**Capacity analysis of Wi-Fi 802.11 b, n, and ac using NetSim**

Applicable Release: v14.0.31 or higher

Applicable Version(s): All (Academic, Standard and Pro)

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**Download Link**

The configuration files (scenario, settings, and other related files) of the examples discussed in this analysis are available for users to import and run in NetSim.

Users can download the files from NetSim’s git-repository.

Link: <https://github.com/NetSim-TETCOS/Performance_Analysis_of_WiFi-802_11/archive/refs/heads/main.zip>

1. Click on the link given and download the folder.
2. Extract the zip folder. The extracted project folder consists of one NetSim Experiments file, namely *Capacity-analysis-of-Wi-Fi-802.11.netsimexp*
3. Import per steps given in section 4.9.1 in NetSim User Manual
4. All the experiments can now be seen folder wise within NetSim > Your Work. It will look like the image shown below.

A screenshot of a computer

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# Single AP-STA, UDP Download throughput for IEEE802.11b with varying distances.

**Objective:** To simulate and analyze the PHY rate and UDP download throughput, as the distance between the AP and the Wi-fi device is increased.

**Scenario:**

A graph with text and arrows

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Fig 1: Network Scenario

**Theory**

If Simulation Time < Application End Time, then

If Simulation Time > Application End Time, then

**MCS Table for 802.11 b**



|  |  |
| --- | --- |
| PHY Rate (Mbps) | Rx Sensitivity (dBm) |
| 11 | -82 |
| 5.5 | -80 |
| 2 | -78 |
| 1 | -76 |

Table 1: 802.11b bit rates and the minimum received signal power and SINR required for achieving each bit rate.

**Radio Propagation**

The radio propagation model is the log-distance model whereby, if a transmitter transmits at power to a receiver at distance (meters) (where it is assumed that , then the received power is given by:

The dB loss is at the distance of meter, and this value holds for the GHz band. Thus, for example, a transmit power of mW, i.e., dBm, with will lead to a received power of dBm, or mW, at the distance of meter, and to dBm at the distance of m.

**Network Configuration:** NetSim parameters are configured as shown below,

|  |  |  |
| --- | --- | --- |
| Interface Parameters | | |
| Standard | IEEE802.11b |
| Operating Frequency | 2.4GHz |
| Channel | 1 (2412MHz) |
| Rate Adaptation | False |
| Retry Limit | 4 |
| RTS Threshold | 3000bytes |
| Buffer Size | 1MB |
| Medium Access Protocol | DCF |
| Frequency Band | 2.4GHz |
| Bandwidth | 20MHz |
| Transmitter Power | 100mW |
| Antenna Gain | 0 |
| Antenna height | 1m |
| Reference distance (d0) | 1m |
| Wireless Link Parameters | | |
| Channel Characteristics | Path Loss Only |
| Path Loss Model | Log Distance |
| Pathloss Exponent () varies | 3.5, 3.0, 2.5 |
| Application Parameters | | |
| Application | CBR |
| Packet Size | 1450 bytes |
| Inter-Arrival Time (µs) | 116 (100Mbps Application Rate) |
| Transport Protocol | UDP |
| Wired Link Parameters | | |
| Wired Link Speed | 1Gbps |
| Wired Link BER | 0.0000001 |
| Wired Link Propagation Delay | 10μs |
| Simulation Parameters | | |
| Simulation Time | 10 seconds |

Table 2: Parameter settings for IEEE802.11b scenarios

**Result:**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| η=3.5 | | | | |
| Distance (m) | **PHY Rate (Mbps)** | **Throughput**  **(Mbps)** | **Rx Power (dBm)** | **Rx Sensitivity (dBm)** |
| 10 | 11 | 5.93 | -55.09 | -76 |
| 20 | 11 | 5.93 | -65.63 | -76 |
| 30 | 11 | 5.93 | -71.79 | -76 |
| 40 | 5.5 | 3.79 | -76.16 | -78 |
| 50 | 2 | 1.68 | -79.55 | -80 |
| 60 | 0 | 0.00 | -82.32 | -82 |

Table 3: Results of pathloss exponent 3.5

Fig 2:Plots for throughput and Data rate for path loss exponent 3.5

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| η=3.0 | | | | |
| Distance (m) | **PHY Rate (Mbps)** | **Throughput**  **(Mbps)** | **Rx Power (dBm)** | **Rx Sensitivity (dBm)** |
| 20 | 11 | 5.93 | -59.12 | -76 |
| 40 | 11 | 5.93 | -68.15 | -76 |
| 60 | 11 | 5.93 | -73.43 | -76 |
| 80 | 5.5 | 3.79 | -77.18 | -78 |
| 90 | 2 | 1.68 | -78.72 | -80 |
| 100 | 1 | 0.89 | -80.09 | -82 |
| 120 | 0 | 0.00 | -82.47 | -82 |

Table 4 :Results of pathloss exponent 3

Fig 3: Plots for throughput and Data rate of path loss exponent 3

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| η=2.5 | | | | |
| Distance (m) | **PHY Rate (Mbps)** | **Throughput**  **(Mbps)** | **Rx Power (dBm)** | **Rx Sensitivity (dBm)** |
| 30 | 11 | 5.93 | -57.02 | -76 |
| 60 | 11 | 5.93 | -64.54 | -76 |
| 90 | 11 | 5.93 | -68.95 | -76 |
| 120 | 11 | 5.93 | -72.07 | -76 |
| 150 | 11 | 5.93 | -74.49 | -76 |
| 180 | 5.5 | 3.79 | -76.47 | -78 |
| 210 | 2 | 1.68 | -78.15 | -80 |
| 240 | 2 | 1.68 | -79.59 | -80 |
| 270 | 1 | 0.89 | -80.87 | -82 |
| 300 | 0 | 0.00 | -82.02 | -82 |

Table 5: Results of pathloss exponent 2.5

Fig 4: Plots for throughput and Data rate of path loss exponent 2.5

# Single AP-STA, UDP Download throughput for IEEE802.11n with varying distances.

**Calculation**

If Simulation Time < Application End Time, then

If Simulation Time > Application End Time, then

|  |  |
| --- | --- |
| PHY Rate (Mbps) | Rx Sensitivity (dBm) |
| 86.7 | -59 |
| 72.2 | -64 |
| 65.0 | -65 |
| 57.8 | -66 |
| 43.3 | -70 |
| 28.9 | -74 |
| 21.7 | -77 |
| 14.4 | -79 |
| 7.2 | -82 |

Table : 802.11n bit rate and the minimum received signal power and SINR required for achieving each bit rate.

