Adapting to the Wireless Channel

COS 598a: Wireless Networking and Sensing Systems

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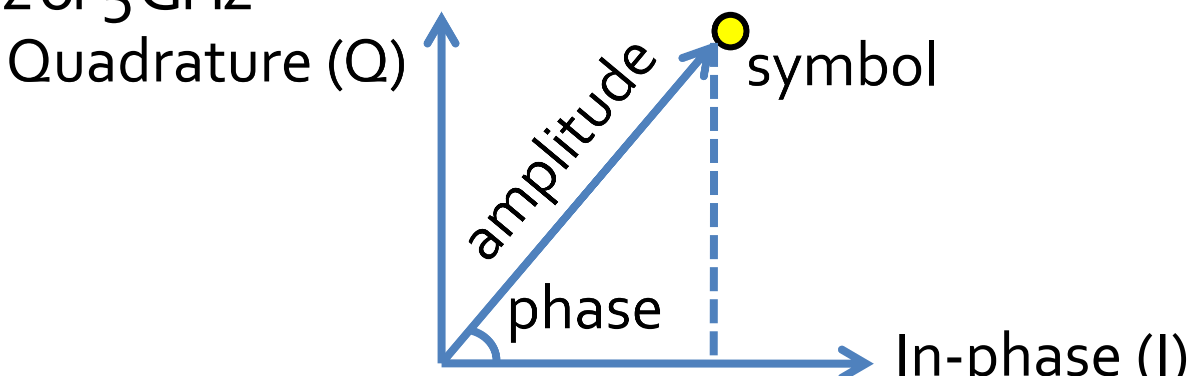
What is modulation?

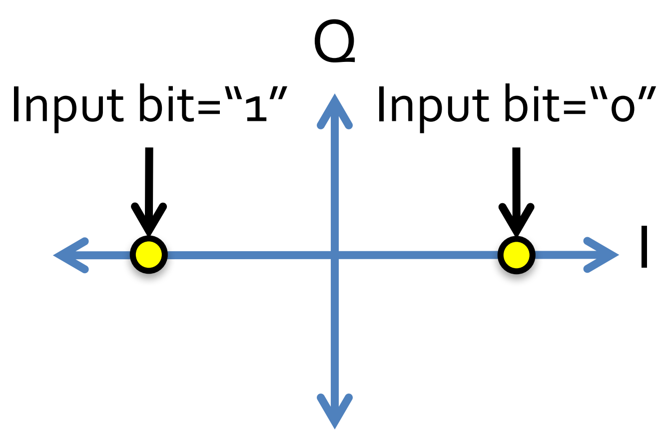
- To ***modulate*** means to **change.** Change what?
  - The **amplitude** and **phase (*i.e.*, angle)** of a ***carrier signal***
  - For 802.11 WiFi local area networks, this carrier signal is usually at 2.4 GHz or 5 GHz



- ***Digital modulation:*** Use only a finite set of choices (*i.e.*, ***symbols***) for how to change the carrier and phase
  - Transmitter and receiver agree upon the symbols beforehand

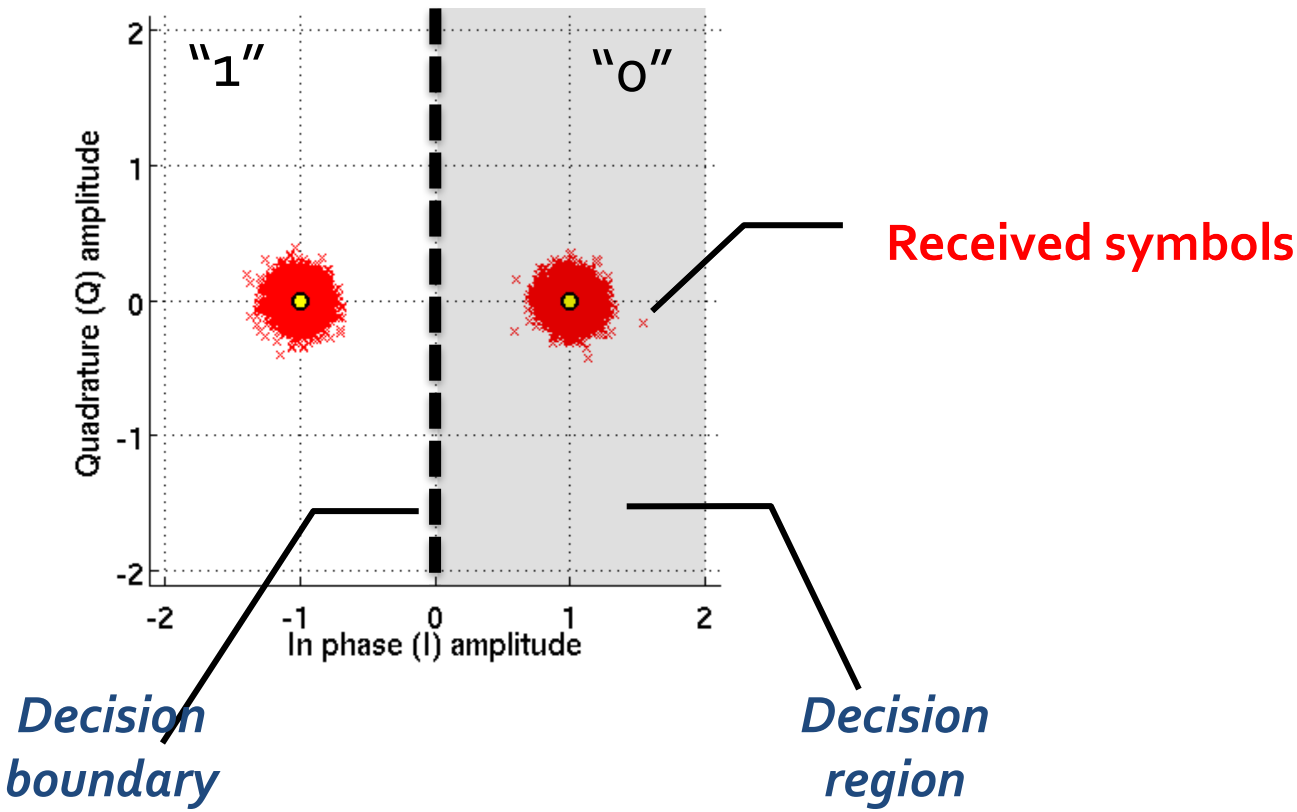
From information bits to symbols…

- Simplest possible scheme
  - Pick two symbols (**binary**)
  - The information bit decides which symbol you transmit
  - So, this is called ***binary phase shift keying***
    - **Sending rate:** 1 bit/symbol



