Learning WiFi using NetSim

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Outline

- About NetSim
- Introduction to WiFi
- WiFi in NetSim
- Basic WiFi experiments
  1. rate adaptation
  2. overheads in wireless communication
  3. random access and packet collisions
- Simulation guidelines
- Suggested exercises

About NetSim

- NetSim: A simulation and emulation tool
  - network design and planning
  - protocol and application modeling
- Highlights
  - technology: cellular networks, WLANs, WSNs, IoTs, VANETs, etc
  - 1000+ nodes
  - GUI
  - performance captured via traces and packet animator
  - external interfacing with Matlab, Wireshark and SUMO
  - support for emulation
  - protocol library source codes with documentation

About NetSim

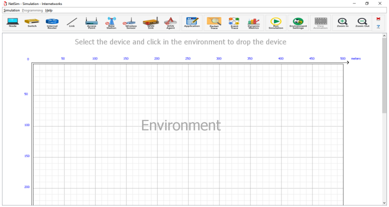

Figure: Configure Network

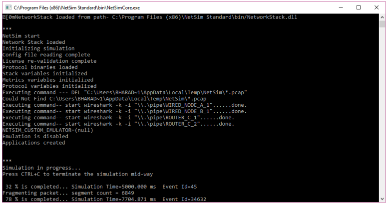

Figure: Run Simulation

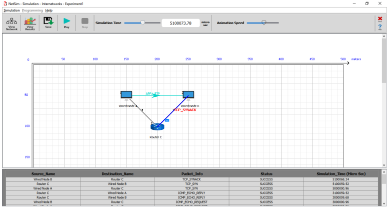

Figure: Visualize Simulation

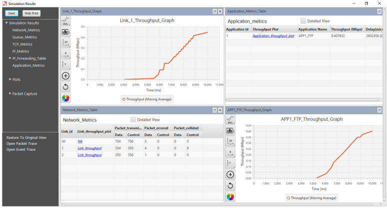

Figure: Measurements and Metrics

Introduction to WiFi

- Radio technology for WLANs based on IEEE 802.11 standards
  - includes MAC and PHY specifications
  - a, b, g, n, ac, ad, af, ah, ax and e
- Highlights
  - features: 256 QAM, MIMO, 160MHz bands, OFDM, 1+ Gbps
  - operation in 2.4 GHz, 5.8 GHz and 60 GHz unlicensed bands
  - primary channel access mechanism is CSMA/CA
  - support for infrastructure and ad hoc mode of operation
  - support for authentication, roaming, security, etc
  - standards are backward compatible

WiFi in NetSim

- IEEE 802.11 standards supported in NetSim
  - a, b, g, n, ac, e and p
  - 2.4 GHz and 5.8 GHz operation
- Features in NetSim
  - upto 256 QAM
  - upto 8 spatial streams
  - single user and multi user MIMO
  - channel bonding upto 160 MHz
  - packet aggregation
  - infrastructure and ad hoc mode of operation
  - effective list of propagation models and mobility models
- WiFi experiments in NetSim experiment manual
  - 5, 6, 8, 9, 10, 15, 16

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  - at PHY, MAC and higher layers
  - overheads reduce effective utilization and throughput
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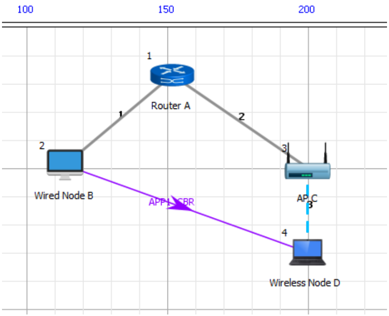
Basic WiFi experiments

1. Rate adaptation
   - study data rate and throughput with distance and transmit power
   - focus on effect of signal quality (and not interference)
2. Communication overheads
   - characterize overheads at PHY, MAC and higher layers
   - study effect of overheads on throughput
3. Random access and packet collisions
   - focus on CSMA/CA
   - study impact on throughput and retransmissions

Rate Adaptation (≈ Ex. 10)

- Objective
  - study data rate and throughput with distance and transmit power
  - relate data rate with RSSI and SNR
- Network setup
  - an IEEE 802.11n link between an access point and a client
  - downlink UDP traffic between a server and the client



Supported MCS and Data Rates

- IEEE 802.11n supports a fixed set of data rates

MCS	Modulation Type	Coding Rate	Data Rate[1]
0	BPSK	1/2	7.2
1	QPSK	1/2	14.4
2	QPSK	3/4	21.7
3	16-QAM	1/2	28.9
4	16-QAM	3/4	43.3
5	64-QAM	2/3	57.8
6	64-QAM	3/4	65
7	64-QAM	5/6	72.2