**Network Configuration:** NetSim parameters to be configured for the devices as shown below,

|  |  |
| --- | --- |
| Interface Parameters | |
| Standard | IEEE802.11n |
| No. of Packet aggregated | 64 |
| Operating Frequency | 2.4GHz |
| Channel | 1 (2412MHz) |
| Rate Adaptation | False |
| Retry Limit | 4 |
| RTS Threshold | 3000bytes |
| Medium Access Protocol | DCF |
| Buffer Size | 100 MB |
| Transmitting Antenna | 1 |
| Receiving Antenna | 1 |
| Guard Interval | 400ns |
| Bandwidth | 20MHz |
| Frequency Band | 2.4GHz |
| Transmitter Power | 100mW |
| Antenna Gain | 0 |
| Antenna height | 1m |
| Reference distance (d0) | 1m |
| Wireless Link Parameters | |
| Channel Characteristics | Path Loss Only |
| Path Loss Model | Log Distance |
| Pathloss Exponent () varying | 3.5, 3.0, 2.5 |
| Application Parameters | |
| Application | CBR |
| Packet Size | 1450 bytes |
| Inter-Arrival Time | 116 (100Mbps Application Rate) |
| Transport Protocol | UDP |
| Wired Link Parameters | |
| Wired Link Speed | 10Gbps |
| Wired Link BER | 0.0000001 |
| Wired Link Propagation Delay | 10μs |
| Simulation Parameters | |
| Simulation Time | 10 seconds |

Table 7:Parameter settings for IEEE802.11n scenarios

**Result:**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| η=3.5 | | | | |
| Distance (m) | **PHY Rate**  **(Mbps)** | **Throughput**  **(Mbps)** | **Rx Power (dBm)** | **Rx Sensitivity (dBm)** |
| 5 | 72.2 | 65.93 | -44.55 | -64 |
| 10 | 72.2 | 65.93 | -55.09 | -64 |
| 15 | 72.2 | 65.93 | -61.25 | -64 |
| 20 | 57.8 | 53.20 | -65.63 | -66 |
| 25 | 43.3 | 40.19 | -69.02 | -70 |
| 30 | 28.9 | 27.05 | -71.79 | -74 |
| 35 | 21.7 | 20.39 | -74.13 | -77 |
| 40 | 21.7 | 20.39 | -76.16 | -77 |
| 45 | 14.4 | 13.59 | -77.95 | -79 |
| 50 | 7.2 | 6.82 | -79.55 | -82 |
| 55 | 7.2 | 6.82 | -81.00 | -82 |
| 60 | 0 | 0.0 | -82.32 | -82 |

Table : Results of pathloss exponent 3.5

Fig : Plots for throughput and Data rate of path loss exponent 3.5

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| =3.0 | | | | |
| Distance (m) | **PHY Rate (Mbps)** | **Throughput**  **(Mbps)** | **Rx Power (dBm)** | **Rx Sensitivity (dBm)** |
| 10 | 72.2 | 65.93 | -50.09 | -64 |
| 20 | 72.2 | 65.93 | -59.12 | -64 |
| 30 | 65 | 59.60 | -64.40 | -65 |
| 40 | 43.3 | 40.19 | -68.15 | -70 |
| 50 | 28.9 | 27.05 | -71.06 | -74 |
| 60 | 28.9 | 27.05 | -73.43 | -74 |
| 70 | 21.7 | 20.39 | -75.44 | -77 |
| 80 | 14.4 | 13.59 | -77.18 | -79 |
| 90 | 14.4 | 13.59 | -78.72 | -79 |
| 100 | 7.2 | 6.82 | -80.09 | -82 |
| 110 | 7.2 | 6.82 | -81.33 | -82 |
| 120 | 7.2 | 0.0 | -82.47 | -82 |

Table : Results of pathloss exponent 3

Fig : Plots for throughput and Data rate of path loss exponent 3

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| =2.5 | | | | |
| Distance (m) | **PHY Rate (Mbps)** | **Throughput**  **(Mbps)** | **Rx Power (dBm)** | **Rx Sensitivity (dBm)** |
| 10 | 72.2 | 65.93 | -45.09 | -64 |
| 30 | 72.2 | 65.93 | -57.02 | -64 |
| 50 | 72.2 | 65.93 | -62.56 | -64 |
| 70 | 43.3 | 40.19 | -66.22 | -70 |
| 90 | 43.3 | 40.19 | -68.95 | -70 |
| 110 | 28.9 | 27.05 | -71.12 | -74 |
| 130 | 28.9 | 27.05 | -72.94 | -74 |
| 150 | 21.7 | 20.39 | -74.49 | -77 |
| 170 | 21.7 | 20.39 | -75.85 | -77 |
| 190 | 14.4 | 13.59 | -77.06 | -79 |
| 210 | 14.4 | 13.59 | -78.15 | -79 |
| 230 | 7.2 | 6.82 | -79.13 | -82 |
| 250 | 7.2 | 6.82 | -80.04 | -82 |
| 270 | 7.2 | 6.82 | -80.87 | -82 |
| 290 | 7.2 | 6.82 | -81.65 | -82 |
| 310 | 0 | 0 | -82.37 | -82 |

Table : Results of pathloss exponent 2.5

Fig : Plots for throughput and Data rate of path loss exponent 2.5

# Single AP-STA, UDP Download throughput for IEEE802.11ac with varying distances

**Calculation:**

If Simulation Time < Application End Time, then

If Simulation Time > Application End Time, then

|  |  |
| --- | --- |
| PHY Rate (Mbps) | Rx Sensitivity |
| 86.7 | -59 |
| 72.2 | -64 |
| 65.0 | -65 |
| 57.8 | -66 |
| 43.3 | -70 |
| 28.9 | -74 |
| 21.7 | -77 |
| 14.4 | -79 |
| 7.2 | -82 |

Table : 802.11ac bit rates and the minimum received signal power and SINR required for achieving each bit rate.