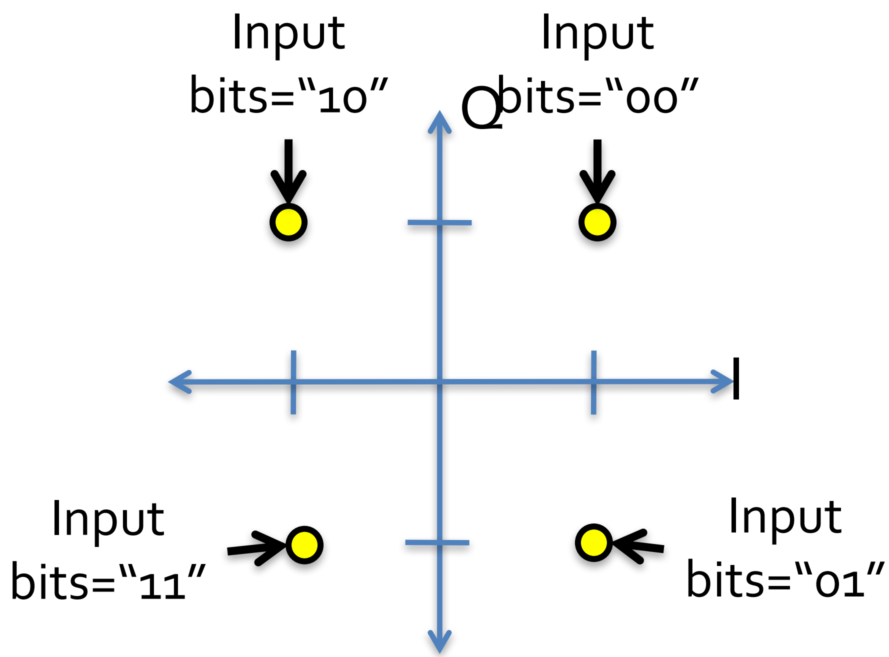
…and back to bits!

Received BPSK constellation



Sending twice as fast

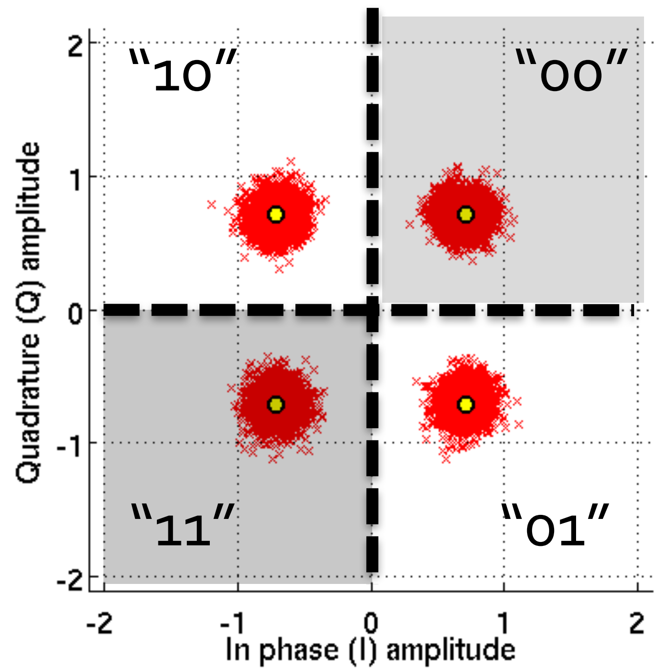
Quadrature phase shift keying (QPSK)



Sending 2 bits/symbol

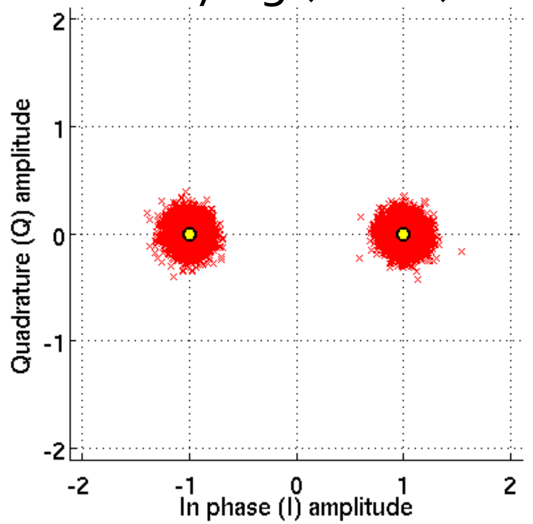
…and back to bits, twice as fast!

Received QPSK constellation

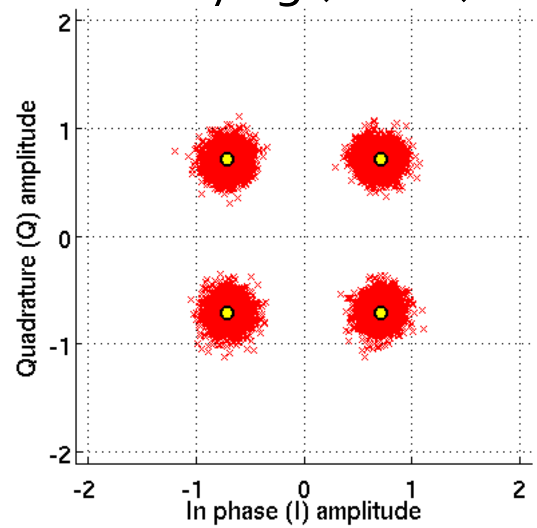


Change modulations, increase bitrate

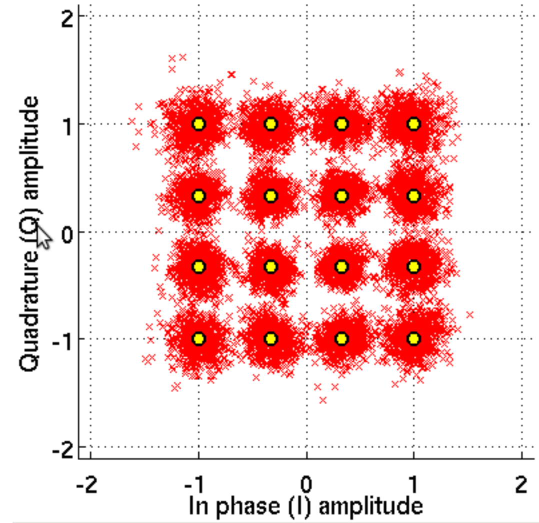
Binary Phase-Shift Keying (BPSK)



Quadrature Phase-Shift Keying (QPSK)



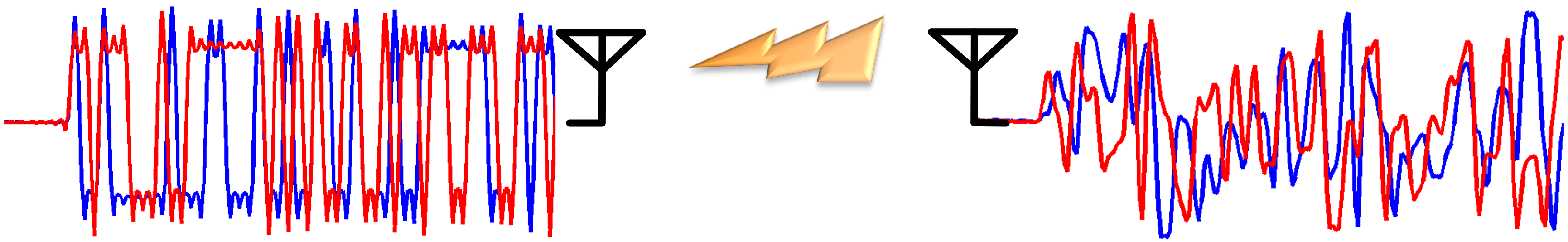
16-Quadrature Amplitude Modulation (16-QAM)

