A Spectrum Consumption Model-based Framework for DSA Experimentation on the COSMOS Testbed

ACM WiNTECH 2021

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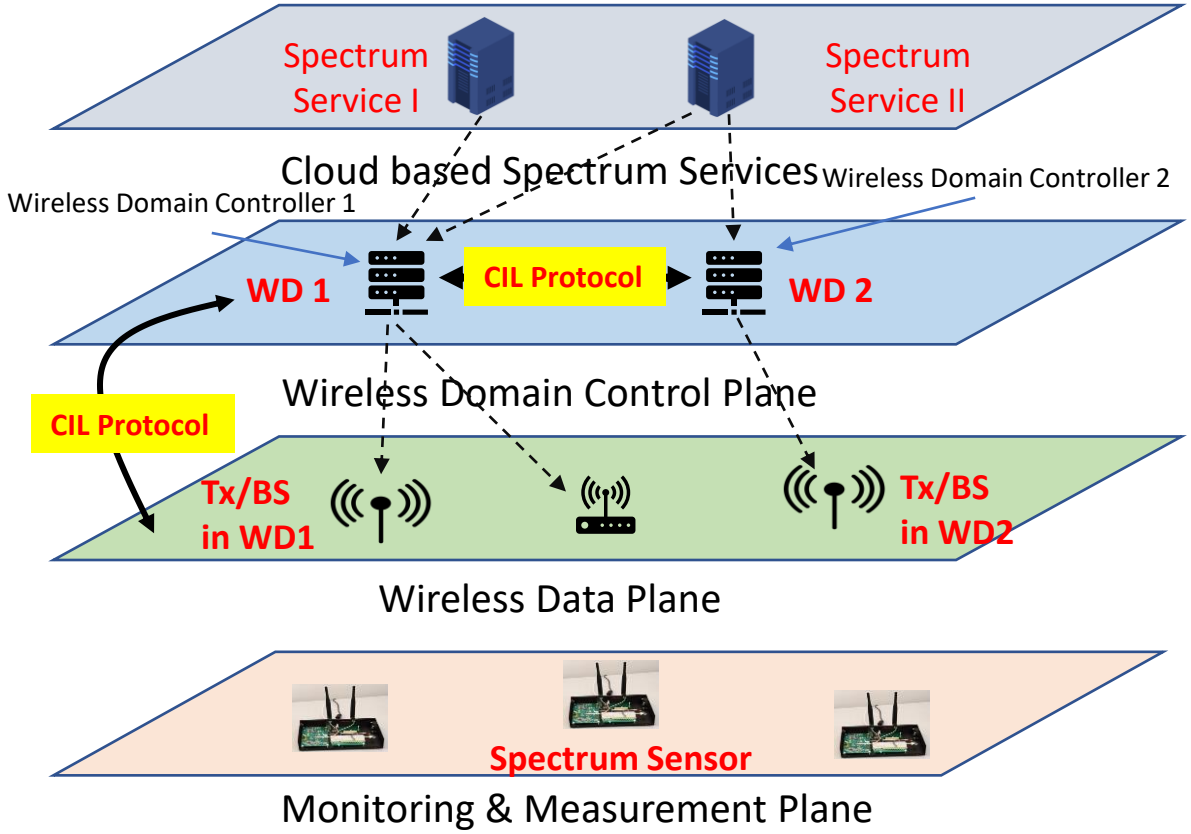
Motivation and Objectives

- Next generation wireless services and applications, including AR, IoT, and Smart-Cities, will increasingly rely on **Dynamic Spectrum Access** (DSA) methods enabling heterogeneous devices to share limited spectrum resources and coexist harmoniously

- We propose a new spectrum management architecture and experimentation framework to be tested in COSMOS

- SCM + CIL are used for spectrum coordination between multiple wireless networks



High Level Dynamic Spectrum Architecture

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Spectrum Consumption Models (SCMs)

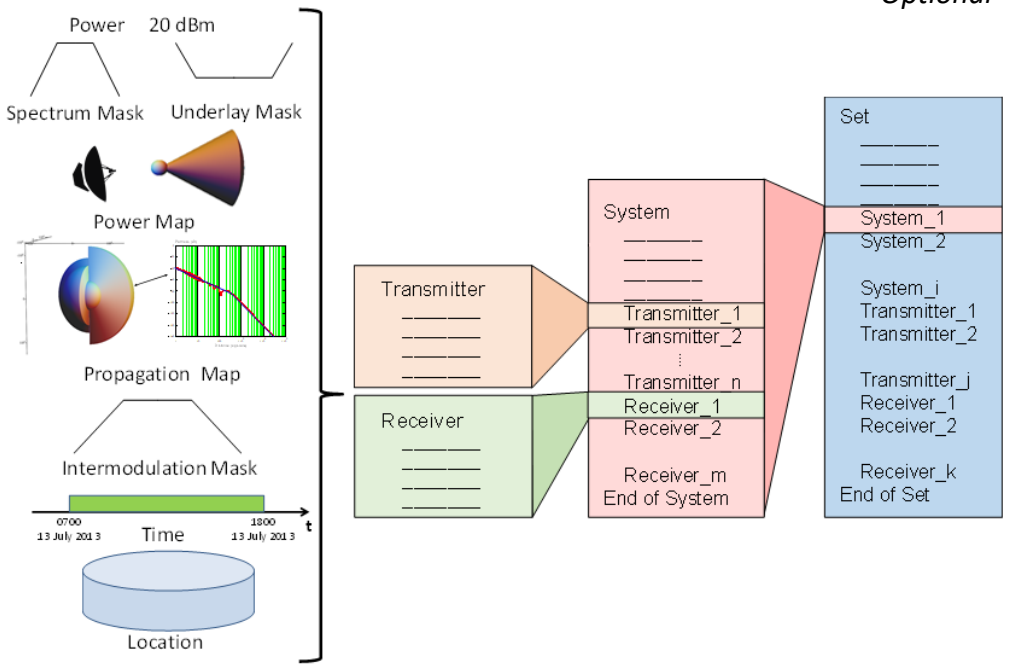
- (Data model that) Provides means to capture all the relevant parameters and phenomena that affect spectrum consumption for a device or spectrum dependent system

- **SCMs** support methods to compute compatibility (i.e., non-interference) between any two models without dependence on external databases of environmental or system data

SCM Constructs (IEEE 1900.5.2)

- Reference power
- Spectrum mask
- Underlay mask
- Power map
- Propagation map
- *Intermodulation masks**
- *Platform**
- Location
- Schedule
- *Minimum power spectral flux density **
- *Protocol or policy **

** Optional*



- Transmitter Model
- Receiver Model
- System Model
  - Consists of transmitter and receiver models that are part of a system
- Sets
  - Collective Consumption Set
  - Spectrum Authorization Set
  - Spectrum Constraint Set

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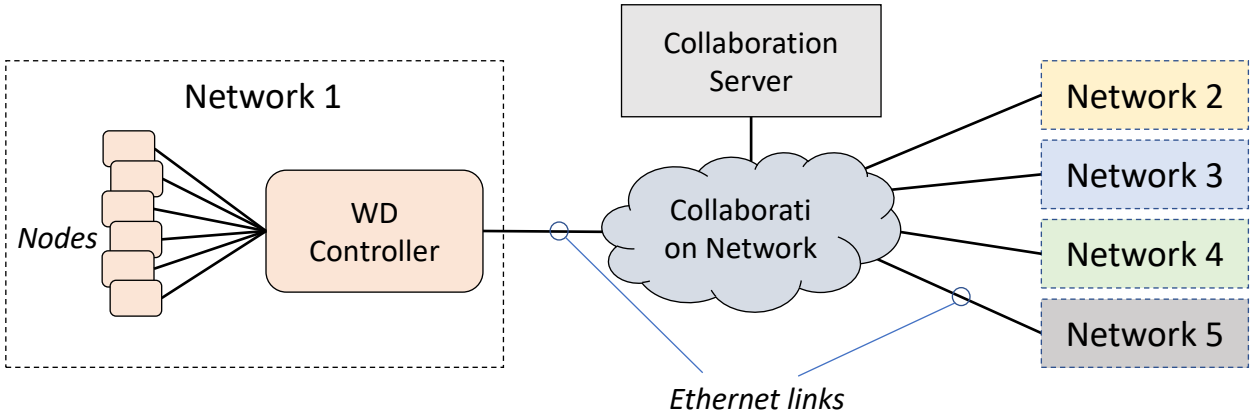
Architecture and Protocol

