Institute for the Wireless Internet of Things at Northeastern University

# RF and Traffic Scenarios Overview

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Platforms for Advanced Wireless Research

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

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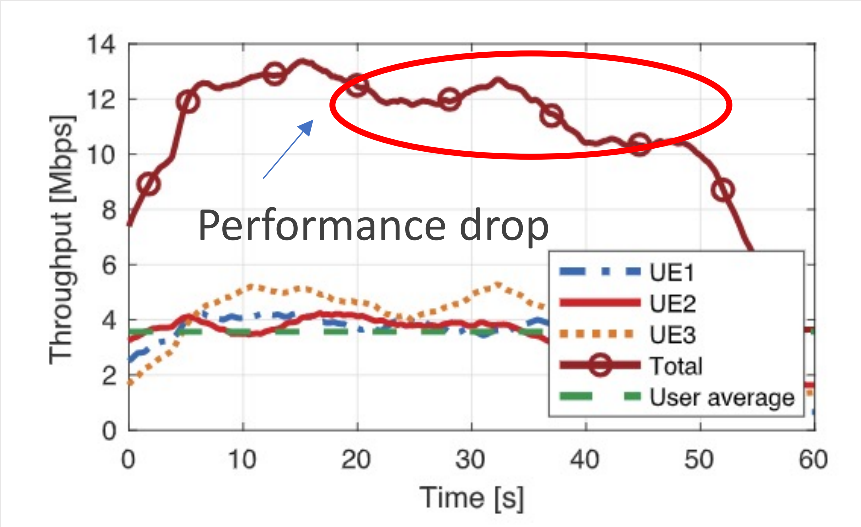
- RF / traffic scenarios are **deterministic**: Experiments w/ same scenario execute the same way
- Will be extended w/ stochastic distributions in the filter taps

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

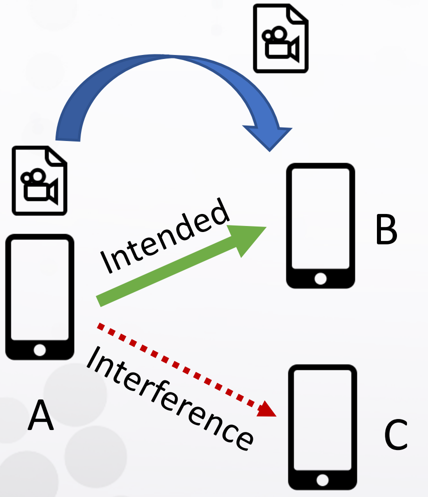



*Is the performance drop due to the* ***channel*** *or* ***bad algorithm design****?*