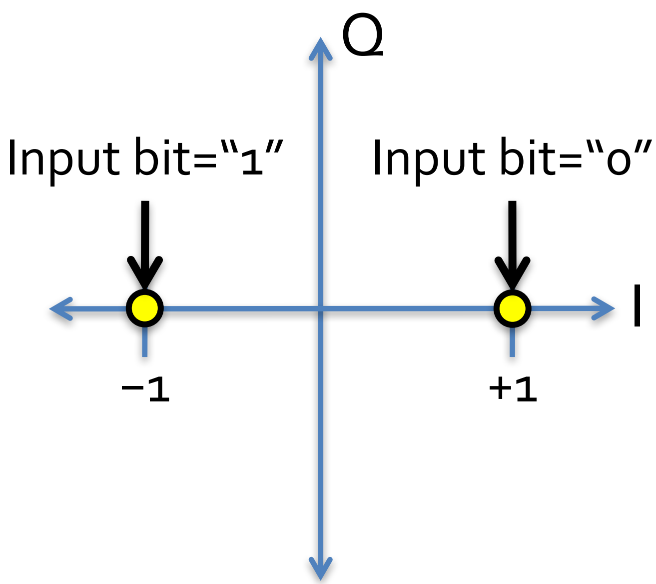


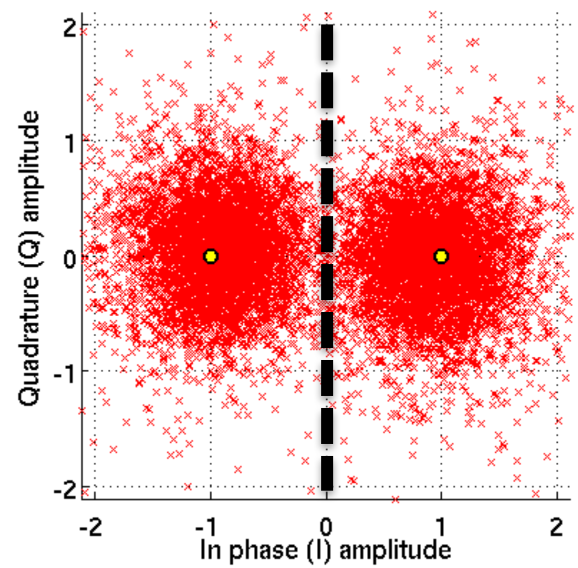
The wireless channel

Transmitted signal

reception: $r(t) = s(t) + n(t)$



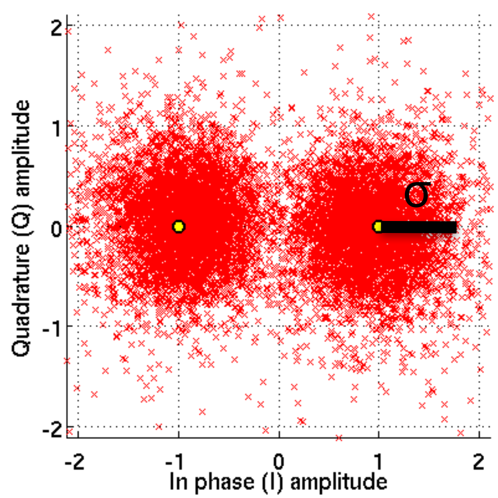




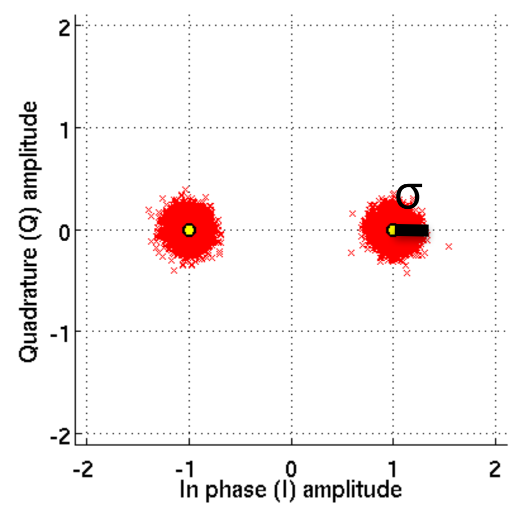
Signal to noise ratio (SNR)

