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# Performance Evaluation of IEEE 802.11ac and 802.11n using NS3

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#### **Abstract**

**Objectives:** In this paper, the performance parameters in the WLANs are discussed and we evaluate the superior performance of the new IEEE 802.11ac standard with respect to 802.11n. **Methods/Analysis:** NS3 is an open source network simulator, the latest version of which (ns-3.24.1) has been appended with features to support 802.11ac. Simulations are performed in NS3 to demonstrate the superior performance of the new 802.11ac standard with respect to 802.11n. Features verified are channel bonding, guard interval and MCS while performance is measured with parameters such as jitter, throughput and delay. **Findings:** IEEE 802.11ac is a Very High Throughput (VHT) WLAN standard that can achieve data rates in the order of 7 Gbps in the 5 GHz band. This has been achieved by enhancing the features in the earlier IEEE 802.11n standard in the MAC and PHY layers. The simulations reveal improvement in throughput, delay and jitter performance with usage of increased bandwidths.

Keywords: Delay, Jitter, NS3, 802.11n, 802.11ac, Throughput, WLAN

# 1. Introduction

802.11n is now an accepted interface on PCs, tablets and smart phones. 802.11ac being a faster version of 802.11n, integrates the advantages of wireless and Gigabit Ethernet. Wireless LAN APs can support more clients, with larger bandwidth, more parallel video streams, higher speeds and lower delays. 802.11ac functions only in the 5-GHz band and hence avoids much of the interference caused by so many other external sources that commonly work in 2.4 GHz ISM band.

Some of the applications that have benefitted from the higher throughput and data rates of 802.11ac are wireless display, HDTV, large files transfer between user and servers, campus and auditorium deployments.

In this paper, using NS3 simulator, we demonstrate the performance improvements in 802.11ac as compared to 802.11n. The contents of this paper are structured as: Section 2 introduces background on WLANS - 802.11n and 802.11ac, while Section 3 brings out capability of ns-3 simulator to analyze wireless LANs. The details of the performance tests simulated and their configuration \*Author for correspondence

is in Section 4. The results of the simulation are in Section 5. A discussion of the results and conclusions derived in this paper and work proposed to be done in future in this area is in Sections 6 and 7 respectively.

# 2. Background for 11n and 11ac

# 2.1 General Concepts

# 2.1.1 PHY Layer Enhancements

#### 2.1.1.1 Multi-Input Multi-Output

Multi-Input Multi-Output (MIMO) is an adaptable technology that can be utilized in several ways. At one extreme is spatial multiplexing; while at the other end we have transmitter and/or receiver diversity. In the case of pure transmitter/receiver diversity, the same data streams are transmitted and received with multiple antennas. The presence of replicas of the data, results in diminished chances of occurrence of errors. This helps in augmenting the robustness of the link. In spatial multiplexing,

the same bandwidth is utilized, to communicate many data streams in both directions at the same time. The data is different between the data streams. Here, the data throughput is enhanced.

#### 2.1.1.2 Channel Bonding

By merging two adjacent 20 MHz channels into a single 40 MHz channel, it is possible to double the available data rate. This approach had been used previously to increase throughput, utilizing neighboring channels at the same time. Each channel is separately modulated and combined at the far end.

#### 2.1.1.3 Guard Interval

Guard Interval is the time between transmitted symbols .802.11n uses complex modulation techniques (i.e. Orthogonal Frequency Division Multiplexing - OFDM), where blocks of input data are coded into a single OFDM symbol. To achieve good performance, the symbol must arrive at the receiver without any interference or noise, thus assuring proper decoding and fewer errors. Inter-symbol interference occurs when the delay between different RF paths to the receiver exceeds the guard interval, causing a reflection of the previous symbol to interfere with the strong signal from the current symbol.

## 2.1.1.4 Transmit Beam Forming

Transmit Beam Forming is a technique of MIMO technology ported into the WLAN chipset to improve the Signal to Noise Ratio (SNR) at the receiver. The presence of multiple signals at the 802.11 client end, improves downlink SNR and the data rate. This reduces coverage holes and increases overall system performance.

