LVX VERITAS VIRTVS

Institute for the Wireless Internet of Things at Northeastern University

RF and Traffic Scenarios Overview

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MITRE

MASSACHUSETTS TECHNOLOGY COLLABORATIVE

COLOSSEUM at Northeastern University

Overview

- Colosseum scenarios
- Why are they important?
- Scenario components
  - RF scenarios
  - Traffic scenarios
- Examples

Scenarios in Colosseum

- Colosseum allows emulation at scale:
  - **256 RF transceivers**
    - >**65K** RF channels
  - Diverse **wireless conditions**
    - Fading
    - Mobility
    - Topologies
  - **Data traffic**
    - Downlink/Uplink
    - Bandwidth
    - Bitrate
    - UDP/TCP

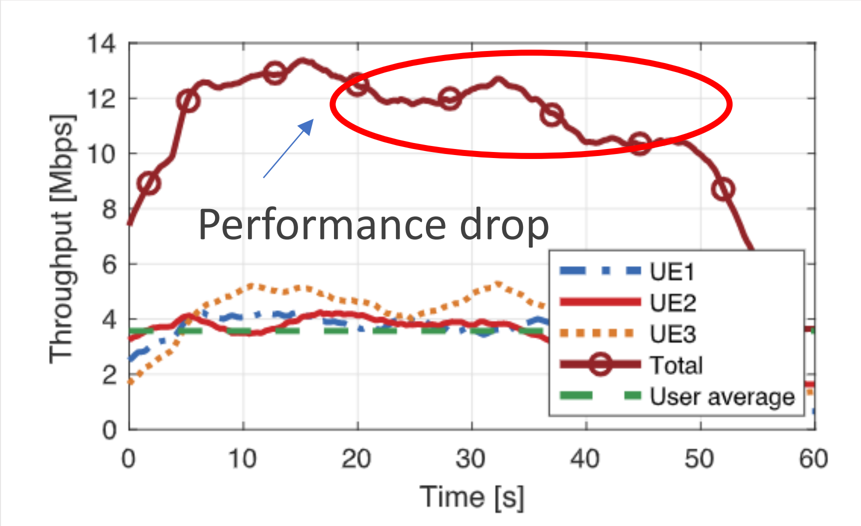
→ **RF Scenarios**

→ **Traffic Scenarios**

Scenarios – The Colosseum Way

- RF / traffic scenarios are **deterministic**: Experiments w/ same scenario execute the same way
- Will be extended w/ stochastic distributions in the filter taps

- Colosseum enables:
  - **Full control** over the wireless channel
    - non stationarity in the **distribution**
    - only keep **desired** channel effects
  - **Reproducibility / repeatability**
  - **Easy comparison** between algorithms

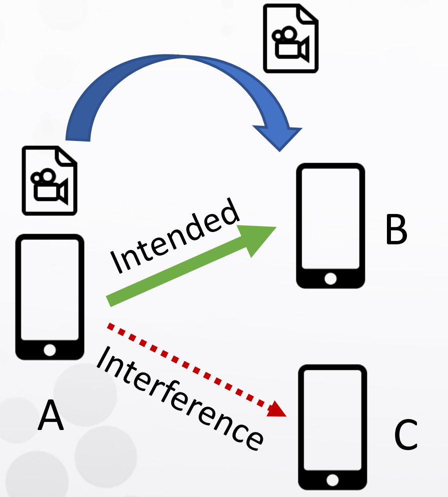


Is the performance drop due to the ***channel*** *or* ***bad algorithm design****?*

An example: performance drop

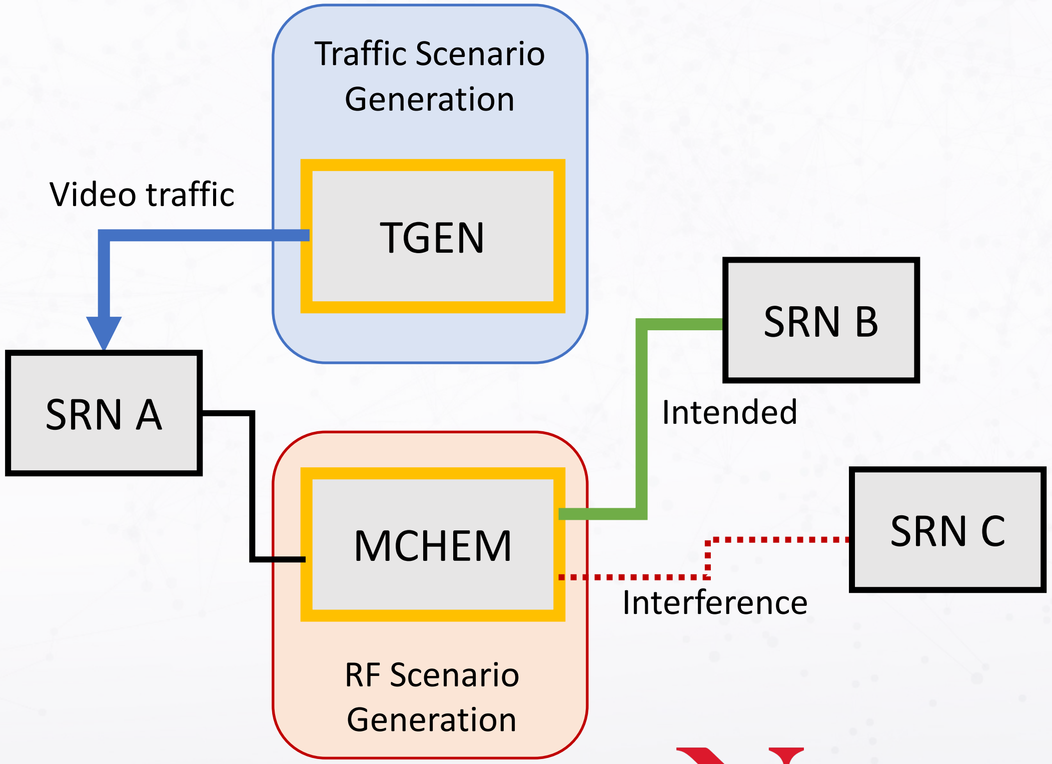
High-level Overview

- Three main components:
  - **Standard Radio Nodes (SRN)**
    - Operates as a radio front-end
  - **Massive Channel EMulator (MCHEM)**
    - Emulates channel conditions
  - **Traffic GENerator (TGEN)**
    - Generate traffic for each node



