WIFI
IEEE 802 Layers

The IEEE 802 family and its relation to the OSI model
Need For Speed

Wireless LAN Applications

Streaming Media (HDTV, DVD)
VoIP
Interactive Gaming
Data Transfer

Require Hundreds of Mbps
IEEE 802.11 Family

- IEEE 802.11
- IEEE 802.11a
- IEEE 802.11b
- IEEE 802.11g
- IEEE 802.11i
- IEEE 802.11e
- IEEE 802.11n
- IEEE 802.11p
- IEEE 802.11s
- IEEE 802.11ac
- IEEE 802.11ad
- IEEE 802.11af
## IEEE 802.11 Family Specifications

<table>
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<tr>
<th>802.11 protocol</th>
<th>Release</th>
<th>Freq. (GHz)</th>
<th>Bandwidth (MHz)</th>
<th>Data rate per stream (Mbit/s)</th>
<th>Allowable MIMO streams</th>
<th>Modulation</th>
<th>Approximate range</th>
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Types of Networks

Ad-hoc

Infrastructure
Wireless Channels → 2.4 GHz
Wireless Channels → 5 GHz

Twelve 802.11a non-overlapping channels

20 MHz

36 40 44 48 52 56 60 64

5 GHz lower and missile UNII bands

149 153 157 161

5 GHz upper UNII band

United States and other countries have approved 11 more channels.

100 104 108 116 120 112 124 128 132 136 140

Twenty-three non-overlapping channels possibly available at 5 GHz.
Medium Access Mechanisms

- The IEEE 802.11 standard specifies three types of access mechanisms.
  - The Distributed Coordination Function (DCF)
    - Mandatory
    - Infrastructure & Ad-hoc modes.
  - The Point Coordination Function (PCF).
    - Optional
    - Infrastructure
  - The Hybrid Coordination Function (HCF).
    - Infrastructure & Ad-hoc modes using IEEE 802.11e (QoS)
DCF Access Mechanism

- Applies a CSMA/CA protocol.

- The DCF allows multiple independent stations to interact without central control, and thus may be used in either ad-hoc or infrastructure networks.

- Before attempting to transmit, each station checks whether the medium is idle. If the medium is not idle, stations defer to each other and employ an orderly exponential backoff algorithm to avoid collisions.
DCF Access Mechanism

- In refining the 802.11 MAC rules, there is a basic set of rules that are always used, and additional rules may be applied depending on the circumstances.

- Two basic rules apply to all transmissions.

- Three optional rules are additional.
DCF Access Mechanism

Basic Rules

1. If the medium has been idle for longer than a specified period of time (DIFS), transmission can begin immediately. Carrier sensing is performed using both a physical medium-dependent method and the virtual (NAV)

   ➢ If the previous frame was received without errors, the medium must be free for at least the DIFS.
   ➢ If the previous transmission contained errors, the medium must be free for another specified amount of time (EIFS).
DCF Access Mechanism

Basic Rules

2. If the medium is busy, the station must wait for the channel to become idle. 802.11 refers to the wait as *access deferral*. *If access is deferred, the station waits for the medium to become idle* for the DIFS and prepares for the exponential backoff procedure.
DCF Access Mechanism

Additional rules may apply in certain situations. Many of these rules depend on the particular situation and are specific to the results of previous transmissions.

1. Error recovery is the responsibility of the station sending a frame. Senders expect acknowledgments for each transmitted frame and are responsible for retrying the transmission until it is successful.

- Positive acknowledgments are the only indication of success. Atomic exchanges must complete in their entirety to be successful. If an acknowledgment is expected and does not arrive, the sender considers the transmission lost and must retry.
DCF Access Mechanism

- All unicast data must be acknowledged.

- Any failure increments a retry counter, and the transmission is retried. A failure can be due to a failure to gain access to the medium or a lack of an acknowledgment. However, there is a longer congestion window when transmissions are retried.
DCF Access Mechanism

2. Multiframe sequences may update the NAV with each step in the transmission procedure. When a station receives a medium reservation that is longer than the current NAV, it updates the NAV. Setting the NAV is done on a frame-by-frame basis.

