Project Report
on
802.11ac - FIFTH GENERATION OF WI-FI
by

Venkata Adithya Bopanna	**(010731201)**
Ravali Peddi	**(010687807)**
Varsha Kodali	**(010701418)**

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Department of Computer Engineering

San Jose State University

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ABSTRACT

IEEE 802.11ac is a wireless networking standard in the 802.11 family which has been proposed to enhance the throughput of IEEE 802.11n beyond Gigabit-per second rates. It promises a Very High Throughput (VHT), and robust communication. These significant performance improvements can be attributed to the novel physical layer (PHY) and medium access control (MAC) features. The key technology of 802.11ac is multi-input and multi-output orthogonal frequency division multiplexing (MIMO-OFDM).

KEYWORDS: IEEE 802.11ac, Wi-Fi, VHT, PHY, MAC, MIMO-OFDM.

1. INTRODUCTION

IEEE 802.11ac also known as Gigabit WIFI is the latest Wi-Fi standard built over the 802.11n by improving the data rates, network robustness and reliability. It is designed to meet the throughput requirements of high definition video and wireless voice applications. The speed and quality improvements of 802.11ac will enable multiple streams of high definition video on home Wi-Fi networks. It deals with few enhancements of physical layer for higher throughput in the 5-GHz band, and to achieve this it extends the techniques that have been used in 802.11n: More antennas, wider channels and more spatial streams, with a number of new features that increase throughput and reliability to a great extent.

1.1 Need for 802.11ac

1) Mobile Applications now require more bandwidth-Video and voice applications require more Bandwidth.
2) Individuals use multiple wireless devices, hence increasing the client congestion for wireless networks.

2. TECHNOLOGY OVERVIEW

Conceptually, 802.11ac has evolved from 802.11n. Many of the techniques employed to increase speed in 802.11ac have become popular after the introduction of MIMO. Unlike 802.11n, which produced major new MAC features to improve efficiency, 802.11ac uses familiar techniques and brings them to a new layer, with one exception. Rather than using MIMO only for increasing the number of data streams sent to a single client, 802.11ac is pioneering a multi-user form of MIMO that enables a single access point (AP) to broadcast to multiple users at the same time.

First, 802.11ac shall achieve a maximum single-station throughput of 500Mbits/sec and multi-station aggregate throughput of 1 Gbits/sec which is measured at the MAC data service access point (SAP), for which the channel bandwidth is 80MHz in the 5-GHz band. As MAC layer has the data rate requirement rather than PHY, it implies that MAC efficiency must be addressed, not just an improvement to the data rate in physical layer.

Second, the 802.11ac amendment shall provide backward compatibility with 802.11a and all the 802.11n devices which operate in the 5-GHz frequency band. To ensure backward compatibility and co-existence, 802.11ac reuses the technical specifications of 802.11n where ever possible.

For example, 802.11ac uses the same PHY modulation in OFDM and also maintains the same coding and interleaving architecture of 802.11n. To meet the efficiency requirements, though some necessary modifications and new features in 802.11ac are required at physical and MAC layers.

2.1 Key features of 802.11ac

Operation Frequency	5-GHz unlicensed band only
Bandwidth	20,40 and 80MHz 160 and 80+80 MHz(Optional)
Modulation schemes	BPSK,QPSK, 16QAM, 64QAM, 256QAM(Optional)
Forward error correction code	Convolutional or LDPC (optional) with a coding rate of 1/2, 2/3, 3/4 or 5/6
MIMO	Space time coding, Single user MIMO, Multi-user MIMO.
Spatial Streams	Up to eight
Beamforming	Respond to transmit beamforming sounding
Aggregated MPDU(A-MDPU)	1,048,575 Octets
Guard interval	Normal guard interval Short guard interval.

They include the following:

Wider channels*:*

802.11ac introduces two new channel sizes: 80 MHz and 160 MHz In some areas, 160 MHz of contiguous spectrum will be tough to find, so 802.11ac introduces two different forms for 160 MHz channels: a single 160 MHz block, and an “80+80 MHz” channel that integrates two separate 80 MHz channels and presents the same capability.

