CS/ECE 439: Wireless Networking

MAC Layer – Multi-Rate

 Fall 2025

GRAINGER ENGINEERING

COMPUTER SCIENCE

What is "Data Rate" really?

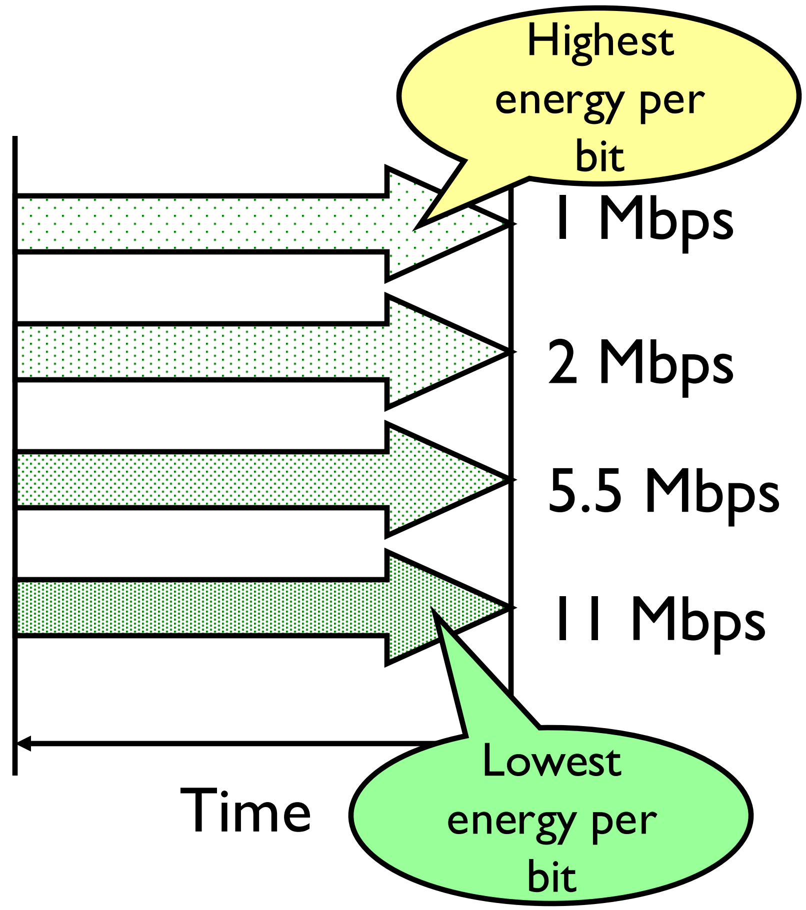
- Number of bits that you transmit per unit time
  - under a fixed energy budget

- Too many bits/s
  - Each bit has little energy -> Hi BER

- Too few bits/s
  - Less BER but lower throughput

802.11b – Transmission rates

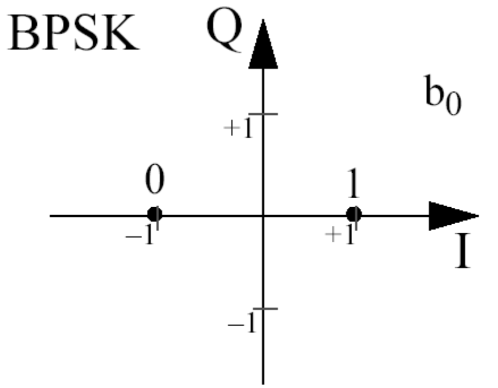
- Optimal rate depends on SINR
  - i.e., interference and current channel conditions

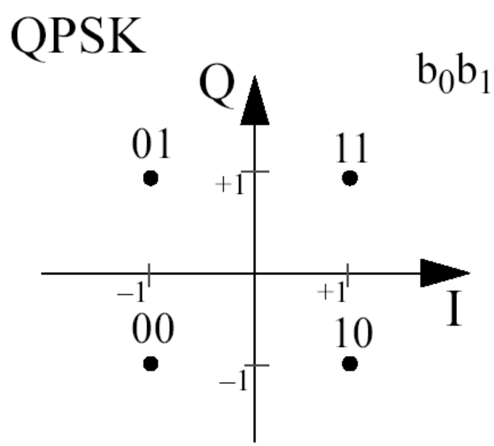


What is Multi-Rate?

- Ability of a wireless card to automatically operate at several different bit-rates
  - (e.g. 1, 2, 5.5, and 11 Mbps for 802.11b)
- Part of most existing wireless standards
- Virtually every wireless card in use today employs multi-rate

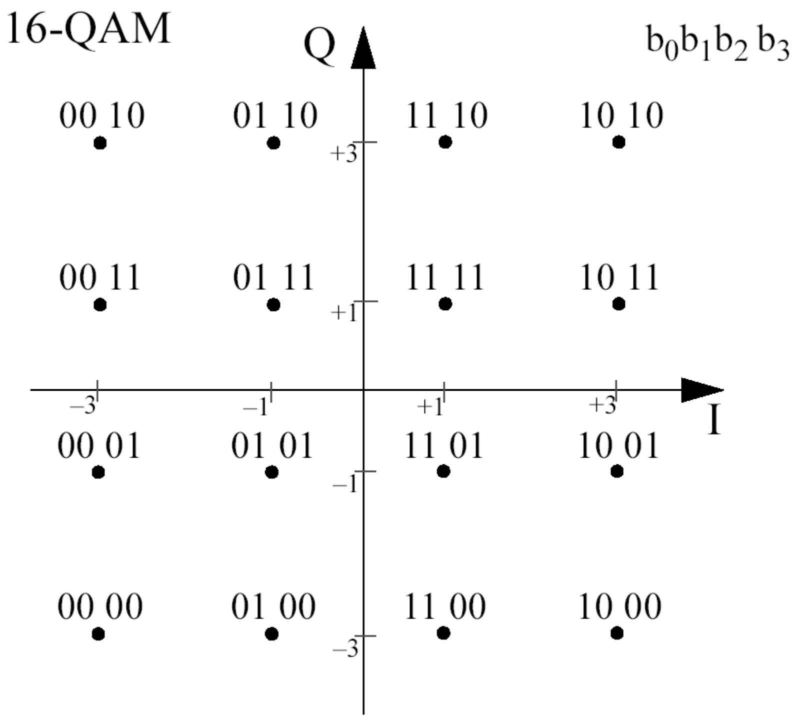
Example Carrier Modulations





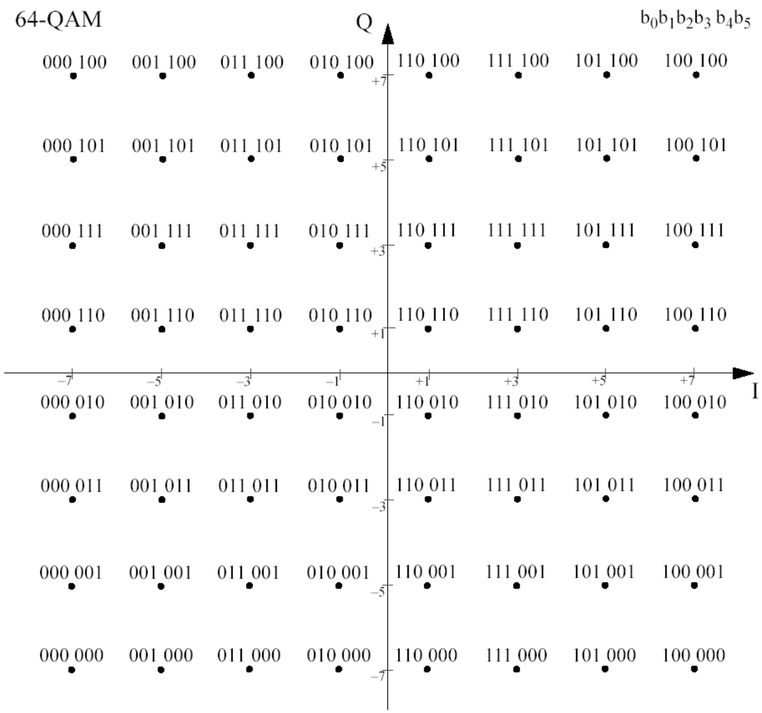
- Binary Phase Shift Keying
  - One bit per symbol
  - Made by the carrier and its inverse
- Quadrature Phase Shift Keying
  - Two bits per symbol
  - Uses quadrature carrier in addition to normal carrier
    - (90° phase shift of carrier)
  - 4 permutations for the inverse or not of the two carriers

Example Carrier Modulations (cont.)



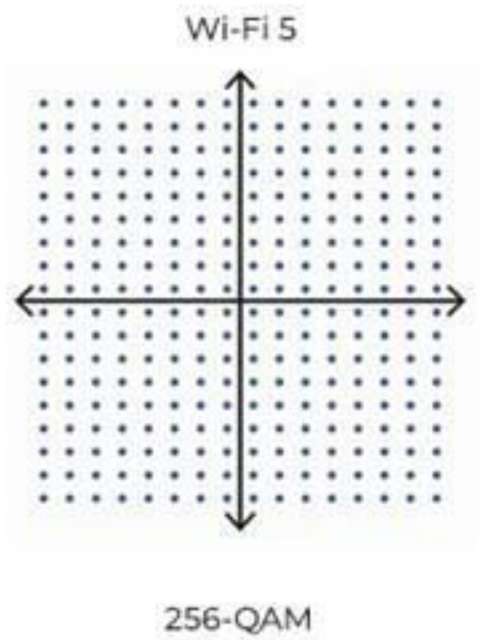
- 16 - Quadrature Amplitude Modulation
  - 4 bits per symbol
  - Also uses quadrature carrier
  - Each carrier is multiplied by +3, +1, -1, or -3
    - (amplitude modulation)
  - 16 possible combinations of the two multiplied carriers

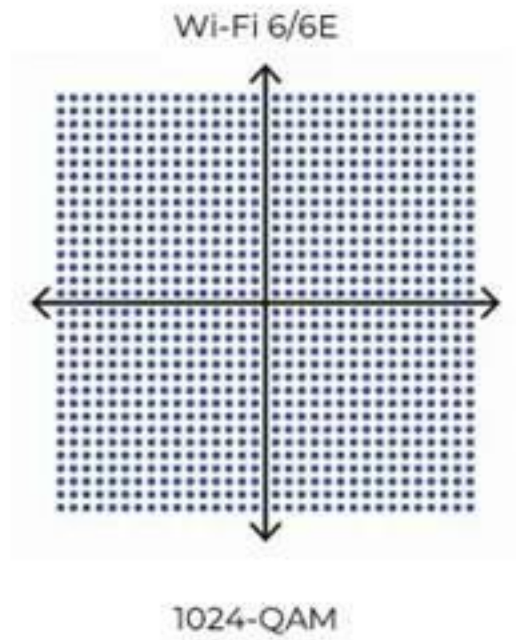
Example Carrier Modulations (cont.)

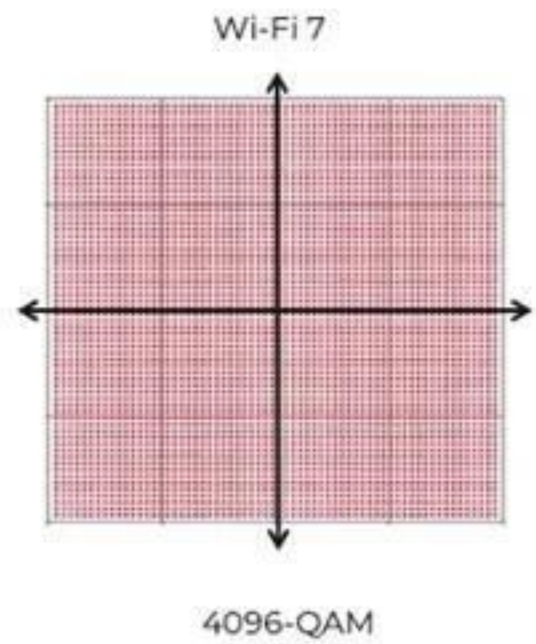


- **64 - Quadrature Amplitude Modulation**
  - 6 bits per symbol
  - Also uses quadrature carrier
  - Each carrier is multiplied by +7, +5, +3, +1, -1, -3, -5, or -7 (amplitude modulation)
  - 64 possible combinations of the two multiplied carriers

Example Carrier Modulations (cont.)







8 bits per symbol | 10 bits per symbol | 12 bits per symbol

802.11a Rates resulting from Carrier Modulation and Coding

Data rate (Mbits/s)	Modulation	Coding rate (R)	Coded bits per subcarrier (N_{BPSC})	Coded bits per OFDM symbol (N_{CBPS})	Data bits per OFDM symbol (N_{DBPS})
6	BPSK	1/2	1	48	24
9	BPSK	3/4	1	48	36
12	QPSK	1/2	2	96	48
18	QPSK	3/4	2	96	72
24	16-QAM	1/2	4	192	96
36	16-QAM	3/4	4	192	144
48	64-QAM	2/3	6	288	192
54	64-QAM	3/4	6	288	216

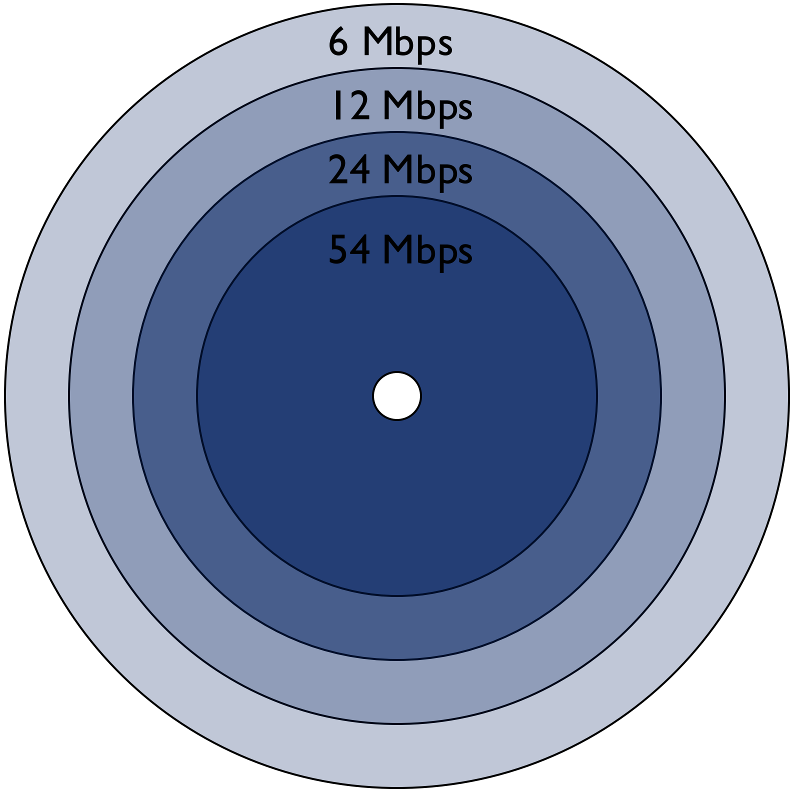
802.11ac Rates resulting from Carrier Modulation and Coding