#### 2.1.1.5 *Modulation and Coding Schemes*

Radio systems have to adapt to the signal and noise characteristics of the RF path and they accomplish this by changing the modulation rate. Here, the receiver SNR is the deciding factor for the transmitter's modulation with a view to optimize the data and error rates. At any point, modulating for a higher data rate will increase the error rate and at some point the increased error rate will decrease the overall data throughput. 802.11a and 802.11gstandards adopted a method called OFDM. OFDM divides a radio channel, into smaller ones, each with its own subcarrier signal. For 802.11a and 802.11g, symbol period is 4 µS, with guard interval of 800 nS. At the maximum data rate, 54 Mbps, each symbol carries 216 data bits. These data bits are spread out over 48 subcarriers. 72 error-correction bits transmitted in each symbol at 54 Mbps, results in 288 bits in the symbol. To squeeze these many bits on each subcarrier, the subcarrier is modulated using 64 QAM or Quadrature Amplitude Modulation. This means that each subcarrier is able to carry 6 bits (a combination of data and error correction bits).

## 2.1.2 Medium Access Control or MAC Layer **Enhancements**

Frame aggregation and block ACK or acknowledgement are supported in both 802.11n and 11ac standards.

#### 2.1.2.1 Frame Aggregation

Whenever a client/AP wishes to transmit in a frame, it contends for an opportunity to do so in the medium, resulting in contention, collision and back off delays. 802.11n includes methods to aggregate frames at stations.

With MAC-layer aggregation, a station with a number of frames to transmit can opt to combine them into an aggregate frame (MAC MPDU). The resulting frame contains fewer headers overhead than would be the case without aggregating and because fewer, larger frames are sent, the contention time on the wireless medium is reduced. The shorter the frames, the lower the efficiency of transport due to the overhead of headers and interframe gaps.

Aggregated MSDU (A-MSDU) and Aggregated-MAC Protocol Data Unit (A-MPDU) are two aggregation mechanisms that reduce overhead in every frame transmitted to a single radio preamble. Legacy ACKs can be used to confirm Aggregated MSDUs, but Block ACKs must be used to confirm Aggregated MPDUs.

#### 2.1.2.2 Block ACK

In the legacy 802.11 a/b/g systems receive station sends an acknowledgment (ACK frame) almost immediately to transmit stations to confirm the reception of each non-multicast/broadcast frame. If this ACK frame is not received, the transmitter retransmits until an ACK is received. The ACK mechanism adds robustness to 802.11 and ensures that all transmitted frames ultimately get to the receiver. But, efficiency of the protocol reduces due to an additional ACK frame in every transmitted frame. This is corrected in the block acknowledgement mechanism,

which sends a single block ACK frame in response to multiple received frames, thus improving efficiency and throughput. This mechanism collects ACKs of individual frames from MPDU aggregation into a single frame sent back by receiver to transmitter. Hence, only the frames that are not acknowledged can be re-transmitted. This selective retransmission using MPDU aggregation is especially effective in noisy environments as compared to MSDU aggregation.

#### 2.2 802.11n

The main parameters of 802.11n protocol<sup>1</sup> are summarized below:

Maximum data rate: 600 Mbps.

RF Band: 2.4 or 5 GHz.

Modulation: CCK, DSSS or OFDM.

Number of spatial streams (or NSS): 1, 2, 3 or 4.

Channel width: 20 or 40 MHz.

#### 2.2.1 Mixed and Greenfield Formats

To enable 802.11n to be backward compatible, two new formats called High Throughput or HT formats, in addition to the legacy (only 802.11 a, b and g) format, are defined for the PHY Layer Convergence Protocol (PLCP) - the Mixed Mode (both 802.11 a, b, g and n) and the Green Field (only 802.11 n).

## 2.2.1.1 Legacy Mode

Legacy mode occurs as 20 MHz or 40 MHz signal. 40 MHz transmission comprises of two adjacent 20 MHz channels.

