Interactions Between the Physical Layer and Upper Layers in Wireless Networks: *The devil is in the details*

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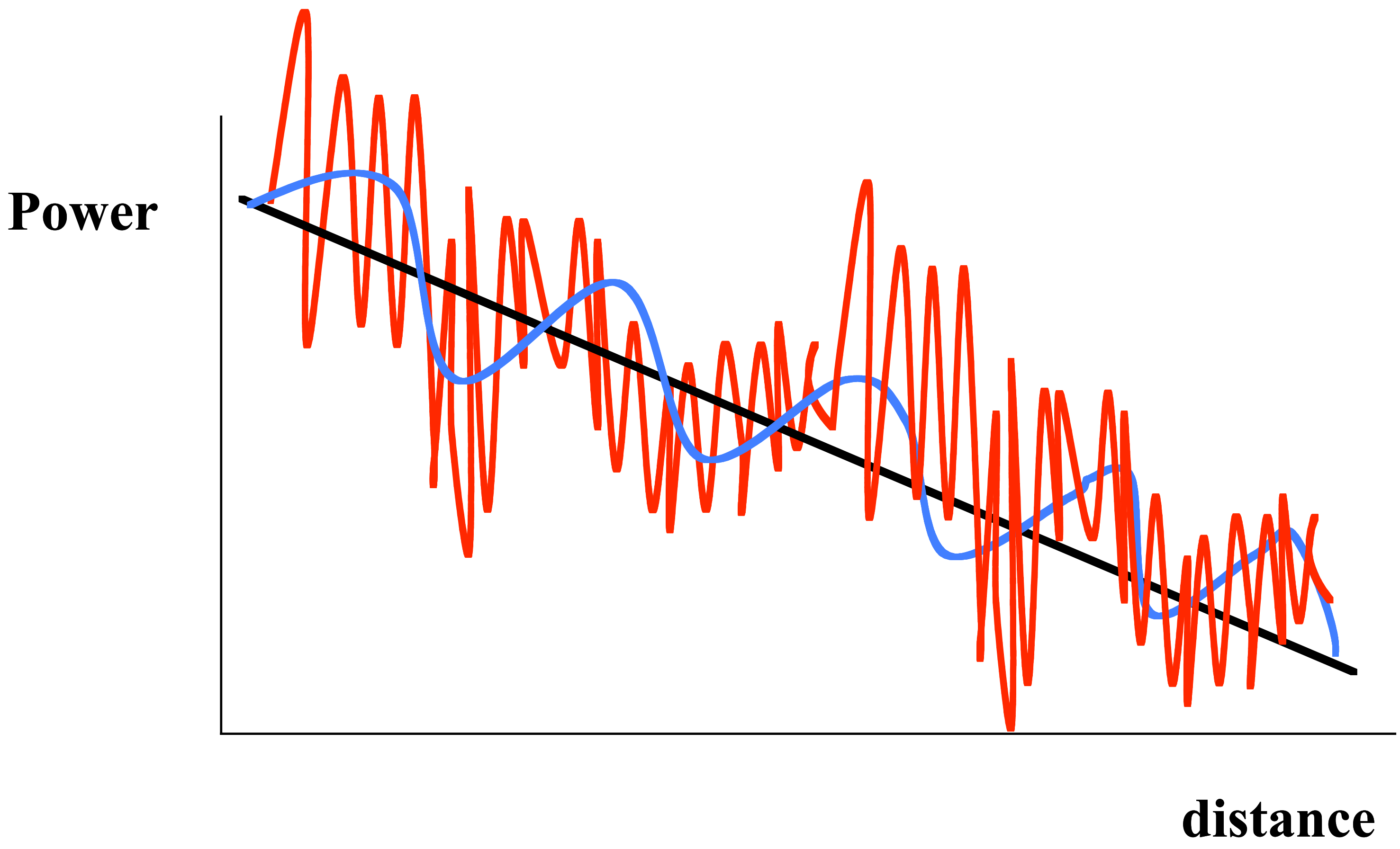
Very Wide Range of Scenarios

	SCENARIOS	RELEVANT ASPECTS	VALUE ADDED PROPOSITIONS
APPLICATION	• Traffic Types – voice, video, data •Traffic Pattern	• Traffic Parameters • Performance •Measures	*Application layer Adaptation*
NETWORK LAYER	• Topology • Mobility • Routing Protocol	• Topology Parameters • Mobility Parameters • Protocol Parameters	*Adaptive routing*
MAC	• IEEE 802.11	• Contention Window • Inter-Frame Spacing	*Adaptive contention window*
PHYSICAL LAYER	• OFDM	• Transmit Power • Data Rate • ED Threshold	• *Power and Rate Adaptation* •*MIMO*
CHANNEL	•Offices, residences •Outdoors	• Path Loss • Fading	*N/A*

Impact of Channel Fading on Packet Error Rate (PER) and Applications Performance

Path Loss, Shadowing, and Small Scale Fading



System Model

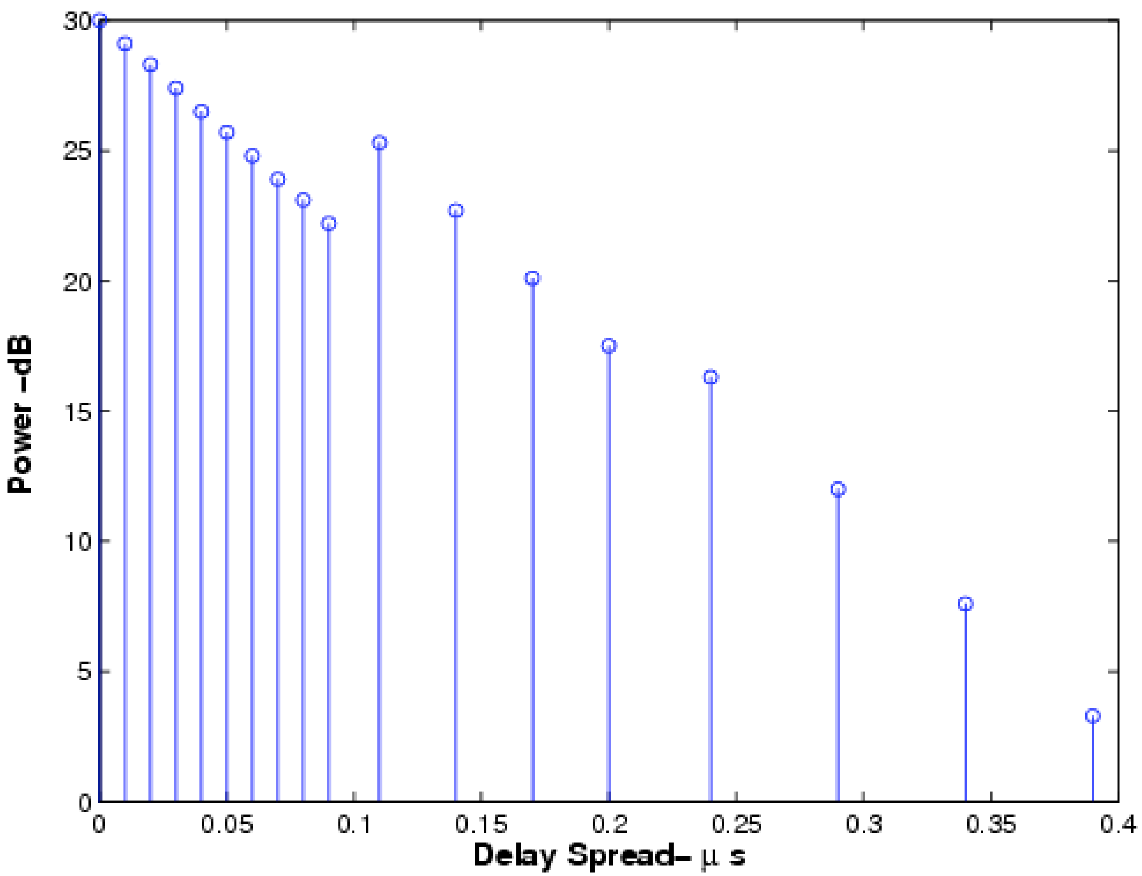
•**Wireless Channel model** – ETSI's channel model A for Typical office environment

• **PHY Layer** - IEEE 802.11a/g (OFDM-based)

• **MAC Layer** - IEEE 802.11 DCF (CSMA/CA with 7 retries)

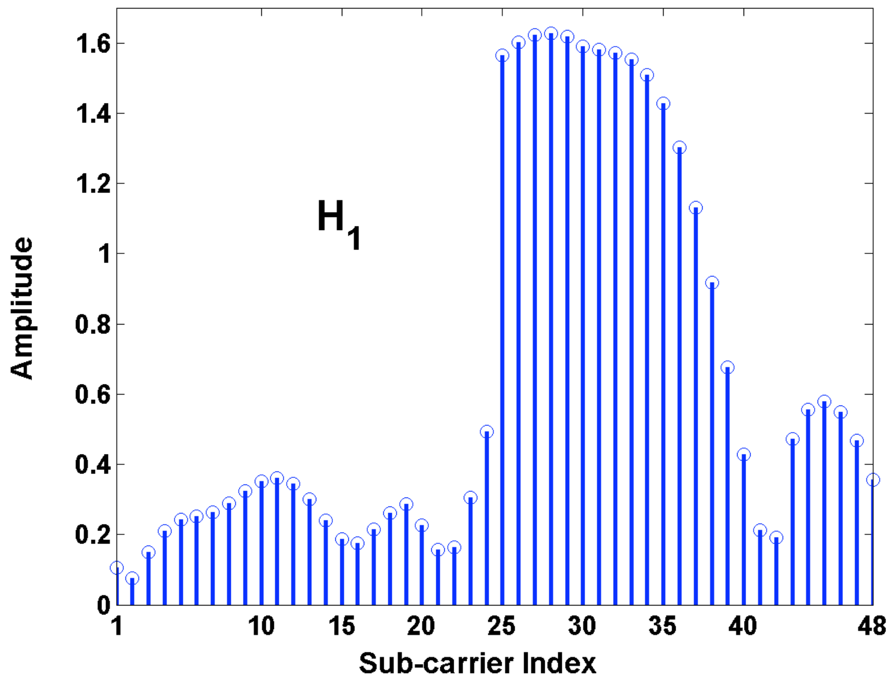
•**Application** - VoIP (20ms speech/packet = 228 bytes frames)

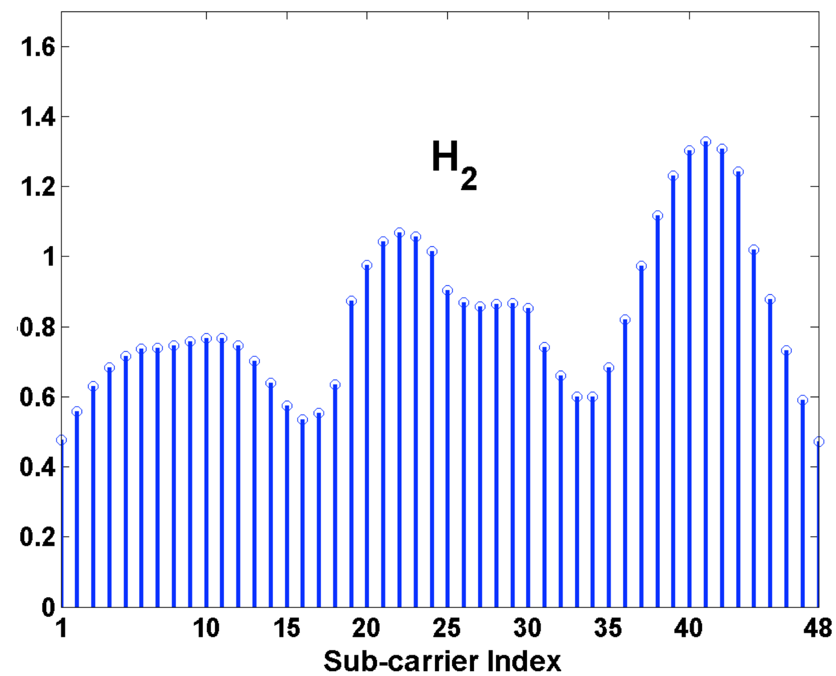
ETSI Channel Model A
Multipath Components



