Reproducible MIMO Operation in ns-3 using Trace-based Wi-Fi Rate Adaptation

Workshop on ns-3 2021

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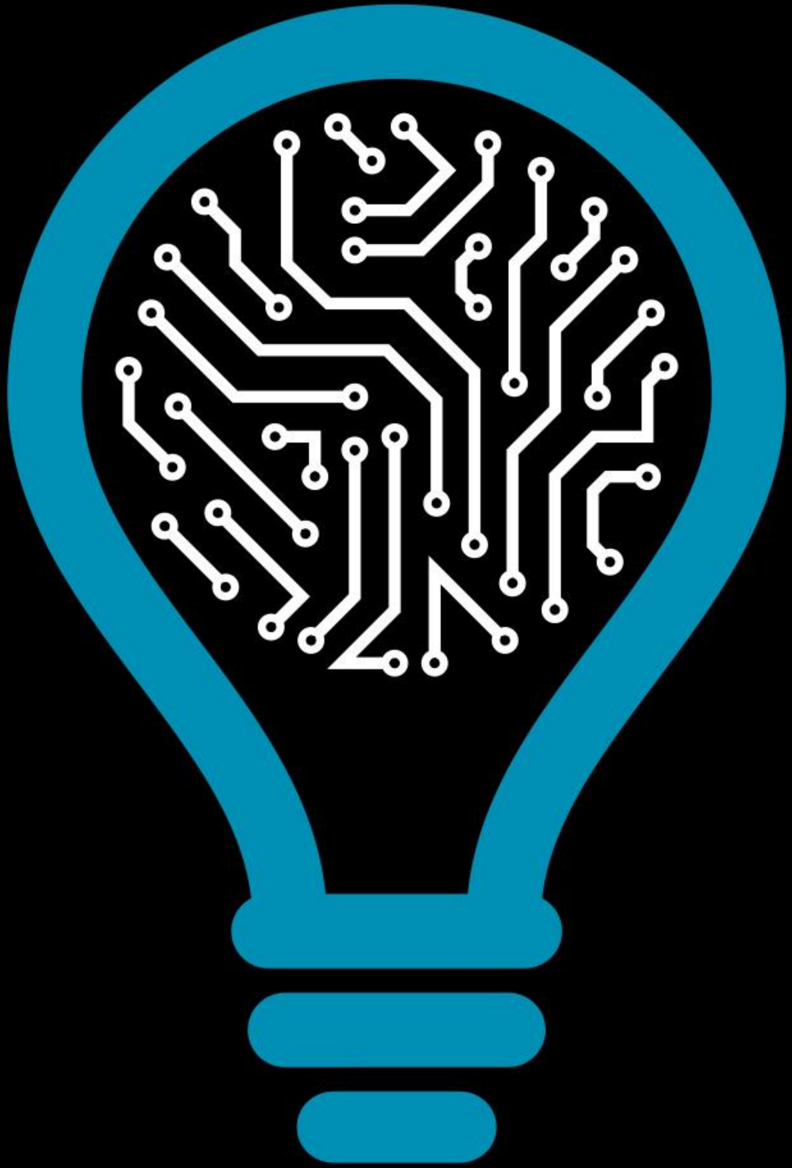


- Background and Motivation
- Trace-based Simulation Approach
- Problem
- Trace-based Wi-Fi Rate Adaptation
- Evaluation Results
- Conclusions
- Future Work

Background and Motivation

Problem

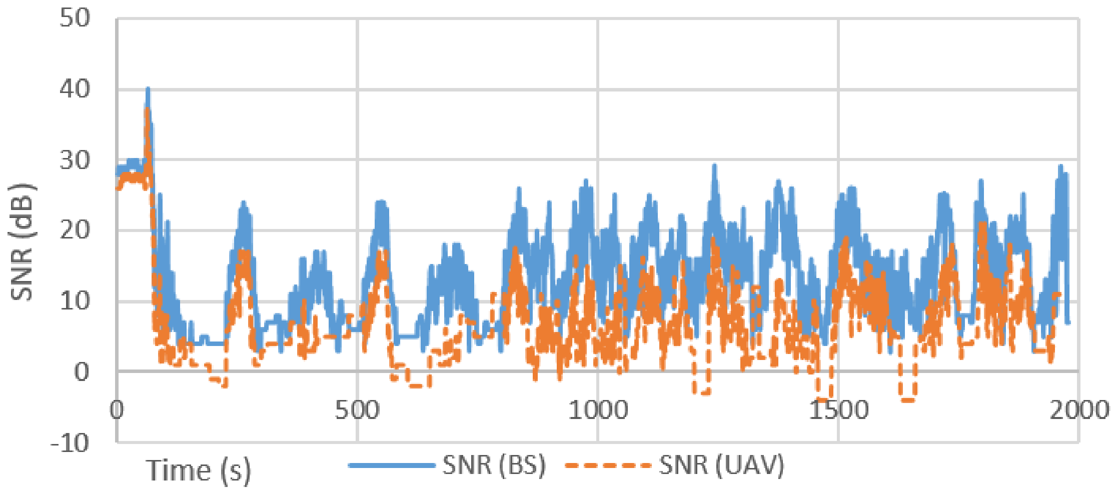
- Emerging Testbeds experiments **are difficult to repeat and reproduce**
  - **Unstable physical conditions**
  - **Cost and operational constraints**
  - **Simulation** is too **optimistic**