***An example: performance drop***

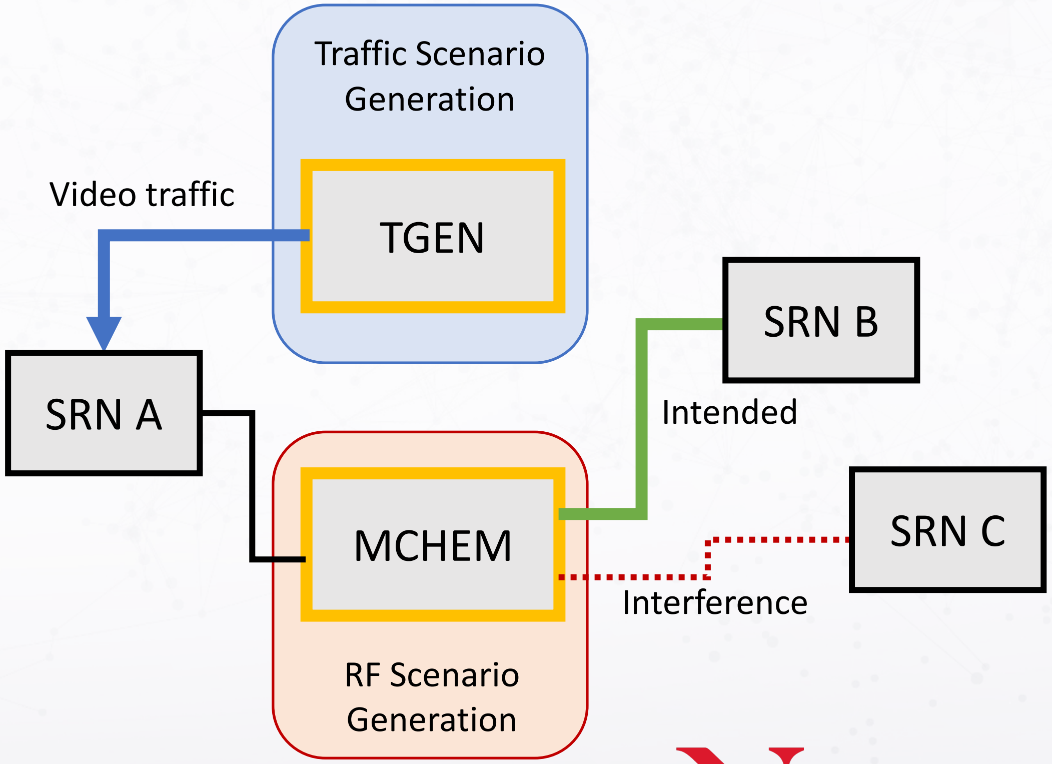
# High-level Overview

- 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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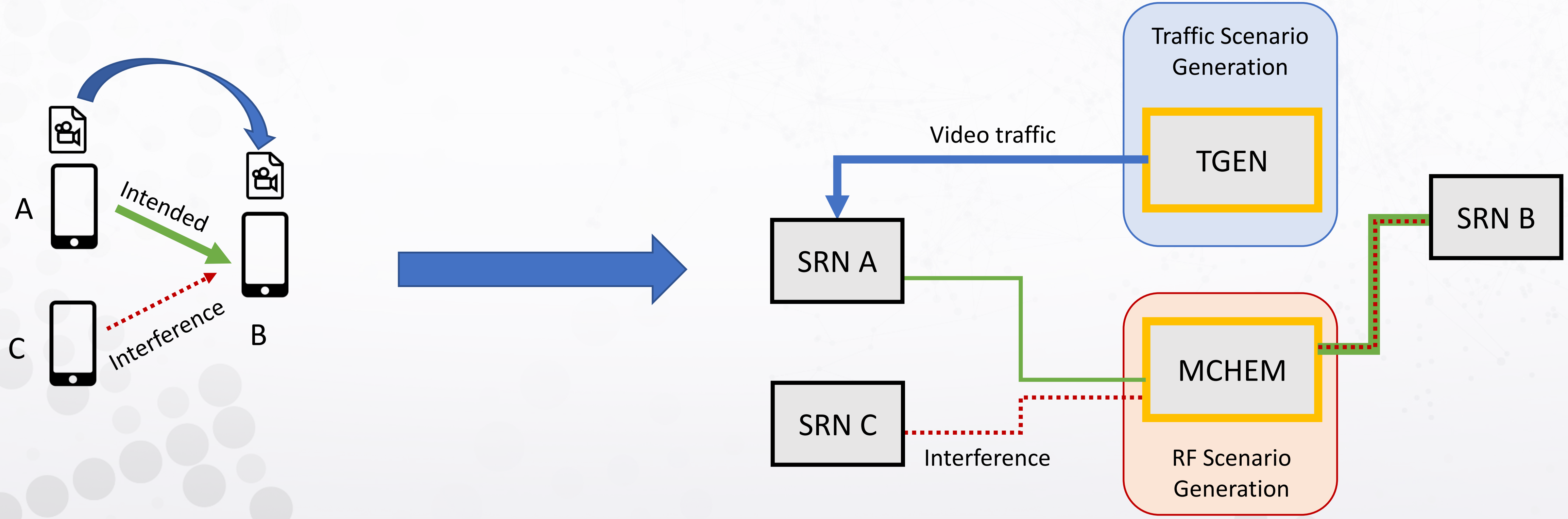
# High-level Overview, Cont'd

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

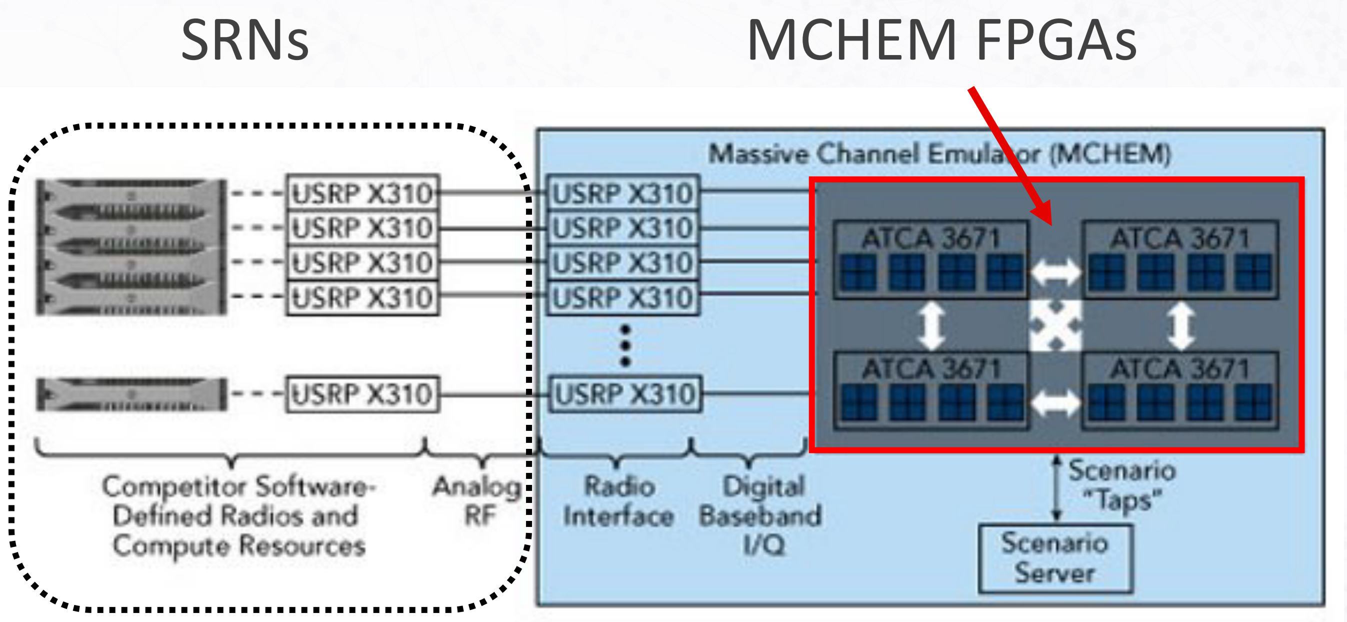
- **Each node can experience interference from all the other 255 transceivers**



# RF Scenarios – Wireless Channel Modeling

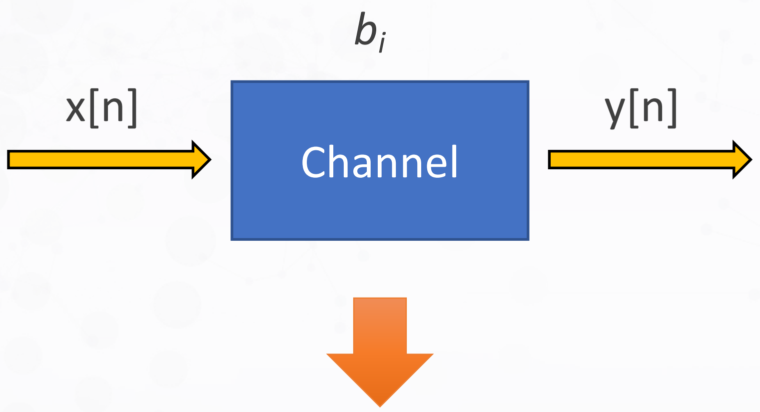
- **Wireless channel:**
  - Modeled as a Finite Impulse response (FIR)
  - 512 complex-valued FIR taps
    - 512 delays (or paths) for the same signal
  - Stored in the Scenario Server

