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802.11a Wireless Networks: Principles and Performance

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Agenda

Wireless LAN Introduction

- Markets and applications

802.11a Principles

- Phy and MAC overview – OFDM and CSMA/CA

Atheros Solution

- Two-chip CMOS solution

802.11a Performance

- Actual operation in a typical office environment

Questions?

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802.11b (Wi-Fi) → 802.11a (Wi-Fi5)

Wireless Local Area Networks (WLANs)

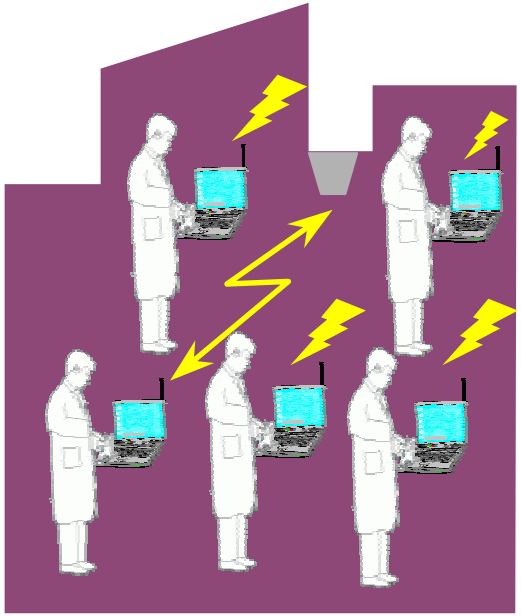
11b: Untethered connectivity

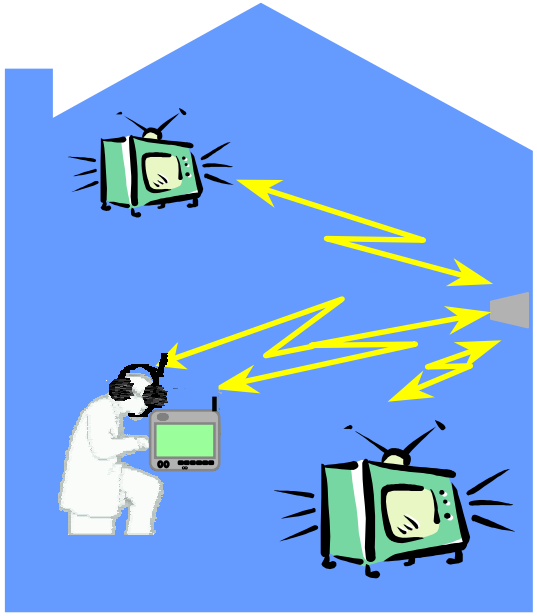
11a: Increased capacity or reduced cost

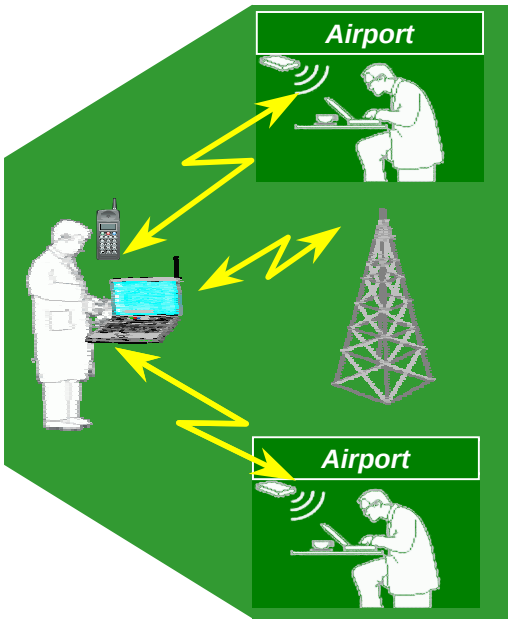
Multimedia capable

Hot-spot coverage

WAN / LAN bridge







Office

Home

"Hot-spots"

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802.11a Principles

Orthogonal Frequency Division Multiplexing (OFDM)

- Multipath effects
- Combating with OFDM
- Cyclic prefix

802.11a physical layer

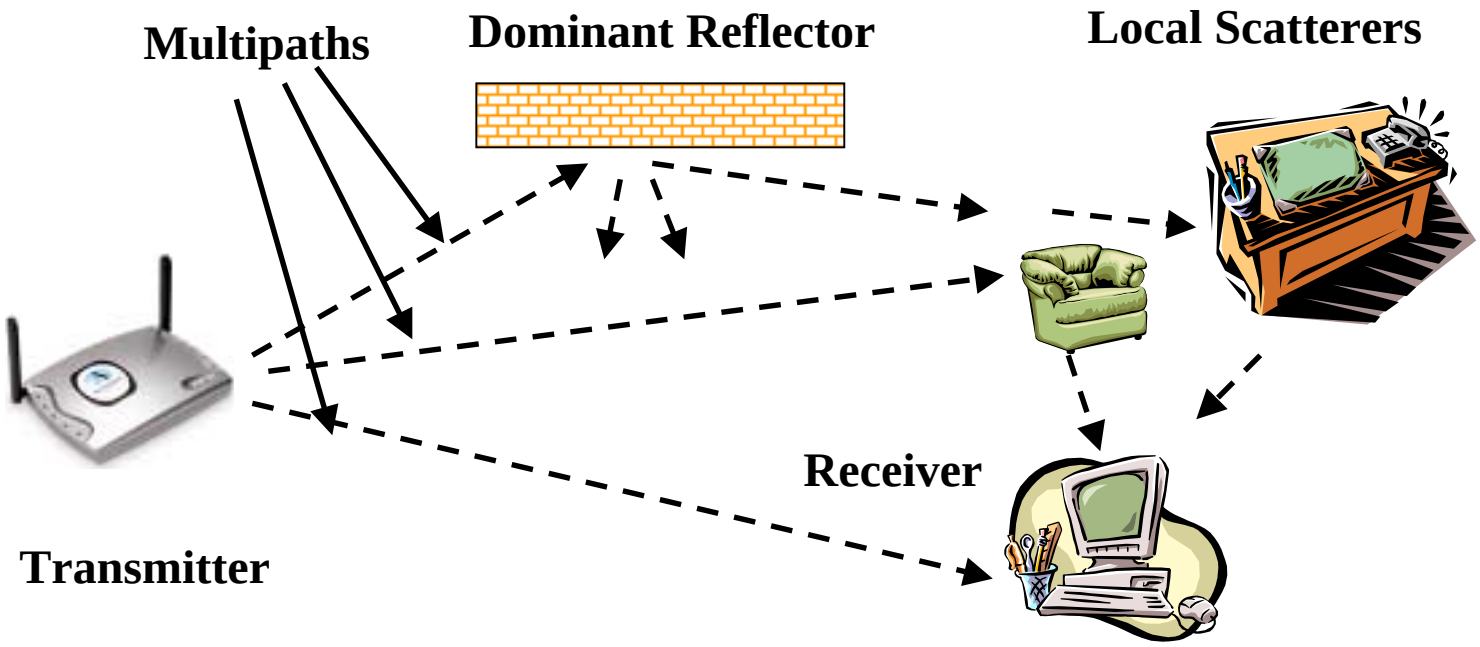
- Packet format
- Data rates: modulation and error correction
- 5GHz spectrum regulations

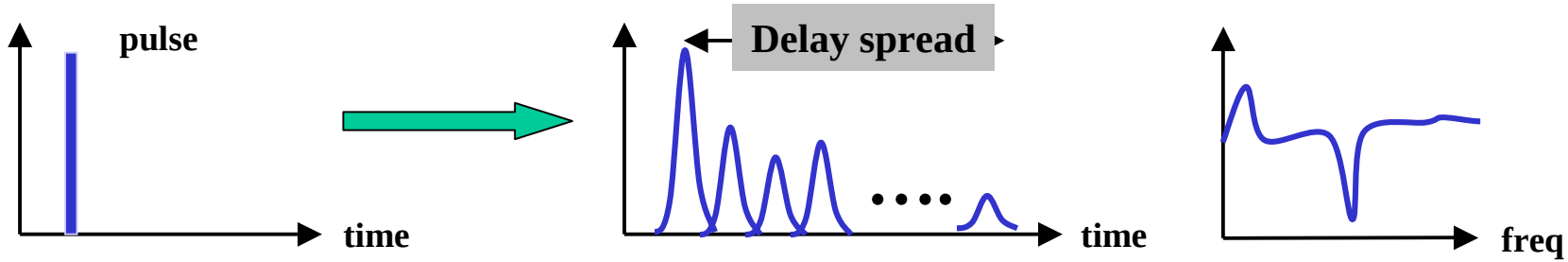
802.11 MAC basics

- Overview
- Carrier-sense multiple access with collision avoidance (CSMA/CA)