- Typical indoor non-line of sight office environment
- RMS delay spread =50ns
- Independent Rayleigh fading on the paths

Fading Realizations and PER





PER = 0.99

PER < 10^{-4}

R= 24 Mbps SNR_{rec} = 18.6 dB

SNR and SNR_{rec}

- $SNR_{rec} = f(SNR, H)$
- $SNR = P_t + G_t + G_r - P_{loss} - N_{power} - I_m$
- $N_{power} = 10\log10(K.T.B) + NF$
  - K, Boltzman constant
  - T, temperature
  - B, bandwidth
  - NF, noise figure

Keenan-Motley

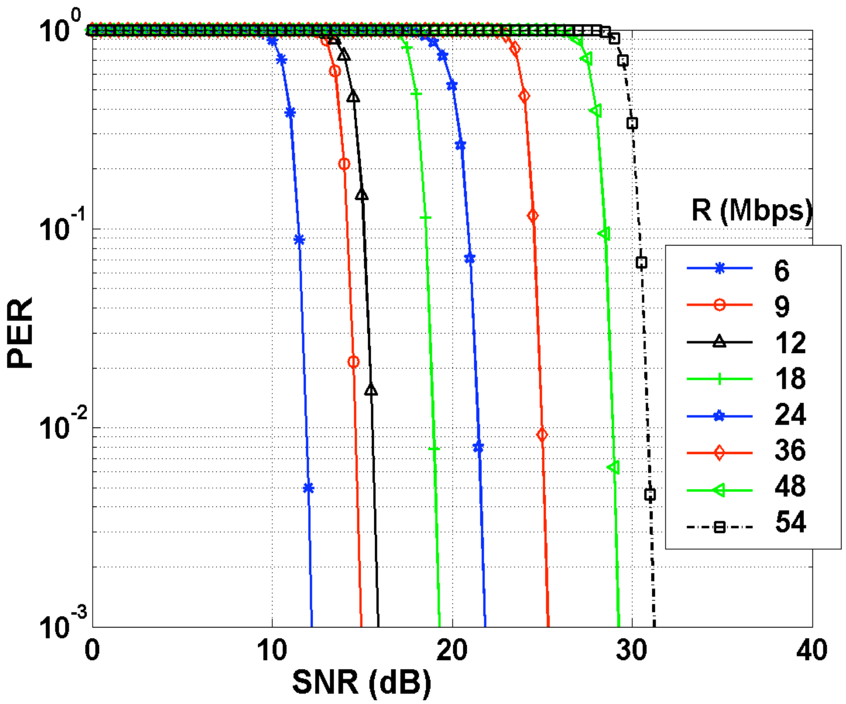
- $P_{loss} = P_{free\text{-}space}(d, \lambda) + a \bullet d$

Parameters	Values
Carrier Frequency	5.3 GHz
P_t	23 dBm (200 mw)
G_t	0 dBi
G_r	0 dBi
Implementation Margin	5 dB
Bandwidth	20 MHz
Noise Figure	10 dB
a	0.44 dB/m

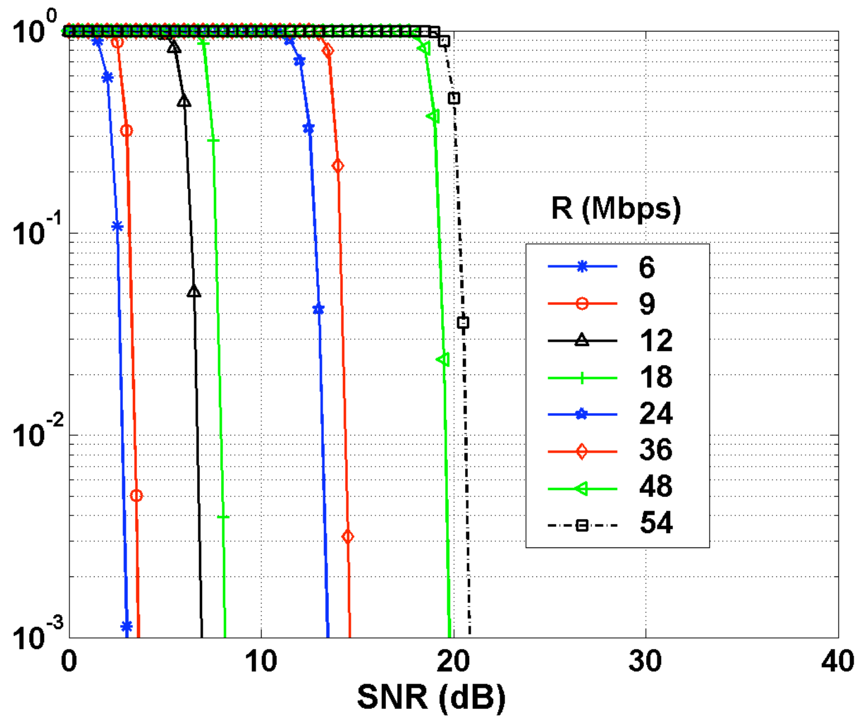
DISTANCE

SNR-dB	5	10	15	20	25	30	35
d-meters	52	44	36	28	23	17	12

Fading Realizations and PER

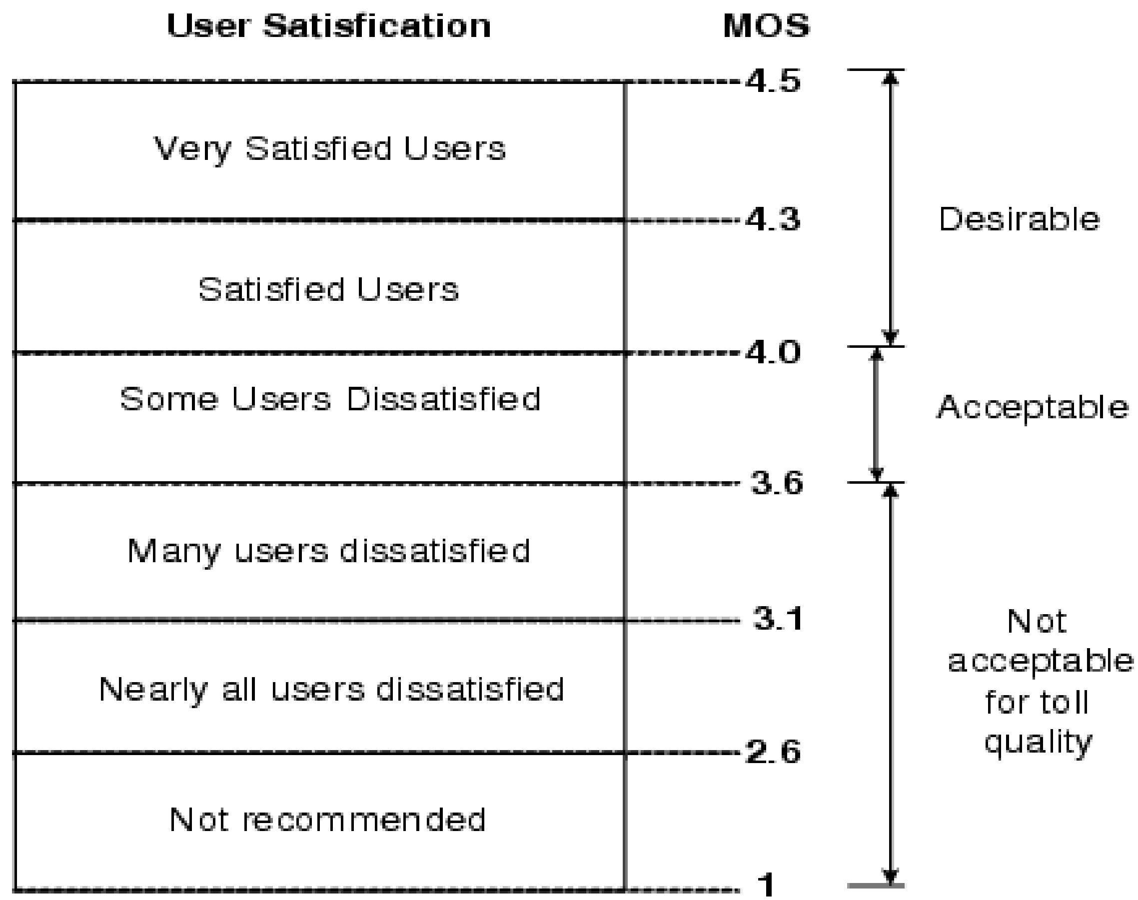


PER vs. SNR for $\mathbf{H}_1$

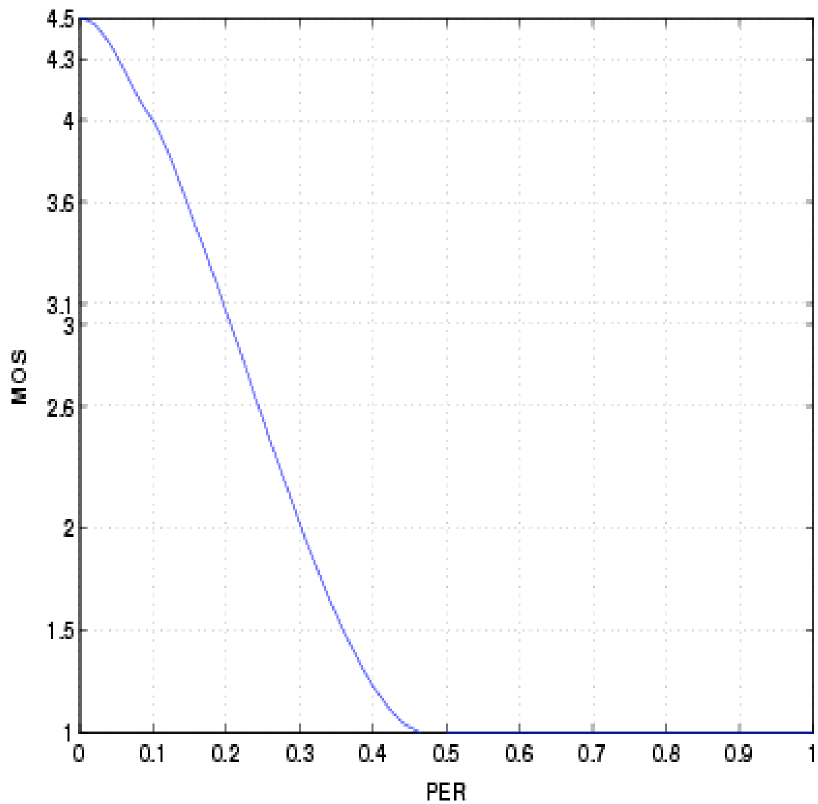


PER vs. SNR for $\mathbf{H}_2$

VoIP Quality Assessment: Mean Opinion Score (MOS)

