802.11 a/g OFDM PHY

802.11 wireless networks, chapter 11
OFDM wireless LANs, part of chapter 3

S-72.333, Postgraduate Course in Radio Communications

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Outline

- Introduction
- OFDM overview
- OFDM in 802.11a
- 802.11a vs. 802.11g
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Introduction

- IEEE 802.11 standards:

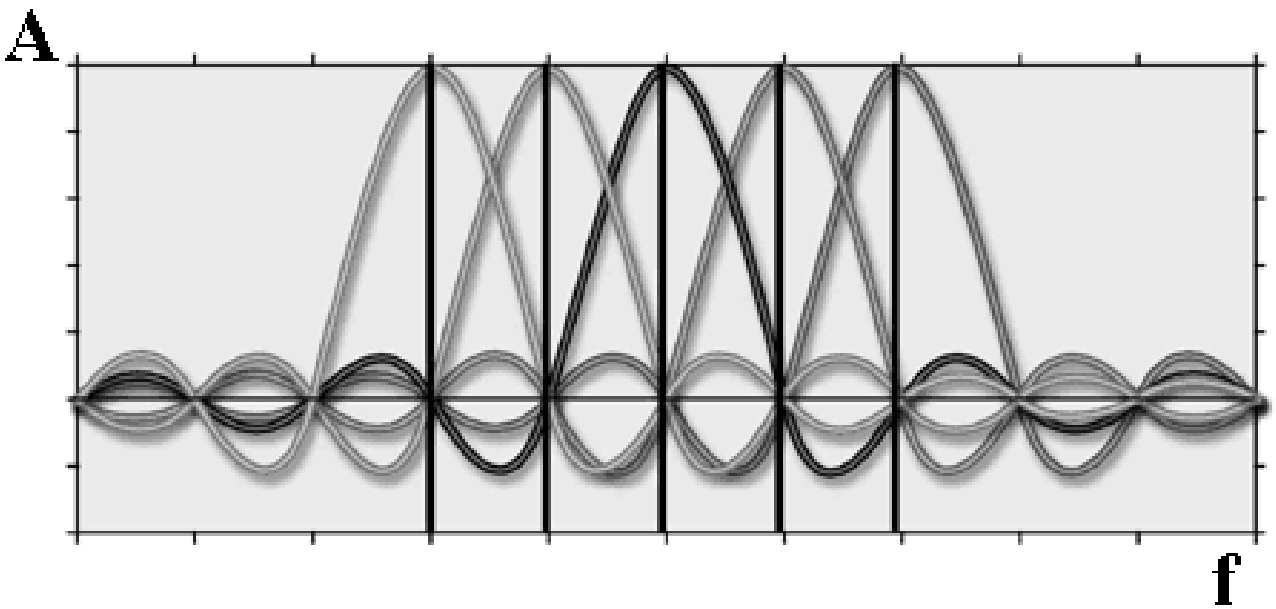
	802.11b	*802.11a*	*802.11g*
Standard approved	July 1999	July 1999	June 2003
Maximum data rate	11 Mbps	54 Mbps	54 Mbps
Modulation	CCK	OFDM	OFDM and CCK
Data rates	1, 2, 5.5, 11 Mbps	6, 9, 12, 18, 24, 36, 48, 54 Mbps	CCK: 1, 2, 5.5, 11 OFDM: 6, 9, 12, 18, 24, 36, 48, 54 Mbps
Frequencies	2.4–2.497 GHz	5.15–5.35 GHz 5.425–5.675 GHz 5.725–5.875 GHz	2.4–2.497 GHz

- Currently, 802.11b the most common. 802.11a/g, however, are increasing their popularity.
- Products of all three standards in the market

