Wi-Fi simulations with ns-3

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- Credit is due to ns-3's long list of Wi-Fi module maintainers
  - Mathieu Lacage, Nicola Balco, Ghada Badawy, Getachew Redietab, Matias Richart, Stefano Avallone **(current),** Sebastien Deronne **(current)**
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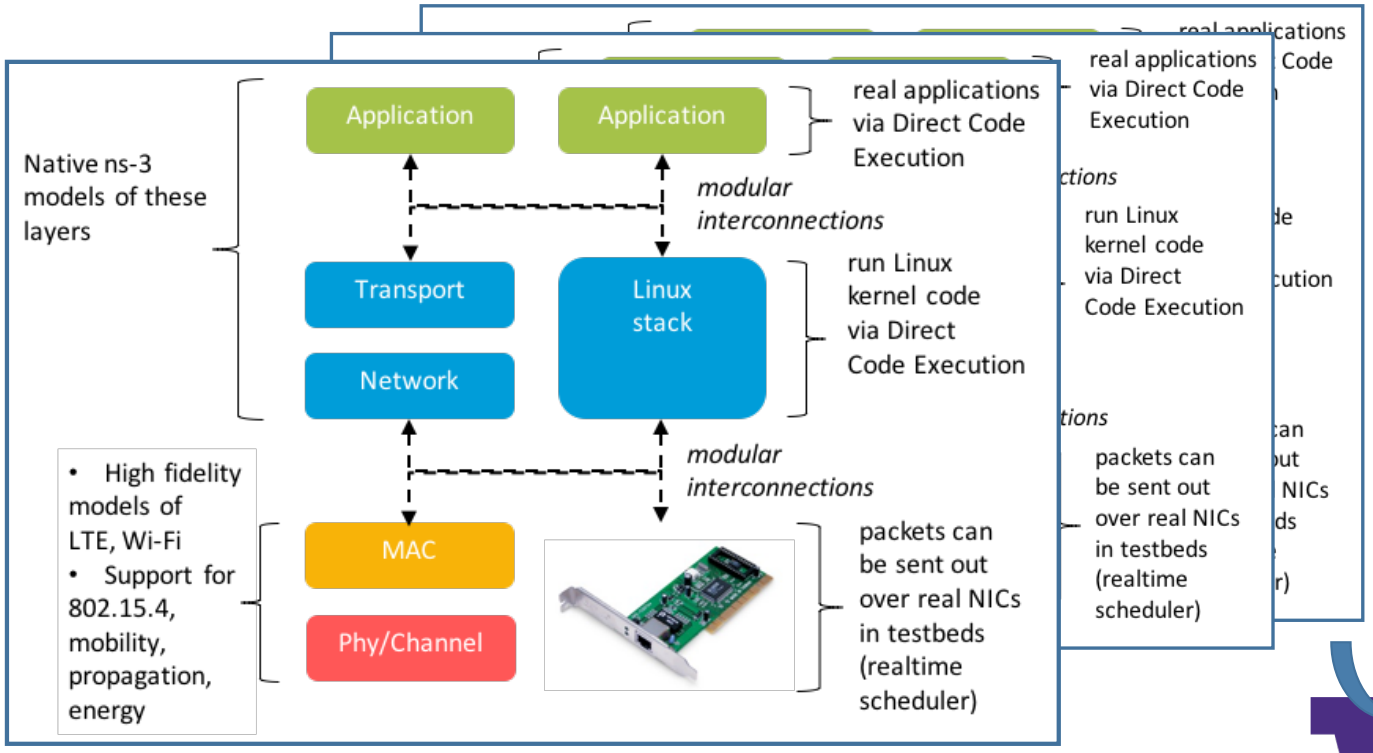
Goals of this tutoral

- Explain why you might use ns-3 to study or learn about Wi-Fi networking
- Illustrate some basic aspects of Wi-Fi
- Show how you can get started with ns-3 Wi-Fi simulations already written by others
- Answer your questions

What is ns-3?

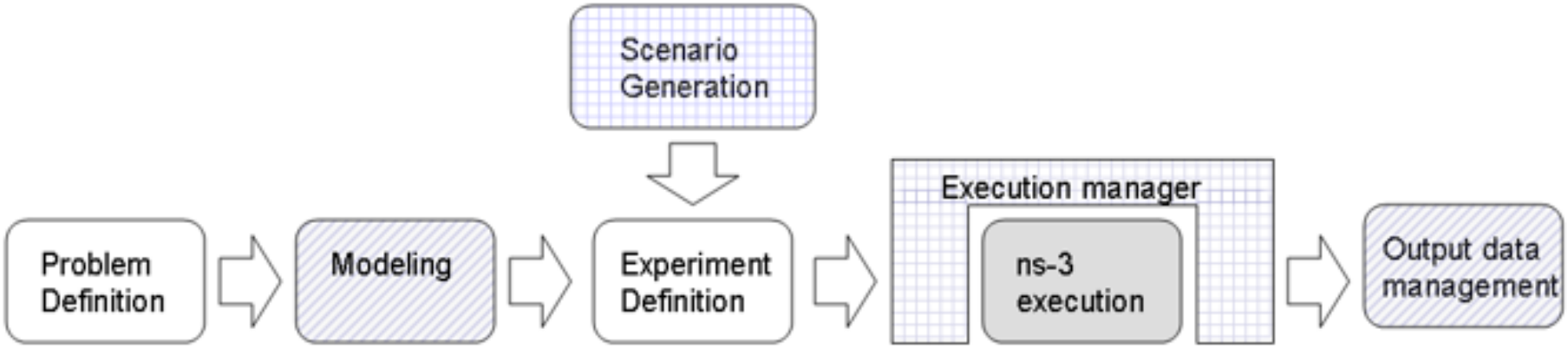
> ns-3 is a leading open source, **packet-level network simulator** oriented towards network research, featuring a **high-performance core** enabling **parallelization across a cluster** (for large scenarios), **ability to run real code**, and **interaction with testbeds**

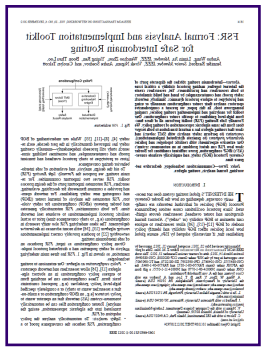
Runs on a single machine



or partitioned across a cluster

The ns-3 research workflow





Outline of this tutoral

The tutorial will be example driven

1. Getting ns-3 up and running
2. Basic concepts of ns-3's discrete-event simulation
3. Detailed walkthrough of a simple Wi-Fi example program
4. Examples and descriptions of additional Wi-Fi model features
5. Progressing from examples to validation to developing new algorithms

Prerequisites

- Some experience with command-line coding on Linux or macOS
- Some experience with or understanding of C++
- Basic understanding of Wi-Fi networks
- New users are recommended to work through the ns-3 tutorial
  - HTML: https://www.nsnam.org/docs/tutorial/html/index.html
  - PDF: https://www.nsnam.org/docs/tutorial/ns-3-tutorial.pdf

Obtaining ns-3

- Most resources are linked from the ns-3 main website at https://www.nsnam.org
- ns-3 is developed and maintained on GitLab.com at https://gitlab.com/nsnam/ns-3-dev
- We will use a pre-release version of ns-3.36 (about to be released): https://www.nsnam.org/release/ns-allinone-3.36.rc1.tar.bz2
- If you are using an earlier or later version of ns-3, please be aware that some things may have changed

Building ns-3

- (Demo) Download ns-3
- (Demo) Configure ns-3
- (Demo) Build ns-3
- (Demo) Run programs

For more information, read the tutorial Quick Start:
https://www.nsnam.org/docs/tutorial/html/quick-start.html

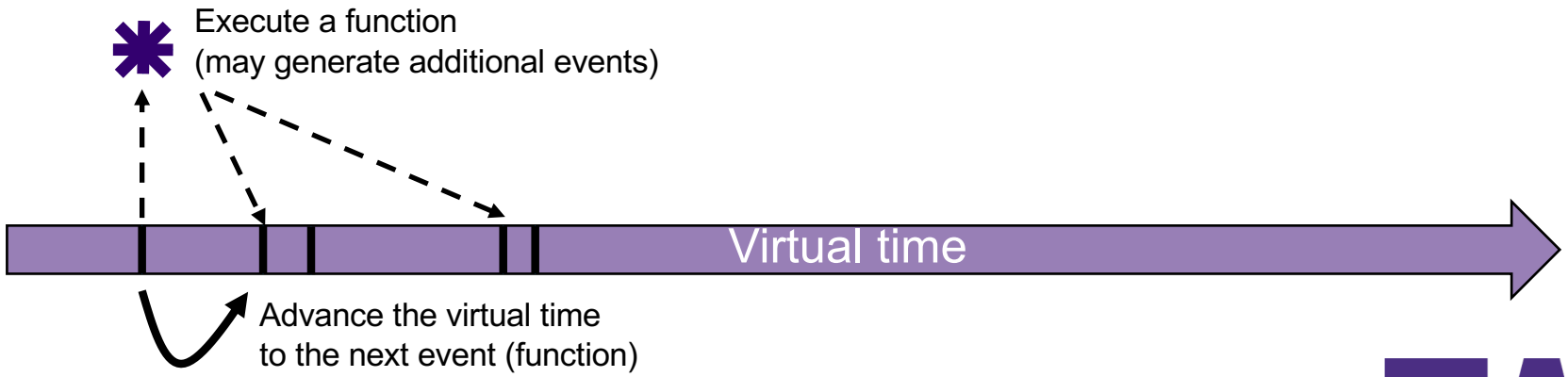
Discrete-event simulation basics

We are trying to represent the operation of a network within a single C++ program

- We need a notion of ***virtual time*** and of ***events*** that occur at specified (virtual) times
- We need a data structure (***scheduler***) to hold all of these events in temporal order
- We need an object (***simulator***) to walk the list of events and execute them at the correct virtual time
- We can choose to ignore things that conceptually might occur between our events of interest, focusing only on the (***discrete***) times with interesting events

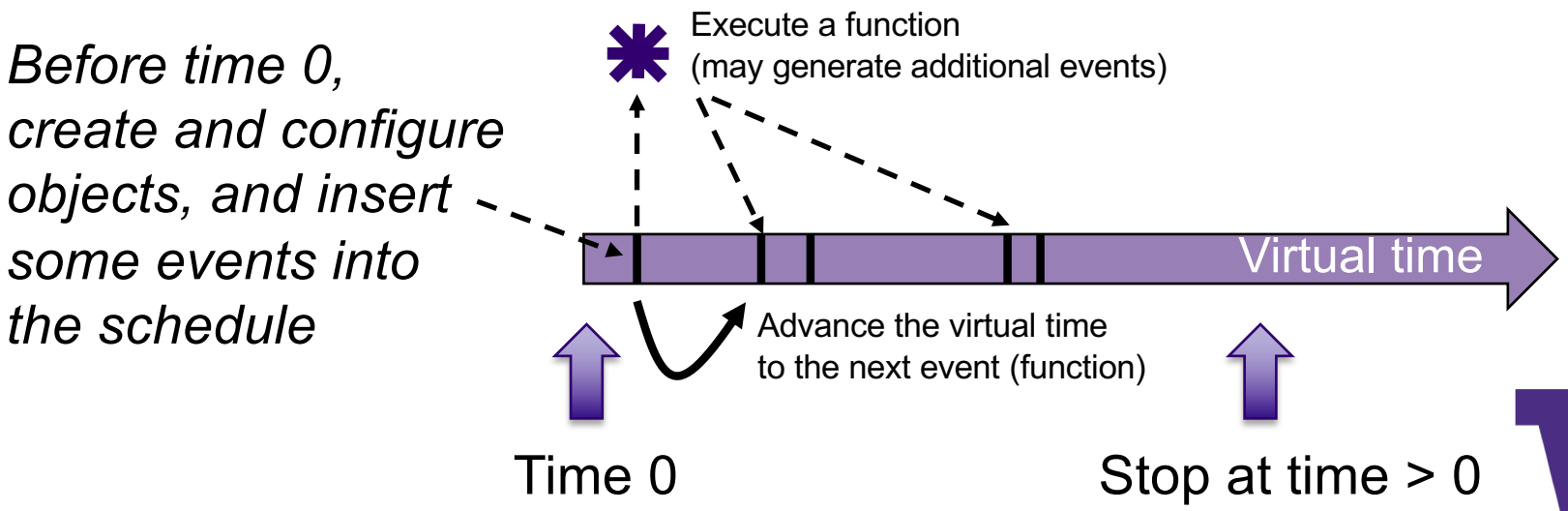
Discrete-event simulation basics (cont.)