**Network Configuration:** NetSim parameters to be configured as shown below,

|  |  |
| --- | --- |
| Interface Parameters | |
| Standard | IEEE802.11ac |
| No. of Packet aggregated | 1024 |
| Operating Frequency | 5GHz |
| Channel | 36 (5180MHz) |
| Rate Adaptation | False |
| Retry Limit | 4 |
| RTS Threshold | 3000bytes |
| Medium Access Protocol | DCF |
| Buffer Size | 100 MB |
| Transmitting Antenna | 1 |
| Receiving Antenna | 1 |
| Guard Interval | 400ns |
| Bandwidth | 20MHz |
| Frequency Band | 5GHz |
| Transmitter Power | 100mW |
| Antenna Gain | 0 |
| Antenna height | 1m |
| Reference distance (d0) | 1m |
| Wireless Link Parameters | |
| Channel Characteristics | Path Loss Only |
| Path Loss Model | Log Distance |
| Pathloss Exponent () varying | 3.5, 3.0, 2.5 |
| Application Parameters | |
| Application | CBR |
| Packet Size | 1450 bytes |
| Inter-Arrival Time (µs) | 116 (100Mbps Application Rate) |
| Transport Protocol | UDP |
| Wired Link Parameters | |
| Wired Link Speed | 10Gbps |
| Wired Link BER | 0.0000001 |
| Wired Link Propagation Delay | 10μs |
| Simulation Parameters | |
| Simulation Time | 10 seconds |

Table 12: Parameter settings for IEEE802.11ac scenarios

**Result:**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| =3.5 | | | | |
| Distance (m) | **PHY Rate (Mbps)** | **Throughput**  **(Mbps)** | **Rx Power (dBm)** | **Rx Sensitivity (dBm)** |
| 5 | 86.7 | 82.12 | -51.19 | -59 |
| 10 | 72.2 | 68.44 | -61.73 | -64 |
| 15 | 43.3 | 41.11 | -67.89 | -70 |
| 20 | 28.9 | 27.46 | -72.26 | -74 |
| 25 | 21.7 | 20.62 | -75.66 | -77 |
| 30 | 14.4 | 13.69 | -78.43 | -79 |
| 35 | 7.2 | 6.85 | -80.77 | -82 |
| 40 | 0.0 | 0.00 | -82.80 | -82 |

Fig : Results of pathloss exponent 3.5

Fig : Plots for throughput and Data rate of path loss exponent 3.5

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| =3.0 | | | | |
| Distance (m) | **PHY Rate (Mbps)** | **Throughput**  **(Mbps)** | **Rx Power (dBm)** | **Rx Sensitivity (dBm)** |
| 5 | 86.7 | 82.12 | -47.70 | -59 |
| 10 | 86.7 | 82.12 | -56.73 | -59 |
| 15 | 72.2 | 68.44 | -62.01 | -64 |
| 20 | 57.8 | 54.84 | -65.76 | -66 |
| 25 | 43.3 | 41.11 | -68.67 | -70 |
| 30 | 28.9 | 27.46 | -71.04 | -74 |
| 35 | 28.9 | 27.46 | -73.05 | -74 |
| 40 | 21.7 | 20.62 | -74.79 | -77 |
| 45 | 21.7 | 20.62 | -76.33 | -77 |
| 50 | 14.4 | 13.69 | -77.70 | -79 |
| 55 | 14.4 | 13.69 | -78.94 | -79 |
| 60 | 7.2 | 6.85 | -80.07 | -82 |
| 65 | 7.2 | 6.85 | -81.12 | -82 |
| 70 | 0.0 | 0.00 | -82.08 | -82 |

Fig : Results of pathloss exponent 3

Fig : Plots for throughput and Data rate of path loss exponent 3

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| =2.5 | | | | |
| Distance (m) | **PHY Rate (Mbps)** | **Throughput**  **(Mbps)** | **Rx Power (dBm)** | **Rx Sensitivity (dBm)** |
| 5 | 86.7 | 82.12 | -44.20 | -59 |
| 10 | 86.7 | 82.12 | -51.73 | -59 |
| 15 | 86.7 | 82.12 | -56.13 | -59 |
| 20 | 72.2 | 68.44 | -59.25 | -64 |
| 25 | 72.2 | 68.44 | -61.68 | -64 |
| 30 | 72.2 | 68.44 | -63.66 | -64 |
| 35 | 57.8 | 54.84 | -65.33 | -66 |
| 40 | 43.3 | 41.11 | -66.78 | -70 |
| 45 | 43.3 | 41.11 | -68.06 | -70 |
| 50 | 43.3 | 41.11 | -69.20 | -70 |
| 55 | 28.9 | 27.46 | -70.24 | -74 |
| 60 | 28.9 | 27.46 | -71.18 | -74 |
| 65 | 28.9 | 27.46 | -72.05 | -74 |
| 70 | 28.9 | 27.46 | -72.86 | -74 |
| 75 | 28.9 | 27.46 | -73.61 | -74 |
| 80 | 21.7 | 20.62 | -74.31 | -77 |
| 85 | 21.7 | 20.62 | -74.96 | -77 |
| 90 | 21.7 | 20.62 | -75.58 | -77 |
| 95 | 21.7 | 20.62 | -76.17 | -77 |
| 100 | 21.7 | 20.62 | -76.73 | -77 |
| 105 | 14.4 | 13.69 | -77.26 | -79 |
| 110 | 14.4 | 13.69 | -77.76 | -79 |
| 115 | 14.4 | 13.69 | -78.25 | -79 |
| 120 | 14.4 | 13.69 | -78.71 | -79 |
| 125 | 7.2 | 6.85 | -79.15 | -82 |
| 130 | 7.2 | 6.85 | -79.58 | -82 |
| 135 | 7.2 | 6.85 | -79.99 | -82 |
| 140 | 7.2 | 6.85 | -80.38 | -82 |
| 145 | 7.2 | 6.85 | -80.76 | -82 |
| 150 | 7.2 | 6.85 | -81.13 | -82 |
| 155 | 7.2 | 6.85 | -81.49 | -82 |
| 160 | 7.2 | 6.85 | -81.83 | -82 |
| 165 | 0.0 | 0.00 | -82.17 | -82 |
| 170 | 0.0 | 0.00 | -82.49 | -82 |