Objective

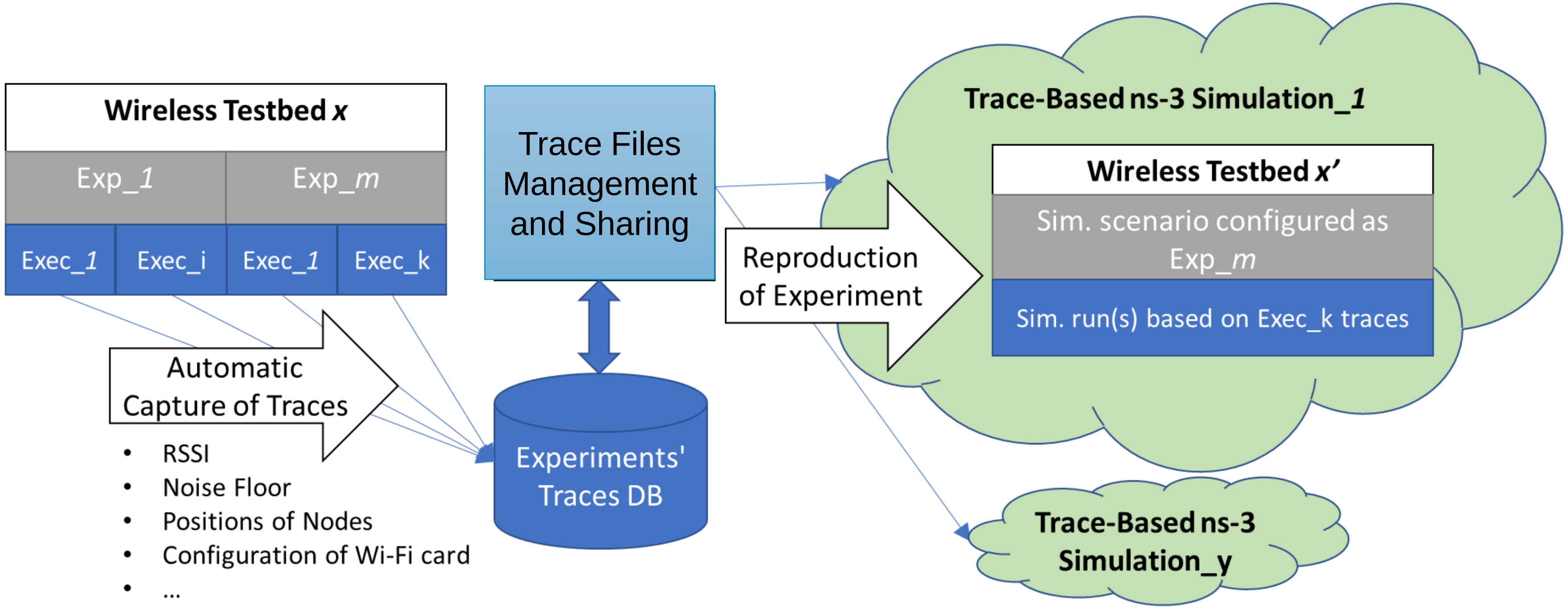
- Enable **repeatable** and **reproducible experiments without access to the testbed**
  - Accurately reproduce Real-World Experiments conditions in ns-3

Trace-based Simulation Approach

- **Capture Traces of Real Experiments**
  - Position of Nodes
    - GPS or cartesian coordinates
  - Radio link quality
    - Signal-to-Noise Ratio (SNR)
    - Other metrics