- Simulation time moves in discrete jumps from event to event
- C++ functions schedule events to occur at specific simulation times
- A simulation scheduler orders the event execution
- Simulation::Run() executes a single-threaded event list
- Simulation stops at specified time or when events end



ns-3 simulation basics and terminology

- A simulation 'run' or 'replication' usually consists of the following workflow
  1. Before the notional 'time 0', create the scenario objects and pre-populate the scheduler with some initial events
  2. Define stopping criteria; either a specific future virtual time, or when certain criteria are met
  3. Start the simulation (which initializes objects, at 'time 0')



Virtual time in ns-3

- Time is stored as a large integer in ns-3
  - Minimize floating point discrepancies across platforms
- Special Time classes are provided to manipulate time (such as standard arithmetic operators)
- Default time resolution is nanoseconds, but can be set to other resolutions
  - Note: Changing resolution is not well used/tested
- Time objects can be set by floating-point values and can export floating-point values

```
double timeDouble = t.GetSeconds();
```

  - Best practice is to avoid floating point conversions where possible and use Time arithmetic operators

Key building blocks: Callback and function pointer

> C++ methods are often invoked directly on objects

```
int main (int argc, char *argv[])
{
  CommandLine cmd (__FILE__);
  cmd.Parse (argc, argv);

  MyModel model;
  Ptr<UniformRandomVariable> v = CreateObject<UniformRandomVariable> ();
  v->SetAttribute ("Min", DoubleValue (10));
  v->SetAttribute ("Max", DoubleValue (20));

  Simulator::Schedule (Seconds (10.0), &ExampleFunction, &model);

  Simulator::Schedule (Seconds (v->GetValue ()), &RandomFunction);

  EventId id = Simulator::Schedule (Seconds (30.0), &CancelledEvent);
  Simulator::Cancel (id);
```

Unlike CommandLine.Parse(), we more generally need to call functions at some future (virtual) time.

Some program element could assign a function pointer, and a (later) program statement could call (execute) the method

Program excerpt:
src/core/examples/sample-simulator.cc (lines 103-118)

Events in ns-3

- Events are just functions (callbacks) that execute at a simulated time
  - nothing is special about functions or class methods that can be used as events
- Events have IDs to allow them to be cancelled or to test their status

Simulator and Scheduler

- The Simulator class holds a scheduler, and provides the API to schedule events, start, stop, and cleanup memory
- Several scheduler data structures (calendar, heap, list, map) are possible
- "Realtime" simulation implementation aligns the simulation time to wall-clock time
  - two policies (hard and soft limit) available when the simulation and real time diverge

(Demo) sample-simulator.cc

```
int main (int argc, char *argv[])
{
  CommandLine cmd (__FILE__);
  cmd.Parse (argc, argv);

  MyModel model;
  Ptr<UniformRandomVariable> v = CreateObject<UniformRandomVariable> ();
  v->SetAttribute ("Min", DoubleValue (10));
  v->SetAttribute ("Max", DoubleValue (20));

  Simulator::Schedule (Seconds (10.0), &ExampleFunction, &model);

  Simulator::Schedule (Seconds (v->GetValue ()), &RandomFunction);

  EventId id = Simulator::Schedule (Seconds (30.0), &CancelledEvent);
  Simulator::Cancel (id);

  Simulator::Schedule (Seconds (25.0),
    [] ()
    {
      std::cout << "Code within a lambda expression at time "
                << Simulator::Now ().As (Time::S)
                << std::endl;
    });

  Simulator::Run ();

  Simulator::Destroy ();
}
```

Program excerpt:
src/core/examples/sample-simulator.cc (lines 103-131)

CommandLine arguments

- Add CommandLine to your program if you want command-line argument parsing

```
int main (int argc, char *argv[])
{
  CommandLine cmd (__FILE__);
  cmd.Parse (argc, argv);
```

- Passing --PrintHelp to programs will display command line options, if CommandLine is enabled

```
./ns3 run "sample-simulator --PrintHelp"

sample-simulator [General Arguments]

General Arguments:
    --PrintGlobals:              Print the list of globals.
    --PrintGroups:               Print the list of groups.
    --PrintGroup=[group]:        Print all TypeIds of group.
    --PrintTypeIds:              Print all TypeIds.
    --PrintAttributes=[typeid]:  Print all attributes of typeid.
    --PrintVersion:              Print the ns-3 version.
    --PrintHelp:                 Print this help message.
```

Random Variables and Run Number

- Many ns-3 objects use random variables to model random behavior of a model, or to force randomness in a protocol
  - e.g. random placement of nodes in a topology

- Many simulation uses involve running a number of ***independent replications*** of the same scenario, by changing the random variable streams in use
  - In ns-3, this is typically performed by incrementing the simulation ***run number***

```
./ns3 run 'sample-simulator --RngRun=2'

NS_GLOBAL_VALUE="RngRun=2" ./ns3 run sample-simulator
```

Random Variables

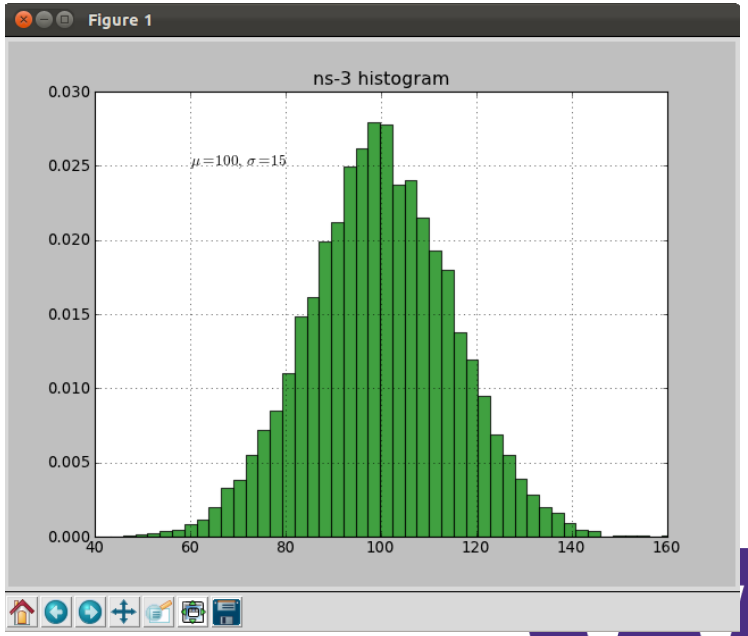
- Currently implemented distributions
  - Uniform: values uniformly distributed in an interval
  - Constant: value is always the same (not really random)
  - Sequential: return a sequential list of predefined values
  - Exponential: exponential distribution (poisson process)
  - Normal (gaussian), Log-Normal, Pareto, Weibull, Triangular, Zipf, Zeta, Deterministic, Empirical

```
#  Demonstrate use of ns-3 as a random number generator integrated with
#  plotting tools.

import numpy as np
import matplotlib.pyplot as plt
import ns.core

# mu, var = 100, 225
rng = ns.core.NormalRandomVariable()
rng.SetAttribute("Mean", ns.core.DoubleValue(100.0))
rng.SetAttribute("Variance", ns.core.DoubleValue(225.0))
x = [rng.GetValue() for t in range(10000)]

## Make a probability density histogram
density = 1
facecolor='g'
alpha=0.75
# n, bins, patches = plt.hist(x, 50, density=1, facecolor='g', alpha=0.75)
plt.hist(x, 50, density=1, facecolor='g', alpha=0.75)
plt.title('ns-3 histogram')
plt.text(60, .025, r'$\mu=100,\ \sigma=15$')
plt.axis([40, 160, 0, 0.03])
plt.grid(True)
plt.show()
```



from src/core/examples/sample-rng-plot.py

Discrete-event simulation basics

- Scheduler, events, simulator, random variables (✓)
- Packets
- Nodes, NetDevices
- MobilityModel/Position
- Wireless channels

(Demo) wifi-simple-infra.cc

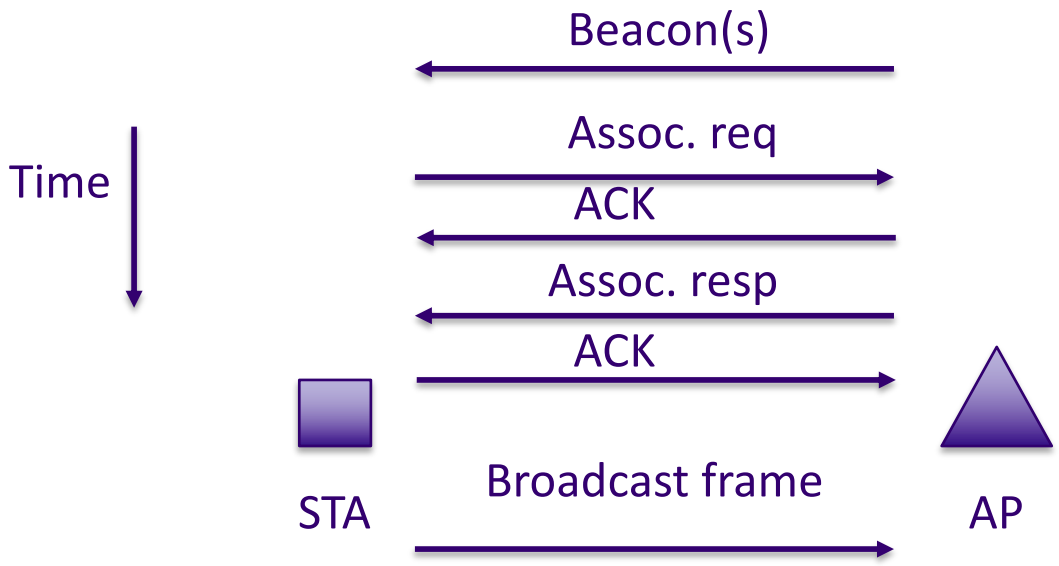
```
./ns3 run wifi-simple-infra
```

> Program output (pcap)

> View Wireshark

> GenerateTraffic()

> `ap-wifi-mac.cc:  packet->AddHeader (beacon);`



Packets

- Figure source: ns-3 Model Library documentation
- Key methods: AddHeader(), RemoveHeader()