Logic representation

Colosseum implementation



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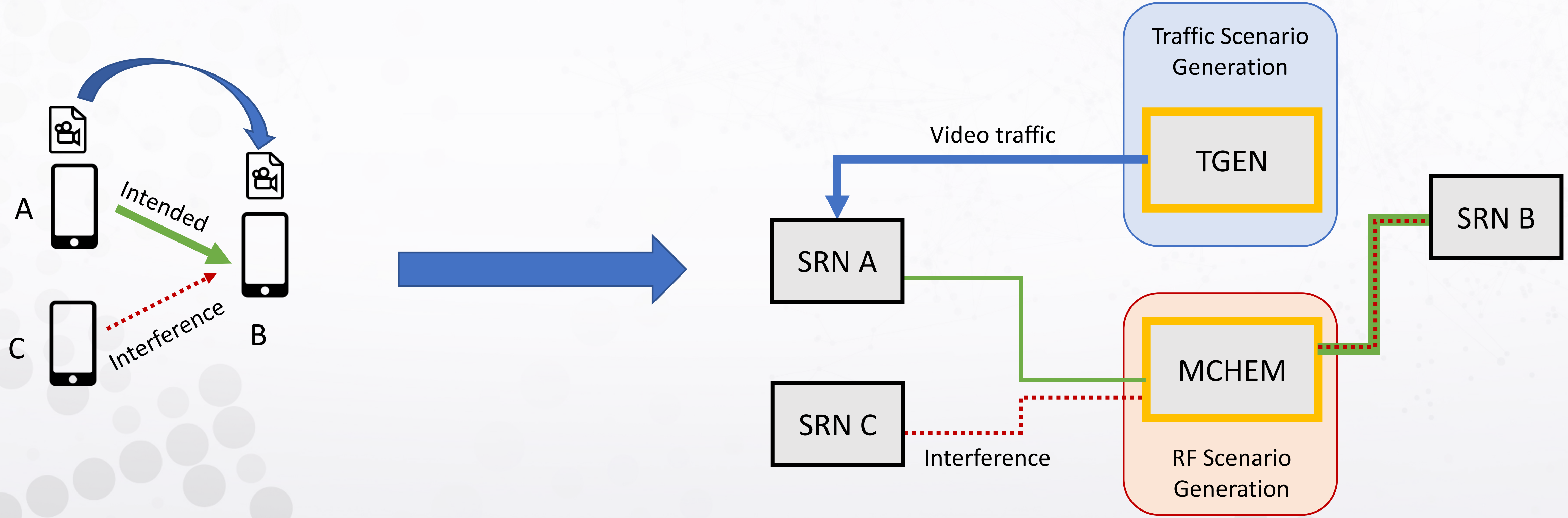
High-level Overview, Cont'd

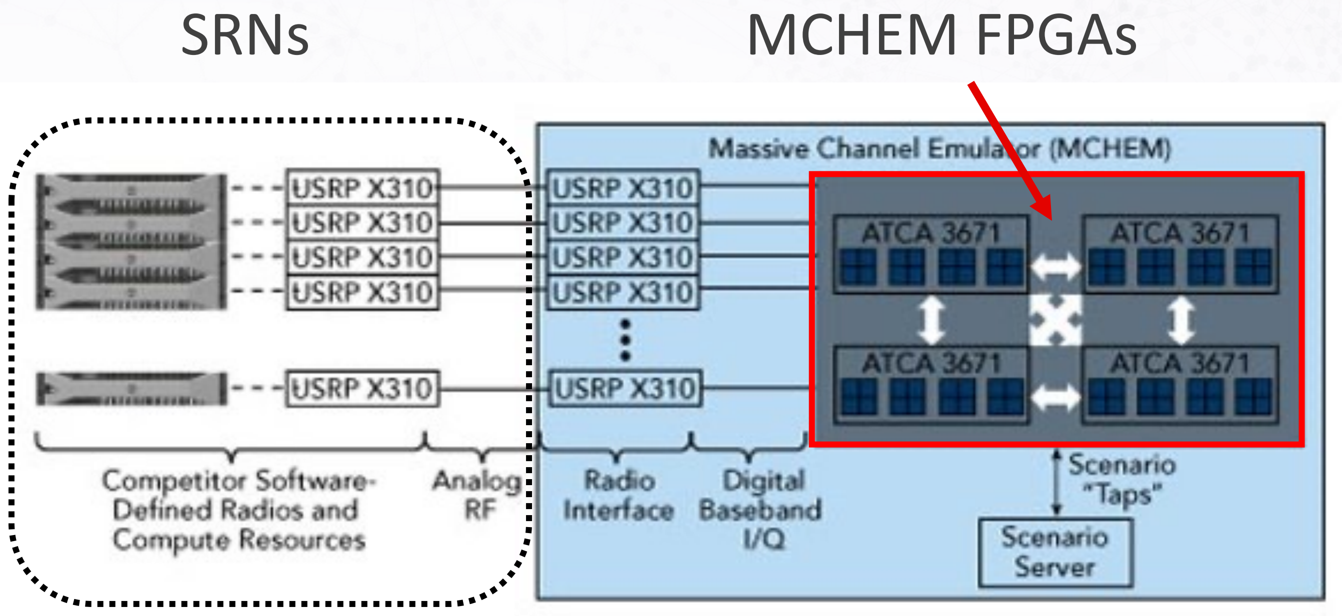
- All signals are **summed** at the receiver

- **Each node can experience interference from all the other 255 transceivers**



RF Scenarios – Wireless Channel Modeling

- **Wireless channel:**
  - Modeled as a Finite Impulse response (FIR)
  - 512 complex-valued FIR taps
    - 512 delays (or paths) for the same signal
  - Stored in the Scenario Server



- The channel is **emulated** by **MCHEM**
  1. SRNs generate signals
  2. MCHEM applies the taps to SRNs' signals
     - FPGA-based FIR filtering
  3. Signals are forwarded to SRNs