- Measured in ***decibels (dB):*** 10 times $\log_{10}$ of a quantity

SNR = 8 dB

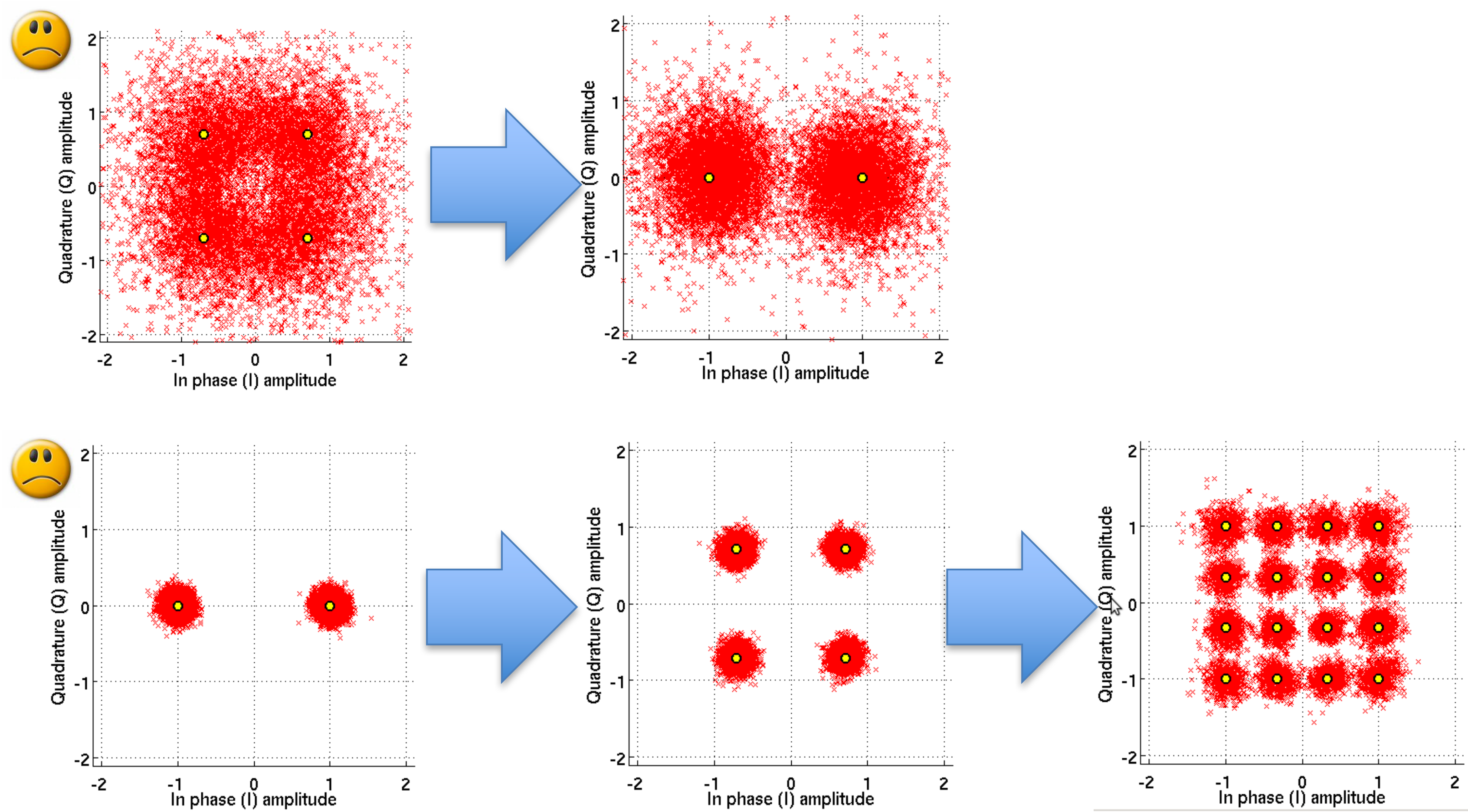


SNR = 20 dB

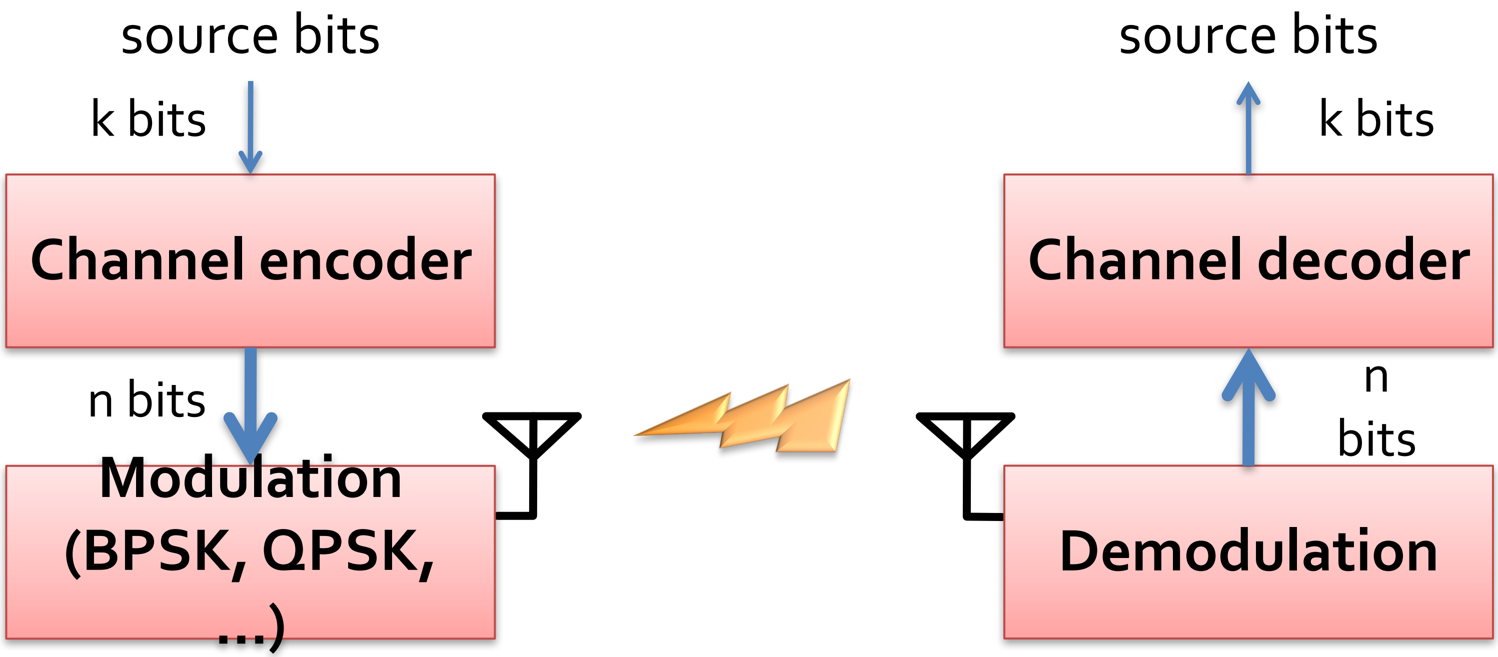


$$\text{SNR (dB)} = 10 \log_{10} (\text{ signal power / noise power})$$
$$= 10 \log_{10} (1^2 / \sigma^2) \quad \text{(assuming Gaussian noise)}$$
$$= -20 \log_{10} \sigma$$