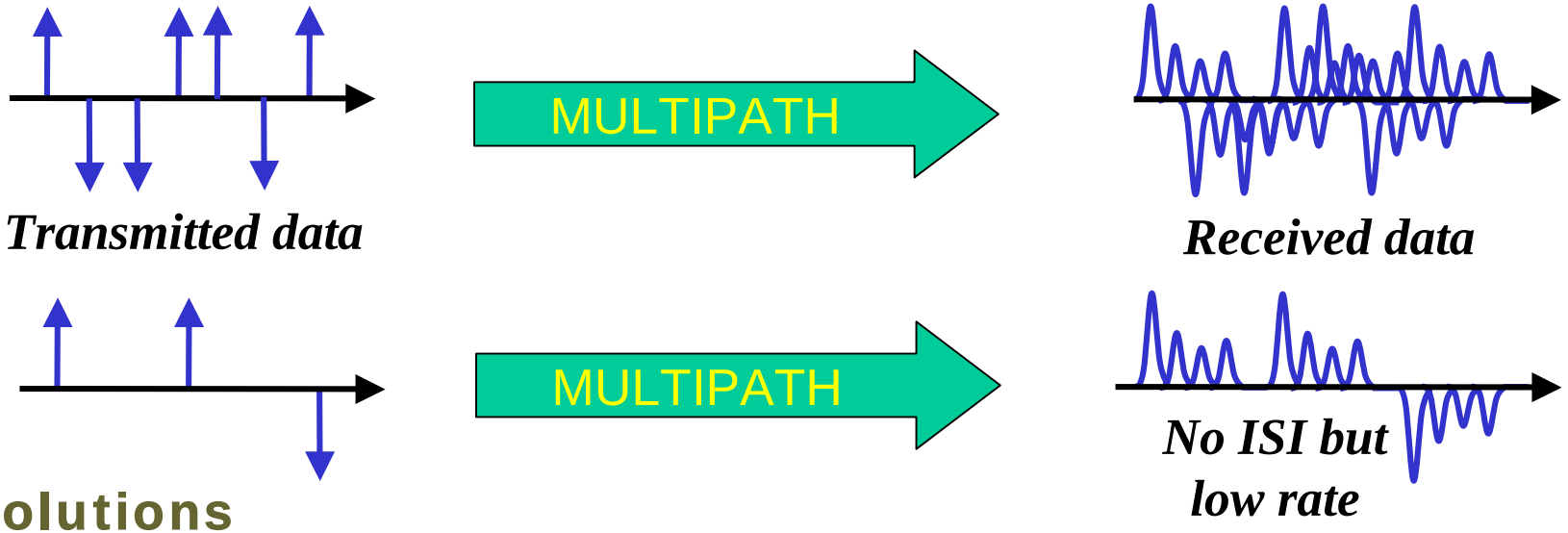
IEEE 802.11 task groups

Multipath Effects





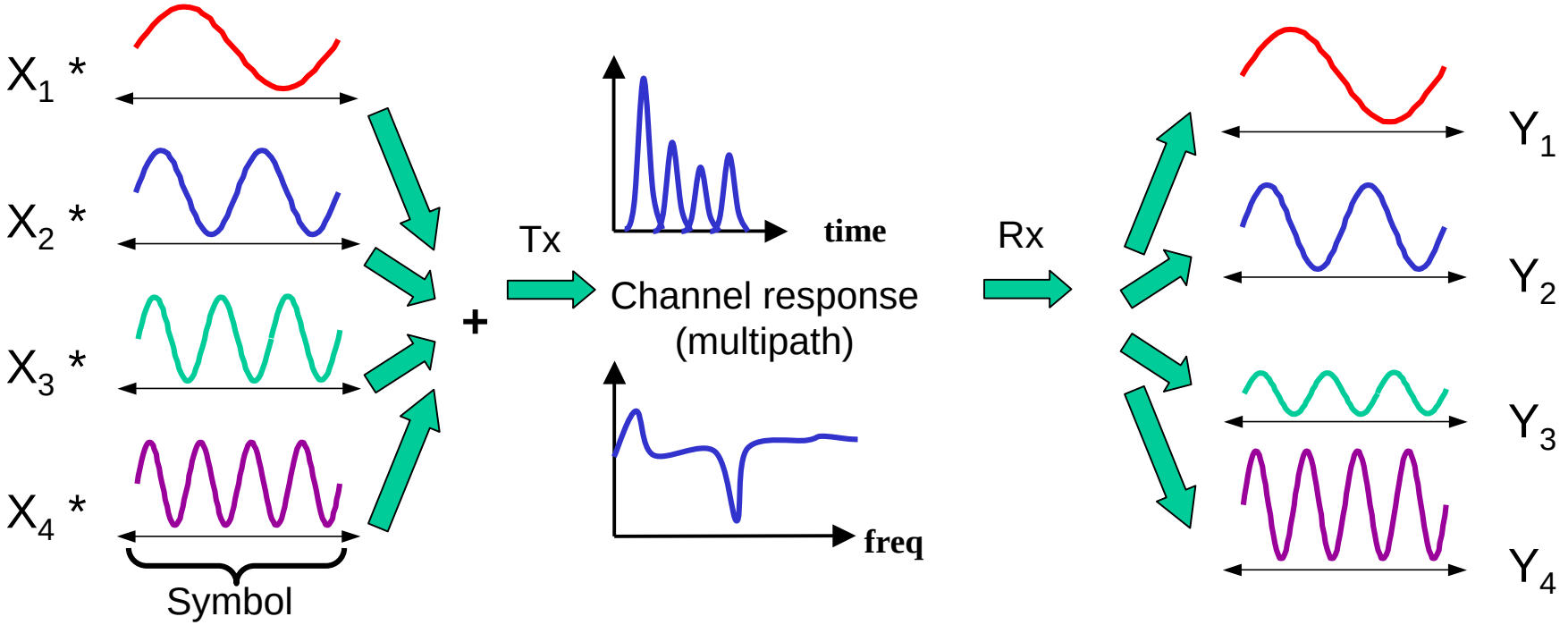
Inter-Symbol Interference (ISI)

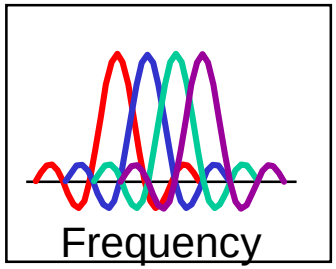


Solutions

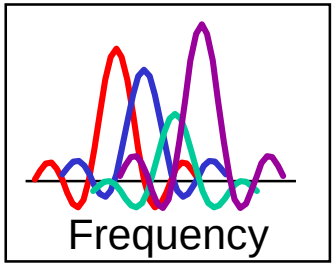
- **Lower data rate**
- **Equalization**
  - Complexity, performance
- **Code as multiple low-rate streams**
  - Each stream at different frequency - OFDM

Introduction to OFDM Modulation



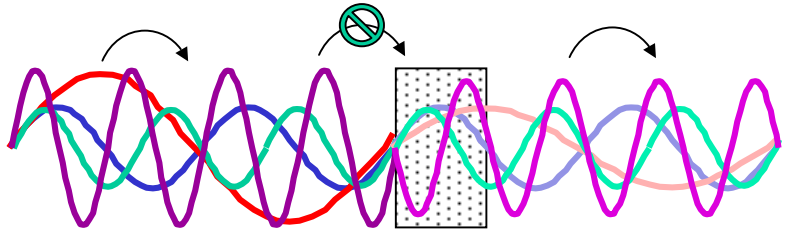


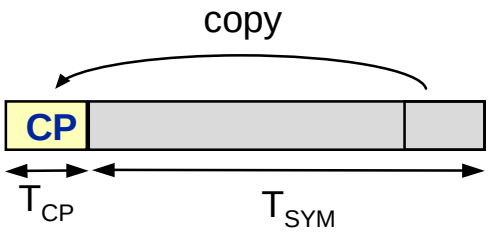
- **Different data per tone (via FFT)**
- **Multipath just scales tones**
- **Tones remain orthogonal even with multipath**
  - Cyclic prefix between symbols