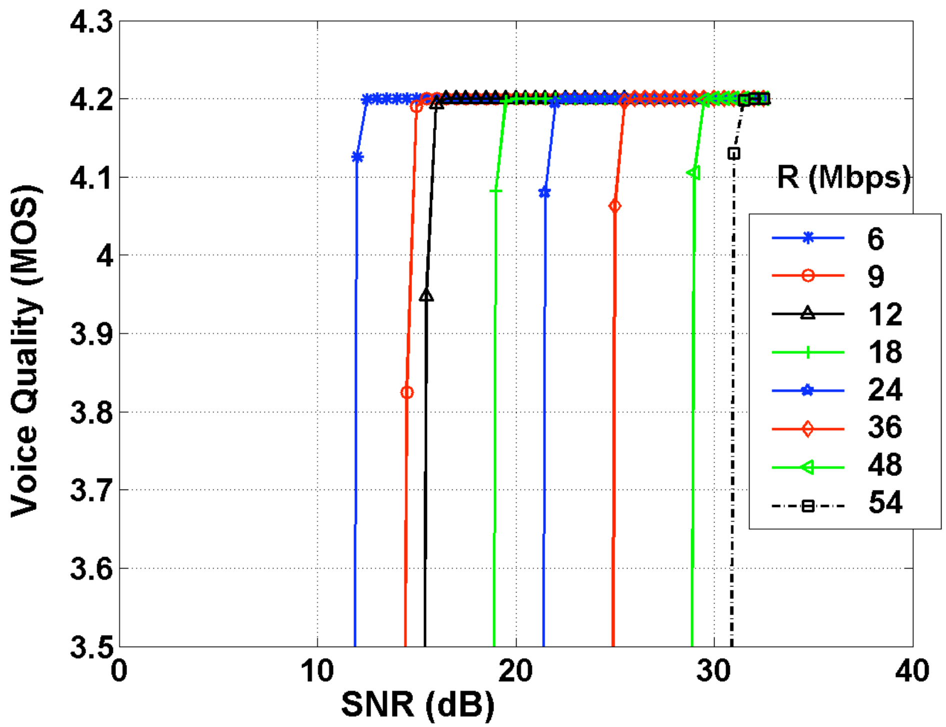


MOS-PER Relationship

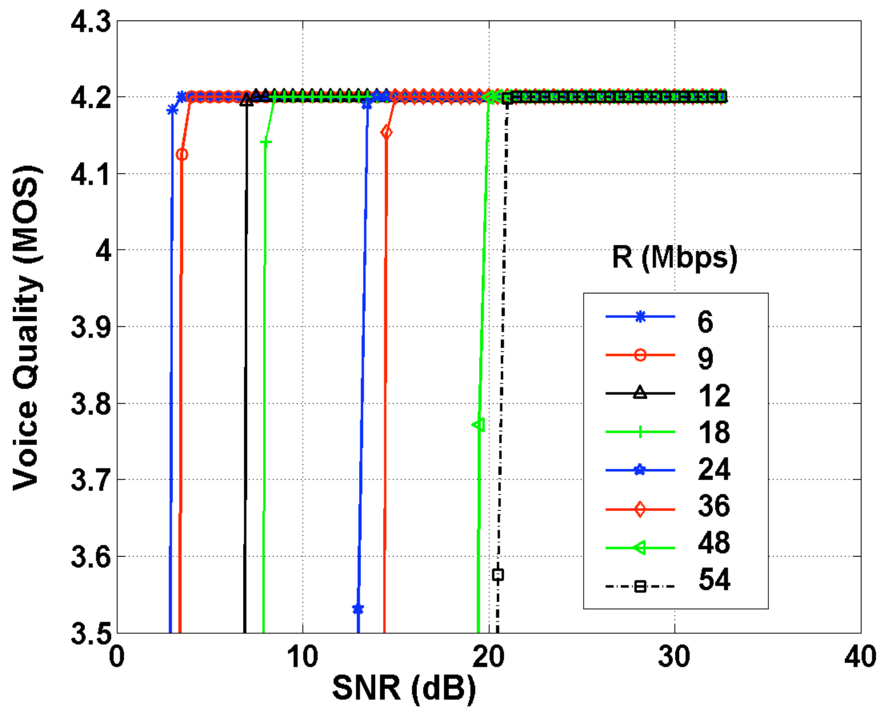


MOS vs. PER for G.711 with PLC

Voice Quality

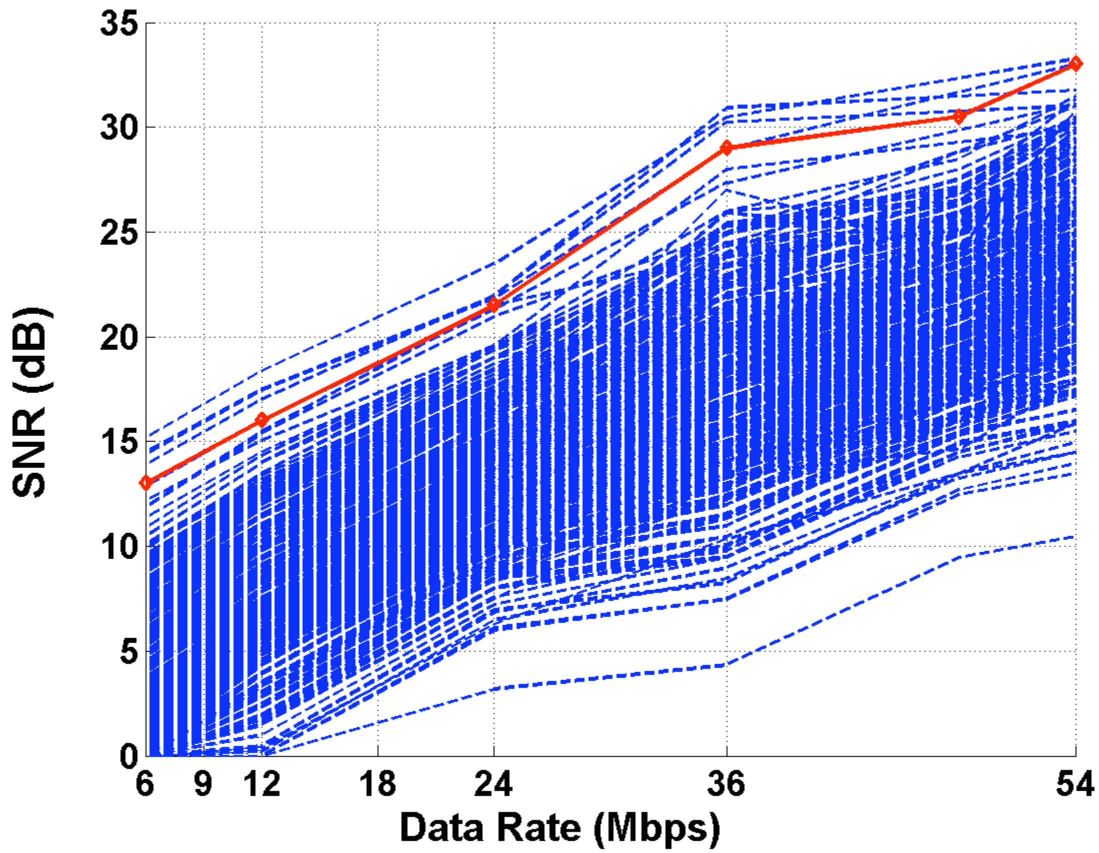


H_1



H_2

SNR Vs. Data Rate Tradeoff



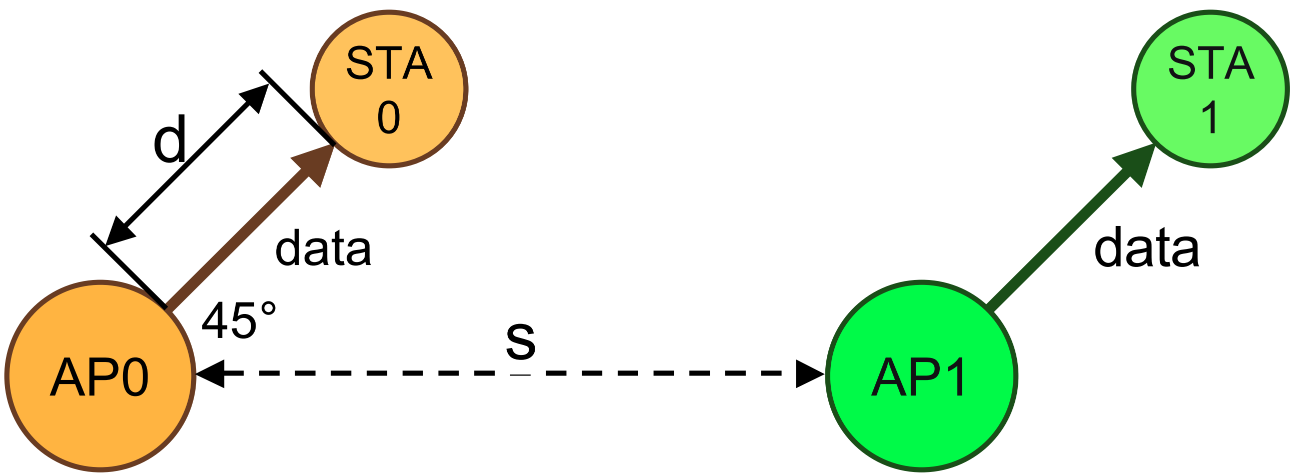
99th percentile

$MOS_{target} = 4$

Coexistence of Multiple Links:

Interactions between the Physical Layer and the MAC Layer

A Simple Scenario:
Video Streaming



Even with this simple case there are many parameters regarding:
Topology, Wireless Channel, Physical and MAC Layers, and Application Characteristics.

An Accurate Simulation Tool

802.11 MAC layer protocol

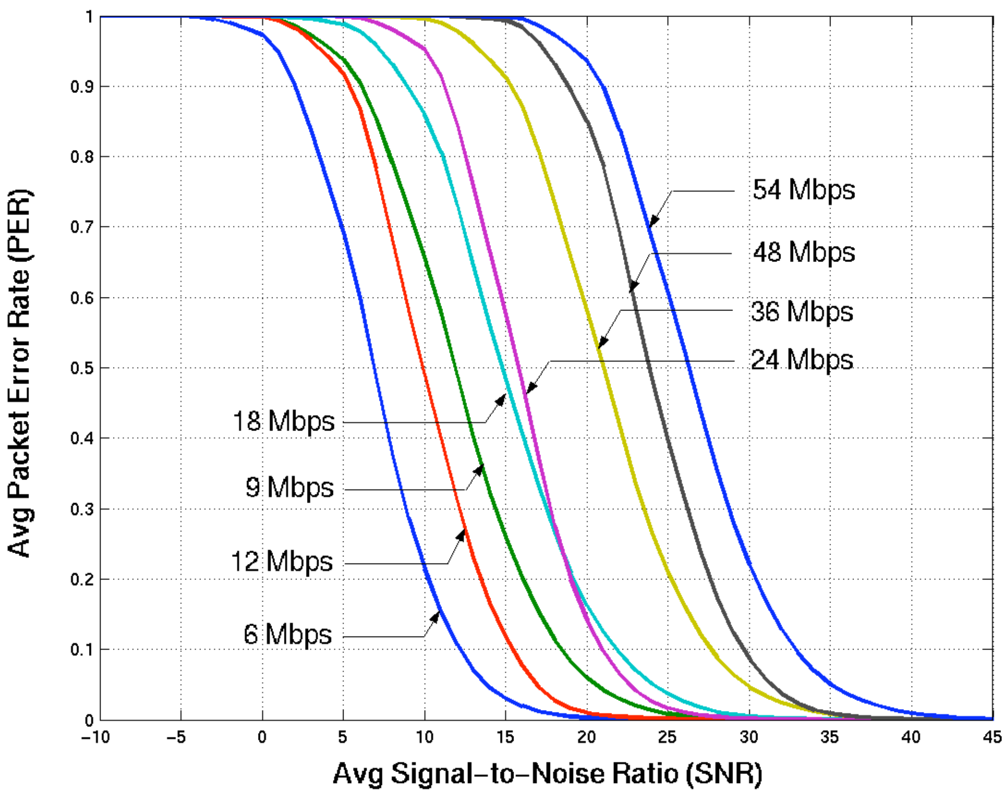
- Distributed Coordination Function (CSMA/CA)
- 802.11e enhancements

802.11a/g OFDM PHY characteristics

- Channel modeling including path loss and fading
- Accurate models for receiver: synchronization, PER