- 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



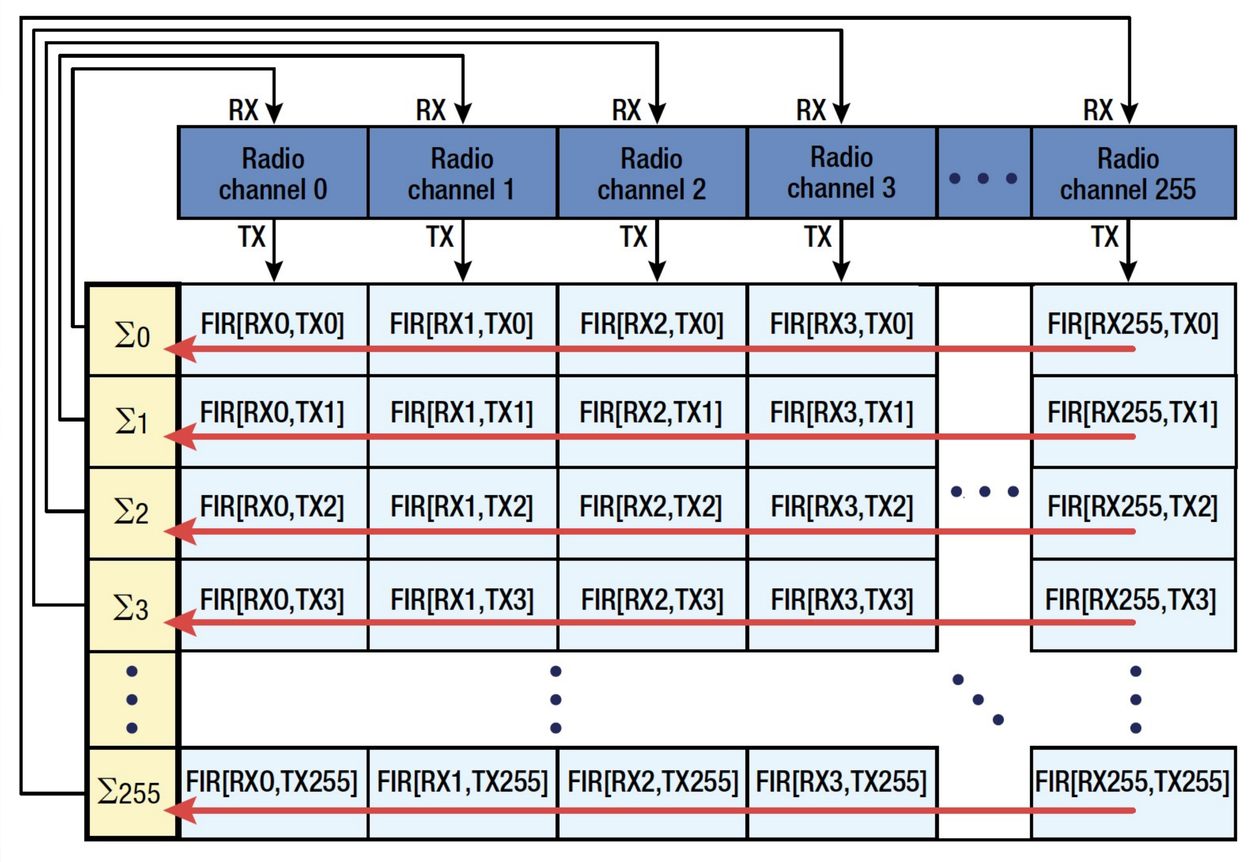
# Why FIR Filters?

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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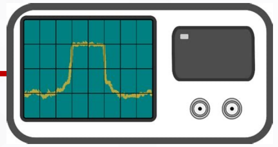
# Ways to Generate Filter Taps