Trace-based Simulation (TS) Approach



- **Reproduce Traces in ns-3**
  - Configuration of Wi-Fi Cards → Channel, BW, standard, etc.
  - Positions of Nodes → WaypointMobilityModel
  - Link Quality → Trace-based Simulation Models

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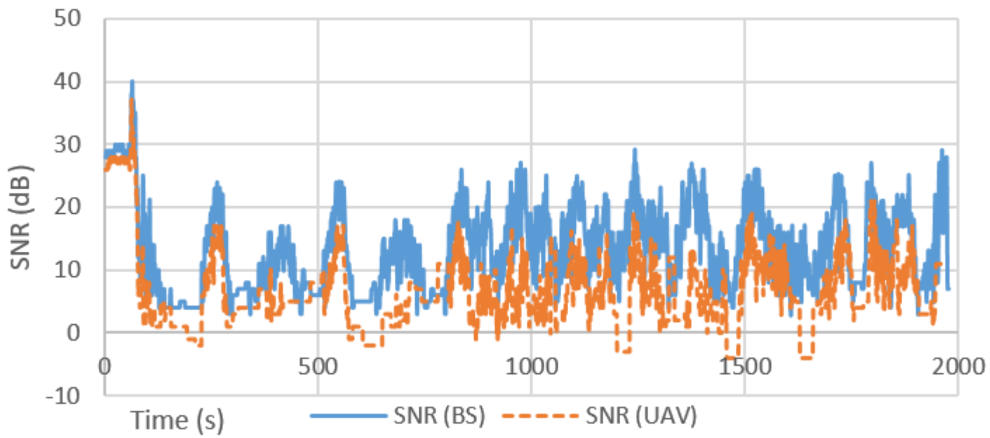
Trace-based Propagation Loss

Background



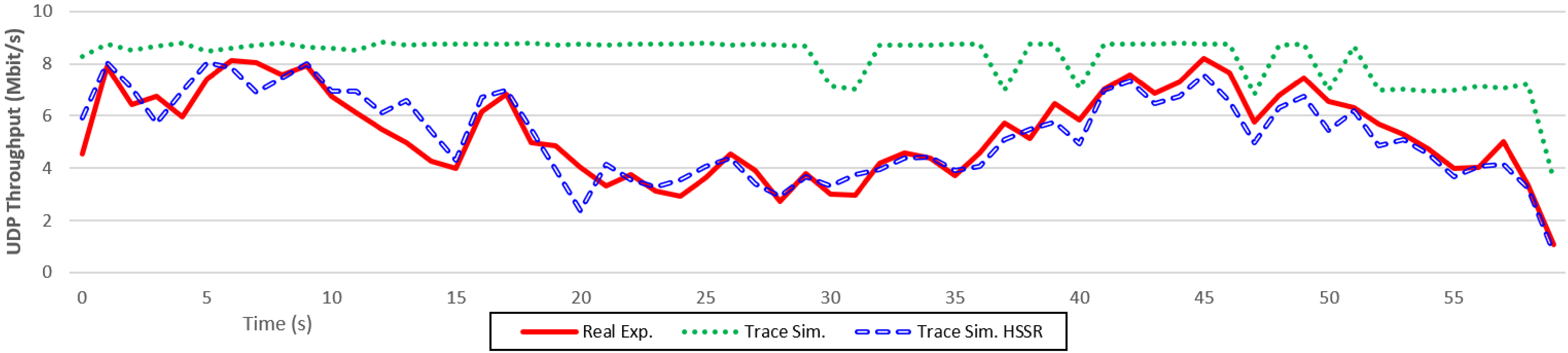
- Reproduces the **asymmetric SNR** between neighboring nodes
  - Each successfully received frame is a valid **RSSI** sample
  - The reported **noise floor** is also considered

- ErrorRateModel
  - *Input:* PHY rate, Frame size, SNR (from real node)
  - *Output:* FER

Trace-based Propagation Loss

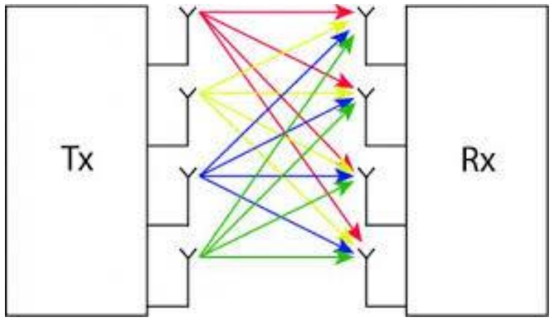
Background

- FER causes frame retransmissions → closer to real **throughput and delay**
  - ns-3 Minstrel **auto-rate** adaptation is used