MCS	Modulation	Bits per symbol	Coding Ratio	20 Mhz		40 Mhz		80 Mhz		160 Mhz	
				800 ns	400 ns	800 ns	400 ns	800 ns	400 ns	800 ns	400 ns
1 Spatial Stream				Data Rates(Mbps)							
MCS0	BPSK	1	½	6.5	7.2	13.5	15.0	29.3	32.5	58.5	65.0
MCS1	QPSK	2	½	13.0	14.4	27.0	30.0	58.5	65.0	117.0	130.0
MCS2	QPSK	2	¾	19.5	21.7	40.5	45.0	87.8	97.5	175.5	195.0
MCS3	16-QAM	4	½	26.0	28.9	54.0	60.0	117.0	130.0	234.0	260.0
MCS4	16-QAM	4	¾	39.0	43.3	81.0	90.0	175.5	195.0	351.0	390.0
MCS5	64-QAM	6	2/3	52.0	57.8	108.0	120.0	234.0	260.0	468.0	520.0
MCS6	64-QAM	6	¾	58.5	65.0	121.5	135.0	263.3	292.5	526.5	585.0
MCS7	64-QAM	6	5/6	65.0	72.2	135.0	150.0	292.5	325.0	585.0	650.0
MCS8	256-QAM	8	¾	78.0	86.7	162.0	180.0	351.0	390.0	702.0	780.0
MCS9	256-QAM	8	5/6	N/A	N/A	180.0	200.0	390.0	433.3	780.0	888.7
8 Spatial streams				Data Rates(Mbps)							
MCS0	BPSK	1	½	52.0	57.8	108.0	120.0	234.0	260.0	468.0	520.0
MCS1	QPSK	2	½	104.0	115.6	216.0	240.0	468.0	520.0	936.0	1040
MCS2	QPSK	2	¾	156.0	173.3	324.0	360.0	702.0	780.0	1404	1560
MCS3	16-QAM	4	½	208.0	231.1	432.0	480.0	936.0	1040	1872	2080
MCS4	16-QAM	4	¾	312.0	346.7	648.0	720.0	1404	1560	2808	3120
MCS5	64-QAM	6	2/3	416.0	482.2	884.0	960.0	1872	2080	3744	4160
MCS6	64-QAM	6	¾	468.0	520.0	972.0	1080	1200	2340	4120	4680
MCS7	64-QAM	6	5/6	520	577.8	1080	1200	2340	2600	4680	5200
MCS8	256-QAM	8	¾	624.0	693.3	1296	1440	2808	3120	5616	6240
MCS9	256-QAM	8	5/6	N/A	N/A	1440	1600	3120	3466	6240	6933

802.11ax Rates resulting from Carrier Modulation and Coding

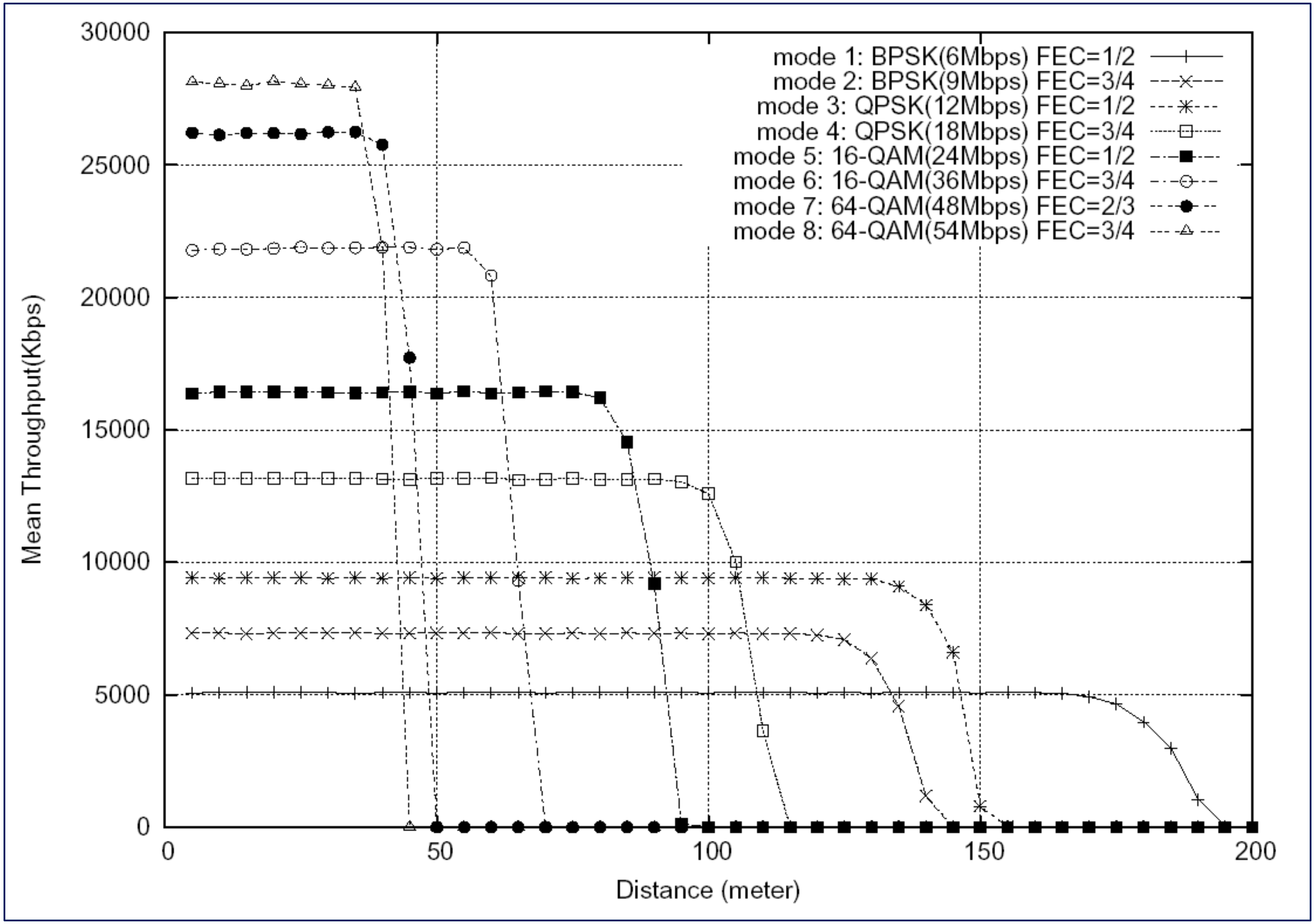
MCS Index	Spatial Stream	Modulation	Coding	OFDM (802.11ax)											
				20MHz			40MHz			80MHz			160MHz		
				0.8µs GI	1.6µs GI	3.2µs GI	0.8µs GI	1.6µs GI	3.2µs GI	0.8µs GI	1.6µs GI	3.2µs GI	0.8µs GI	1.6µs GI	3.2µs GI
0	1	BPSQ	1/2	8.6	8.1	7.3	17.2	16.3	14.6	36.0	34.0	30.6	72.1	68.1	61.3
1	1	QPSK	1/2	17.2	16.3	14.6	34.4	32.5	29.3	72.1	68.1	61.3	144.1	136.1	122.5
2	1	QPSK	3/4	25.8	24.4	21.9	51.6	48.8	43.9	108.1	102.1	91.9	216.2	204.2	183.8
3	1	16-QAM	1/2	34.4	32.5	29.3	68.8	65.0	58.5	144.1	136.1	122.5	288.2	272.2	245.0
4	1	16-QAM	3/4	51.6	48.8	43.9	103.2	97.5	87.8	216.2	204.2	183.8	432.4	408.3	367.5
5	1	64-QAM	2/3	68.8	65.0	58.5	137.6	130.0	117.0	288.2	272.2	245.0	576.5	544.4	490.0
6	1	64-QAM	3/4	77.4	73.1	65.8	154.9	146.3	131.6	324.3	306.3	275.6	648.5	612.5	551.3
7	1	64-QAM	5/6	86.0	81.3	73.1	172.1	162.5	146.3	360.3	340.3	306.3	720.6	680.6	612.5
8	1	256-QAM	3/4	103.2	97.5	87.8	206.5	195.0	175.5	432.4	408.3	367.5	864.7	816.7	735.0
9	1	256-QAM	5/6	114.7	108.3	97.5	229.4	216.7	195.0	480.4	453.7	408.3	960.8	907.4	816.7
10	1	1024-QAM	3/4	129.0	121.9	109.7	258.1	243.8	219.4	540.4	510.4	459.4	1080.9	1020.8	918.8
11	1	1024-QAM	5/6	143.4	135.4	121.9	286.8	270.8	243.8	600.5	567.1	510.4	1201.0	1134.3	1020.8
0	2	BPSQ	1/2	17.2	16.3	14.6	34.4	32.5	29.3	72.1	68.1	61.3	144.1	136.1	122.5
1	2	QPSK	1/2	34.4	32.5	29.3	68.8	65.0	58.5	144.1	136.1	122.5	288.2	272.2	245.0
2	2	QPSK	3/4	51.6	48.8	43.9	103.2	97.5	87.8	216.2	204.2	183.8	432.4	408.3	367.5
3	2	16-QAM	1/2	68.8	65.0	58.5	137.6	130.0	117.0	288.2	272.2	245.0	576.5	544.4	490.0
4	2	16-QAM	3/4	103.2	97.5	87.8	206.5	195.0	175.5	432.4	408.3	367.5	864.7	816.7	735.0
5	2	64-QAM	2/3	137.6	130.0	117.0	275.3	260.0	234.0	576.5	544.4	490.0	1152.9	1088.9	980.0
6	2	64-QAM	3/4	154.9	146.3	131.6	309.7	292.5	263.3	648.5	612.5	551.3	1297.1	1225.0	1102.5
7	2	64-QAM	5/6	172.1	162.5	146.3	344.1	325.0	292.5	720.6	680.6	612.5	1441.2	1361.1	1225.0
8	2	256-QAM	3/4	206.5	195.0	175.5	412.9	390.0	351.0	864.7	816.7	735.0	1729.4	1633.3	1470.0
9	2	256-QAM	5/6	229.4	216.7	195.0	458.8	433.3	390.0	960.8	907.4	816.7	1921.6	1814.8	1633.3
10	2	1024-QAM	3/4	258.1	243.8	219.4	516.2	487.5	438.8	1080.9	1020.8	918.8	2161.8	2041.7	1837.5
11	2	1024-QAM	5/6	286.8	270.8	243.8	573.5	541.7	487.5	1201.0	1134.3	1020.8	2402.0	2268.5	2041.7
0	3	BPSQ	1/2	25.8	24.4	21.9	51.6	48.8	43.9	108.1	102.1	91.9	216.2	204.2	183.8
1	3	QPSK	1/2	51.6	48.8	43.9	103.2	97.5	87.8	216.2	204.2	183.8	432.4	408.3	367.5
2	3	QPSK	3/4	77.4	73.1	65.8	154.9	146.3	131.6	324.3	306.3	275.6	648.5	612.5	551.3
3	3	16-QAM	1/2	103.2	97.5	87.8	206.5	195.0	175.5	432.4	408.3	367.5	864.7	816.7	735.0
4	3	16-QAM	3/4	154.9	146.3	131.6	309.7	292.5	263.3	648.5	612.5	551.3	1297.1	1225.0	1102.5
5	3	64-QAM	2/3	206.5	195.0	175.5	412.9	390.0	351.0	864.7	816.7	735.0	1729.4	1633.3	1470.0
6	3	64-QAM	3/4	232.3	219.4	197.4	464.6	438.8	394.9	972.8	918.8	826.9	1945.6	1837.5	1653.8
7	3	64-QAM	5/6	258.1	243.8	219.4	516.2	487.5	438.8	1080.9	1020.8	918.8	2161.8	2041.7	1837.5
8	3	256-QAM	3/4	309.7	292.5	263.3	619.4	585.0	526.5	1297.1	1225.0	1102.5	2594.1	2450.0	2205.0
9	3	256-QAM	5/6	344.1	325.0	292.5	688.2	650.0	585.0	1441.2	1361.1	1225.0	2882.4	2722.2	2450.0
10	3	1024-QAM	3/4	387.1	365.6	329.1	774.3	731.3	658.1	1621.3	1531.3	1378.1	3242.6	3062.5	2756.3
11	3	1024-QAM	5/6	430.1	406.3	365.6	860.3	812.5	731.3	1801.5	1701.4	1531.3	3602.9	3402.8	3062.5

Advantage of Multi-Rate?

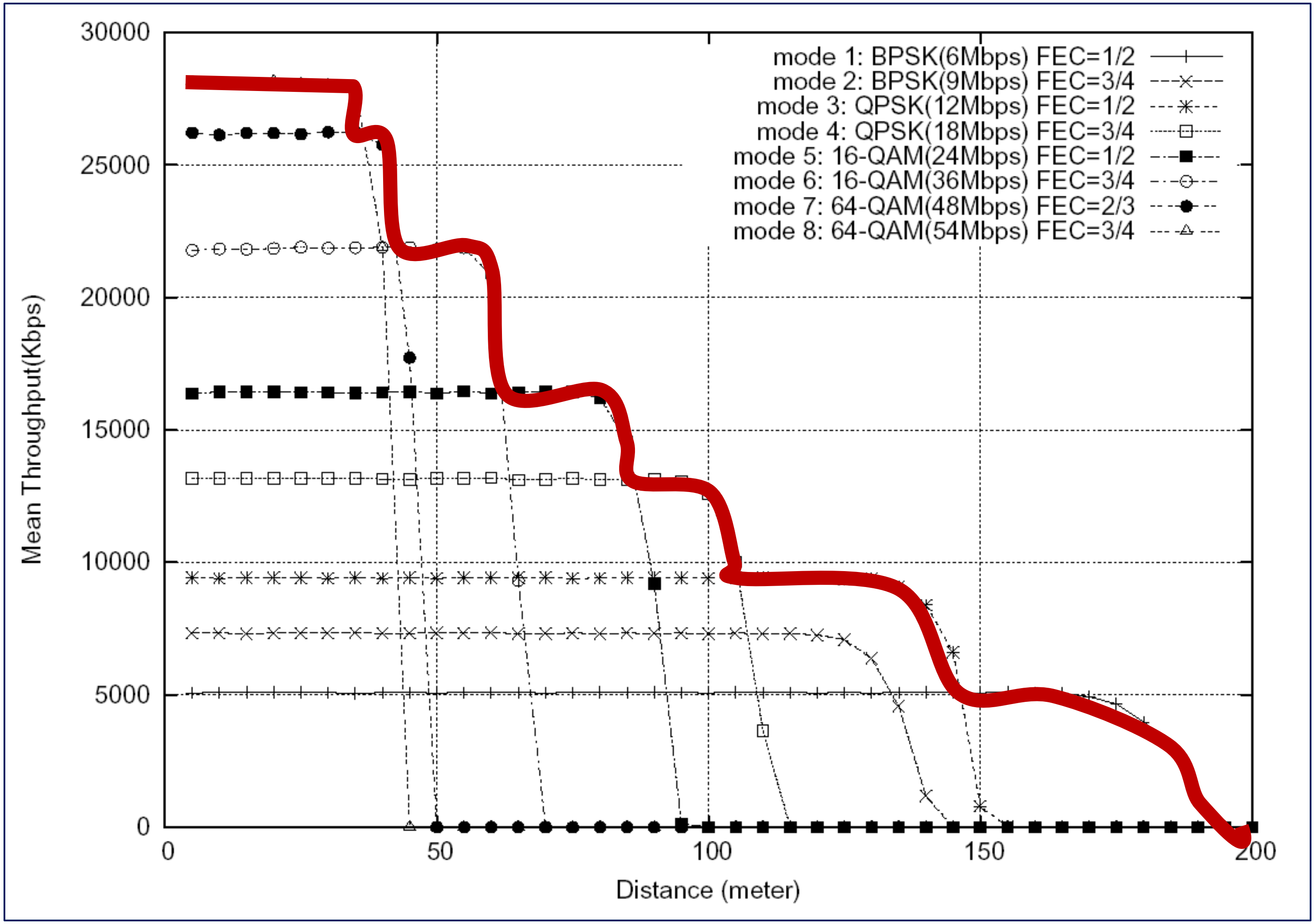


- Direct relationship between communication rate and the channel quality required for that rate
- As distance increases, channel quality decreases
  - Tradeoff between communication range and link speed
- Multi-rate provides flexibility to meet both consumer demands