Modulation adaptation



Error control coding

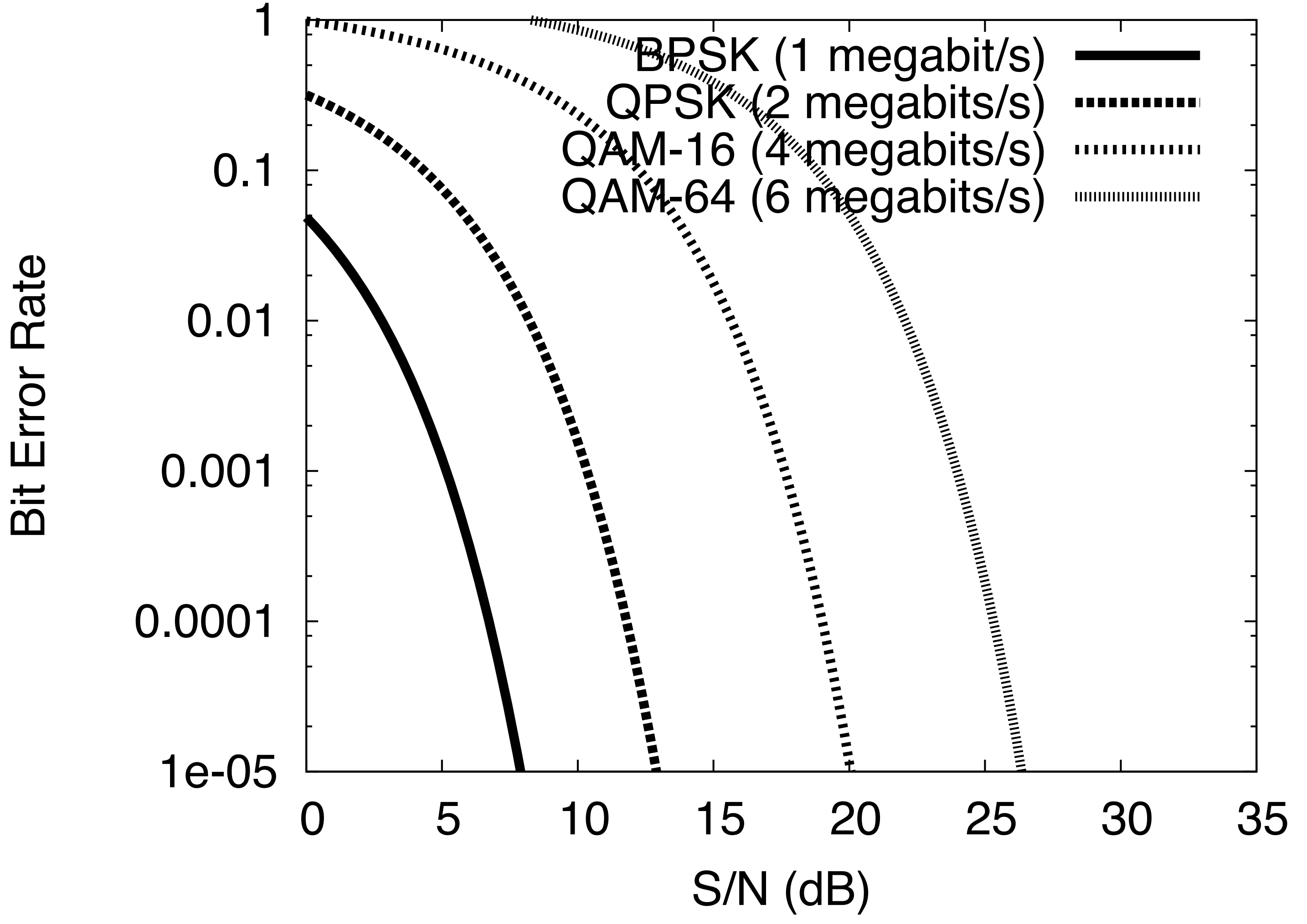


Code rate: R = k/n

802.11: adapt code rate, modulation

Bit-rate	802.11 Standards	DSSS or OFDM	Modulation	Bits per Symbol	Coding Rate	Mega-Symbols per second
1	b	DSSS	BPSK	1	1/11	11
2	b	DSSS	QPSK	2	1/11	11
5.5	b	DSSS	CCK	1	4/8	11
11	b	DSSS	CCK	2	4/8	11
6	a/g	OFDM	BPSK	1	1/2	12
9	a/g	OFDM	BPSK	1	3/4	12
12	a/g	OFDM	QPSK	2	1/2	12
18	a/g	OFDM	QPSK	2	3/4	12
24	a/g	OFDM	QAM-16	4	1/2	12
36	a/g	OFDM	QAM-16	4	3/4	12
48	a/g	OFDM	QAM-64	6	2/3	12
54	a/g	OFDM	QAM-64	6	3/4	12

BER vs SNR



BPSK (1 megabit/s)
QPSK (2 megabits/s)
QAM-16 (4 megabits/s)
QAM-64 (6 megabits/s)
Bit Error Rate
1
0.1
0.01
0.001
0.0001
1e-05
0
5
10
15
20
25
30
35
S/N (dB)