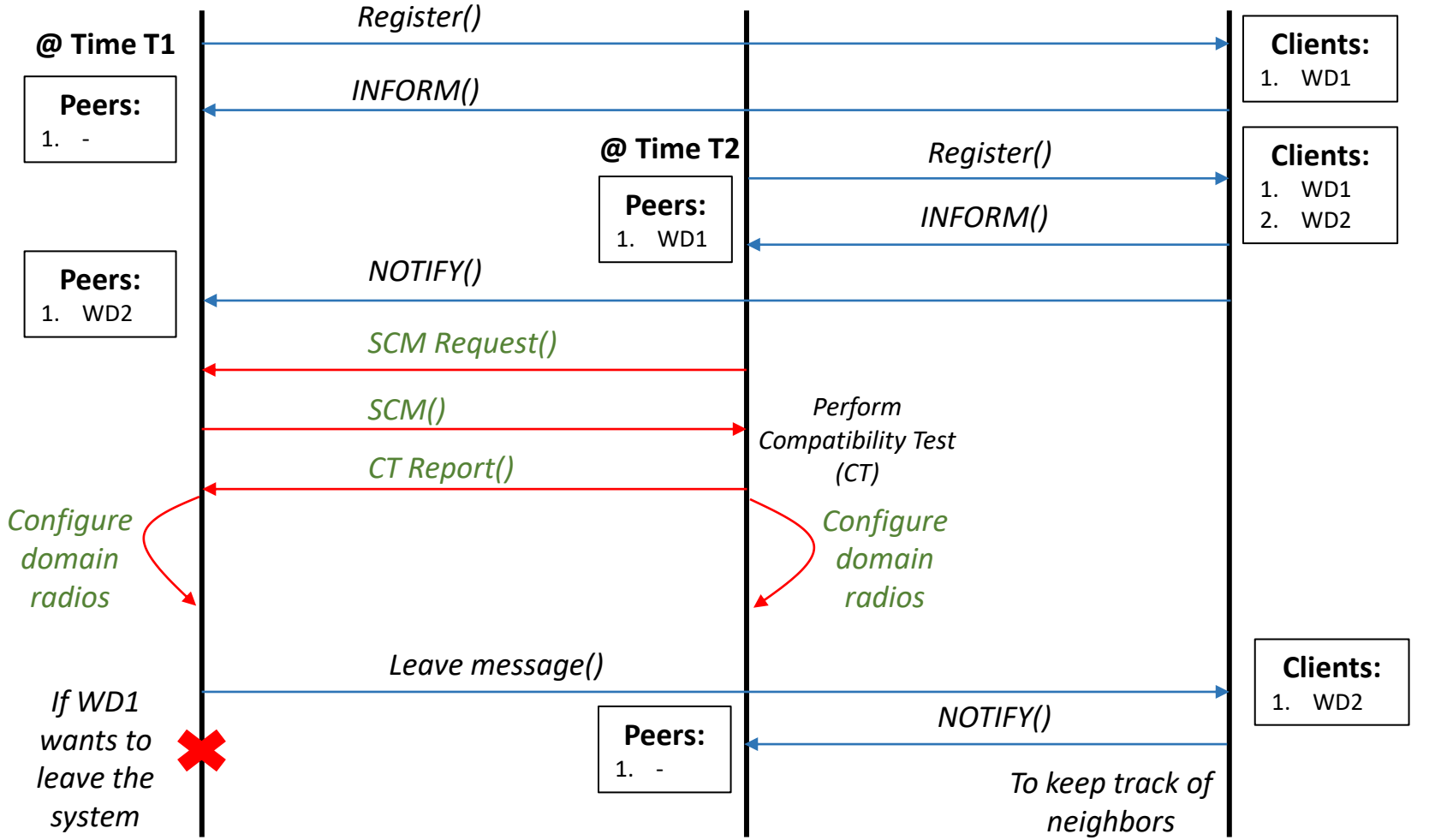


- **CIL** – collaboratively designed by competitors for DARPA SC2 as a language enabling coordination and synchronization between independent networks
- Implemented as a PUB/SUB service for several types of messages
- In our work, we extended CIL to support the exchange of protobuf representations of **SCMs** and other configuration and event messages

CIL Protocol:

- Register () :
  - *Generated by WD to register with collaboration server/System*
- Inform ():
  - *Informs newly joined peer about existing peers*
- Notify ():
  - *Notifies existing peers about the new joined peer*
- SCM Request ():
  - *Message to request SCMs from peers*
- SCM ():
  - *Message to send SCM to the requester (protobuf)*
- CT Report ():
  - Sends compatibility test report to peers
- Calibrate Radios ():
  - *Message to calibrate SDRs with respective gain, frequency, modulation, etc.*
- Leave ():
  - *Generated by WD to exit the system*

Timing Diagram: (DARPA CIL + SCM)



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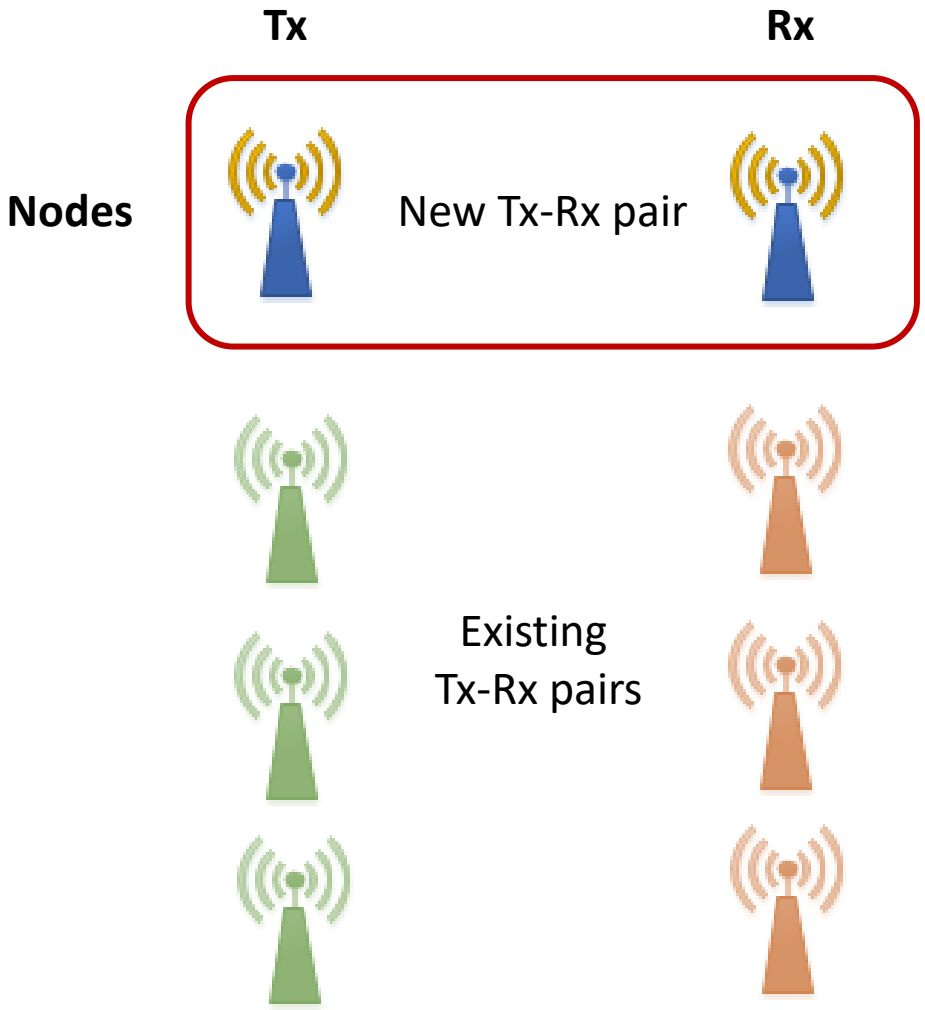
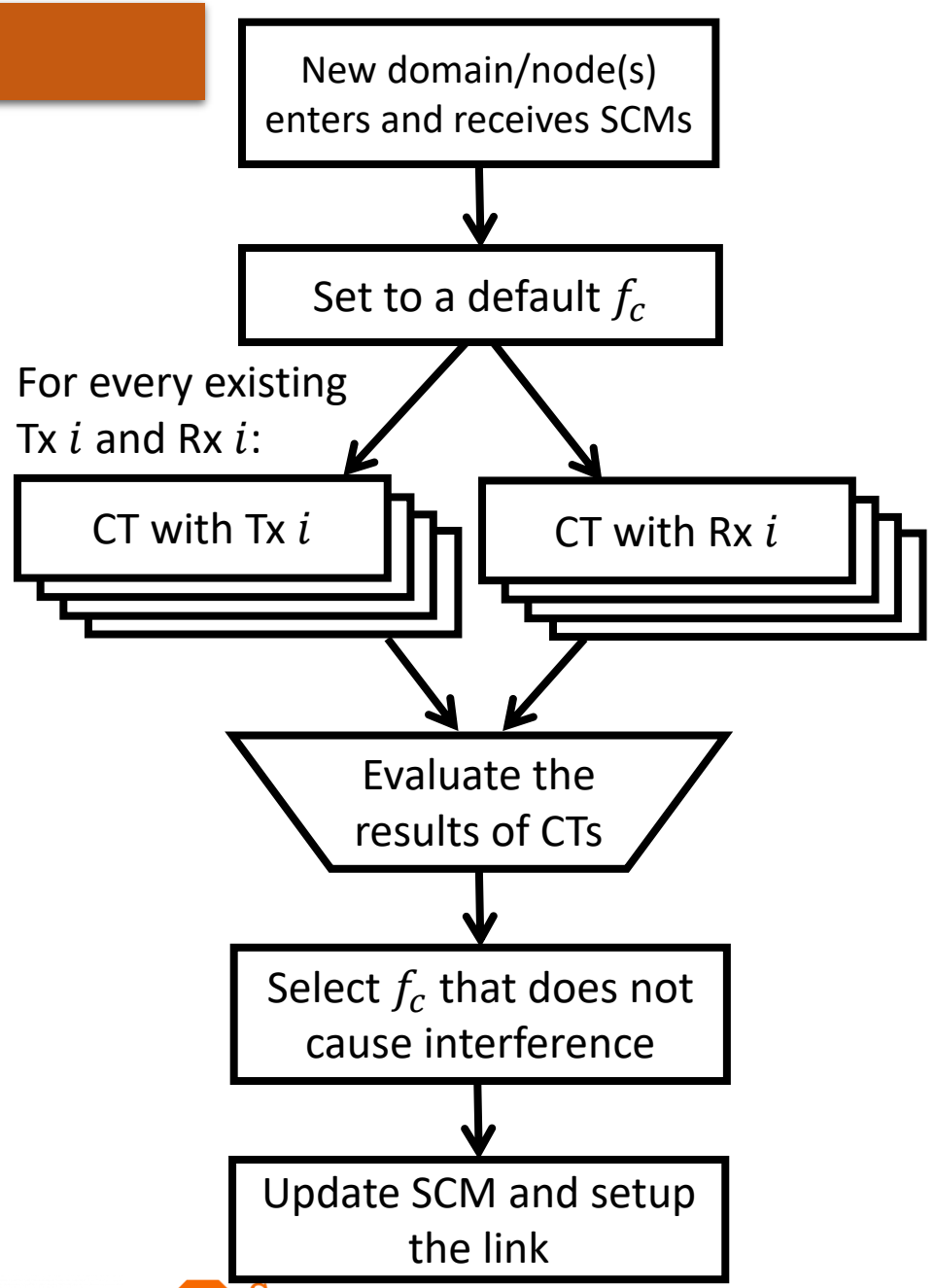
Algorithm: Illustrative Implementation