3. The following types of frames can be transmitted after the SIFS and thus receive maximum priority: acknowledgments, the CTS in an RTS/CTS exchange sequence.
   - Once a station has transmitted the first frame in a sequence, it has gained control of the channel. Any additional frames and their acknowledgments can be sent using the short interframe space, which locks out any other stations.
   - Additional frames in the sequence update the NAV for the expected additional time the medium will be used.
Short Interframe Space (SIFS)

- The SIFS is used for the highest-priority transmissions, such as positive acknowledgments.

- High-priority transmissions can begin once the SIFS has elapsed.

- Once these high-priority transmissions begin, the medium becomes busy, so frames transmitted after the SIFS has elapsed have priority over frames that can be transmitted only after longer intervals.
DCF Interframe Space (DIFS)

- The DIFS is the minimum medium idle time for contention-based services.
- Stations may have immediate access to the medium if it has been free for a period longer than the DIFS.
- Data packets are sent after DIFS.
Extended Interframe Space (EIFS)

- It is used only when there is an error in frame transmission.
- It is not a fixed interval.
- Vendors usually apply DIFS in their product instead of EIFS.
Error Recovery with the DCF

- Error detection and correction is up to the station that begins an atomic frame exchange.
- When an error is detected, the station with data must resend the frame.
- Errors must be detected by the sending station.
- In some cases, the sender can infer frame loss by the lack of a positive acknowledgment from the receiver.
- Retry counters are incremented when frames are retransmitted.
Backoff with the DCF

- After frame transmission has completed and the DIFS has elapsed, stations may attempt to transmit congestion-based data.
- A period called the *contention window or backoff window follows the DIFS.*
- This window is divided into slots.
- Slot length is medium-dependent; higher-speed physical layers use shorter slot times.
- Stations pick a random slot and wait for that slot before attempting to access the medium.
- All slots are equally likely selections.
- When several stations are attempting to transmit, the station that picks the first slot (the station with the lowest random number) wins.
Backoff with the DCF

- The backoff time is selected from a larger range each time a transmission fails.
- Contention window sizes are always 1 less than a power of 2 (e.g., 31, 63, 127, 255).
- Each time the retry counter increases, the contention window moves to the next greatest power of two.
- The contention window is usually limited to 1023 slots.
- When the contention window reaches its maximum size, it remains there until it can be reset.
- Allowing long contention windows when several competing stations are attempting to gain access to the medium keeps the MAC algorithms stable even under maximum load.
- The contention window is reset to its minimum size when frames are transmitted successfully, or the associated retry counter is reached, and the frame is discarded.
Backoff with the DCF

Diagram showing the backoff process with the DCF:
- Initial attempt: Previous frame + DIFS + 31 slots
- 1st retransmission: Previous frame + DIFS + 63 slots
- 2nd retransmission: Previous frame + DIFS + 127 slots
- 3rd retransmission: Previous frame + DIFS + 255 slots
- 4th retransmission: Previous frame + DIFS + 511 slots
- 5th retransmission: Previous frame + DIFS + Contention window = 1,023 slots
- 6th retransmission: Previous frame + DIFS + Contention window = 1,023 slots
Short and Long Retry Limits

- The backoff time is selected from a larger range each time a transmission fails.
- The limits define the number of MAC retries for different types of packets.
- The short retries are incremented whenever a control frame or a short frame smaller than the RTS threshold) is retransmitted.
- Long retries are incremented when a long packet frame is retransmitted.
- If either of these retries reach their respective limits (short or long depending on the size of the data frame), the frame is automatically discarded.
IEEE 802.11

DCF Access Mechanism Problems
Wireless Transmission Range

- Wireless domain is accompanied with many impairments that makes it hard to distinguish the transmission range boundaries, sometimes to the point where each node may not be able to communicate with every other node in the wireless network.
The Hidden Node (Terminal) Problem