- **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

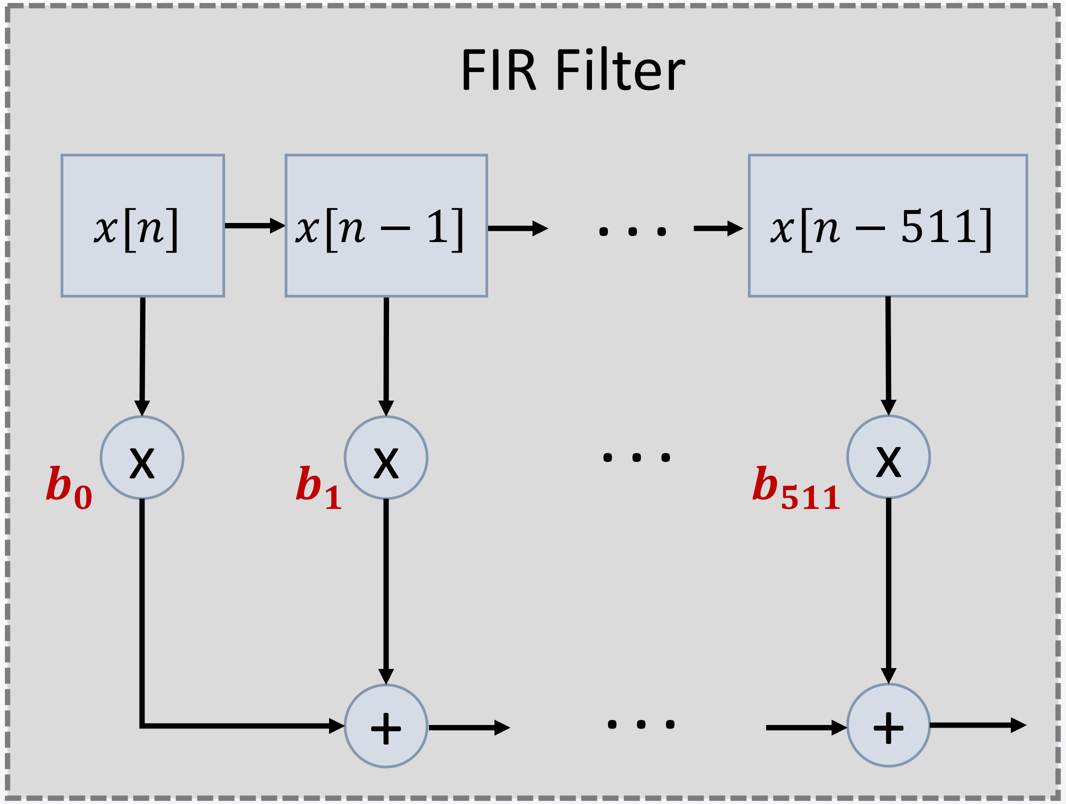
$b_i$

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

Calibrate w/ measurements

Taps Approximation

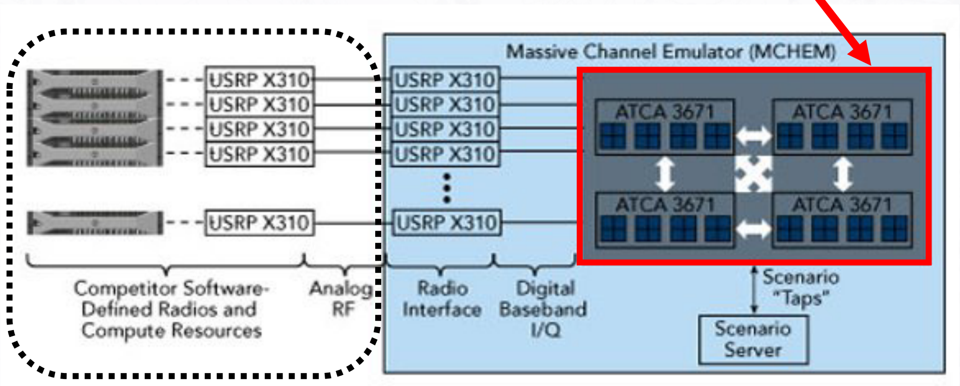
$b_i$



# 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!

SRNs MCHEM FPGAs




- 4 taps are a good **trade-off** between **complexity** and **accuracy**

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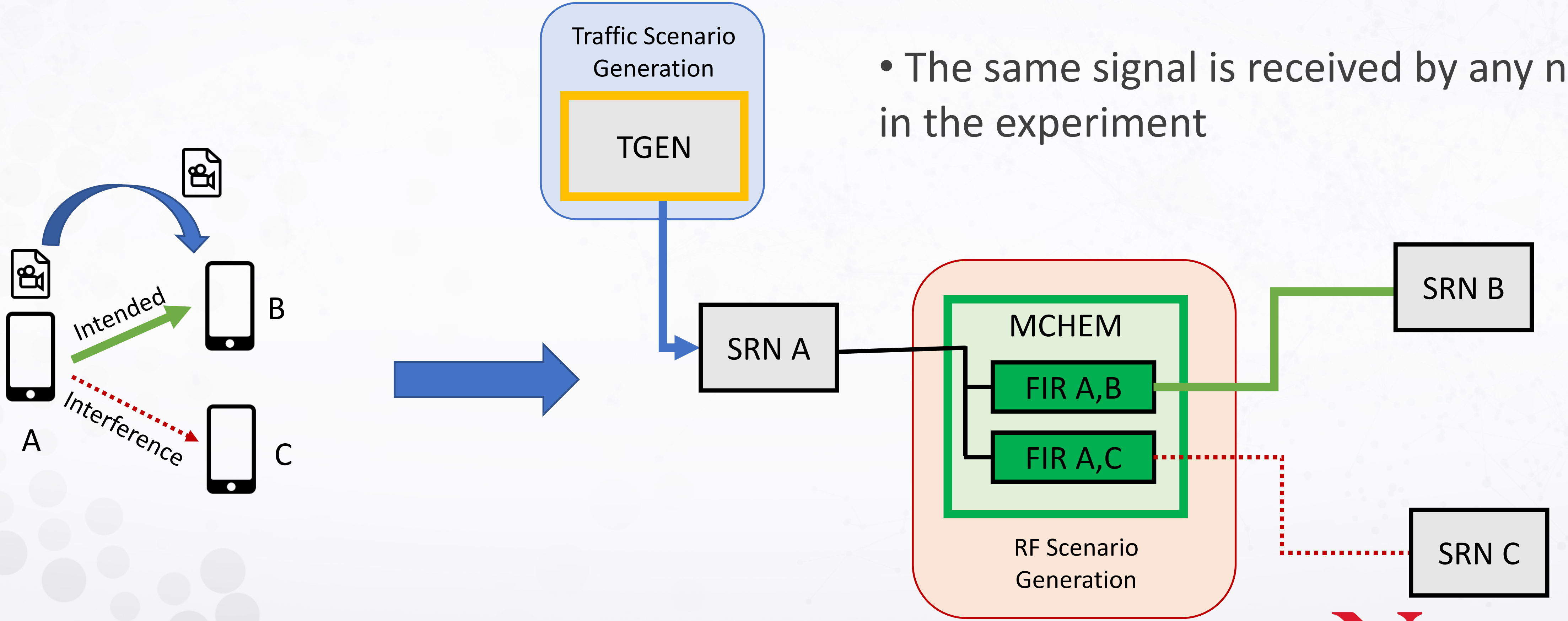
# RF Scenarios in Practice