The HT signal is divided into 64 sub-carriers in 20 MHz mode and 128 sub-carriers in 40 MHz. The former has 4 pilot signals in sub-carriers -21, -7, 7 and 21 while the latter has 6 in -53, -25, -11, 11, 25, 53. In the 20 MHz legacy mode, signal is transmitted on sub-carriers -26 to -1 and 1 to 26, with 0 being the centre carrier and on -28 to -1 and 1 to 28 in HT mode. The 40 MHz signal uses sub-carriers -58 to -2 and 2 to 58 for transmission

In terms of the frames that are transmitted conform to the legacy 802.11a/g OFDM format.

#### **2.2.1.2** *Mixed Mode*

In this 802.11n mode, transmit packets have the legacy 802.11a/g preamble and the new MIMO training sequence format.

#### 2.2.1.3 Greenfield Mode

HT packets in this mode do not have a legacy compatible part or any legacy element resulting in a much higher data throughput.

#### 2.2.4 802.11n MIMO

Spatial multiplexing is central to 802.11n. While APs must implement between two to four spatial streams, stations can have just one.

## 2.2.5 Channel Bonding

802.11n devices are designed for 20/40 MHz wide channels in ISM or UNII band.

The 5 GHz band has 24 non-overlapping channels 20 MHz wide or 12 non-overlapping channels 40 MHz wide by channel bonding. The 2.4 GHz band has 3 non-overlapping channels 20 MHz wide or 1 non-overlapping channel 40 MHz wide by channel bonding, thus using only two thirds of the available frequency capacity. Also, 40 MHz operation involves the risk of interfering with operational legacy networks in 2.4 GHz band. Hence channel bonding is more effective in the 5 GHz frequency.

When using the 40 MHz bonded channel, 802.11n has an additional advantage. While a small portion of the channel is reserved on either side of a 20 MHz channel to reduce co-channel interference, this is not done for 40 MHz channels. It is now possible to pack more OFDM subcarriers in a 20 MHz or 40 MHz channel. The additional subcarriers add bandwidth to the channel, permitting enhanced data rates for a given modulation type. Subcarriers are enhanced from 48 to 52 numbers in a 20 MHz channel and to 108 in a 40 MHz channel. By combining the two 20 MHz channels through this method, slightly more than double of the data rate is made possible (for 40 MHz).

#### 2.2.6 Guard Interval

While guard interval is 800 ns duration in legacy 802.11a/g devices leading to unwanted idle time, it may be reduced to 400 ns Shorter Guard Interval (SGI) in 802.11n with the disadvantage of higher interference and reduced throughput. SGI, an optional feature, can be used when the path difference between the fastest and slowest RF paths is less than the SGI limit. Under such conditions, SGI reduces the symbol time from 4 microseconds to 3.6 microseconds thereby increasing the symbol rate by 10% while keeping adequate symbol separation.

## 2.2.7 Modulation and Coding Schemes (MCS)

The PHY data rate, ranging from 6.5 Mbps to 600 Mbps in 802.11n APs and stations is dependent on and is a combination of NSS, channel width, guard interval width, modulation and coding rate and MCS is a simple integer assigned to each combination.

802.11a/g/n alike use OFDM and a 4 μs symbol. However in 802.11n, the data rate can be increased to 65 Mbps, for a single-transmit radio with 52 sub-carriers in the place of 48. 802.11n also enables up to eight data rates and four transmitters leading to 32 modes in a 20 MHz channel. Maximum data rate of 130, 195 and 260 Mbps can be achieved with 2, 3 and 4 transmitters respectively. Similarly in a 40 MHz channel, 108 subcarriers ensure data rates like 135, 270, 405 and 540 Mbps for one through four transmitters, respectively. Also, the eight data rates for 4 transmitters give 32 modes in the 40 MHz channel too. Further using SGI, data rates, for example in 40 MHz channels, are enhanced to 150 Mbps per transmitter and 600 Mbps for a four-transmitter 802.11n radio.