OFDM overview

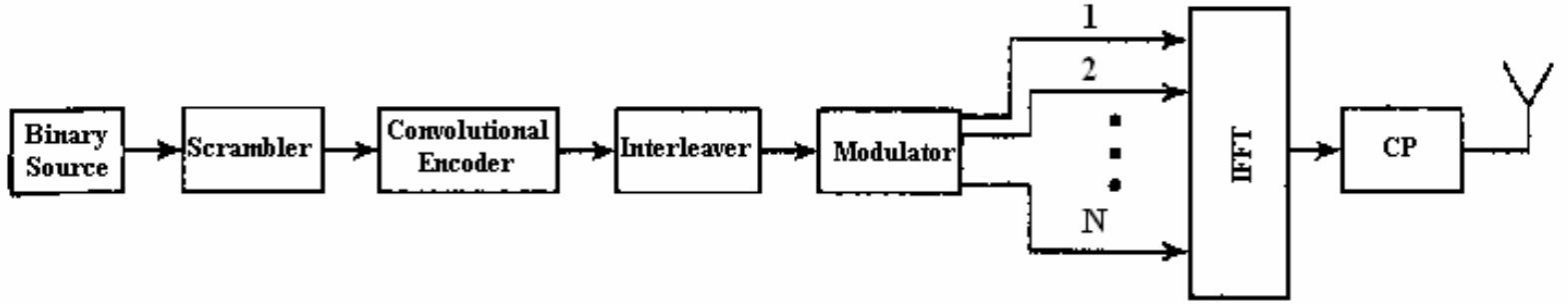
- Available bandwidth divided into subcarriers
- Subcarriers overlapping but orthogonal with respect to each other

  ⇒ at the peak of each subcarrier, the other subcarriers have zero amplitude



OFDM overview

- OFDM transmitter block diagram (N subcarries):



- After modulation, N parallel symbol streams (at 1/*N* of the original rate) are fed to the N-point Inverse Fast Fourier Transformer (IFFT)
- After IFFT, cyclic prefix (CP) is added (see the next slide) at the beginning of the symbol

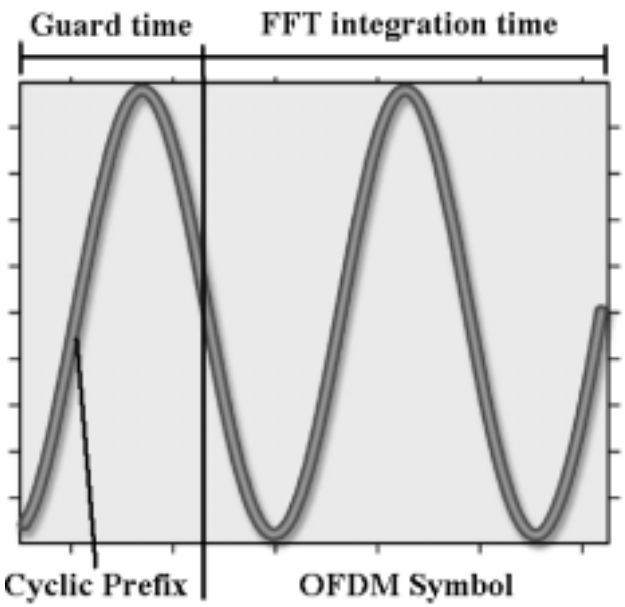
OFDM overview

- Problems in OFDM:
  - Frequency shift due to e.g. Doppler effect

  ⇒ Inter-carrier interference (*ICI*)
  - If large delay spread

  ⇒ Inter-symbol interference (*ISI*)

- OFDM solution: *guard time* and *cyclic prefix*.
  - Orthogonality maintained
  - Works well for delays shorter than the guard time

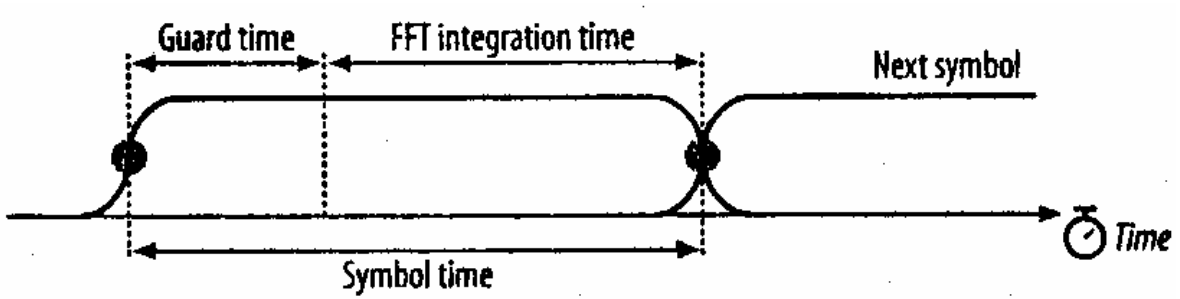


OFDM overview

- Strictly speaking, convolution coding is not part of OFDM. However, OFDM usually operated in applications with deep fading.