- In the figure, node 2 can communicate with both nodes 1 and 3 (within the transmission ranges of both).
- Nodes 1 and 3 cannot communicate directly since the radio waves cannot reach the full distance from 1 to 3.
- From the perspective of node 1, node 3 is a "hidden" node. Also, from the perspective of node 3, node 1 is a "hidden" node.
- If node 1 wants to transmit to node 2, node 3 won’t hear the transmission.
- Thus, if node 3 also decided to transmit to node 2 while an on-going transmission occurs from node 1 to node 2, a collision occurs at node 2 without the knowledge of either node 1 or 3.
The Hidden Node (Terminal) Solution

To prevent collisions, 802.11 allows stations to use Request to Send (RTS) and Clear to Send (CTS) signals to clear out an area.
The Hidden Node (Terminal) Solution

(a) Range of A's transmitter

(b) Range of B's transmitter
The Hidden Node (Terminal) Solution

- Node 1 has a frame to send; it initiates the process by sending an RTS frame.
- The RTS frame serves several purposes: in addition to reserving the radio link for transmission, it silences any stations that hear it.
- If the target station receives an RTS, it responds with a CTS.
- Like the RTS frame, the CTS frame silences stations in the immediate vicinity.
- Once the RTS/CTS exchange is complete, node 1 can transmit its frames without worry of interference from any hidden nodes.
- Hidden nodes beyond the range of the sending station are silenced by the CTS from the receiver.
- When the RTS/CTS clearing procedure is used, any frames must be positively acknowledged.
The Hidden Node (Terminal) Solution

- The multiframe RTS/CTS transmission procedure consumes a fair amount of capacity, especially because of the additional latency incurred before transmission can commence.

- Usually DCF access mechanism with CTS/RTS frame exchange is used only in high-capacity environments and environments with significant contention on transmission. For lower-capacity environments, it is not necessary.
Network Allocation Vector

- All stations receiving RTS or CTS will set their NAV for the given duration.

Why?
IEEE 802.11

Performance Analysis
Using
Markov Chains
The Station Model
Throughput / Station Model

\[
\frac{1}{P(S)} = L + x + \frac{zb\left(1 + \frac{W - 1}{2(1-b)}\right)}{1 - f^{M+1}} + \frac{z}{g(1 - f^{M+1})} + \frac{4bf - 2(b + 2f) - 4bf^{M+2} + 2bf^{M+1} + W\left(1 - 2^m f^{m+1}\right)}{2(1-b)(1 - f^{M+1})(1-f)(1-2f)} + \frac{1 + 2f^{M+2} - f^{M+1} - Wf + W\left(2^{m+1} f^{m+2} - 2^m + f^{m+1}\right)}{2(1-b)(1 - f^{M+1})(1-f)(1-2f)} + \frac{f\left(L + \frac{1-(1-b)^r}{b}\right)}{1 - f}
\]

Throughput = \(P(S)LR\)
The Channel Model
Background

IEEE 802.11 Performance Anomaly
IEEE 802.11 Performance Anomaly

- All the IEEE 802.11 family support more than one transmission speed.
- 802.11b provides 11 Mbps transmission with a fallback to 5.5, 2 and 1 Mbps.
- Stations lower their speeds in the presence of errors.

Why is it important to analyze the network when stations transmit at different speeds?
IEEE 802.11 Performance Anomaly

- It was showed in the literature that when one station that sends data at a low rate competes with other stations, the throughput of all stations is significantly limited.

- Fast stations see their throughput decreased roughly to the order of magnitude of slow station’s throughput.
IEEE 802.11 Performance Anomaly

- The fair access to the channel provided by CSMA/CA makes a slow station captures the channel a longer period of time than stations transmitting data at full rate.

- 802.11b -- A slow station transmitting at 1 Mb/s capture the channel eleven times longer than stations transmitting at 11 Mb/s.