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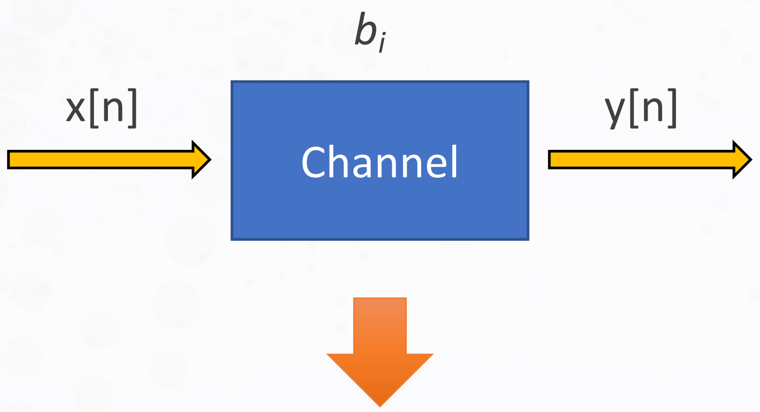
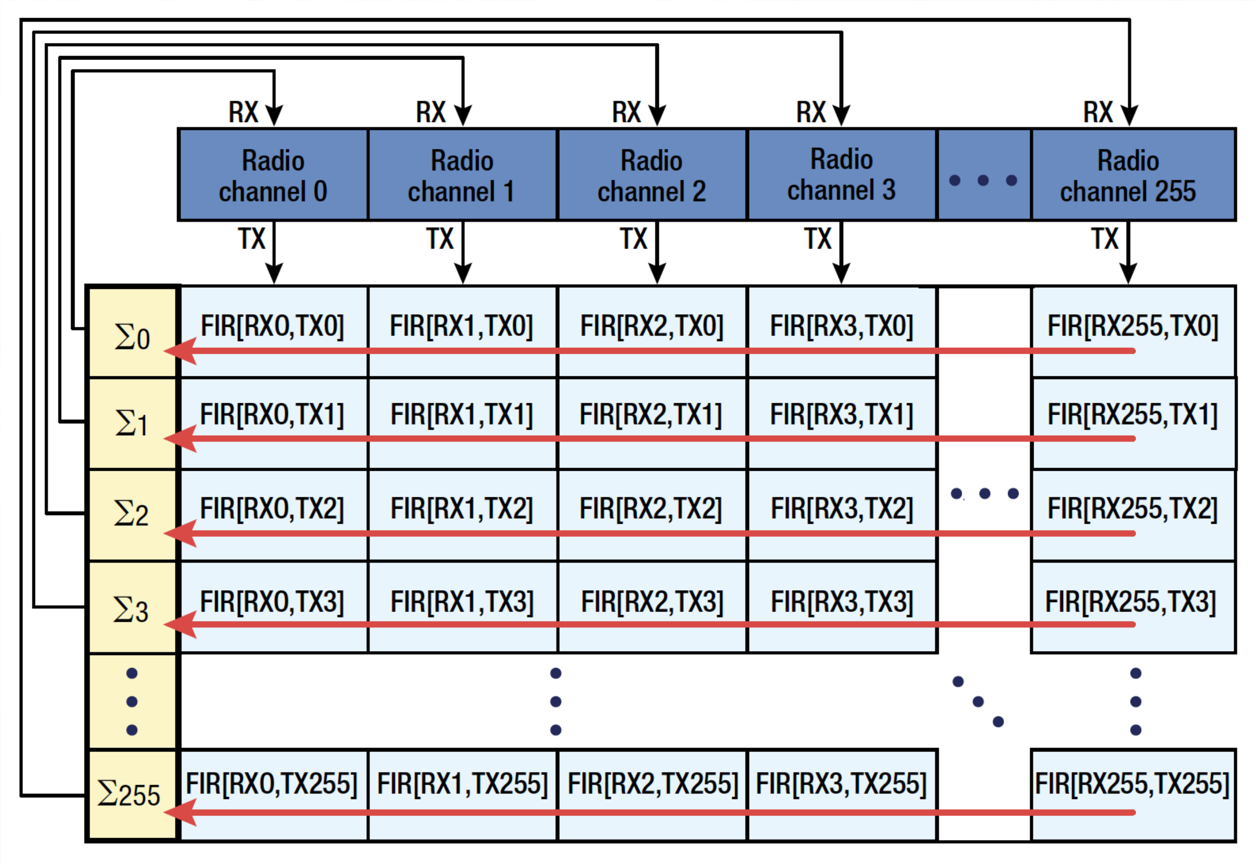
Why FIR Filters?

The received signal is the **convolution** in time of the transmitted signal and the channel impulse response



$$y[n] = b_0 x[n] + b_1 x[n-1] + \cdots + b_N x[n-N]$$
$$= \sum_{i=0}^{N} b_i \cdot x[n-i],$$

FIR taps



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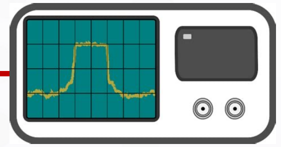
Ways to Generate Filter Taps