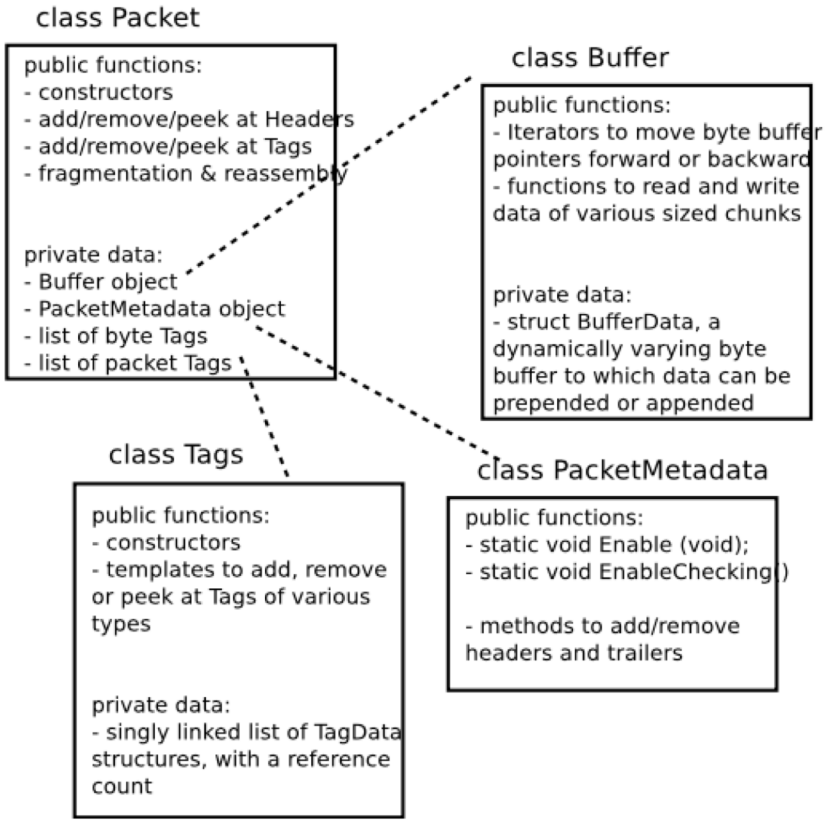
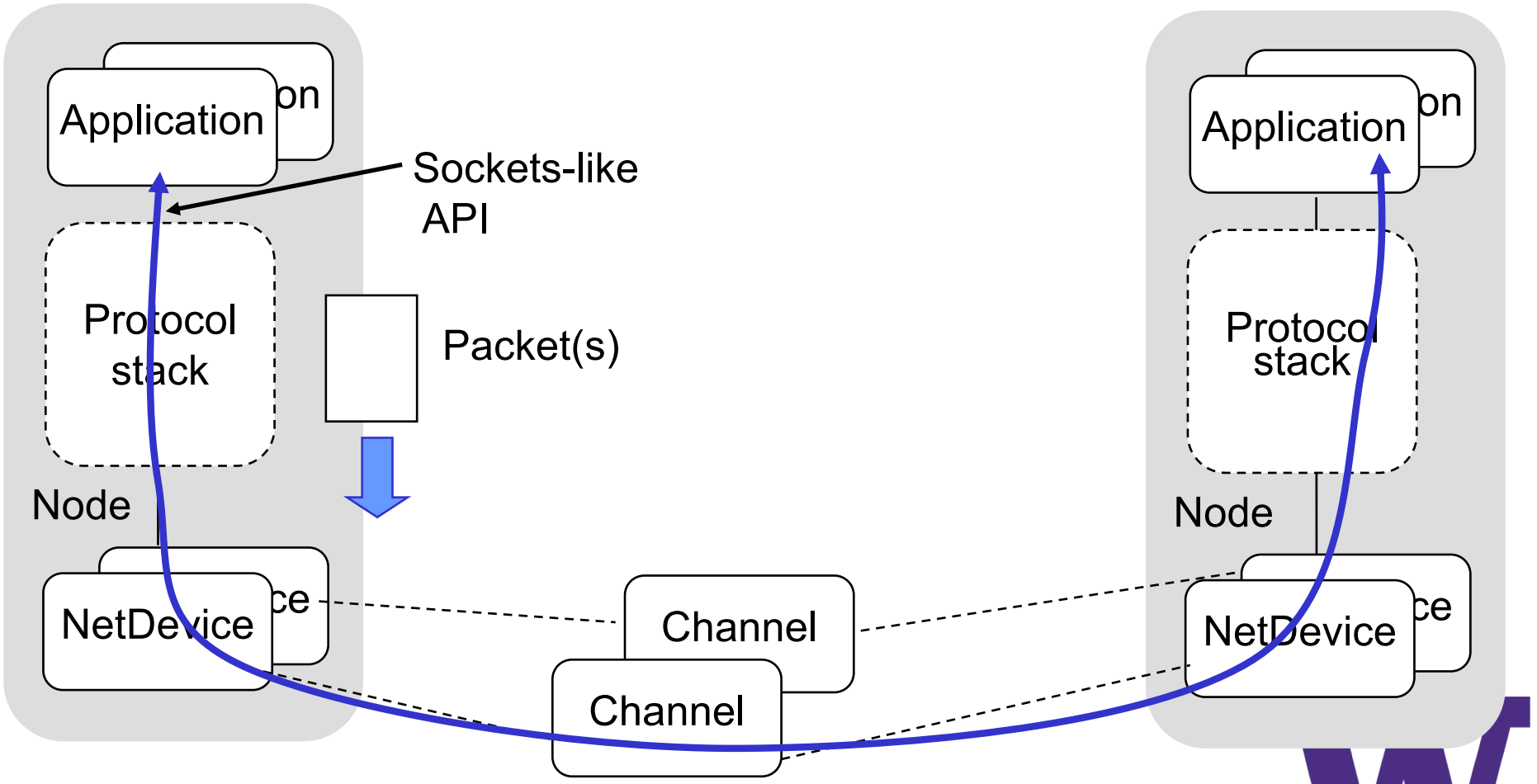


Fig. 1: Implementation overview of Packet class.

Nodes, Applications, NetDevices

> Most simulations involve packet exchanges such as depicted below



Mobility and position

- ns-3 position is represented on a 3D Cartesian (x,y,z) coordinate system
- The MobilityHelper combines a **mobility model** and **position allocator**.
- Position Allocators setup initial position of nodes (only used when simulation starts):
  - **List:** allocate positions from a deterministic list specified by the user;
  - **Grid:** allocate positions on a rectangular 2D grid (row first or column first);
  - **Random position allocators:** allocate random positions within a selected form (rectangle, circle, …).
- Mobility models specify how nodes will move during the simulation:
  - **Constant:** position, velocity or acceleration;
  - **Waypoint:** specify the location for a given time (time-position pairs);
  - **Trace-file based:** parse files and convert into ns-3 mobility events, support mobility tools such as SUMO, BonnMotion (using NS2 format) , TraNS

Propagation

- Propagation module defines:
  - Propagation loss models:
    Calculate the Rx signal power considering the Tx signal power and the respective Rx and Tx antennas positions.
  - Propagation delay models:
    Calculate the time for signals to travel from the TX antennas to RX antennas.
- Propagation delay models almost always set to:
  - ConstantSpeedPropagationDelayModel: In this model, the signal travels with constant speed (defaulting to speed of light in vacuum)

Propagation (cont.)

- Propagation loss models:
  - Many propagation loss models are implemented:
    - ✓ Abstract propagation loss models:
      FixedRss, Range, Random, Matrix, …
    - ✓ Deterministic path loss models:
      Friis, LogDistance, ThreeLogDistance, TwoRayGround, …
    - ✓ Stochastic fading models:
      Nakagami, Jakes, …

Propagation (cont.)

– A propagation loss model can be “chained” to another one, making a list. The final Rx power takes into account all the chained models.
Example: path loss model + shadowing model + fading model

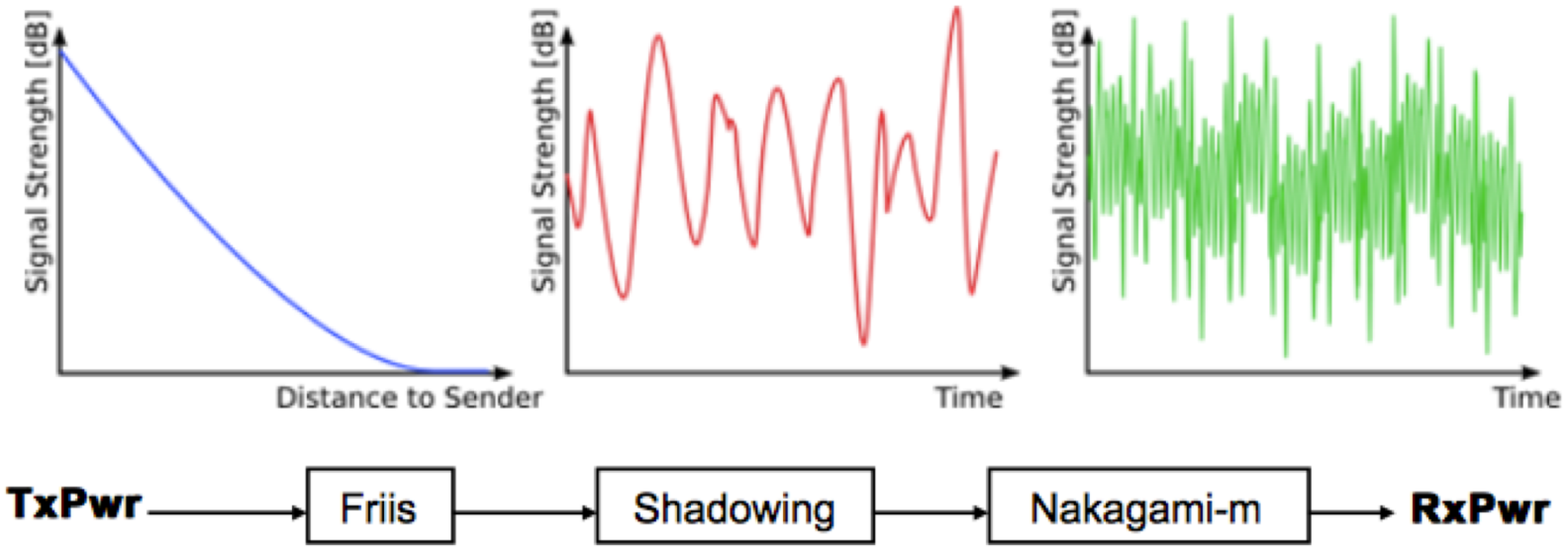


Figure source: Unknown

Wifi channels

> Two options are supported:

1. YansWifiChannel (simple single-band model)
   - Use if there is no frequency-selective fading model, and if there is no interference from foreign sources
   - Default YansWifiChannelHelper will add a "LogDistancePropagationLossModel" with path loss exponent value of 3
2. SpectrumChannel (fine-grained band decomposition)
   - Use if more detailed frequency selective models are needed, or in a mixed-signal environment
   - Default SpectrumWifiChannelHelper wil add a "FriisSpectrumPropagationLossModel" (power falls as square of distance)

SpectrumChannel illustration

> Figure source: ns-3 Model Library documentation

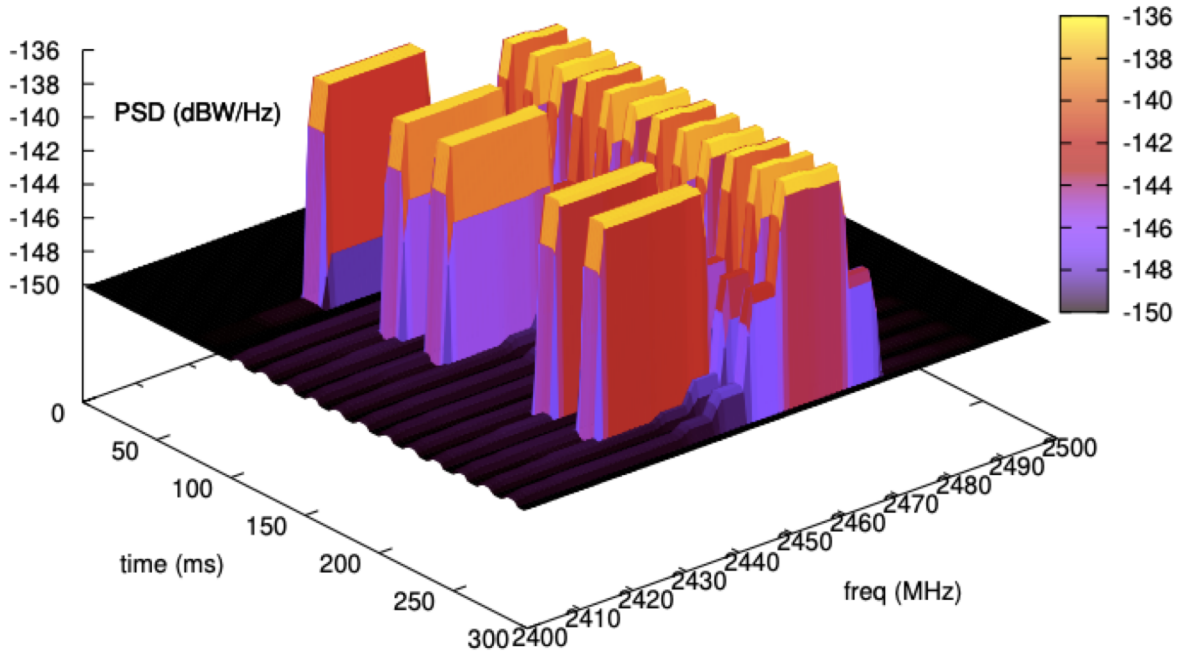
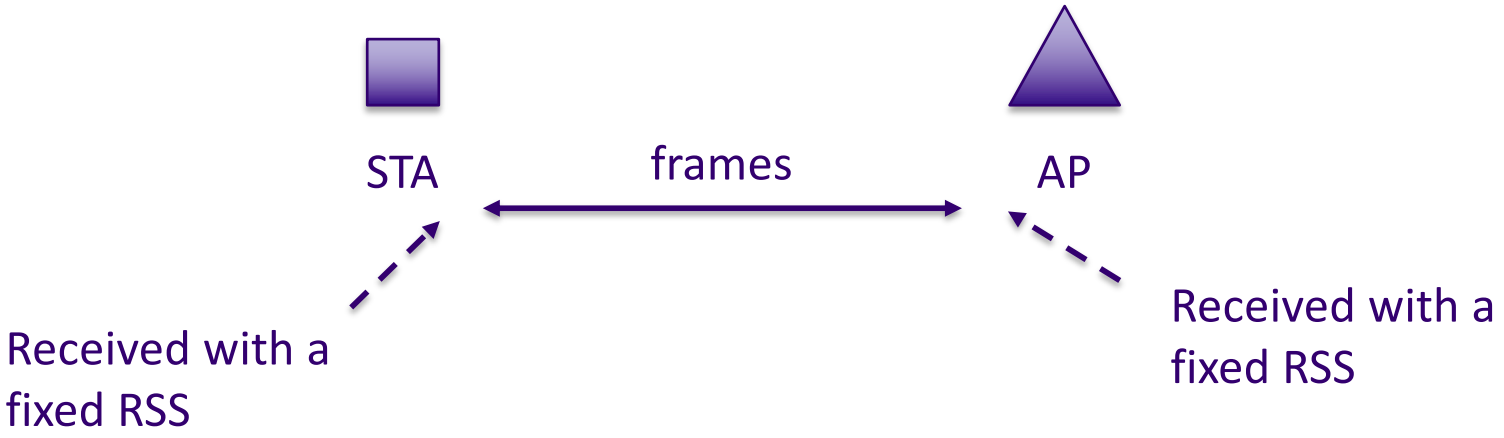


Fig. 1: Spectrogram produced by a spectrum analyzer in a scenario involving wifi signals interfered by a microwave oven, as simulated by the example `adhoc-aloha-ideal-phy-with-microwave-oven`.