MCS can take values from 0 to 77. MCS-0 to MCS-31 have same modulation and coding on all 4 Spatial Streams (SS) and MCS-32 to MCS-77 define different combinations of modulation and coding on each stream. As an example, MCS-33 is identified as 16-QAM, QPSK on SS-1 and SS-2, while MCS-77 is configured as 64-QAM on SS-1, 2 and 3 with 16-QAM on SS-4. As per 802.11n protocol APs must, as a minimum, support MCS-0 through MCS-15 and stations, MCS-0 to 7. Support for further MCS values is optional.

Note: 802.11n uses 5/6 coding, a higher rate than the previous maximum of 3/4 in 802.11a/g.

## 2.2.8 Antenna Technology

Beam forming and diversity features are as a result of enhanced antenna technologies in 802.11n protocol.

#### 2.3 802.11ac

IEEE 802.11ac protocol provides a Very High Throughput (VHT) of 7 Gbps in the 5.8 GHz ISM band, thus aiding streaming of high definition video at high speeds. Salient features of 802.11ac protocol<sup>2</sup> are:

- Frequency band: 5.8 GHz ISM band.
- Maximum data rate: 6.93 Gbps.
- Transmission bandwidth: 20, 40, & 80 MHz. 160 & 80
   + 80 MHz optional.
- Modulation formats: BPSK, QPSK, 16-QAM, 64-QAM.
   256-QAM optional.
- MIMO: Both single and multi-user MIMO with up to 8 spatial streams (SS). 1 Spatial Stream is mandatory. Optional features are 2 to 8 SS, TX beam forming, Multi-user-MIMO.

The IEEE 802.11ac protocol (also called as Gigabit Wi-Fi standard) has built on techniques utilized in earlier 802.11 standards and added new techniques to achieve VHT.

#### 2.3.1 NMIMO and MU-MIMO

With MIMO technique, 802.11ac standard supports 8 SS and using MU-MIMO different streams can support different users providing variety of multiple access schemes.

MU-MIMO is a technology that uses equipment having spatial awareness of various remote users and enables transmission of different data frames to various users at the same time. It also employs advanced queuing systems to avail the opportunity to transmit data to multiple clients at the appropriate time.

## 2.3.2 Channel Bonding

The 802.11ac standard uses 80 MHz or 160 MHz or two 80 MHz blocks channel bandwidths. This variability is achieved with automatic radio tuning and higher-bandwidth channels are used to optimize spectrum.

#### 2.3.3 MCS

In addition to the values included in 802.11n, 256-QAM is optional.

# 3. ns-3 Support

ns-3 provides an extensible network simulation<sup>3</sup> platform, for study and research in the networking field. It is a free, open source project aiming to build a discrete event network simulator. ns-3 provides models to demonstrate functioning of packet data networks, and offers a simulation engine for users to simulate and experiment. ns-3 is written in multiple languages (C++/OTcl). The ns3-3.24.1<sup>4</sup> version of ns-3 released in September 2015 is used for the analysis in this paper. The simulations are

performed for 11ac with infrastructure mode operation support for 802.11ac physical layers and ``Constant Rate Wifi Manager``. Currently, 802.11n is better supported in ns3 with features like MSDU aggregation or MPDU aggregation or both (two-level aggregation) in 2.4 and 5 GHz bands.

## 4. Performance Test

In the scenario, an Access Point or AP and STA are connected in an infrastructure WLAN. The output of the test case is the UDP throughput, jitter and delay for every HT/VHT bit rate value, which depends on the MCS value (0 to 7)/(0 to 9), the channel width (20 or 40 MHz)/(20, 40, 80 or 160 MHz) and the guard interval (long or short). The PHY bit rate is constant over the complete simulation run. Configuration parameters are listed in Table 1.