- **OK** for Single-In Single-Out (**SISO**), **insufficient** for Multiple-In Multiple-Out (**MIMO**)

Problem



- **Real World**
  - **Network interfaces** collect the Channel State Information (**CSI**)
  - **Multipath environment** influences
    - **Number of effective radio streams**
    - **TX antennas selection**

- **Pure Simulation**
  - Number of radio streams = number of antennas
    - Streams are independent

- **Trace-based Simulation**
  - **SNR trace** alone is **not enough for MIMO** scenarios

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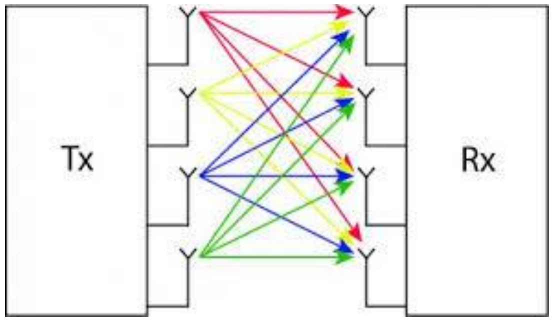
Trace-based Wi-Fi Rate Adaptation



- Captures and Reproduces the **MCS** and **number of radio** streams used to transmit frames to each of the neighboring nodes
  - Each successfully received frame is a valid sample
  - A **Trace-based Wi-Fi Station Manager** is used to reproduce the traces
- Resulting **auto-rate adaptation** is now **deterministic**, based on the real traces
- **Frame losses** remain **stochastic**, based on the ns-3 **ErrorRateModel**
  - **MCS** is, however, **not affected by** MAC layer **retransmissions**

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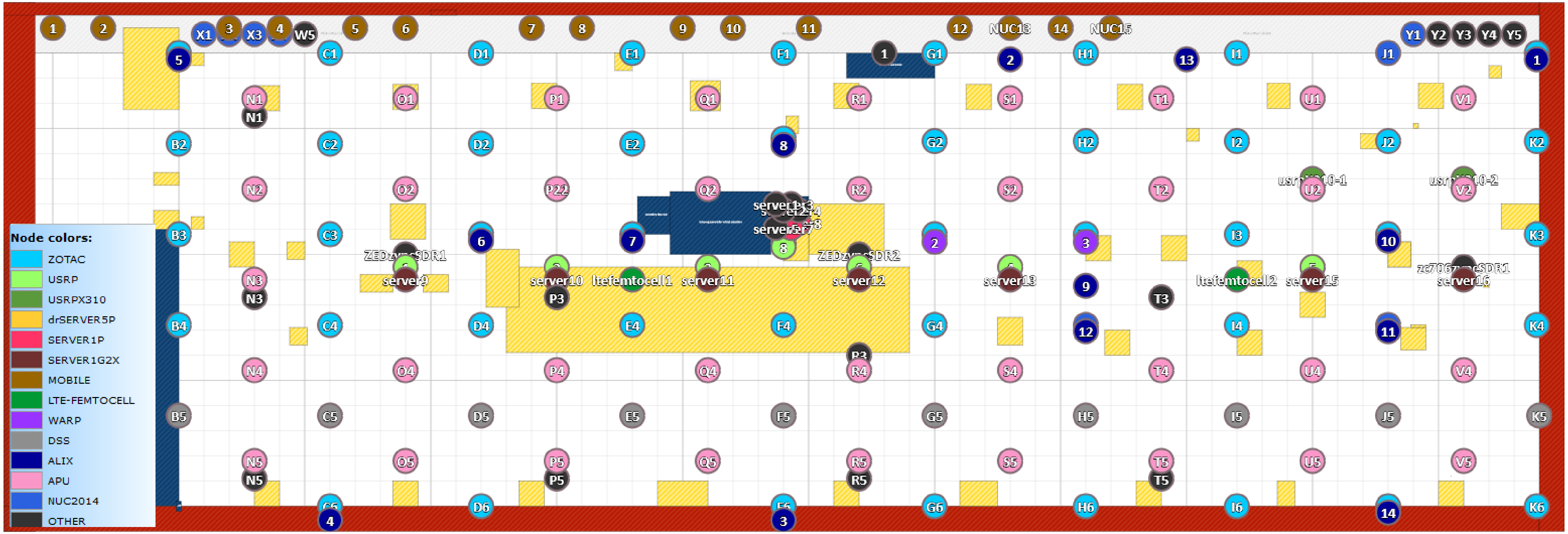
Experimental Setup