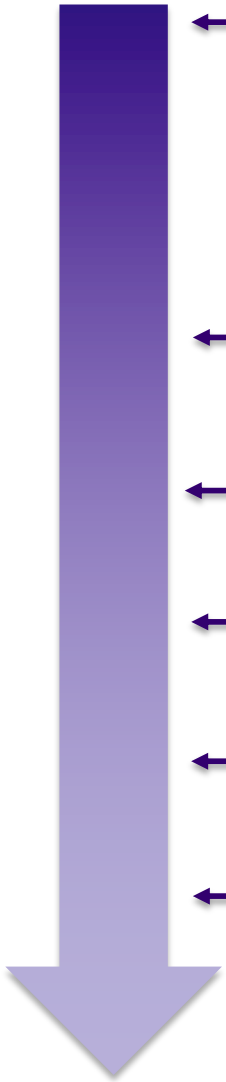
(Demo) wifi-simple-infra.cc

- wifi-simple-infra.cc uses a special 'FixedRss' propagation loss model that enforces that the received signal strength (RSS) is a configured value
- Packet delivery is governed by a **preamble detection model** and a **Wi-Fi error model**



Signal strength and Wi-Fi

- dBm is reference to decibels over 1 mW
- 0 dBm = 1 mW
- +/- 3 dB = */÷ a factor of 2 on a linear scale
- +/- 10 dB = */÷ a factor of 10 on a linear scale



16 dBm: Maximum Wi-Fi transmit power at 5 GHz

-62 dBm: Required "Energy Detection" threshold

-82 dBm: Required "Preamble Detection" threshold

-90 dBm: Minimal received power level in typical cards

-94 dBm: Noise power including default 7 dB WifiPhy noise figure

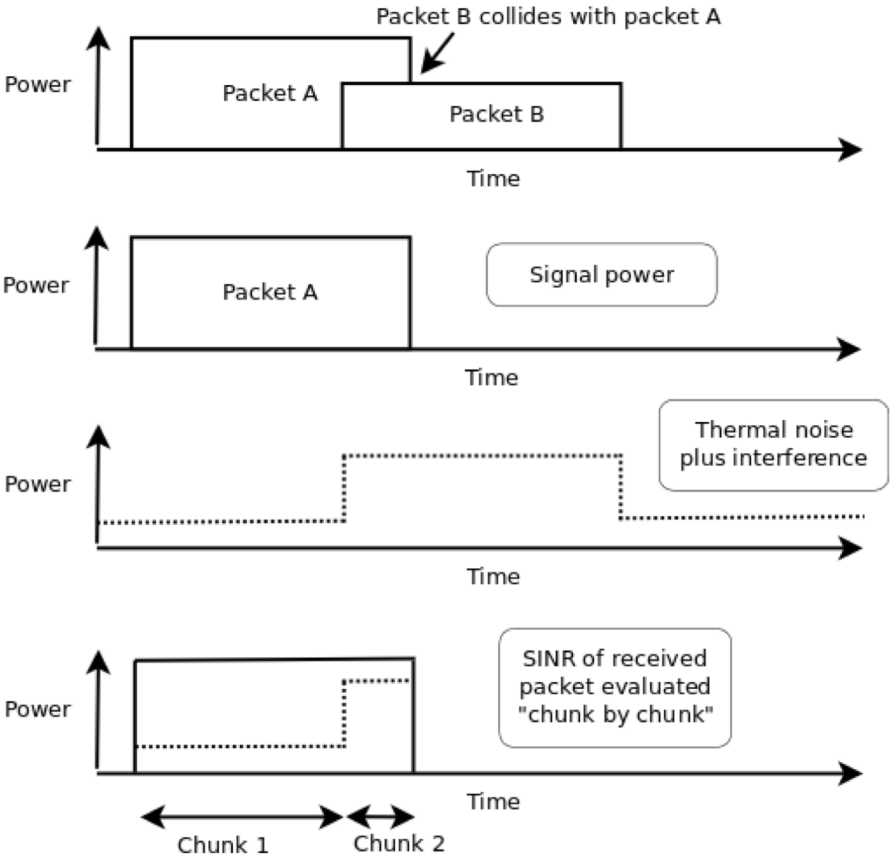
-101 dBm: Thermal noise floor for 20 MHz at room temp.

Signal to noise ratio

- (Signal + gain) power/(Noise + interference) power
- Typically expressed in decibels (dB)
- 0 dB -> signal power equals the noise power (ratio of 1)
- Different modulations require different levels of SNR to decode successfully
- Gains (e.g. directional antennas, amplifiers) can contribute to the numerator
- Propagation losses reduce the signal power at the receiver
- Thermal noise and noise figure contribute to the denominator

Interference handling and error models

- Interference (if any) is handled by adding the interfering signal's power to the noise power
- Figure source: ns-3 Model Library documentation



SNIR function over time

Error models

- DSSS error models are derived analytically
  - See: https://www.nsnam.org/~pei/80211b.pdf
- OFDM error models are derived from MATLAB(TM) Wireless LAN System Toolbox
  - See: https://depts.washington.edu/funlab/wp-content/uploads/2017/05/Technical-report-on-validation-of-error-models-for-802.11n.pdf
- Perror (probability of packet error)

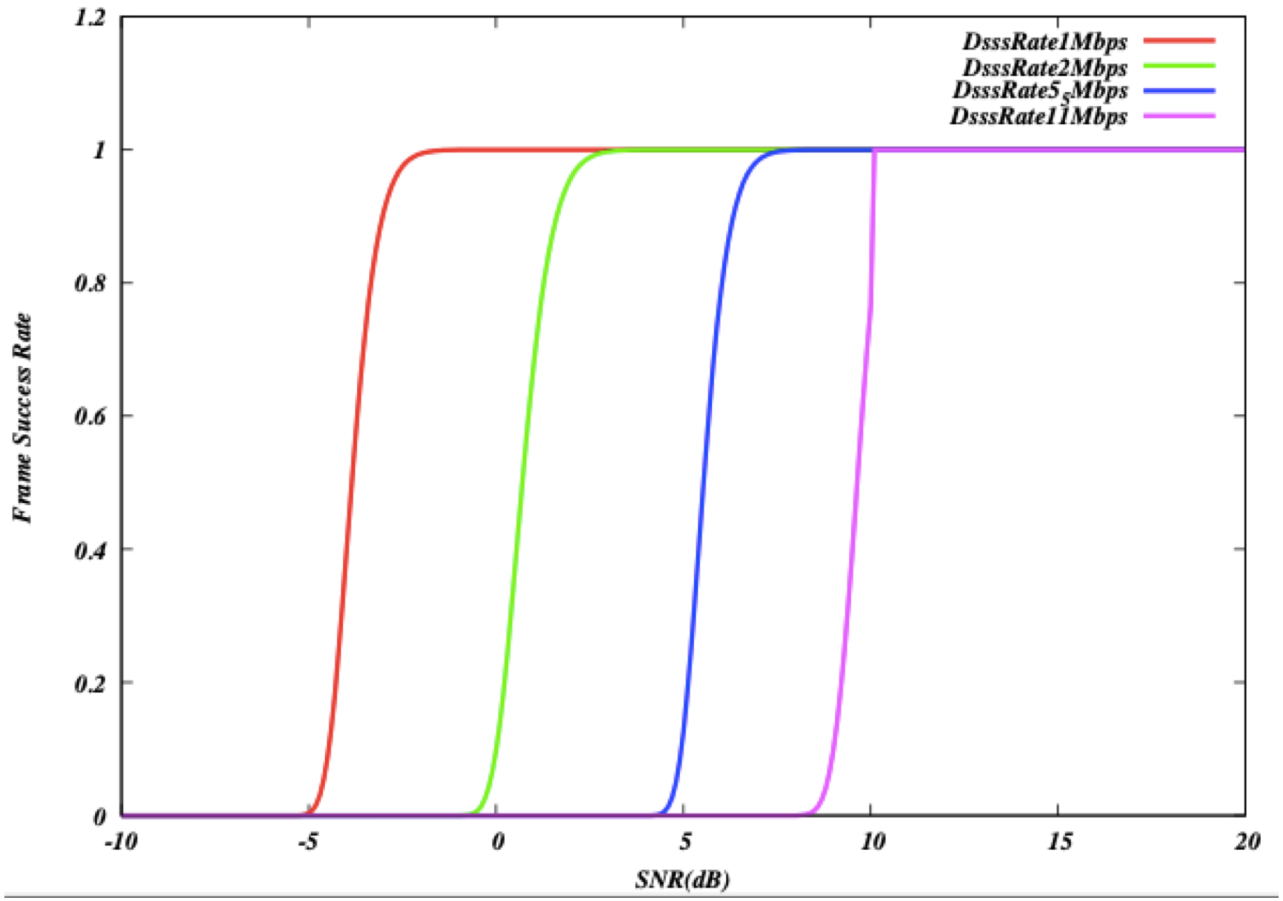
  = 1 - (Psuccess1)(Psuccess2)(Psuccess3)... (for all chunks)
- Psuccess (N-bit chunk at given BER)

  = 1 - (1 - BER)^N

Example PER curves

> Figure from ‘examples/wireless/wifi-dsss-validation.cc’

```
$ ./ns3 run wifi-dsss-validation
$ gnuplot frame-success-rate-dsss.plt
```