Table 1. Simulation settings

Simulation Time	10 seconds	
Mobility Model	Constant position mobility model	
Payload Size	1472 bytes	
Rate Manager	Constant Rate WiFi Manager	
Standard	802.11n	802.11ac
SCI	Short GI, Long GI	Short GI, Long GI
Channel bonding	20,40 MHz	20,40,80,160 MHz
MCS	MCS-0 to MCS-8	MCS-0 to MCS-6

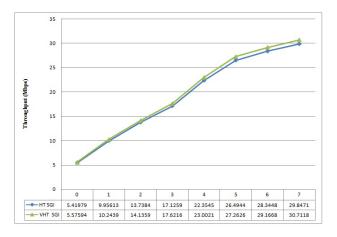


Figure 1. Throughput vs. MCS; Short GI and 20 MHz bandwidth.

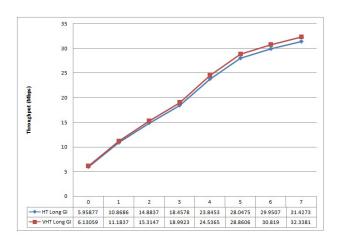
# 5. Results

Throughput in 802.11ac and 802.11n protocols is plotted for MCS values 1 to 8 for short and long GI in Figures 1 and 2 with channel bonding when bandwidth is 20 MHz.

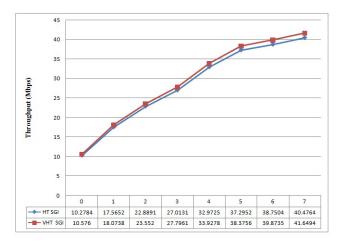
Throughput in 802.11ac and 802.11n protocols is plotted for MCS values 1 to 8 for short and long GI in Figures 3 and 4 with channel bonding when bandwidth is 40 MHz

The next parameter analyzed is mean delay, with channel bonding concept when bandwidth is 20 MHz and 40 MHz for both short and long GI. The results are plotted in Figures 5 to 8

In Figures 9 to 12 mean jitter is studied, with channel bonding concept when bandwidth is 20 MHz and 40 MHz for both short and long GI.



**Figure 2.** Throughput vs. MCS; Long GI 20 MHz bandwidth.



**Figure 3.** Throughput vs. MCS; Short GI and 40 MHz bandwidth.

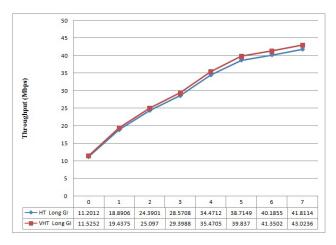
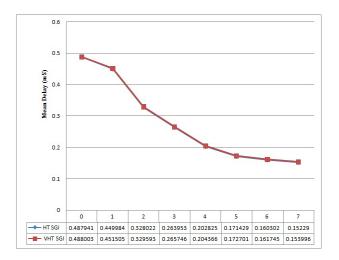
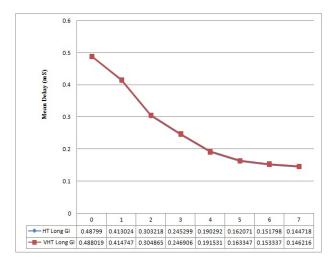


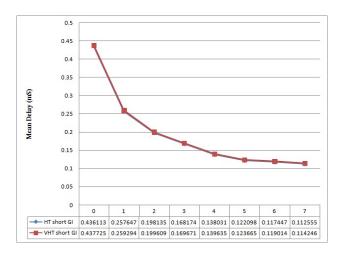
Figure 4. Throughput vs. MCS; Long GI and 40 MHz.



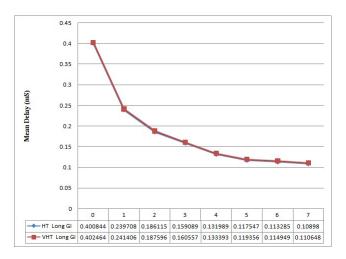
**Figure 5.** Mean delay vs. MCS, SGI, 20 MHz bandwidth.