Fed4FIRE+ **w-iLab.2** Testbed, used in the context of **SIMBED+ Project**



■ = 1 m²

- ZOTAC nodes (light blue)
- Varying distance and TX power

Experimental Setup

Zotac nodes

- OS: Ubuntu 14.04 LTS x64
- CPU: Intel D525 (2x 1.8 GHz)
- RAM: 4GB
- NIC1: 802.11abgn 3x3 MIMO Sparklan with AR9280 chipset (ath9k driver)
- NIC2: 802.11a/b/g/n/ac 3x3 MIMO Compex WLE900VX with QCA9880 chipset (ath10k driver)

Configuration

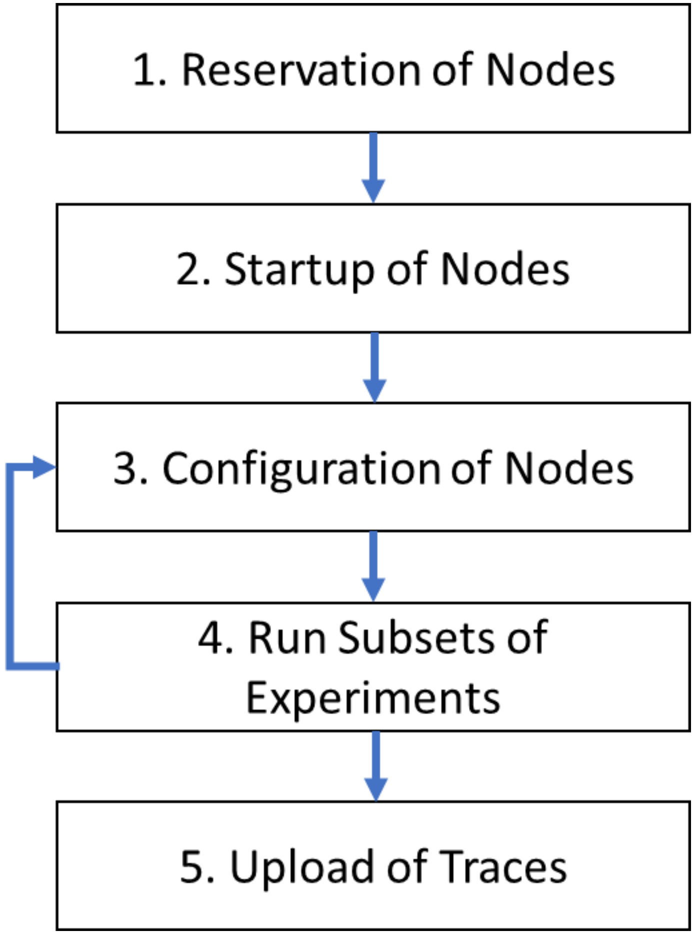
- Channel: 5220 MHz
- TX-Power: 0 to 17 dBm, 1 dBm steps
- IEEE Standard: 802.11a (SISO) / 802.11n/ac (MIMO 3x3), ah-hoc, auto-rate
- BW: 20 / 40 MHz