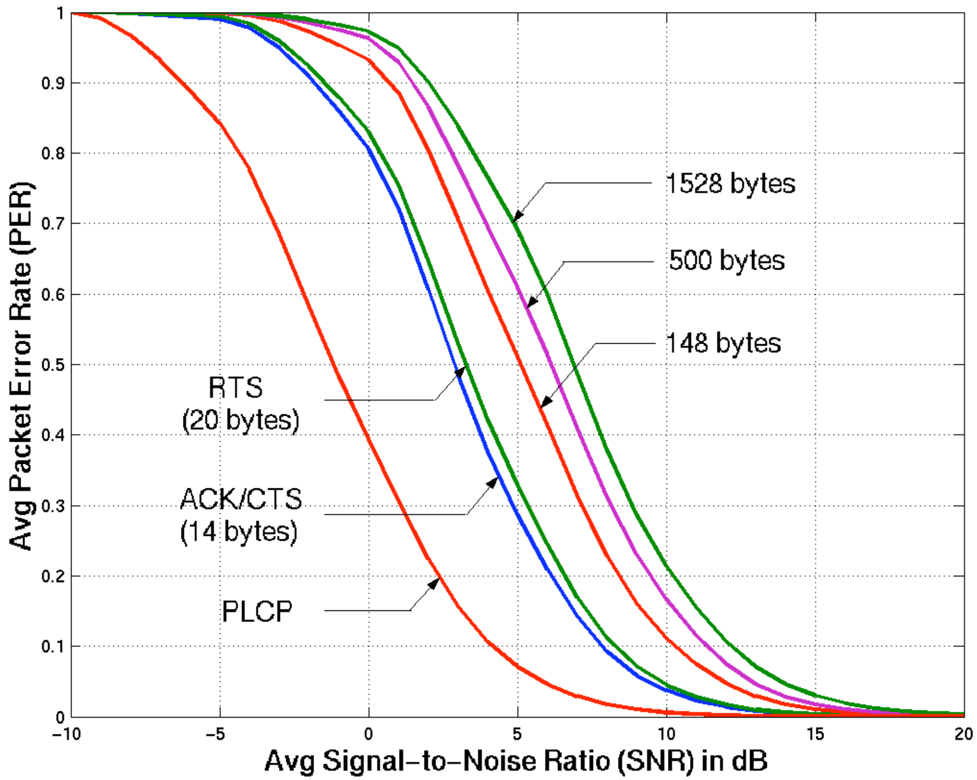
Application layer

Average Packet Error Rate for Various Data Rates



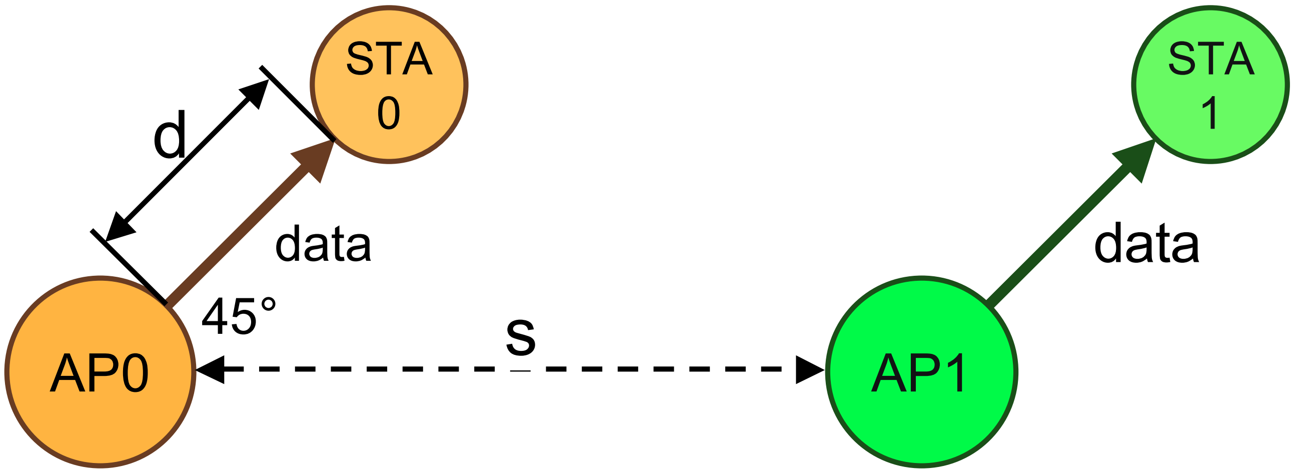
- IEEE 802.11a
- ETSI Channel A
- MAC frame size = 1528 bytes

Packet Error Rate for Different Packet Size



- IEEE 802.11a
- ETSI Channel A
- 6 Mbps

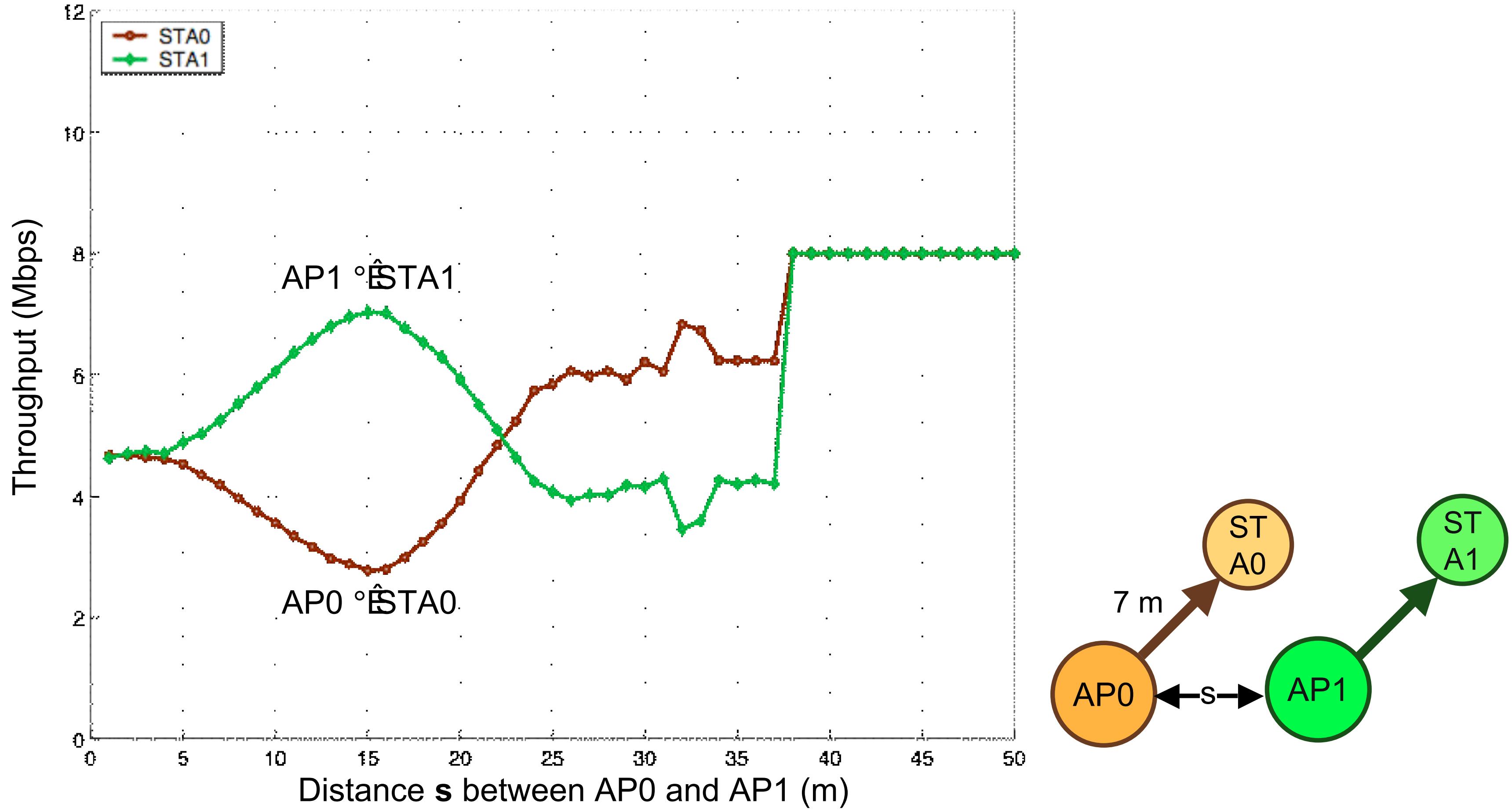
A Simple Scenario:
Sustainable video throughput



PHY 12 Mbps
Video 8 Mbps
d = 7 m
ED = -95 dBm

Video Throughput

(Phy 12 Mbps, Video 8 Mbps, d = 7 m, ED = -95 dBm)



Factors

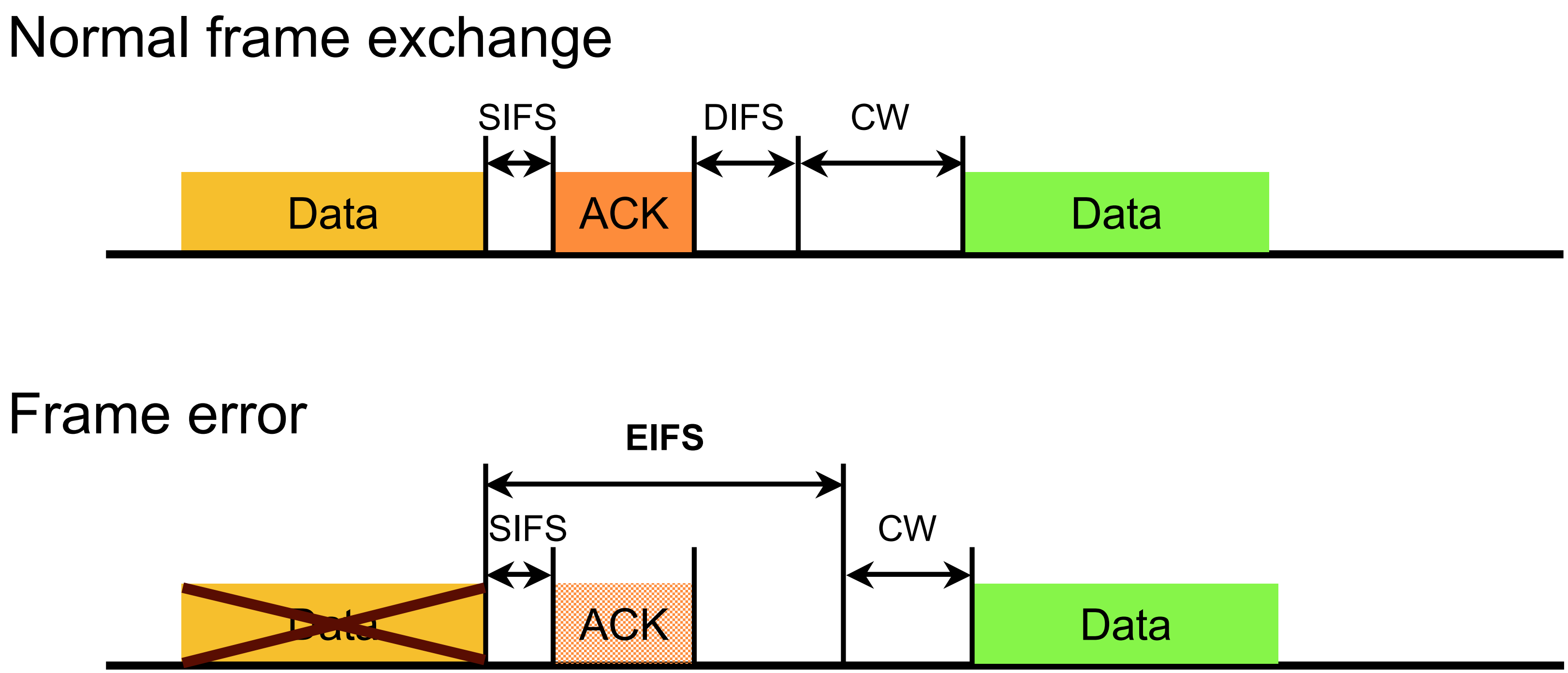
- Blocking: 802.11 Carrier Sense Multiple Access prevents simultaneous packet transmissions from both APs

- MAC layer behavior: Interframe Spacing depends on whether the last detected packet is received correctly or not

- Interference: packet reception corrupted due to simultaneous transmission (no blocking)