- 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***

| Stage | Duration | Link SNR | Offered Traffic / Flow |
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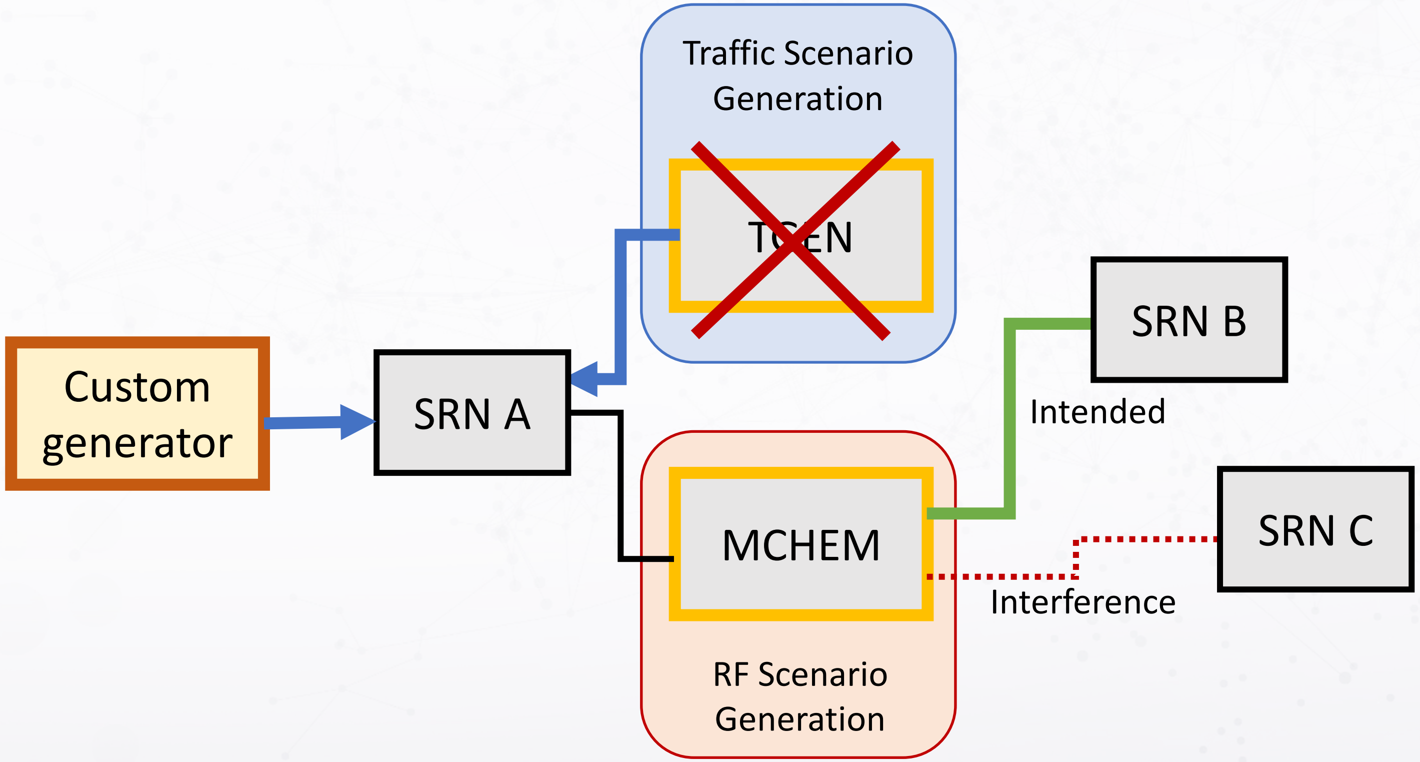
# Traffic Scenarios - Customization