Link/PHY checks packet integrity

Throughput = delivery rate × bitrate = $(1 - \text{BER})^n$ × bitrate

Network layer

Packet delivery rate = $(1-\text{BER})^n$

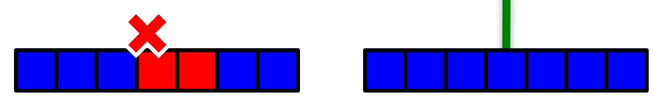
packet

Frame checksum: pass only entirely correct frames

Link layer

Physical layer

BER

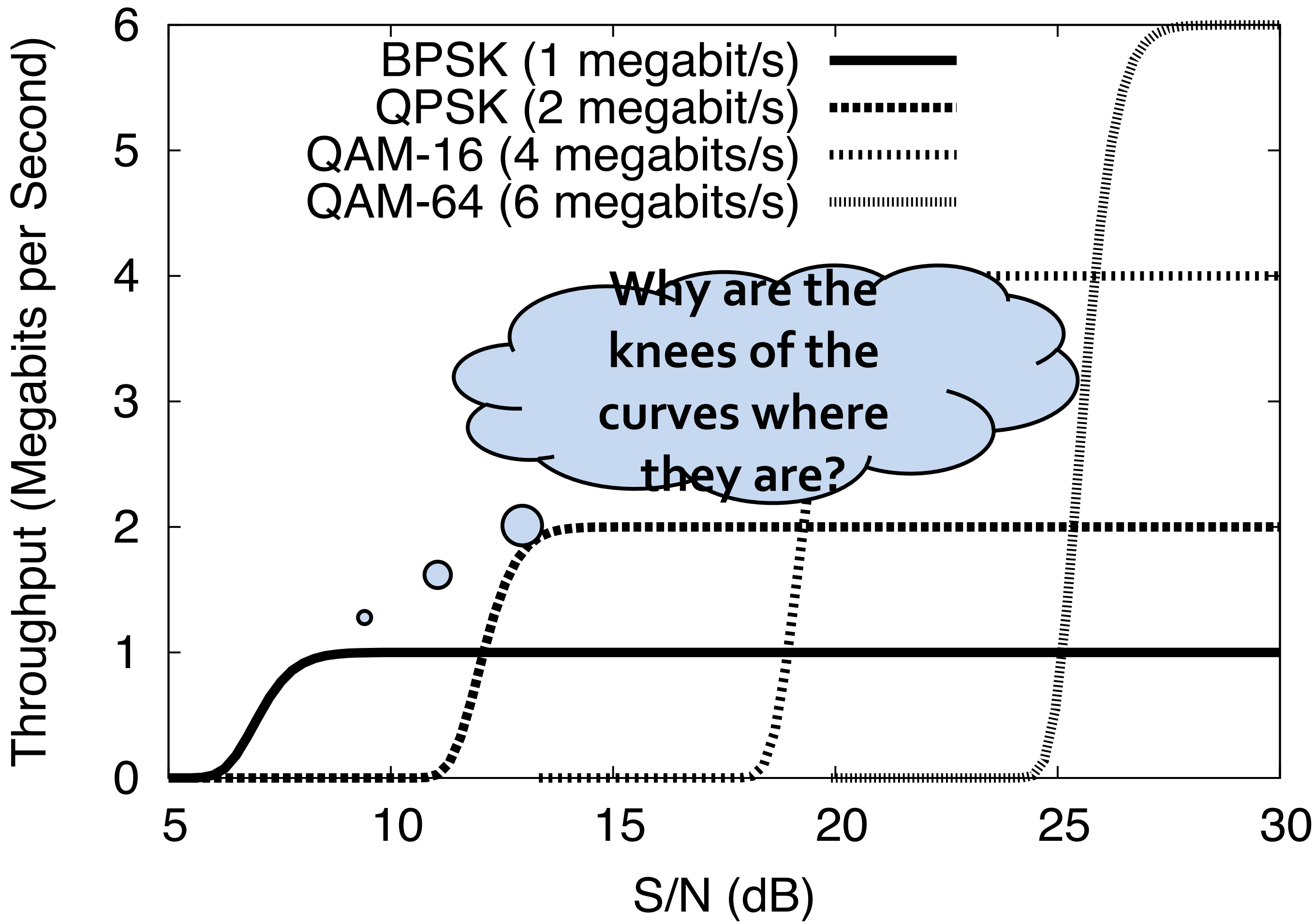


- Change modulation
- Change coding rate

$n = 1500 \times 8$ bits

Packetized throughput

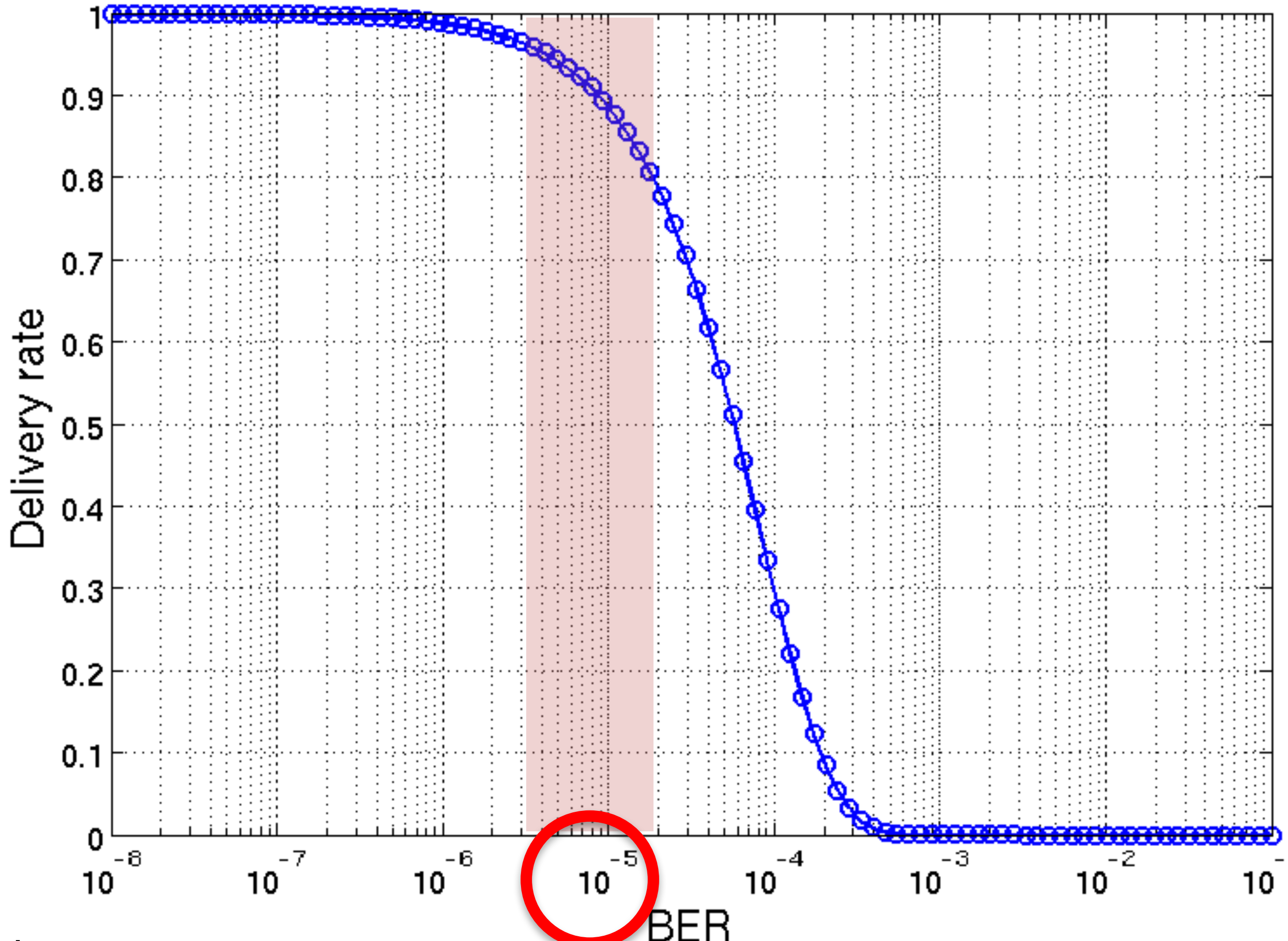
Throughput = delivery rate × bitrate = $(1 - \text{BER})^n$ × bitrate



n = 1500 × 8 bits

Delivery rate vs BER

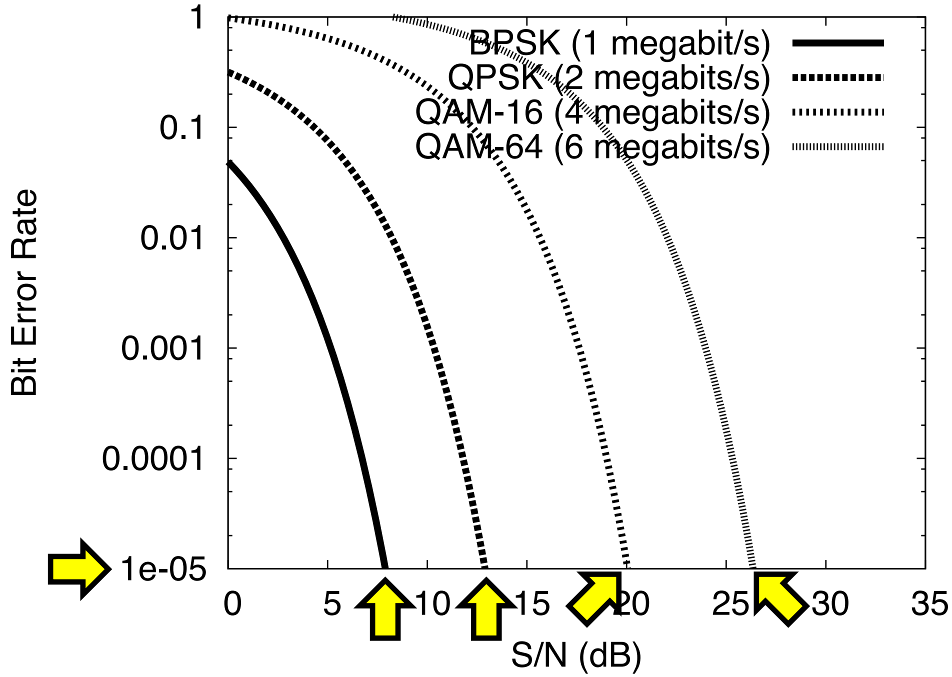
Throughput = delivery rate × bitrate = $(1 - BER)^n$ × bitrate



n = 1500 × 8 bits

BER vs SNR

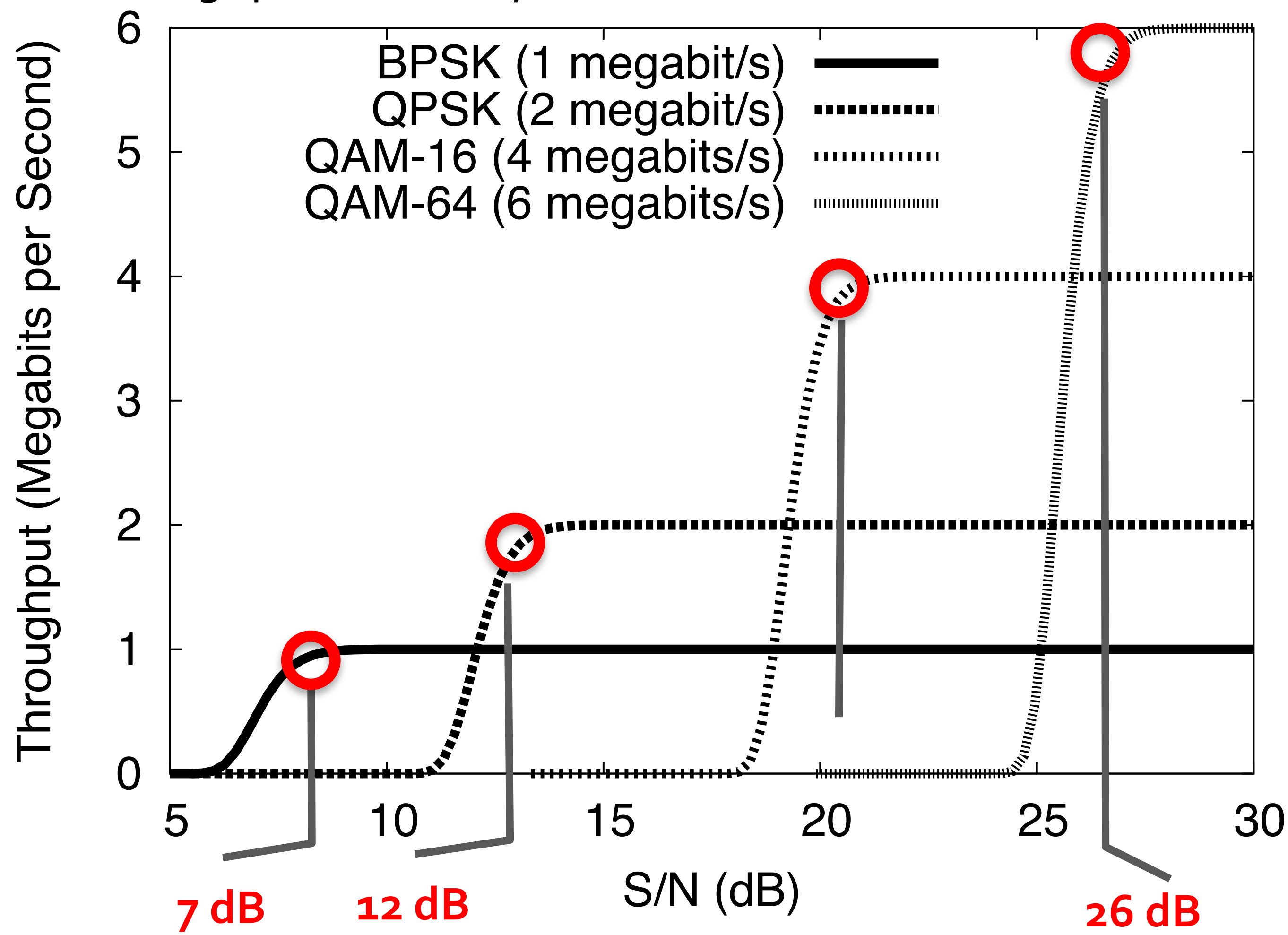
- For each modulation: *What are the SNRs required for BER < 10^{-5}?*