Throughput vs. Distance for 802.11a

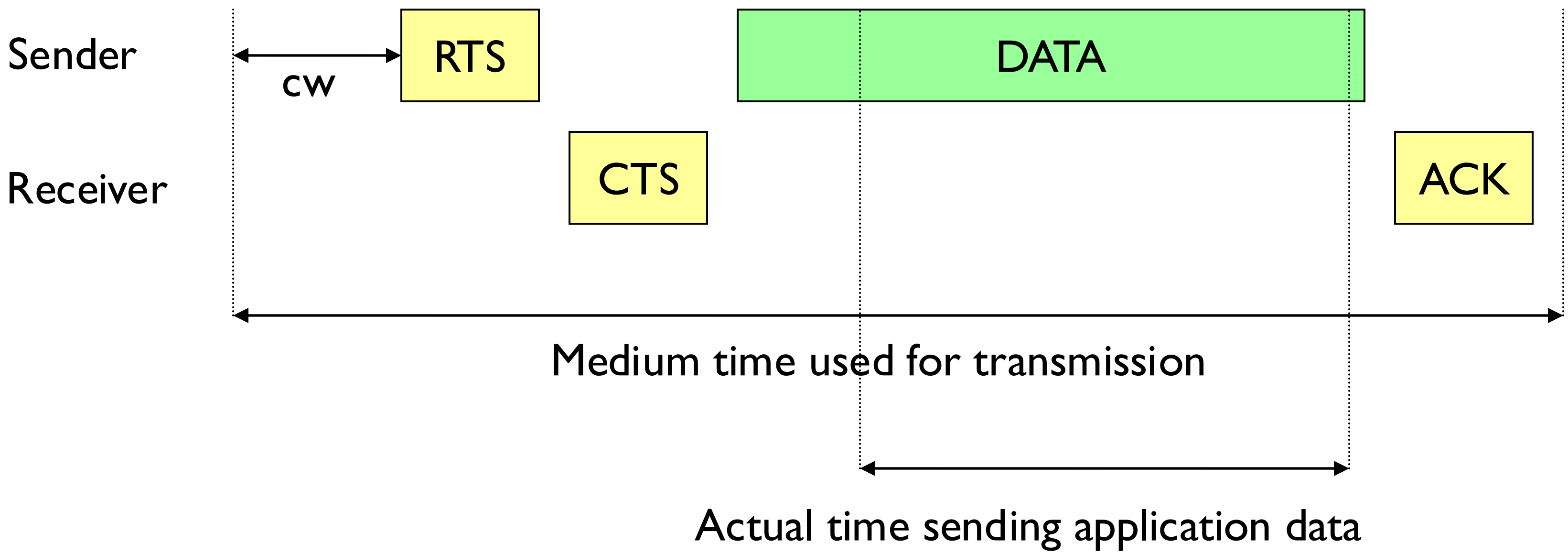


Throughput vs. Distance for 802.11a

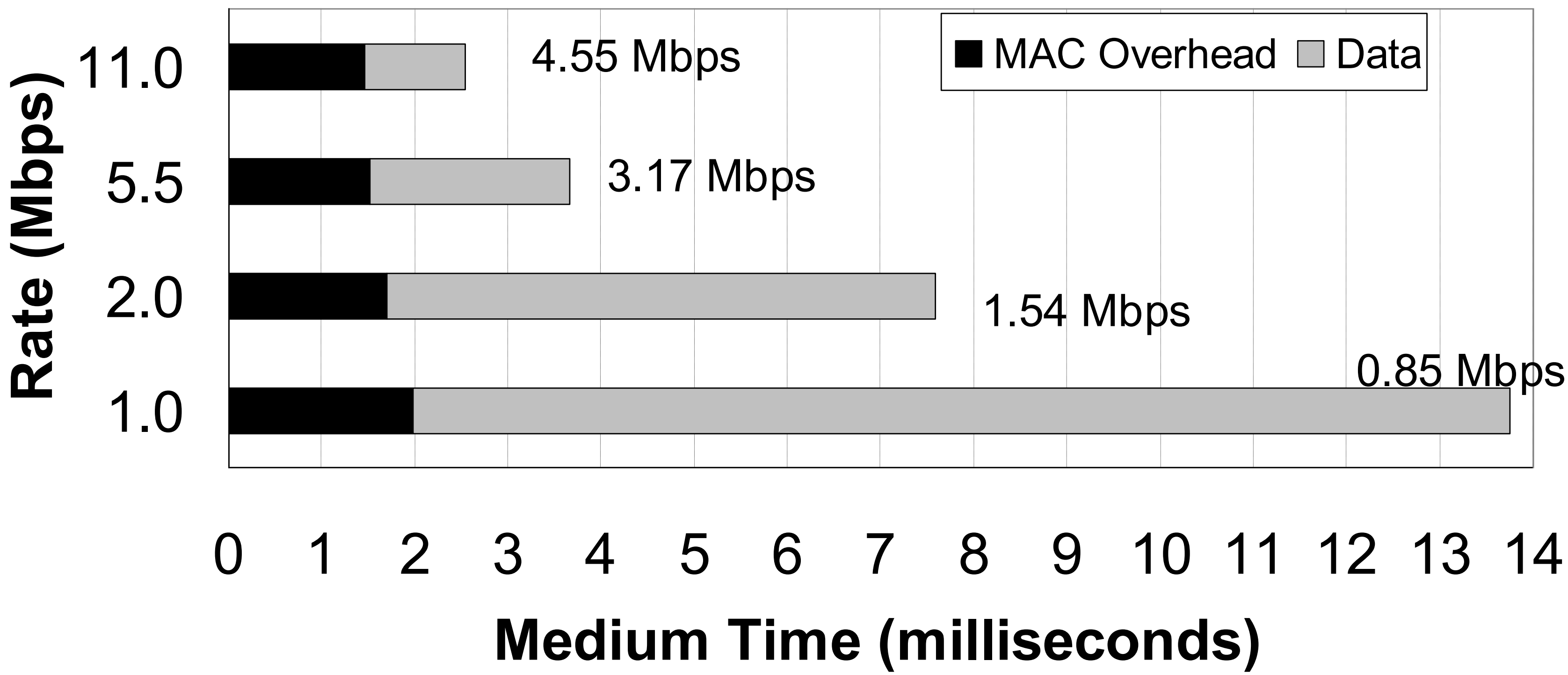


802.11 Frame Exchange Overhead

- Not all time is spent sending actual data



802.11b Frame Exchange Duration



Medium Time consumed to transmit 1500 byte packet

Multi-rate Frame in 802.11b

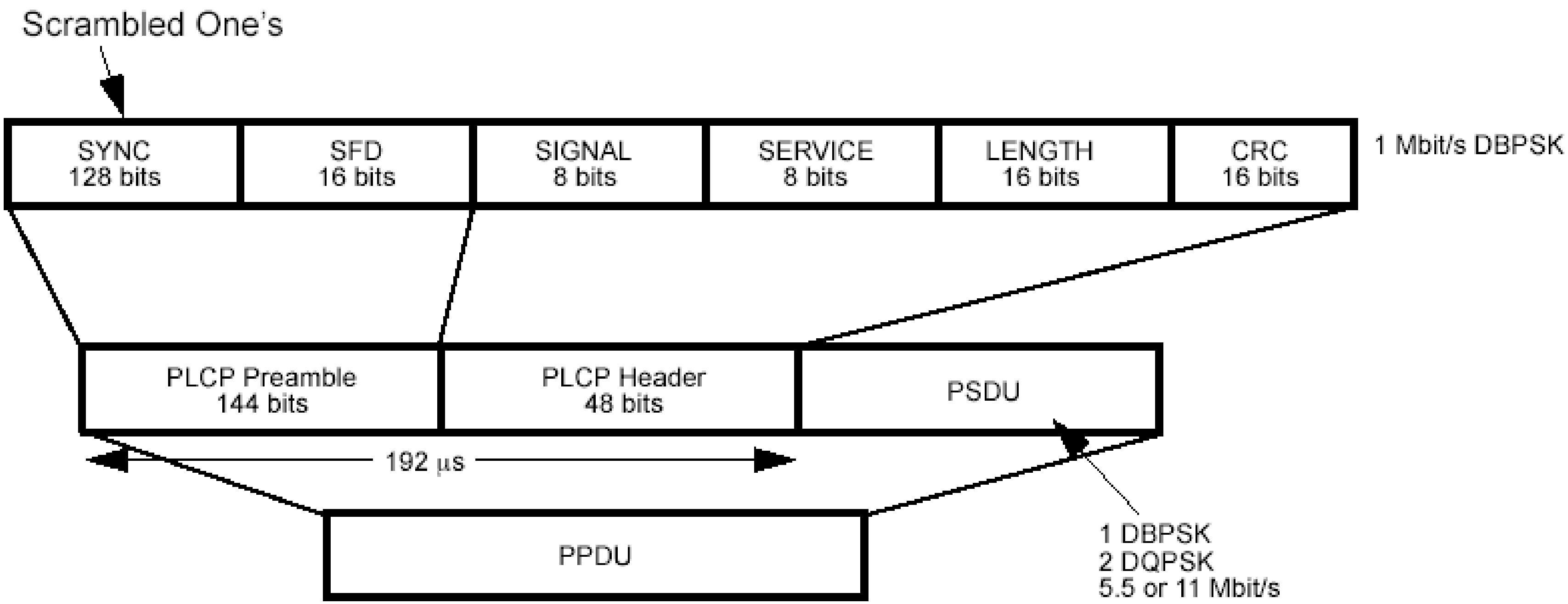
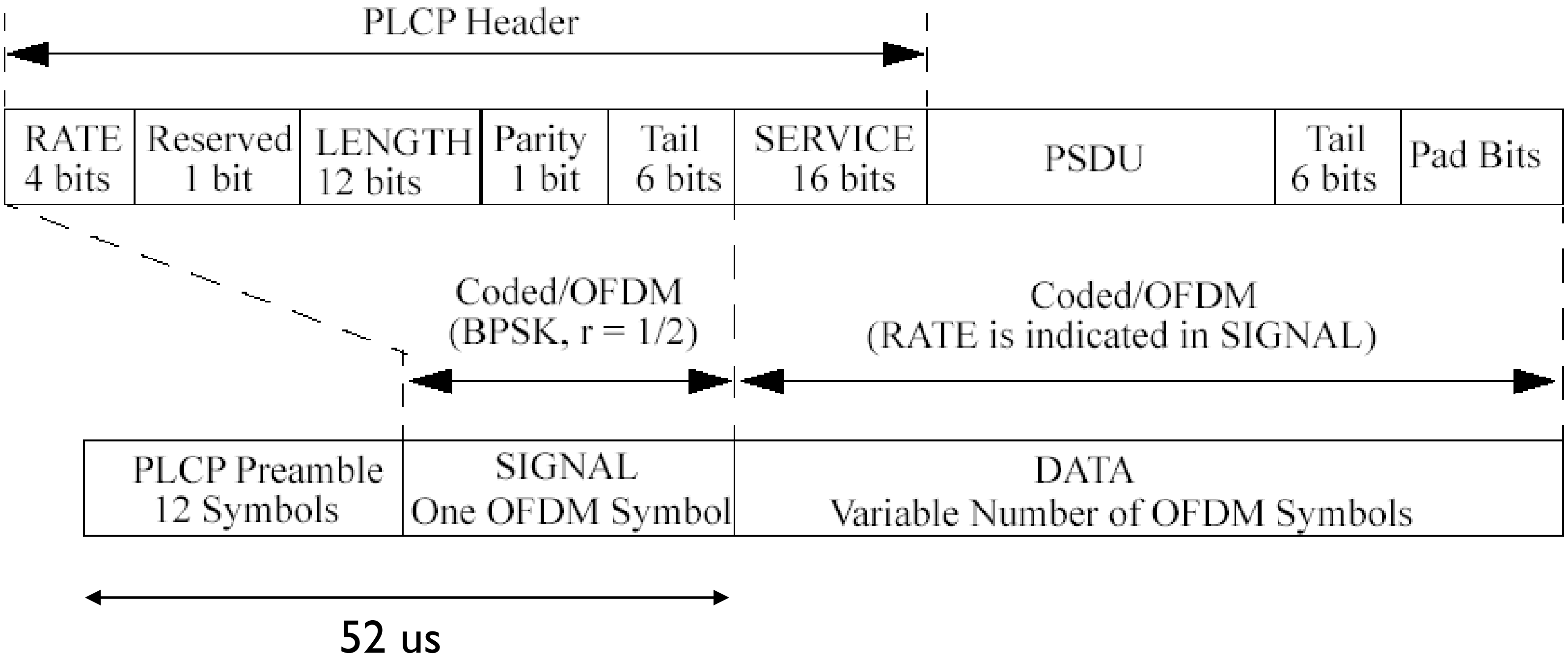
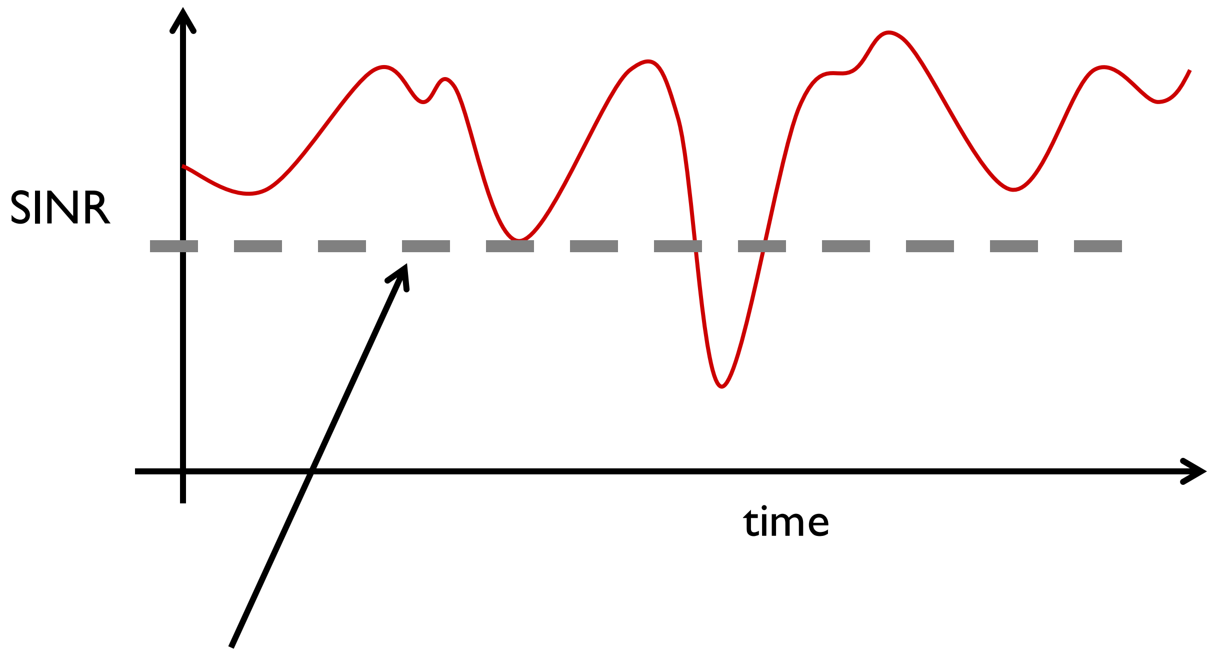