Extended Interframe Space

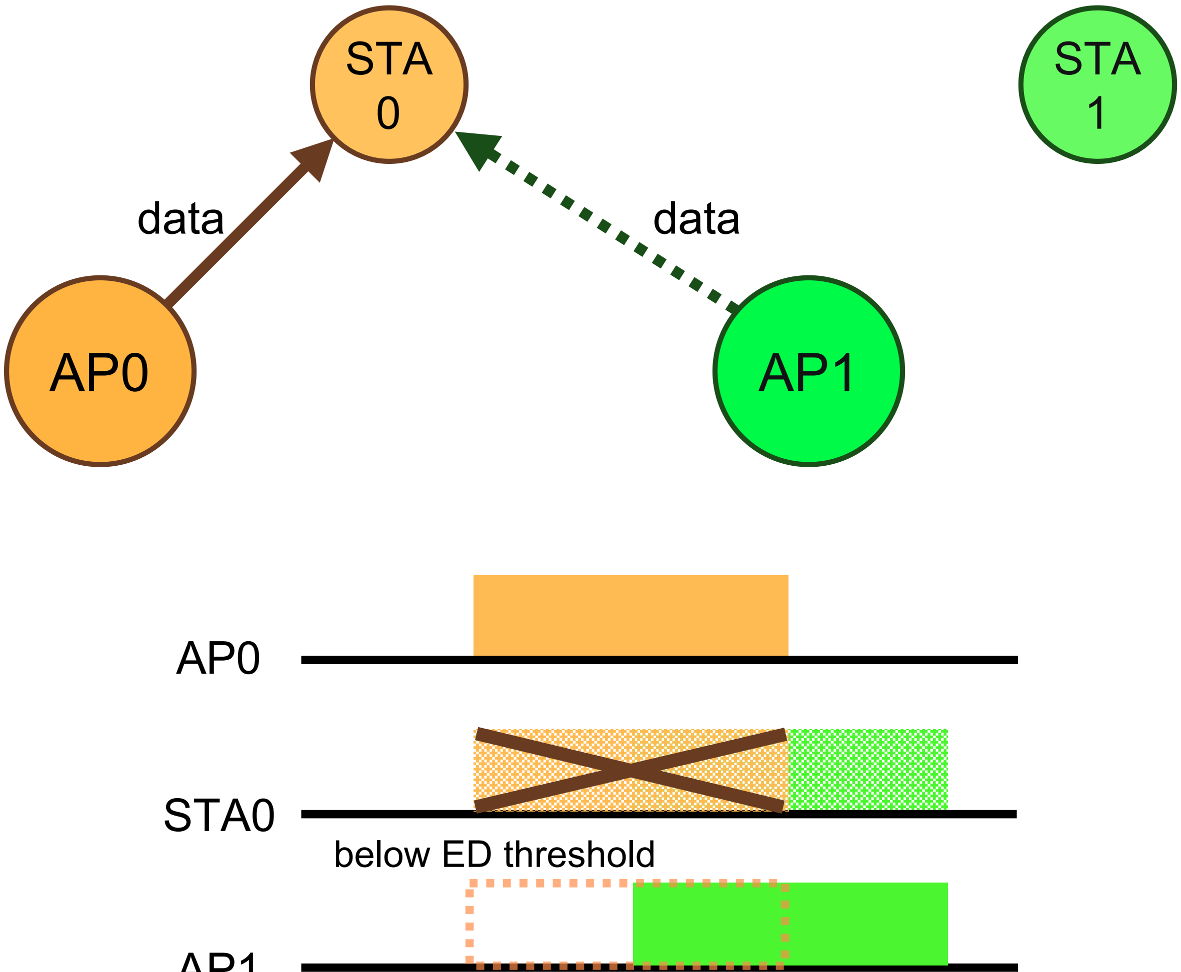
802.11 MAC Protocol



SIFS, DIFS, EIFS: Interframe space / CW: Contention Window (random)

EIFS is used to protect an eventual ACK transmitted by the intended receiver.

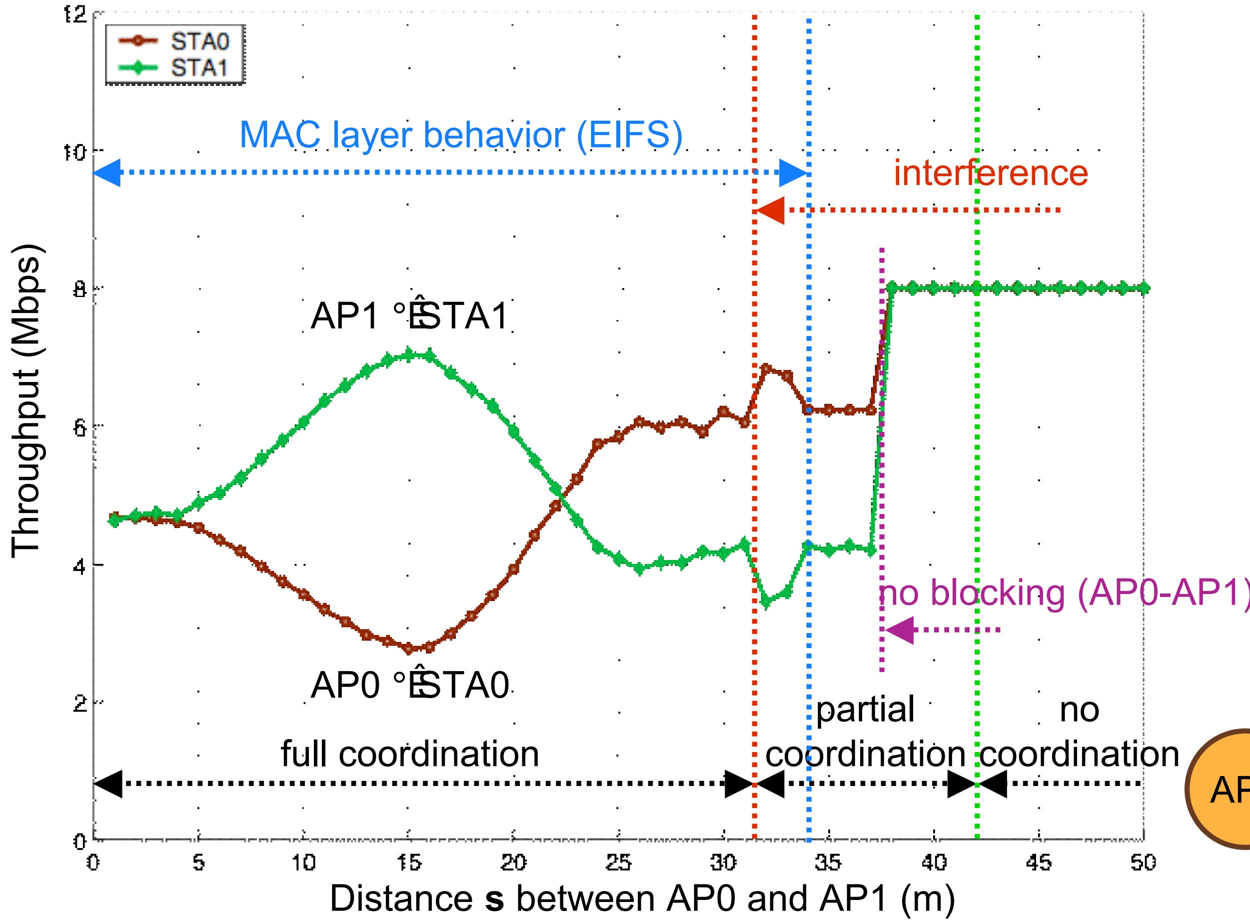
Interference Effect

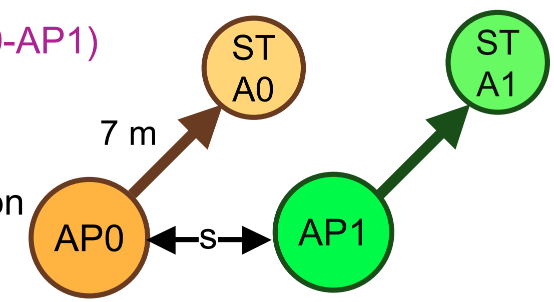


Interference from AP1 causes high probability of error at STA0.

Video Throughput

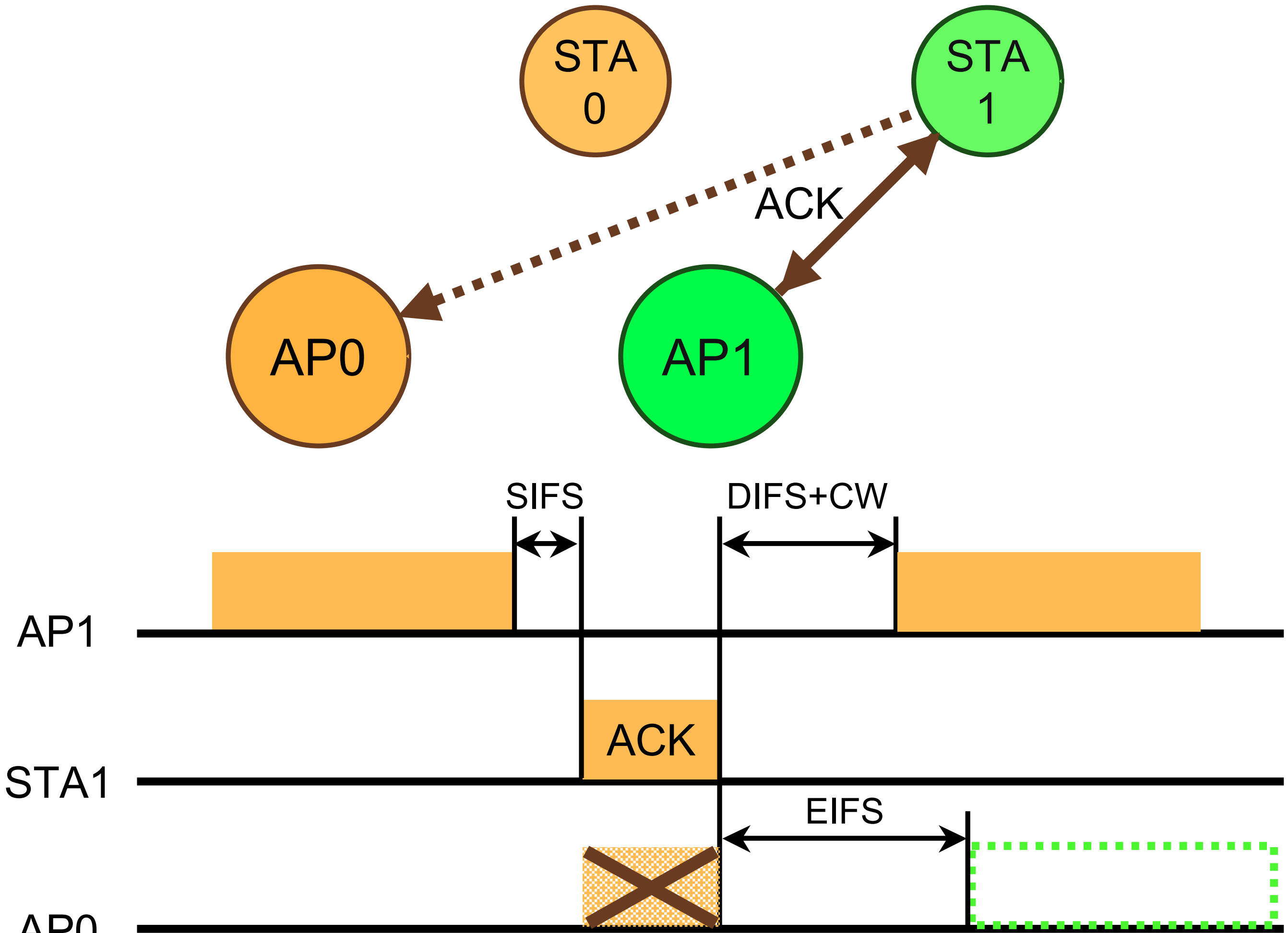
(Phy 12 Mbps, Video 8 Mbps, d = 7 m, ED = -95 dBm)





