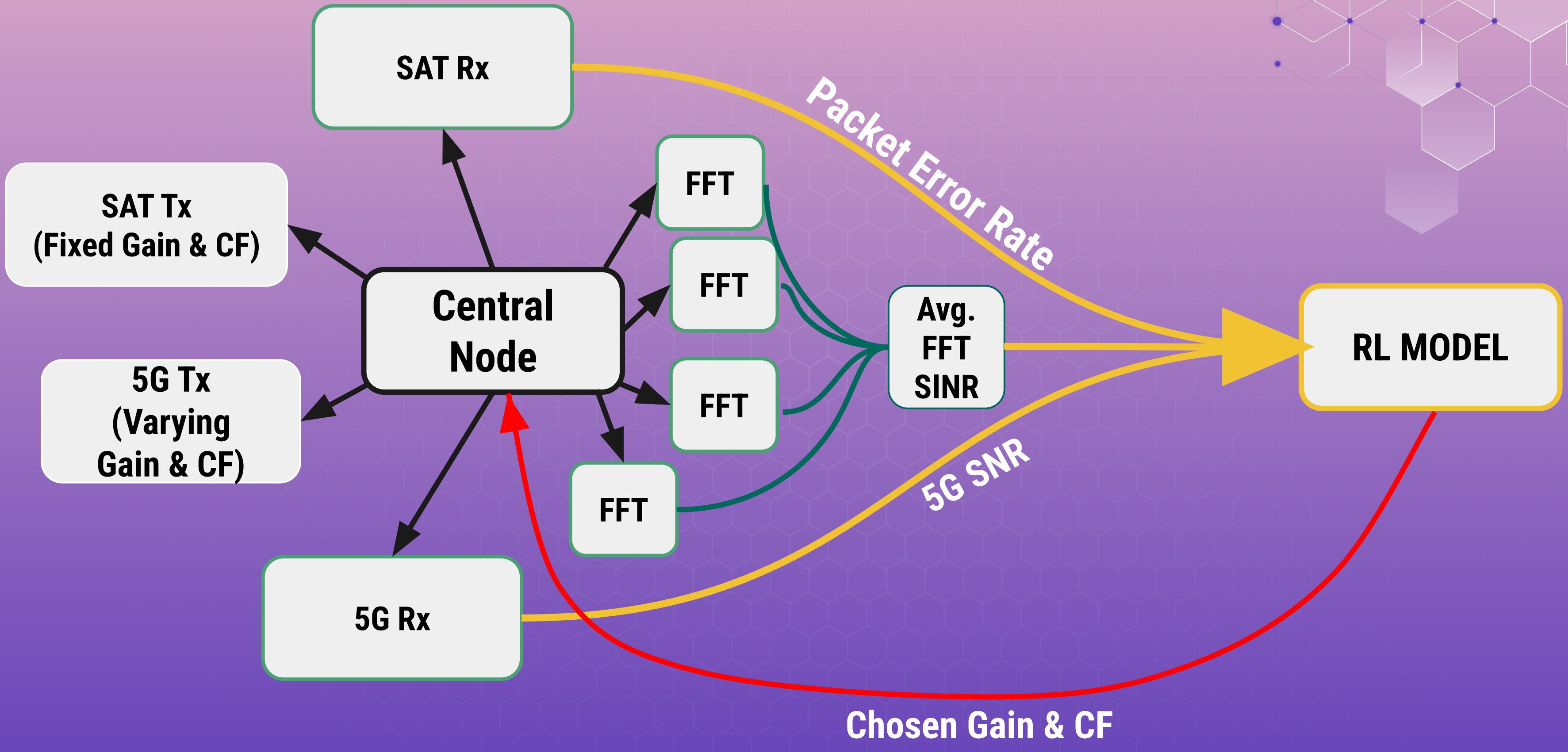
Weights used to calculate total reward

$$\text{reward} = \text{fft\_score} + \text{ofdm\_score} + \text{per\_score} + \text{cf\_score}$$

Penalty for using OFDM CF with no overlap (not coexistence)