Fig : Results of pathloss exponent 2.5

Fig : Plots for throughput and Data rate of path loss exponent 2.5

# Single AP-STA, UDP Download throughput for 802.11 n and 802.11 ac with varying antenna count.

**Network Scenario:**

A graph with a line and arrows

Description automatically generated

Fig 14: Network Scenario-802.11n and ac

**Network Configuration:** NetSim parameters to be configured for the devices as shown below,

|  |  |  |
| --- | --- | --- |
| Device Name | x-coordinate | y-coordinate |
| Access Point\_3 | 250 | 0 |
| Wireless Node\_4 | 250 | 50 |

|  |  |
| --- | --- |
| Interface Parameters | |
| Standard | IEEE802.11n, IEEE802.11ac |
| No. of Packet aggregated | 64, 1024 |
| Channel | 1 (2412MHz),36 (5180MHz) |
| Rate Adaptation | False |
| Retry Limit | 4 |
| RTS Threshold | 3000bytes |
| Medium Access Protocol | DCF |
| Buffer Size | 100 MB |
| Transmitting Antenna | 1 |
| Receiving Antenna | 1 |
| Guard Interval | 400ns |
| Bandwidth | 20MHz |
| Frequency Band | 2.4/ 5GHz |
| Transmitter Power | 100mW |
| Antenna Gain | 0 |
| Antenna height | 1m |
| Reference distance (d0) | 1m |
| Wireless Link Parameters | |
| Channel Characteristics | No Path Loss |
| Application Parameters | |
| Application | CBR |
| Packet Size | 1450 bytes |
| Inter-Arrival Time | 38/16 μs (300/ 725 Mbps Application Rate) |
| Transport Protocol | UDP |
| Wired Link Parameters | |
| Wired Link Speed | 10Gbps |
| Wired Link BER | 0.0000001 |
| Wired Link Propagation Delay | 10μs |
| Simulation Parameters | |
| Simulation Time | 10 seconds |

Table 13:Network Configuration for IEEE802.11n and ac

**Results:**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| IEEE802.11n | | | |  |
| Tx/Rx Antenna | **PHY Rate (Mbps)** | **Rx Power (dBm)** | **Rx Sensitivity (dBm)** | **Throughput**  **(Mbps)** |
| 1x1 | 72.2 | -20.00 | -64.00 | 65.94 |
| 2x2 | 144.4 | -20.00 | -64.00 | 127.93 |
| 3x3 | 216.7 | -20.00 | -64.00 | 185.42 |
| 4x4 | 288.9 | -20.00 | -64.00 | 240.76 |

Table 14:Results of IEEE802.11n

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| IEEE802.11ac | | | |  |
| Tx/Rx Antenna | **PHY Rate (Mbps)** | **Rx Power (dBm)** | **Rx Sensitivity (dBm)** | **Throughput**  **(Mbps)** |
| 1x1 | 86.7 | -20.00 | -59.00 | 82.18 |
| 2x2 | 173.3 | -20.00 | -59.00 | 163.90 |
| 3x3 | 288.9 | -20.00 | -57.00 | 272.37 |
| 4x4 | 346.7 | -20.00 | -59.00 | 326.46 |
| 5x5 | 433.3 | -20.00 | -59.00 | 407.11 |
| 6x6 | 577.8 | -20.00 | -57.00 | 540.74 |
| 7x7 | 606.7 | -20.00 | -59.00 | 567.44 |
| 8x8 | 693.3 | -20.00 | -59.00 | 646.91 |

Table 15: Results of IEEE802.11ac

# Single AP-STA, UDP Download throughput for 802.11 n and 802.11 ac with varying packet aggregation count.

**Network Configuration:**

A graph with arrows and a line

Description automatically generated

Fig 15: Network scenario

**Network Configuration:** NetSim parameters to be configure for the devices as shown below,

|  |  |  |
| --- | --- | --- |
| Device Name | x-coordinate | y-coordinate |
| Access Point\_3 | 250 | 0 |
| Wireless Node\_4 | 250 | 10 |

|  |  |
| --- | --- |
| Interface Parameters | |
| Standard | IEEE802.11n |
| No. of Packet aggregated | 64 |
| Channel | 1(2412MHz) |
| Rate Adaptation | False |
| Retry Limit | 4 |
| RTS Threshold | 3000bytes |
| Medium Access Protocol | DCF |
| Buffer Size | 100 MB |
| Transmitting Antenna | 1 |
| Receiving Antenna | 1 |
| Guard Interval | 400ns |
| Bandwidth | 20MHz |
| Frequency Band | 2.4GHz |
| Transmitter Power | 100mW |
| Antenna Gain | 0 |
| Antenna height | 1m |
| Reference distance (d0) | 1m |
| Wireless Link Parameters | |
| Channel Characteristics | Path Loss Only |
| Path Loss Model | Log Distance |
| Pathloss Exponent (η) | 2.5 |
| Application Parameters | |
| Application | CBR |
| Packet Size | 1450 bytes |
| Inter-Arrival Time (µs) | 116 (100Mbps Application Rate) |
| Transport Protocol | UDP |
| Wired Link Parameters | |
| Wired Link Speed | 100Mbps |
| Wired Link BER | 0.0000001 |
| Propagation Delay | 5μs |
| Simulation Parameters | |
| Simulation Time | 10 seconds |

Table 16: Network Configuration for IEEE802.11n

**Results:**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| IEEE802.11n | | | | |
| Packet Aggregation | **PHY Rate (Mbps)** | **Rx Power (dBm)** | **Rx Sensitivity (dBm)** | **Throughput**  **(Mbps)** |
| 1 | 72.2 | -45.09 | -64 | 23.87 |
| 2 | 72.2 | -45.09 | -64 | 35.45 |
| 4 | 72.2 | -45.09 | -64 | 41.06 |
| 8 | 72.2 | -45.09 | -64 | 51.44 |
| 16 | 72.2 | -45.09 | -64 | 58.81 |
| 32 | 72.2 | -45.09 | -64 | 63.38 |
| 64 | 72.2 | -45.09 | -64 | 65.93 |

Table 17: Results of IEEE802.11n

**Note**: RTS/CTS is triggered when packet aggregation count is 4. This is the reason the increase in throughput from 2 to 4 packets aggregated is lower than the increase in throughput from 1 to 2 packets aggregated.