  ⇒ Convolution coding often used for error correction in conjunction with OFDM (COFDM)

- In OFDM, cosine windowing is often used to bring the signal gradually up and down:



OFDM in 802.11a

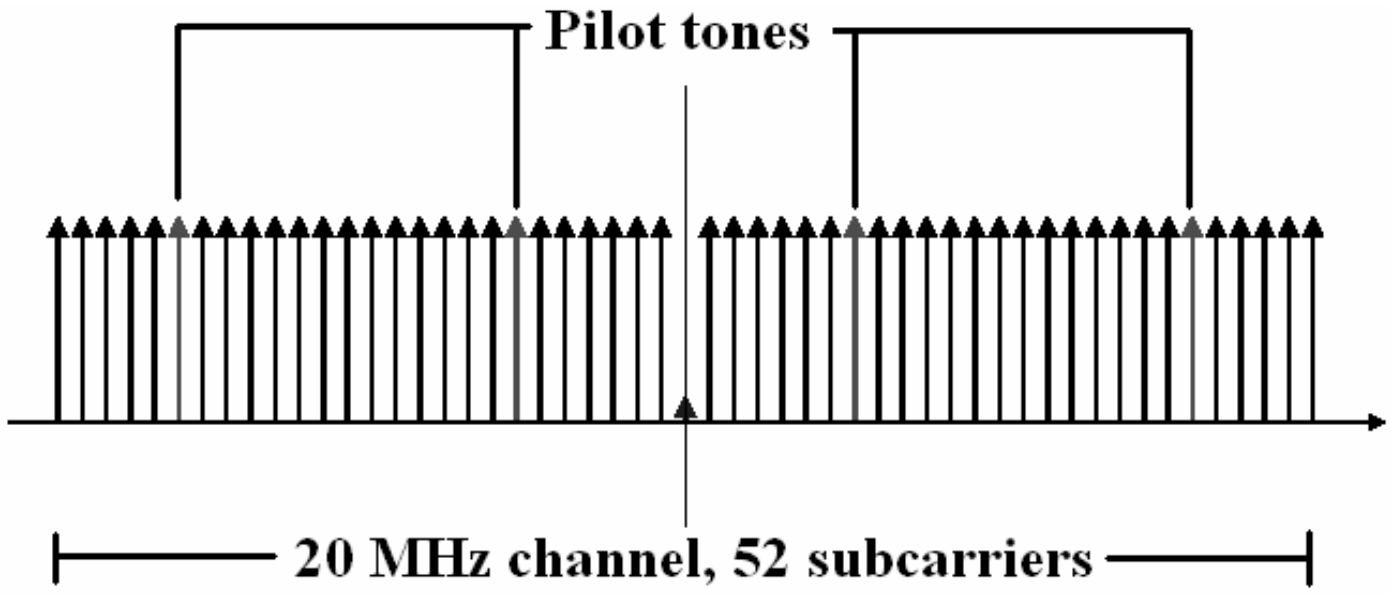
- Wide variety of choices in modulation and coding

  ⇒ data rates from low and reliable to high and more fragile can be realized

Data rate:	6, 9, 12, 18, 36, 48 or 54 Mbps
Modulation:	BPSK, QPSK, 16-QAM or 64-QAM
Coding rates:	1/2, 9/16, 2/3 or 3/4
Number of Subcarriers:	52
Number of Pilot Tones:	4
OFDM Symbol Duration:	4 μ sec
Guard Interval:	800 η sec
Subcarrier Spacing:	312.5 kHz
Signal Bandwidth:	16.66 MHz
Channel Spacing:	20 MHz