256-QAM:

256-QAM, rate 3/4 and 5/6 are added as optional modes. For the initial case with only one spatial stream in a 20 MHz channel, there will be an extension for the previous highest rate of 802.11n from 65 Mbps (long guard interval) to 78 Mbps and 86.7 Mbps respectively, a 20% and 33% improvement. Prior to 802.11ac, wireless LAN devices transmitted six bits in a symbol period. Simply by using a denser modulation that supports more data bits, it is possible to transmit eight bits per symbol period, which imparts a gain of 30%.

Beamforming:

Beamforming in 802.11n required two devices to carry out mutually agreeable beamforming functions from the available menu of selections. Very few vendors implemented the same choices, and as a consequence, there was virtually no cross-vendor beamforming compatibility. With the key features of 802.11ac related to beamforming, however, a simplification was needed to enable the core technology.

More spatial streams and multi-user MIMO (MU-MIMO)

802.11ac increases the spatial streams up to eight when compared to 802.11n’s four spatial streams, at the AP. These additional spatial streams can be used to transmit to multiple users in parallel. With this ability, 802.11ac will speed up networks even more than which might be evident from just counting at the data rate.

Figure 2.1 compares the single-user MIMO technologies used in 802.11n with the new multi-user MIMO in 802.11ac. In Figure 2.1(a) all of the spatial streams are directed to one receiving device. In 2013, multiple spatial streams were a commonplace technical innovation, supported in every 802.11n AP and almost every client device. In contrast, Figure 2.1(b) shows what it means for a MIMO transmitter to be multi-user. In the figure, the access point is transmitting four simultaneous spatial streams. The magic of MU-MIMO is that the four spatial streams are being transmitted to three separate devices. Two of the spatial streams are transmitted to a laptop supporting high-speed data transmission. Each of the other two spatial streams is transmitted to a single-stream device, such as a phone or tablet computer. To keep the three transmissions separate, the AP uses beamforming to focus each of the transmissions toward its respective receiver. For this type of scenario to work, it is necessary that the receivers are located in different enough directions that focused transmissions avoid interfering with each other.