With coordination: MAC layer behavior determines sharing of bandwidth

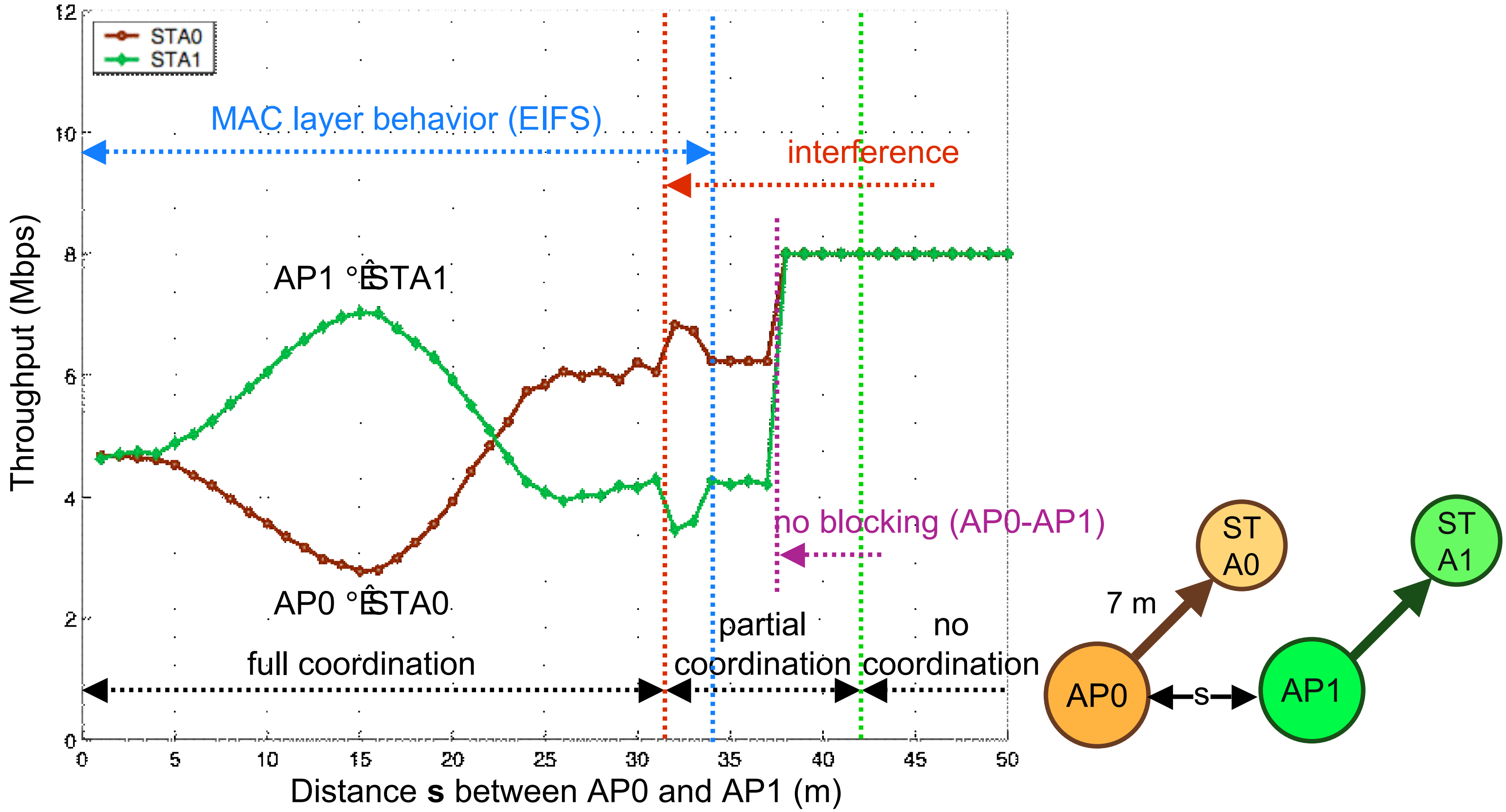
EIFS Effect



Channel is captured by AP1 more frequently.

Video Throughput

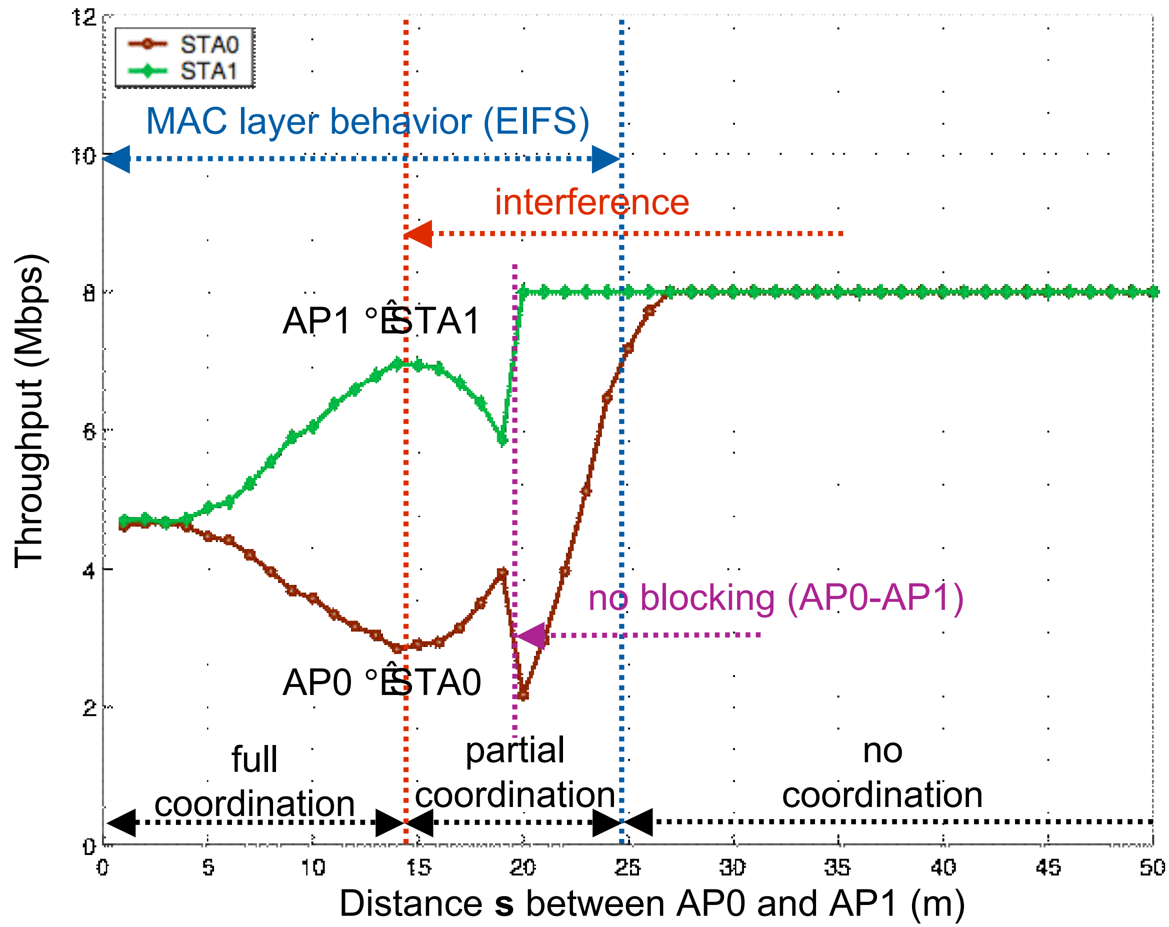
(Phy 12 Mbps, Video 8 Mbps, d = 7 m, ED = -95 dBm)

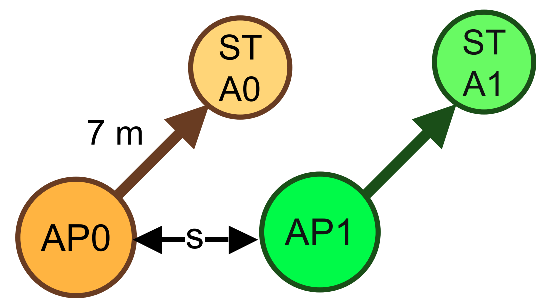


Without coordination: interference is the main cause of the results

Video Throughput

(Phy 12 Mbps, Video 8 Mbps, d = 7 m, ***ED = -85 dBm***)

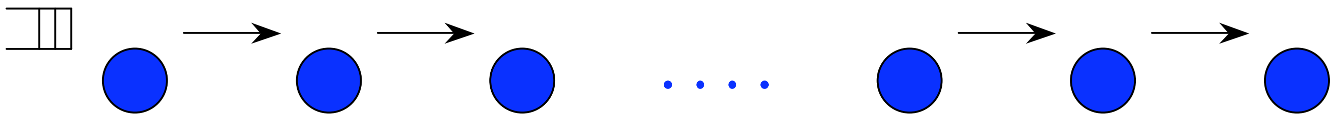




Without coordination: interference is the main cause of the results

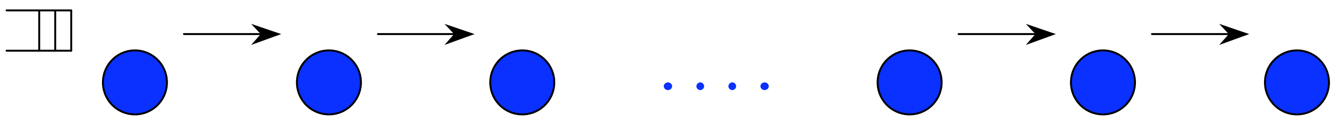
Impact of Path Loss and Physical Layer Parameters on the throughput of Multi-hop Wireless Networks

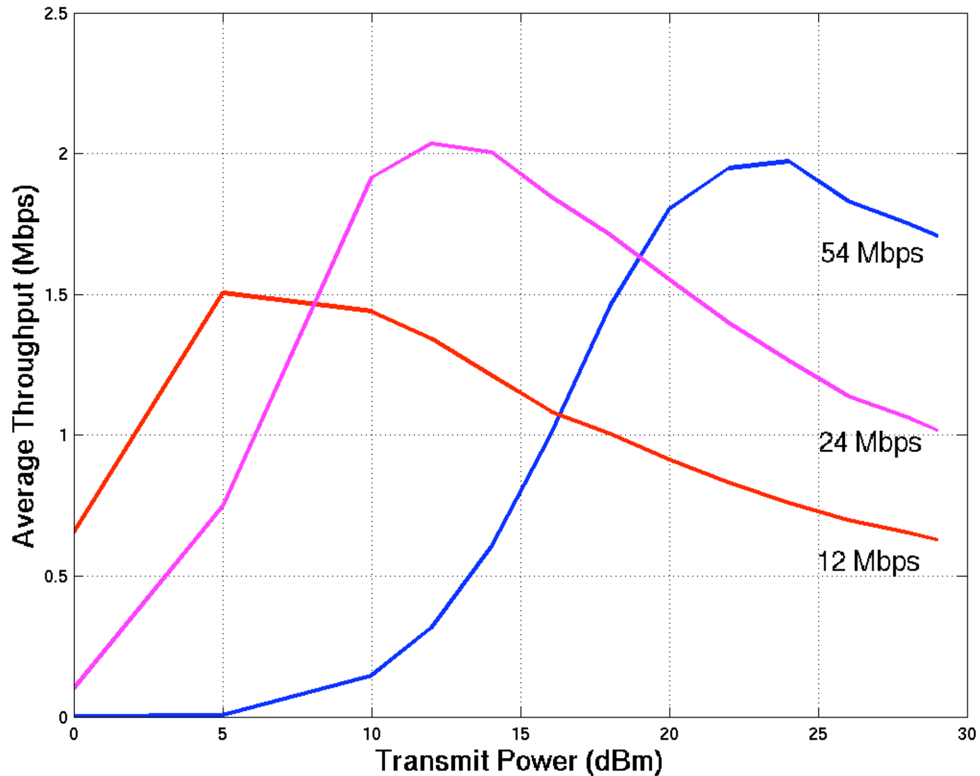
Throughput of a Linear Multihop Wireless Network



- **Wireless Channel Characteristics**
  - Path Loss (exponent _)
  - Fading
- **MAC Layer Parameters**
  - TDMA: Separation between nodes transmitting simultaneously
  - 802.11: Energy Detect Threshold
  - Slotted ALOHA: Probability of transmission in a time slot
- **Physical Layer**
  - Transmission Power
  - Data Rate
  - Receiver Performance
- **Network Characteristics**
  - Distance between nodes in the string
- **Traffic Patterns**
  - Saturated Traffic at each node
  - Traffic injected from one end of the string to the other