- **Mathematical model**
  - Deterministic/added randomness, no ground truth

$$20\,log_{10}(d) + 20\,log_{10}(f) + 92.45$$

b_i

- **On-site measurements**
  - Realistic but site/time specific



Taps Approximation

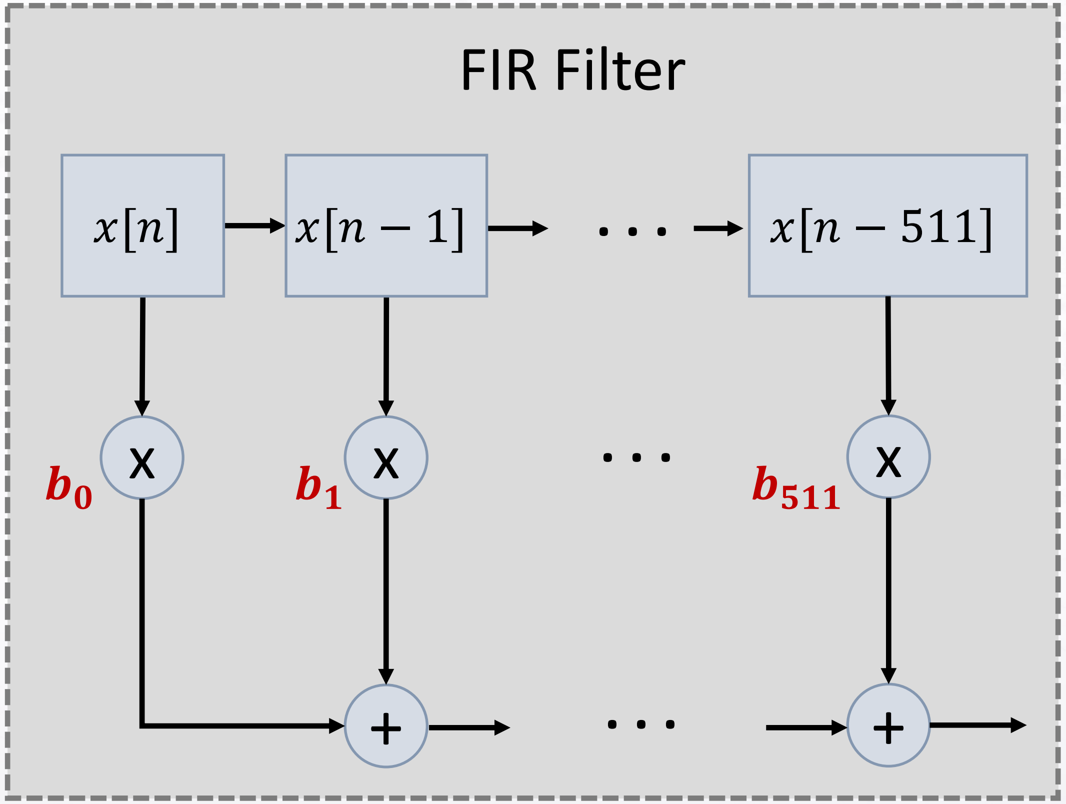
b_i

- **Software-based (ray tracer)**
  - Accurate but complex

Calibrate w/ measurements

Taps Approximation

b_i

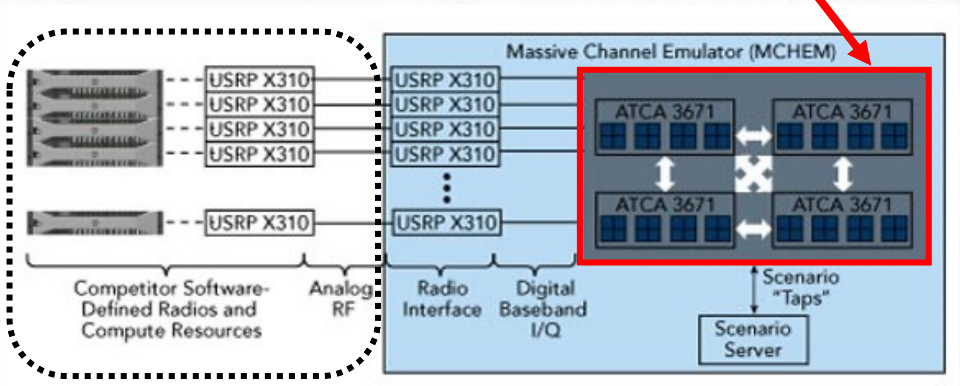


Complexity vs. Accuracy

- **FIR taps:**
  - 512 complex-valued FIR taps
  - **Sparse filter: only 4 are non-zero**
- **Why?**
  - Colosseum has 1 ms channel resolution
  - Scenarios are **VERY** complex
  - **Example:**
    - single-tap
    - 50 nodes
    - 10 minutes duration
    - > 100 GB storage needed (FIR taps only!!)
    - > 2 hours to generate taps on servers w/ 24 CPUs and 96 GB of RAM → don't try this at home!
- 4 taps are a good **trade-off** between **complexity** and **accuracy**

SRNs

MCHEM FPGAs



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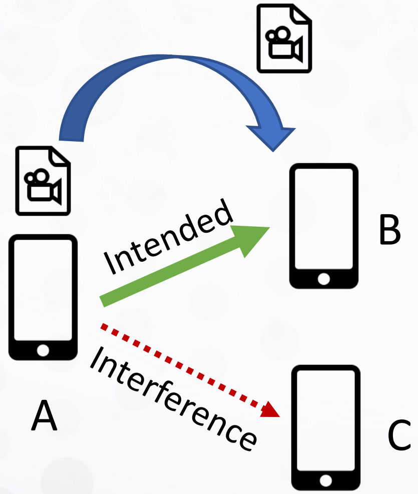
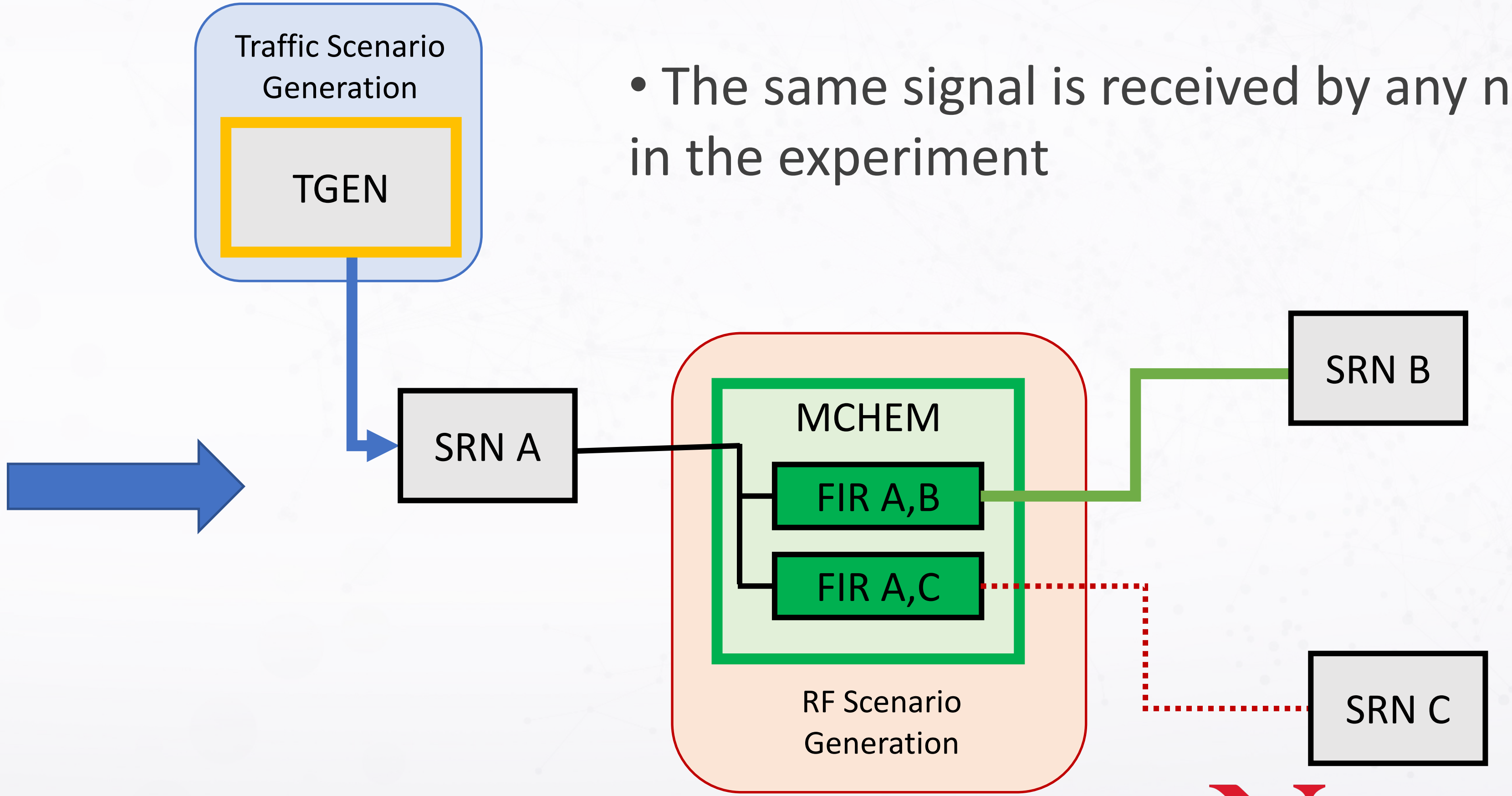
RF Scenarios in Practice