[1] 20 MHz, single spatial stream, 400ns GI

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$$\frac{1}{3.6 \times 10^{-6}} \frac{\text{symbols}}{\text{second}} \times 6 \frac{\text{bits}}{\text{symbol}} \times \frac{5}{6} \times 52 \text{ sub-carriers} = 72.2 \text{ Mbps}$$

[1] 20 MHz, single spatial stream, 400ns GI

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- RA select MCS based on RSSI, SNR, retransmission count, etc

[2] 20 MHz, single spatial stream, 400ns GI

Rate Adaptation: Experiment Configuration

WiFi Radio	
Standard	802.11n
Band	2.4 GHz
Channel	1
Bandwidth	20 MHz
Transmit Power	20 dBm and 10 dBm
Rate Adaptation	False

Wireless Channel and Link	
Channel Characteristics	Path Loss Only
Path Loss Model	Log_Distance
Path Loss Exponent	3.5
Mobility Model	Constant
AP - Client Distance	Variable

Rate Adaptation: Experiment Configuration (Contd. . .)

Application Properties	
Application	CBR
Transport Protocol	UDP
Packet Size	1450 bytes
Interarrival Time	116 microseconds
TCP	Disabled

Miscellaneous	
Wired Link Capacity	1 Gbps
Wired Link Delay	10 microseconds
Simulation Time	10 seconds

- choice of parameters ensures a saturated MAC queue
- packet trace must be enabled before the simulation

Performance Measurements

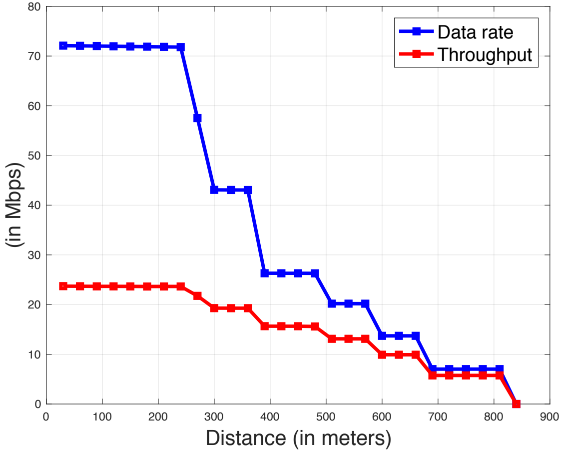
- Data rate (from Packet Trace)

$$\text{DATA RATE} = \frac{\text{PHY\_LAYER\_PAYLOAD} * 8}{(\text{PHY\_LAYER\_END\_TIME} - \text{PHY\_LAYER\_ARRIVAL\_TIME} - 40)}$$

- Average Throughput (from Packet Trace)

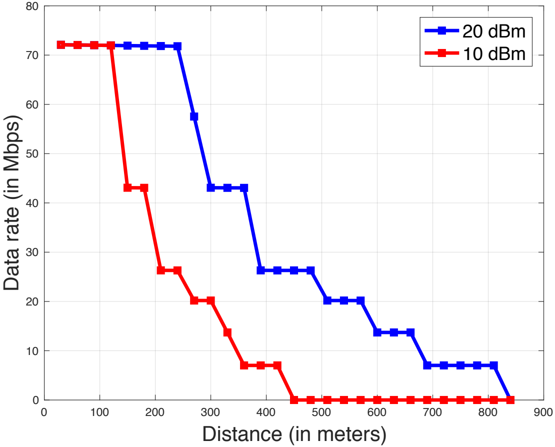
$$\text{AVERAGE THROUGHPUT} = \frac{\text{APPLICATION\_BYTES\_RECEIVED} * 8.0}{\text{SIMULATION\_TIME}}$$

Data Rate and Throughput with Distance



- data rate and throughput decreases with distance
- data rates correspond to recommend rates of 802.11n

Data Rate with Distance and Transmit Power



- data rate decreases as transmit power decreases
- coverage (range) decreases as transmit power decreases

Data Rate, RSSI and SNR

- Rate Adaptation False recommends MCS based on the table below

MCS	Data Rate	RSSI (in dBm)
0	7.2	-82
1	14.4	-79
2	21.7	-77
3	28.9	-74
4	43.3	-70
5	57.8	-66
6	65	-65
7	72.2	-64