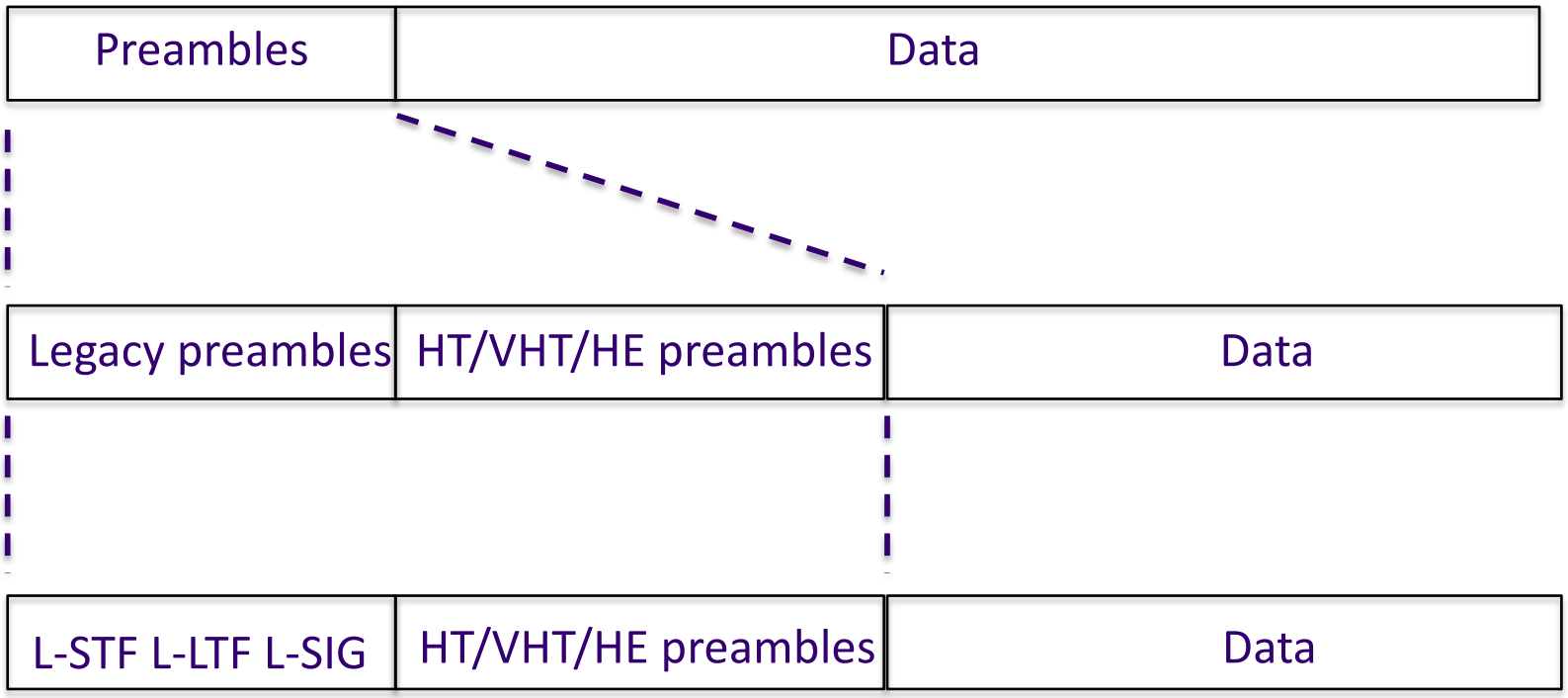


Wi-Fi evolution

	Rates	Freq.	Modulation	Other
802.11	1,2Mbps	2.4 GHz	DSSS	22 MHz overlapping channels
802.11b	1,2,5.5,11 Mbps	2.4 GHz	DSSS/CCK	22 MHz overlapping channels
802.11a	6..54Mbps	5 GHz	OFDM	20 MHz channels
802.11g	1..54Mbps	2.4/5GHz	OFDM in 5 GHz, DSSS/CCK in 2.4 GHz	
802.11n	6..600Mbps	2.4/5GHz	OFDM	MIMO, WMM, 20/40 MHz
802.11ac	up to 7Gbps	5 GHz	OFDM	beamforming, DL MU-MIMO 20/40/80/160 MHz
802.11ax	up to 9.6Gbps	2.4/5/6 GHz	OFDM/ OFDMA	DL/UL MU-MIMO, spatial reuse, TWT
802.11be	up to 40Gbps	2.4/5/6 GHz	OFDM/ OFDMA	320MHz, AP coordination, TSN, MLO, ...

Preamble detection and frame capture models

> In practice, a WiFi frame is first detected (and synchronized) via a PLCP preamble field

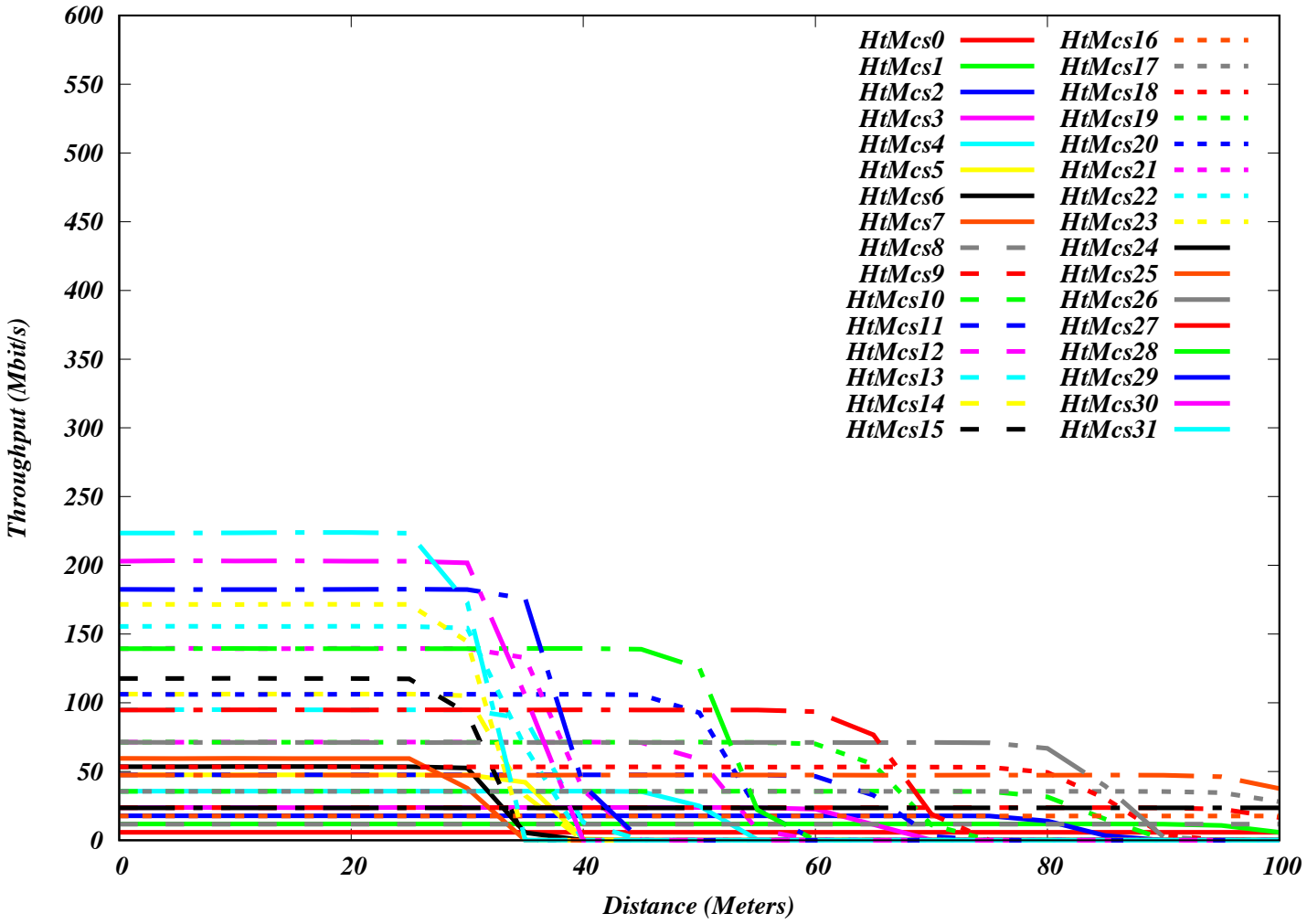


Preamble detection and frame capture models

- A **'ThresholdPreambleDetectionModel'** is configured by default by the Wi-Fi helpers
  - "Threshold" attribute: default 4 dB
  - "MinimumRssi" attribute: default -82 dBm
- A **'SimpleFrameCaptureModel'** is available but must be added (WifiHelper::SetFrameCaptureModel())
  - Only enabled for YansWifiPhyHelper
  - "Window" attribute: default 16us
  - "Margin" attribute: default 5 dB

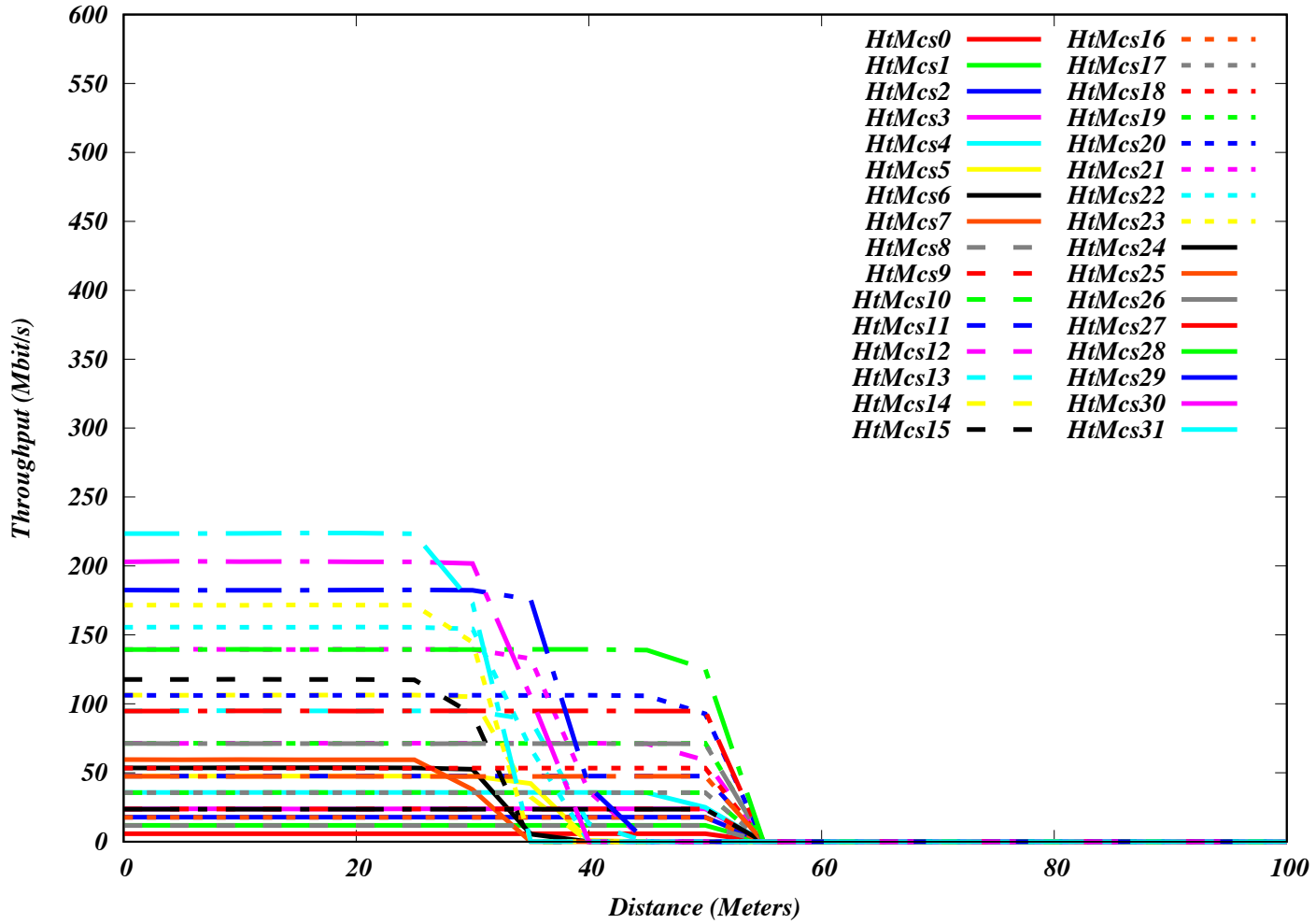
Throughput vs distance for 802.11n modulation

```
./ns3 run 'wifi-80211n-mimo --preambleDetection=0'
```



Throughput vs distance for 802.11n modulation

```
./ns3 run 'wifi-80211n-mimo --preambleDetection=1'
```