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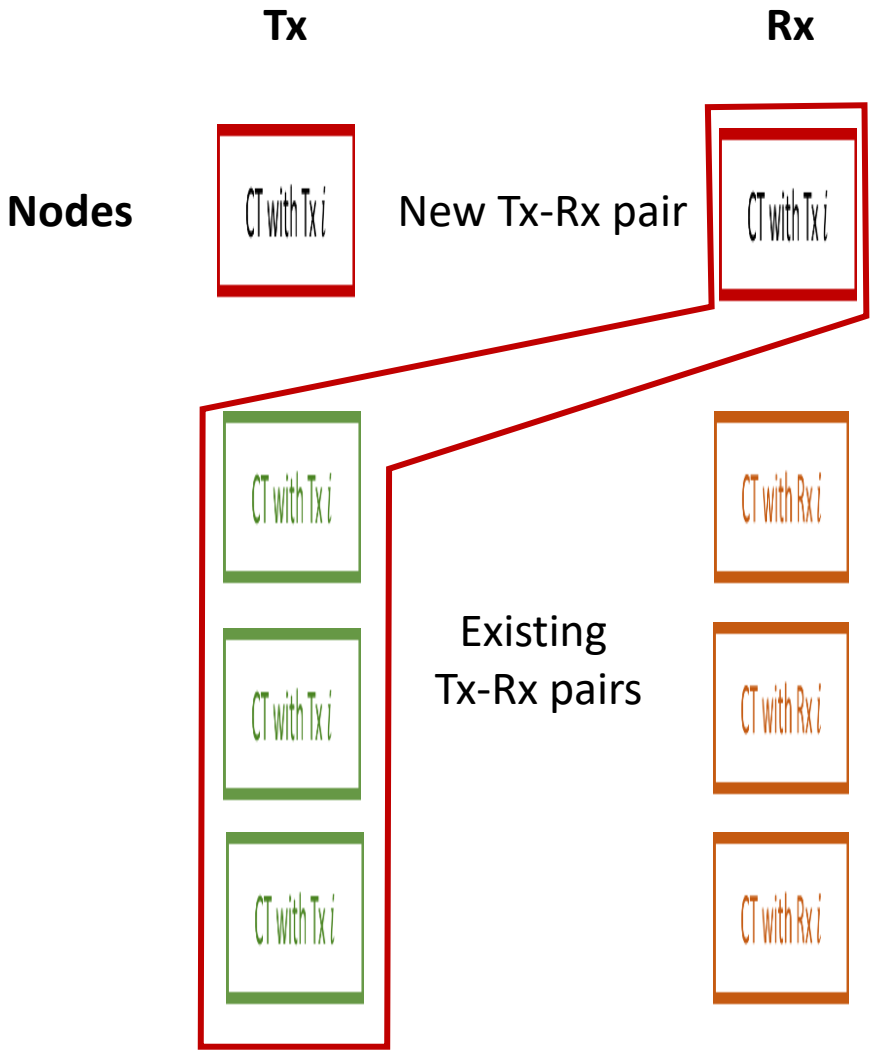
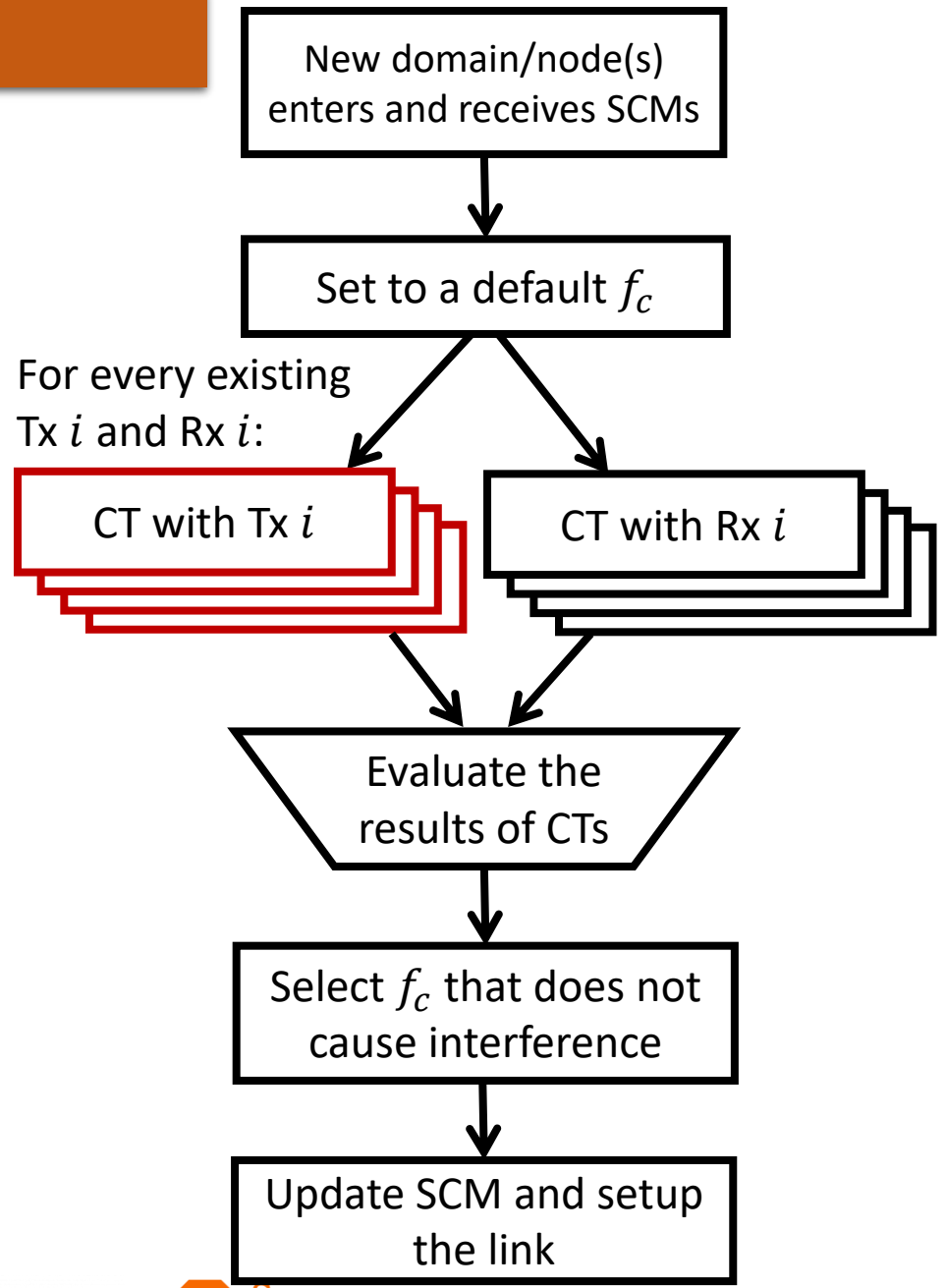
Algorithm: Current Implementation