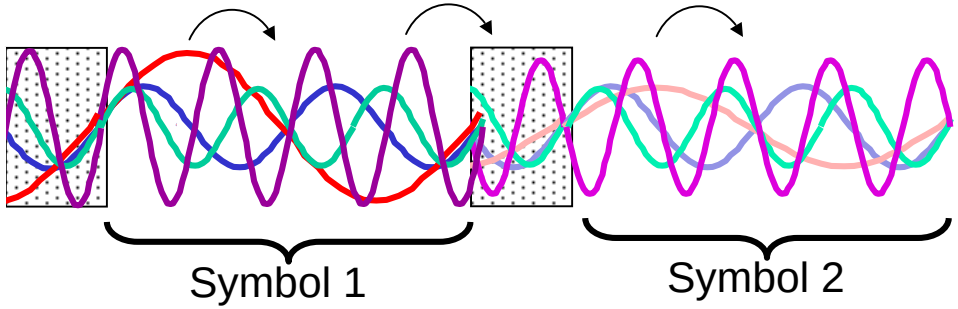
OFDM Cyclic Prefix

No CP



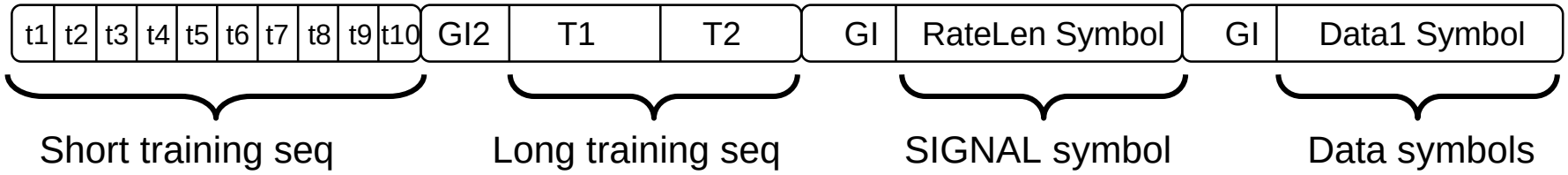


With CP



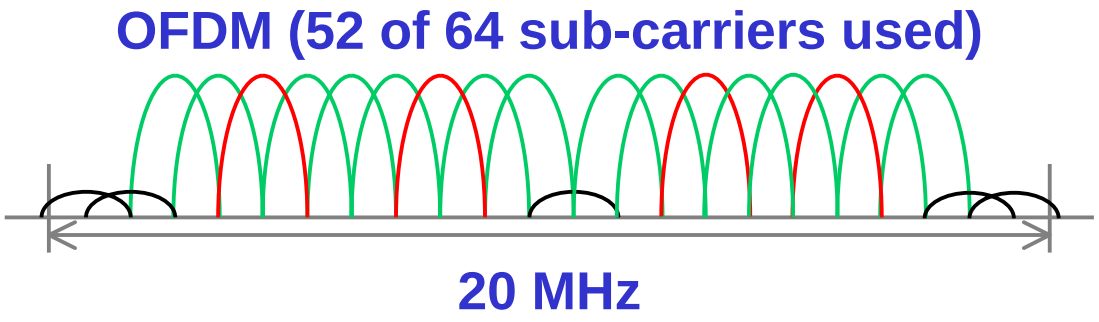
- **Using sinusoidal tones, echoes within symbols ok**
- **However cross-symbol echoes still corrupt**
- **Cyclic prefix prepends end of symbol to beginning**
- **Receiver ignores prefix period (guard interval)**
- **Prefix is length of longest expected echo length**
  Short compared to symbol duration for efficiency

802.11a Physical Layer Data Format



- **"Short" training sequence**
  - 10 symbols of 0.8us each
  - Used for AGC and frequency offset estimation
- **"Long" training sequence**
  - 2 symbols of 3.2 us each + 1.6us guard interval
  - Used for channel estimation
- **"SIGNAL" field**
  - Indicates data rate and length of remaining data
  - Coded in lowest rate
- **Data symbols**
  - Coded in one of eight data rates from 6 Mbps to 54 Mbps

Symbol Encoding



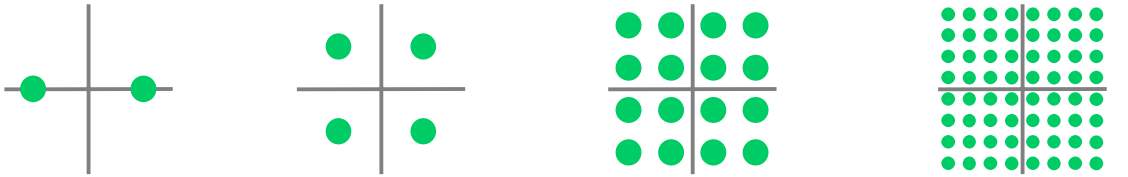
Channel sampled at 20MHz

- 64-sample (3.2us) symbols
- 16-sample (0.8us) cyclic prefix / guard interval
- 250 Ksymbols per second

Of 64 the subcarriers:

- 12 zero subcarriers (in black) on sides and center
  - Side is frequency guard band leaving 16.5MHz occupied BW
  - Center subcarrrier is zero for DC offset / carrier leak rejection
- 48 data subcarriers (in green) per symbol
- 4 pilots subcarriers (in red) per symbol for synchronization / tracking

Data Encoding



Data subcarrier encoding

- BPSK, QPSK, 16QAM, 64QAM
- 1, 2, 4, 6 bits/subcarrier

Error corrective coding

- 1/2, 2/3, or 3/4 rate convolutional code
- Increased robustness
- Subcarriers interleaved before coding

Overall data rates:

- 6, 9, 12, 18, 24, 36, 48, 54 Mbps
- Lowest: 48 * 1 * 1/2 * 250K = 6 Mbps
- Highest: 48 * 6 * 3/4 * 250K = 54 Mbps

5GHz Spectrum Regulations

- Different applications use different bands. 12 channels total in US.
- FCC designed 5-GHz for "wide-band use" and "high rate digital systems"

	5.15 – 5.25GHz	5.25 - 5.35GHz	5.470 – 5.725GHz	5.725 – 5.825GHz
U.S.	40mW (Max) 160mW (EIRP) Indoor	200mW (Max) 800mW (EIRP) Indoor/Outdoor		800mW (Max) 3.2 or 160W (EIRP) Indoor / Outdoor
Europe	200mW (EIRP) Indoor		1W (EIRP) Indoor/Outdoor	25mW (EIRP) (5.725-5.875GHz)
Japan	200mW (EIRP) Indoor			

- 2.4GHz allows 3 channels in US, most of Europe, 1 in France/Spain/Japan
  1000mW in US, 100mW EIRP in Europe, 10mW/MHz in Japan

802.11 Wireless LAN MAC Services

802.11a and 802.11b share same 802.11 MAC

Basic LAN service

- **Replaces Ethernet**
  - Seamlessly used by higher level protocols such as TCP/IP
- **“Best effort” datagram service**
  - Tailored for wireless environment
- **CSMA/CA (“wireless Ethernet”)**

Special services for wireless environment

- **Roaming**
- **Power management**
- **Security**

Enterprise, small office, home, consumer electronics

802.11 Network Architecture

Infrastructure mode

- **Access Point (AP)**
  - Essentially a bridge between wireless cells and wired infrastructure
  - Provides authentication, packet forwarding
- **Stations associate with a particular AP**
- **Stations may roam with no loss of service**
  - Roaming mechanism provides redundancy and robustness in addition to mobility

Ad-hoc mode

- **Ad-hoc mode allows operation without any AP**

Multi-Access Scheme

802.11 uses carrier-sense multiple access with collision avoidance (CSMA/CA)

CSMA/CA transmit operation

- Wait until medium free for random amount of time and send data
- After collision (or error) exponentially increase duration and retry

Ethernet uses carrier-sense multiple access with collision detection (CSMA/CD)

- Ethernet-style collision detection impossible for wireless system
  - A single radio is either transmitting or receiving - but not simultaneously

Optional request-to-send (RTS) / clear-to-send (CTS)

- Useful for hidden node situations
- Decreases throughput efficiency

IEEE 802.11 Task Groups

802.11 Task Groups extend both 802.11a & 802.11b

- **Task Group E for quality of service (QoS):**
  Enhance 802.11 MAC to improve and manage quality of service and provide classes of service (e.g. for multimedia, etc)
- **Take Group F for multi-vendor AP interoperability:**
  Develop recommended practices for Inter-Access Point Protocol (IAPP) to achieve distribution system wide multi-vendor access point interoperability
- **Task Group G for higher rate 802.11b:**
  Develop new PHY extension to enhance the performance of 802.11b compatible networks by increasing the achievable data rates
- **Task Group H for regulatory approval in Europe:**
  Enhance the 802.11 MAC and 802.11a PHY to provide Dynamic Frequency Selection (DFS), and Transmit Power Control (TPC)
- **Task Group I for advanced security:**
  Enhance the 802.11 Medium Access Control (MAC) to improve security and authentication mechanisms

802.11a is a Reality Today

Higher Performance: Atheros AR5000 enables new applications

- IEEE 802.11a standard-compliant up to 54Mbps
- Support for speeds up to 72Mbps in Atheros Turbo Mode™
- 100+ Mbps is being supported by Atheros customers
- 128-bit WEP at full line speed, 802.1x authentication, dynamic key exchange and key caching

Cost-effective: Atheros highly-integrated all-CMOS two-chip set

- Complete solution with "Radio-on-a-Chip" (RoC) & MAC / Baseband
- All in standard process 0.25 micron digital CMOS – The sweet spot!
- Elimination of external SAW filters, VCOs, RAM, flash memory, etc.