- Colosseum has a FIR for each pair (A,B)
- The same signal is received by any node in the experiment

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RF Scenarios – Front-end Details

- RF scenarios also specify:
  - Bandwidth
  - SNR
  - Frequency
  - Number of nodes

Example

Stage	Duration	Link SNR	Offered Traffic / Flow
0	15 sec	20 dB	NaN
1	120 sec	20 dB	1.25 Mbps
2	120 sec	15 dB	1.25 Mbps
3	120 sec	10 dB	1.25 Mbps
4	120 sec	5 dB	1.25 Mbps
5	120 sec	20 dB	1.25 Mbps
6	15 sec	20 dB	NaN

Label	Value
Version	Practice
RF ID	9988
RF Description	Single tap; large scale
Scenario BW (MHz)	10
Traffic ID	99880
Traffic Description	Streaming UDP
Center Frequency	1000.0 MHz
Number of Incumbent Nodes	0
Number of Competitor Nodes	10

From: https://colosseumneu.freshdesk.com/support/solutions/articles/61000276224-scenarios-summary-list

Traffic Scenarios - TGEN

- Scenarios include pre-defined traffic through TGEN

- TGEN is based on Multi-GENerator (MGEN)
  - https://github.com/USNavalResearchLaboratory/mgen
  - Tool to generate TCP/UDP traffic
  - Open-source
  - Specify:
    - Duration
    - Type of traffic
    - Bitrate
    - Etc.

Example

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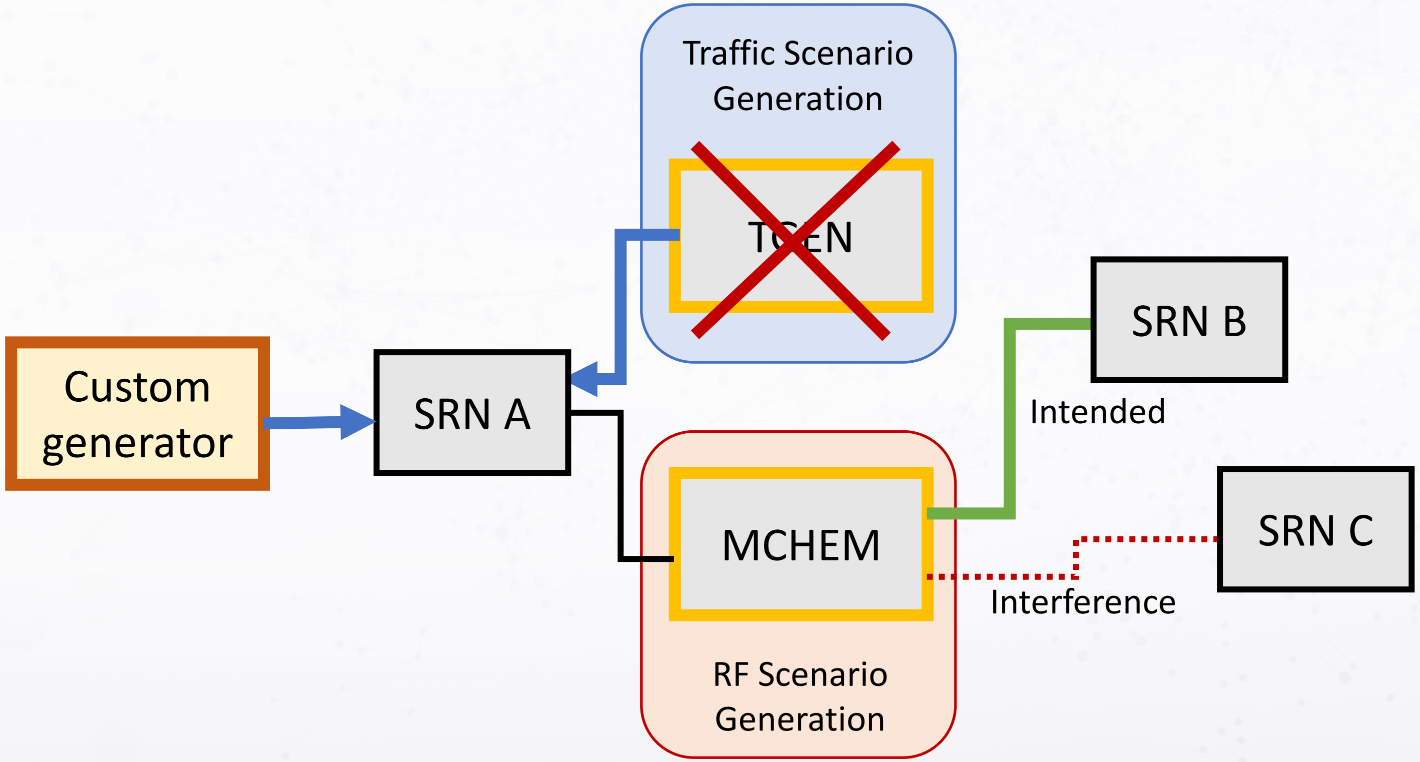
Traffic Scenarios - Customization