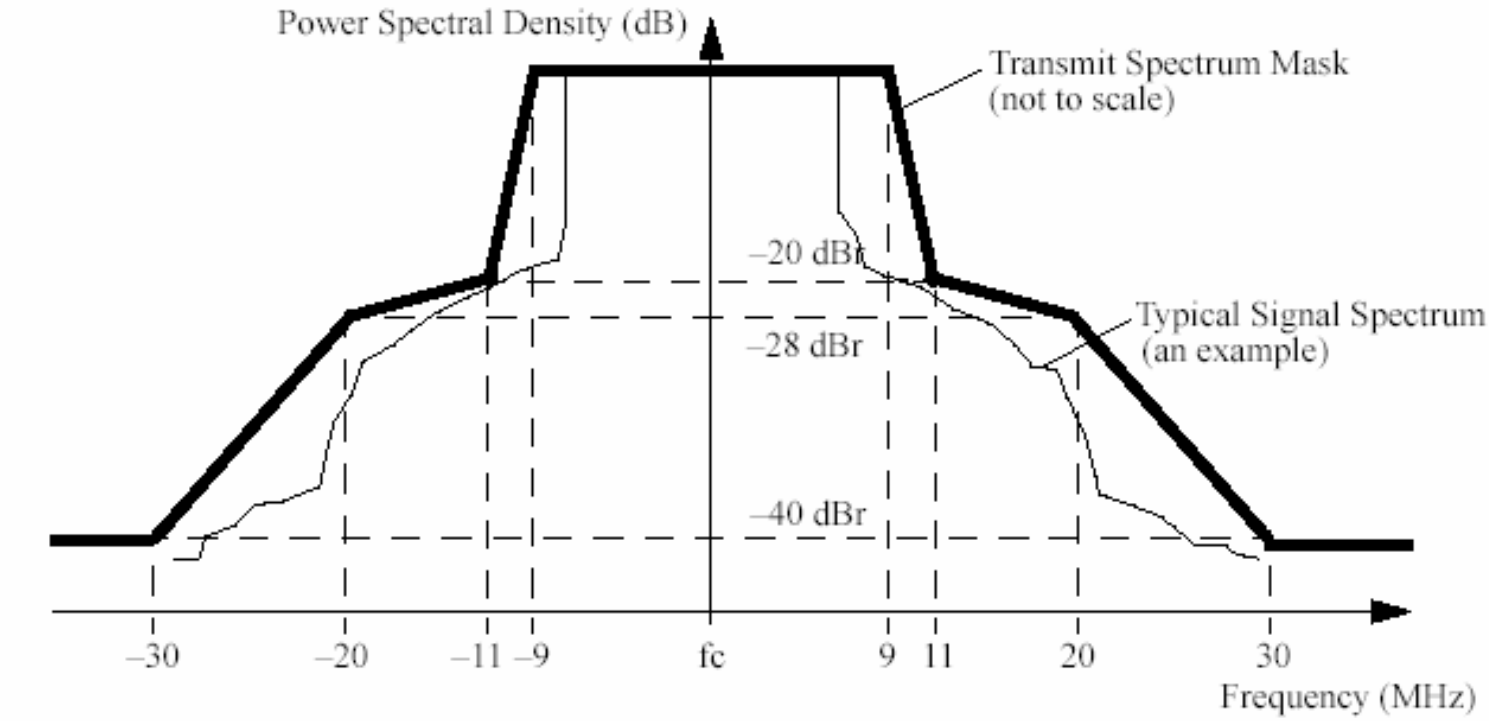
OFDM PHY in 802.11a

- Structure of an 20 MHz OFDM channel. Pilot carriers are used for monitoring path shifts and ICI.



OFDM PHY in 802.11a

- Transmit spectrum mask for 802.11a. The center frequency of the next carrier at 20 MHz.



OFDM PHY in 802.11a

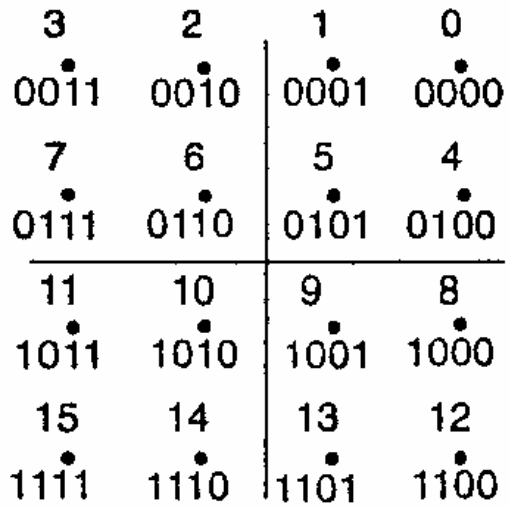
- Encoding details for each data rate in 802.11a PHY:

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

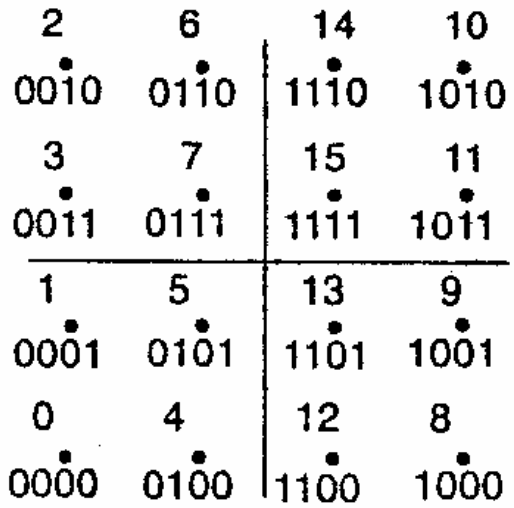
- Support is required for 6, 12 and 24 Mbps
- Either ½, ¾ or 2/3 of the coded bits are redundant

OFDM PHY in 802.11a

- Constellation point labeling in 802.11a (16QAM):



Natural order

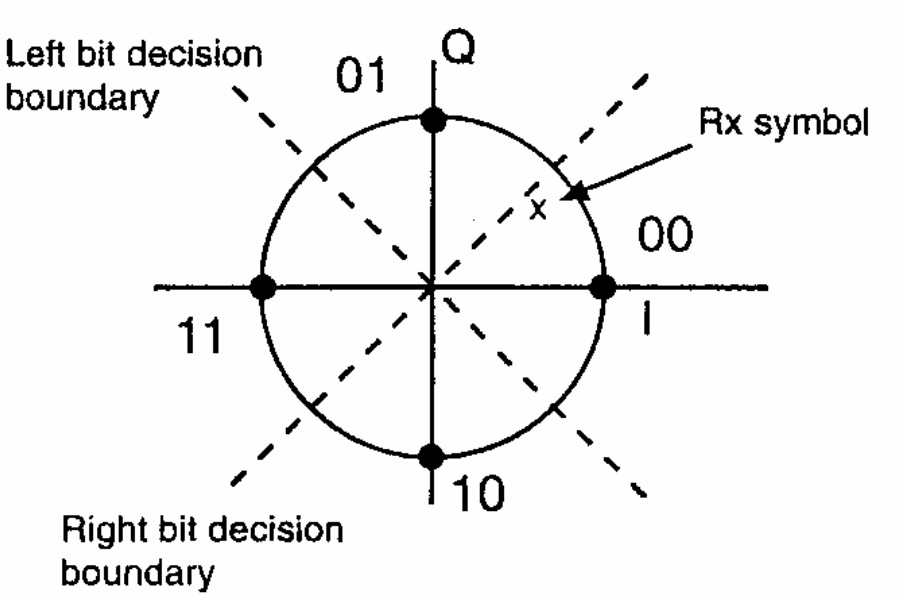


Gray coded

- In gray code, two-bit errors impossible between neighboring points

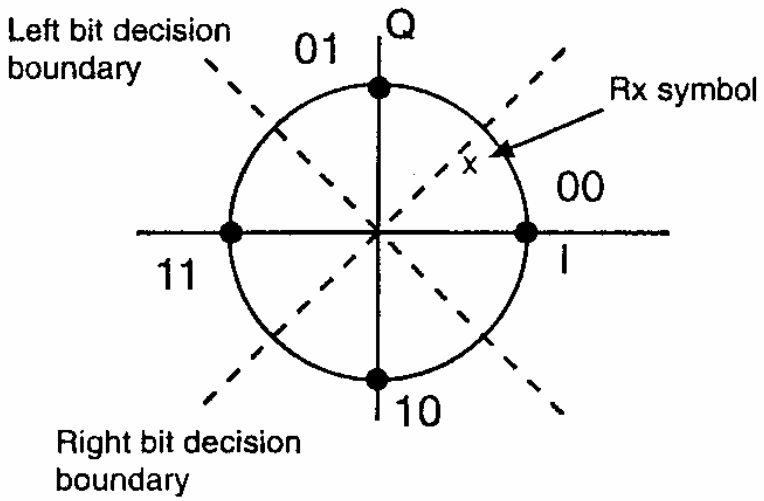
OFDM PHY in 802.11a

- Hard and soft decision demodulators:
  - *Hard decision:* Output of the modulator zeros and ones. Constellation point closest to the received symbol is selected. For example, decision boundaries of QPSK constellation:



OFDM PHY in 802.11a

- *Soft decision:* Output of the modulator retains information about the reliability of the decision. The reliability of the detected bits coded in the absolute value of the bits. The absolute value is the distance to the decision boundary.

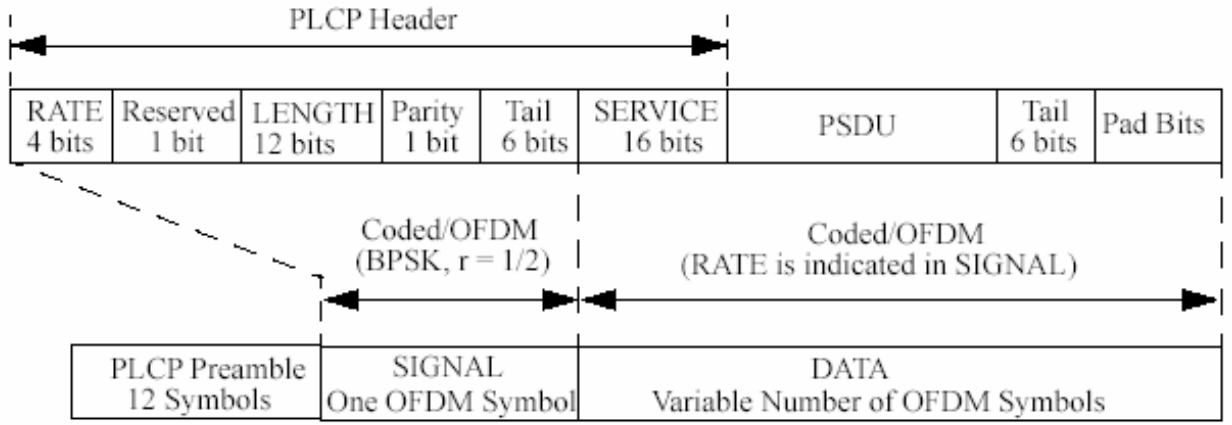


- Soft decision can greatly improve the performance of channel coding chemes

⇒ used in OFDM PHY of 802.11a!!

OFDM PHY in 802.11a

- PLCP (Physical Layer Convergence Precedure): Boundary between MAC and wireless medium. OFDM 802.11a PLCP framing format:



  - *PLCP preamble:* used for synchronization of various timers between the transmitter and the receiver.
  - *Rate:* Indicate the data rate applied in the DATA-field
  - *Length:* Number of bytes in the embedded MAC frame
  - *Tail:* 0-bits used to unwind the convolution code
  - *Service:* Transmitted in the data field at the data rate of the MAC frame. Currently used to initialize the MAC frame scrambler
  - *Pad Bits:* Data field required to be integer multiple of block size => padding

OFDM 802.11a vs. 802.11g

- Good sides of OFDM 802.11a compared to OFDM 802.11g
  - The unlicenced 5.2 GHz band provides more spectrum space than the 2.4 GHz band. In addition, there are few devices on the market operating at 5.2 GHz, whereas 2.4 GHz is heavily used.
- Drawbacks of OFDM 802.11a compared to OFDM 802.11g
  - Higher frequencies have higher path losses