Bianchi analysis/validation

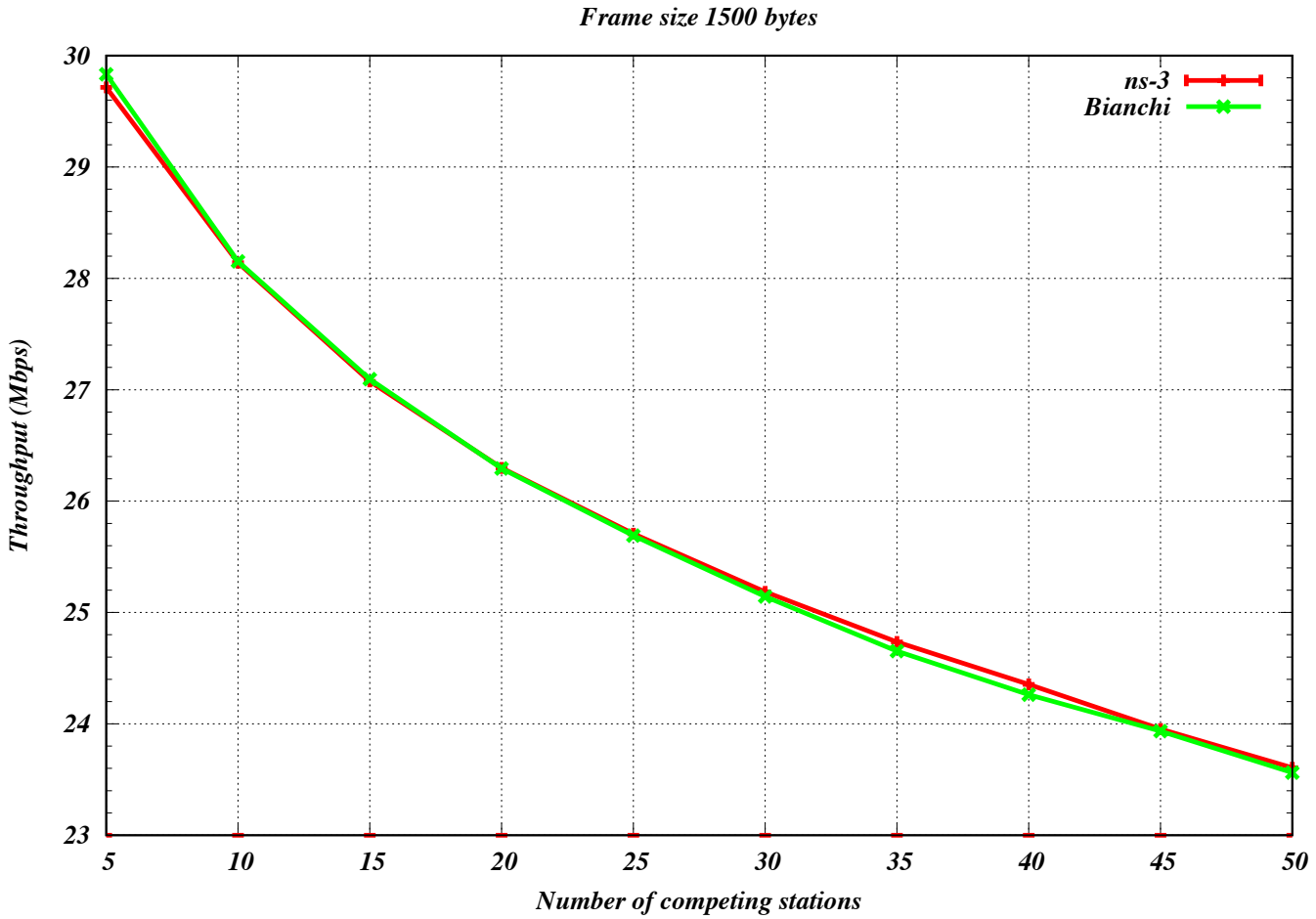
- Analytical work by Bianchi [*] bounded the performance of the Wi-Fi DCF under saturating traffic
- ns-3 simulations (src/wifi/examples/wifi-bianchi.cc) have been used to validate the simulator against this analysis, for many versions of the Wi-Fi standard
  - accounting for differences in overhead and operation

[*] G. Bianchi, "Performance analysis of the IEEE 802.11 distributed coordination function," in *IEEE Journal on Selected Areas in Communications*, vol. 18, no. 3, pp. 535-547, March 2000

Example Bianchi plot

> Default results for 802.11a, 5 to 50 nodes, adhoc network

> ./ns3 run 'wifi-bianchi'



ConstantRateWifiManager

- Many ns-3 programs disable dynamic rate control and provide specific rates for both the data and control/management frames
- Sample code is shown below:

```
std::ostringstream oss;
oss << "HeMcs" << mcs;
wifi.SetRemoteStationManager ("ns3::ConstantRateWifiManager","DataMode", StringValue (oss.str ()),
                              "ControlMode", StringValue (oss.str ()));
```

Ideal rate control

- ns-3 contains an idealized dynamic rate control manager (IdealWifiManager) that adjusts the sending rate based on the last SNR received on the remote STA
  - The sender has access to the receiver's statistics
  - The highest throughput MCS that is supported by the provided SNR is selected
  - A configurable BER threshold (default 1e-6) is used for deciding whether an MCS (SNR) is viable

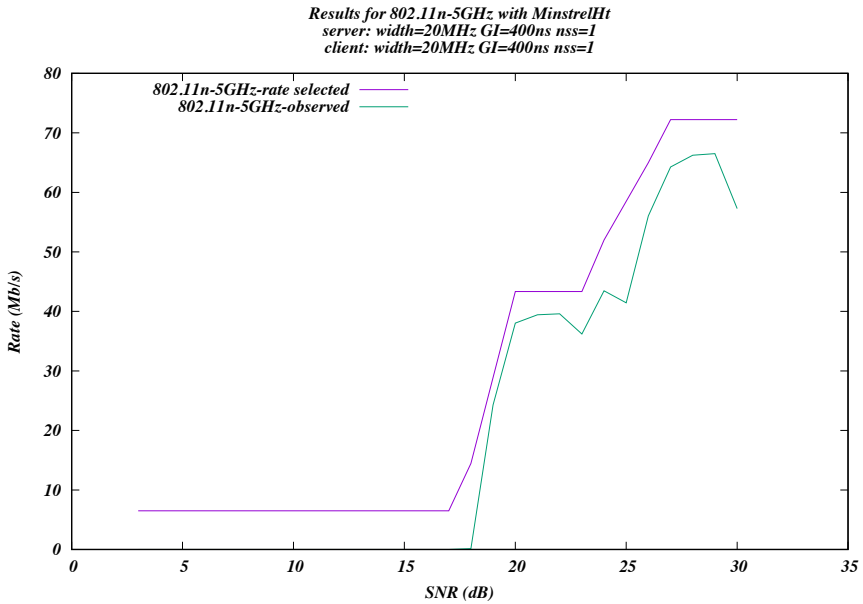
Minstrel rate control

- Overall philosophy is that it is hard to pick a rate based on available SNR figures from Linux drivers, and instead a better approach is to search for good rates via trial-and-error
- Minstrel dedicates 10% of its packets to probe for other rates that might offer an improved performance
  - called ”Lookaround” rates
  - makes use of an exponentially weighted moving average (EWMA) on packet success statistics
  - Details are available in ns-3, or Yin et al, “Rate control in the mac80211 framework: Overview, evaluation and improvements,” Computer Networks 81, 2015.
- ns-3 contains MinstrelWifiManager for legacy 802.11 standards, and MinstrelHtWifiManager for 802.11n/ac

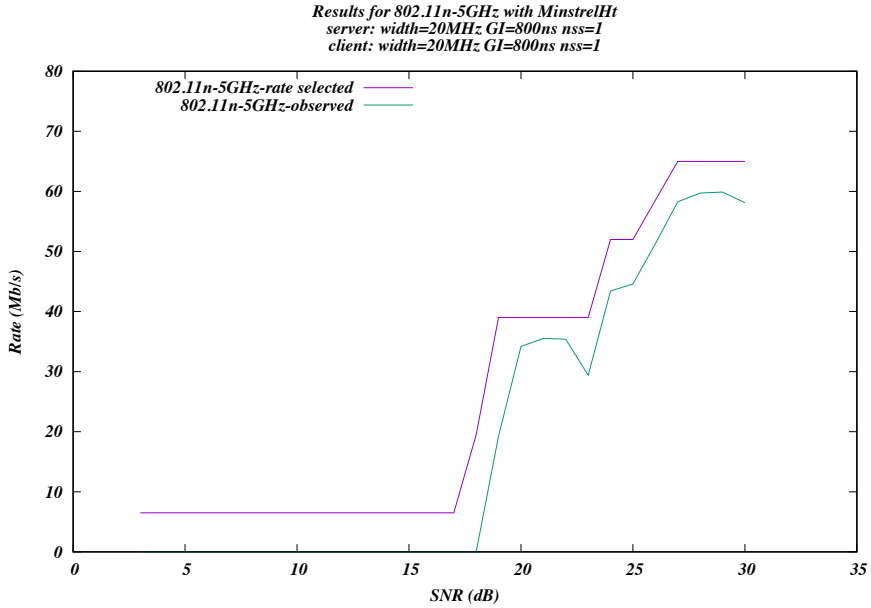
Example Minstrel plot

> Compare short and long guard interval performance for MinstrelHt at 802.11n-5GHz, 20 MHz channel, 1 stream

```
./ns3 run 'wifi-manager-example --standard=802.11n-5GHz --
serverShortGuardInterval=800 --clientShortGuardInterval=800 --
wifiManager=MinstrelHt'
```



400ns

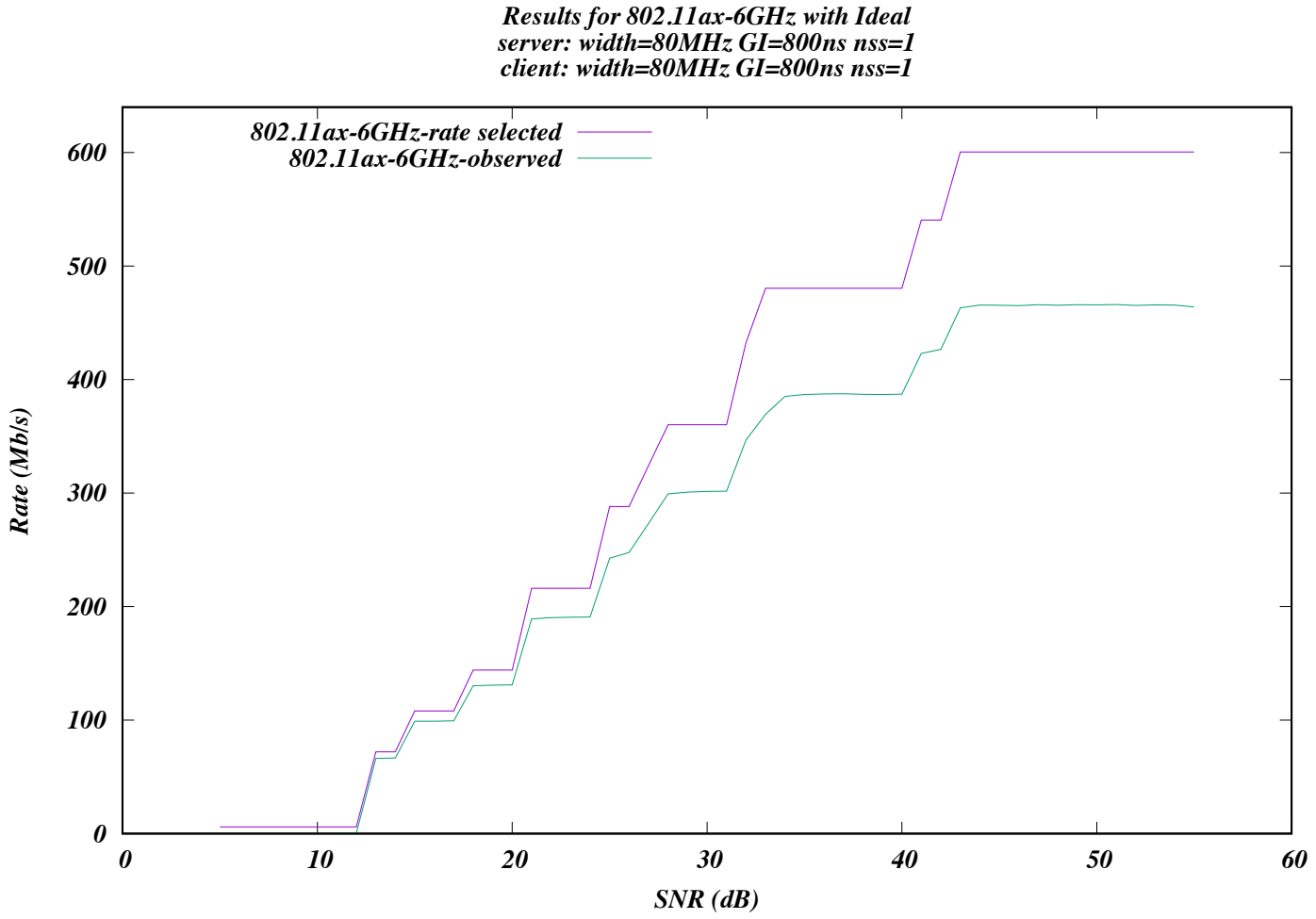


800ns

Example Ideal plot

> 802.11ax in 6GHz with IdealWifiManager

```
./ns3 run 'wifi-manager-example --standard=802.11ax-6GHz'
```



Wi-Fi 6 (802.11ax) support

- **11ax frame formats**
- **OBSS PD spatial reuse** for dense networks
- **DL OFDMA** and **UL OFDMA** (including support for the MU EDCA Parameter Set)
- **Multi-user management frames** (e.g. MU-BAR)
- Round-robin **multi-user scheduler**

Upcoming Wi-Fi extensions

Initial Wi-Fi 7 (802.11be) components are under development by Stefano Avallone and Sebastien Deronne

- New frame formats, support for new modulation types, wider channels
- **Multi-link operation** (MLO)
- **Multi-AP coordination**

Finish integration of new **fast fading MIMO error models**

- https://www.nsnam.org/research/wns3/wns3-2021/tutorials/

Integrate 802.11ad (WiGig) extensions

- https://gitlab.com/sderonne/ns-3-dev/-/tree/wigig_module

Examples to review

- wifi-simple-infra.cc
- wifi-80211n-mimo.cc
- wifi-hidden-terminal.cc
- wifi-manager-example.cc
- wifi-spatial-reuse.cc
- wireless-animation.cc (netanim)

References

- General: Eldad Perahia and Robert Stacey, “Next Generation Wireless LANs,” Second Edition, Cambridge University Press, 2013
- Standards documents (IEEE 802.11-2016, IEEE 802.11ax-2021)
- ns-3 specific:
  - Lacage, Henderson,"Yet another network simulator." *Proceeding from the 2006 workshop on ns-2: the IP network simulator*. 2006.
  - Lanante Jr., Roy, Carpenter, Deronne, Improved Abstraction for Clear Channel Assessment in ns-3 802.11 WLAN Model, WNS3 2019.
  - Avallone, Imputato, Redieteab, Ghosh and Roy, "Will OFDMA Improve the Performance of 802.11 Wifi Networks?," in *IEEE Wireless Communications*, vol. 28, no. 3, pp. 100-107, June 2021.
  - Magrin, *Avallone, Roy, and Zorzi, Validation of the ns-3 802.11ax OFDMA implementation, WNS3 2021.*

Conduct Research with ns-3 Wi-Fi models

UNIVERSITY of WASHINGTON

How to use ns-3 Wi-Fi models to conduct your own research?