Effect of Transmission Power





_ = 4.1

d = 5 m

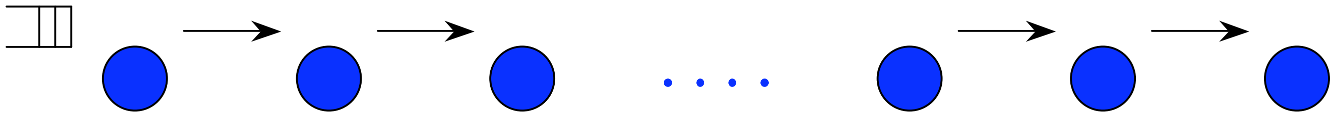
ED = -91 dBm

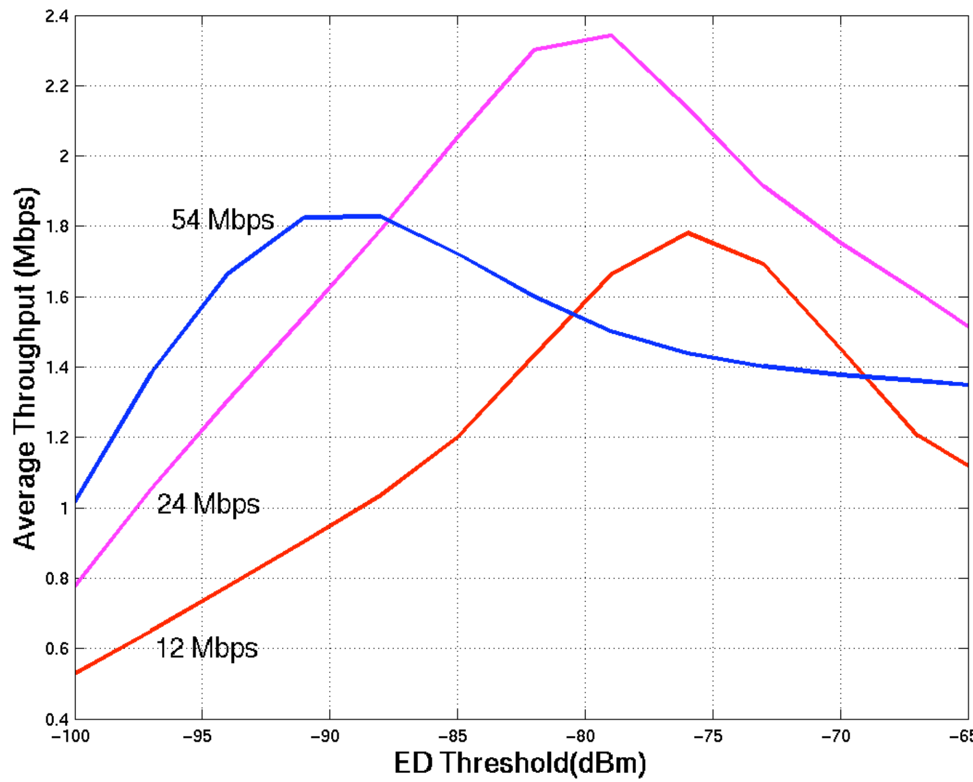
CS = -85 dBm

Decrease in performance on the link between a transmitter and a receiver

Decrease in the number of simultaneous transmissions due to excessive blocking

Effect of Energy Detect Threshold





_ = 4.1

d = 5 m

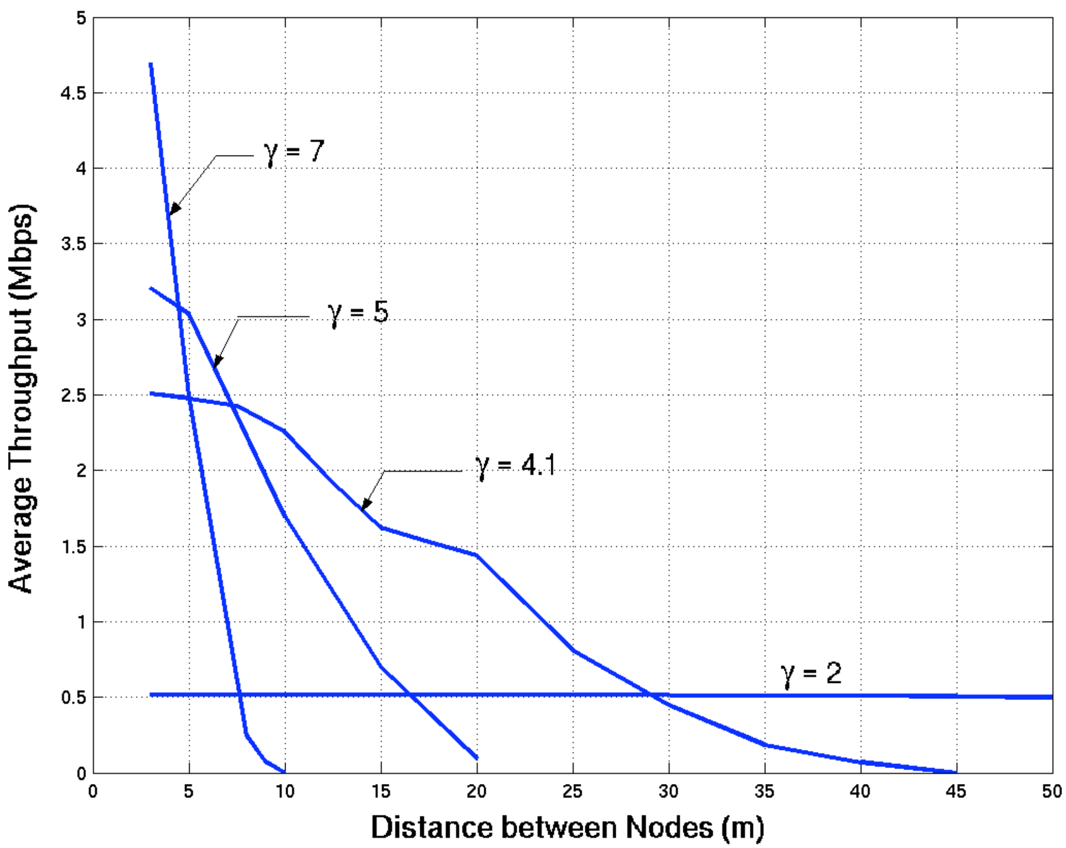
P_t = 20 dBm

CS = -85 dBm

Decrease in the number of simultaneous transmissions due to excessive blocking

Excessive interference due to increased number of simultaneous transmissions

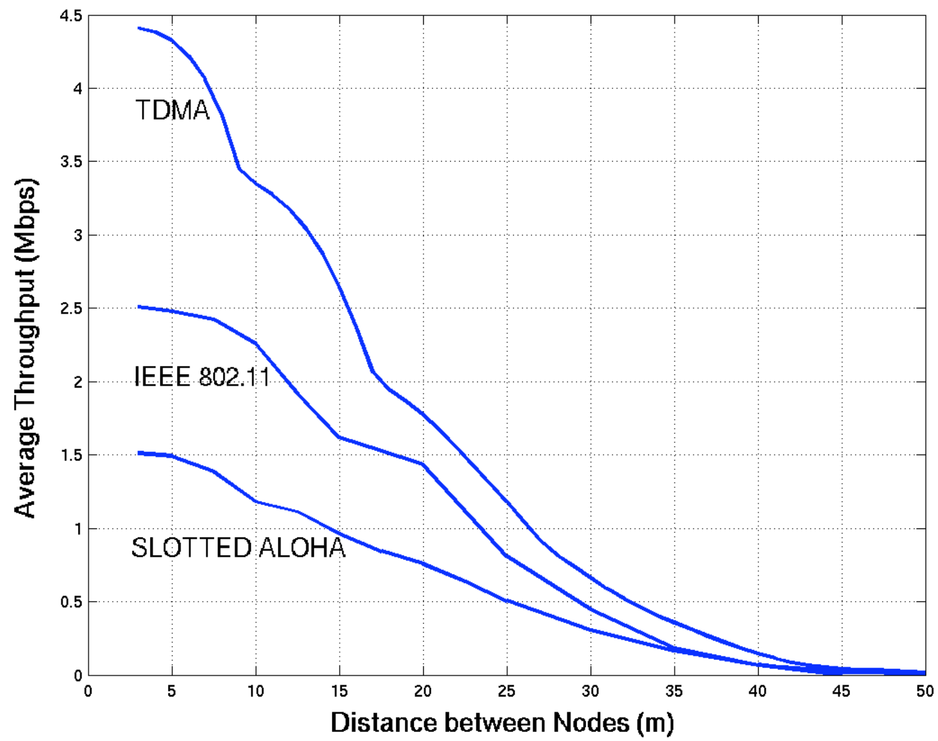
Effect of Path Loss



Throughput is optimized over transmission power, data rate, and energy detect threshold.

Transmission power is limited to a maximum as allowed by IEEE 802.11

Effect of MAC Scheme



_ = 4.1

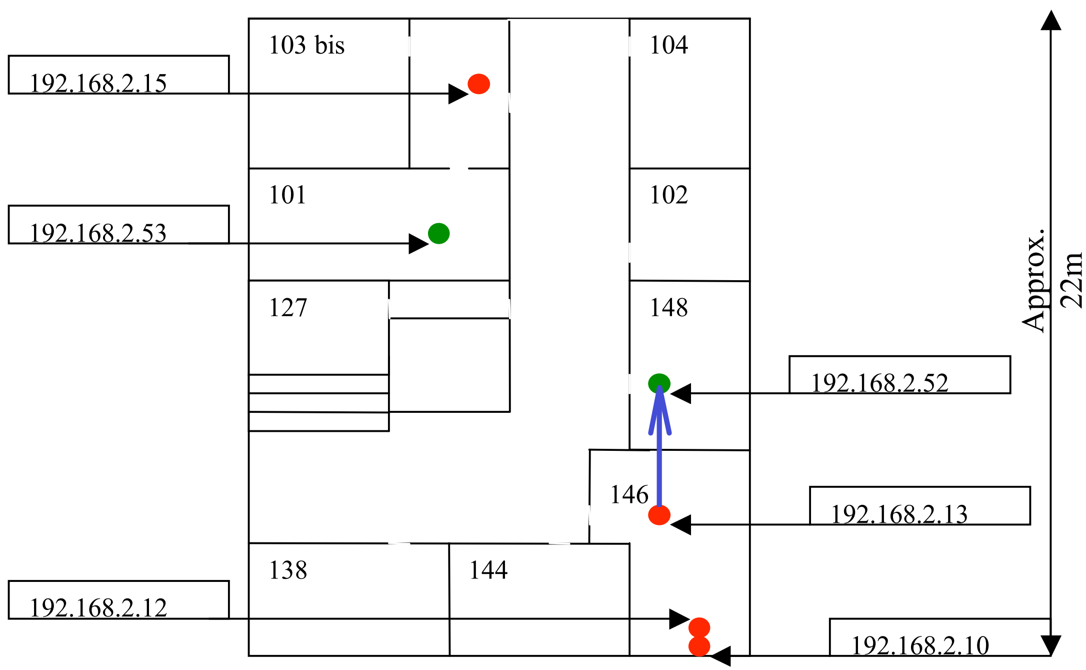
CSMA throughput is optimized over transmission power, data rate, and energy detect threshold.