Reality: Atheros-driven™ 11a products in volume production NOW

- Client cards and access points available from partners include: Actiontec™, Intel®, MobileLAN™, Netgear®, Proxim, SMC® Networks, Sony, TDK®, UltraDevices

Applications and Solutions

Card Access

- PC OEMs and SOHO
- Full range of client products including CardBus, Mini PCI and PCI

Intel

- Enterprise, small-medium business, education, verticals and OEM
- Complete line to include access point, CardBus PC Card, PCI, Starter Kit, Mini PCI

Intermec

- Enterprise, SOHO, industrial/manufacturing and retail access point and client card

Proxim

- Enterprise including corporate, education, healthcare and government
- Harmony 802.11a Access Point and Harmony 802.11a PC Card

SMC Networks

- CardBus PC card and Access Point

Sony

- CardBus PC card and Access Point

TDK

- PC OEM and retail. CardBus and Mini PCI client cards, value line and feature rich access points and multi-function Mini PCI client solutions

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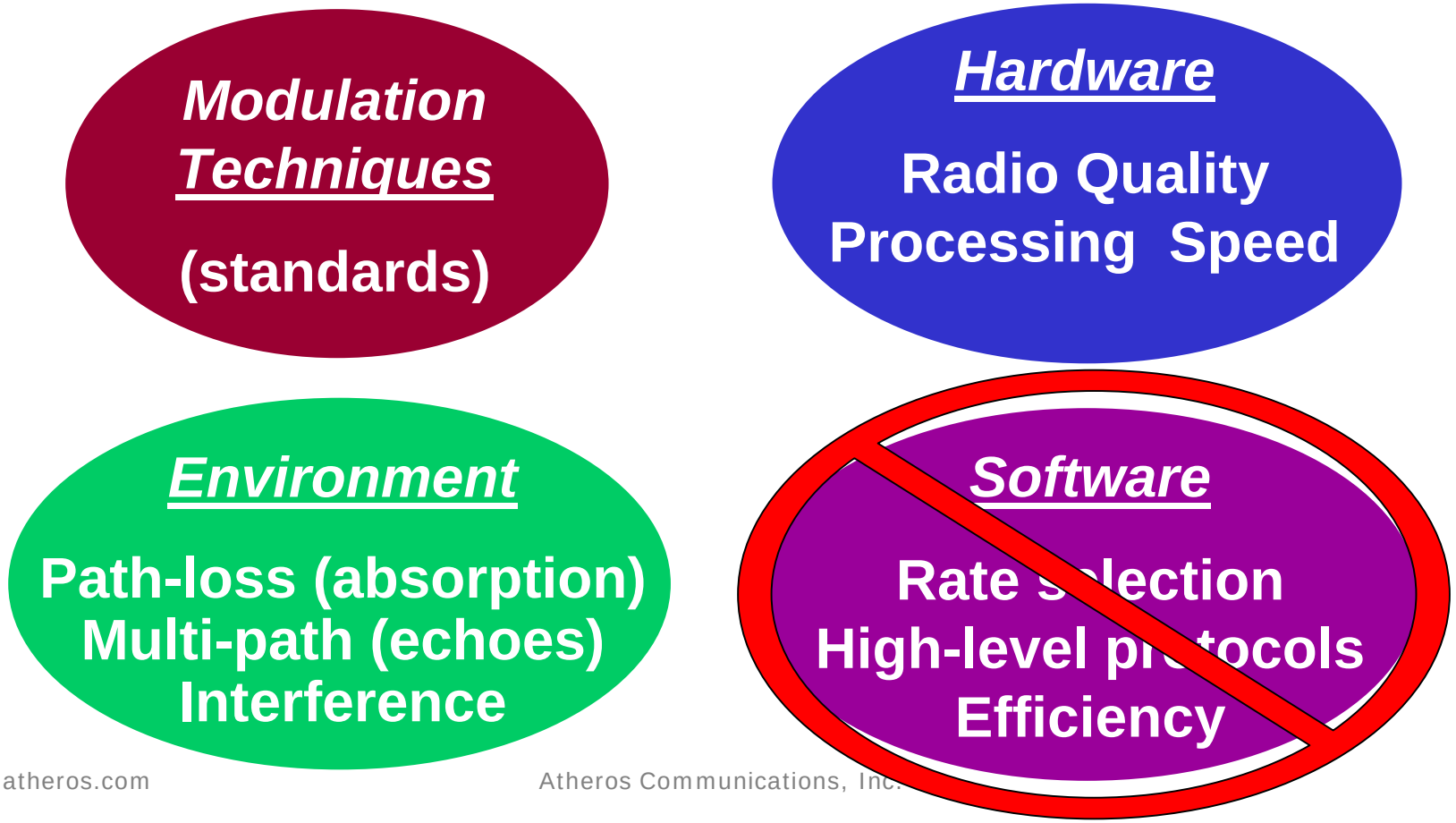
802.11a/b WLAN Comparison

	802.11a	802.11b
Standard Approved	Sept. 1999	Sept. 1999
Available Bandwidth	300MHz	83.5MHz
Frequency of Operation	5.15-5.35GHz, 5.725-5.825GHz	2.40-2.4835GHz
Number of Non-Overlapping Channels	12	3
Data Rate per Channel	6, 9, 12, 18, 24, 36, 48, 54Mbps	1, 2, 5.5, 11Mbps
Modulation Type	OFDM	DSSS

Evaluating WLAN Performance

Many factors affect WLAN performance…



802.11a/b Performance Measurements

Environment

- Typical office environment (up to 225 ft. diameter)
- Initial tests at Atheros' Sunnyvale office
- Fixed access point, client moved to 80 locations in cubicles and offices
- Future testing in other environments

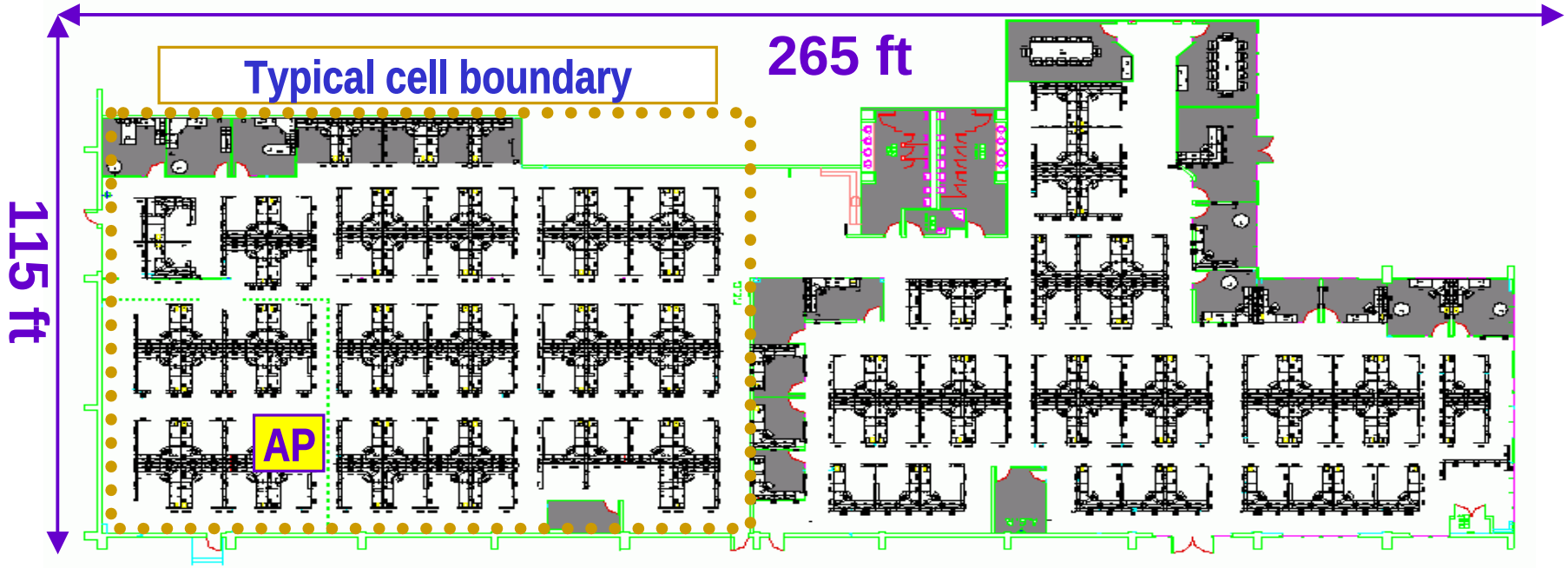
Hardware

- Atheros 802.11a PC Card reference design
- 802.11b PC Card and Access Point from a leading vendor
- Future testing with 802.11a APs and software

Methodology

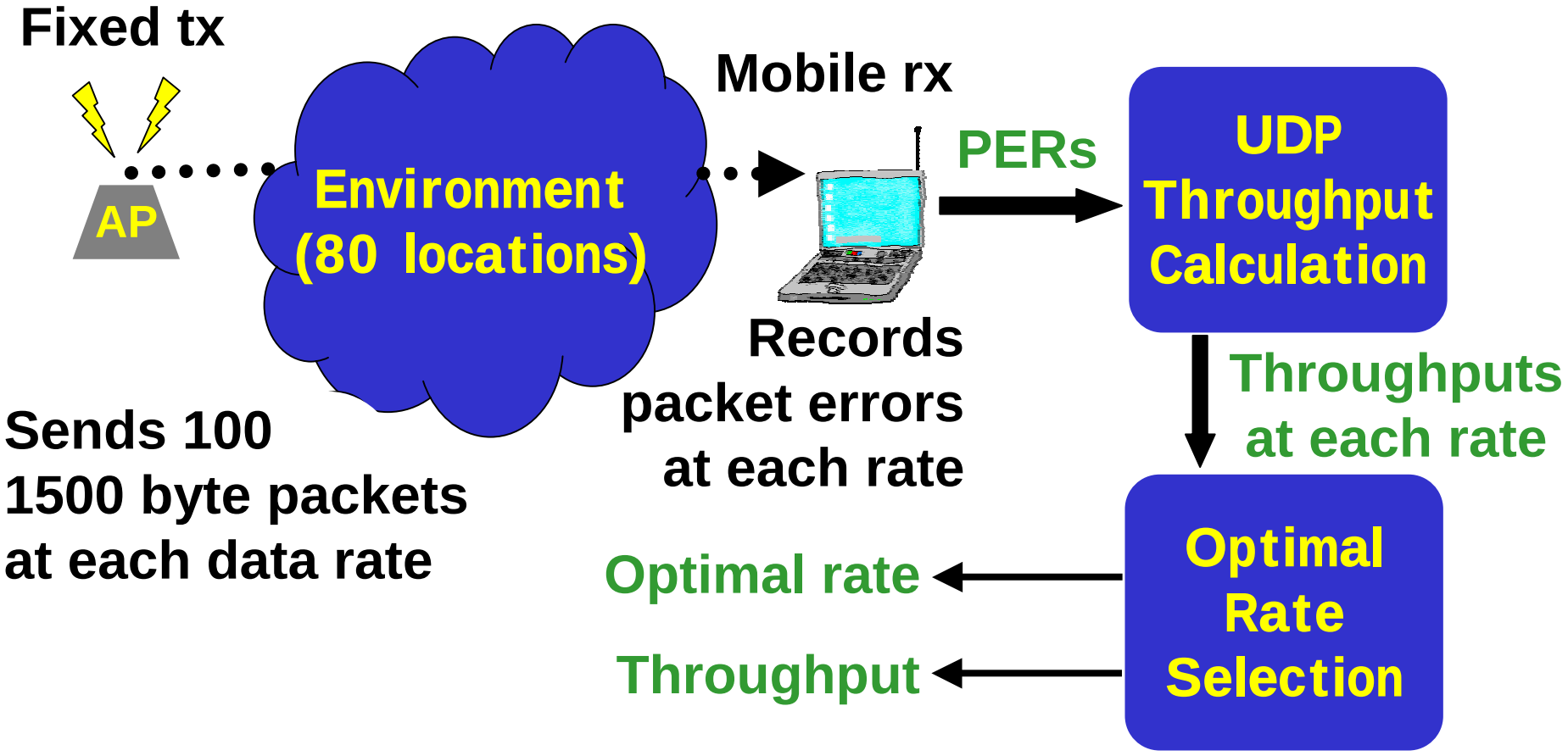
- Physical-layer testing
- Packet error rates used to determine performance
- See Atheros white paper at www.atheros.com for more details