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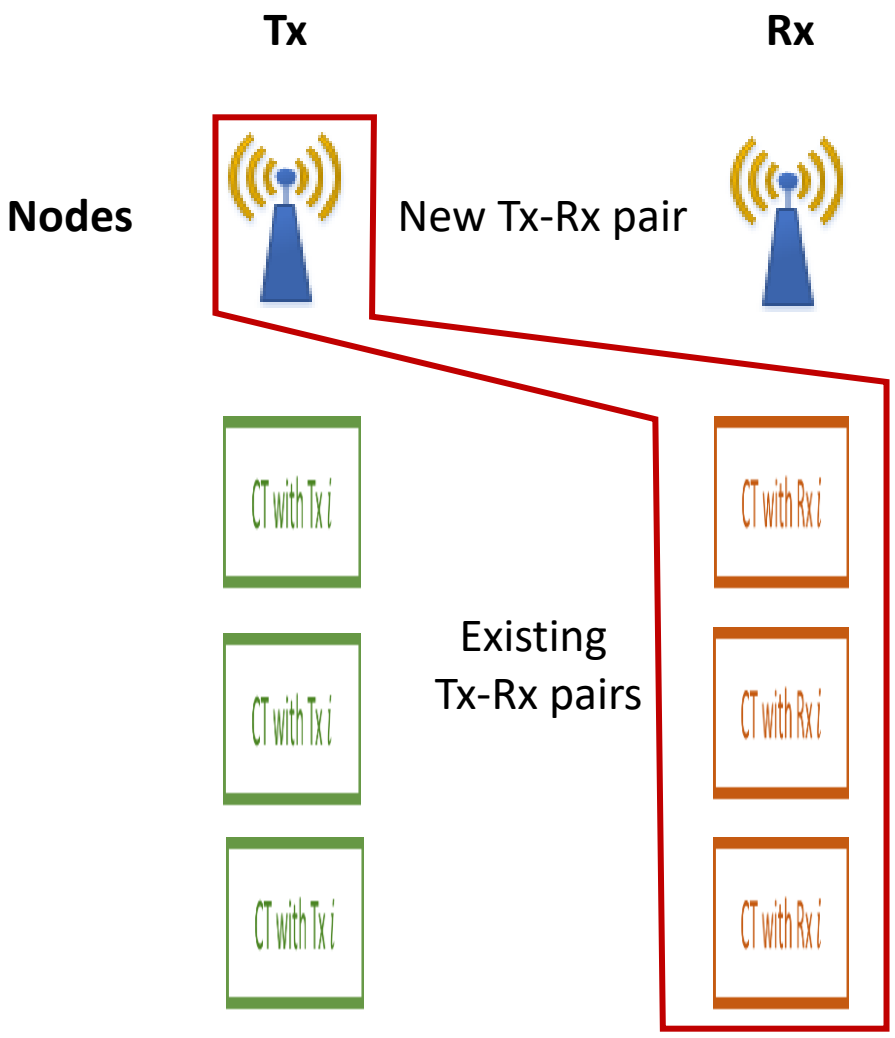
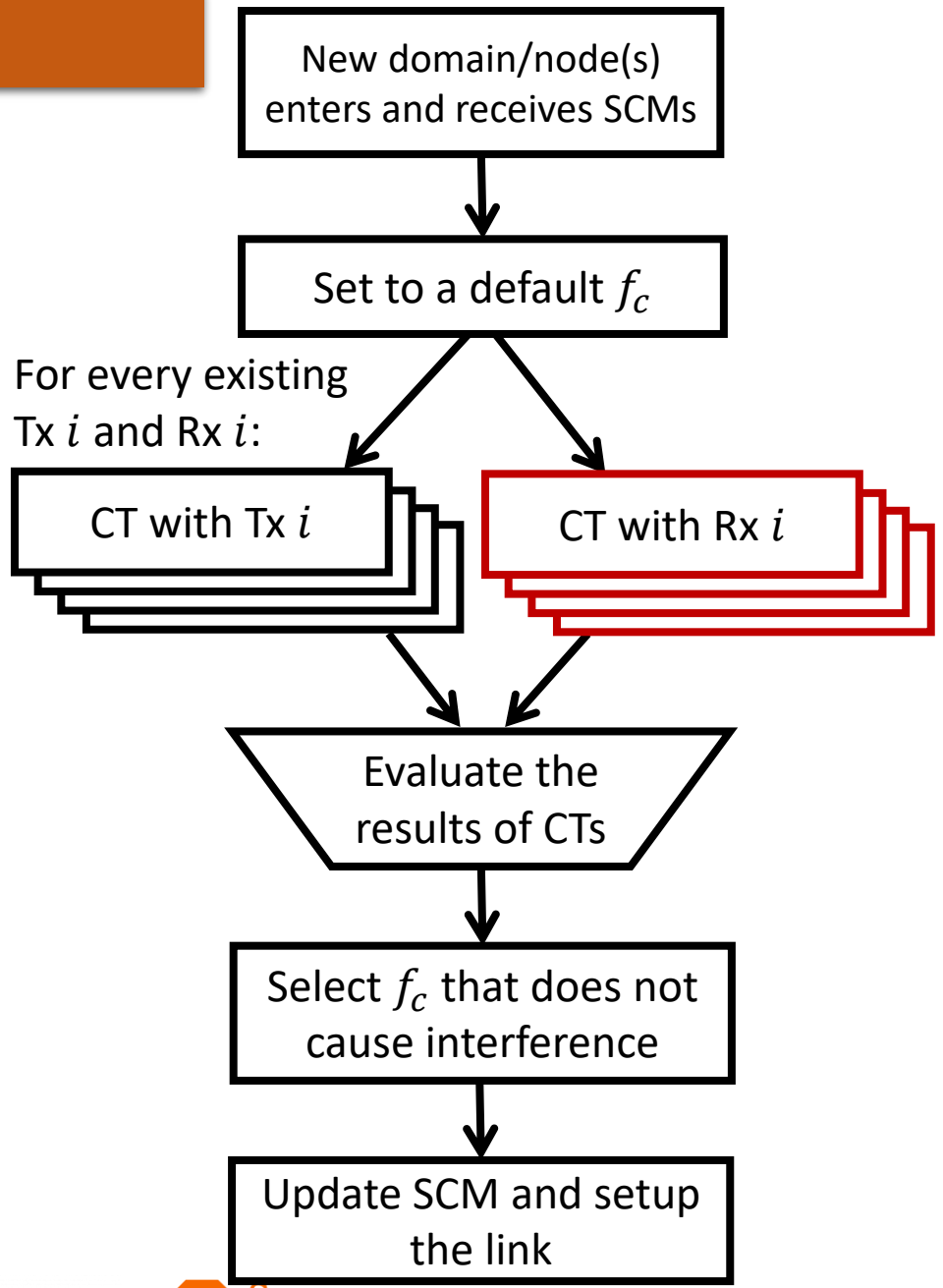
Algorithm: Current Implementation





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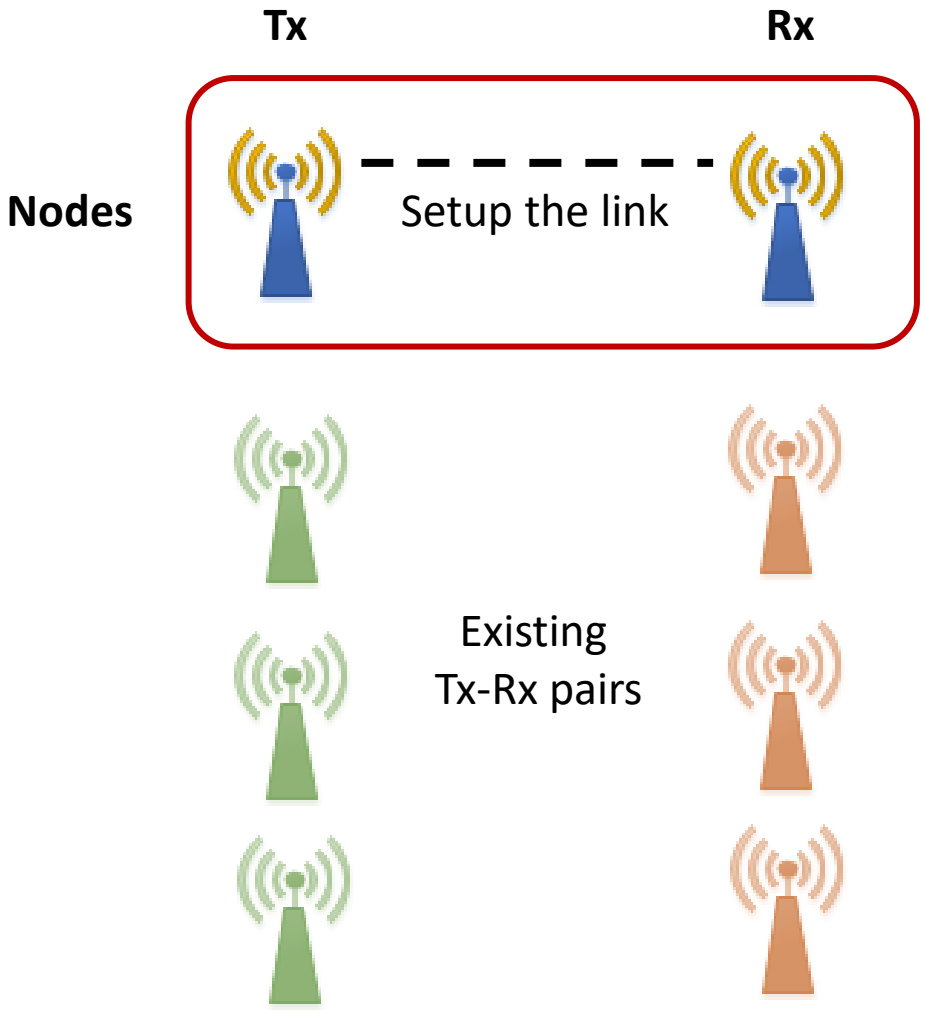