- **Severe degradation in the actual received throughput.**

> Almost in every wireless network that has several users, there is at least one user transmit data at a slow rate due to channel fading, interference or …
The Channel Model
The Station Model (Fast & Slow)
Throughput / Station Model

\[
\frac{1}{P(S_f)} = L1_f + x + \frac{z_f b \left( 1 + \frac{W - 1}{2(1-b)} \right)}{1 - f_f^{M+1}} + \frac{z_f}{g_f (1 - f_f^{M+1})} + \frac{4bf_f - 2(b + 2f_f) - 4bf_f^{M+2} + 2bf_f^{M+1} + W(1 - 2^m f_f^{m+1})}{2(1-b)(1 - f_f^{M+1})(1 - f_f)(1 - 2f_f)} + \frac{1 + 2f_f^{M+2} - f_f^{M+1} - Wf_f}{2(1-b)(1 - f_f^{M+1})(1 - f_f)(1 - 2f_f)} + \frac{f_f \left( L2_f + \frac{1 - (1-b)^r}{b} \right)}{1 - f_f}
\]

Throughput$_f = P(S_f) L1_f R_f$
Quality of Service

IEEE 802.11e
Recently, research efforts over wireless LAN are gradually migrated to provision of Quality of Service (QoS) for real-time multimedia services.

The following Five key parameters are used for differentiation:

- Minimum Contention Window (CWmin)
- Maximum Contention Window size (CWmax)
- Arbitration Inter-Frame Space (AIFS)
- Virtual Collision Handler
- TXOP

IEEE 802.11e
IEEE 802.11e / Four Access Categories

AC1

AC2

AC3

AC4

Virtual Collision
IEEE 802.11e / AIFS[AC]
### Table 8-105—Default EDCA Parameter Set element parameter values if dot11OCBActivated is false

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<td>(aCWmin+1)/2 – 1</td>
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<td>(aCWmin+1)/4 – 1</td>
<td>(aCWmin+1)/2 – 1</td>
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<td>3.264 ms</td>
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IEEE 802.11e / Queue Model

Station Model

Queue Model
The Queue Model
IEEE 802.11e / Queue Model
IEEE 802.11e / Queue Model

\[
\frac{1}{P(S_q)} = L_1 + x + AIFS_q + \frac{z_q}{(1 - f_q^{M_q+1})} + \frac{z_q}{(1 - f_q^{M_q+1})g_q(1 - h_q)} + \frac{1}{1 - f_q^{M_q+1}(1 - z_q) - z_q f_q^{M_q+1}} + \frac{z_q b}{(1 - f_q^{M_q+1}) (1 - z_q) - z_q f_q^{M_q+1}) (1 - 2b - h_q + b^2 + h_q b)} \\
+ \frac{1}{2} \frac{z_q b(1 + (AIFS_q - 1)(1 - b))(W_q - 1)}{(1 - f_q^{M_q+1}) (1 - z_q) - z_q f_q^{M_q+1}) (1 - b)^{AIFS_q}} + \frac{z_q b(1 + (AIFS_q - 1)(1 - b - h_q))}{(1 - f_q^{M_q+1}) (1 - z_q) - z_q f_q^{M_q+1}) (1 - 2b - h_q + b^2 + h_q b) \\
+ \left[ \frac{-2 f_q + 2^{m_q} W_q f_q^{m_q+1} + W_q f_q - 2^{(m_q+1)} f_q^{M_q+2} W_q + 2 f_q^{M_q+2} - f_q^{M_q+1} - W_q + 1}{(1 - f_q^{M_q+1})(1 - f_q)(1 - 2 f_q)} \right] \left[ \frac{(AIFS_q b - b - AIFS_q)(1 - b)^{-AIFS_q}}{2} \right] + \frac{AIFS_q (b + h_q) - b - h_q - AIFS_q}{(1 - 2b - h_q + b^2 + h_q b)(f - 1)} + \frac{f_q (bL2 + 1 - (1 - b)^r)}{(1 - f_q)b} \\
\]
High Throughput (HT)

IEEE 802.11n
IEEE 802.11n

IEEE 802.11n is an enhanced standard to significantly improve the performance of the conventional 802.11.

Many techniques at the physical (PHY) and medium access control (MAC) layers were introduced to enhance the achievable throughput.