TDMA throughput is optimized over the TDMA frame length

Slotted Aloha throughput is optimized over the rate of transmissions

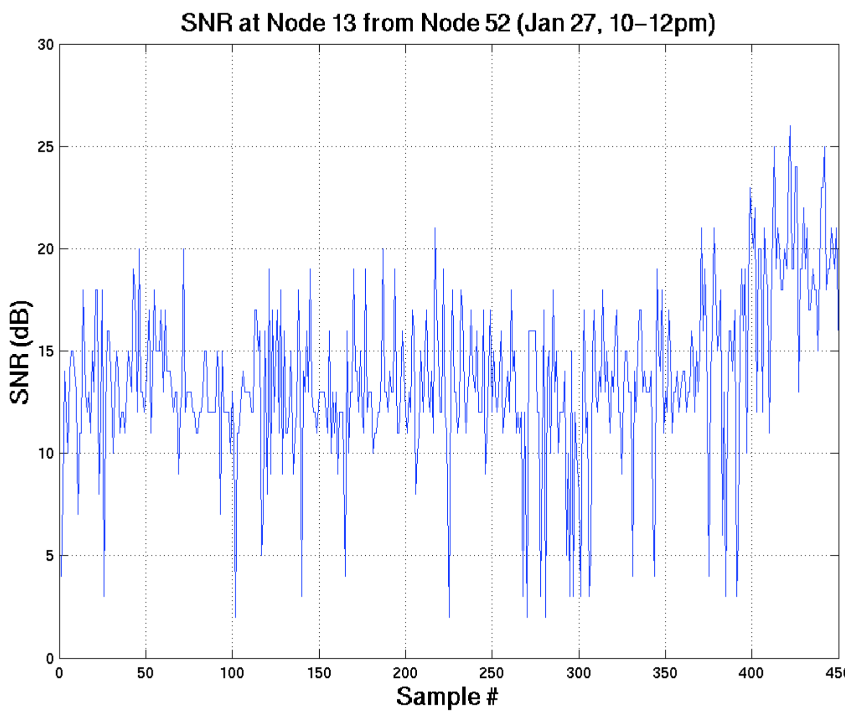
Impact of Channel Variability on Routing

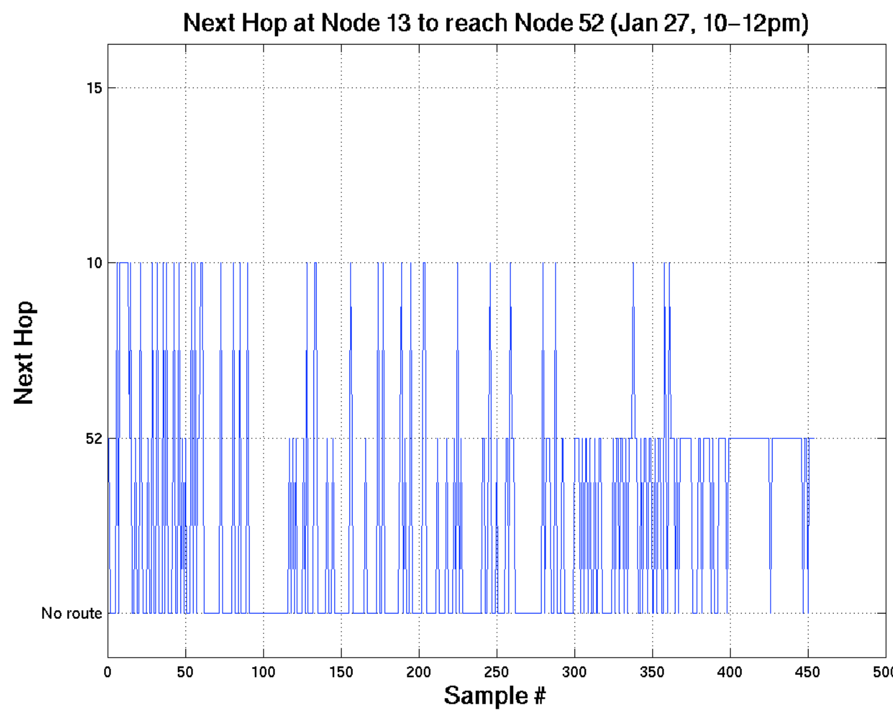
FTRD Lannion Testbed



- 10 nodes in office environment (only 6 shown above in partial map)
- Measurements of SNR on links and routing tables at each node for 24 hours with samples every 15 seconds

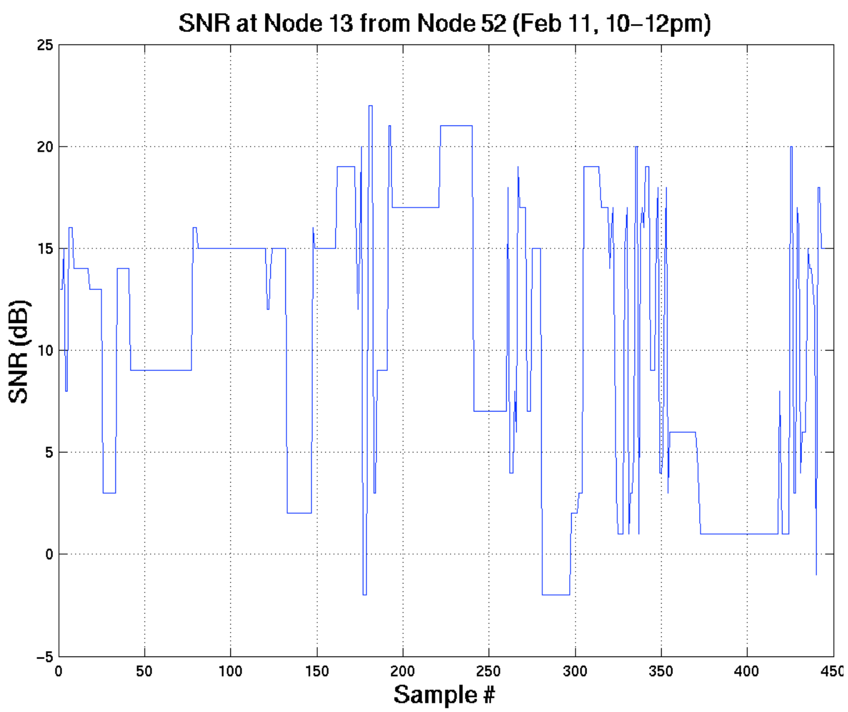
SNR Variation and Routing Oscillations

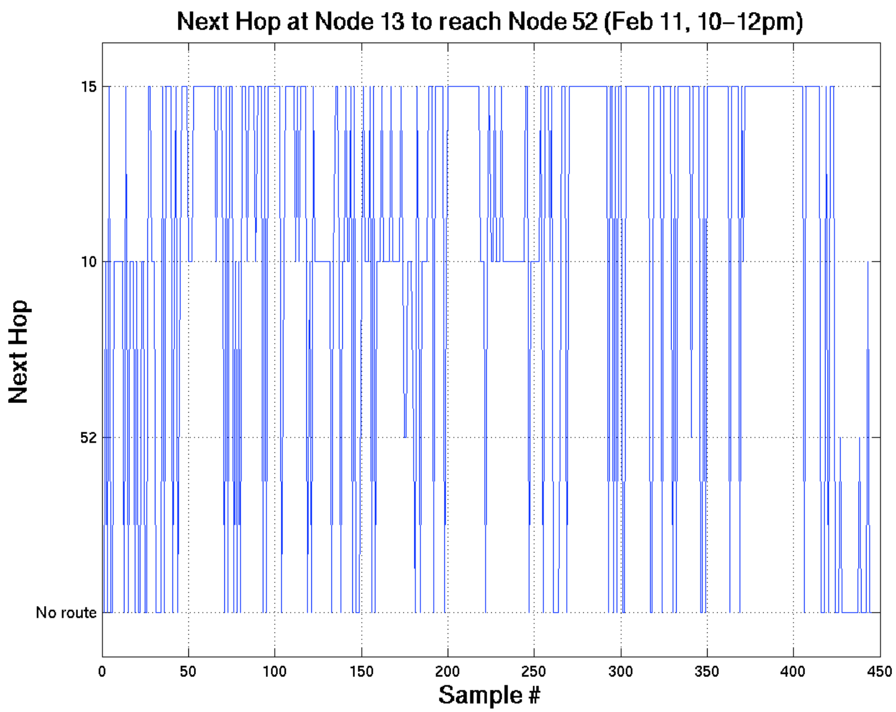




- With average SNR around 10-12 dB, the packet error rate is high
- Low SNR & variability of SNR result in change of routes from one sample to another– e.g. next hop at node 13 to reach 52 changes from sample to sample – 52, 10, 15 or no route

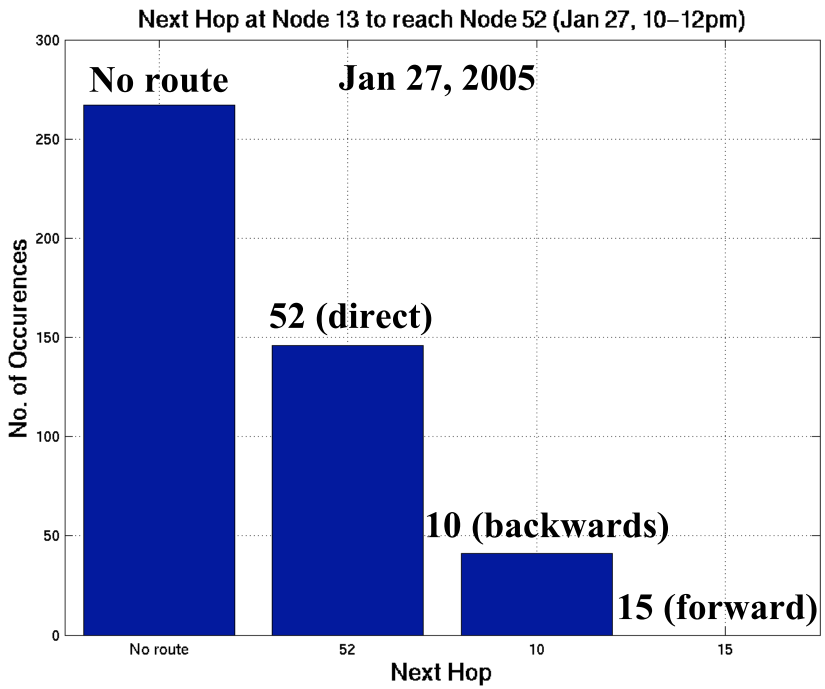
Same Destination on a Different Day

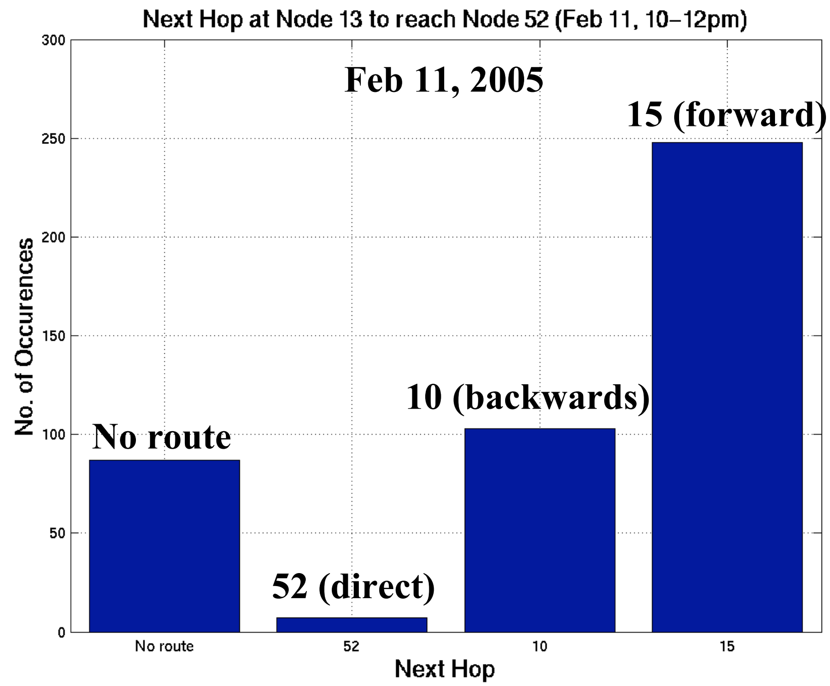




- Same time (10-12 pm) but on a different day (Feb 11 instead of Jan 27)
- Similar average SNR (8-10 dB), but bigger spread (-2 to 22 dB)
- Instead of oscillating between 52 and 10 (going backwards), it now oscillates between 10 (going backward) and 15 (going forward)

Challenges in Simulator Calibration





- Changes in environment result in very different distribution of routes on two different days
- Not practical to try to model exact variations
- More important to see similar variability in simulator, so that problems can be seen, and solutions can be tested via simulations
- What is the right level of modeling accuracy to say that undesirable behavior can be captured via simulations without testing ?

END