- Phase 1: Validate the modules in ns-3
  - Start with the existing examples
  - System level validation
  - Compare with well known theoretical model/other simulation tools
- Phase 2: Build new scenarios and explore with different parameters
  - Investigate the impact on different parameters: power, moving speed..
  - Build more complex scenarios : single cell->multi cells
  - Evaluate the performance and verify the guess
- Phase 3: Build and test new algorithms
  - Machine learning algorithms in wireless communication
  - Optimization approaches
  - New modules and new features

Phase 1: Validation work for Wi-Fi modules in ns-3

> Validation Examples

Validate the development of ns-3 Wi-Fi module against the well-known analytical model for different network setups.

- DCF validation for different Wi-Fi standards: 802.11 a/b/g/ax
  - https://gitlab.com/nsnam/ns-3-dev/-/blob/master/src/wifi/examples/wifi-bianchi.cc

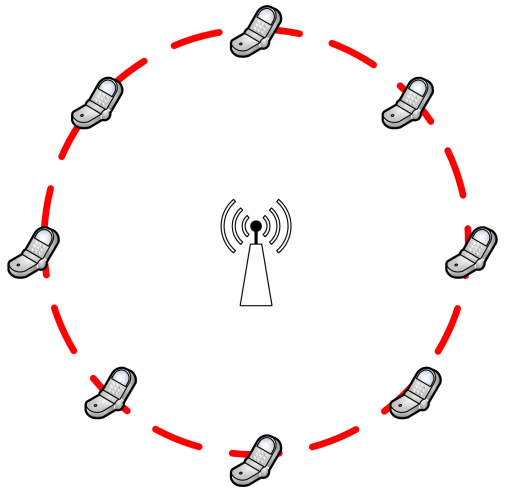
- 802.11ax OFDMA validation [1]:
  - https://github.com/signetlabdei/ofdma-validation

[1] Davide Magrin, Stefano Avallone, Sumit Roy, and Michele Zorzi. 2021. Validation of the ns-3 802.11ax OFDMA implementation. *In Proceedings of the Workshop on ns-3 (WNS3 '21).* Association for Computing Machinery, New York, NY, USA, 1–8. DOI:https://doi.org/10.1145/3460797.3460798

Phase 1: Validate the modules in ns-3

> Basic DCF validation recap

- Simulation setup:
  - Infrastructure mode: One AP and multiple stations
  - Traffic: Uplink traffic only.
  - Stations locate at the same distance (close) to the AP
  - Transmission with same power and MCS
  - Saturation mode



- Key assumptions for the analytical model:
  - No PHY errors, so packet losses only caused by the collision
  - Stations are all the same

- AP and stations may run on different powers
- Increase distances, PHY error may also occur and change the backoff window procedure.

Phase 2: Build new scenarios and explore with different parameters

> 6 GHz Power Role and Unequal Power Setup [2]

- U.S Federal Communications Commission (FCC) has adopted new rules to open the 6 GHz bands for unlicensed access
- The new ruling limits operation by a Power Spectral Density (PSD) limit in 6 GHz bands that differs from the total average power independent of the channel bandwidth in 5 GHz bands.
- Unequal power of the Access Points (AP) and stations (STA) also impact the system performance in wireless local area networks (WLANs).

Table 1: (Max) Average Transmit power vs. channel bandwidth: Indoor Operation

Device type	Frequency	Max power for bandwidth			
		20 MHz	40 MHz	80 MHz	160 MHz
Low power AP	6 GHz	18.01 dBm	21.02 dBm	24.03 dBm	27.04 dBm
	5 GHz	30 dBm	30 dBm	30 dBm	30 dBm
Low power STA	6 GHz	12.04 dBm	15.05 dBm	18.06 dBm	21.07 dBm
	5 GHz	24 dBm	24 dBm	24 dBm	24 dBm

[2] Hao Yin, Sumit Roy, and Sian Jin. 2022. IEEE WLANs in 5 vs 6 GHz: A Comparative Study. *To be published in the Workshop on ns-3 (WNS3 '22).*

Phase 2: Build new scenarios and explore with different parameters

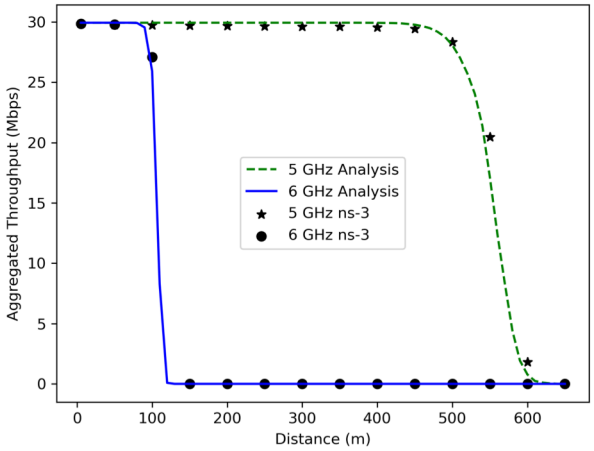
> 6 GHz Power Rule and Unequal Power Setup

- How can we build the new scenario to test these two setups? (Demo and codes)
  - Downlink setups
  - Power rules

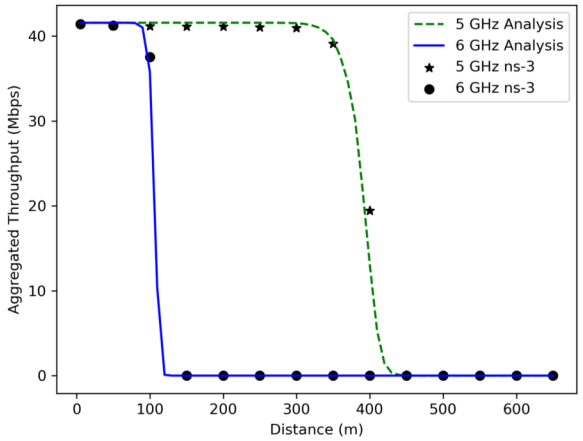
Phase 2: Build new scenarios and explore with different parameters

> 6 GHz Power Rule and Unequal Power Setup

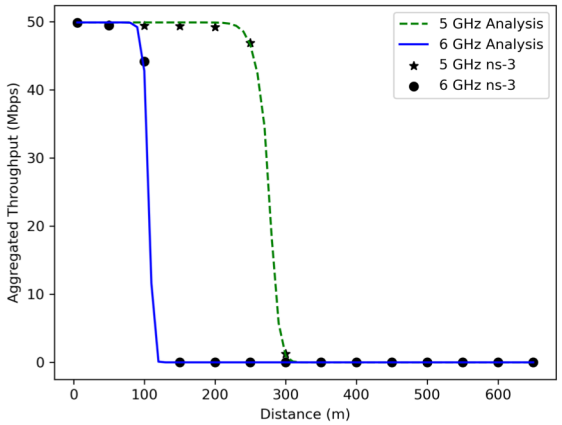
- 6 GHz power rule results Codes: https://github.com/Mauriyin/ns3



20 MHz



40 MHz



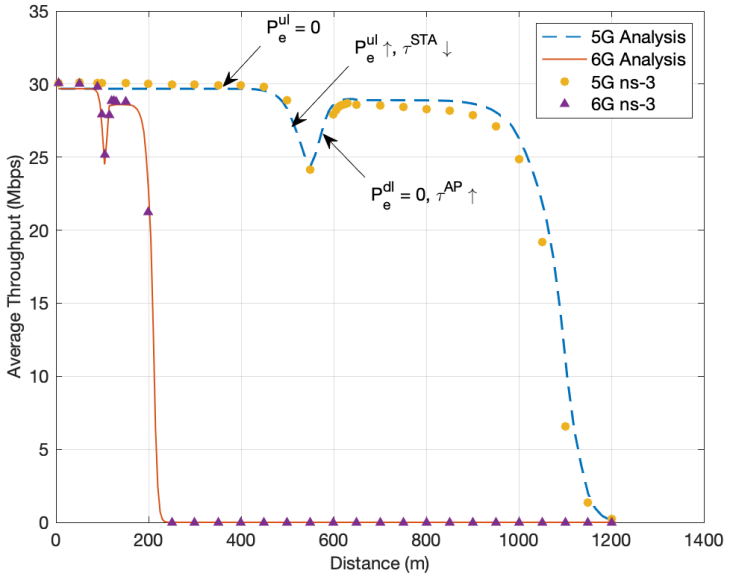
80 MHz

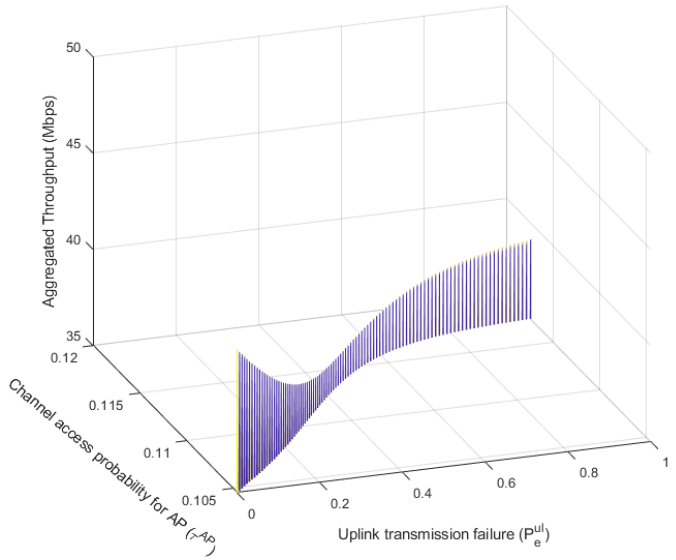
- As the distance increases, the received power and SNR decreases, the packet error rate increases, and the aggregated throughput drops.
- As the channel bandwidth increases, the transmission range of the 5 GHz band decreases while the transmission range in the 6 GHz band remains the same

Phase 2: Build new scenarios and explore with different parameters

> 6 GHz Power Rule and Unequal Power Setup

- Unequal Power results

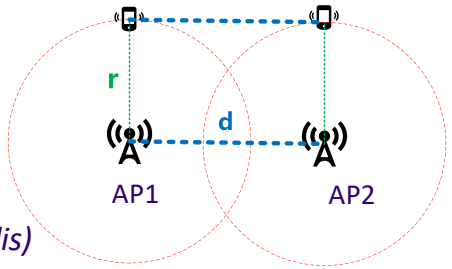




- 1st Drop: STA PER increases. STA power decreases to margin, and the STA has some packets successfully trasmitted but not to 0 (still 5 nodes, backoff window [Cwmin, CWmax]);
- Increase: All the STAs' tpt drops to 0 (backoff window Cwmax, lower collision probability), only AP sending packets successfully
- 2nd Drop: AP power decreases to margin, AP PER increases

Phase 2: Build new scenarios and explore with different parameters

> Multi-BSS Setup [3]



Axis:
AP1 (0, 0) AP2 (d, 0)
STA1 (0, r) STA2 (d, r)

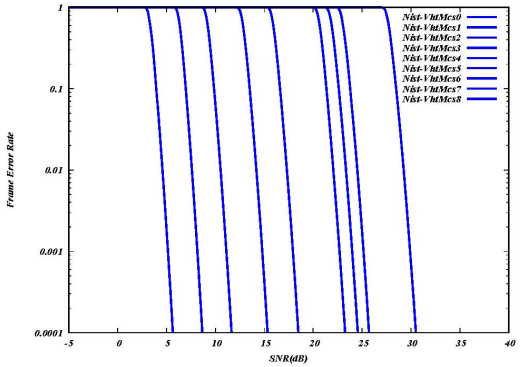
2 Overlapping BSS:

- ALL STAs are in the same position for each BSS
- CCA: -82 dBm, TX power: 20 dBm
- Log distance path loss (PL) model -> PL is a function of distance: *PL(dis)*
- Change *d* and *r* to simulate different cases.
- Uplink Only

$$\text{SNIR} = \frac{P_{rx}}{(P_{in}+Noise)}$$

$$P_{rx} = P_{tx} - PL(r)$$

$$P_{in} = P_{tx} - PL(\sqrt{r^2 + d^2})$$



SINR vs PER

Conditions that 2 STAs can transmit at the same time:

- 2 STAs are in different BSS
- SINR > *Threshold(MCS)*, for example, we need around 5 dB SNIR for MCS 0

[3] R. Kajihara, H. Wenkai, L. Lanante, M. Kurosaki and H. Ochi, "Performance Analysis Model of IEEE 802.11 CSMA/CA for Multi-BSS Environment," 2020 IEEE 31st Annual International Symposium on Personal, Indoor and Mobile Radio Communications, 2020, pp. 1-7, doi: 10.1109/PIMRC48278.2020.9217235.