Atheros Office Environment



- AP fixed (elevated) at far end
- 80 test locations in cubicles & offices

Physical-Layer Testing for 11a and 11b



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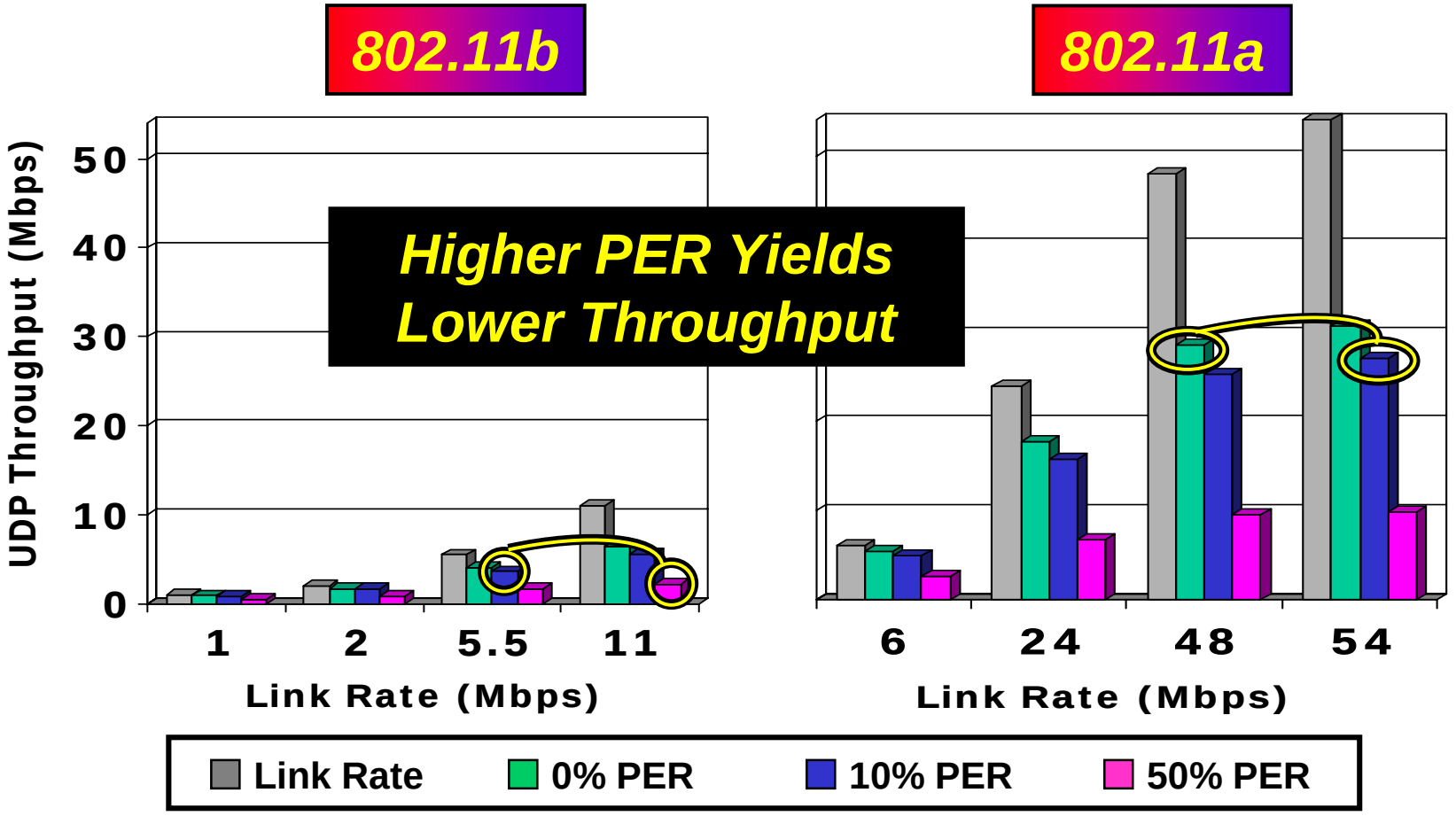
Understanding UDP Throughput



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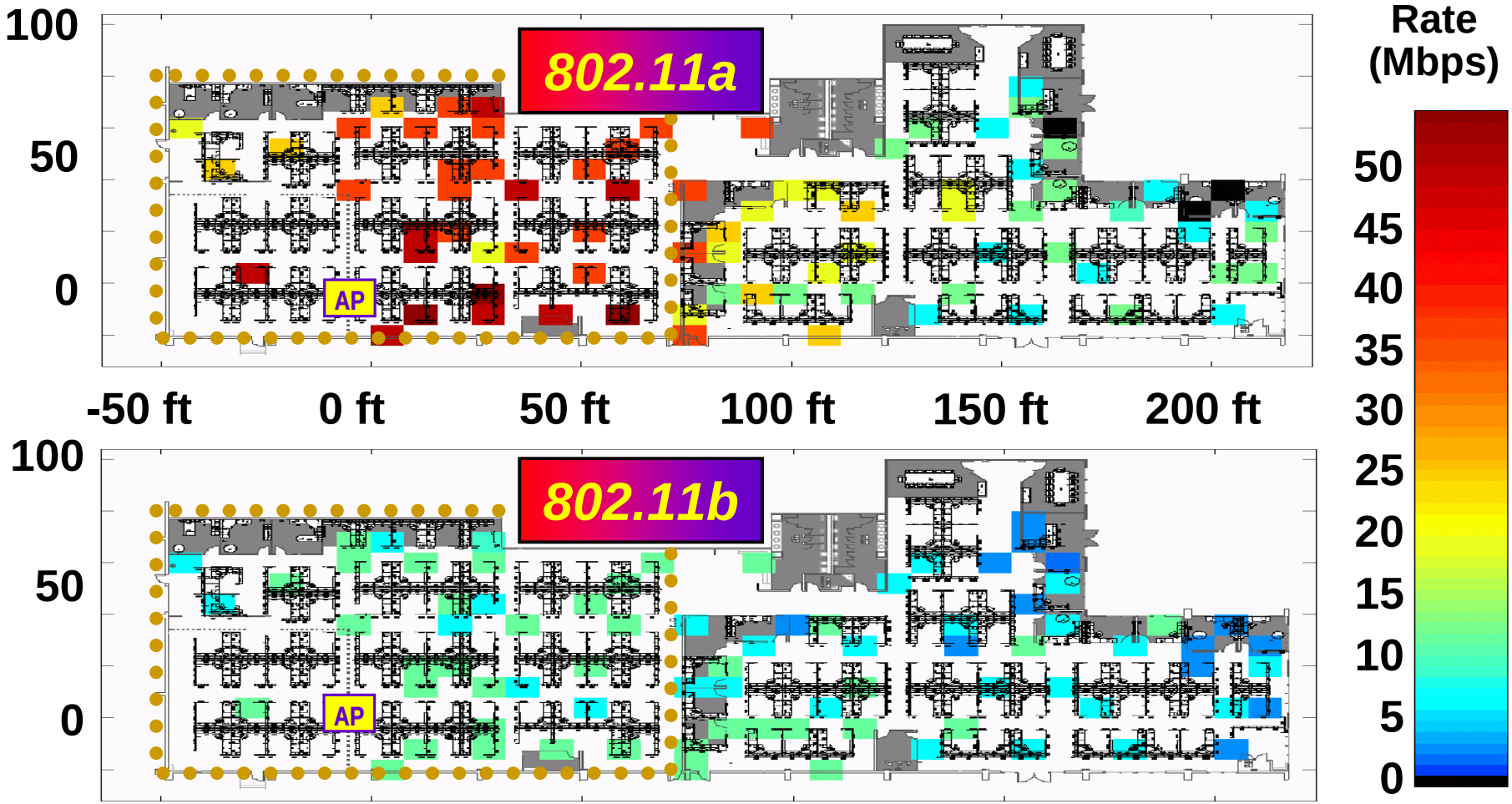
Optimal Data Link Rate