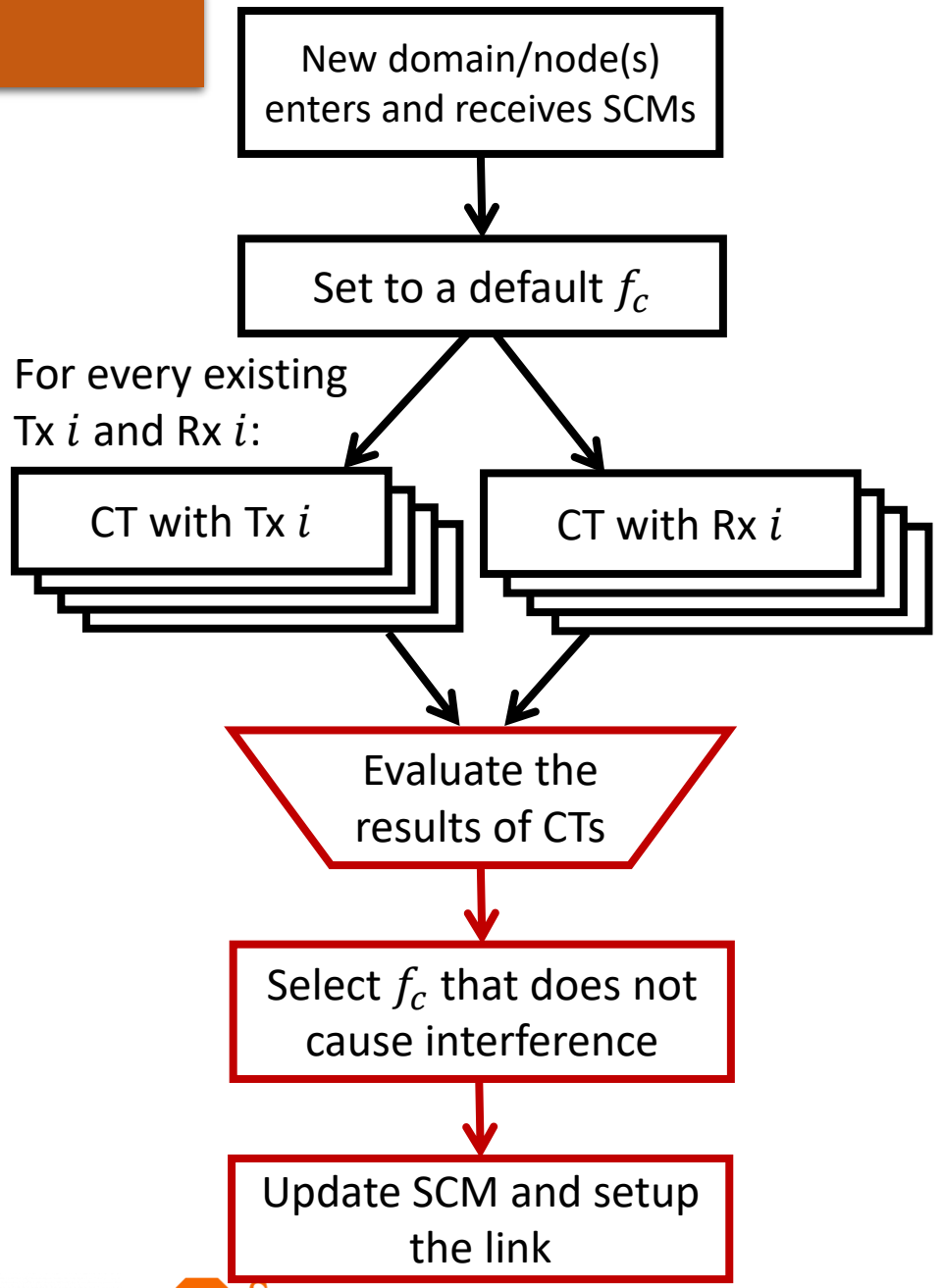

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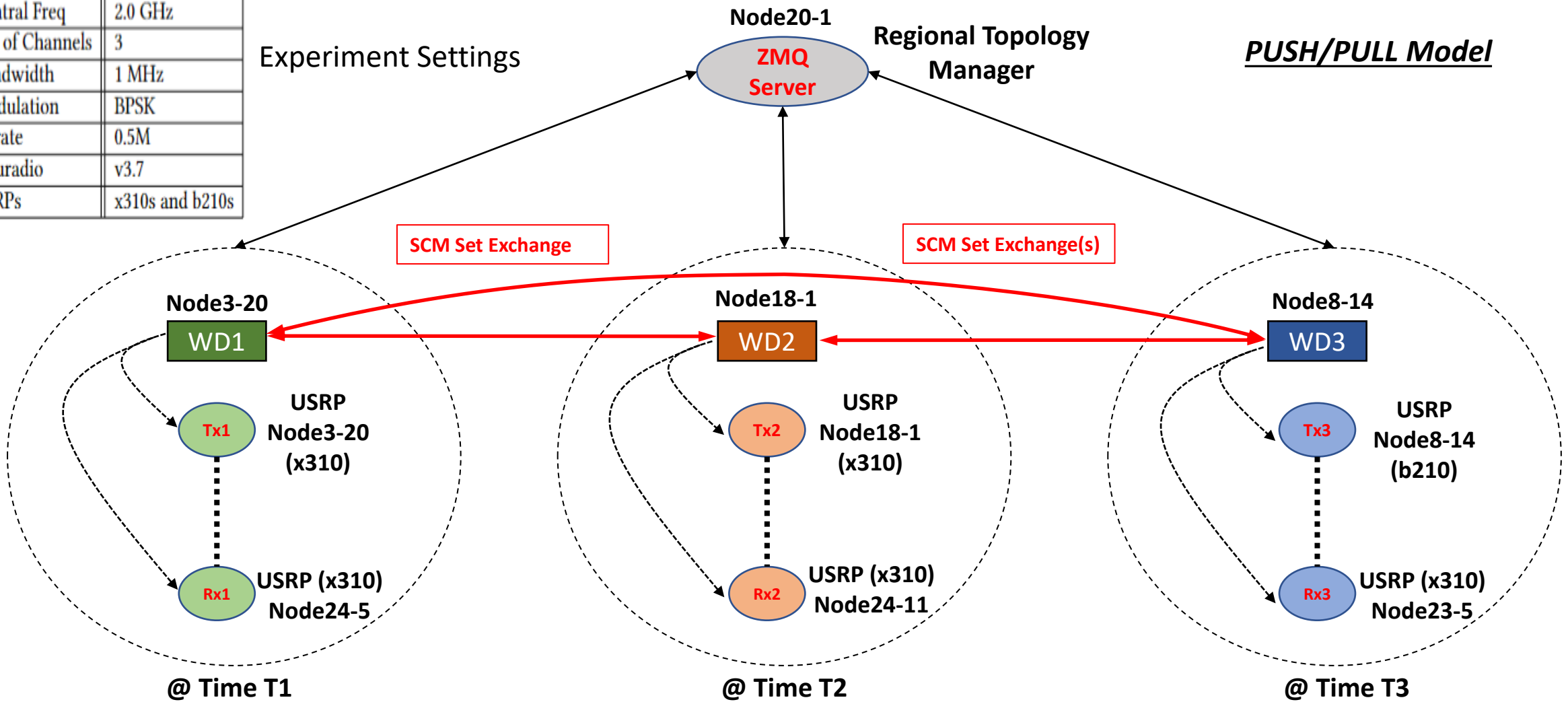
Experimental Setup: COSMOS Sandbox (ORBIT GRID)

Parameter	Value
Central Freq	2.0 GHz
No. of Channels	3
Bandwidth	1 MHz
Modulation	BPSK
Bitrate	0.5M
Gnuradio	v3.7
USRPs	x310s and b210s

Experiment Settings



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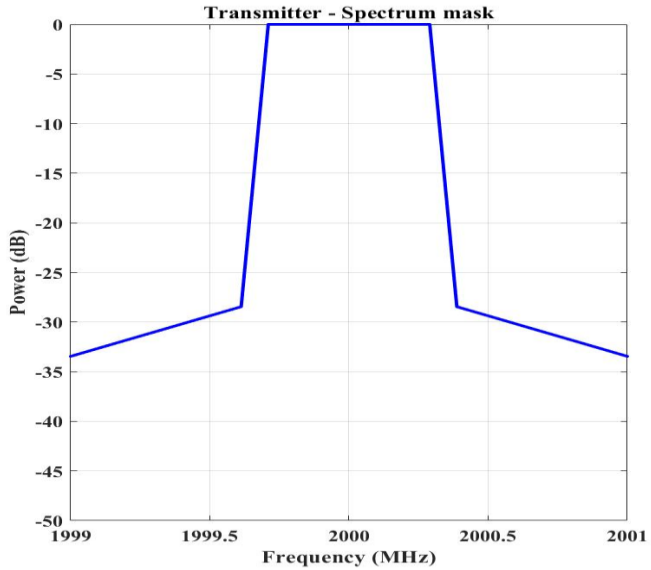
Experimental Setup: SCM Generation

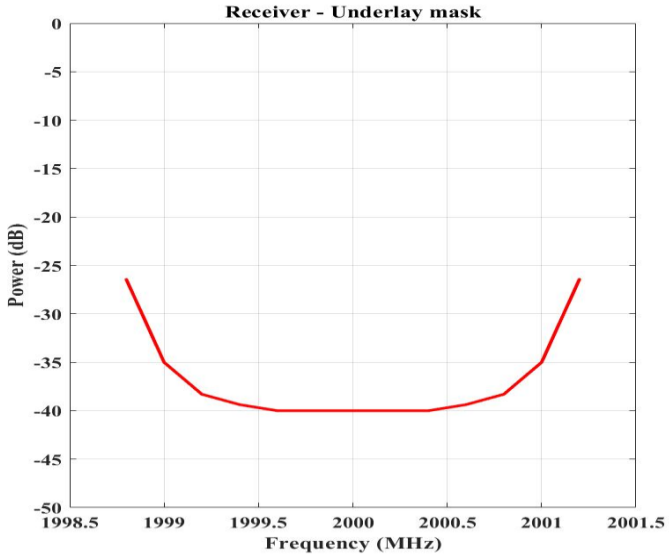
```
- <spectrumMask>
    <resolutionBW>0.002</resolutionBW>
  - <scmMask>
      <refFrequency>0.0</refFrequency>
    - <inflectionPnt>
        <frequency>1999.0</frequency>
        <relativePower>-33.45</relativePower>
      </inflectionPnt>
    - <inflectionPnt>
        <frequency>1999.6125</frequency>
        <relativePower>-28.45</relativePower>
      </inflectionPnt>
    - <inflectionPnt>
        <frequency>1999.71</frequency>
        <relativePower>0.0</relativePower>
      </inflectionPnt>
    - <inflectionPnt>
        <frequency>2000.29</frequency>
        <relativePower>0.0</relativePower>
      </inflectionPnt>
    - <inflectionPnt>
        <frequency>2000.3875</frequency>
        <relativePower>-28.45</relativePower>
      </inflectionPnt>
    - <inflectionPnt>
        <frequency>2001.0</frequency>
        <relativePower>-33.45</relativePower>
      </inflectionPnt>
    </scmMask>
  </spectrumMask>
```

Transmitter spectrum mask
Device: x310 and b210

```
- <underlayMask maskPowerMarginMethod="TotalPower">
    <resolutionBW>0.002</resolutionBW>
  - <scmMask>
    - <inflectionPnt>
        <frequency>1998.8</frequency>
        <relativePower>-26.4485</relativePower>
      </inflectionPnt>
    - <inflectionPnt>
        <frequency>1999.0</frequency>
        <relativePower>-35.0021</relativePower>
      </inflectionPnt>
    - <inflectionPnt>
        <frequency>1999.2</frequency>
        <relativePower>-38.298</relativePower>
      </inflectionPnt>
    - <inflectionPnt>
        <frequency>1999.4</frequency>
        <relativePower>-39.3706</relativePower>
      </inflectionPnt>
    - <inflectionPnt>
        <frequency>1999.6</frequency>
        <relativePower>-40.0</relativePower>
      </inflectionPnt>
    - <inflectionPnt>
        <frequency>1999.8</frequency>
        <relativePower>-40.0</relativePower>
      </inflectionPnt>
    - <inflectionPnt>
        <frequency>2000.0</frequency>
        <relativePower>-40.0</relativePower>
      </inflectionPnt>
    + <inflectionPnt>
    + <inflectionPnt>
    + <inflectionPnt>
    + <inflectionPnt>
    + <inflectionPnt>
    + <inflectionPnt>
    </scmMask>
  </underlayMask>
```