- BPSK: 7 dB; QPSK: 12 dB; 16-QAM: 20 dB; 64-QAM: 26 dB

Packetized throughput

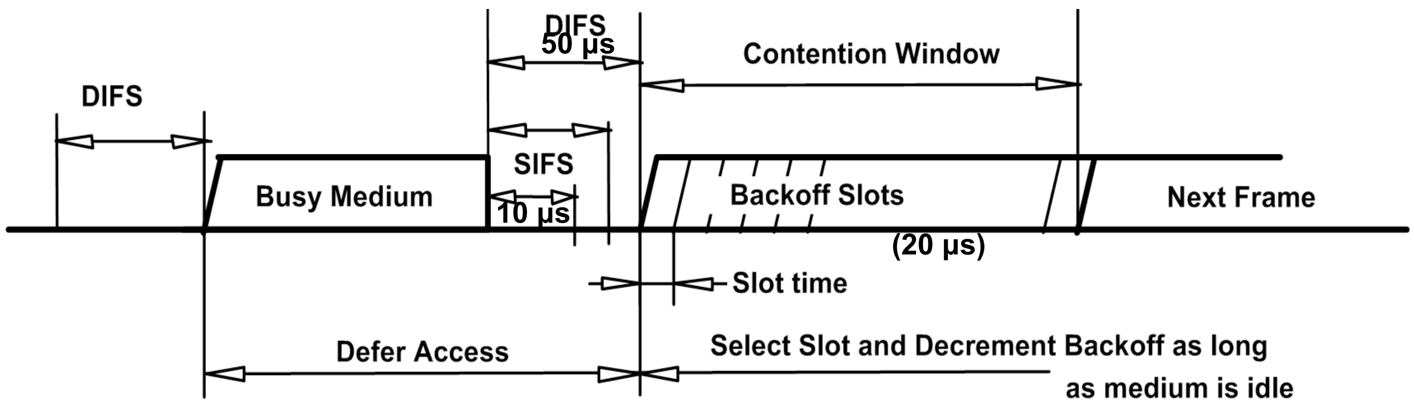
Throughput = delivery rate × bitrate = $(1 - \text{BER})^n$ × bitrate



$n = 1500 \times 8$ bits

Measuring time to send a packet

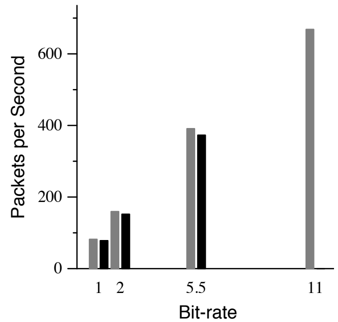
Assume unicast, RTS/CTS is disabled. Let's go to the spec (802.11b DSSS values):



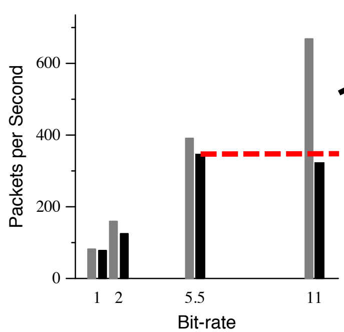
$$\text{tx\_time}(\text{bitrate}, r, N) = \text{DIFS} + \text{backoff}(r) + (r+1)\left(\text{SIFS} + \text{ACK} + \text{HEADER} + \frac{8 \cdot N}{\text{bitrate}}\right)$$

- Similar to MACAW
  - Key difference: **as long as medium is idle**

SampleRate in operation



Steep

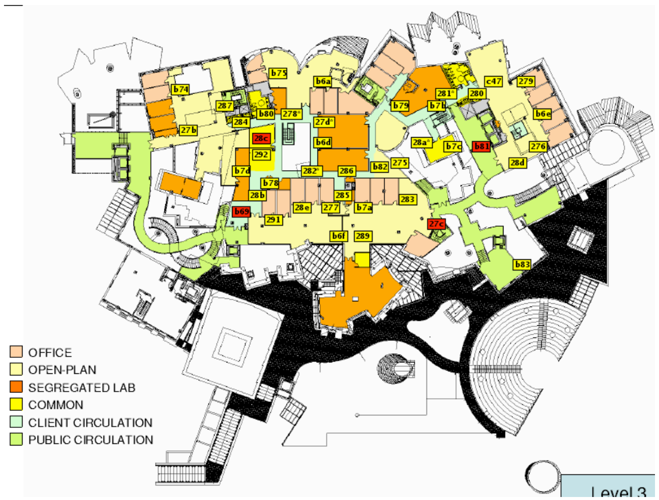


Gradual

Bit-rate	Tries	Packets Ack'ed	Succ. Fails	Total TX Time	Avg TX Time	Lossless TX Time
11	16	0	4	250404	∞	1873
5.5	100	100	0	297600	2976	2976
2	0	0	0	0	-	6834
1	0	0	0	0	-	12995
11	28	14	0	52654	3761	1873
5.5	50	46	0	148814	3235	2976
2	0	0	0	0	-	6834
1	0	0	0	0	-	12995