Phase 2: Build new scenarios and explore with different parameters

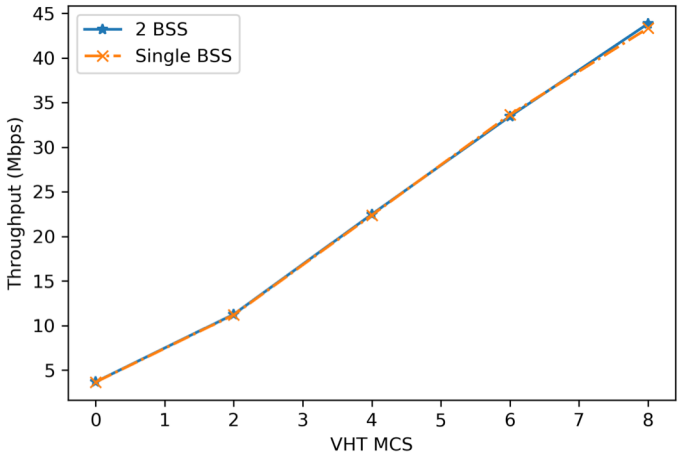
> Multi-BSS Setup

Codes: https://gitlab.com/haoyinyh/ns-3-dev/-/tree/multibss

Case 1: Equivalent case:

- Setup: r = 8m, d = 5m
  - Every node is in the carrier sensing range (can sense each other)
  - SINR = 2 dB -> No simultaneous transmission for ALL MCS
  - Expectation: 2 BSS is equivalent to one larger cell
- Results:

Parameters	Value
P_{rx}	-61.6 dBm
P_{in}	-64.6 dBm
Noise	-128 dBm
SINR	2 dB



Total 50 STAs

- 2 BSS is equivalent to one larger cell
- All the results are validated against the Bianchi model

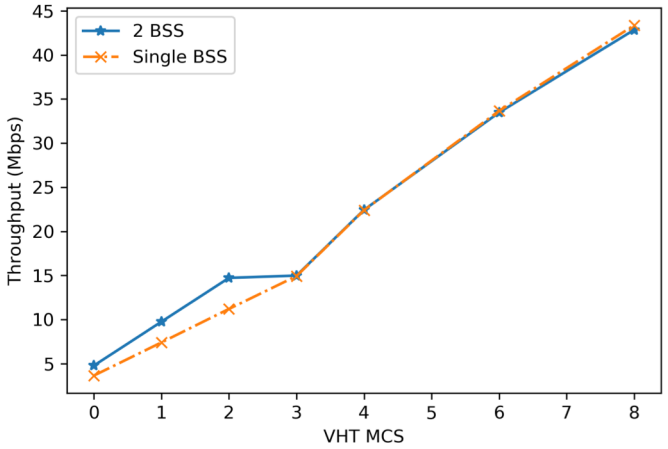
Phase 2: Build new scenarios and explore with different parameters

> Multi-BSS Setup

Case 2: Simultaneous transmission

- Setup: r = 10m, d = 20m
  - Every node is in the carrier sensing range (can sense each other)
  - SINR = 12 dB -> Can support simultaneous transmission at MCS 0/1/2
  - Expectation: 2 BSS has larger throughput in MCS 0/1/2 than one large cell
- Results:

Parameters	Value
P_{rx}	-65 dBm
P_{in}	-77.2 dBm
Noise	-128 dBm
SINR	12 dB



Total 50 STAs

Simultaneous transmission happens when MCS < 3

The multi-BSS throughput is larger when MCS < 3

Large single BSS throughput is also validated against the Bianchi model (similar with case 1)

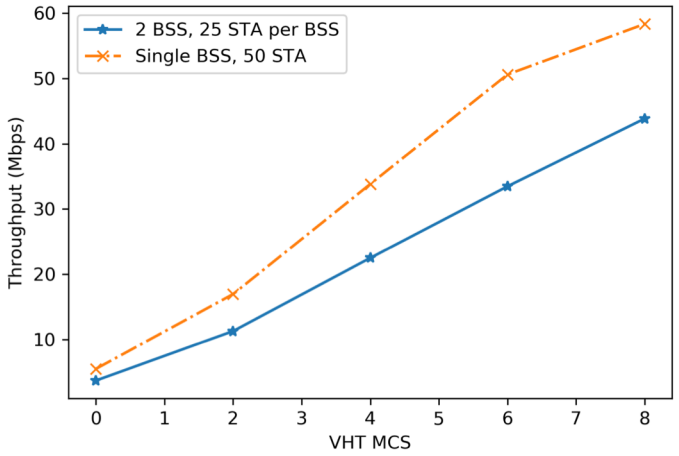
Phase 2: Build new scenarios and explore with different parameters

> Multi-BSS Setup

Case 3: Simultaneous transmission

- Setup: r = 3m, d = 20m
  - Every node is in the carrier sensing range (can sense each other)
  - SINR = 28.9 dB -> Can support simultaneous transmission at all MCSs
  - Expectation: 2 BSS has larger throughput in all MCSs than one large cell
- Results:

Parameters	Value
P_{rx}	-46.7 dBm
P_{in}	-75 dBm
Noise	-128 dBm
SINR	28.9 dB



Total 50 STAs

- Simultaneous transmission happens for all MCSs
- The multi-BSS throughput is larger
- Large single BSS throughput is also validated against the Bianchi model (similar with case 1)

Phase 3: Build and test new algorithms

> Wi-Fi Rate Control Algorithms [4]

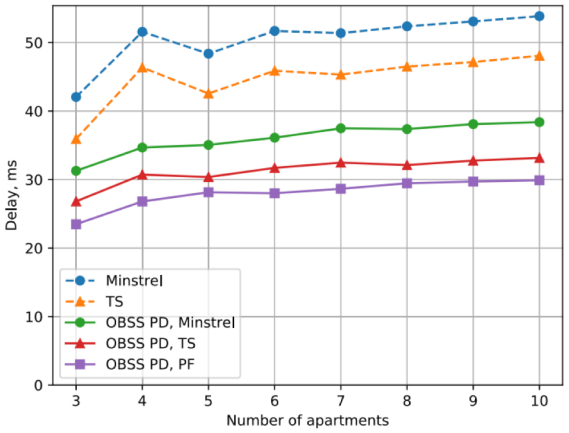


FIGURE 13. **Results for the residential building.**

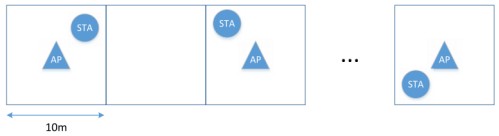


FIGURE 12. **Residential building scenario.**

- **TS:** MAB algorithm, using binomial distribution to approximate the success probability and then select the MCS (arm). Using Thompson sampling (TS) approach to calculate reward.
- **PF:** Estimate the channel SINR, then using TS to approach to approximate the SINR distribution, and then select the MCS based on the SINR.
- **OBSS PD:** Using OBSS PD to enable spatial reuse setup. The same way to calculate the OBSS PD: Threshold = Average RSSI − Margin (Margin is a positive value that considers channel quality fluctuations).

Benefits from RL (reinforcement learning):

- Explore the optimal way to search the (sub-)optimal setup <-> randomly search in traditional ways .
- Learn from the environment -> 'remember' similar situations.
- Capable for the optimization in large and complex scenario.

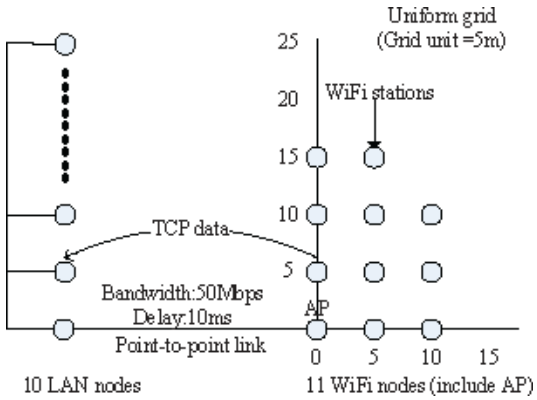
Deep RL? MAB?

[4] A. Krotov, A. Kiryanov and E. Khorov, "Rate Control With Spatial Reuse for Wi-Fi 6 Dense Deployments," in IEEE Access, vol. 8, pp. 168898-168909, 2020, doi: 10.1109/ACCESS.2020.3023552.

Phase 3: Build and test new algorithms

> Simulation Scenario

- Created by modifying the file " examples/tutorials/third.cc" in ns-3.
- The topology contains 10 wired LAN nodes connected to each other and one of the nodes is connected to the stationary Access Point(AP) of the Wireless Network using a point to point link with 50Mbps bandwidth and 10ms delay.
- Reference code: https://github.com/DodiyaParth/802.11ac_compatible_RAAs_Performance_Analysis_in_NS3



Simulation Scenario [3]

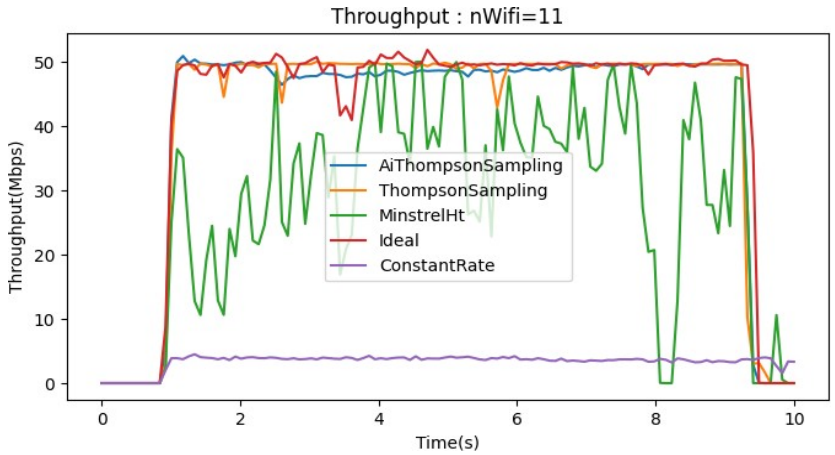
[5] Huang, Tingpei, et al. "A comparative simulation study of rate adaptation algorithms in wireless LANs." *International Journal of Sensor Networks* 14.1 (2013): 9-21.

Phase 3: Build and test new algorithms

> Simulation

Codes: https://github.com/hust-diangroup/ns3-ai

Error Rate Model	NistErrorRateModel
Channel Delay Model	ConstantSpeedPropagationDelay Model
Channel Loss Model	LogDistancePropagationLossMode l
MAC(Station/AP) Type	Sta WifiMac/ ApWifiMac
Application Data Rate	1 Mbps
Packet Size	1024 bytes
Mobility Model	RandomDirectional2dMobilityMo del
Mobility Speed	Random Variable : U(15.0 mps, 20.0 mps)
Simulation Topology of Wifi nodes	Grid, rectangle range: (-100m, 100m, -100m, 100m)



Under same scenario, how's the performance of different algorithms.

- Calculate the throughput every second with different rate control algorithms.
- Change the total node numbers and simulation duration to compare the results.

Thank you!

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