- Users can use custom traffic generators

- Examples:
  - iPerf2
  - iPerf3
  - Netperf
  - MTR

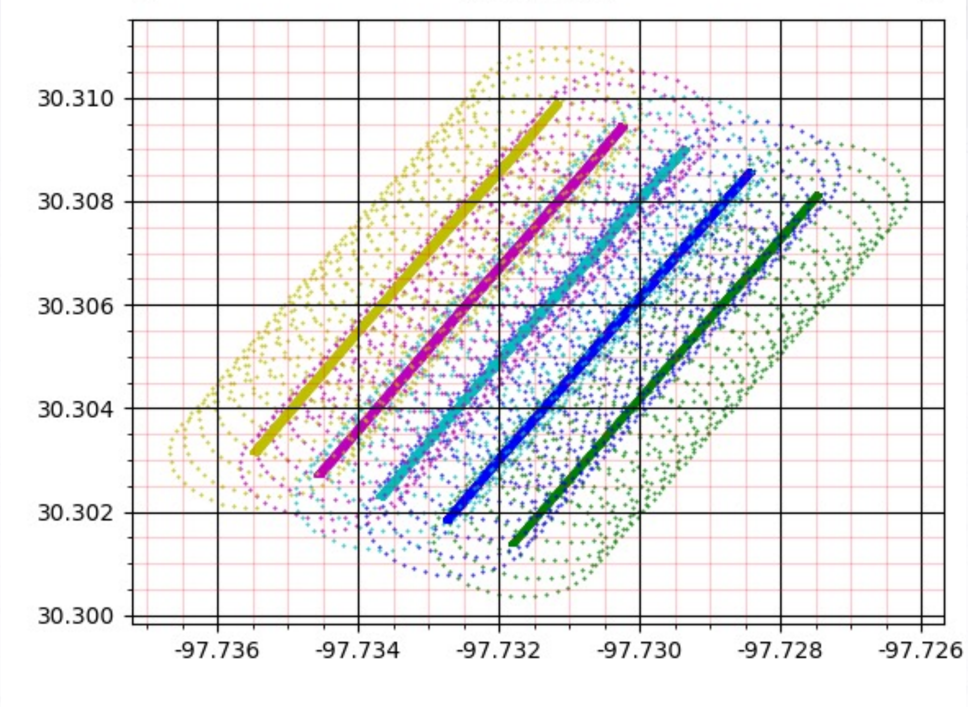
- TGEN gets bypassed



# 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.

# Pathloss Example

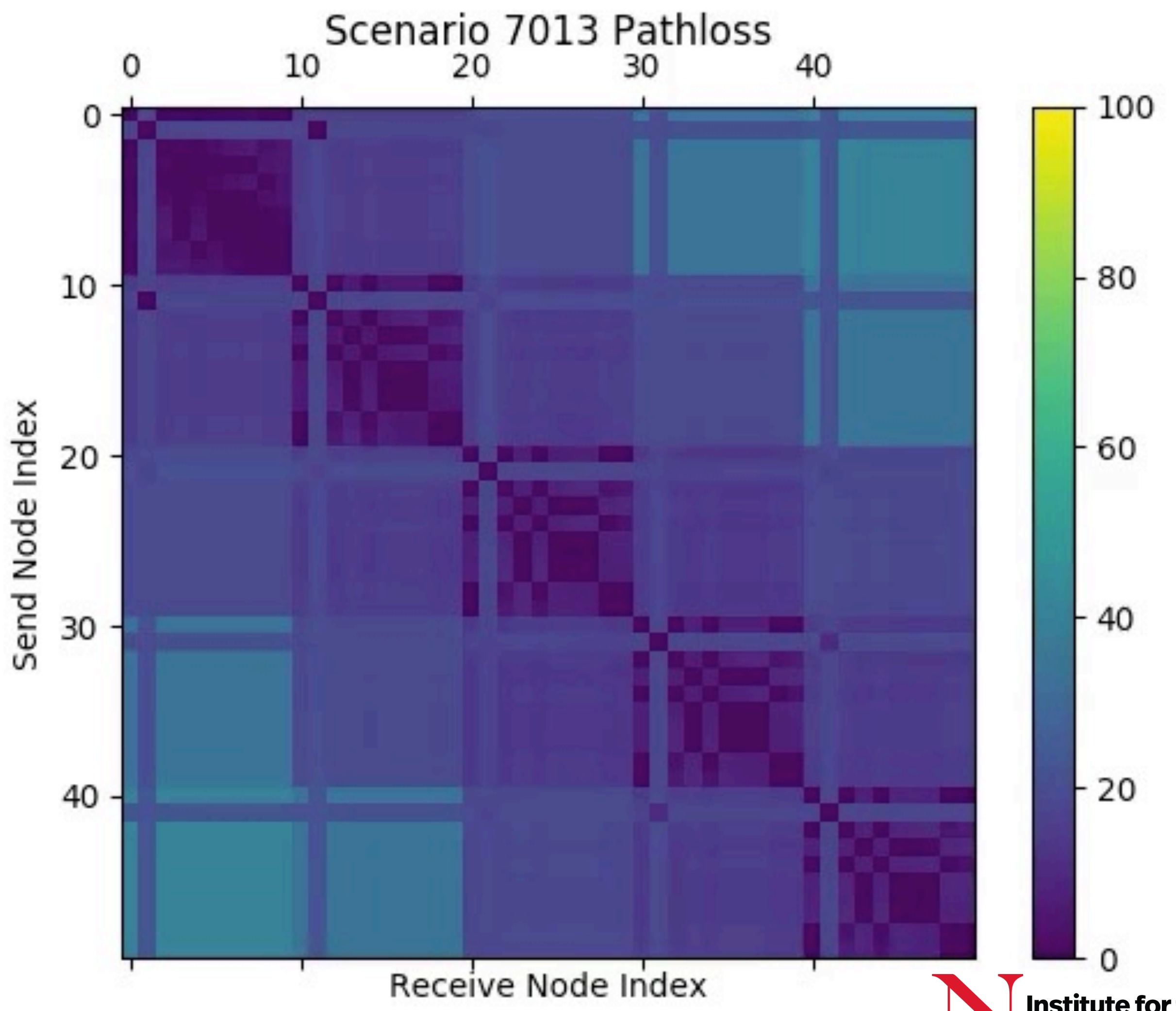
5 teams / networks

