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 Solutions
- Two-chip all-CMOS 802.11a client and integrated access point
- Three-chip all-CMOS combination 802.11a/g/b chipset
  (Just received Networld+Interop “Best In Show” grand prize!!)

802.11a vs. 802.11b Performance
- Actual operation in a typical office environment

Questions?
Wireless Local Area Networks (WLANs)

11b: Untethered connectivity
11a: Increased capacity or reduced cost

Hot-spot coverage
Multimedia capable
WAN / LAN bridge

Office
Home
“Hot-spots”
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 and 2.4GHz spectrum regulations

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

IEEE 802.11 task groups
Multipath Effects

Multipaths

Dominant Reflector

Local Scatterers

Transmitter

Receiver

Delay spread

pulse

time

Delay spread

time

freq
Inter-Symbol Interference (ISI)

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

Transmitted data

MULTIPATH

Received data

No ISI but low rate
Introduction to OFDM Modulation

- Different data per tone (via FFT)
- Multipath just scales tones
- Tones remain orthogonal even with multipath
  - Cyclic prefix between symbols
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 subcarrier 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: $48 \times 1 \times 1/2 \times 250K = 6 \text{ Mbps}$
- Highest: $48 \times 6 \times 3/4 \times 250K = 54 \text{ Mbps}$
FCC designed 5GHz for “wide-band use” and “high rate digital systems”
- Different applications use different bands
- 13 channels total in US

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<tr>
<td><strong>U.S.</strong></td>
<td>40mW (Max)</td>
<td>200mW (Max)</td>
<td>800mW (EIRP)</td>
<td>800mW (Max)*</td>
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<tr>
<td></td>
<td>160mW (EIRP) Indoor</td>
<td>800mW (EIRP) Indoor/Outdoor</td>
<td></td>
<td>3.2 or 160W (EIRP) Indoor / Outdoor</td>
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<tr>
<td><strong>Europe</strong></td>
<td>200mW (EIRP) Indoor</td>
<td>1W (EIRP) Indoor/Outdoor</td>
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<td>25mW (EIRP) (5.725-5.875GHz)</td>
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<tr>
<td><strong>Japan</strong></td>
<td>200mW (EIRP) Indoor</td>
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* ISM interim waiver currently limits 5.825-5.850GHz to 100mW
- 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

www.atheros.com  Atheros Communications, Inc. 12
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**
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)

- **Task 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 leveraging high-rate OFDM coding used in 802.11a

- **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 encryption and authentication mechanisms
Atheros AR5000 and AR5001 Families

1st Gen 802.11a WLAN Chipset (AR5000) In Products Today!
- Complete solution with “Radio-on-a-Chip” (RoC) & MAC / Baseband
- All in standard process 0.25 micron digital CMOS
- Elimination of external SAW filters, VCOs, RAM, flash memory, etc.

2nd Gen Advanced 802.11a WLAN Chipset (AR5001A)
- Enhanced AES and TKIP security, Quality of Service (QoS)
- International support from 5.150-5.850 GHz with DFS and TPC
- 108Mbps Atheros Turbo Mode™

2nd Gen Combo 802.11a/g/b WLAN Chipset (AR5001X)
- World’s first combination Wireless LAN chipset
- Seamless roaming between 2.4/5 GHz, AES/TKIP/WEP, countries and networks
- All the advanced functionality of the AR5001A

2nd Gen Integrated 802.11a Access Point Chipset (AR5001AP)
- Unprecedented integration – world’s first two-chip access point solution
- Cost-effective design with enterprise-class 802.1x, VLAN, VPN features
Atheros-Driven™ Products Widely Available
### 802.11a/b WLAN Comparison

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<tr>
<th></th>
<th>802.11a</th>
<th>802.11b</th>
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<tbody>
<tr>
<td><strong>Standard Approved</strong></td>
<td>Sept. 1999</td>
<td>Sept. 1999</td>
</tr>
<tr>
<td><strong>Available Bandwidth</strong></td>
<td>325 MHz</td>
<td>83.5 MHz</td>
</tr>
<tr>
<td><strong>Frequency of Operation</strong></td>
<td>5.15-5.35 GHz, 5.725-5.850 GHz</td>
<td>2.40-2.4835 GHz</td>
</tr>
<tr>
<td><strong>Number of Non-Overlapping Channels</strong></td>
<td>13</td>
<td>3</td>
</tr>
<tr>
<td><strong>Data Rate per Channel</strong></td>
<td>6, 9, 12, 18, 24, 36, 48, 54 Mbps</td>
<td>1, 2, 5.5, 11 Mbps</td>
</tr>
<tr>
<td><strong>Modulation Type</strong></td>
<td>OFDM</td>
<td>DSSS</td>
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Many factors affect WLAN performance...

**Modulation Techniques**
(standards)

**Hardware**
Radio Quality Processing Speed

**Environment**
Path-loss (absorption)
Multi-path (echoes)
Interference

**Software**
Rate selection
High-level protocols
Efficiency
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
- Currently testing in other environments

Hardware
- Atheros 1st generation 802.11a PC Card reference design
- 802.11b PC Card and Access Point from a leading vendor
- Currently testing with 2nd generation 802.11a/g/b cards 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

Fixed tx

Sends 100 1500 byte packets at each data rate

Mobile rx

Environment (80 locations)

Records packet errors at each rate

UDP Throughput Calculation

Throughputs at each rate

Optimal rate Selection

Optimal rate

Throughput

www.atheros.com Atheros Communications, Inc. 24
Understanding UDP Throughput

Higher PER Yields Lower Throughput
Optimal Data Link Rate

802.11a

802.11b
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.
1500 Byte UDP Throughput

Throughput (Mbps)

802.11a

802.11b
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
Received Signal Strength Indication

802.11a

802.11b
What is System Capacity?

System Capacity is total throughput in a multi-cell deployment.

\[
\text{System Capacity} = \text{Number of Cells} \times \text{Cell Throughput} \times \text{CCI Penalty}
\]

Co-Channel Interference (CCI) Penalty depends on:
- Number of Cells
- Cell Diameter
Higher System Capacity

- Large areas with 802.11a or 11a/g will suffer less Co-Channel Interference (CCI) than with 802.11b or 11b/g – 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

**Graph:**
- **X-axis:** Cell Diameter (ft)
- **Y-axis:** Throughput (Mbps)

- **Line 1:**
  - Label: 11a - 8 cell - no CCI
  - Color: Blue
  - Throughput: 8x

- **Line 2:**
  - Label: 11b - 3 cell - no CCI
  - Color: Red
  - Throughput: 14x

- **Line 3:**
  - Label: 11b - 8 cell - CCI
  - Color: Red
  - Throughput: 4x

Legend:
- 11a - 8 cell - no CCI
- 11b - 3 cell - no CCI
- 11b - 8 cell - CCI
Performance and Cost Implications

802.11b
36.5 Mbps
200,000 ft²

Cost

802.11a
40.4 Mbps

Speed

802.11a
158.3 Mbps
Conclusions

High performance 802.11a/g/b wireless LAN is here
- OFDM allows robust performance in typical environments
- Atheros all-CMOS WLAN chipsets perfect for many applications
- 2nd generation a/g/b combo client and integrated access point improve performance, maintain legacy compatibility, and reduce cost

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
- Currently testing in other environments with 2nd generation products and application-level 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