Figure 127—Long PLCP PPDU format

Multi-rate Frame in 802.11a

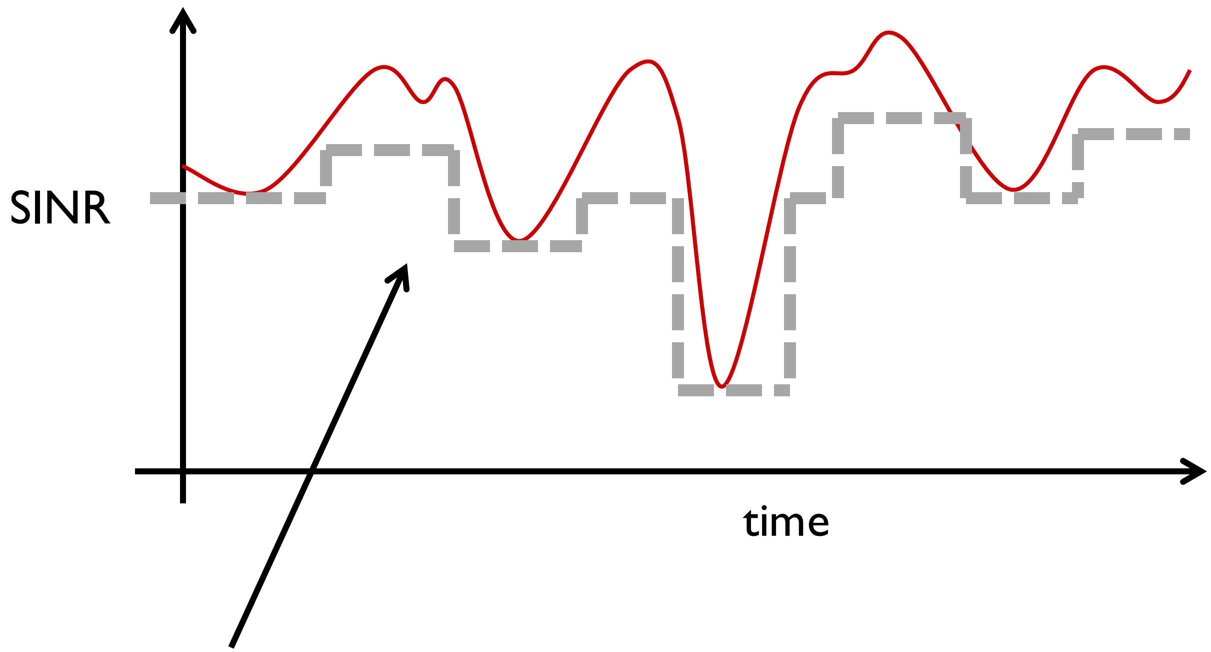


How do we choose modulation rates?



- Estimate a value of SINR
- Choose a corresponding rate that would transmit packets correctly most of the times
- Failure in some cases of fading
  - Live with it

Adaptive Rate-Control



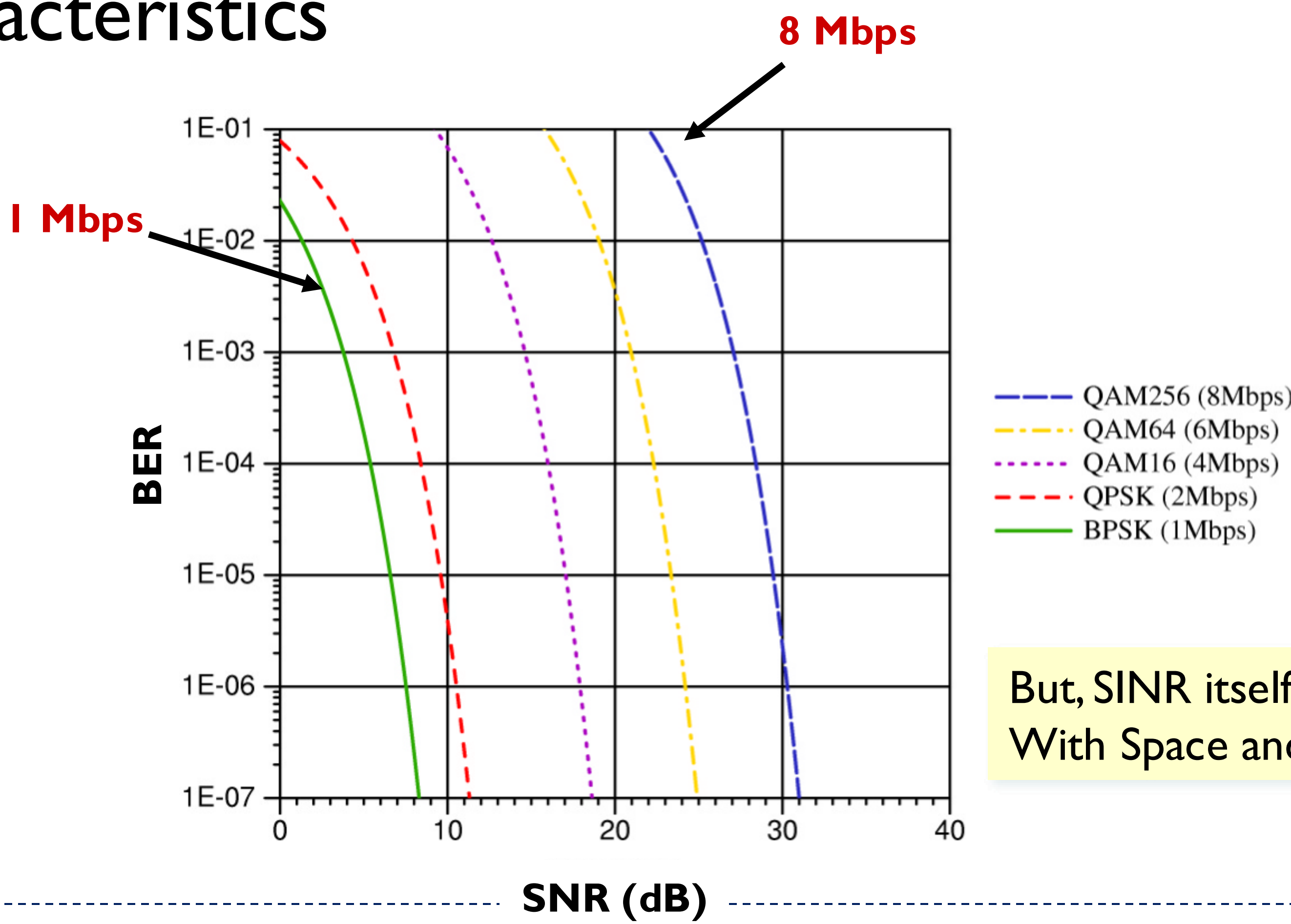
- Observe the current value of SINR
  - Use as indicator of near-future value
- Choose corresponding rate of modulation
- Repeat
  - Controls rate if channel conditions have changed

Seems simple, but …

- Rate control has variety of implications
  - Any single MAC protocol solves part of the puzzle
- Important to understand e2e implications
  - Does routing protocols get affected?
  - Does TCP get affected?
  - …
- Good to make a start at the MAC layer
  - ARF
  - RBAR
  - OAR
  - …

Problem

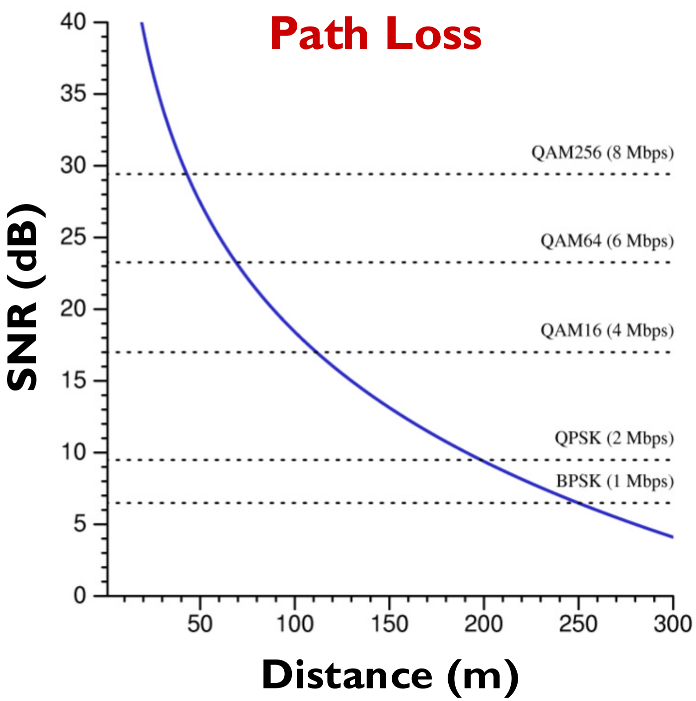
- Modulation schemes have different error characteristics

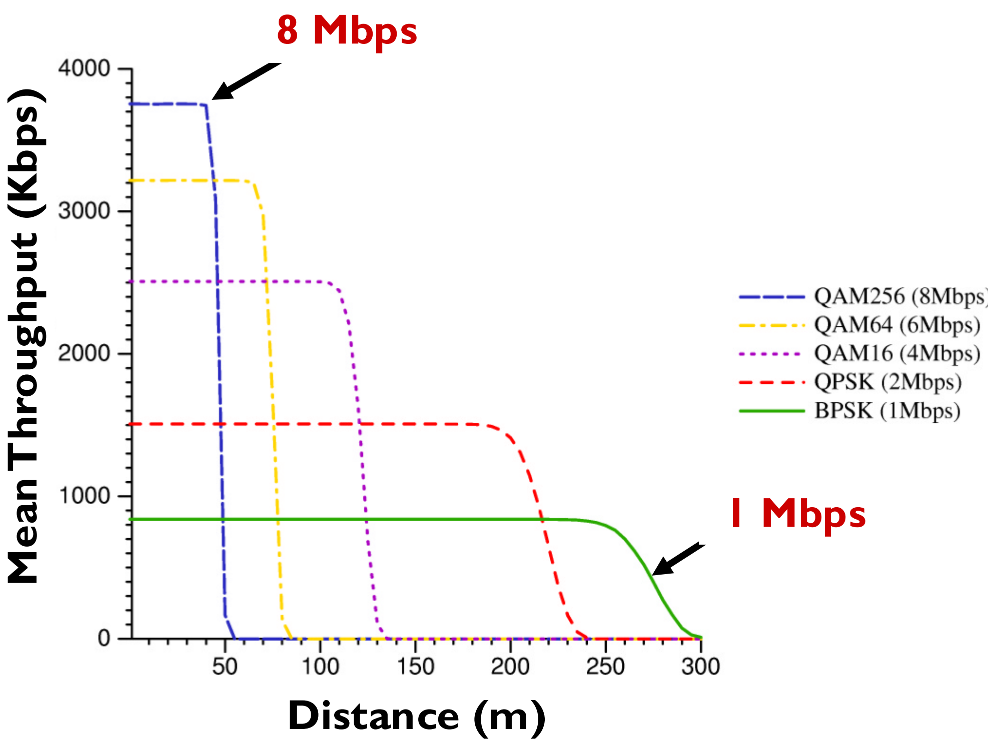


But, SINR itself varies With Space and Time

Impact

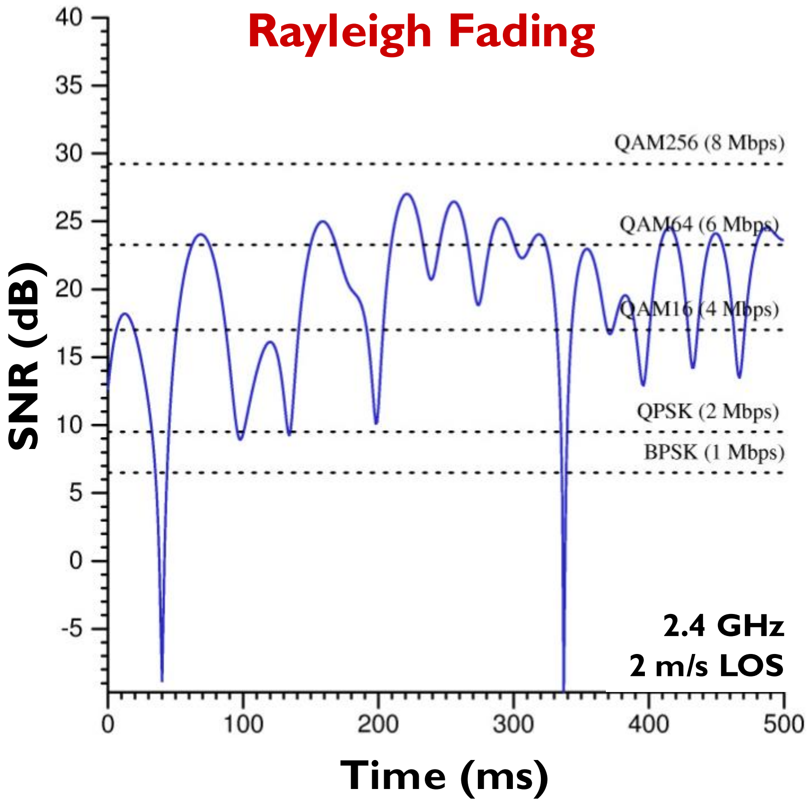
- Large-scale variation with distance (Path loss)



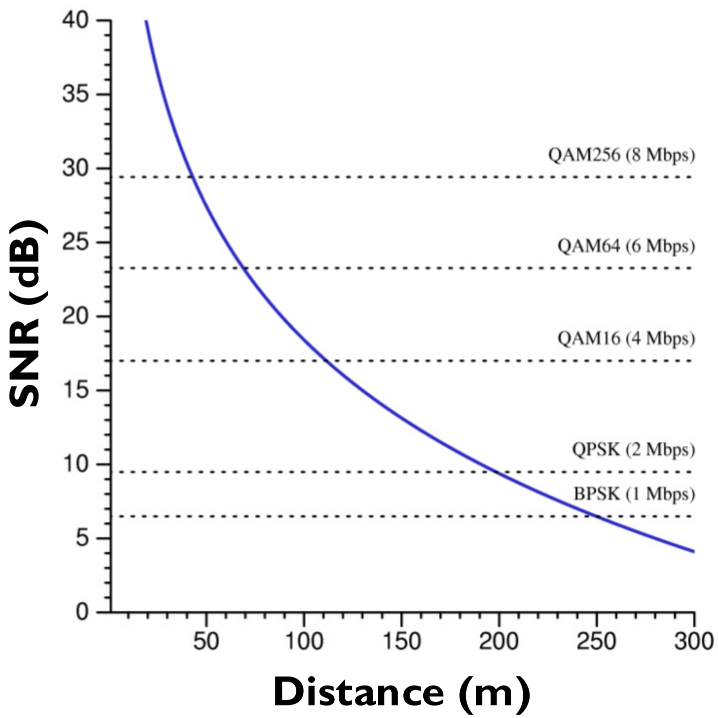


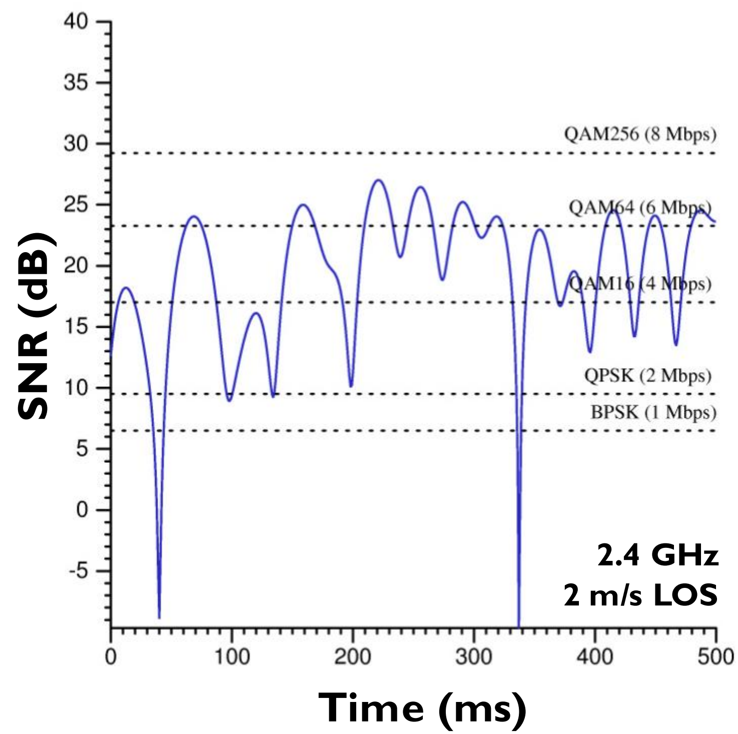
Impact

- Small-scale variation with time (Fading)