- Users can use custom traffic generators

- Examples:
  - iPerf2
  - iPerf3
  - Netperf
  - MTR

- TGEN gets bypassed



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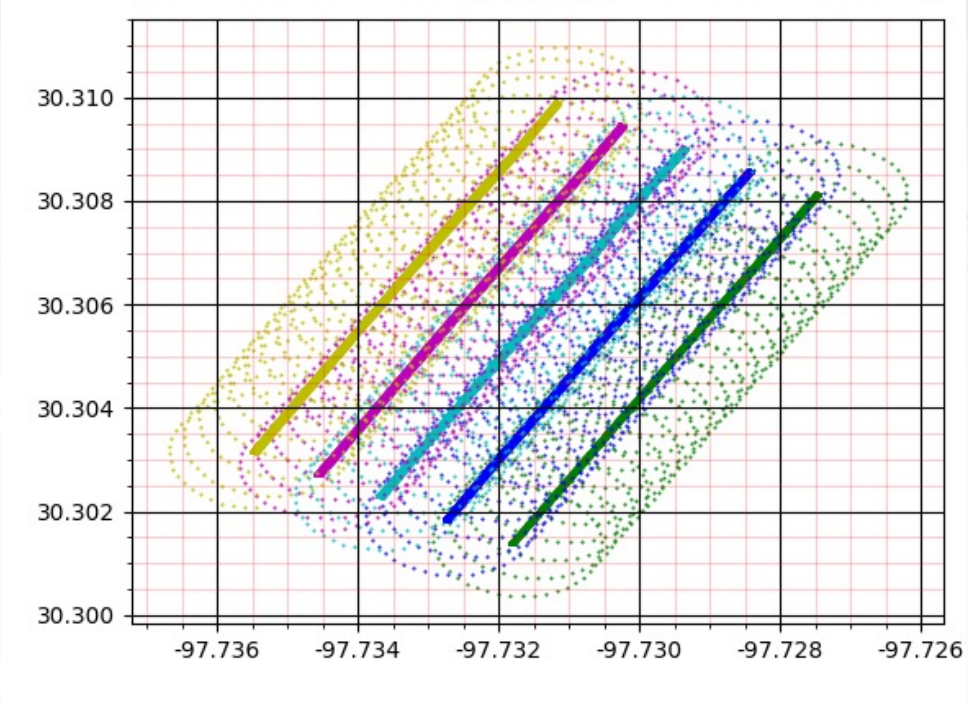
Sample Scenario: Alleys of Austin



A platoon from the Texas Army National Guard at Camp Mabry is practicing urban maneuvers and communications in Austin.

The platoon is split into five squads consisting of 9 squad members and one UAV.

The squads move through the Heritage neighborhood in the following three stages:

- Stage 1: The squads progress from five starting locations and establish basic voice communications.
- Stage 2: The squads begin to also exchange video and images.
- Stage 3: The squads significantly increase their traffic.

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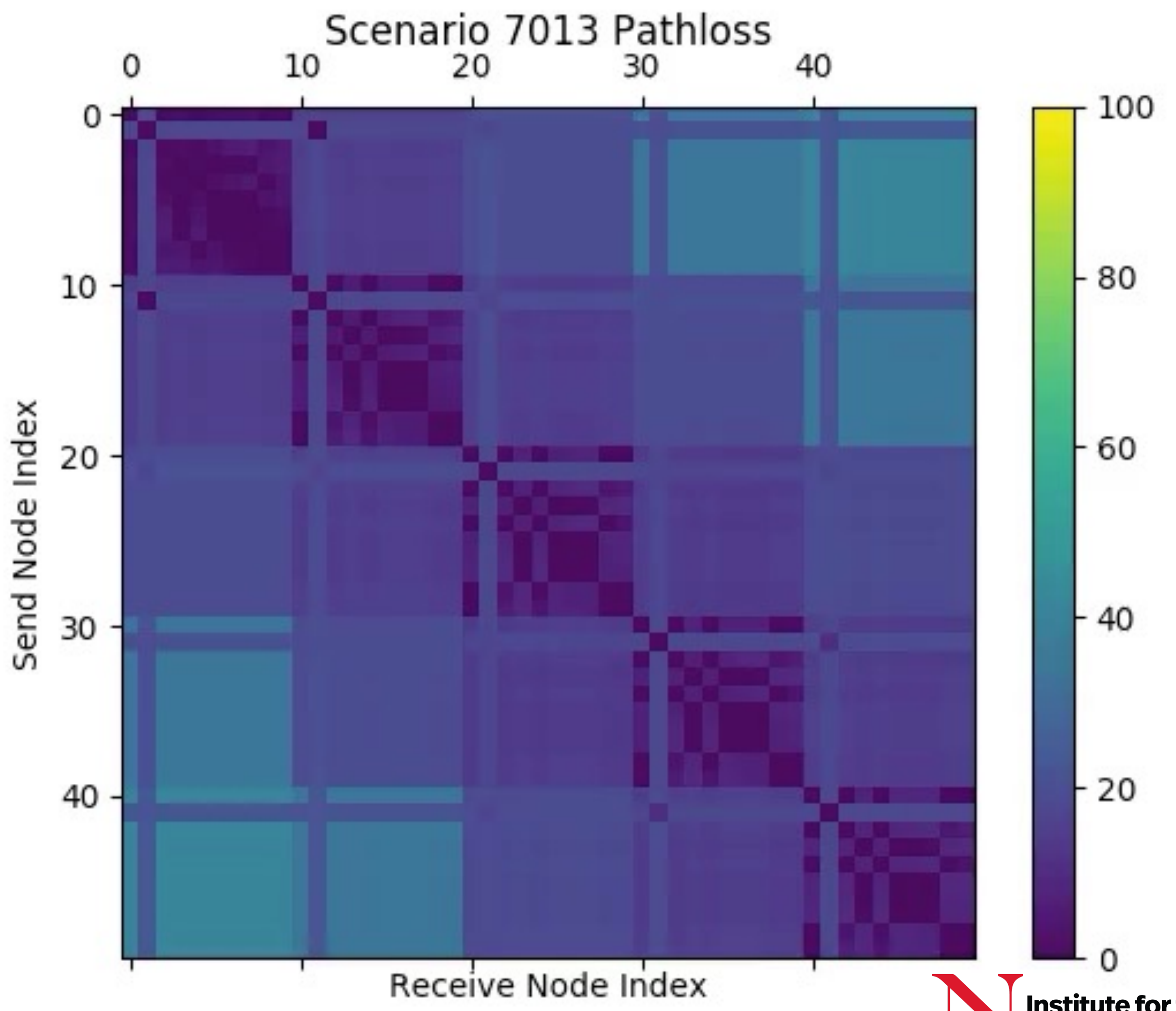
Pathloss Example