Multiple-Input-Multiple-Output (MIMO) technology is the Booming factor in enhancing throughput of IEEE 802.11n.
MIMO

- Multiple antennas at the receiver and the transmitter.
- The presence of multiple elements at both ends of the communication link opens up independent channels (streams) for transmission in the presence of multi-path or rich scattering.

Spatial Diversity, dependent data are sent on the different streams. → Increase Range

Spatial Multiplexing, multiple independent data are sent on the different streams. → Increase Capacity
Physical Layer Enhancements

- Enhancements were introduced on IEEE 802.11n PHY to achieve a 600Mbps nominal rate.

What are the enhancements on the legacy IEEE 802.11g to achieve the high throughput of IEEE 802.11n?

- Let’s start with the maximum throughput of 802.11g which is 54 Mbps, and see what techniques 802.11n applies to boost it to 600 Mbps in the following slides.
Physical Layer Enhancements

- **More subcarriers:** 802.11g has 48 OFDM data subcarriers. 802.11n increases this number to 52, thereby boosting throughput from 54Mbps to 58.5 Mbps.

- **FEC:** 802.11g has a maximum FEC (Forward Error Correction) coding rate of 3/4. 802.11n squeezes some redundancy out of this with a 5/6 coding rate, boosting the link rate from 58.5 Mbps to 65 Mbps.
Physical Layer Enhancements

- **Guard Interval:** 802.11a has Guard Interval between transmissions of 800ns. 802.11n has an option to reduce this to 400ns, which boosts the throughput from 65 Mbps to 72.2 Mbps.

- **MIMO:** by using spatial multiplexing, the throughput of a system goes up linearly with each extra antenna at both ends. Two antennas at each end double the throughput, three antennas at each end triple it, and four quadruple it. The maximum number of antennas in the receive and transmit arrays specified by 802.11n is four. This allows four simultaneous 72.2 Mbps streams, yielding a total throughput of 288.9 Mbps.
Physical Layer Enhancements

- **40 MHz channels:** all previous versions of 802.11 have a channel bandwidth of 20MHz. 802.11n has an optional mode where the channel bandwidth is 40 MHz. While the channel bandwidth is doubled, the number of data subcarriers is slightly more than doubled, going from 52 to 108. This yields a total channel throughput of 150 Mbps. So again combining four channels with MIMO, the throughput goes up to **600 Mbps**
MAC Enhancements

- In IEEE 802.11 family, the actual received throughput is much less than the nominal rate of the standard. For example, the maximum achievable throughput of IEEE 802.11g is around 27Mbps which is far less than the nominal rate 54Mbps. This happens because of the following factors:
  - The MAC header.
  - The control packets such as ACK, RTS and CTS.
  - The backoff algorithm.

- Enhancements were introduced on IEEE 902.11n MAC to reduce the effect of these factors. The two main enhancements are:
  - Frame Aggregation.
  - Block Acknowledgments.
Frame Aggregation

There are two standard mechanisms to perform frame aggregations at the MAC layer in IEEE 802.11n

- **(A-MSDU)**
  - Aggregation of MAC Service Data Units (MSDUs) at the top of the MAC.

- **(A-MPDU)**
  - Aggregation of MAC Protocol Data Units (MPDUs) at the bottom of the MAC.
Frame Aggregation / A-MSDU

Frame Format for A-MSDU
Frame Aggregation / A-MPDU

Diagram showing the frame format for A-MPDU, with subframes and MPDU components.
Block Acknowledgments

- Block ACK is a kind of Automatic Repeat Request (ARQ) mechanism with selective refusal functionality.

- Block ACK cuts the wait time between frame transmission and allows just the missing frames or frames received in error to be resent by checking a bitmap.

- Block ACK can significantly improve protocol efficiency and throughput.
IEEE 802.11n

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<tr>
<td>31</td>
<td>4</td>
<td>64-QAM</td>
<td>5/6</td>
<td>260.00</td>
</tr>
</tbody>
</table>
Very High Throughput (VHT)

IEEE 802.11ac
IEEE 802.11ac

- IEEE 802.11n is an enhanced standard to significantly improve the date rate of the conventional 802.11.