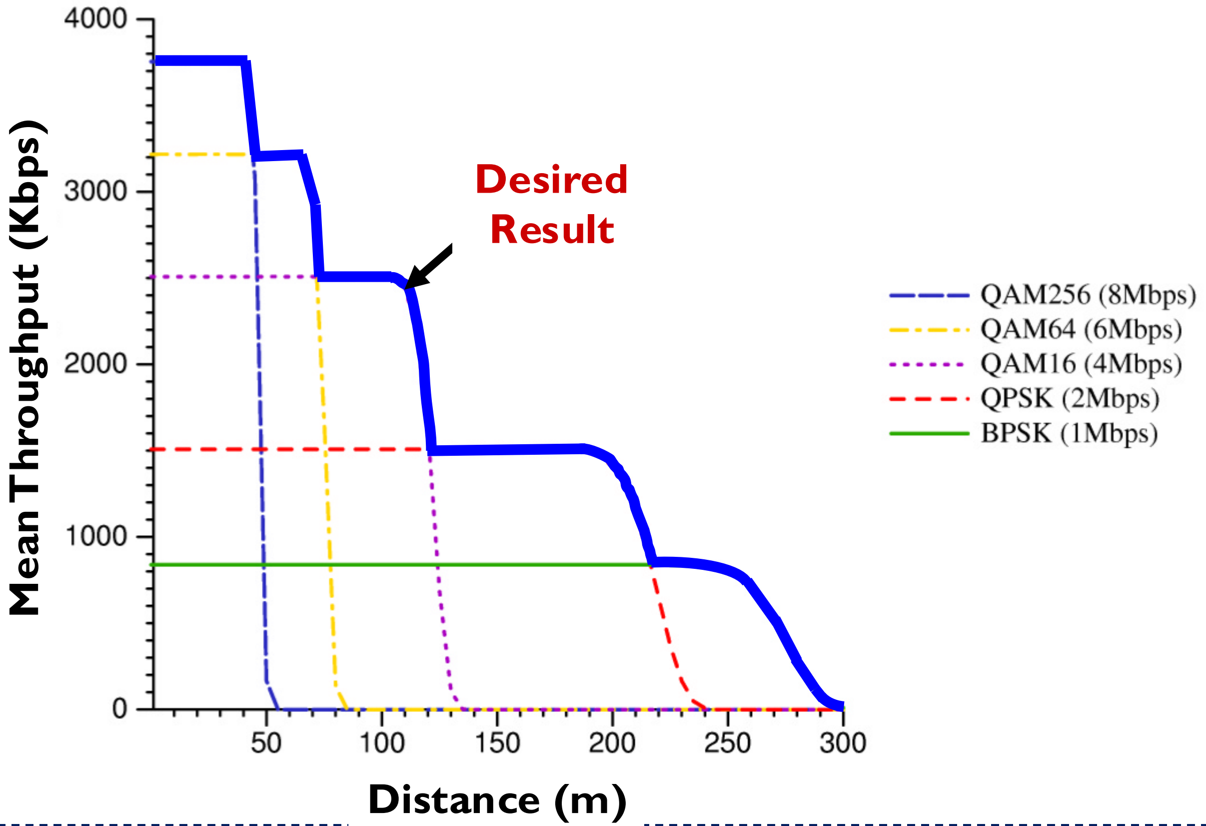
Which modulation scheme is best?





Answer → Rate Adaptation

- Dynamically choose the best modulation scheme for the channel conditions



Design Issues

- How frequently should we adapt the rate?
  - Signal can vary rapidly depending on
    - carrier frequency
    - node speed
    - interference
    - etc.
- For conventional hardware at pedestrian speeds, rate adaptation is feasible on a per-packet basis

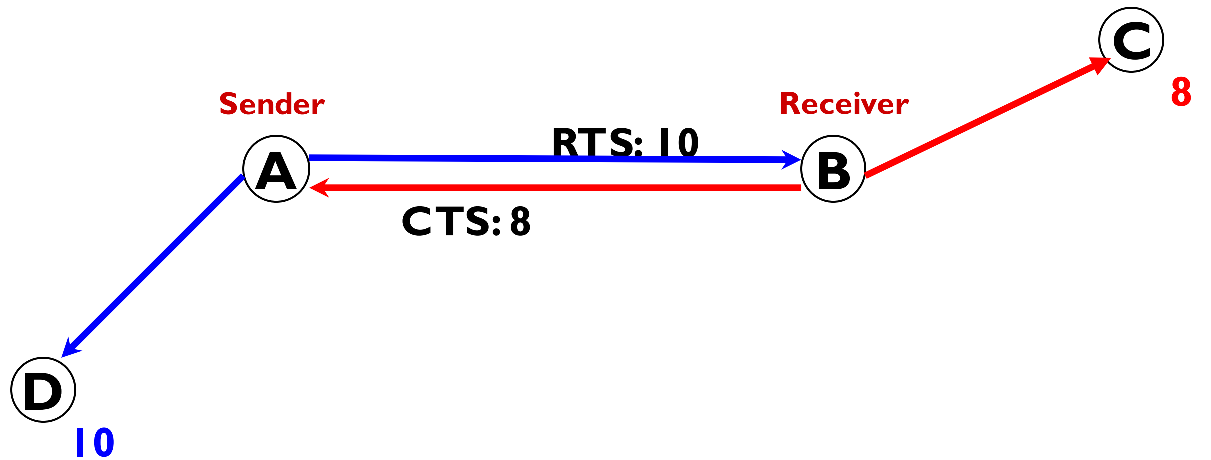
Adaptation → At Which Layer ?

- Cellular networks
  - Adaptation at the physical layer
- Impractical for 802.11 in WLANs ← Why?

Adaptation → At Which Layer ?

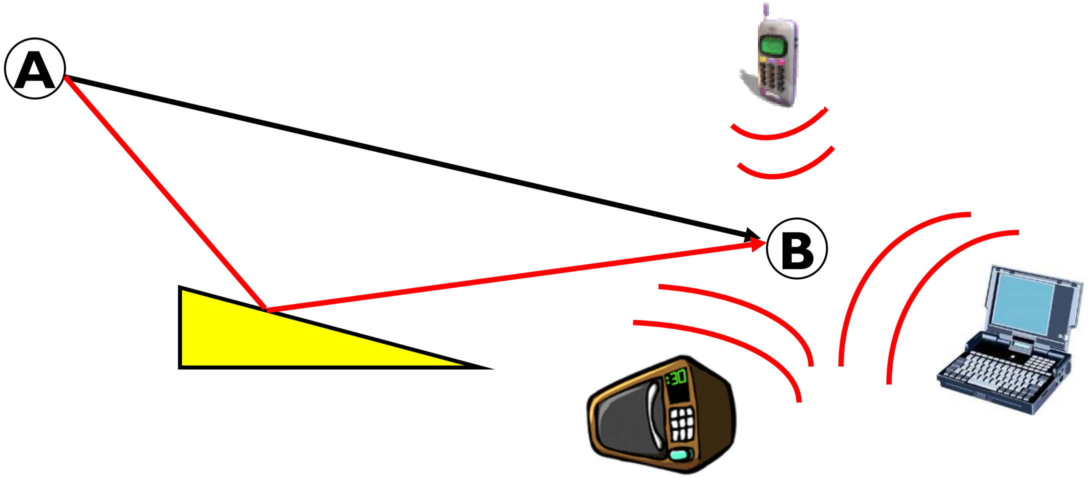
- Cellular networks
  - Adaptation at the physical layer
- Impractical for legacy 802.11 in WLANs ← Why?

RTS/CTS requires that the *rate be known in advance*



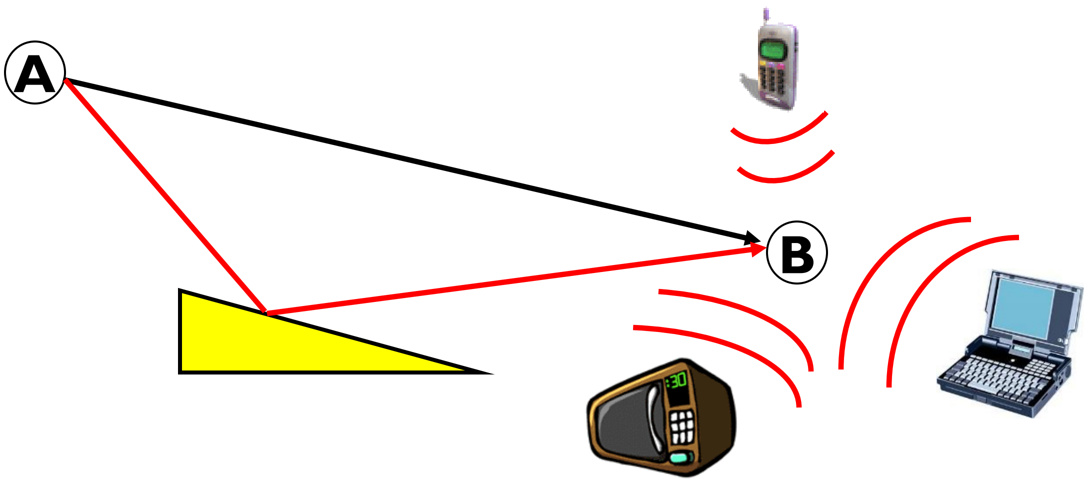
- For WLANs, rate adaptation is best handled at the MAC layer

Who should select the data rate?



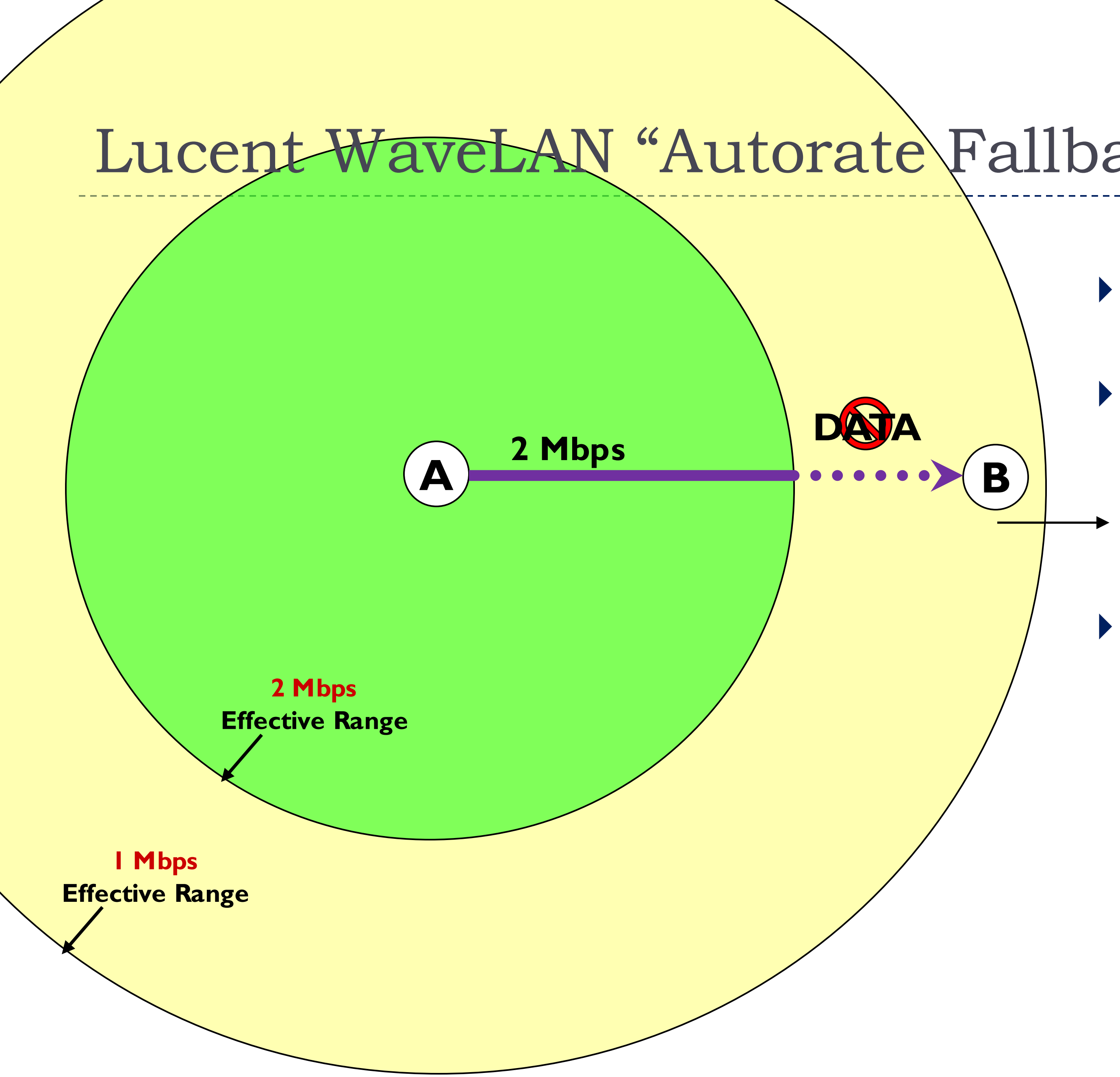
Who should select the data rate?

- Collision is at the receiver
- Channel conditions are only known at the receiver
  - SS, interference, noise, BER, etc.