**Throughput calculation for packet aggregation = 1 (No aggregation)**

,

where,

**Throughput calculation for packet aggregation = 2**

**Throughput calculation for packet aggregation = 4 (RTS/CTS Triggered)**

**Network Configuration:** NetSim parameters to be configure for the devices as shown below,

|  |  |  |
| --- | --- | --- |
| Device Name | x-coordinate | y-coordinate |
| Access Point\_3 | 200 | 0 |
| Wireless Node\_4 | 200 | 30 |

|  |  |
| --- | --- |
| Interface Parameters | |
| Standard | IEEE802.11ac |
| No. of Packet aggregated | 1024 |
| Channel | 36(5180MHz) |
| Rate Adaptation | False |
| Retry Limit | 4 |
| RTS Threshold | 3000bytes |
| Medium Access Protocol | DCF |
| Buffer Size | 100 MB |
| Transmitting Antenna | 1 |
| Receiving Antenna | 1 |
| Guard Interval | 400ns |
| Bandwidth | 20MHz |
| Frequency Band | 5GHz |
| Transmitter Power | 100mW |
| Antenna Gain | 0 |
| Antenna height | 1m |
| Reference distance (d0) | 1m |
| Wireless Link Parameters | |
| Channel Characteristics | Path Loss Only |
| Path Loss Model | Log Distance |
| Pathloss Exponent (η) | 2.5 |
| Application Parameters | |
| Application | CBR |
| Packet Size | 1450 bytes |
| Inter-Arrival Time (µs) | 116 (100Mbps Application Rate) |
| Transport Protocol | UDP |
| Wired Link Parameters | |
| Wired Link Speed | 100Mbps |
| Wired Link BER | 0.0000001 |
| Wired Link Propagation Delay | 5μs |
| Simulation Parameters | |
| Simulation Time | 10 seconds |

Table 18:Network Configuration for IEEE802.11ac

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| IEEE802.11ac | | | | |
| Packet Aggregation | **PHY Rate (Mbps)** | **Rx Power** | **Rx Sensitivity** | **Throughput**  **(Mbps)** |
| 1 | 72.2 | -63.66 | -64.00 | 21.50 |
| 2 | 72.2 | -63.66 | -64.00 | 32.76 |
| 4 | 72.2 | -63.66 | -64.00 | 38.54 |
| 8 | 72.2 | -63.66 | -64.00 | 49.39 |
| 16 | 72.2 | -63.66 | -64.00 | 57.46 |
| 32 | 72.2 | -63.66 | -64.00 | 62.58 |
| 64 | 72.2 | -63.66 | -64.00 | 65.49 |
| 128 | 72.2 | -63.66 | -64.00 | 67.04 |
| 256 | 72.2 | -63.66 | -64.00 | 67.84 |
| 512 | 72.2 | -63.66 | -64.00 | 68.24 |
| 1024 | 72.2 | -63.66 | -64.00 | 68.44 |

Table 19:Results of IEEE802.11ac

**Note**: RTS/CTS is triggered when packet aggregation count is 4. This is the reason the increase in throughput from 2 to 4 packets aggregated is lower than the increase in throughput from 1 to 2 packets aggregated.

**Throughput calculation for packet aggregation = 1 (No aggregation)**

**Throughput calculation for packet aggregation = 2**

**Throughput calculation for packet aggregation = 4 (RTS/CTS Triggered)**

throughput for 802.11n and 802.11 ac, with MIMO and Packet Aggregation (Max UDP throughput case)

**Network Scenario:**

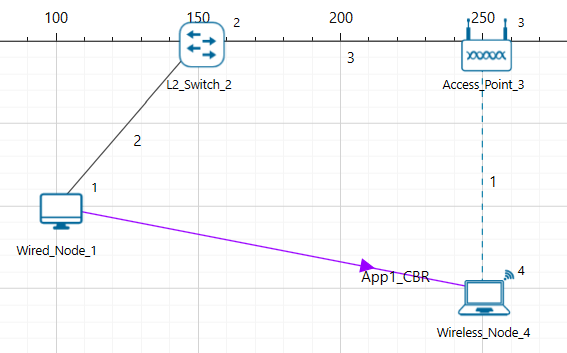
****

Fig 16:Network Scenario

NetSim parameters to be configured for the devices as shown below,

**Case:1**

**For 802.11n device configuration is as follows:**

|  |  |  |
| --- | --- | --- |
| Device Name | x-coordinate | y-coordinate |
| Access Point\_3 | 250 | 0 |
| Wireless Node\_4 | 250 | 10 |

|  |  |  |
| --- | --- | --- |
| Interface Parameters | | |
| Standard | IEEE802.11n |
| No. of Packet aggregated | 64 |
| Channel | 1 (2412MHz),36 (5180MHz) |
| Rate Adaptation | False |
| Retry Limit | 4 |
| RTS Threshold | 3000bytes |
| Medium Access Protocol | DCF |
| Buffer Size | 100 MB |
| Guard Interval | 400ns |
| Bandwidth | 20,40MHz |
| Frequency Band | 2.4/ 5GHz |
| Transmitter Power | 100mW |
| Antenna Gain | 0 |
| Antenna height | 1m |
| Reference distance (d0) | 1m |
| Wireless Link Parameters | | |
| Channel Characteristics | Path Loss Only |
| Path Loss Model | Log Distance |
| Pathloss Exponent (η) | 2.5 |
| Application Parameters | | |
| Application | CBR |
| Packet Size | 1450 bytes |
| Inter-Arrival Time | 11 μs (1000 Mbps Application Rate) |
| Transport Protocol | UDP |
| Wired Link Parameters | | |
| Wired Link Speed | 1Gbps |
| Wired Link BER | 0.0000001 |
| Wired Link Propagation Delay | 10μs |
| Simulation Parameters | | |
| Simulation Time | 10 seconds |