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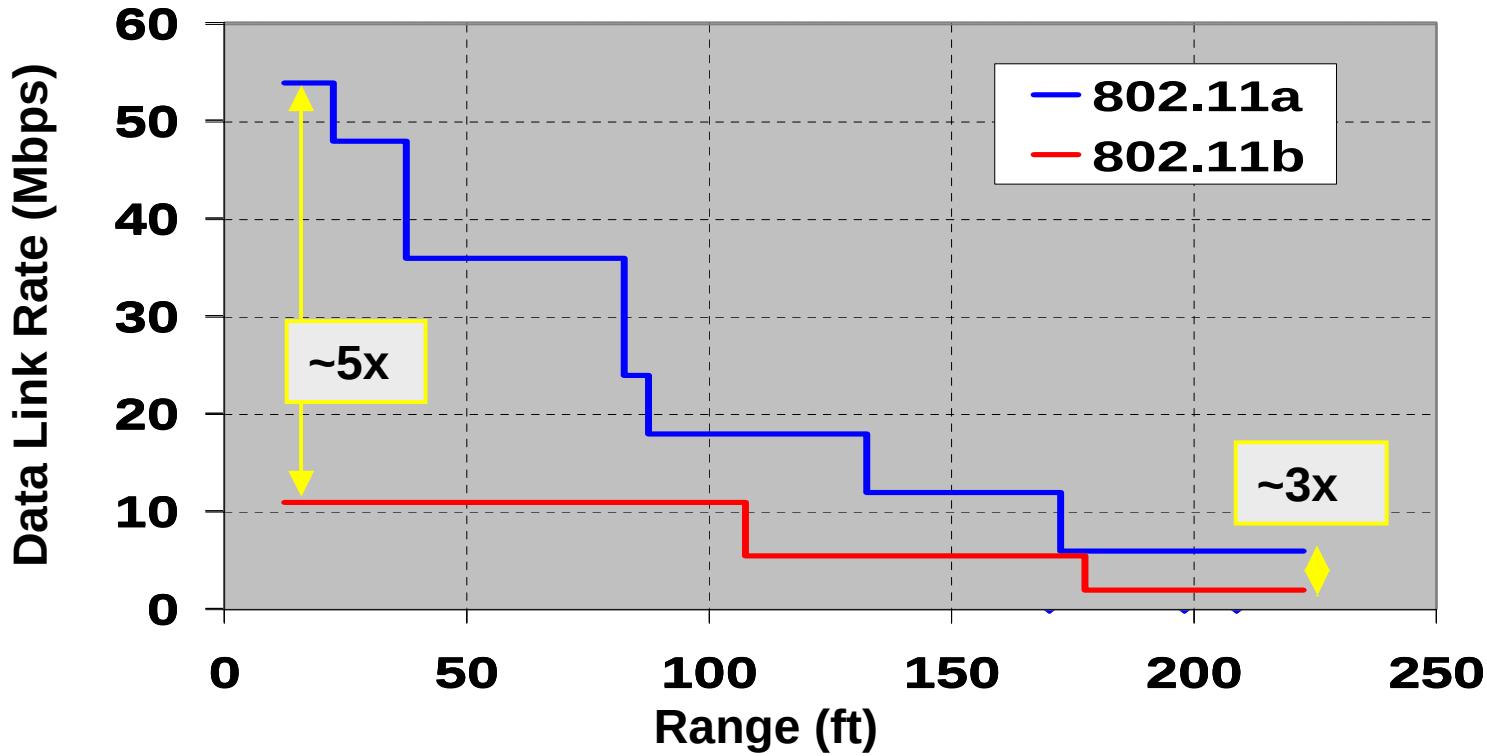
Higher Measured Link Rates with 11a

Link rates of 802.11a are 2 to 5 times those of 802.11b at the same distance when tested to 225 feet



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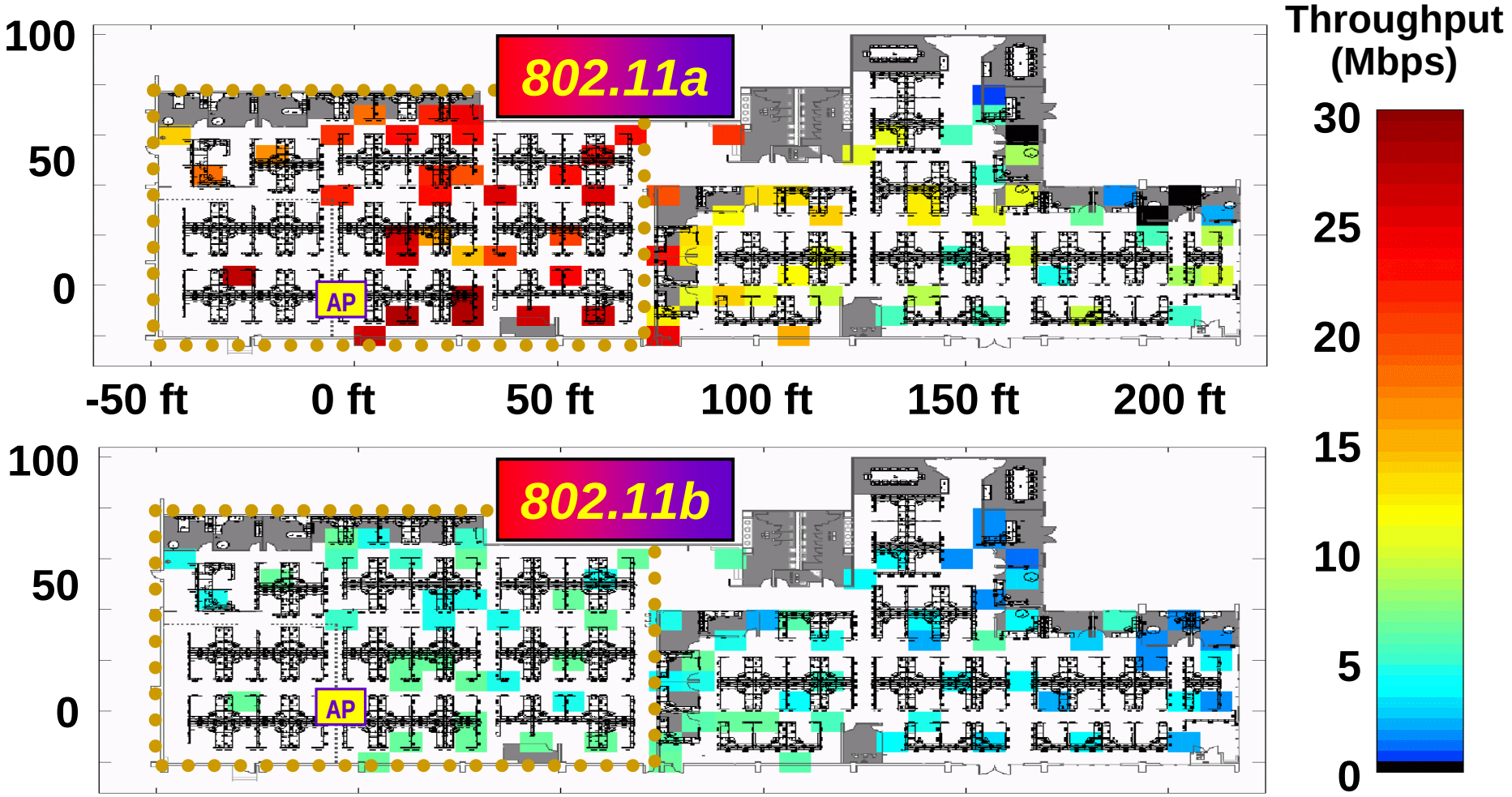
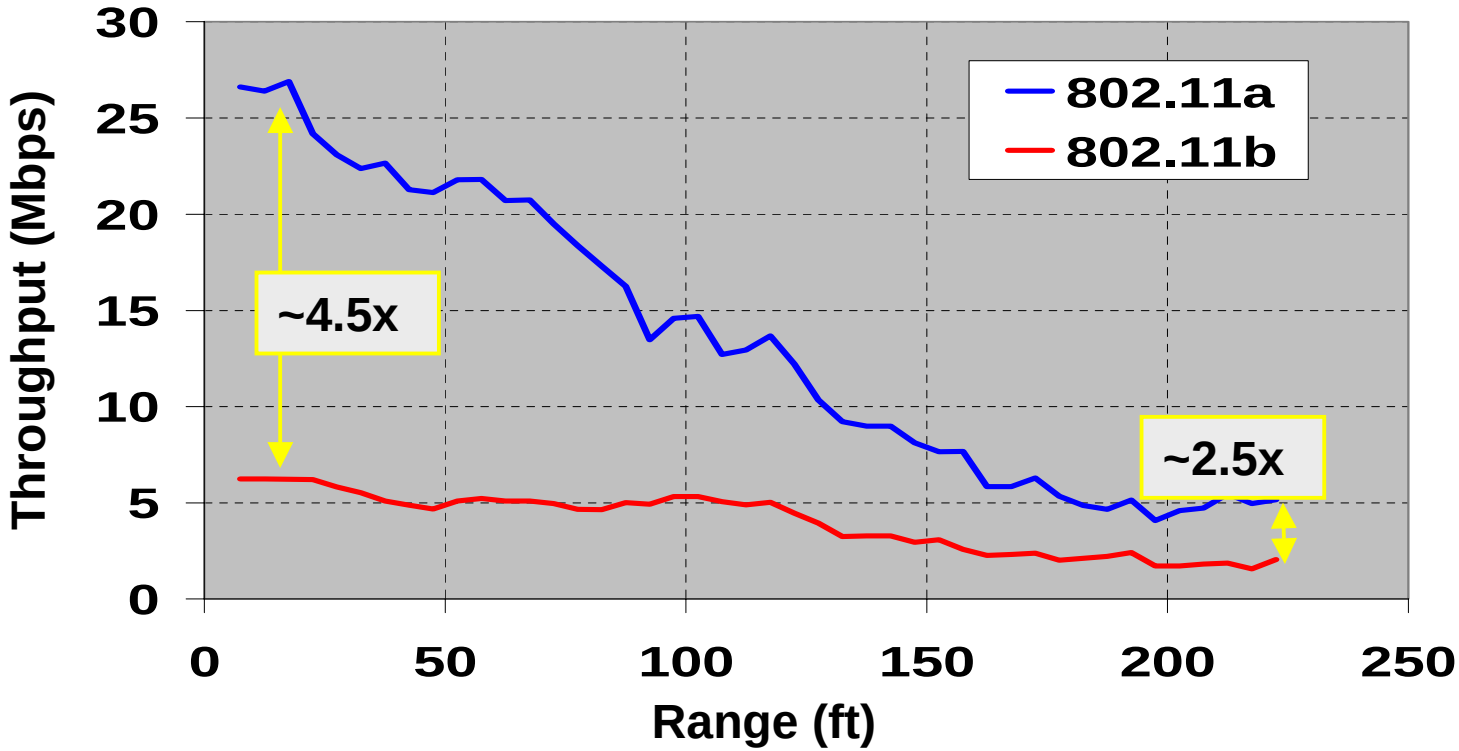
1500 Byte UDP Throughput