**Figure 6.** Mean delay vs. MCS, Long GI, 20 MHz bandwidth.



**Figure 7.** Mean delay vs. MCS, Short GI, 40 MHz bandwidth.

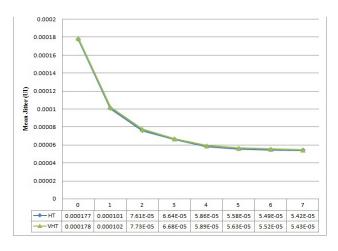


**Figure 8.** Mean delay vs. MCS, Long GI, 40 MHz bandwidth.

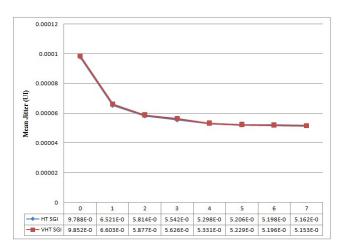
The effect of channel bonding on throughput is simulated in Figures 13 and 14 for short and long GI. The above simulation is done when the stations are separated by 1 m.

Similarly, the variation of mean delay with MCS at different bandwidths for short and long GI is plotted in Figures 15 and 16. The above simulation is done when the stations are separated by 10 m.

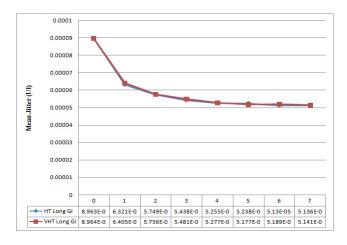
Similar to mean delay, mean jitter also varies with varying bandwidth. This is seen in Figures 17 and 18 for short and long GI. The above simulation is done when the stations are separated by 10 m.



**Figure 9.** Mean jitter vs. MCS, Short GI, 20 MHz bandwidth.



**Figure 10.** Mean jitter vs. MCS, Long GI, 20 MHz bandwidth.

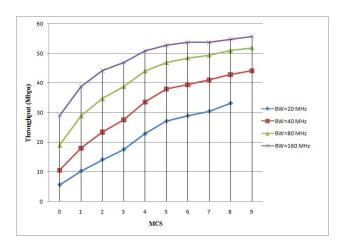


**Figure 11.** Mean jitter vs. MCS for Short GI with 40 MHz bandwidth.

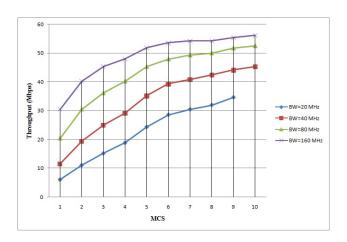
# 6. Discussion

From the values of throughput in Figures 1 and 2 it is observed that higher MCS values give a better throughput irrespective of GI value. Long GI exhibits better throughput compared to short GI at all MCS values in both 11n and 11ac protocols.

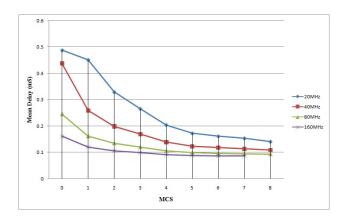
In Figure 1 VHT is 23 Mbps for MCS-4 but only 22.35 Mbps in HT. This trend is observed for the other MCS values too and also for long GI in Figure 2. The improvement in throughput in 802.11ac protocol is proportionately more at higher MCS values. Hence, 802.11ac is exhibiting better throughput compared to 802.11n even at 20 MHz bandwidth.



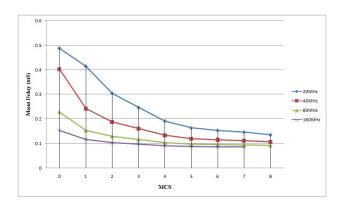
**Figure 12.** Mean jitter vs. MCS for Long GI with 40 MHz bandwidth.



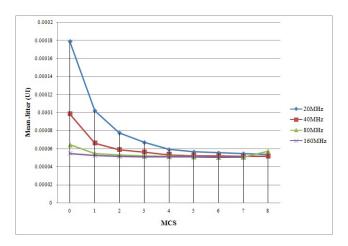
**Figure 13.** Throughput vs. MCS for Short GI with 20, 40, 80, 160 MHz bandwidth.