5 teams / networks

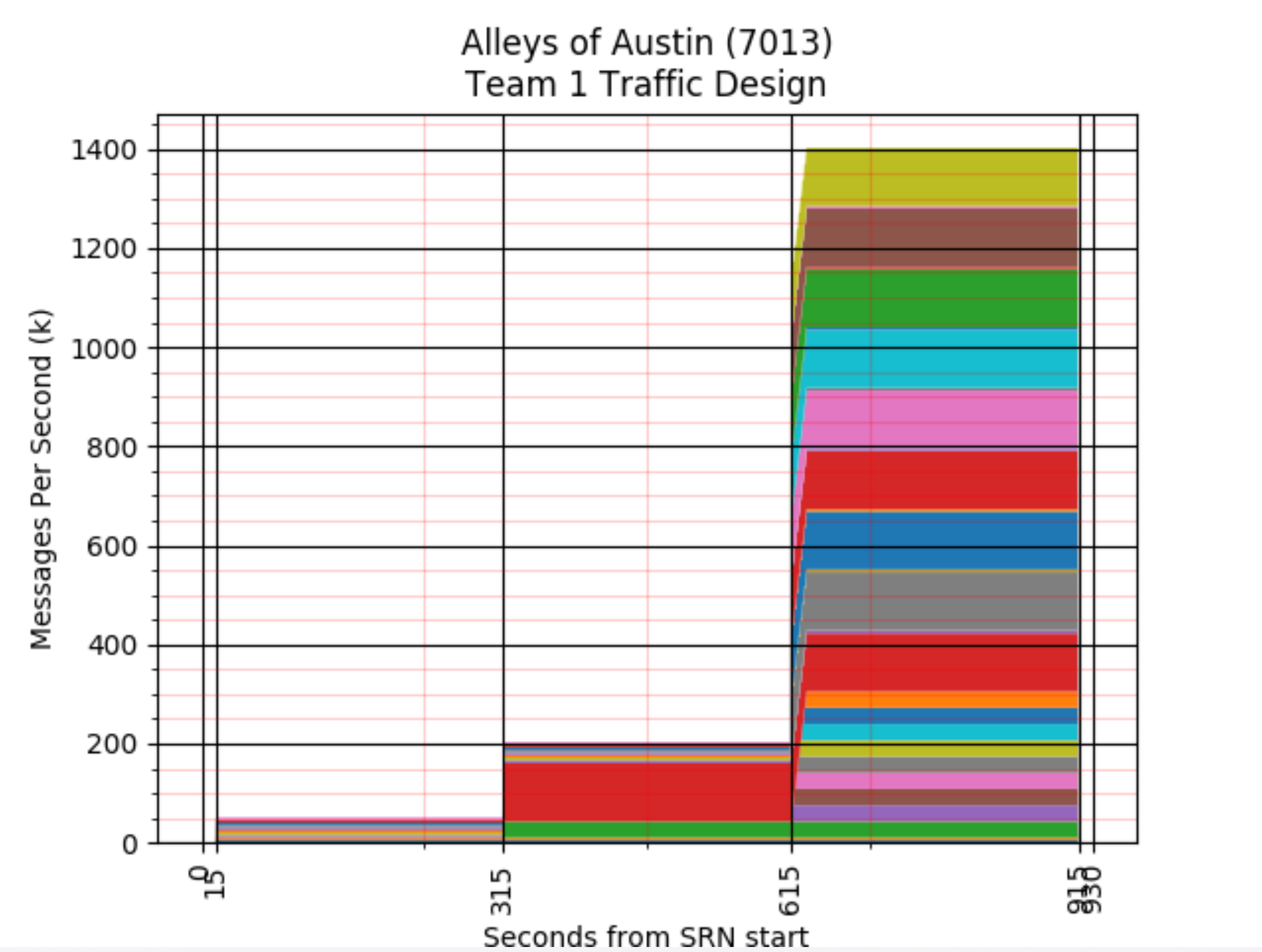
10 nodes per team
- 1 leader with the gateway radio
- 8 ground soldiers following
- 1 UAV circling overhead

930 seconds scenario
- 15 seconds scenario startup
- 3x5 minutes of traffic
- 15 seconds scenario teardown



RF Traffic

- Stage 1 (15-315 s)
  - Basic voice communications
- Stage 2 (315-615 s)
  - Also exchange video and images
- Stage 3 (615-915 s)
  - Significant traffic increase



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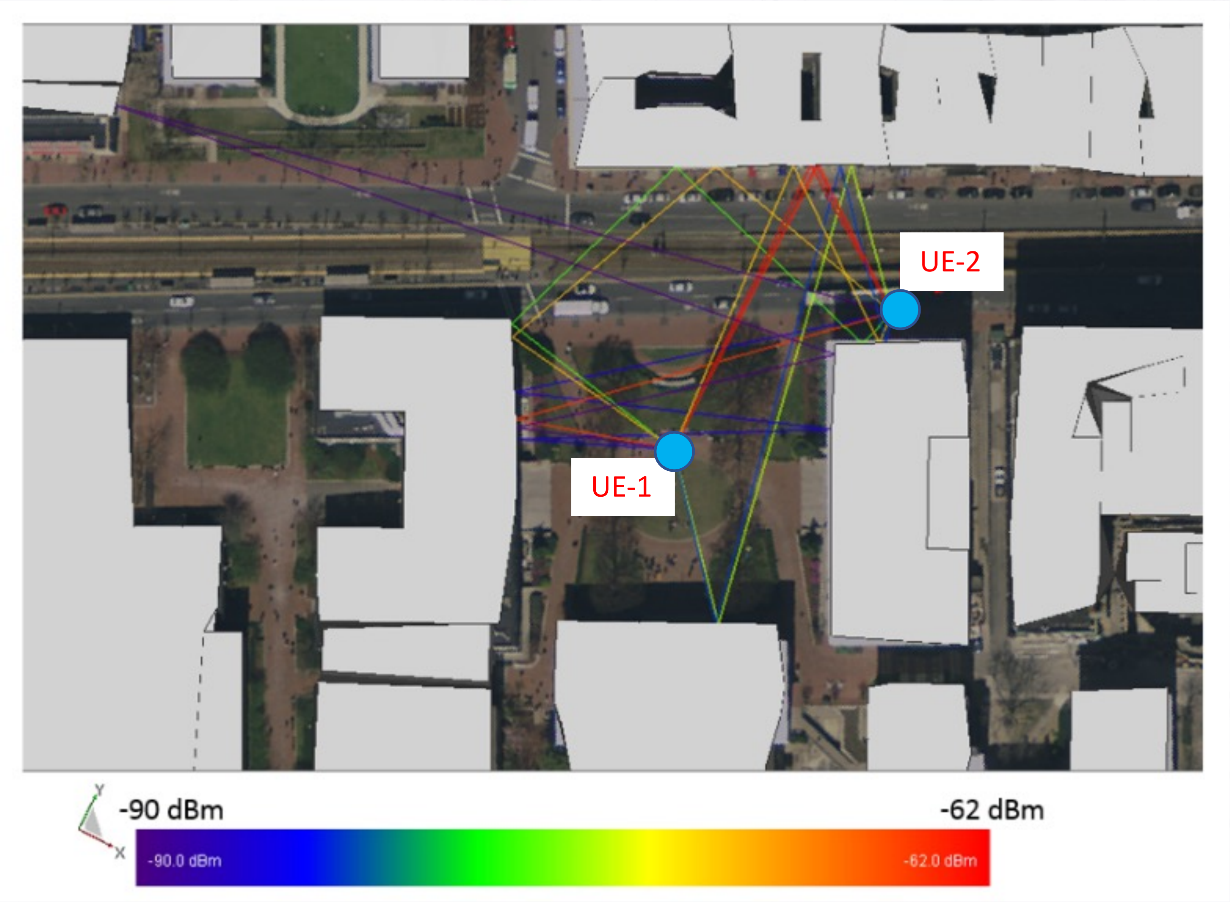
From Ray Tracers to Colosseum Scenario