**Fo802.11ac, device configuration is as follows:**

|  |  |  |
| --- | --- | --- |
| Device Name | x-coordinate | y-coordinate |
| Access Point\_3 | 200 | 0 |
| Wireless Node\_4 | 200 | 10 |

|  |  |
| --- | --- |
| Interface Parameters | |
| Standard | IEEE802.11ac |
| No. of Packet aggregated | 1024 |
| Channel | 36 (5180MHz) |
| Rate Adaptation | False |
| Retry Limit | 4 |
| RTS Threshold | 3000bytes |
| Buffer Size | 100 MB |
| Guard Interval | 400ns |
| Bandwidth | 20,40,80,160MHz |
| Frequency Band | 5GHz |
| Transmitter Power | 100mW |
| Antenna Gain | 0 |
| Antenna height | 1m |
| Reference distance (d0) | 1m |
| Wireless Link Parameters | |
| Channel Characteristics | Path Loss Only |
| Path Loss Model | Log Distance |
| Pathloss Exponent (η) | 2.5 |
| Application Parameters | |
| Application | CBR |
| Packet Size | 1450 bytes |
| Inter-Arrival Time | 11,5,2,1 μs (1000,2000,5800,11600 Mbps Application Rates) |
| Transport Protocol | UDP |
| Wired Link Parameters | |
| Wired Link Speed | 1Gbps for 20MHz bandwidth & 10Gbps for 40,80,160MHz bandwidths |
| Wired Link BER | 0.0000001 |
| Wired Link Propagation Delay | 10μs |
| Simulation Parameters | |
| Simulation Time | 10 seconds |

**Case:2**

**For 802.11n device configuration is as follows:**

|  |  |  |
| --- | --- | --- |
| Device Name | x-coordinate | y-coordinate |
| Access Point\_3 | 250 | 0 |
| Wireless Node\_4 | 250 | 30 |

|  |  |  |
| --- | --- | --- |
| Interface Parameters | | |
| Standard | IEEE802.11n |
| No. of Packet aggregated | 64 |
| Channel | 1 (2412MHz),36 (5180MHz) |
| Rate Adaptation | False |
| Retry Limit | 4 |
| RTS Threshold | 3000bytes |
| Medium Access Protocol | DCF |
| Buffer Size | 100 MB |
| Guard Interval | 400ns |
| Bandwidth | 20,40MHz |
| Frequency Band | 2.4/ 5GHz |
| Transmitter Power | 100mW |
| Antenna Gain | 0 |
| Antenna height | 1m |
| Reference distance (d0) | 1m |
| Wireless Link Parameters | | |
| Channel Characteristics | No Pathloss |
| Application Parameters | | |
| Application | CBR |
| Packet Size | 1450 bytes |
| Inter-Arrival Time | 11 μs (1000 Mbps Application Rate) |
| Transport Protocol | UDP |
| Wired Link Parameters | | |
| Wired Link Speed | 1Gbps |
| Wired Link BER | 0 |
| Wired Link Propagation Delay | 0 μs |
| Simulation Parameters | | |
| Simulation Time | 10 seconds |

**For 802.11ac device configuration is as follows:**

|  |  |  |
| --- | --- | --- |
| Device Name | x-coordinate | y-coordinate |
| Access Point\_3 | 200 | 0 |
| Wireless Node\_4 | 200 | 30 |

|  |  |  |
| --- | --- | --- |
| Interface Parameters | | |
| Standard | IEEE802.11ac |
| No. of Packet aggregated | 1024 |
| Channel | 36 (5180MHz) |
| Rate Adaptation | False |
| Retry Limit | 4 |
| RTS Threshold | 3000bytes |
| Medium Access Protocol | DCF |
| Buffer Size | 100 MB |
| Guard Interval | 400ns |
| Bandwidth | 20,40,80,160MHz |
| Frequency Band | 5GHz |
| Slot Time | 9µs |
| SIFS | 16µs |
|  | 15 slots |
| Transmitter Power | 100mW |
| Transmitting Antennas | 8 |
| Receiving Antennas | 8 |
| Antenna Gain | 0 |
| Antenna height | 1m |
| Reference distance (d0) | 1m |
| Wireless Link Parameters | | |
| Channel Characteristics | No Path Loss |
| Application Parameters | | |
| Application | CBR |
| Packet Size | 1450 bytes |
| Inter-Arrival Time | 2 μs (5800 Mbps Application Rates) |
| Transport Protocol | UDP |
| Wired Link Parameters | | |
| Wired Link Speed | 10Gbps |
| Wired Link BER | 0 |
| Wired Link Propagation Delay | 0 μs |
| Simulation Parameters | | |
| Simulation Time | 10 seconds |

**Throughput calculation for packet aggregation = 64 (RTS/CTS Triggered)**

|  |  |
| --- | --- |
|  | PHY rate (Mbps) |
| ACK PHY Rate | 520 |
| RTS PHY Rate |
| CTS PHY Rate |
| Data PHY Rate | 6933.3 |

**Note:** The above given PHY rates value calculated from packet trace except for PHY rate for data packets which is got by adding code to the 802.11 project.

**Results:**

**Case-1:**

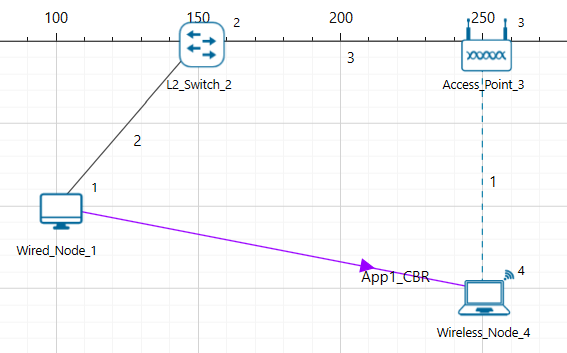
|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| With Pathloss | | | | | | |
| Standard | **Frequency**  **Band (GHz)** | **PHY Rate (Mbps)** | **Band width**  **(MHz)** | **Antenna Count** | **Packets Aggregated** | **Throughput**  **(Mbps)** |
| 802.11 n | 2.4 | 288.9 | 20 | 4\*4 | 64 | 240.78 |
|  | 5 | 600 | 40 | 4\*4 | 64 | 464.40 |
| 802.11 ac | 5 | 693.3 | 20 | 8\*8 | 1024 | 647.05 |
|  | 5 | 1600 | 40 | 8\*8 | 1024 | 1459.89 |
|  | 5 | 3120 | 80 | 8\*8 | 1024 | 2744.35 |
|  | 5 | 5200 | 160 | 8\*8 | 1024 | 4358.39 |