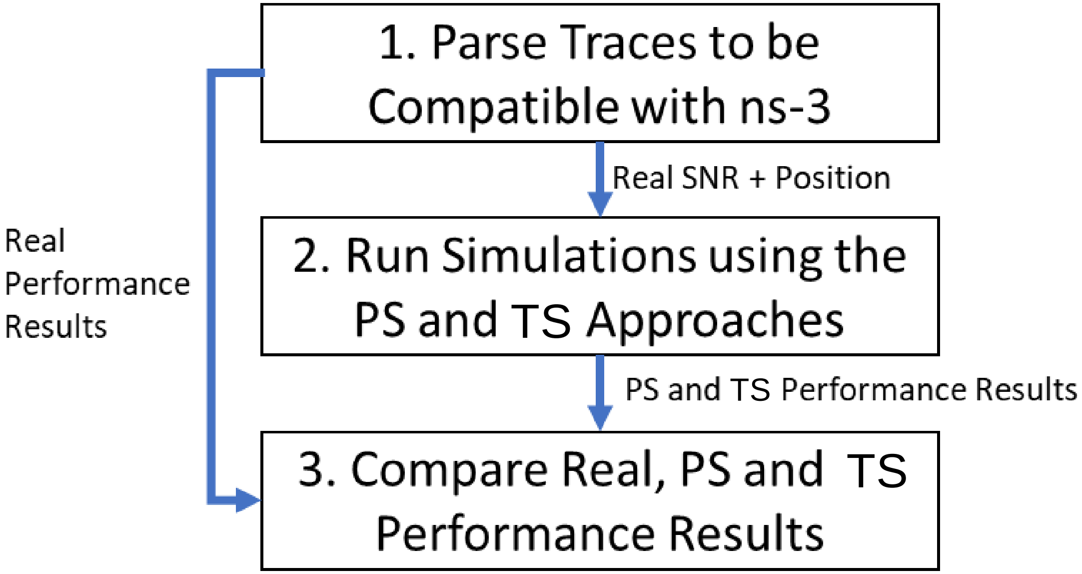
Network Traffic

- UDP flows with **offered load above link capacity**
    - **Unidirectional** (A→B and A←B) and **bi-directional** (A ←→B)

Experimentation and Evaluation Methodology

Real *vs* Pure Simulation (PS) *vs* Trace-based Simulation (TS)