- It is still under standardization.

- Latest Draft is 5.0 (01-02-2013)

- Shall operate in the 5GHz frequency band.

- Very High Data rate (around 6GHz)
IEEE 802.11ac Enhancements

- Channel aggregation
  Mandatory 80 MHz (Maximum)
  Optional 160 MHz.

- More MIMO spatial streams
  Eight spatial streams (Maximum)

- 256-QAM at rates 3/4 and 5/6. *(optional)*

- Beamforming with standardized sounding and feedback for compatibility issues between vendors.
IEEE 802.11ac Enhancements
Multi-user MIMO ((MU-MIMO))

- Multiple STAs transmit or receive independent data streams simultaneously.

- Downlink MU-MIMO, one transmitting device (usually the AP), multiple receiving devices. *(optional)*
IEEE 802.11ac Enhancements
SU-MIMO vs. MU-MIMO

SU-MIMO
- 20Mbps Data 1
- 20Mbps Data 2
- 40Mbps
MIMO Base Station
MIMO Handset

MU-MIMO
- 20Mbps Data 1
- 20Mbps Data 2
- 20Mbps
MIMO Base Station
MIMO Handset

MIMO Handset
## IEEE 802.11ac Scenarios

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Typical Client Form Factor</th>
<th>PHY Link Rate</th>
<th>Aggregate Capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-antenna AP, 1-antenna STA, 80MHz</td>
<td>Handheld</td>
<td>433 Mbit/s</td>
<td>433 Mbit/s</td>
</tr>
<tr>
<td>2-antenna AP, 2-antenna STA, 80MHz</td>
<td>Tablet, Laptop</td>
<td>867 Mbit/s</td>
<td>867 Mbit/s</td>
</tr>
<tr>
<td>1-antenna AP, 1-antenna STA, 160MHz</td>
<td>Handheld</td>
<td>867 Mbit/s</td>
<td>867 Mbit/s</td>
</tr>
<tr>
<td>2-antenna AP, 2-antenna STA, 160MHz</td>
<td>Tablet, Laptop</td>
<td>1.69 Gbit/s</td>
<td>1.69 Gbit/s</td>
</tr>
<tr>
<td>4-antenna AP, four 1-antenna STAs, 160MHz (MU-MIMO)</td>
<td>Handheld</td>
<td>867 Mbit/s to each STA</td>
<td>3.39 Gbit/s</td>
</tr>
<tr>
<td>8-antenna AP, 160MHz (MU-MIMO)</td>
<td>Digital TV, Set-top Box, Tablet, Laptop, PC, Handheld</td>
<td>3.39 Gbit/s to 4-antenna STA 1.69 Gbit/s to 2-antenna STA 867 Mbit/s to each 1-antenna STA</td>
<td>6.77 Gbit/s</td>
</tr>
<tr>
<td>8-antenna AP, four 2-antenna STAs, 160MHz (MU-MIMO)</td>
<td>Digital TV, Tablet, Laptop, PC</td>
<td>1.69 Gbit/s to each STA</td>
<td>6.77 Gbit/s</td>
</tr>
</tbody>
</table>
### Theoretical throughput for single Spatial Stream (in Mb/s)