Evaluation methodology

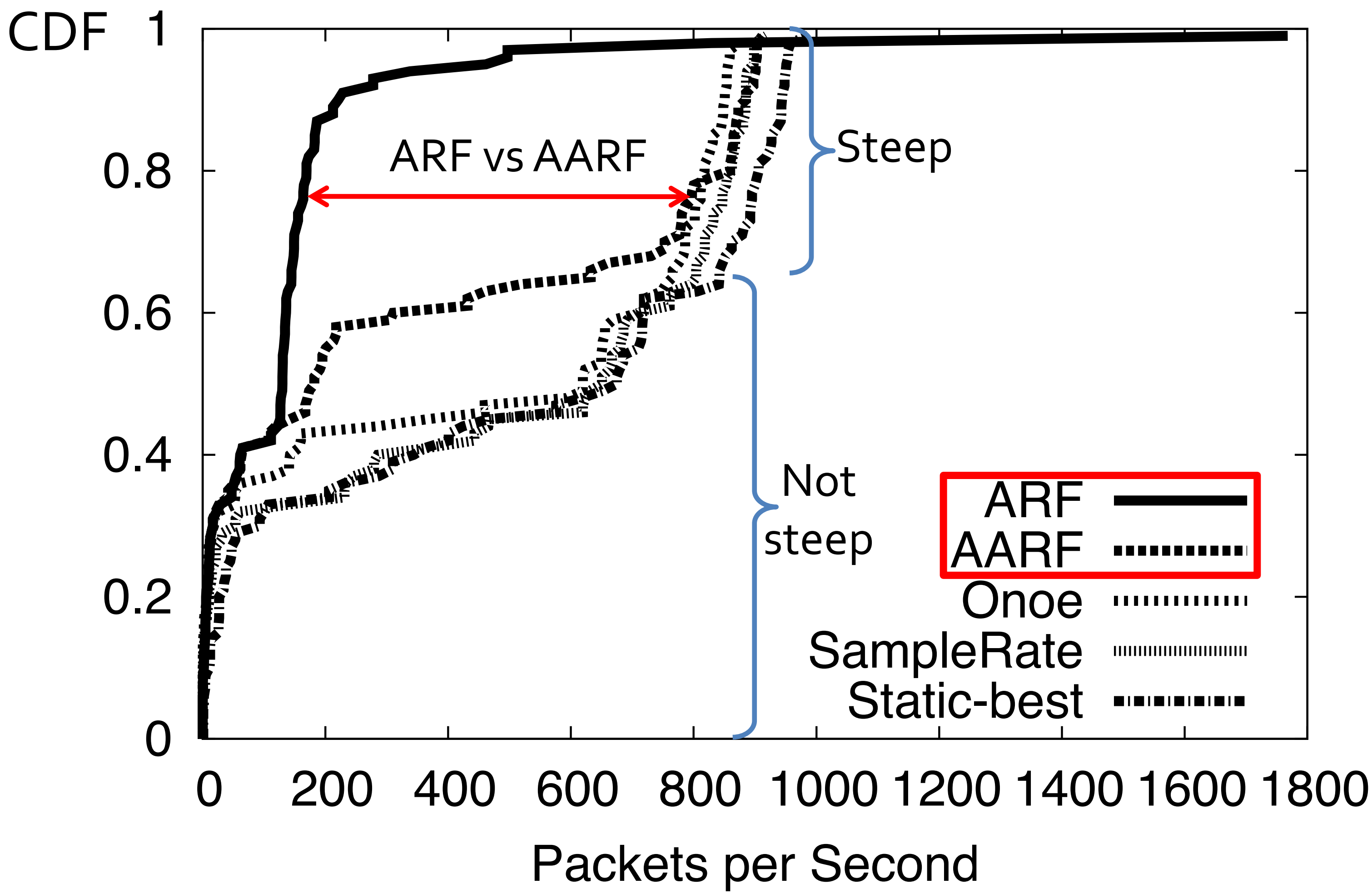
Indoor testbed: 45 node a/b/g



Outdoor testbed: 38 node b/g

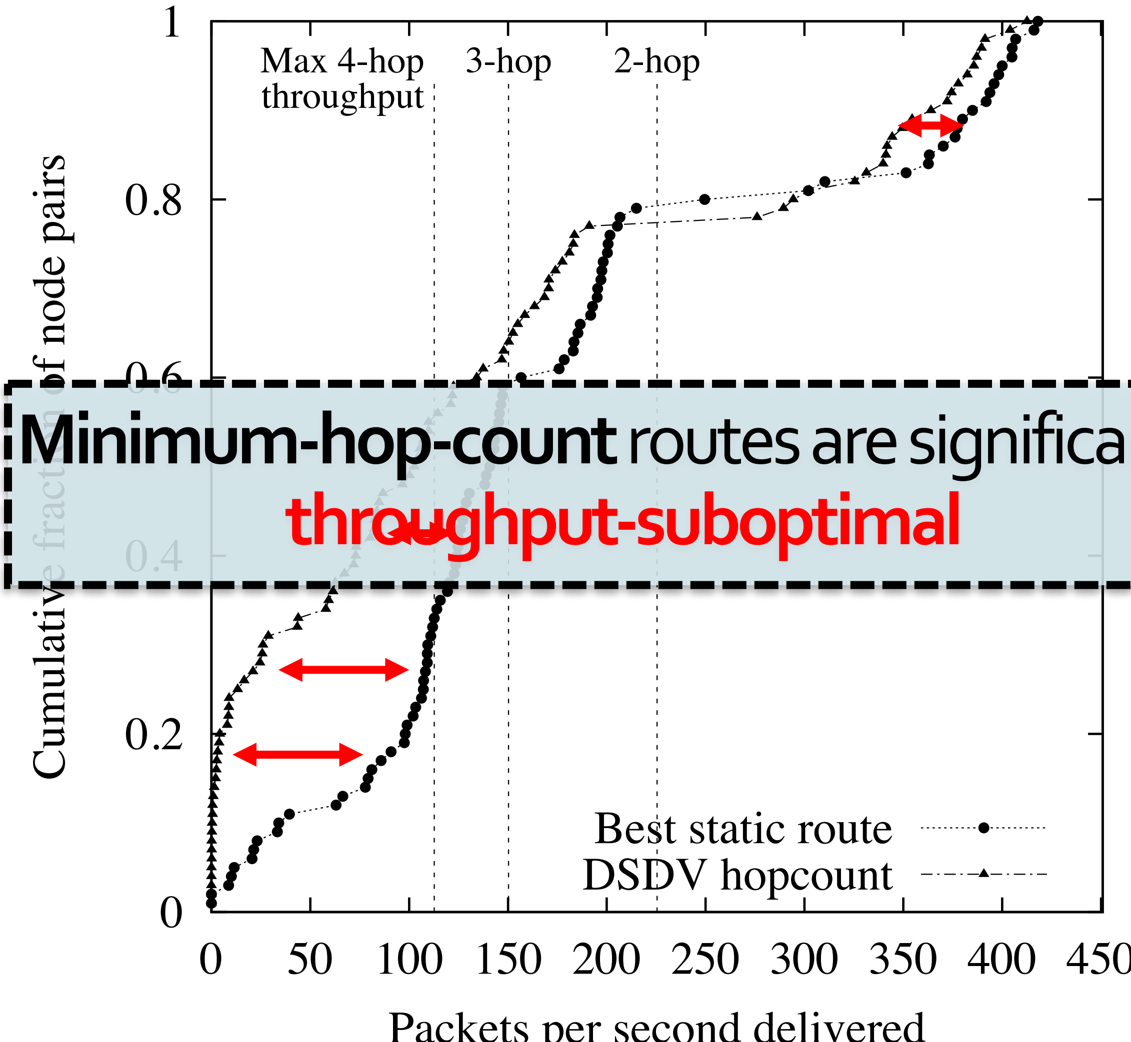
- Select **random** links in testbed with non-zero throughput
- Test each link **in isolation** for 30 seconds
  - Sender transmits 1500-byte UDP unicast packets as fast as possible
- Run bit rate adaptation schemes: SampleRate, ARF, AARF, ONOE
- **Static best** comparison point: for each bitrate, fix bitrate, test throughput

Indoor 802.11a Performance



Evidence that ARF spends too much time trying higher bit rates

Hop count and throughput



Minimum-hop-count routes are significantly **throughput-suboptimal**