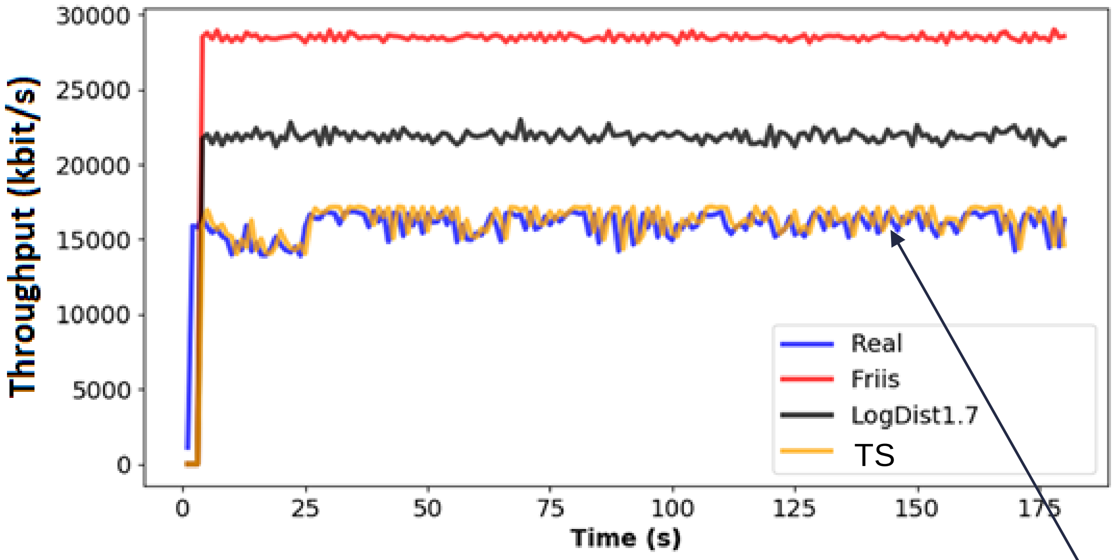




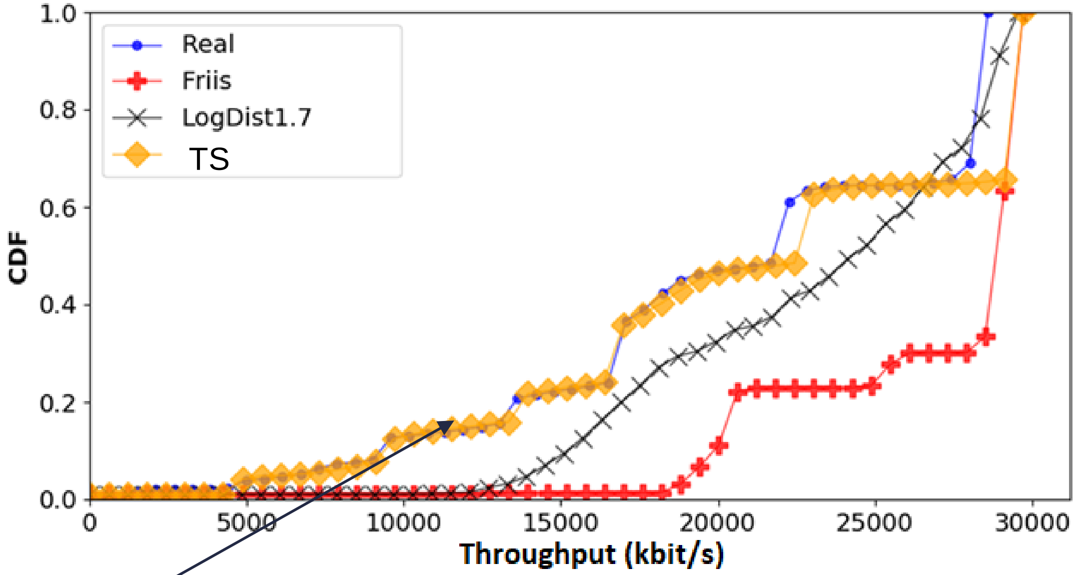
Trace-based Wi-Fi Rate Adaptation

Evaluation – Static Scenario @ Wi-Lab.2 (SIMBED+ Project)
802.11a, SISO

Example of an experiment



CDF of the throughput samples



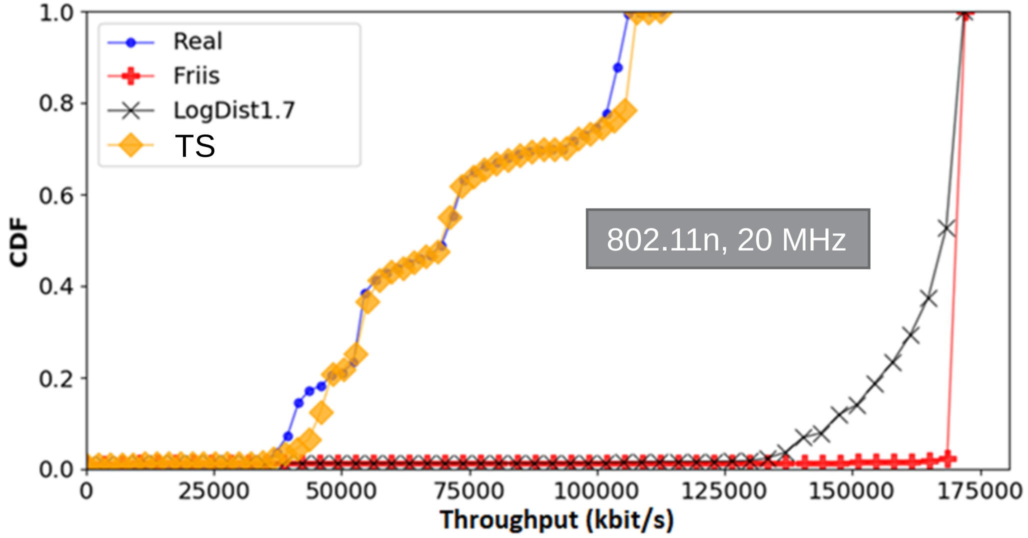
TS results very close to Real

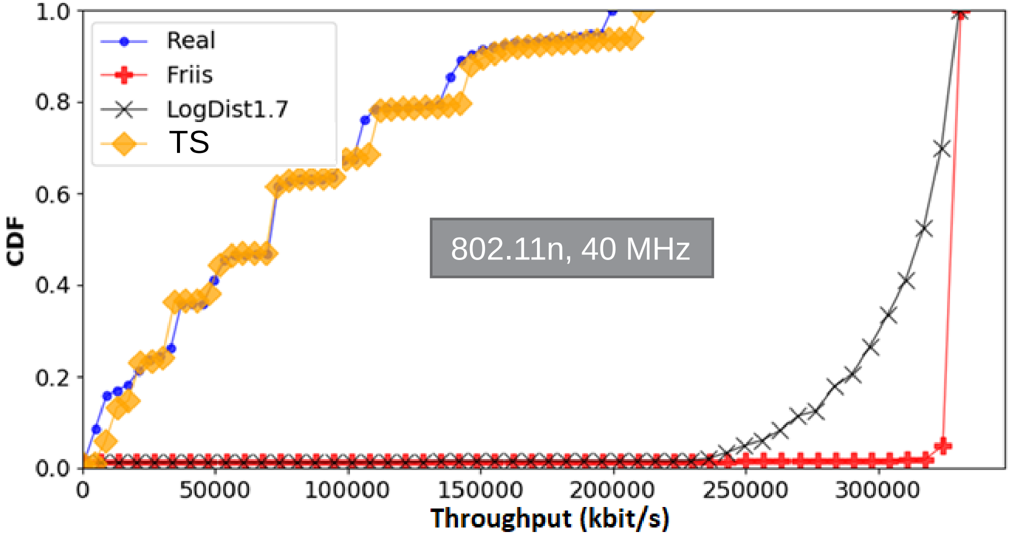
Trace-based Wi-Fi Rate Adaptation

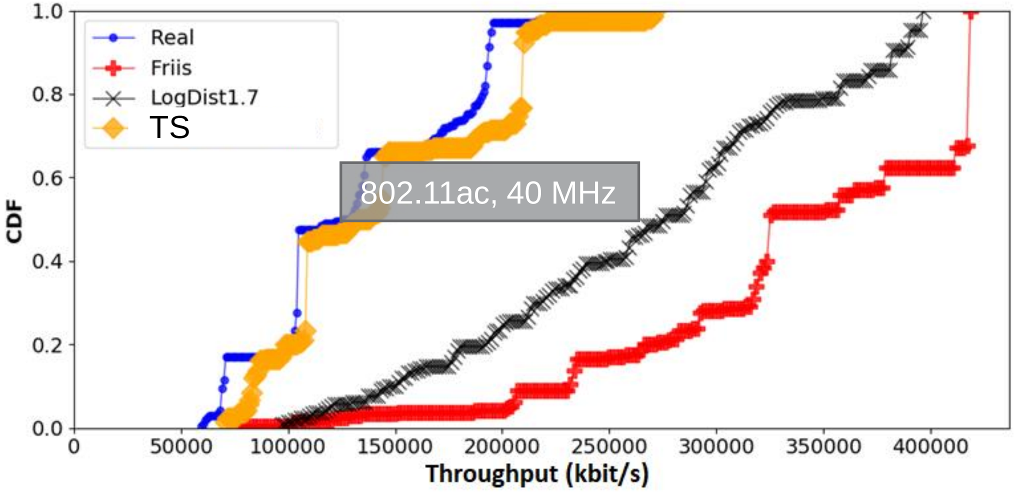
Evaluation – Static Scenario @ Wi-Lab.2 (SIMBED+ Project)

802.11n/ac, MIMO 3x3, 20/40 MHz

CDF of the throughput samples







TS results very close to Real

Current Limitations

- Lower frame losses and slightly optimistic throughput compared to the real experiment
    - Only successfully received frames are sampled
- Auto-rate adaptation becomes static (i.e. statistically dependent on the real experiment)
- TS depends on direct unicast traffic to sample the PHY rate between the nodes
    - Overhearing ACKs, Beacons, etc., is not enough

Main Conclusions

- The **TS approach** now supports realistic reproduction of **MIMO** experiments
  - **SNR** (Asymmetric)
  - **MIMO** operation (MCS and number of radio streams)
    - Works even if the real rate-adaptation algorithm is not implemented in ns-3
- TS enable **ns-3** to be used to replay past experiments
    - **Saves resources**
    - **Perpetuates experiments**, even if the original **testbeds cease to exist**
    - Allows Traces to be referenced in **scientific publications, e.g.**