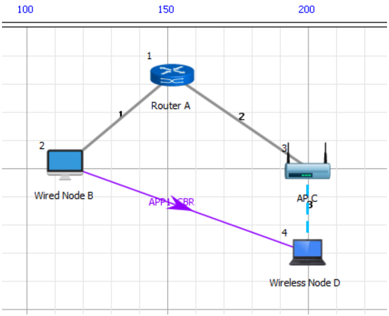
$$\text{RSSI (in dBm)} = 10\log_{10}(P_t) - 10\eta\log_{10}(d) - K(\eta)$$

Rate Adaptation: Inferences

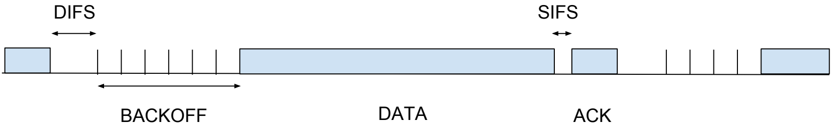
- Rate adaptation in WiFi
  - data rate and throughput decreases with distance
  - data rate, throughput and coverage decreases with transmit power
  - key insight - RSSI determines MCS and data rate
  - data rate may be adapted due to interference as well
  - rate adaptation algorithms is a popular topic of research
- Application throughput is significantly less than PHY data rate
  - wireless communication has overheads
  - throughput suffers due to higher layer overheads as well

Communication Overheads ($\approx$ Ex. 6)

- Objective
  - characterize overheads at PHY, MAC and higher layers
  - predict average throughput of a WiFi link
- Network setup
  - an IEEE 802.11n link between an access point and a client
  - downlink UDP traffic between a server and a client

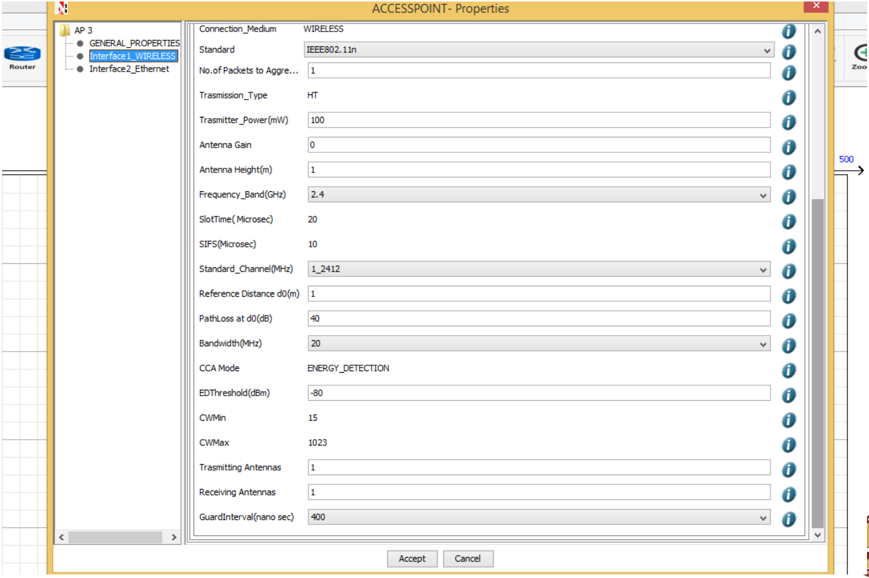


Basic Access Mechanism in IEEE 802.11 WLANs



- Average time to transmit a packet comprises of
  - DIFS
  - backoff duration
  - data packet transmission time
  - SIFS
  - MAC ACK transmission time

Communication Overheads: NetSim Configuration



Communication Overheads: NetSim Configuration

Timing Information	
SIFS	10 μsec
Slot Time	20 μsec
DIFS	SIFS + 2 * Slot Time = 50 μsec
CWmin	15 slots
Average Backoff	$\frac{\text{CWmin}}{2}$ * Slot Time = 150 μsec

Communication Overheads: Experiment Configuration

WiFi Radio	
Standard	802.11n
Band	2.4 GHz
Channel	1
Bandwidth	20 MHz
Transmit Power	20 dBm
Rate Adaptation	False
Wireless Access	Basic Access

Wireless Channel and Link	
Channel Characteristics	Path Loss Only
Path Loss Model	Log_Distance
Path Loss Exponent	3.5
Mobility Model	Constant
AP - Client Distance	30m

Communication Overheads: Experiment Configuration

Application Properties	
Application	CBR
Transport Protocol	UDP
Packet Size	1450 bytes
Interarrival Time	116 microseconds
TCP	Disabled