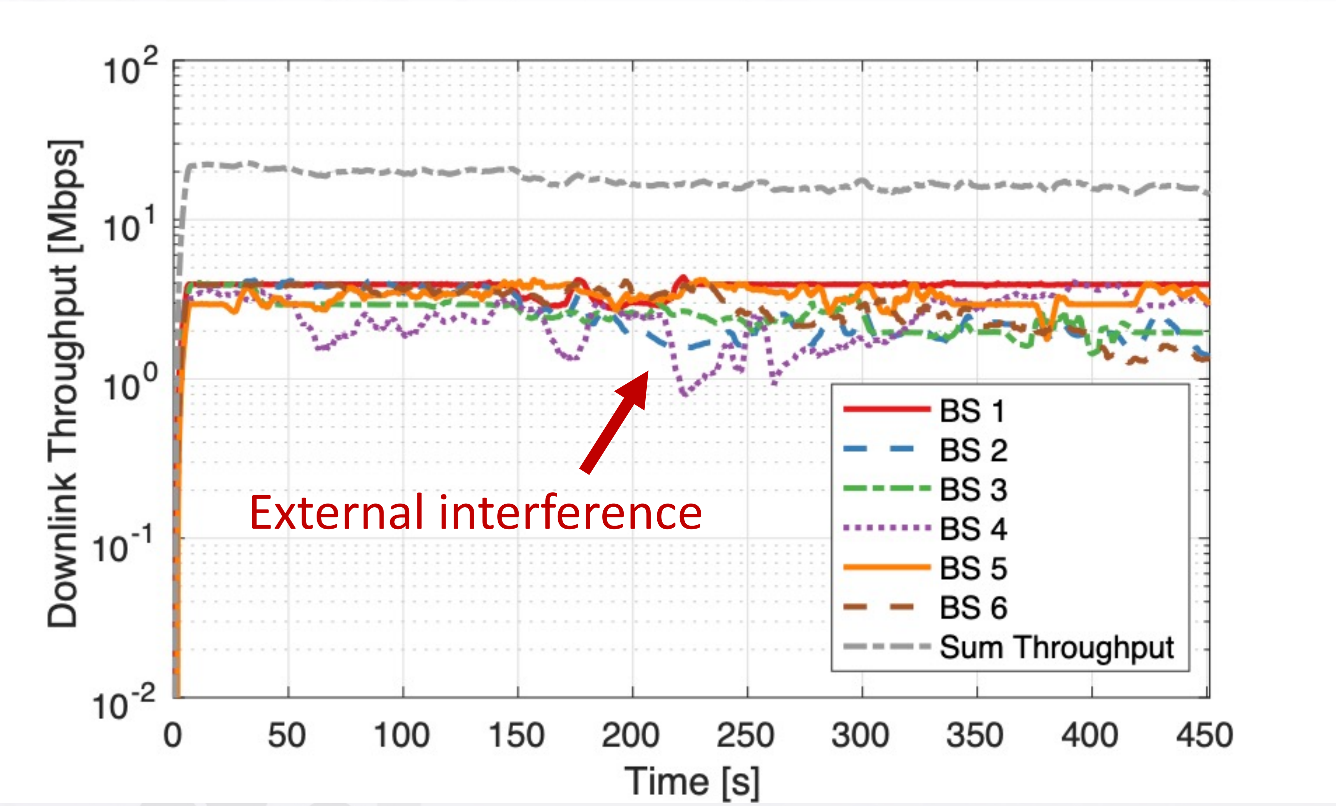
- Model a high-resolution 3D scenario through ray-tracing software
- Outdoor environment, *Krentzman Quadrant at Northeastern University*
- Applied material properties at desired carrier frequencies obtained from ITU model
- Get channel taps from ray tracing software and feed them to Colosseum



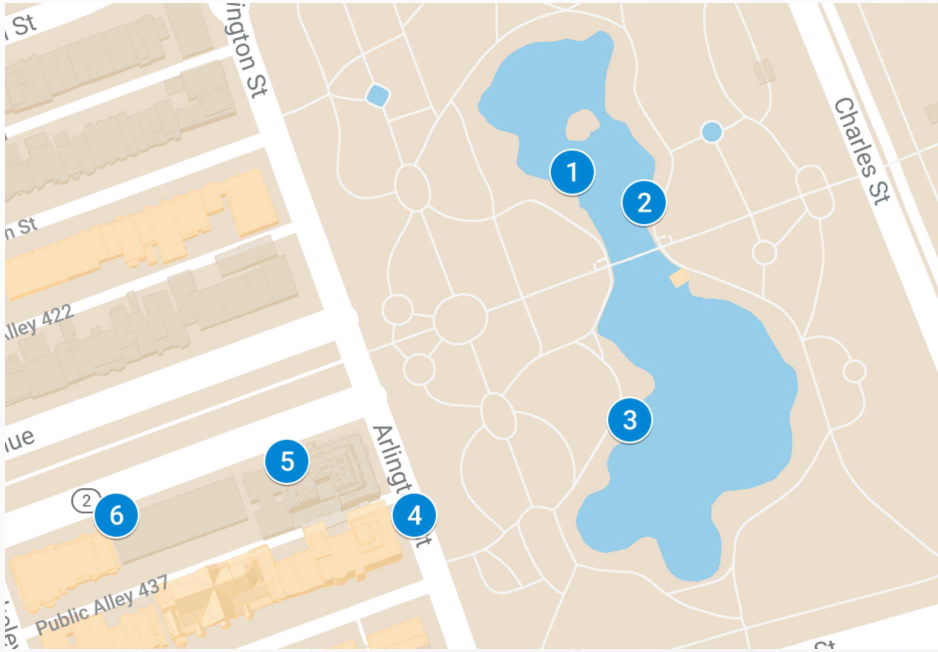
M. Tehrani Moayyed, L. Bonati, P. Johari, T. Melodia, and S. Basagni. Creating RF Scenarios for Large-scale, Real-time Wireless Channel Emulators. In *Proceedings of IEEE MedComNet 2021*, Virtual conference, June 15-17, 2021

Colosseum 5G Scenario Example

- Cellular network w/ 6 interfering base stations & 24 users
- Downlink video streaming
- Pedestrian user mobility
- Real-world scenario with base station locations in the Boston Public Garden



Downlink throughput



Base station locations

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Thank You! (Questions?)