Receiver underlay mask
Device: x310





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Topology Setup: COSMOS Sandbox (ORBIT GRID)

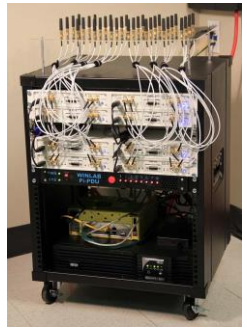
MIMO Rack 24-5

MIMO Rack 23-5

MIMO Rack 24-11

All 3 links will interfere with each other if on the same channel

3 channels:
1999e6, 2000e6, 2001e6



MIMO Rack 23-11

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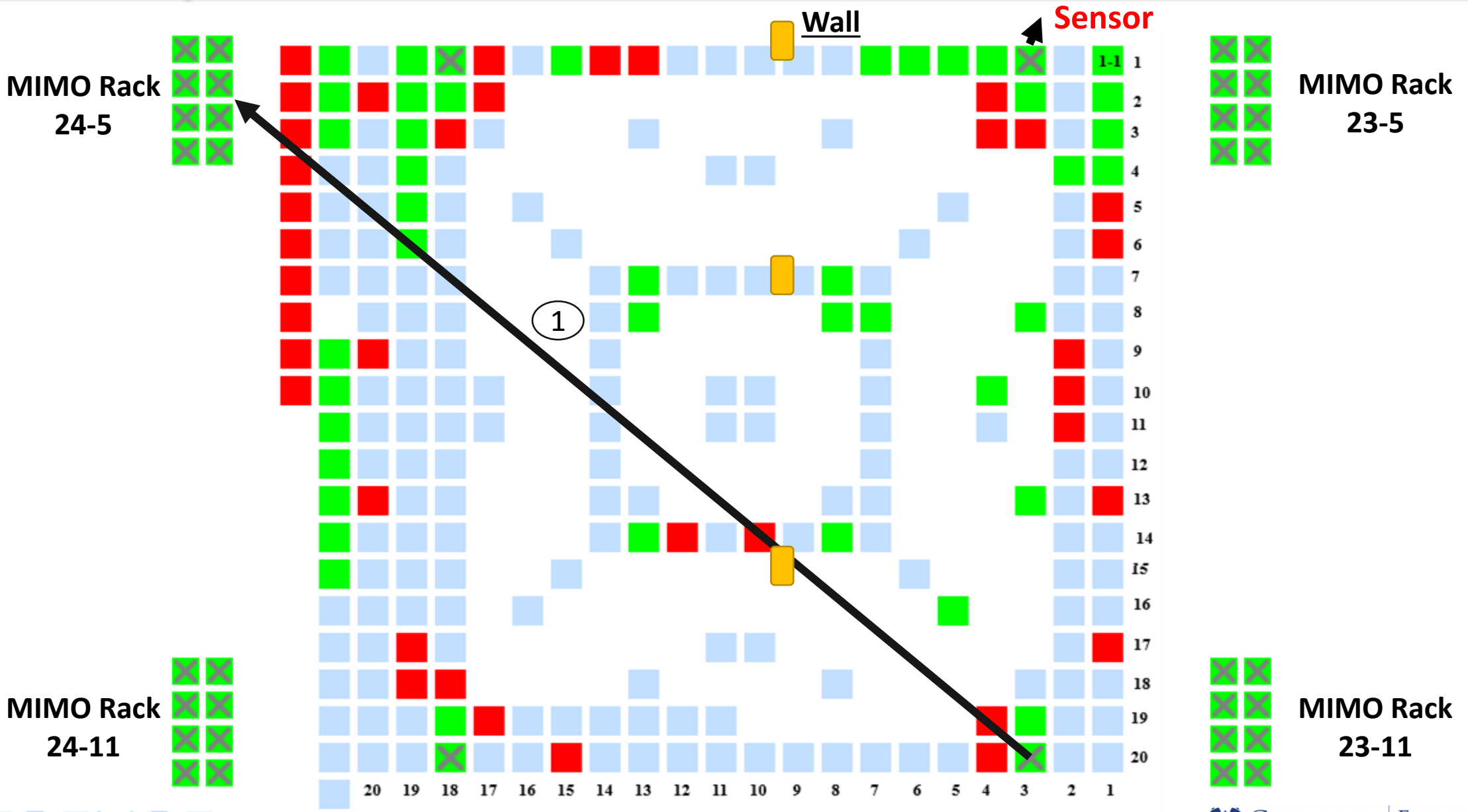
Link 1 Setup



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Receiver1

Terminal Sessions View X server Tools Games Settings Macros Help

```
root@node3-20:~/sii# python3 sii_client.py --server-ip 10.10.21.2 --client-ip 10.10.3.20 --tx-usrp-args "resource=R
IO0" --rx-usrp-args "type=x300,addr=10.10.24.5" -gTx 10 --id 1 --tx-scm SCMs/demo/TX_3_20_BPSK.xml --rx-scm SCMs/de
mo/RX_24_5_BPSK.xml
```

3. WD1

```
root@node3-20:~/sii# tail -f rx_out.log
```

4. Receiver1

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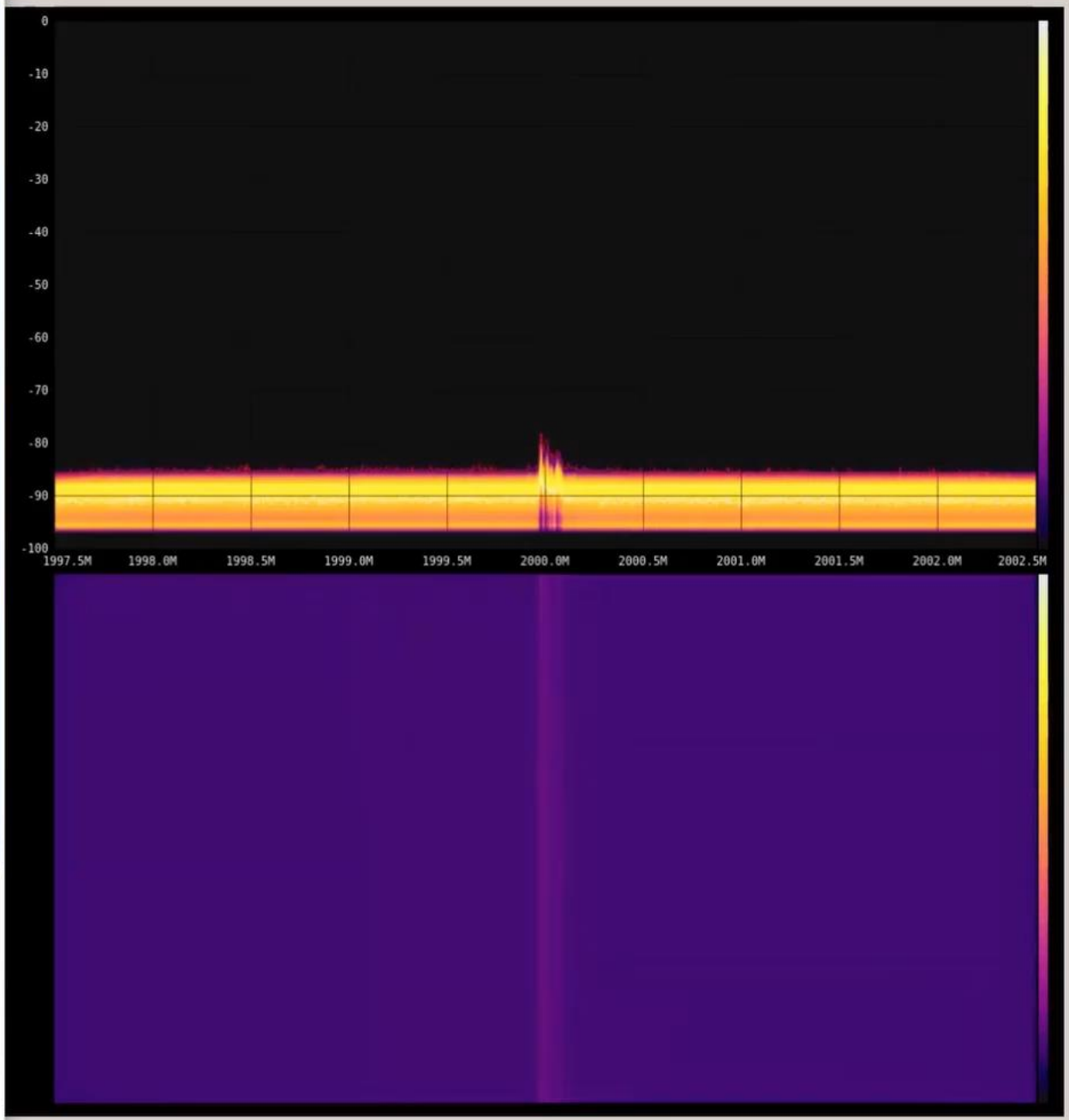
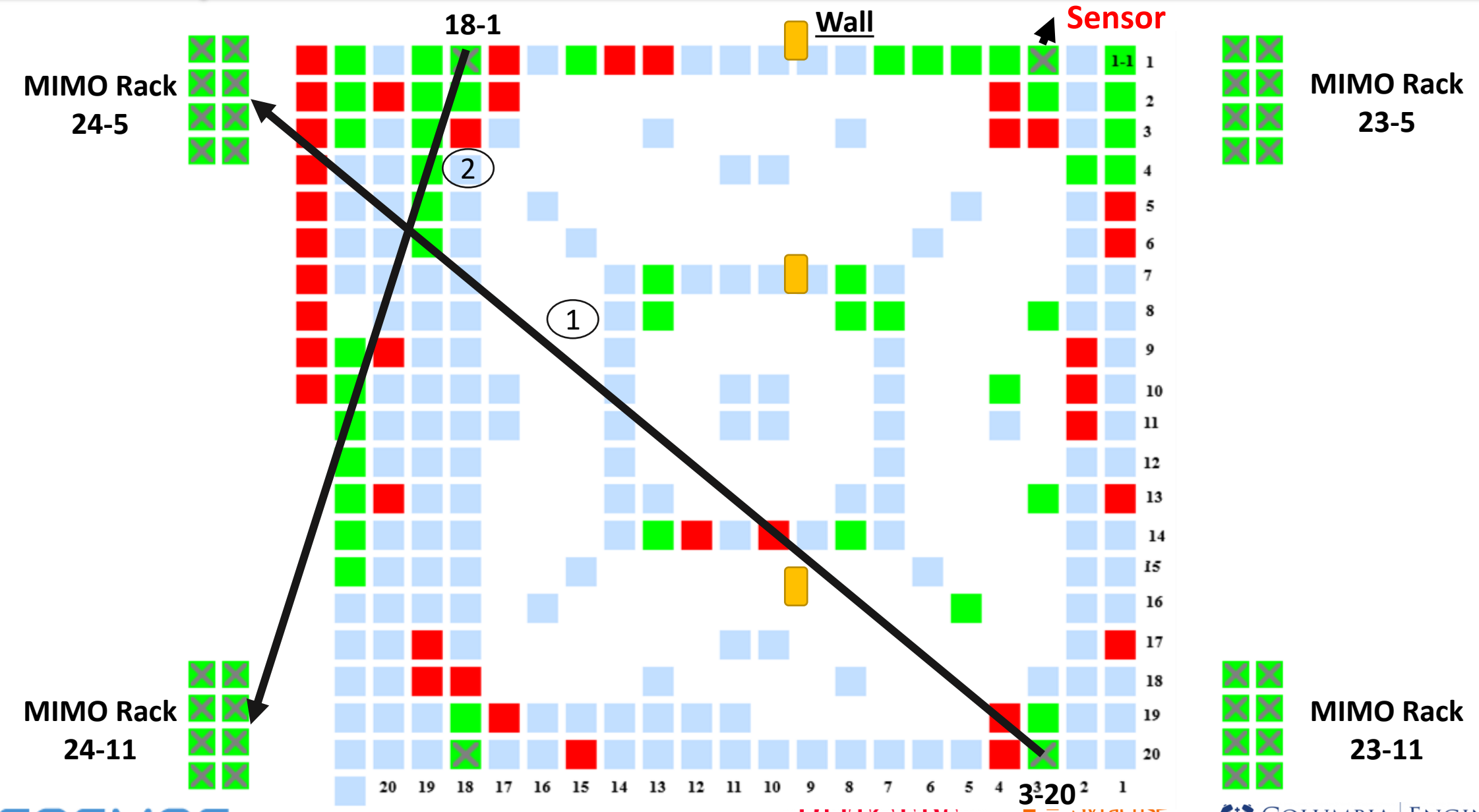