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

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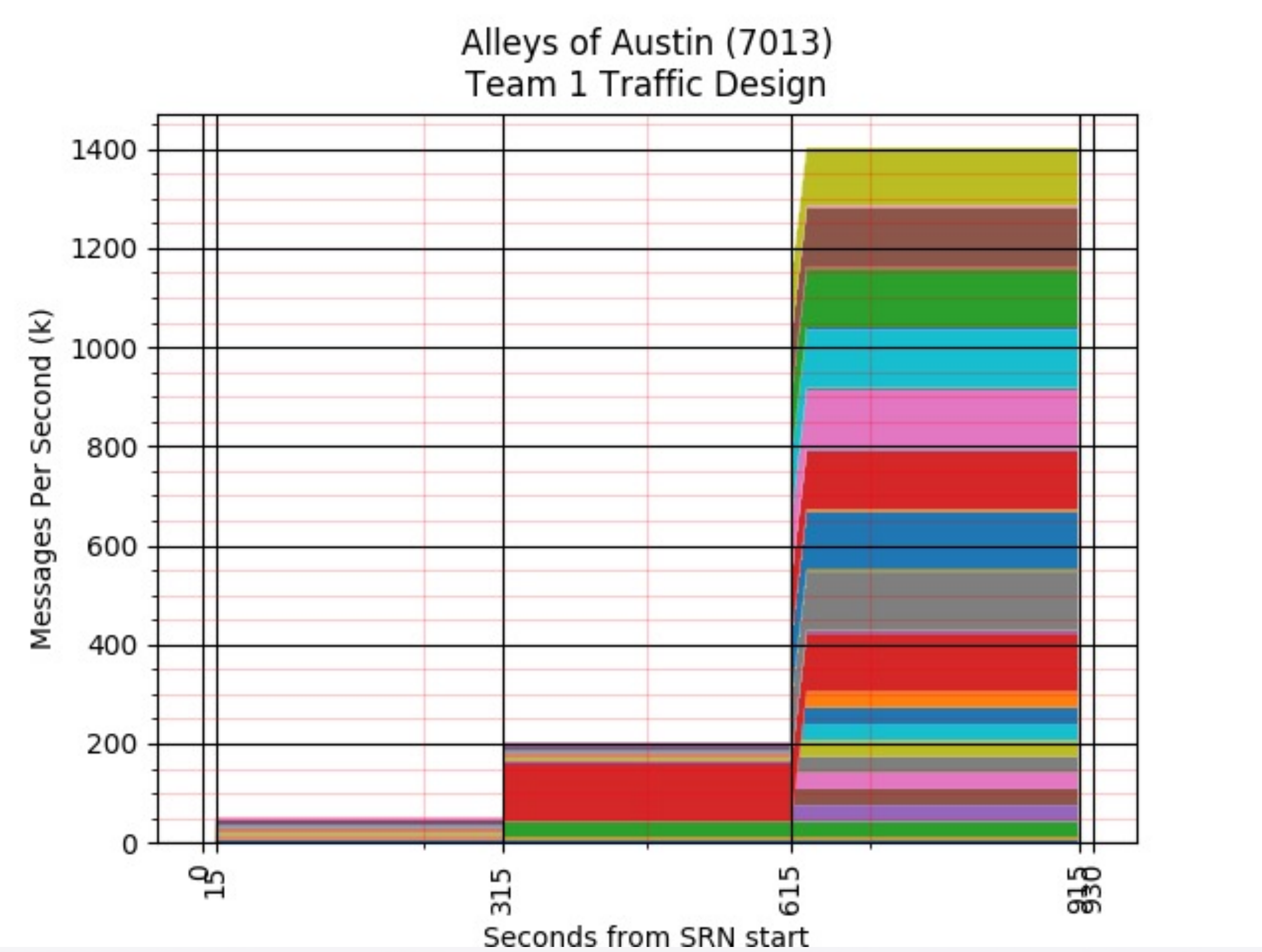
# RF Traffic

- 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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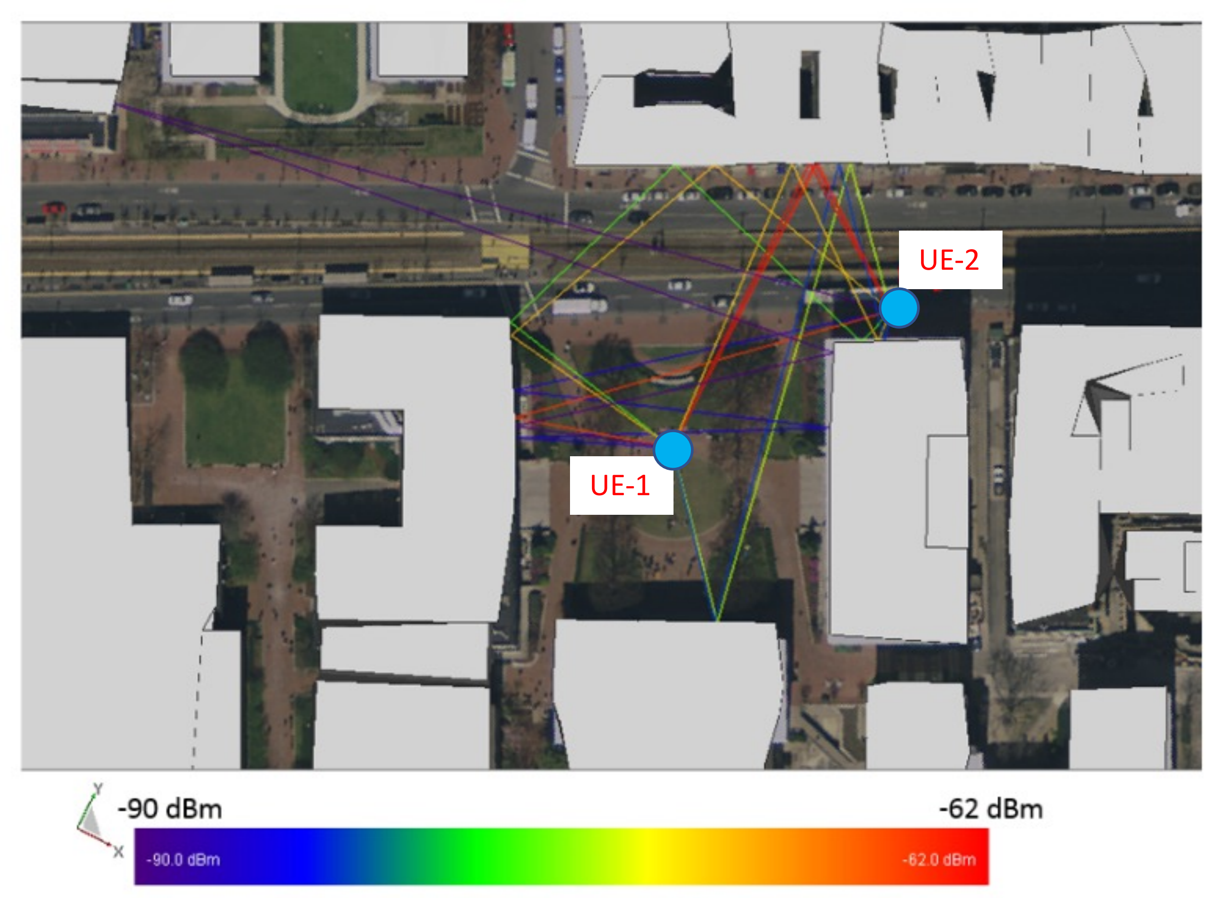
# From Ray Tracers to Colosseum Scenario

