What is WiFi?
- Better known as IEEE 802.11
- Available many-where
- Replacement for wired networks
- Convenience
- Easier to deploy in some environments
- Main ‘core’ flavors
  - a, b, g, and n

Network Stack
- Application
- Upper Layers
- Data link layer
- MAC
- PHY

Challenges of WiFi
- Bandwidth Capacity
- Coordination
- Packet Loss
- Connectivity
- Wireless Interference

WiFi
- Today WiFi is taken for granted, but it is non-trivial to provide a working implementation and to keep a WLAN operating properly.
**802.11 Overview**

<table>
<thead>
<tr>
<th>802.11</th>
<th>802.11 b/g/n</th>
<th>802.11 a/n</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency</td>
<td>2.4 GHz</td>
<td>5GHz</td>
</tr>
<tr>
<td>Bandwidth</td>
<td>20/40 MHz</td>
<td>20/40 MHz</td>
</tr>
<tr>
<td>Speeds</td>
<td>1-150 Mbps</td>
<td>1-150 Mbps</td>
</tr>
<tr>
<td>Pros</td>
<td>Better object penetration</td>
<td>Less crowded</td>
</tr>
<tr>
<td>Cons</td>
<td>Very crowded</td>
<td>Weaker object penetration</td>
</tr>
</tbody>
</table>

**WLAN**
- Wireless Local Area Network
- Operates on a specific channel (frequency)
- Bandwidth capacity is shared
- Distributed Coordination Function
- Various speeds to transmit data at

**BSS Architecture**
- BSS - Basic Service Set
- Independent BSS (Ad-Hoc) - IBSS
- Infrastructure BSS (AP)

**Channels**
- 2.4 GHz has 11 usable channels (in the US)
- Overlap exists
- Channel 6 will overlap and interfere with Channels 4, 5, 7, and 8
- Commonly used Channels are 1, 6, and 11 because of separation.

**2.4 GHz Channels**
- Frequency Leakage
- Region of Interference
- "Frequency Leakage"
2.4 GHz Channels

Using appropriately spaced channels leads to limited interference.

Real World Trace

ND Wireless

- 3 BSS per Access Point (BSS)
- ND-Secure
- ND-Guest
- Nomad
- Only Channels 1, 6, and 11 are used

Transmission Speeds
## Modulation

Transmission speed corresponds to a signal modulation scheme.

<table>
<thead>
<tr>
<th>Speed (Mbps)</th>
<th>Modulation</th>
<th>Coding Rate</th>
<th>Coded Bits / Carrier</th>
<th>Coded Bits / Symbol</th>
<th>Data Bits / Symbol</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>BPSK</td>
<td>1/2</td>
<td>1</td>
<td>48</td>
<td>24</td>
</tr>
<tr>
<td>9</td>
<td>BPSK</td>
<td>3/4</td>
<td>1</td>
<td>48</td>
<td>36</td>
</tr>
<tr>
<td>12</td>
<td>QPSK</td>
<td>1/2</td>
<td>2</td>
<td>96</td>
<td>48</td>
</tr>
<tr>
<td>18</td>
<td>QPSK</td>
<td>3/4</td>
<td>2</td>
<td>96</td>
<td>72</td>
</tr>
<tr>
<td>24</td>
<td>16-QAM</td>
<td>1/2</td>
<td>4</td>
<td>192</td>
<td>96</td>
</tr>
<tr>
<td>36</td>
<td>16-QAM</td>
<td>3/4</td>
<td>4</td>
<td>192</td>
<td>114</td>
</tr>
<tr>
<td>48</td>
<td>64-QAM</td>
<td>2/3</td>
<td>6</td>
<td>288</td>
<td>192</td>
</tr>
<tr>
<td>54</td>
<td>64-QAM</td>
<td>3/4</td>
<td>6</td>
<td>288</td>
<td>216</td>
</tr>
</tbody>
</table>

Transmission speed corresponds to a signal modulation scheme.

## Packet Transmission

- Every data frame sent needs to be acknowledged.
- Traditional semantics:
  - Send a data packet, wait for an acknowledgment packet.
  - The acknowledgments are low-level 802.11 Hardware layer ACKs, even when sending UDP traffic low-level ACKs are present (and frames may be retransmitted).

## 802.11 Transmission

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## Hidden Node

- Carrier-sense range

## Collision Prevention

- RTS/CTS - Request To Send / Clear To Send
  - The RTS frame reserves the channel for use.
  - The CTS frame "silences" all other nodes allowing the requesting node to begin transmitting
  - HUGE Performance Penalty.
  - Typically turned off.
802.11 Channel Access

- Gaining access to the channel is costly and sending one data packet per acquisition is not very efficient.
- Packets can (will) become lost and will be retransmitted.
- This behavior delays new data from being sent.