**Case-2:**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| With No Pathloss | | | | | | |
| Standard | **Frequency**  **Band (GHz)** | **PHY Rate (Mbps)** | **Band width**  **(MHz)** | **Antenna Count** | **Packets Aggregated** | **Throughput**  **(Mbps)** |
| 802.11 n | 2.4 | 288.9 | 20 | 4\*4 | 64 | 240.78 |
|  | 5 | 600 | 40 | 4\*4 | 64 | 464.40 |
| 802.11 ac | 5 | 693.3 | 20 | 8\*8 | 1024 | 647.16 |
|  | 5 | 1600 | 40 | 8\*8 | 1024 | 1459.98 |
|  | 5 | 3466.7 | 80 | 8\*8 | 1024 | 3024.28 |
|  | 5 | 6933.3 | 160 | 8\*8 | 1024 | 5361.43 |

# Single AP-STA, UDP download throughput for 802.11n and 802.11 ac, for short and long packets (with MIMO and Packet Aggregation)

**Network Scenario:**

****

NetSim parameters to be configured for the devices as shown below,

**For 802.11n device configuration is as follows:**

|  |  |  |
| --- | --- | --- |
| Device Name | x-coordinate | y-coordinate |
| Access Point\_3 | 250 | 0 |
| Wireless Node\_4 | 250 | 30 |

|  |  |  |
| --- | --- | --- |
| Interface Parameters | | |
| Standard | IEEE802.11n |
| No. of Packet aggregated | 64 |
| Channel | 1 (2412)MHz / 36 (5180MHz) |
| Rate Adaptation | False |
| Retry Limit | 4 |
| RTS Threshold | 3000bytes |
| Medium Access Protocol | DCF |
| Buffer Size | 100 MB |
| Guard Interval | 400ns |
| Bandwidth | 20,40MHz |
| Frequency Band | 2.4/ 5GHz |
| Transmitter Power | 100mW |
| Antenna Gain | 0 |
| Antenna height | 1m |
| Reference distance (d0) | 1m |
| Wireless Link Parameters | | |
| Channel Characteristics | No Pathloss |
| Application Parameters | | |
| Application | CBR |
| Packet Size | 1450/100 bytes |
| Inter-Arrival Time | 11/1 μs (1000 Mbps Application Rate) |
| Transport Protocol | UDP |
| Wired Link Parameters | | |
| Wired Link Speed | 1Gbps |
| Wired Link BER | 0.0000001 |
| Wired Link Propagation Delay | 10μs |
| Simulation Parameters | | |
| Simulation Time | 10 seconds |

**For 802.11ac device configuration is as follows:**

|  |  |  |
| --- | --- | --- |
| Device Name | x-coordinate | y-coordinate |
| Access Point\_3 | 250 | 0 |
| Wireless Node\_4 | 250 | 10 |

|  |  |  |
| --- | --- | --- |
| Interface Parameters | | |
| Standard | IEEE802.11ac |
| No. of Packet aggregated | 1024 |
| Channel | 36 (5180MHz) |
| Rate Adaptation | False |
| Retry Limit | 4 |
| RTS Threshold | 3000bytes |
| Medium Access Protocol | DCF |
| Buffer Size | 100 MB |
| Guard Interval | 400ns |
| Bandwidth | 20,40,80,160MHz |
| Frequency Band | 5GHz |
| Transmitter Power | 100mW |
| Antenna Gain | 0 |
| Antenna height | 1m |
| Reference distance (d0) | 1m |
| Wireless Link Parameters | | |
| Channel Characteristics | No Path Loss |
| Application Parameters | | |
| Application | CBR |
| Packet Size | 1450/100 bytes |
| Inter-Arrival Time | 11,5,2,1/1 μs (1000,2000,5800,11600 Mbps Application Rates for packet size 1450bytes and 800Mbps for 100 bytes) |
| Transport Protocol | UDP |
| Wired Link Parameters | | |
| Wired Link Speed | 1Gbps for 20MHz bandwidth & 10Gbps for 40,80,160MHz bandwidths |
| Wired Link BER | 0.0000001 |
| Wired Link Propagation Delay | 10μs |
| Simulation Parameters | | |
| Simulation Time | 10 seconds |

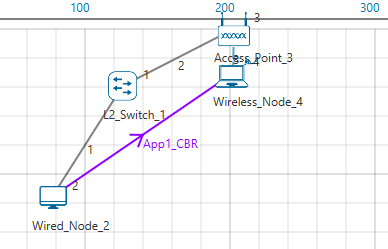
**Results:**

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Standard | Packet Size (B) | Frequency  Band (GHz) | Band width | PHY Rate (Mbps) | Antenna Count | Packets Aggregated | Throughput  (Mbps) |
| 802.11 n | 1450 | 2.4 | 20 | 288.9 | 4\*4 | 64 | 240.77 |
|  | 100 | 2.4 | 20 | 288.9 | 4\*4 | 64 | 74.39 |
| 802.11 n | 1450 | 5 | 40 | 600 | 4\*4 | 64 | 464.40 |
|  | 100 | 5 | 40 | 600 | 4\*4 | 64 | 114.96 |
| 802.11 ac | 1450 | 5 | 20 | 693.3 | 8\*8 | 1024 | 647.05 |
|  | 1450 | 5 | 40 | 1600 | 8\*8 | 1024 | 1459.98 |
|  | 1450 | 5 | 80 | 3466.7 | 8\*8 | 1024 | 2744.35 |
|  | 1450 | 5 | 160 | 6933.3 | 8\*8 | 1024 | 4358.39 |
|  | 100 | 5 | 20 | 693.3 | 8\*8 | 1024 | 344.24 |
|  | 100 | 5 | 40 | 1600 | 8\*8 | 1024 | 674.39 |
|  | 100 | 5 | 80 | 3466.7 | 8\*8 | 1024 | 738.31 |
|  | 100 | 5 | 160 | 6933.3 | 8\*8 | 1024 | 738.34 |

**Note:** Currently, the minimum Inter-arrival-time available in NetSim is 1 μs. Hence, the maximum generation-rate possible for 100B packet size is 800Mbps.