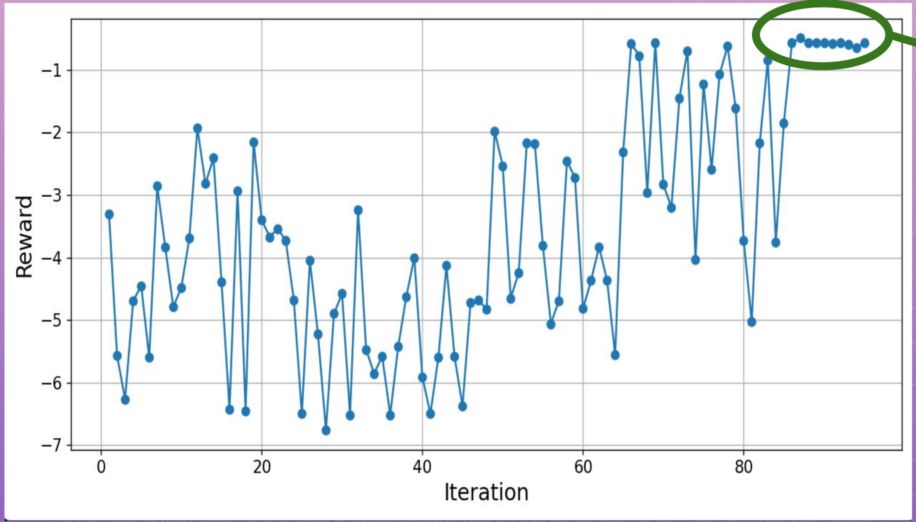
$$\text{reward} -= 0.5 \quad \text{if cf\_mhz} \in \text{NO\_OVERLAP\_FREQS}$$

Pipeline

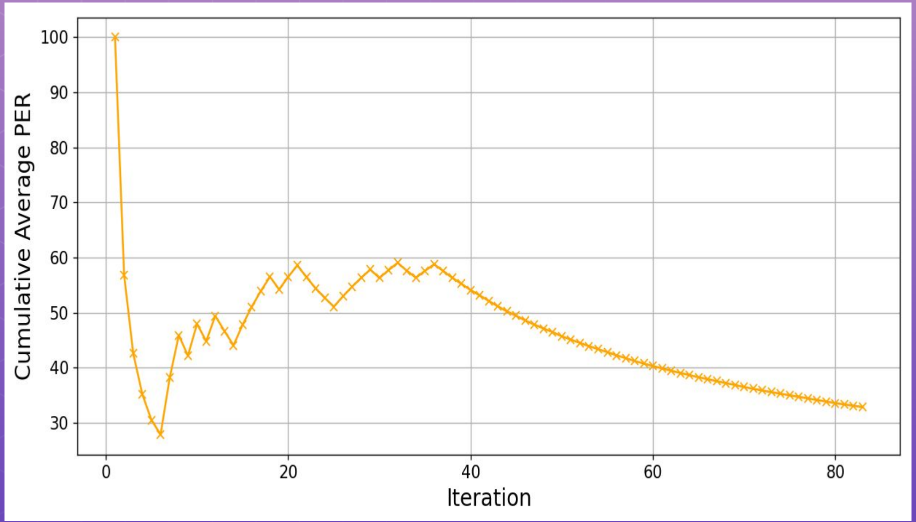


SAT Rx
SAT Tx
(Fixed Gain & CF)
5G Tx
(Varying
Gain & CF)
Central
Node
5G Rx
FFT
FFT
FFT
FFT
Avg.
FFT
SINR
Packet Error Rate
5G SNR
RL MODEL
Chosen Gain & CF

Results



Reward Saturation



FUTURE WORK

Action Space

Implement SAT Rx location and directional antenna changes into the action space.

Bit Error Rate (BER)

Utilize BER as a more accurate performance metric compared to PER

Deep Q-Networks (DQN)

Experiment w/ DQN using policy and target networks, w/ a replay buffer for stabilized training.

THANKS!
ANY QUESTIONS?