Link 2 Setup



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Receiver1

Terminal Sessions View X server Tools Games Settings Macros Help

```
root@node18-1:~/sii# python3 sii_client.py --server-ip 10.10.21.2 --client-ip 10.10.18.1 --tx-usrp-args "resource=RIO0" --rx-usrp-args "type=x300,addr=10.10.24.11" -gTx 10 --id 2 --tx-scm SCMs/demo/TX_18_1_BPSK.xml --rx-scm SCMs/demo/RX_24_11_BPSK.xml
```

5. WD2

```
root@node18-1:~/sii# tail -f rx_out.log
```

6. Receiver2

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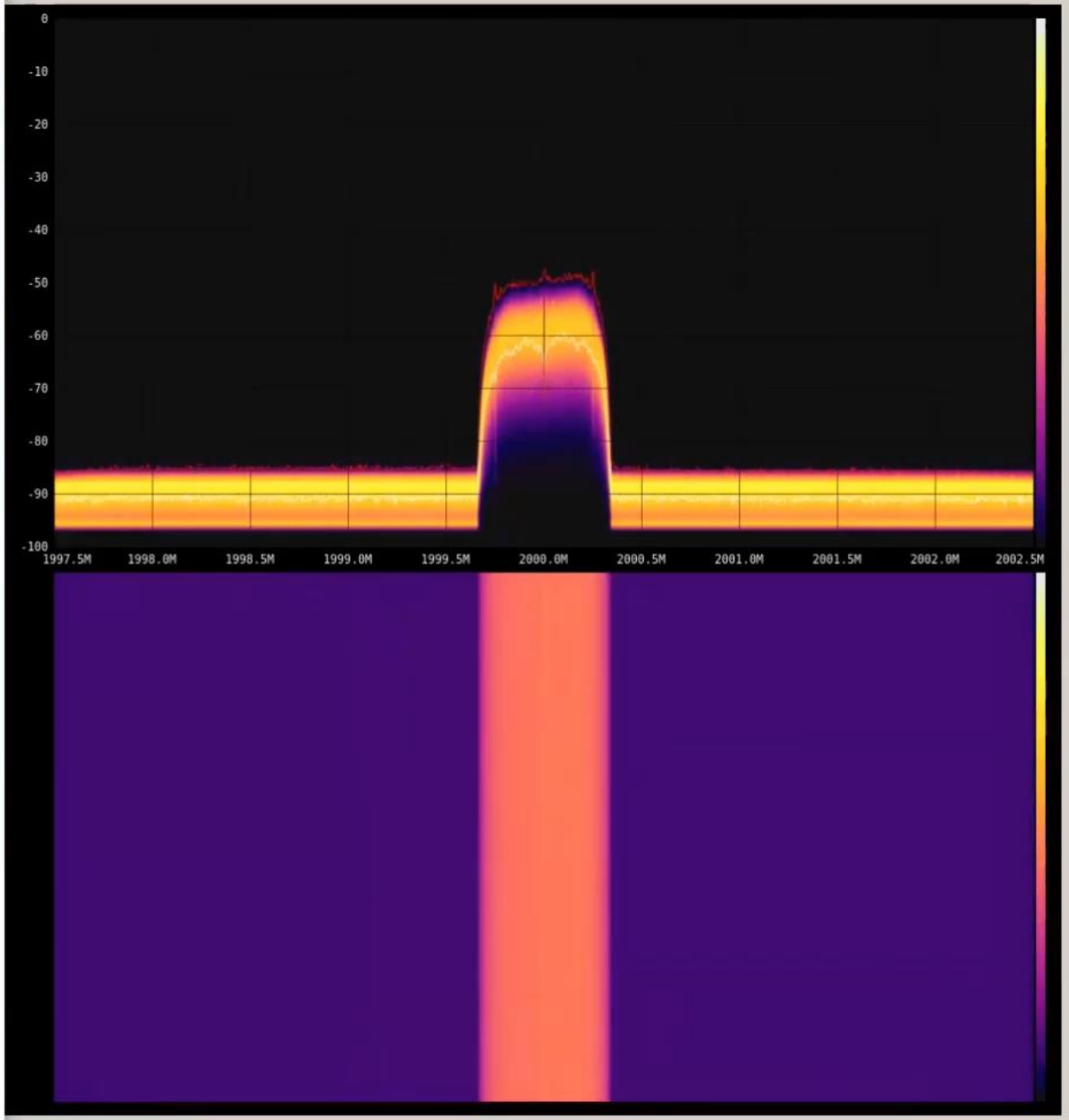
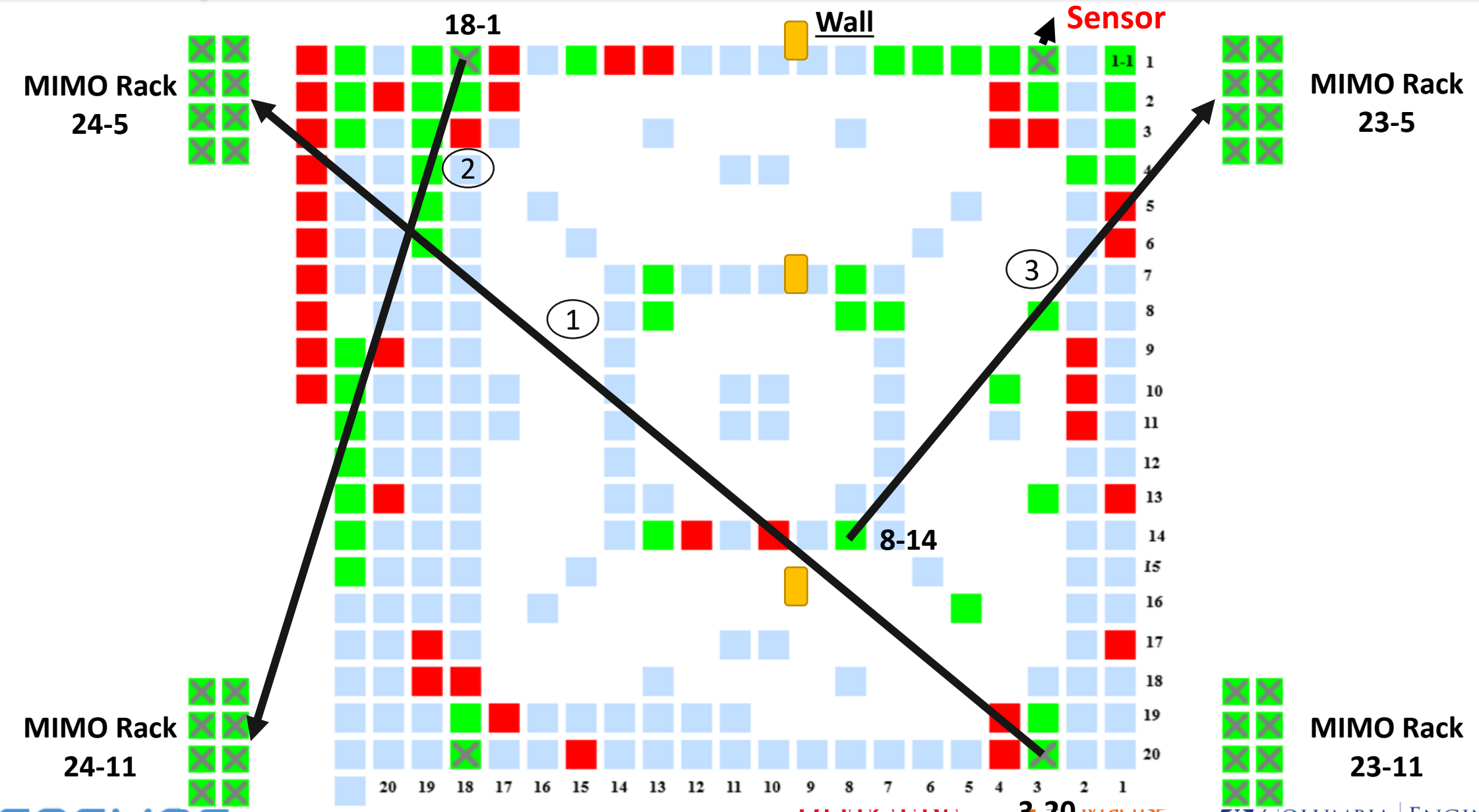