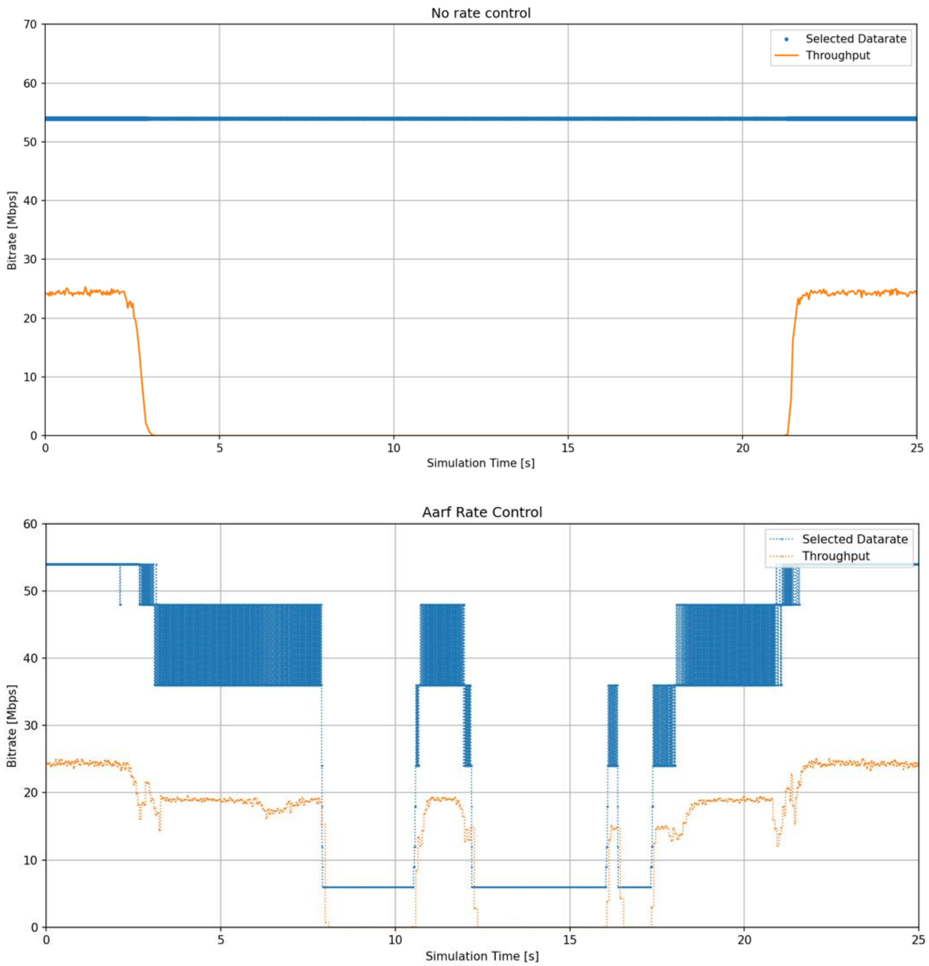
- The receiver is best positioned to select data rate

Lucent WaveLAN "Autorate Fallback" (ARF)

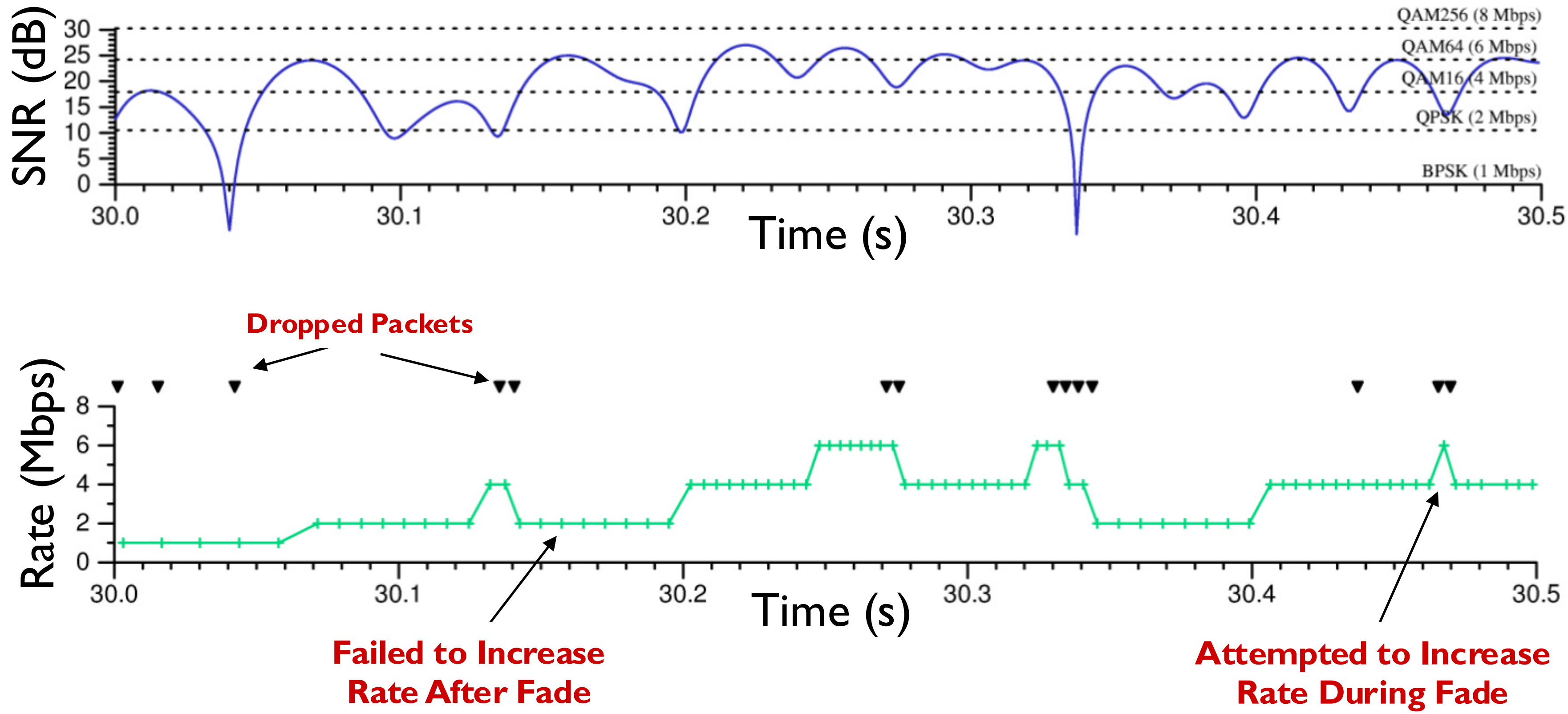


- Lost ACKs indicate link quality
- Sender decreases rate after
  - N consecutive ACKS are lost
- Sender increases rate after
  - Y consecutive ACKS are received or
  - T secs have elapsed since last attempt

Autorate Fallback Example



Performance of ARF



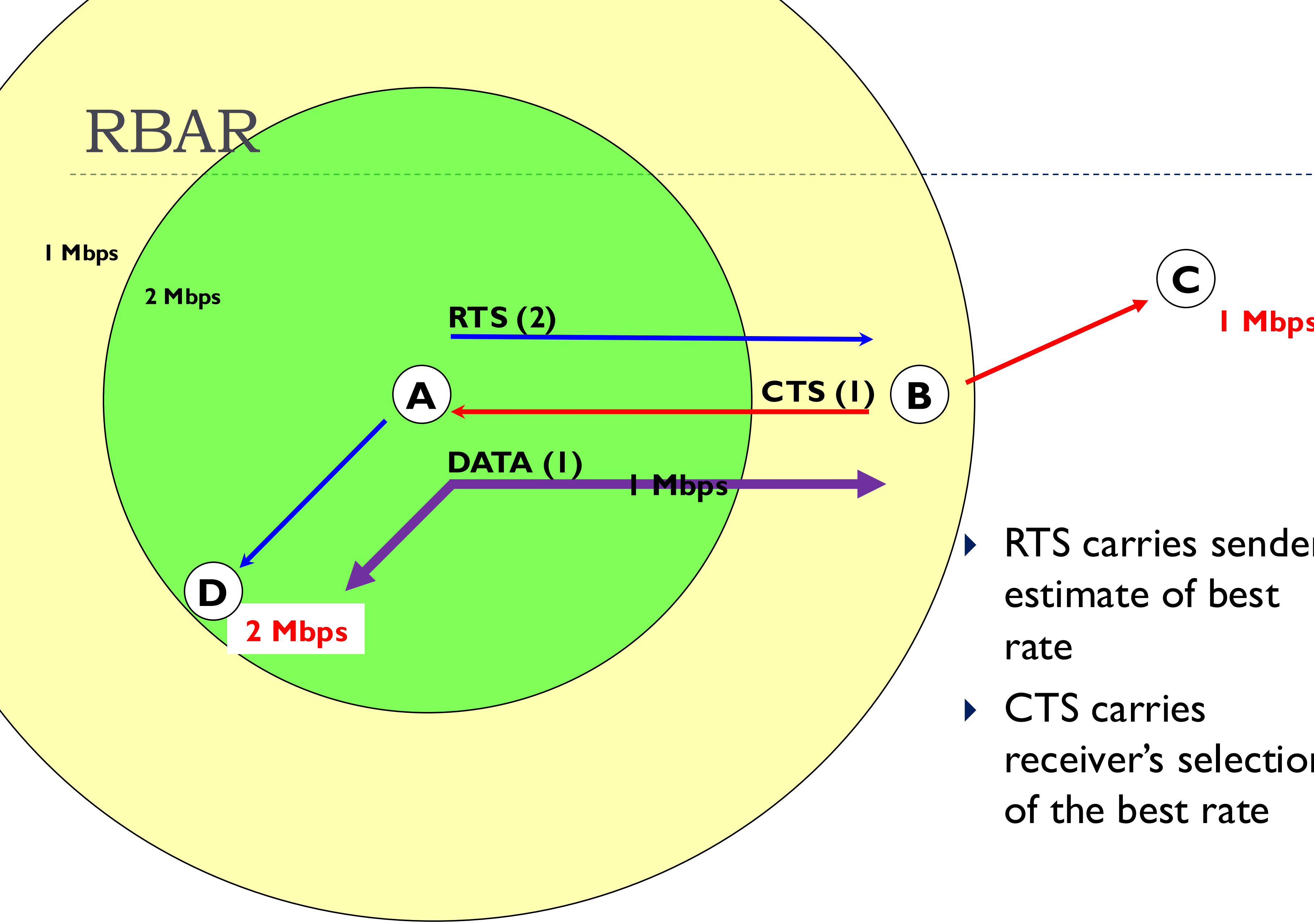
- Slow to adapt to channel conditions
- Choice of N, Y, T may not be best for all situations

Receiver-Based Autorate (RBAR)

- Move the rate adaptation mechanism to the receiver
  - Better channel quality information = better rate selection

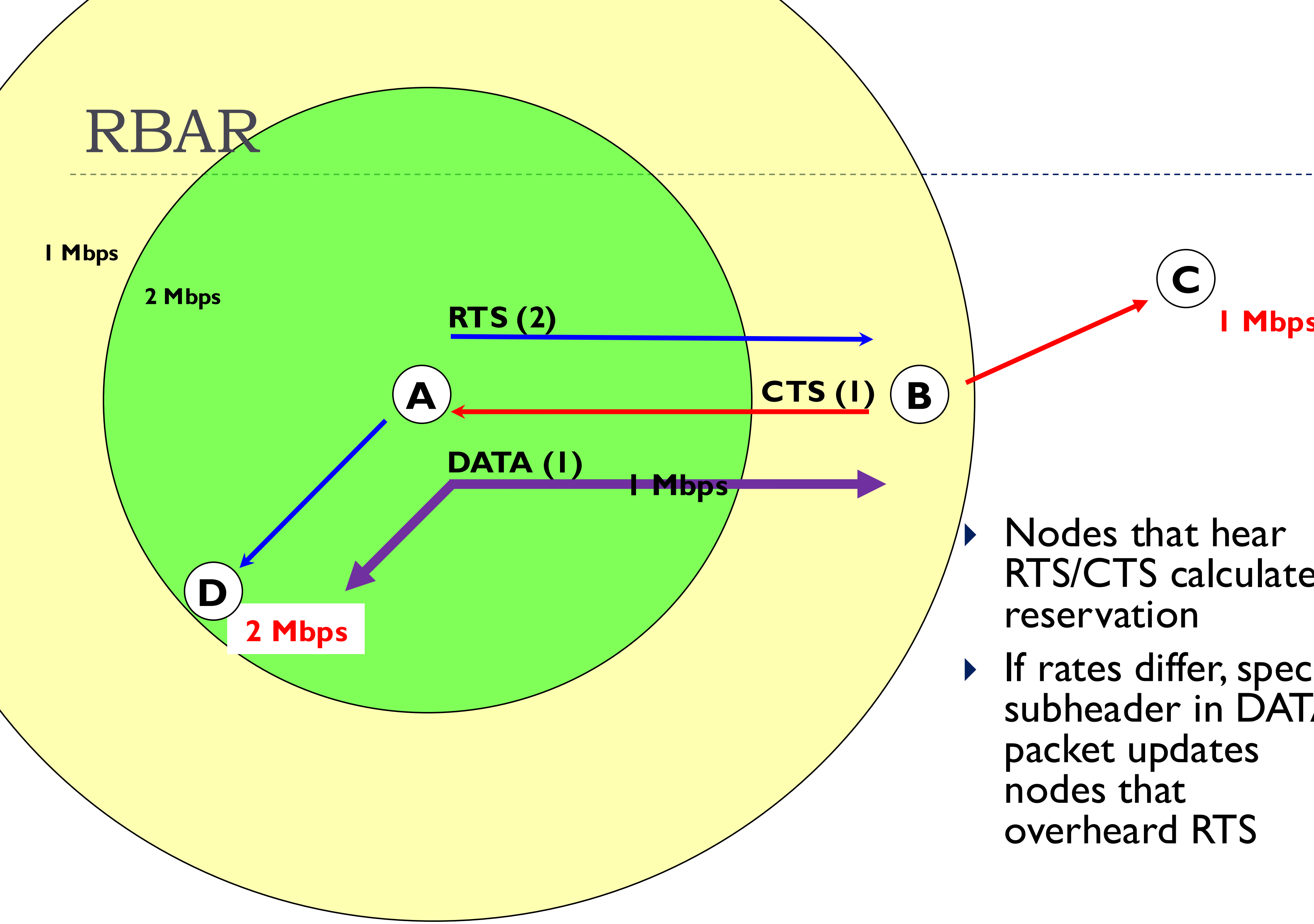
- Utilize the RTS/CTS exchange to
  - Provide the receiver with a signal to sample (RTS)
  - Carry feedback (data rate) to the sender (CTS)

RBAR



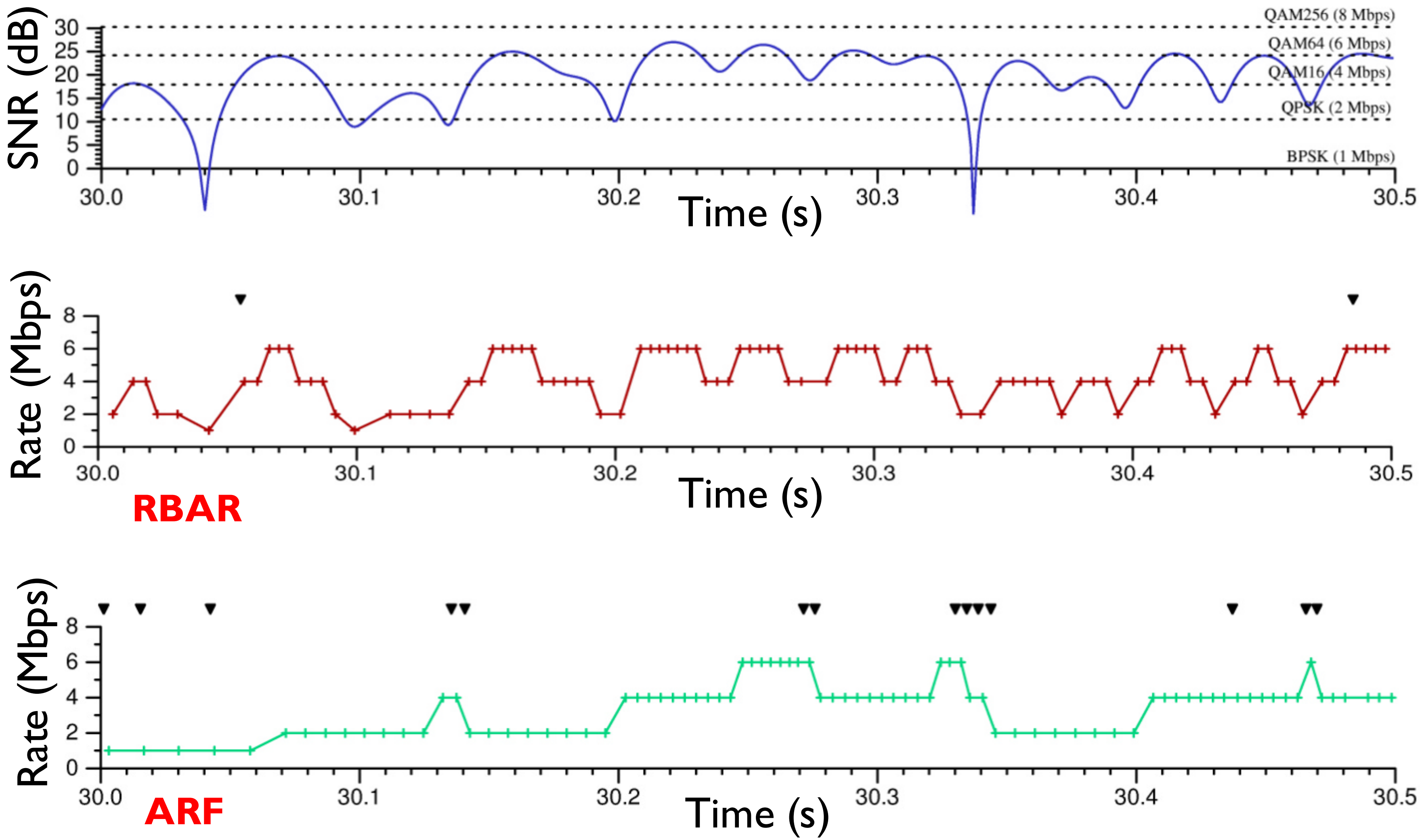
- RTS carries sender's estimate of best rate
- CTS carries receiver's selection of the best rate