**Figure 14.** Throughput vs. MCS for Long GI with 20, 40, 80, 160 MHz bandwidth.

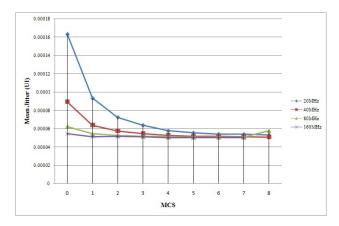


**Figure 15.** Mean delay vs. MCS for Short GI with 20, 40, 80, 160 MHz bandwidth.

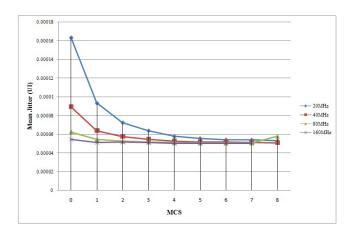


**Figure 16.** Mean delay vs. MCS for Long GI with 20, 40, 80, 160 MHz bandwidth.

The inferences derived in the above paragraphs for the throughput results of the 2 protocols at 20 MHz bandwidth is also observed for 40 MHz in Figures 3 and 4.



**Figure 17.** Mean jitter vs. MCS for Short GI with 20, 40, 80, 160 MHz bandwidth.



**Figure 18.** Mean jitter vs. MCS for Long GI with 20, 40, 80, 160 MHz bandwidth.

In Figures 13 and 14 throughput shows an almost linear improvement for 20, 40, 80 and 160 MHz from MCS-0 to MCS-5, after which the slope is slightly reduced. Improvement in throughput with bandwidth is also established unconditionally at both long and short GIs.

Mean delay is showing a constant improvement with higher MCS values at both 20 MHz and 40 MHz bandwidths and for both the protocols studied.

At MCS-2 mean delay in the 802.11n protocol is 0.328 for short GI (Figure 5) and 0.303 (Figure 6) for long GI. Similarly the values are 0.329 and 0.304 respectively for 802.11ac protocol with 20 MHz bandwidth. Hence mean delay is less for long GI as compared to short GI.

As seen in Figures 9 and 10, at MCS-6 mean jitter in the 802.11n protocol is 5.49e-5 UI for short GI and 5.40e-5 UI for long GI. Similarly the values are 5.52e-5 UI and 5.43e-5 UI respectively for 802.11ac protocol with 20

MHz bandwidth. Hence mean jitter is also less for long GI as compared to short GI as in the case for mean delay. The behavioral response of mean jitter at 20 MHz bandwidth (Figures 9 and 10) follows a similar trend as mean delay.

For any MCS, 802.11ac is not displaying improvement over 802.11n at 20 and 40 MHz bandwidth for both mean delay and mean jitter.

But we observe reduced delay in 802.11ac at higher bandwidths.

In 802.11ac, both delay and jitter performance shows improvement with bandwidth; the improvement is more marked at lower MCS values.

## 7. Conclusion and Future Work

As expected, the two protocols 802.11ac and 802.11n do not differ much in terms of performance as far as 20 MHz and 40 MHz bandwidths are concerned. This is the case with all parameters (throughput, delay and jitter). However, from the results above it is seen that marginal improvement is present at higher values of MCS and at 40 MHz. With higher bandwidths (80 and 160 MHz) 802.11ac protocol cannot be compared with 802.11n; but the real benefits of 802.11ac are visible now (again with 256 QAM also available) in the case of all parameters - throughput, delay and jitter.

The version of ns3 (ns-3.24.1) used in this paper, does not support simulations using MIMO, transmit beam forming and MU-MIMO. Only "Constant Rate Wifi Manager" is supported by 802.11n or 802.11ac. Presently, there is no model for cross-channel interference or coupling. It is proposed to analyze in further detail other performance aspects of 11ac, including effect of aggregation and interference, using upcoming ns3 releases.

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