Miscellaneous	
Wired Link Capacity	1 Gbps
Wired Link Delay	10 microseconds
Simulation Time	10 seconds

- parameters ensures a wireless bottleneck and saturated MAC queue
- packet trace must be enabled before the simulation

Communication Overheads: Packet Transmission Time

$$\begin{aligned} \text{MPDU Size} &= 1450 + \text{UDP Header} + \text{IP Header} + \text{MAC Header} \\ &= 1450 + 8 + 20 + 40 \text{ bytes} \\ &= 1518 \text{ bytes} \end{aligned}$$

$$\begin{aligned} \text{Packet Transmission Time} &= \text{PHY Overheads} + \frac{\text{MPDU Size}}{\text{Data Rate}} \\ &= 40 + \frac{1518 * 8}{72.2}\ \mu\text{sec} \\ &= 40 + 169.2\ \mu\text{sec} \\ &= 209.2\ \mu\text{sec} \end{aligned}$$

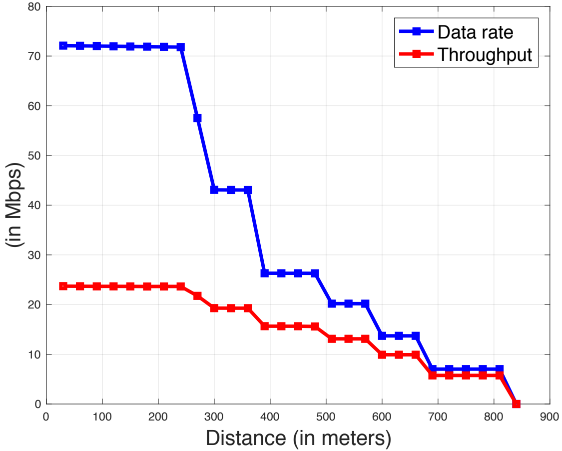
$$\begin{aligned} \text{ACK Transmission Time} &= \text{PHY Overheads} + \frac{\text{ACK Packet Size}}{\text{ACK Data Rate}} \\ &= 40 + \frac{32 * 8}{7.2}\ \mu\text{sec} \\ &= 76\ \mu\text{sec} \end{aligned}$$

Communication Overheads: Average Throughput

$$\text{AVERAGE TIME PER PACKET} \approx 50 + 150 + 209.2 + 10 + 76 \ \mu\text{sec} = 495.2 \ \mu\text{sec}$$

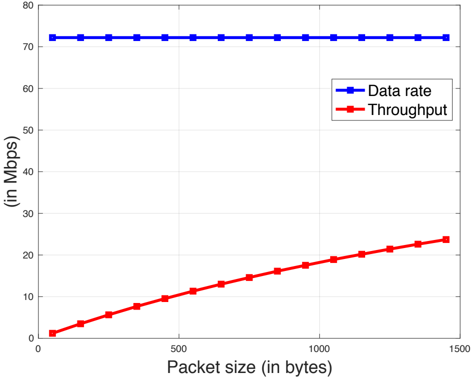
$$\text{AVERAGE THROUGHPUT} \approx \frac{\text{APPLICATION PAYLOAD}}{\text{AVERAGE TIME PER PACKET}} = \frac{1450 * 8}{495.2} \text{ Mbps} = 23.42 \text{ Mbps}$$

Communication Overheads: Data Rate and Throughput



- throughput significantly less when data rate is high
- communication overheads are insignificant at low data rates

Communication Overheads: Effect of Packet Size



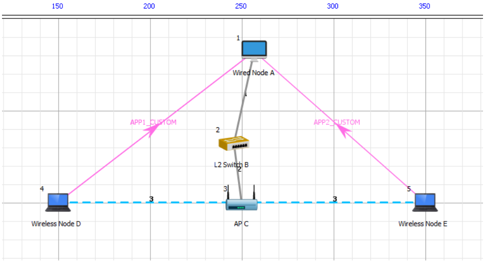
- throughput significantly less when packet size is small
- communication overheads are insignificant when packet sizes are large

Communication Overheads: Inferences

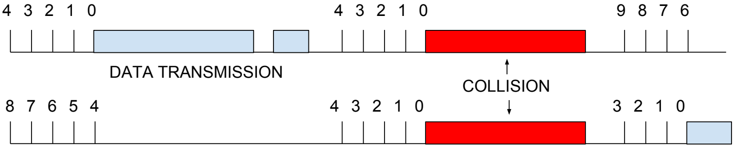
- Communication overheads in WiFi
  - includes PHY, MAC and higher layer overheads
  - overheads are significant at higher data rates and smaller packet sizes
  - contention and channel errors can significantly affect performance
  - higher layers may have additional overheads as well (e.g., TCP ACK)
- Mechanisms to improve performance
  - packet aggregation (AMPDU and AMSDU)
  - backoff differentiation and bandwidth management
  - MU-MIMO in IEEE 802.11ac
  - OFDMA in IEEE 802.11ax