RBAR

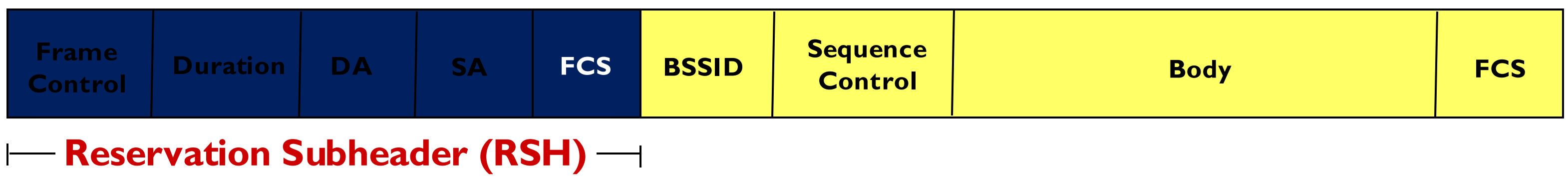


- Nodes that hear RTS/CTS calculate reservation
- If rates differ, special subheader in DATA packet updates nodes that overheard RTS

Performance of RBAR



Implementation into 802.11n



- Encode data rate and packet length in duration field of frames
  - Rate can be changed by receiver
  - Length can be used to select rate
  - Reservations are calculated using encoded rate and length

- New DATA frame type with Reservation Subheader (RSH)
  - Reservation fields protected by additional frame check sequence
  - RSH is sent at same rate as RTS/CTS

- New frame is only needed when receiver suggests rate change

RBAR Summary

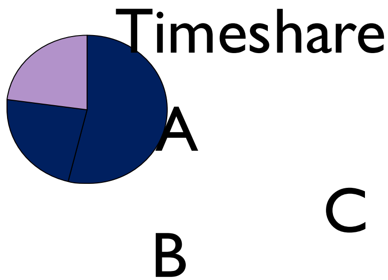
- Modulation schemes have different error characteristics
- Significant performance improvement may be achieved by MAC-level adaptive modulation
- Receiver-based schemes may perform best
  - Proposed Receiver-Based Auto-Rate (RBAR) protocol
  - Implementation into 802.11
- Future thoughts …
  - RBAR without use of RTS/CTS
  - RBAR based on the size of packets
  - Routing protocols for networks with variable rate links

Can we do better?

- Consider the situation below
  - ARF?
  - RBAR?

Motivation

- What if A and B are both at 56Mbps, and C is often at 2Mbps?
- Slowest node gets the most absolute time on channel?



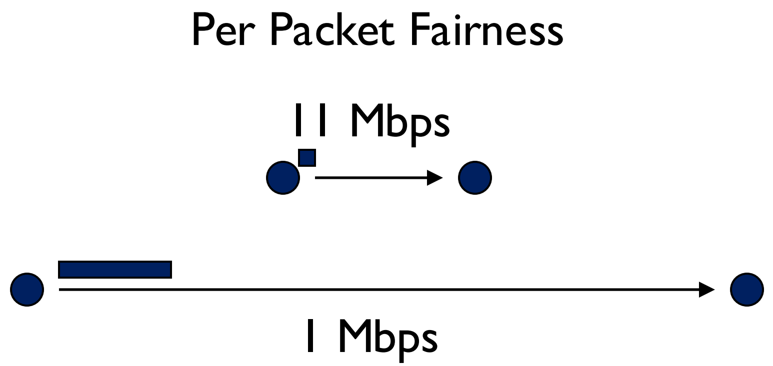
Throughput Fairness vs Temporal Fairness

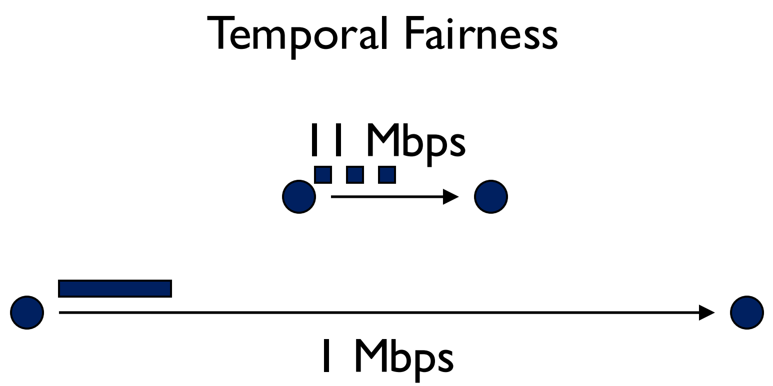
MAC Layer Fairness Models

- Per Packet Fairness
  - If two adjacent senders continuously are attempting to send packets, they should each send the same number of packets
- Temporal Fairness
  - If two adjacent senders are continuously attempting to send packets, they should each be able to send for the same amount of medium time.
- In single rate networks these are the SAME!

Temporal Fairness Example

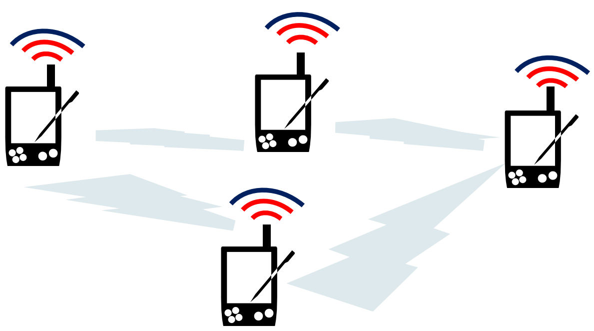
	802.11 Packet Fairness	OAR Temporal Fairness
11 Mbps Link	0.896	3.533
1 Mbps Link	0.713	0.450
Total Throughput	1.609	3.983





Opportunistic Scheduling

- Goal
  - Exploit short-time-scale channel quality variations to increase throughput
- Issue
  - Maintaining temporal fairness (time share) of each node
- Challenge
  - Channel info available only upon transmission



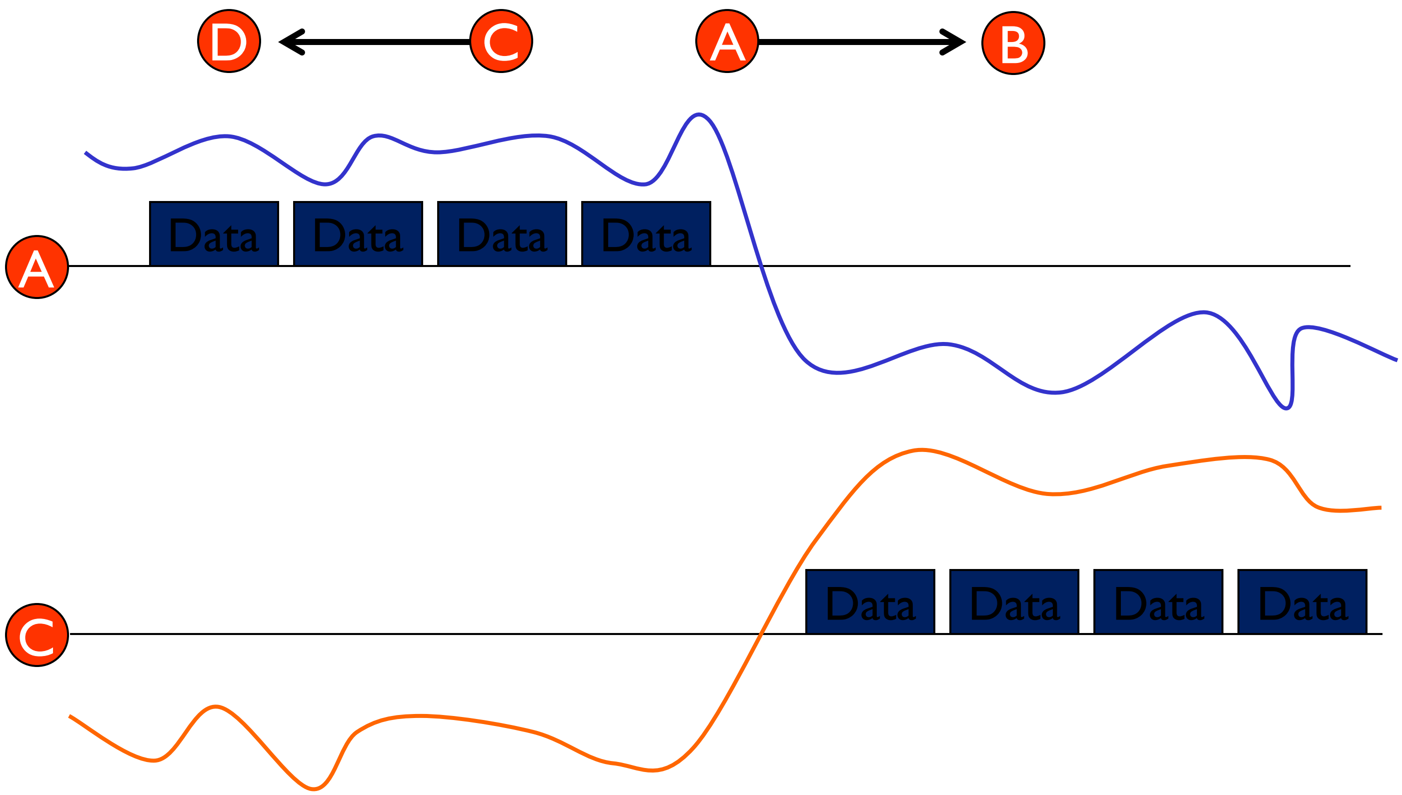
Opportunistic Auto-Rate (OAR)

- In many networks, there is intrinsic diversity
  - Exploiting this diversity can offer benefits
  - Transmit more when channel quality is high
    - else, free the channel quickly

- RBAR does not exploit this diversity
  - It optimizes per-link throughput

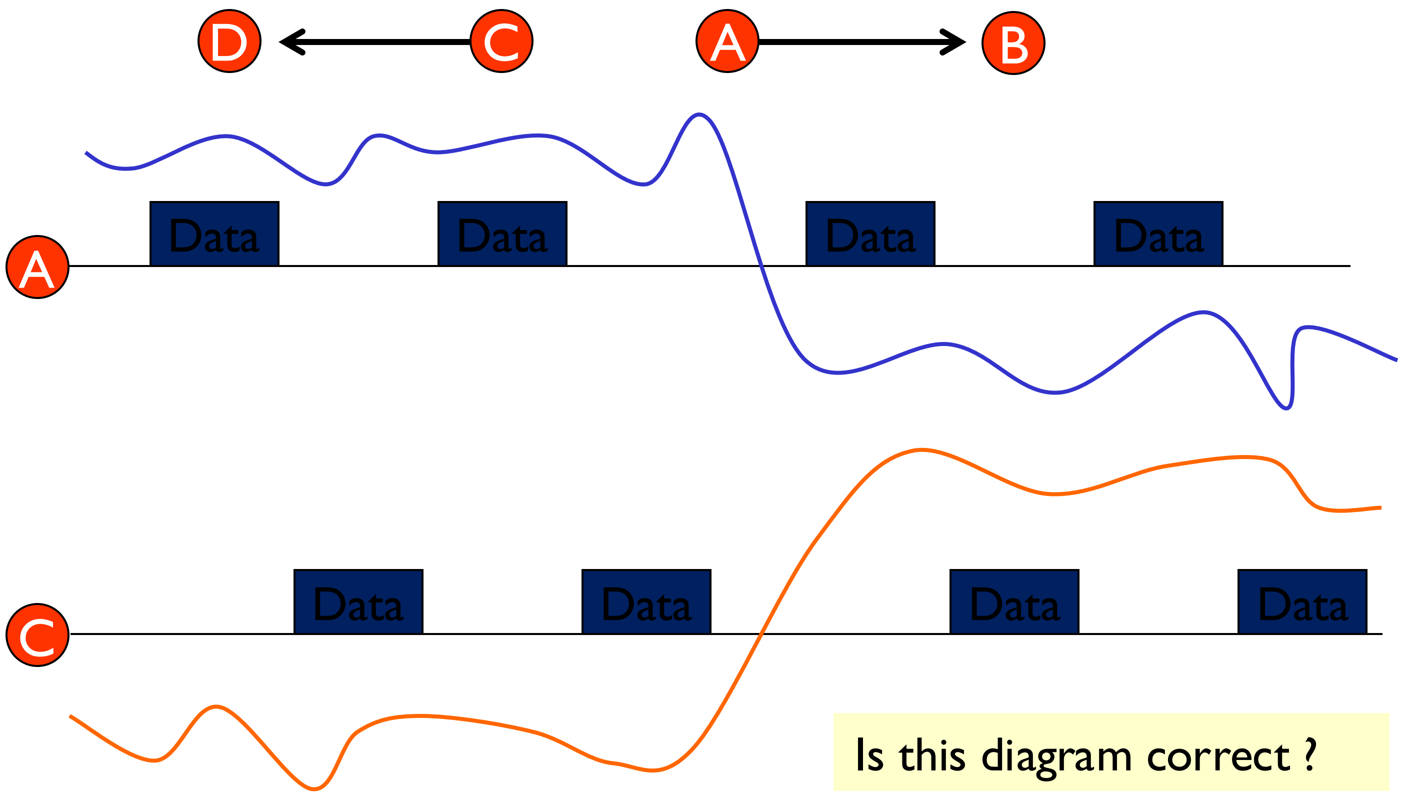
OAR Idea

- Basic Idea
  - Bad channel: transmit minimum number of packets
  - Good channel: transmit as much as possible



Why is OAR better?

