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

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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.

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*High Level Dynamic Spectrum Architecture*
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

SCM Constructs

- 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
Architecture and Protocol

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

- **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
To keep track of neighbors

Regional Topology Manager (Controller)

Wireless Domain Controllers

Configure domain radios

Configure domain radios

Perform Compatibility Test (CT)

CT Report()

SCM()

SCM Request()

NOTIFY()

INFORM()

Register()

Clients:
1. WD1
2. WD2

Clients:
1. WD1

Clients:
1. WD2

Peers:
1. WD1

Peers:
1. WD2

Peers:
1. -

Peers:
1. -

If WD1 wants to leave the system

Configure domain radios

WD1 [Tx1, Rx1]

WD2 [Tx2, Rx2]

RTM

@ Time T1

@ Time T2

@ Time T1

INFORM()

@ Time T2

INFORM()
New domain/node(s) enters and receives SCMs

Set to a default $f_c$

For every existing Tx $i$ and Rx $i$:

CT with Tx $i$

CT with Rx $i$

Evaluate the results of CTs

Select $f_c$ that does not cause interference

Update SCM and setup the link
Algorithm: Current Implementation

New domain/node(s) enters and receives SCMs

Set to a default $f_c$

For every existing $Tx_i$ and $Rx_i$:

- CT with $Tx_i$
- CT with $Rx_i$

Evaluate the results of CTs

Select $f_c$ that does not cause interference

Update SCM and setup the link
Algorithm: Current Implementation

New domain/node(s) enters and receives SCMs

Set to a default $f_c$

For every existing Tx $i$ and Rx $i$:

CT with Tx $i$

CT with Rx $i$

Evaluate the results of CTs

Select $f_c$ that does not cause interference

Update SCM and setup the link

Nodes

Tx

Rx

New Tx-Rx pair

Existing Tx-Rx pairs

Algorithm: Current Implementation
Algorithm: Current Implementation

New domain/node(s) enters and receives SCMs

Set to a default $f_c$

For every existing Tx $i$ and Rx $i$:

- CT with Tx $i$
- CT with Rx $i$

Evaluate the results of CTs

Select $f_c$ that does not cause interference

Update SCM and setup the link

Nodes

- Tx
- Rx

Setup the link

Existing Tx-Rx pairs
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

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**Node20-1**
- **ZMQ Server**
- **Regional Topology Manager**

**Node18-1**
- **USRP**
- **Node18-1** (x310)

**Node8-14**
- **USRP**
- **Node8-14** (b210)

**WD1**
- **USRP**
- **Node3-20** (x310)

**WD2**
- **USRP**
- **Node18-1** (x310)

**WD3**
- **USRP**
- **Node8-14** (b210)

**SCM Set Exchange**

**SCM Set Exchange(s)**

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**@ Time T1**

**@ Time T2**

**@ Time T3**

**PUSH/PULL Model**

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**Experiment Settings**
Experimental Setup: SCM Generation

Transmitter spectrum mask
Device: x310 and b210

Receiver underlay mask
Device: x310
Topology Setup: COSMOS Sandbox (ORBIT GRID)

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

3 channels:
1999e6, 2000e6, 2001e6
Link 1 Setup

MIMO Rack 24-5

MIMO Rack 24-11

MIMO Rack 23-5

MIMO Rack 23-11

Wall

Sensor
Link 3 Setup

MIMO Rack 24-5

MIMO Rack 23-5

MIMO Rack 23-11

MIMO Rack 24-11

Wall

Sensor
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
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
Thank you!