Higher Measured Throughput with 11a

11a provides 2.5 to 4.5 times the 1500-byte UDP throughput of 11b

- **Even greater benefits due to reduced interference from other users thanks to more spectrum at 5GHz**



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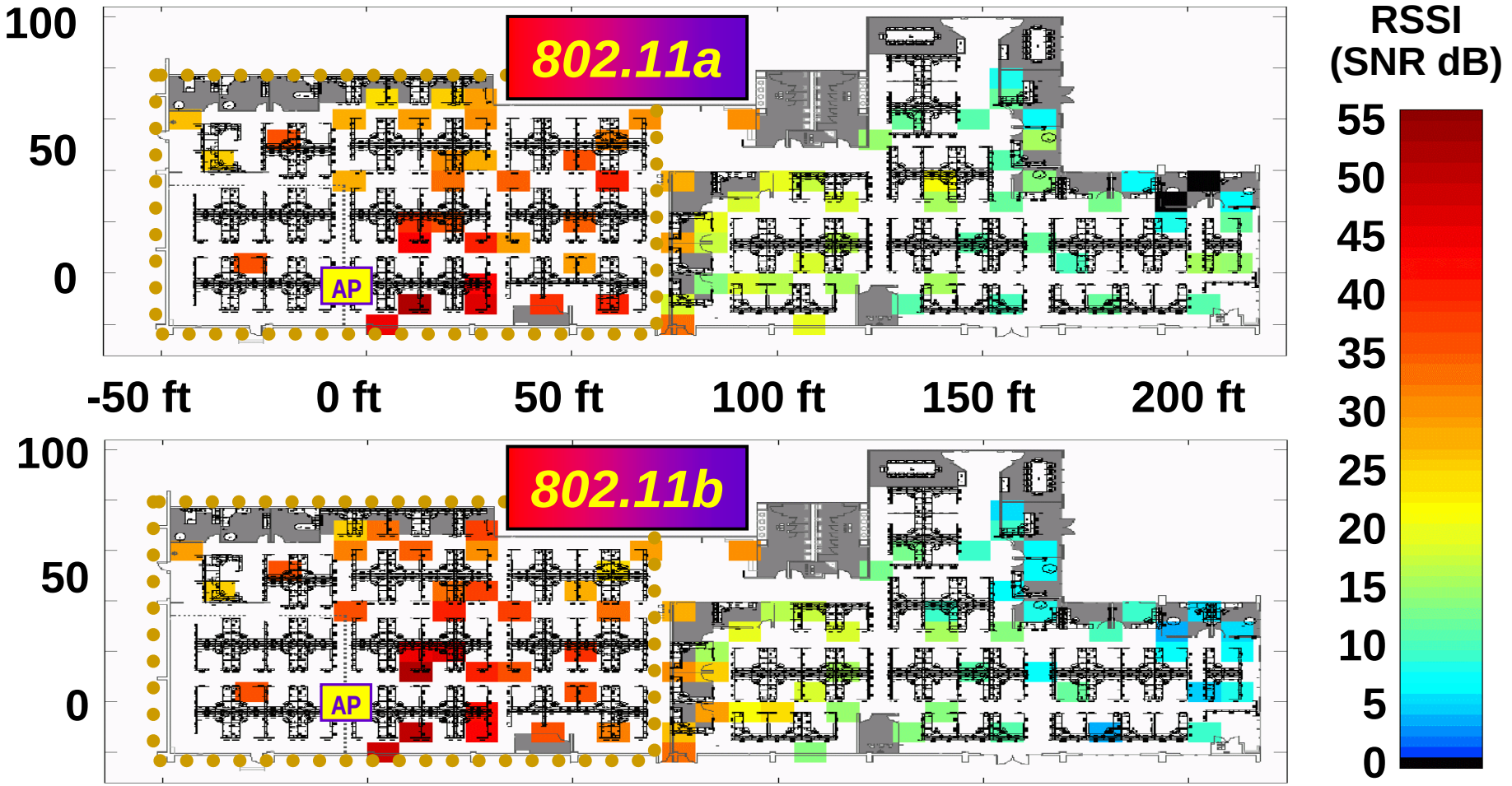
Received Signal Strength Indication



What is System Capacity?

System Capacity is total throughput in a multi-cell deployment

System Capacity = Number of Cells X Cell Throughput X CCI Penalty

Co-Channel Interference (CCI) Penalty depends on:

- Number of Cells
- Cell Diameter

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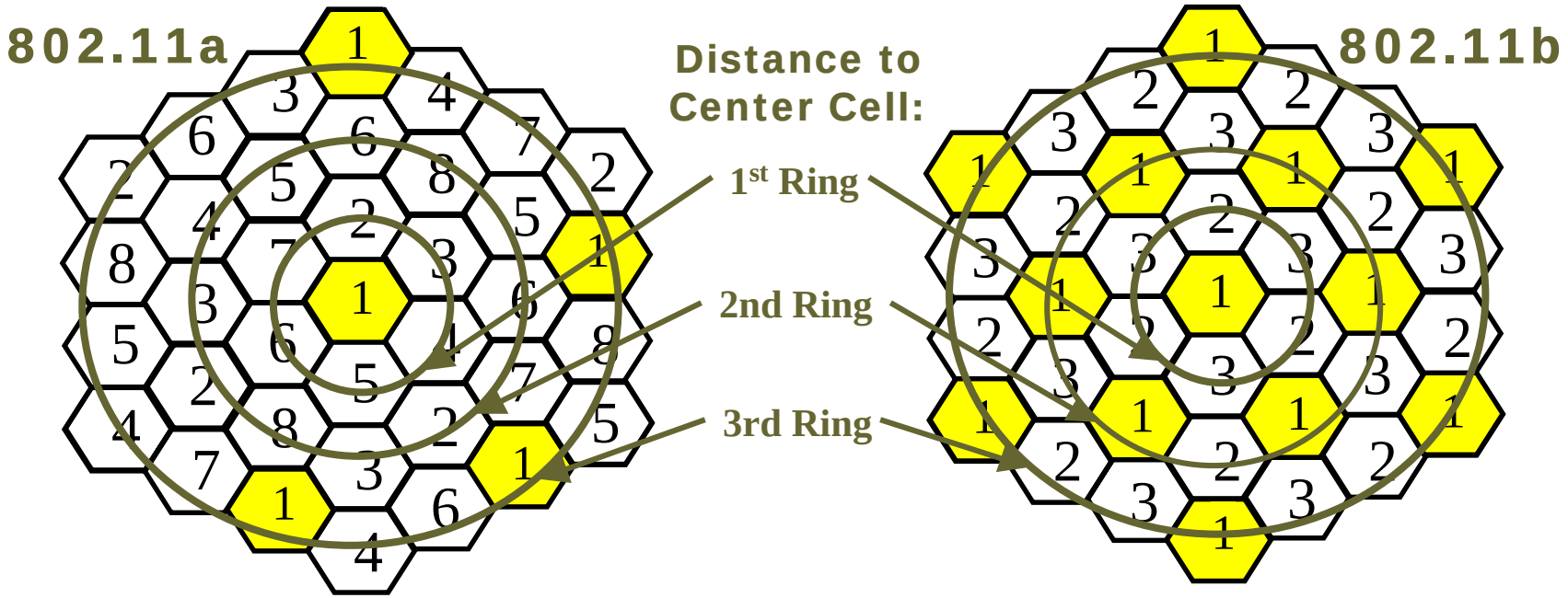
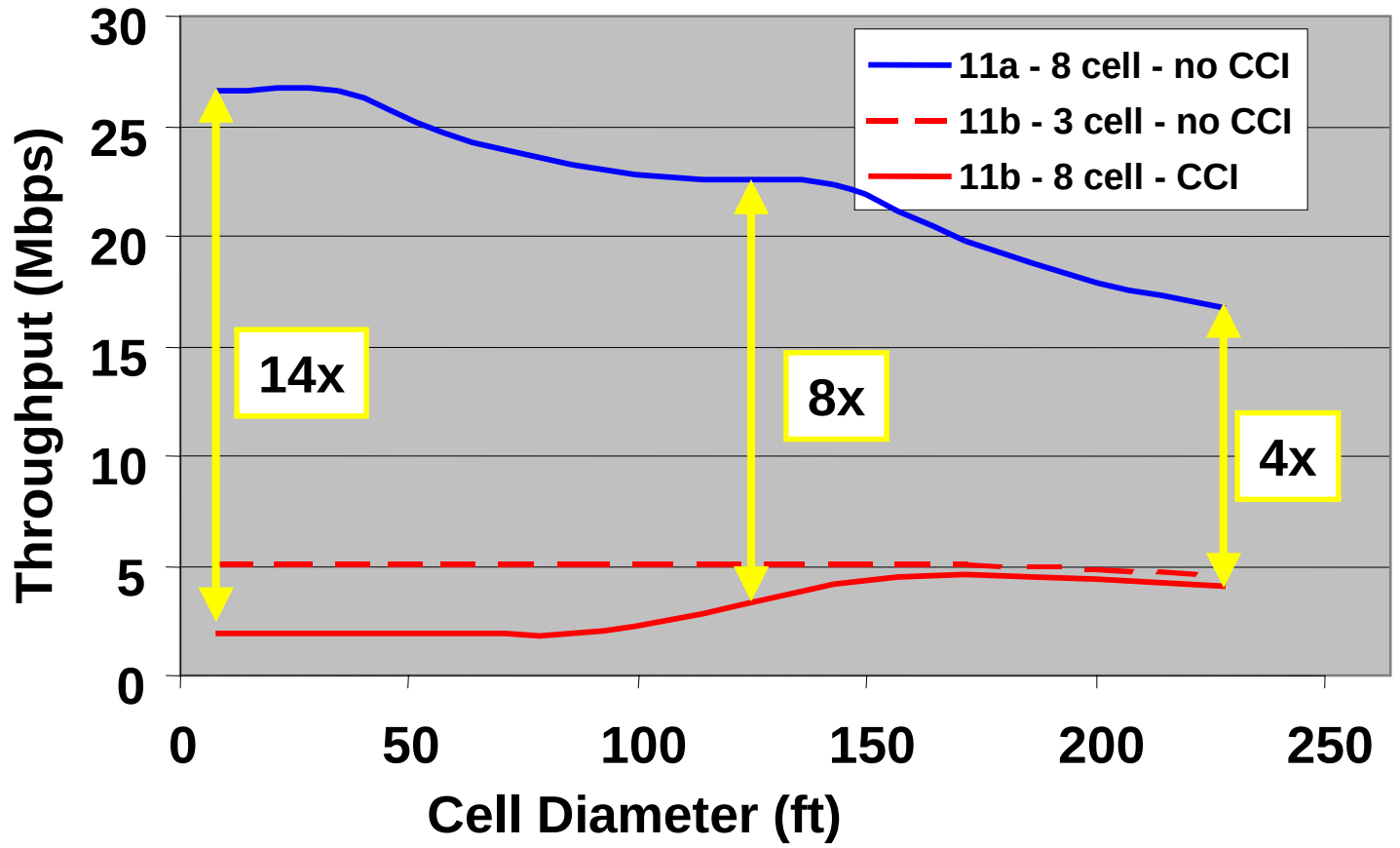
Higher System Capacity

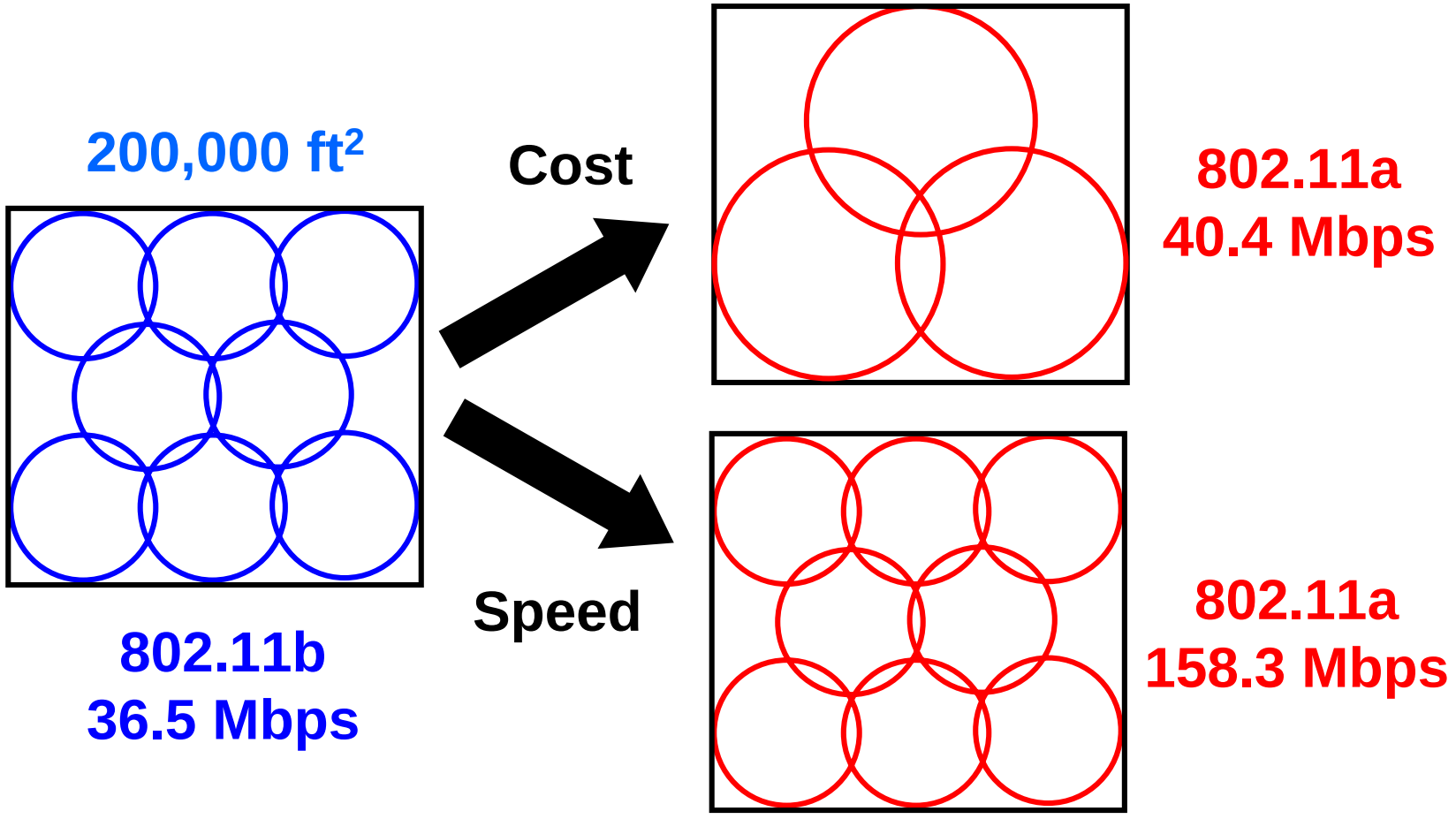


- Large areas with 802.11a will suffer less Co-Channel Interference (CCI) than with 802.11b – resulting in higher system capacity
- Many cell systems can also include multi-story deployments
- Interference can come from other neighbors in multi-dwelling units
- Increased capacity in large enterprises, public 'hot spots', etc

Average Cell Throughput Comparison



Performance and Cost Implications



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Conclusions

High performance 802.11a wireless LAN is here

- OFDM allows robust performance in typical environments
- Atheros all-CMOS 2-chip set WLAN perfect for many applications

Performance measurements in office environment

- 11a speeds 4-5x 11b in typical deployment
- 11a typically >2x 11b throughput to 225 ft
- Similar path loss between 11a & 11b
- Future testing in other environments, with Atheros AP reference designs and software

System capacity implications

- For an 8 cell system, 802.11a has 8x the system capacity of 802.11b at typical cell radius of 65 ft
- Increased system capacity provides more choices – either lower deployment cost or higher performance

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