<table>
<thead>
<tr>
<th>MCS index</th>
<th>Modulation type</th>
<th>Coding rate</th>
<th>20 MHz channels</th>
<th>40 MHz channels</th>
<th>80 MHz channels</th>
<th>160 MHz channels</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>800 ns Gi</td>
<td>400 ns Gi</td>
<td>800 ns Gi</td>
<td>400 ns Gi</td>
</tr>
<tr>
<td>0</td>
<td>BPSK</td>
<td>1/2</td>
<td>6.5</td>
<td>7.2</td>
<td>13.5</td>
<td>15</td>
</tr>
<tr>
<td>1</td>
<td>QPSK</td>
<td>1/2</td>
<td>13</td>
<td>14.4</td>
<td>27</td>
<td>30</td>
</tr>
<tr>
<td>2</td>
<td>QPSK</td>
<td>3/4</td>
<td>19.5</td>
<td>21.7</td>
<td>40.5</td>
<td>45</td>
</tr>
<tr>
<td>3</td>
<td>16-QAM</td>
<td>1/2</td>
<td>26</td>
<td>28.9</td>
<td>54</td>
<td>60</td>
</tr>
<tr>
<td>4</td>
<td>16-QAM</td>
<td>3/4</td>
<td>39</td>
<td>43.3</td>
<td>81</td>
<td>90</td>
</tr>
<tr>
<td>5</td>
<td>64-QAM</td>
<td>2/3</td>
<td>52</td>
<td>57.8</td>
<td>108</td>
<td>120</td>
</tr>
<tr>
<td>6</td>
<td>64-QAM</td>
<td>3/4</td>
<td>58.5</td>
<td>65</td>
<td>121.5</td>
<td>135</td>
</tr>
<tr>
<td>7</td>
<td>64-QAM</td>
<td>5/6</td>
<td>65</td>
<td>72.2</td>
<td>135</td>
<td>150</td>
</tr>
<tr>
<td>8</td>
<td>256-QAM</td>
<td>3/4</td>
<td>78</td>
<td>86.7</td>
<td>162</td>
<td>180</td>
</tr>
<tr>
<td>9</td>
<td>256-QAM</td>
<td>5/6</td>
<td>N/A</td>
<td>N/A</td>
<td>180</td>
<td>200</td>
</tr>
</tbody>
</table>
Wireless Access in Vehicular Environment

IEEE 802.11p
IEEE 802.11p

- IEEE 802.11p is a standard to add wireless access in vehicular environment (WAVE).
- Supports Intelligent Transportation Systems (ITS) applications.
- Supports V2V, V2I communications.
- Operates in the 5.9 GHz frequency band.
IEEE 802.11p

- Operates using the EDCA access mechanism introduced in IEEE802.11e with some modifications.

- Supports QoS applications.

- Operates when dot11OCBActivated of the IEEE802.11 standard parameter is set to TRUE.

- Key features,
  - Minimizing initial setup time between communicating devices.
  - Using smaller channel bandwidth.
## IEEE 802.11p / QoS

Tabular data showing parameters for different ACs. The table includes columns for AC, CWmin, CWmax, AIFS, and TXOP limit. Here are the details:

<table>
<thead>
<tr>
<th>AC</th>
<th>CWmin</th>
<th>CWmax</th>
<th>AIFS</th>
<th>TXOP Limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>AC_BK</td>
<td>aCWmin</td>
<td>aCWmax</td>
<td>9</td>
<td>0</td>
</tr>
<tr>
<td>AC_BE</td>
<td>aCWmin</td>
<td>aCWmax</td>
<td>6</td>
<td>0</td>
</tr>
<tr>
<td>AC_VI</td>
<td>(aCWmin+1)/2−1</td>
<td>aCWmin</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>AC_VO</td>
<td>(aCWmin+1)/4−1</td>
<td>(aCWmin+1)/2−1</td>
<td>2</td>
<td>0</td>
</tr>
</tbody>
</table>

Table 8-106—Default EDCA parameter set for STA operation if dot11OCBActivated is true.
IEEE 802.11p / Channel Bandwidth

- The OFDM system also provides a “half-clocked” operation using 10 MHz channel spacings.

- Data communications capabilities of 3, 4.5, 6, 9, 12, 18, 24, and 27 Mb/s.

- The support of transmitting and receiving at data rates of 3, 6, and 12 Mb/s is mandatory when using 10 MHz channel spacing.
IEEE 802.11p & IEEE 1609

- The IEEE 1609 Family of Standards for Wireless Access in Vehicular Environments (WAVE) define an architecture and a complementary, standardized set of services and interfaces that collectively enable secure vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) wireless communications.
- Together these standards are designed to provide the foundation for a broad range of applications in the transportation environment, including vehicle safety, automated tolling, enhanced navigation, traffic management and many others.
- IEEE 1609 is a higher layer standard based on the IEEE 802.11p
THE END