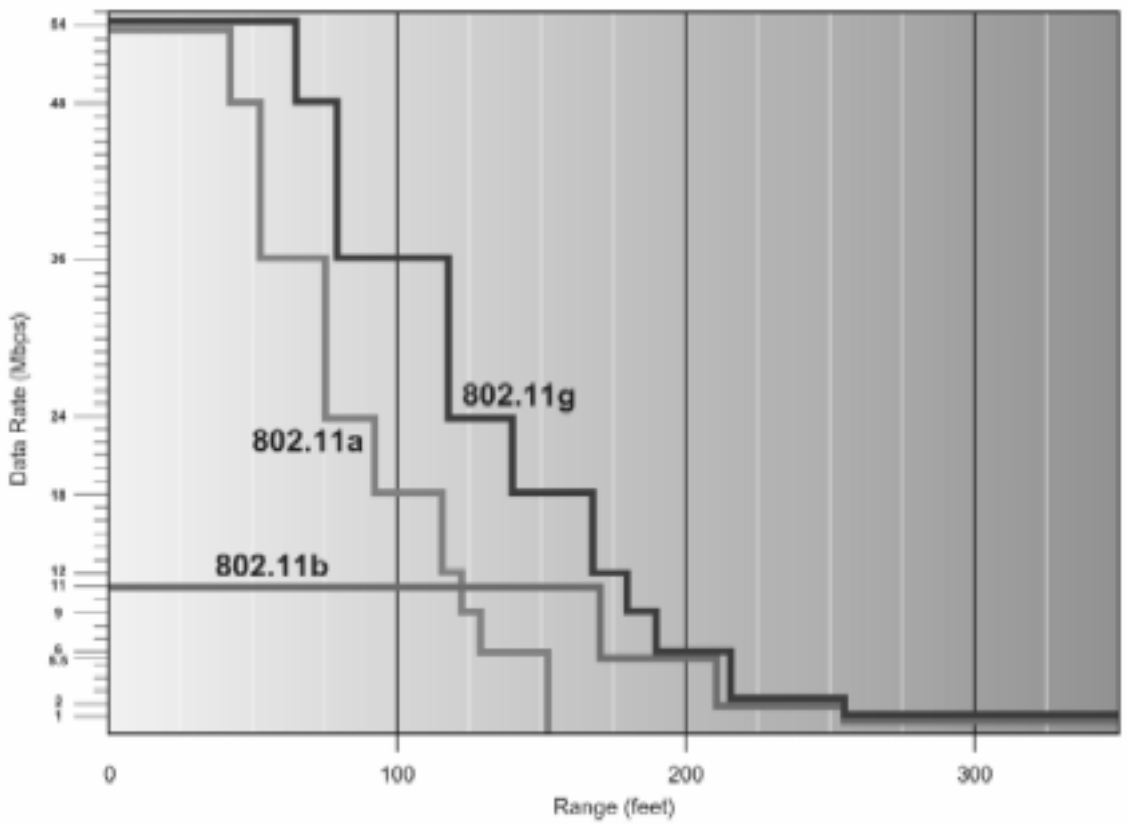
  ⇒ 802.11a base stations have to be deployed more densely than 802.11b/g base stations. At the highest data rates, line of sight usually needed
  - Not compatible with the most popular standard 802.11b

WLAN Technology Characteristics

WLAN Technology	*Peak Speed*	*Capacity*	*Range*	*802.11b Compatible*	*Cost*
802.11b	Medium	Low	High	Yes	Low
802.11a	High	High	Low	No	Medium
802.11g	High	Medium	High	Yes	Low

OFDM 802.11a vs. 802.11g

- Data rates vs. operating distances of different 802.11 standards:



Discussion

- Both OFDM 802.11a and OFDM 802.11g have their good sides and drawbacks.
- 802.11g, however, is more promising due to larger operating distance and compatibility with the widely used older 802.11 standards
- The standardization of 802.11g is first step towards dual-band WLANs capable of operating at 2.4 GHz and 5.2 GHz using OFDM (forward compatibility of 802.11g with 802.11a)

References

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[5] http://www.54g.org/docs/802.11g-WP104-RDS1.pdf

[6] http://nwest.nist.gov/mtg3/papers/chayat.pdf

[7] http://www.sss-mag.com/pdf/802_11g_whitepaper.pdf

[8] http://www.commsdesign.com/design_corner/OEG20020201S0035

[9] http://www.skydsp.com/publications/4thyrthesis/

[10] http://www.iec.org/online/tutorials/ofdm/topic04.html?Next.x=40&Next.y=18

Homework

- Compare the performance of different coherent modulations schemes (ASK, PSK, QAM). Why FSK cannot be used in OFDM applications? Justify the selection of BPSK, QPSK, 16-QAM and 64-QAM for 802.11a WLANs.

Thank You!

Questions?