Link 3 Setup



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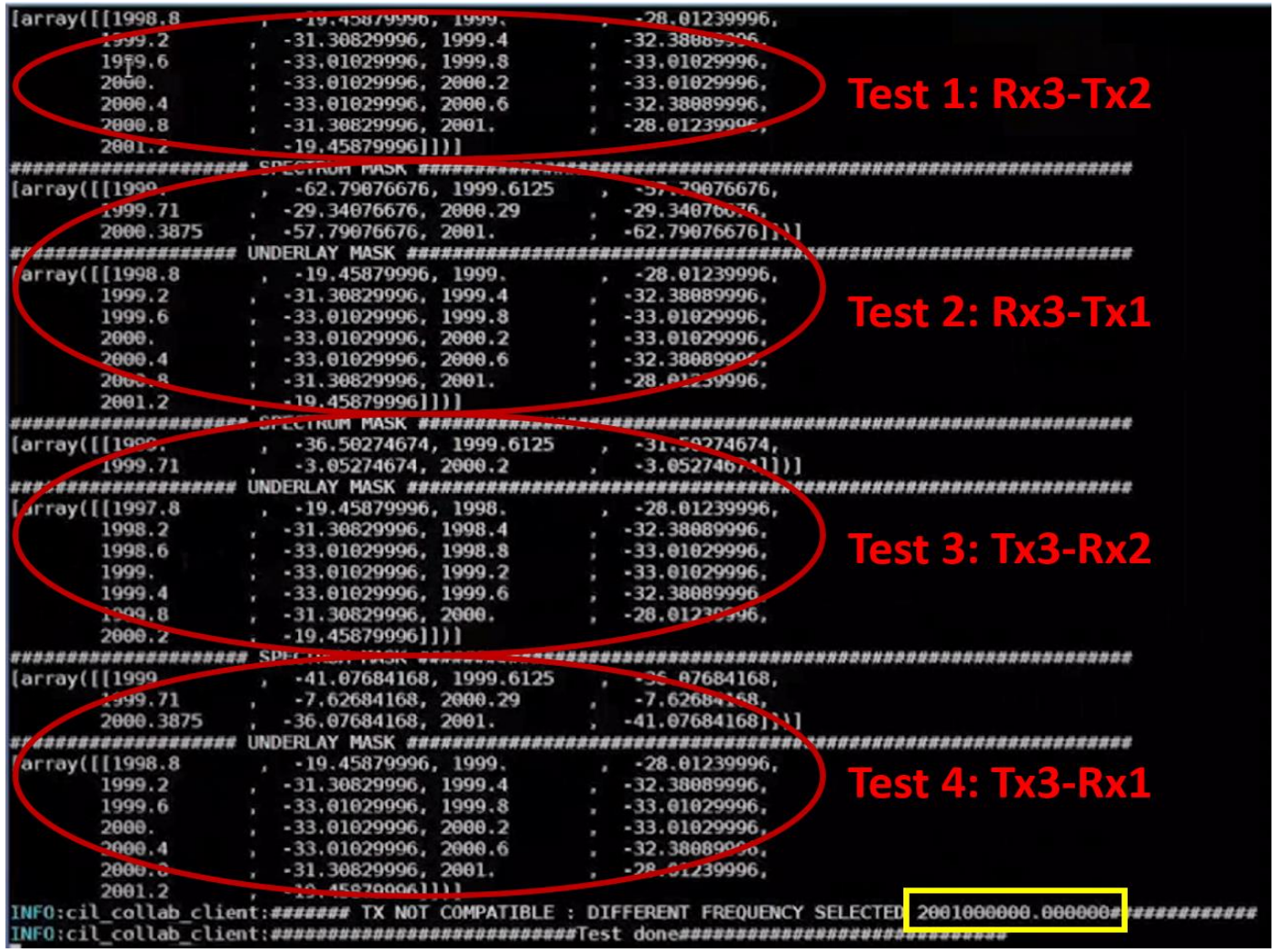
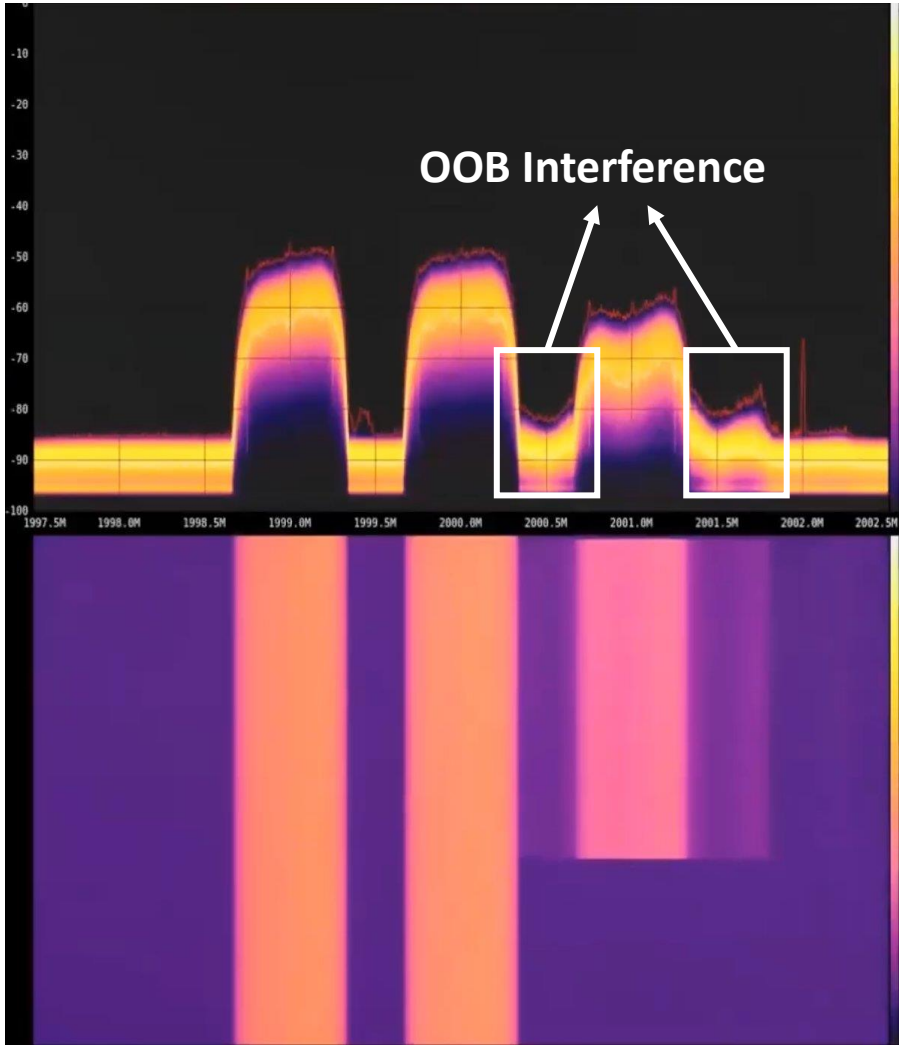


List of compatibility tests between WD3's devices (Tx3 and Rx3) and existing Tx/Rx devices



Fosphor visualization showing the spectrum occupancy when the third network start operating

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Conclusion and Future Work:

Conclusion:

- Designed and implemented a framework on the COSMOS testbed that enables experimentation and research of dynamic spectrum access mechanisms
- A modified version of CIL developed by DARPA was used to enable exchange of SCM messages between wireless networks
- We demonstrated the capabilities of the developed framework using an experiment with 3 networks, joining at different times and performing DSA coordination automatically using SCMs

Future Work:

- Large scale evaluation of Dynamic Spectrum Access with SCMs involving more complex algorithms
  - Frequency adjustments
  - Power adjustments
  - Impact of aggregate interference

- Distributed Spectrum Access with SCMs
  - Using Deep Reinforcement Learning

- Design and development of SCMs for mmWave devices

3. WD1

```
root@node3-20:~/sii# python3 sii_client.py --server-ip 10.10.21.2 --client-ip 10.10.3.20 --tx-usrp-args "resource=RIO0" --rx-usrp-args "type=x300,addr=10.10.24.5" -gTx 10 --id 1 --tx-scm SCMs/demo/TX_3_20_BPSK.xml --rx-scm SCMs/demo/RX_24_5_BPSK.xml
```

5. WD2

```
root@node18-1:~/sii#
```

7. WD3

```
root@node8-14:~/sii#
```

4. Receiver1

```
root@node3-20:~/sii# tail -f rx_out.log
```

6. Receiver2

```
root@node18-1:~/sii# tail -f rx_out.log
```

8. Receiver3

```
root@node8-14:~/sii# tail -f rx_out.log
```

Thank you!

10. Server

```
root@node21-2:~/sc2-cil/examples# python3 ./collab_server.py --server-ip 10.10.21.2 --message-timeout 30
Collaboration Server starting, CTRL-C to exit
INFO:collab_server:Collaboration Server listening on host 10.10.21.2 and port 5556
```

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