# Single AP-STA, TCP download throughput for 802.11n and 802.11 ac, with MIMO and Packet Aggregation (Max TCP throughput case)

**Network Scenario**



NetSim parameters to be configured for the devices as shown below,

**For 802.11n device configuration is as follows:**

|  |  |  |
| --- | --- | --- |
| Device Name | x-coordinate | y-coordinate |
| Access Point\_3 | 200 | 0 |
| Wireless Node\_4 | 200 | 30 |

|  |  |
| --- | --- |
| Interface Parameters | |
| Standard | IEEE802.11n |
| No. of Packet aggregated | 64 |
| Channel | 1 (2412MHz) |
| Rate Adaptation | False |
| Retry Limit | 4 |
| RTS Threshold | 3000bytes |
| Medium Access Protocol | DCF |
| Buffer Size | 100 MB |
| Guard Interval | 400ns |
| Bandwidth | 20MHz/ 40MHz |
| Frequency Band | 2.4/ 5GHz |
| Transmitter Power | 100mW |
| Antenna Gain | 0 |
| Antenna height | 1m |
| Transport Layer Parameters | |
| Congestion Control Algorithm (Wired Node and Wireless Node) | BIC |
| Wireless Link Parameters | |
| Channel Characteristics | Pathloss only |
| Pathloss Model | Log Distance |
| Pathloss Exponent | 2.5 |
| Application Parameters | |
| Application | CBR |
| Packet Size | 1450 bytes |
| Inter-Arrival Time | 11 μs |
| Transport Protocol | TCP |
| Wired Link Parameters | |
| Wired Link Speed | 1Gbps |
| Wired Link BER | 0 |
| Wired Link Propagation Delay | 0 |
| Simulation Parameters | |
| Simulation Time | 10 seconds |

**For 802.11ac device configuration is as follows:**

|  |  |  |
| --- | --- | --- |
| Device Name | x-coordinate | y-coordinate |
| Access Point\_3 | 200 | 0 |
| Wireless Node\_4 | 200 | 10 |

|  |  |  |
| --- | --- | --- |
| Interface Parameters | | |
| Standard | IEEE802.11ac |
| No. of Packet aggregated | 1024 |
| Channel | 36 (5180MHz) |
| Rate Adaptation | False |
| Retry Limit | 4 |
| RTS Threshold | 3000bytes |
| Medium Access Protocol | DCF |
| Buffer Size | 100 MB |
| Guard Interval | 400ns |
| Bandwidth | 20,40,80,160MHz |
| Frequency Band | 5GHz |
| Transmitter Power | 100mW |
| Antenna Gain | 0 |
| Antenna height | 1m |
| Reference distance (d0) | 1m |
| Transport Layer Parameters | | |
| Congestion Control Algorithm | BIC |
| Wireless Link Parameters | | |
| Channel Characteristics | No Path Loss |
| Application Parameters | | |
| Application | CBR |
| Packet Size | 1450 bytes |
| Inter-Arrival Time | 16, 8, 4, 2 μs |
| Transport Protocol | TCP |
| Wired Link Parameters | | |
| Wired Link Speed | 1Gbps for 20Mhz and 10Gbps for 40, 80 and 160Mhz |
| Wired Link BER | 0 |
| Wired Link Propagation Delay | 0 |
| Simulation Parameters | | |
| Simulation Time | 10 seconds |

**Results:**

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
|  | | | | | | | |
| Standard | **Frequency**  **Band (GHz)** | **PHY Rate (Mbps)** | **Band width** | **Antenna Count** | **Packets Aggregated** | **Transport protocol** | **Throughput**  **(Mbps)** |
| 802.11 n | 2.4 | 288.9 | 20 | 4\*4 | 64 | TCP | 148.12 |
|  | 5 | 360 | 40 | 4\*4 | 64 | TCP | 238.43 |
| 802.11 ac | 5 | 693.3 | 20 | 8\*8 | 64 | TCP | 236.39 |
|  | 5 | 1600 | 40 | 8\*8 | 64 | TCP | 366.65 |
|  | 5 | 3466.7 | 80 | 8\*8 | 64 | TCP | 433.36 |
|  | 5 | 6933.3 | 160 | 8\*8 | 64 | TCP | 470.48 |

# Appendix 1: 802.11 Fixed parameters Table

|  |  |
| --- | --- |
| 802.11b | |
| Slot Time (µs) | 20 |
| DIFS (µs) | 50 |
| SIFS (µs) | 10 |
| ACK / Block ACK Size (B) | 14 |
| RTS Size (B) | 20 |
| CTS Size | 14 |
| ACK / Block ACK PHY rate (Mbps) | 1 |
| RTS PHY rate (Mbps) | 1 |
| CTS PHY rate (Mbps) | 1 |
| Preamble Time (µs) | 192 |

|  |  |
| --- | --- |
| 802.11ac | |
| Slot Time (µs) | 9 |
| DIFS (µs) | 34 |
| SIFS (µs) | 16 |
| ACK / Block ACK Size (B) | 152 |
| RTS Size (B) | 20 |
| CTS Size | 14 |
| \*ACK / Block ACK PHY rate (Mbps) | |
| \*RTS PHY rate (Mbps) | |
| \*CTS PHY rate (Mbps) | |
| Preamble Time (µs) | 44 |

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| 802.11n | | | | |
|  | **802.11n(2.4GHz)** | | **802.11n(5GHz)** | |
| Slot Time (µs) | 20 | | 9 | |
| DIFS (µs) | 50 | | 34 | |
| SIFS (µs) | 10 | | 16 | |
| ACK / Block ACK Size (B) | 32 | | 152 | |
| RTS Size (B) | 20 | | 20 | |
| CTS Size | 14 | | 14 | |
| \*ACK / Block ACK PHY rate (Mbps) | | | | |
| \*RTS PHY rate (Mbps) | | | | |
| \*CTS PHY rate (Mbps) | | | | |
| Preamble Time (µs) | MIMO Count 1 and 3 | 40 | MIMO Count 1 and 3 | 40 |
| MIMO Count 2 and 4 | 36 | MIMO Count 2 and 4 | 36 |

***(\*):*** *ACK/Block ACK, RTS, and CTS PHY rate vary with varying Channel Characteristics, MIMO count, and Number of Packet Aggregated.*

# Useful References:

Experiments Manual:

1. Wi-Fi: Throughput variation with distance
2. Wi-Fi: UDP Download Throughput

Featured Examples

1. Peak UDP and TCP throughput 802.11ac and 802.11n (Under Section 4.7 of Internetworks manual)
2. 802.11n MIMO (Under Section 4.5 of Internetworks manual)