Random Access and Packet Collisions ($\approx$ Ex. 5)

- Objective
  - study random access mechanism in WiFi
  - evaluate impact on throughput
- Network setup
  - an IEEE 802.11n BSS with an access point and two clients
  - uplink UDP traffic from the two clients to the server



Random Access Mechanism in IEEE 802.11 WLANs



- Primary channel access mechanism in WiFi is CSMA/CA
- All transmissions are deferred (backoff) for collision avoidance
- Nodes carrier sense before a transmission
- Collisions occur when two nodes transmit simultaneously
- Random backoff duration is increased exponentially with collisions

Random Access: Experiment Configuration

WiFi Radio	
Standard	802.11n
Band	2.4 GHz
Channel	1
Bandwidth	20 MHz
Transmit Power	20 dBm
Rate Adaptation	False
Wireless Access	Basic

Wireless Channel and Link	
Channel Characteristics	Path Loss Only
Path Loss Model	Log_Distance
Path Loss Exponent	4.5
Mobility Model	Constant
AP - Client Distance	100m

Random Access: Experiment Configuration

Application Properties	
Application	CBR
Transport Protocol	UDP
Packet Size	1450 bytes
Interarrival Time	116 microseconds
TCP	Disabled
Traffic	Uplink

Miscellaneous	
Wired Link Capacity	1 Gbps
Wired Link Delay	10 microseconds
Simulation Time	10 seconds

- choice of parameters ensures a saturated MAC queue
- packet trace must be enabled before the simulation

Random Access: Performance Measurements

- Attempt rate (from Packet Trace)

$$\text{ATTEMPT RATE} = \frac{\text{NUMBER\_OF\_TRANSMISSIONS}}{\text{SIMULATION\_TIME}}$$

- Collision probability (from Packet Trace)

$$\text{COLLISION PROBABILITY} = \frac{\text{NUMBER\_OF\_COLLIDED\_TRANSMISSIONS}}{\text{NUMBER\_OF\_TRANSMISSIONS}}$$

- Average Throughput (from Packet Trace)

$$\text{AVERAGE THROUGHPUT} = \frac{\text{APPLICATION\_BYTES\_RECEIVED} * 8.0}{\text{SIMULATION\_TIME}}$$

Contention and Random Access

Performance Measures	Single User	Two Users
Attempt Rate (per sec)	1350	1136
Collisions Probability	0	0.65
Average Throughput	15.63 Mbps	4.49 Mbps

Contention and Random Access

Performance Measures	Single User	Two Users
Attempt Rate (per sec)	1350	1136
Collisions Probability	0	0.65
Average Throughput	15.63 Mbps	4.49 Mbps

- Random access leads to collisions and packet loss
    - collision and retransmissions leads to loss in throughput
    - collisions increase channel access delay as well
    - collisions may also affect rate adaptation algorithms

Random Access and Packet Collisions: Inferences

- CSMA/CA in WiFi
  - resolves contention and enables spatial reuse
  - random access leads to collisions and loss in throughput
  - RTS/CTS can minimize collisions and reduce loss in throughput
- Mechanisms to enhance performance
  - RTS/CTS channel access
  - 802.11e to support QoS and differentiation
  - MU-MIMO and OFDMA
  - transmit power control, sensitivity and rate adaptation
  - bandwidth managers

Simulation Guidelines

- Performance varies with AP-client distance and locations
  - interference can vary even with small changes in location
- Protocols and traffic may affect performance in many ways
  - uplink traffic creates more collisions than downlink traffic
  - TCP ACKs can create interference as well
- Random access and spatial reuse
  - spatial reuse is a function of TPC, receiver sensitivity, etc
  - QoS may not be strict

Suggested Exercises

- Evaluate data rate and throughput as a function of RSSI
- Evaluate performance of Minstrel algorithm as a function of distance
- Evaluate throughput and utilization with TCP
- Study average DI/UI throughput as the number of clients increases
- Demonstrate spatial reuse with CSMA/CA

Questions!


obrigado
Dank U
Merci
mahalo
Köszi
спасибо
Grazie
Thank you
mauruuru
Takk
Gracias
Dziękuję
Děkuju
danke
Kiitos