802.11e

- QoS Support for 802.11
- Originally drafted for 802.11g
- Implemented in 802.11n
- Complicates the MAC. Why?
  - throughput improves dramatically
  - approaches wired speeds

802.11e cont’d.

- A-MSDU - Aggregated Mac Service Data Unit
  - Jumbo frame (one header for n packets)
  - If there is an error entire frame needs to be resent
- A-MPDU - Aggregated Mac Payload Data Unit
  - Each sub-frame has its own header
  - Block Ack indicates what was received
  - MAC at TX prunes out what was received and resends what wasn’t.

A-MSDU

A-MPDU

802.11 Channel Access

- After a packet is sent and an ACK is received or an ACK timeout occurs the current sending node ‘gives up’ access to the channel and lets other nodes compete for access via a back-off and countdown timer that ONLY counts down when the channel is detected as idle. First node to grab the channel is granted access to send.
**802.11 Channel Access**

- **Contention-Based Access Using DCF**
  - Two important timing values:
  - **SIFS** - Short Interframe Space
    - Used between RTS/CTS frames and ACKs
  - **DIFS** - DCF Interframe Space
    - Minimum medium idle time

**SIFS & DIFS**

- If a packet is successful, the medium **MUST** be free for at least DIFS.
- ACKs are the only indication of success

**Packet Loss**

- This will inevitably happen
- Loss occurs primarily because of bit corruption
- What caused the corruption?
  - **Primary Suspects**
    - Collisions - someone transmits while you transmit
    - Transience - environmental factors
    - Devices - did not sync properly or was not ready to receive or process a packet

**What happens when a packet is lost?**

- Collision Avoidance (CA) is invoked
- Contention Window (CW) is doubled after every consecutive lost, and reset on success

\[
\begin{align*}
\text{If packet lost} & \\
\text{CW} &= \min(2^\text{CW} \times \text{maxCW}) \\
\text{else} & \\
\text{CW} &= \min\text{CW} \\
\text{backoff} &= \text{randi}([0, (\text{CW} - 1), 1])
\end{align*}
\]
**CSMA/CA**

- **TX Contention Window**

**Contention Window**

- Effectively, every time a consecutive packet is lost, the size of the set of numbers that can be randomly selected from for the backoff timer increases.

**DCF Versus TDMA**

- **Distributed Coordination Function** is how 802.11 operates and decides how nodes are granted permission to transmit on the channel, requires no central authority, provides a probabilistic guarantee.
- **Time Division Multiple Access** assigns time slots to nodes and nodes can only send during a specific time period, requires a central authoring, provides for access in congested networks.

**Packet Syncing**

- How does a device listening to radio waves know when a packet is being sent?
- Preamble and PLCP Header

**Preamble** - sequence of alternating 0's and 1's in order to sync, followed by a set pattern used to delineate the start of the frame.

**Wireless Problems**

- Radio waves propagate throughout an environment
- Signals bounce off objects, and lose power as they propagate
- Not all devices have uniform “hearing” or transmissions
- Antennas
- DCF attempts to manage nodes without centralized control, but problems arise
Wireless Signals

Multipath

Exposed Node

A sends to B
C wants to send to D, but B is using the channel
D is exposed and doesn’t know about the transfer from B to A (outside of carrier sense)

Transmission Speed Selection

Problems with the DCF

- If two nodes are competing for channel access and one sends slower than the other then the faster sending node, while sending at a faster speed, will experience throughput equivalent to that of the slower sending node.

Speed Selection

- There exists many different rates that data can be sent at.
- Transmission speed is controlled ‘automagically’ by rate adaptation algorithms.
- Differing heuristics among algorithms on how to best accomplish this.
- Anomalous behavior results when fast and slow speeds are used by multiple clients sequentially.

Rate Anomaly

54 Mbps

6 Mbps

Slower TX Speed dictates throughput on the channel.
**Why choose a slower speed?**

- Traditional thinking implies that slower speeds are more resilient to failure (lower number of bits per coded symbol).
- However, slower speeds take longer to transmit a packet than at a faster speed, thus making them more susceptible to potential collision.

**How is a transmission speed selected?**

- Rate adaptation algorithms
- Different metrics used to select a speed
- Algorithms ONLY optimize for themselves

**Rate Anomaly**

**Rate Adaptation Landscape**
Future 802.11

- 802.11 ac (enhanced 802.11 a)
- Speeds greater than 1Gbps

802.11 Misc.

- Signal strength from devices can be used for location based positioning technologies.
- Skyhook

End