- 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

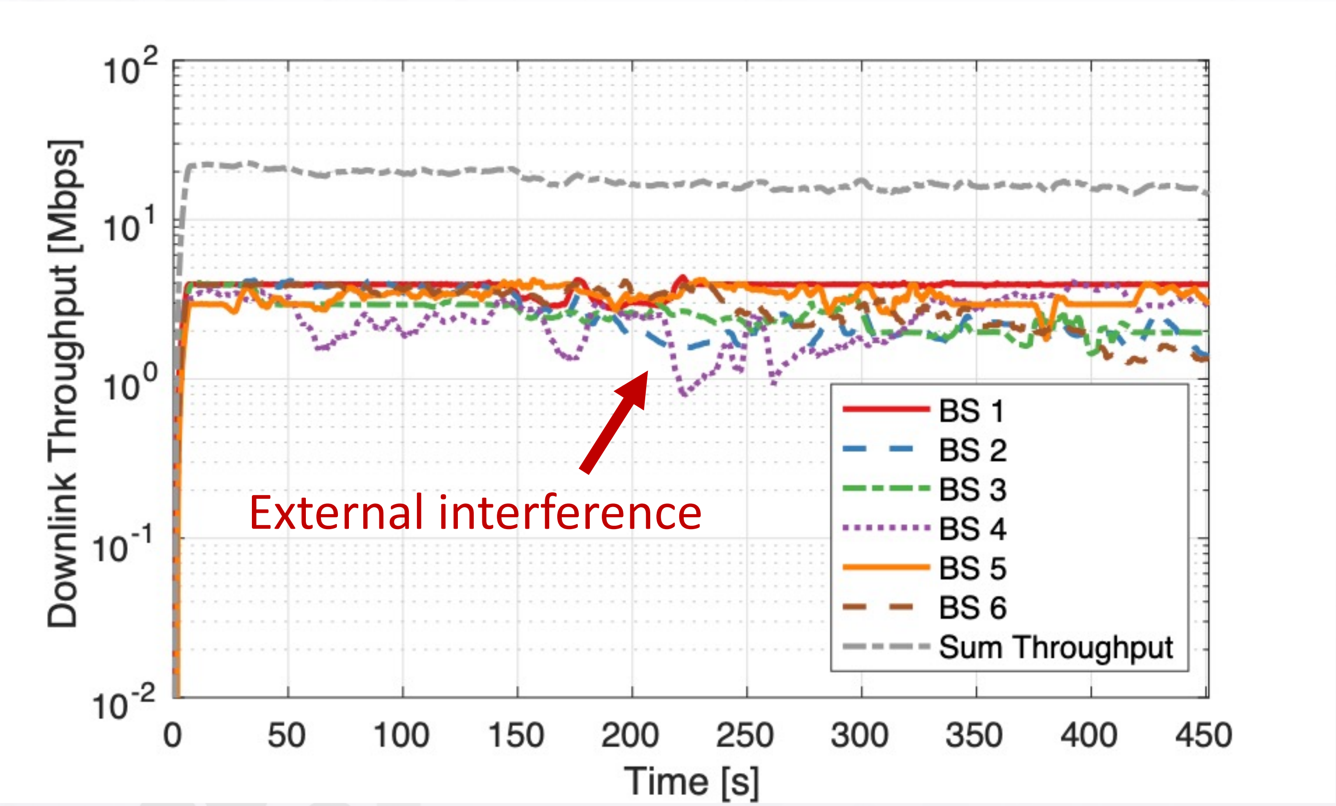




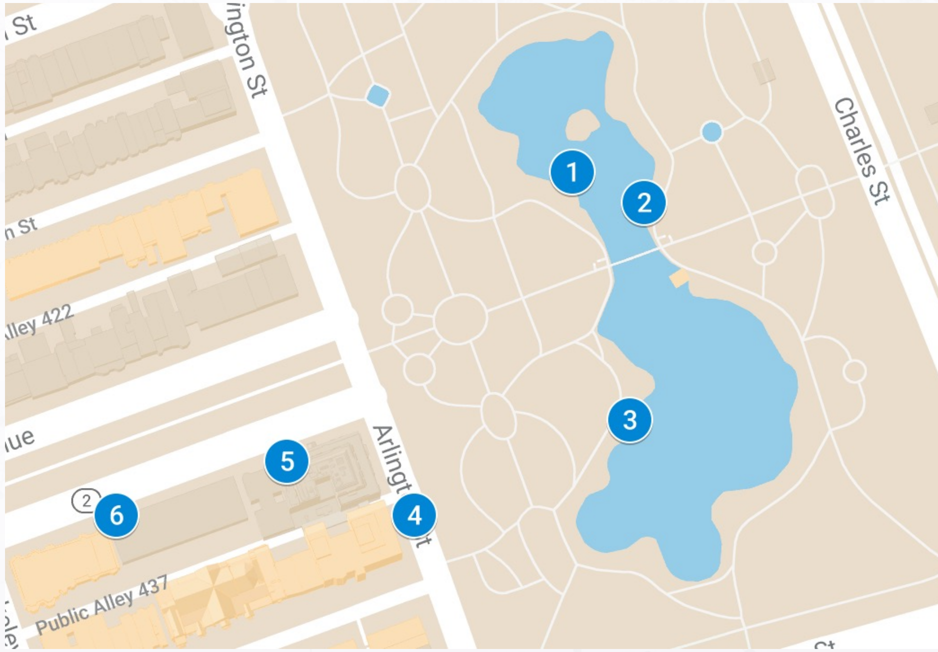

M. Tehrani Moayyed, L. Bonati, P. Johari, T. Melodia, and S. Basagni. Creating RF Scenarios for Large-scale, Real-time Wireless Channel Emulators. In *Proceedings of IEEE MedComNet 2021*, Virtual conference, June 15-17, 2021

# 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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LVX VERITAS VIRTVS

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## Thank You! (Questions?)

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