      - **SIMBED:** https://doi.org/10.5281/zenodo.2634271
      - **SIMBED+:** https://doi.org/10.5281/zenodo.3713270

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Future work

- Keep improving the TS approach
  - Detection of **link failure**
  - Dynamically **adjust traces resolution** to the scenario
  - Add support for **beamforming**

- Assess TS approach applicability to other wireless technologies
  - E.g., Cellular, IEEE 802.15.4

- Software platform to assist the processes of traces **capturing**, **managing** and **sharing**
  - **Share past or real time execution of experiments**

- Fine-tune and learn new **path loss** and **mobility** models
  - Accurate simulations with different **number of nodes**, **mobility** and **duration**

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Trace-based Simulation Approach

Summary and upcoming ns-3 apps

Trace Type	Trace files and its variables	Trace-based ns-3 model
Link Quality	Signal-to-noise ratio (SNR)	**TracePropagationLoss** → Validated in SIMBED
	Channel occupancy	**TraceBasedWiFiChannelOccupancy** **- "Sender" Model** **- "Receiver" Model** → Validated in SIMBED+
	PHY rate/MCS Number of radio streams	**TraceBasedWiFiRateAdaptation** → Validated in SIMBED+
Position of nodes	Cartesian coordinates	**WaypointMobilityModel**

Real SNR

Shared radio spectrum

MIMO

Acknowledgments

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Thank you!

Questions?

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