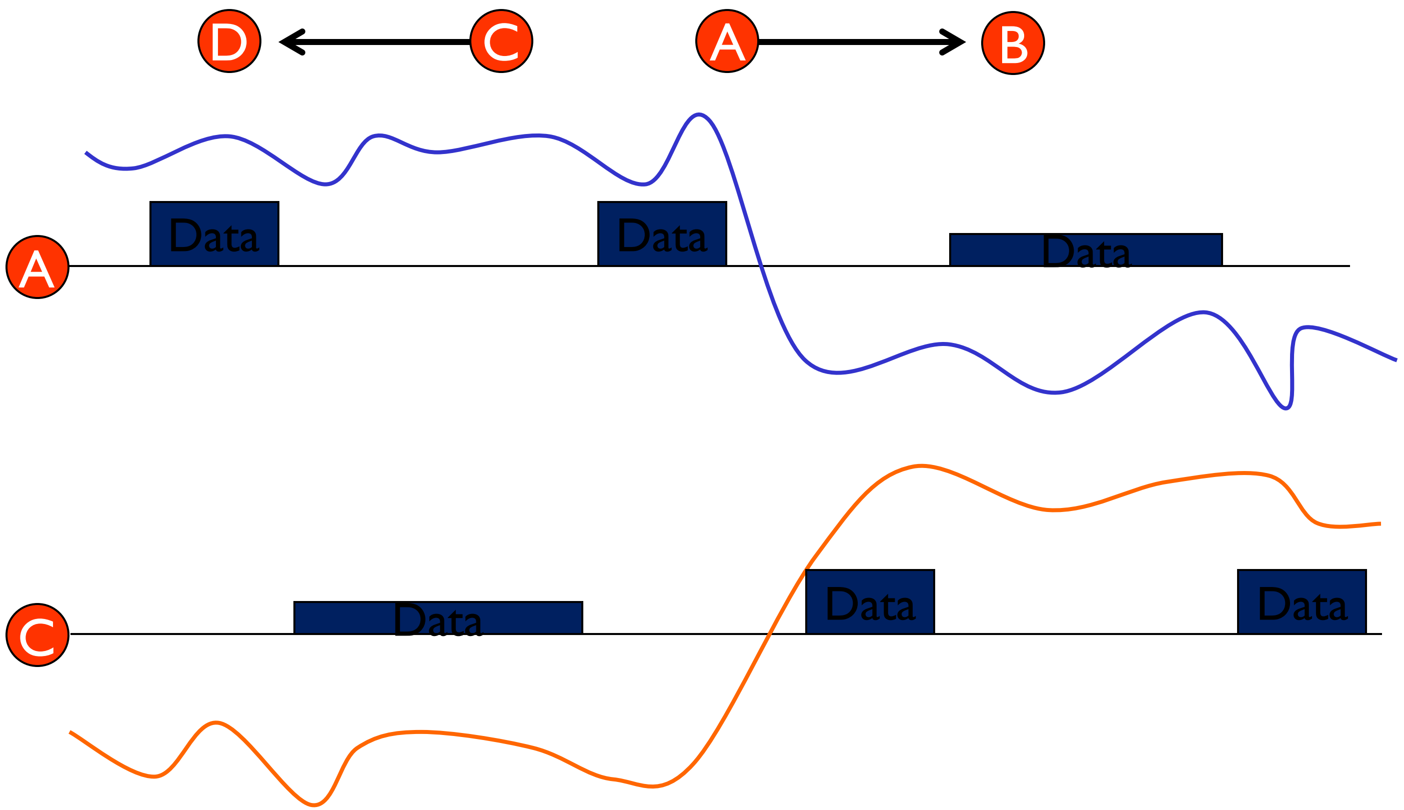
- 802.11 alternates between transmitters A and C
  - Why is that bad



Is this diagram correct ?

Why is OAR better ?

- Bad channel reduces SINR → increases transmit time
  - Fewer packets can be delivered



OAR Protocol Steps

- Transmitter estimates current channel
  - Can use estimation algorithms
  - Can use RBAR, etc.

- If channel better than base rate (2 Mbps)
  - Transmit proportionally more packets
    - e.g., if channel can support 11 Mbps, transmit (11/2 ~ 5) pkts

- OAR upholds temporal fairness
  - Each node gets same duration to transmit
  - Sacrifices throughput fairness → the network gains!!

OAR Protocol

Protocol	Channel Condition					
	BAD		MEDIUM		GOOD	
	Pkts	Rate	Pkts	Rate	Pkts	Rate
802.11	1	2	1	2	1	2
802.11b	1	2	1	5.5	1	11
OAR	1	2	3	5.5	5	11

- Rates in IEEE 802.11b: 2, 5.5, and 11 Mbps

Summary

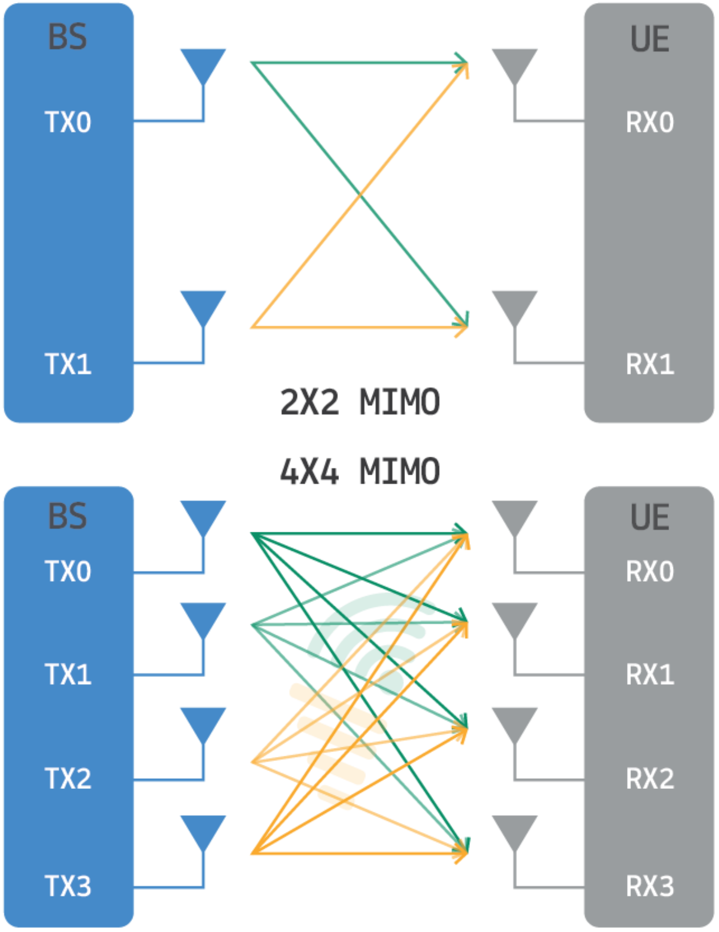
- Rate control can be useful
  - When adapted to channel fluctuations (RBAR)
  - When opportunistically selecting transmitters (OAR)
- Benefits maximal when
  - Channel conditions vary widely in time and space
- Correlation in fluctuation can offset benefits
  - OAR may show negligible gains

802.11n Rate Control

MCS	Modulation	Bits per symbol	Coding Ratio	20 Mhz		40 Mhz		80 Mhz		160 Mhz	
				800 ns	400 ns	800 ns	400 ns	800 ns	400 ns	800 ns	400 ns
1 Spatial Stream				Data Rates(Mbps)							
MCS0	BPSK	1	½	6.5	7.2	13.5	15.0	29.3	32.5	58.5	65.0
MCS1	QPSK	2	½	13.0	14.4	27.0	30.0	58.5	65.0	117.0	130.0
MCS2	QPSK	2	¾	19.5	21.7	40.5	45.0	87.8	97.5	175.5	195.0
MCS3	16-QAM	4	½	26.0	28.9	54.0	60.0	117.0	130.0	234.0	260.0
MCS4	16-QAM	4	¾	39.0	43.3	81.0	90.0	175.5	195.0	351.0	390.0
MCS5	64-QAM	6	2/3	52.0	57.8	108.0	120.0	234.0	260.0	468.0	520.0
MCS6	64-QAM	6	¾	58.5	65.0	121.5	135.0	263.3	292.5	526.5	585.0
MCS7	64-QAM	6	5/6	65.0	72.2	135.0	150.0	292.5	325.0	585.0	650.0
MCS8	256-QAM	8	¾	78.0	86.7	162.0	180.0	351.0	390.0	702.0	780.0
MCS9	256-QAM	8	5/6	N/A	N/A	180.0	200.0	390.0	433.3	780.0	888.7
8 Spatial streams				Data Rates(Mbps)							
MCS0	BPSK	1	½	52.0	57.8	108.0	120.0	234.0	260.0	468.0	520.0
MCS1	QPSK	2	½	104.0	115.6	216.0	240.0	468.0	520.0	936.0	1040
MCS2	QPSK	2	¾	156.0	173.3	324.0	360.0	702.0	780.0	1404	1560
MCS3	16-QAM	4	½	208.0	231.1	432.0	480.0	936.0	1040	1872	2080
MCS4	16-QAM	4	¾	312.0	346.7	648.0	720.0	1404	1560	2808	3120
MCS5	64-QAM	6	2/3	416.0	482.2	884.0	960.0	1872	2080	3744	4160
MCS6	64-QAM	6	¾	468.0	520.0	972.0	1080	1200	2340	4120	4680
MCS7	64-QAM	6	5/6	520	577.8	1080	1200	2340	2600	4680	5200
MCS8	256-QAM	8	¾	624.0	693.3	1296	1440	2808	3120	5616	6240
MCS9	256-QAM	8	5/6	N/A	N/A	1440	1600	3120	3466	6240	6933

802.11n Rate Control

- What is the best configuration?
  - 2x2?
  - 4x4?
- Even more complex with ac or ax
  - 6x6?



802.11ac Rate Control

MCS Index	Spatial Stream	Modulation	Coding	OFDM (802.11ax)											
				20MHz			40MHz			80MHz			160MHz		
				0.8µs GI	1.6µs GI	3.2µs GI	0.8µs GI	1.6µs GI	3.2µs GI	0.8µs GI	1.6µs GI	3.2µs GI	0.8µs GI	1.6µs GI	3.2µs GI
0	1	BPSQ	1/2	8.6	8.1	7.3	17.2	16.3	14.6	36.0	34.0	30.6	72.1	68.1	61.3
1	1	QPSK	1/2	17.2	16.3	14.6	34.4	32.5	29.3	72.1	68.1	61.3	144.1	136.1	122.5
2	1	QPSK	3/4	25.8	24.4	21.9	51.6	48.8	43.9	108.1	102.1	91.9	216.2	204.2	183.8
3	1	16-QAM	1/2	34.4	32.5	29.3	68.8	65.0	58.5	144.1	136.1	122.5	288.2	272.2	245.0
4	1	16-QAM	3/4	51.6	48.8	43.9	103.2	97.5	87.8	216.2	204.2	183.8	432.4	408.3	367.5
5	1	64-QAM	2/3	68.8	65.0	58.5	137.6	130.0	117.0	288.2	272.2	245.0	576.5	544.4	490.0
6	1	64-QAM	3/4	77.4	73.1	65.8	154.9	146.3	131.6	324.3	306.3	275.6	648.5	612.5	551.3
7	1	64-QAM	5/6	86.0	81.3	73.1	172.1	162.5	146.3	360.3	340.3	306.3	720.6	680.6	612.5
8	1	256-QAM	3/4	103.2	97.5	87.8	206.5	195.0	175.5	432.4	408.3	367.5	864.7	816.7	735.0
9	1	256-QAM	5/6	114.7	108.3	97.5	229.4	216.7	195.0	480.4	453.7	408.3	960.8	907.4	816.7
10	1	1024-QAM	3/4	129.0	121.9	109.7	258.1	243.8	219.4	540.4	510.4	459.4	1080.9	1020.8	918.8
11	1	1024-QAM	5/6	143.4	135.4	121.9	286.8	270.8	243.8	600.5	567.1	510.4	1201.0	1134.3	1020.8
0	2	BPSQ	1/2	17.2	16.3	14.6	34.4	32.5	29.3	72.1	68.1	61.3	144.1	136.1	122.5
1	2	QPSK	1/2	34.4	32.5	29.3	68.8	65.0	58.5	144.1	136.1	122.5	288.2	272.2	245.0
2	2	QPSK	3/4	51.6	48.8	43.9	103.2	97.5	87.8	216.2	204.2	183.8	432.4	408.3	367.5
3	2	16-QAM	1/2	68.8	65.0	58.5	137.6	130.0	117.0	288.2	272.2	245.0	576.5	544.4	490.0
4	2	16-QAM	3/4	103.2	97.5	87.8	206.5	195.0	175.5	432.4	408.3	367.5	864.7	816.7	735.0
5	2	64-QAM	2/3	137.6	130.0	117.0	275.3	260.0	234.0	576.5	544.4	490.0	1152.9	1088.9	980.0
6	2	64-QAM	3/4	154.9	146.3	131.6	309.7	292.5	263.3	648.5	612.5	551.3	1297.1	1225.0	1102.5
7	2	64-QAM	5/6	172.1	162.5	146.3	344.1	325.0	292.5	720.6	680.6	612.5	1441.2	1361.1	1225.0
8	2	256-QAM	3/4	206.5	195.0	175.5	412.9	390.0	351.0	864.7	816.7	735.0	1729.4	1633.3	1470.0
9	2	256-QAM	5/6	229.4	216.7	195.0	458.8	433.3	390.0	960.8	907.4	816.7	1921.6	1814.8	1633.3
10	2	1024-QAM	3/4	258.1	243.8	219.4	516.2	487.5	438.8	1080.9	1020.8	918.8	2161.8	2041.7	1837.5
11	2	1024-QAM	5/6	286.8	270.8	243.8	573.5	541.7	487.5	1201.0	1134.3	1020.8	2402.0	2268.5	2041.7
0	3	BPSQ	1/2	25.8	24.4	21.9	51.6	48.8	43.9	108.1	102.1	91.9	216.2	204.2	183.8
1	3	QPSK	1/2	51.6	48.8	43.9	103.2	97.5	87.8	216.2	204.2	183.8	432.4	408.3	367.5
2	3	QPSK	3/4	77.4	73.1	65.8	154.9	146.3	131.6	324.3	306.3	275.6	648.5	612.5	551.3
3	3	16-QAM	1/2	103.2	97.5	87.8	206.5	195.0	175.5	432.4	408.3	367.5	864.7	816.7	735.0
4	3	16-QAM	3/4	154.9	146.3	131.6	309.7	292.5	263.3	648.5	612.5	551.3	1297.1	1225.0	1102.5
5	3	64-QAM	2/3	206.5	195.0	175.5	412.9	390.0	351.0	864.7	816.7	735.0	1729.4	1633.3	1470.0
6	3	64-QAM	3/4	232.3	219.4	197.4	464.6	438.8	394.9	972.8	918.8	826.9	1945.6	1837.5	1653.8
7	3	64-QAM	5/6	258.1	243.8	219.4	516.2	487.5	438.8	1080.9	1020.8	918.8	2161.8	2041.7	1837.5
8	3	256-QAM	3/4	309.7	292.5	263.3	619.4	585.0	526.5	1297.1	1225.0	1102.5	2594.1	2450.0	2205.0
9	3	256-QAM	5/6	344.1	325.0	292.5	688.2	650.0	585.0	1441.2	1361.1	1225.0	2882.4	2722.2	2450.0
10	3	1024-QAM	3/4	387.1	365.6	329.1	774.3	731.3	658.1	1621.3	1531.3	1378.1	3242.6	3062.5	2756.3
11	3	1024-QAM	5/6	430.1	406.3	365.6	860.3	812.5	731.3	1801.5	1701.4	1531.3	3602.9	3402.8	3062.5

802.11ac Rate Control

- OFDMA needs to allocate the Rus without RTS/CTS
  - Typically proprietary algorithms