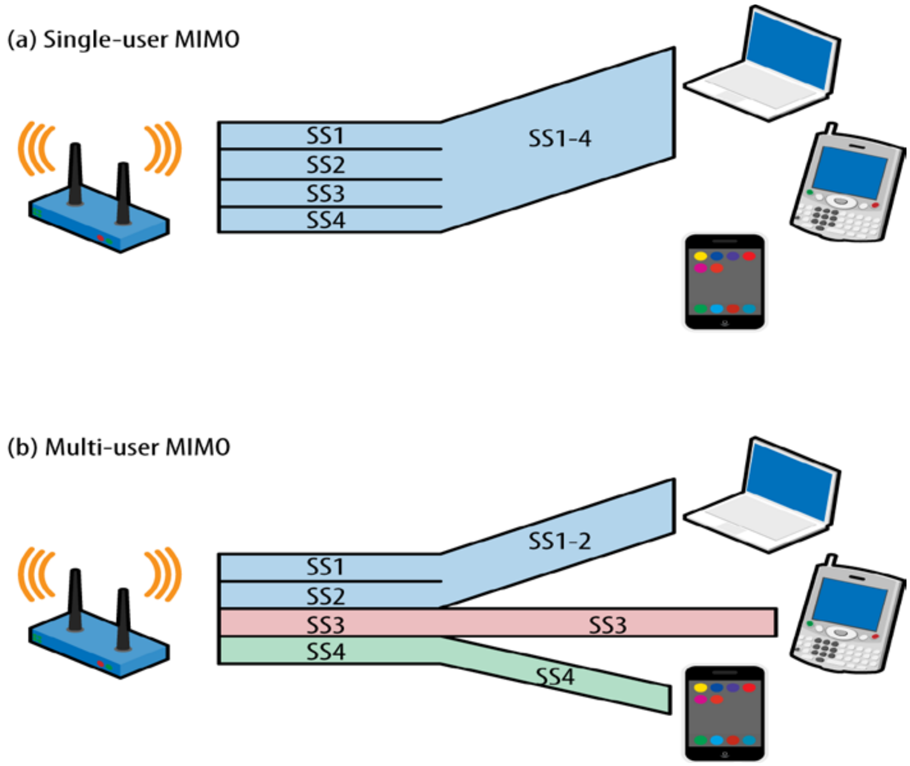

Figure 2.1 Single and Multi-user MIMO comparison

3. PHYSICAL LAYER

3.1 OFDM

High Speeds in 802.11ac can be achieved by enhancing certain features of Physical Layer: higher number of MIMO streams, wide channels, and a fine modulation that can combine more bits at a time. One of the key techniques used in 802.11ac to increase throughput is increasing the number of spatial streams from four to eight spatial streams. Increasing the number of spatial streams therefore would therefore require an antenna array with eight independent radio chains and antennas. This in-turn doubles the throughput over an equivalent 802.11n system. As devices use more spatial streams, the required antenna requires more elements and will grow in size. 802.11ac builds on beamforming by allowing multiple parallel transmissions for multi-user MIMO (MU-MIMO). Instead of having only one transmitter and receiver in the same area, MU-MIMO imparts spatial reusability in which same channel can be used in multiple areas using the same access point. 802.11ac divides the channel into OFDM sub carriers in which each of the subcarrier is used as an independent transmission. OFDM distributes the incoming data bits among the subcarriers. A few subcarriers do not carry user data known as pilot subcarriers are used to measure the channel. To increase the throughput 802.11ac extends the 40MHz channel used in 802.11n to 80MHz channel and also provides an optional channel with 160MHz bandwidth i.e. all the 802.11ac devices are required to support which doubles the size of the spectral channel over 802.11n. Due to the limitations of finding single 160 MHz spectrum, the standard allows for 160 MHz channel which can be either a single contiguous block or two separate 80 MHz channels.

In the figure 3.1, each horizontal line represents the layout of OFDM subcarriers in one particular type of channel, which ranges from the 20 MHz channels to the widest 160MHz channels which are used in 802.11ac.In the figure 3.1, the pilot carriers are represented by the dips down in the line which carry no data but important measurements about the channel. Each subcarrier has equal data-carrying capacity, and therefore, more number is better.

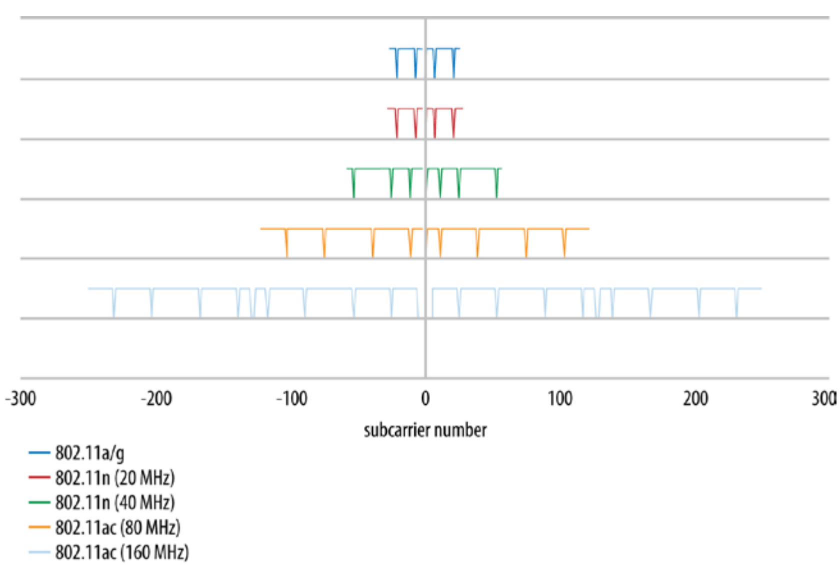

Figure 3.1 Channel layouts in 802.11ac

Bandwidth	Subcarrier range	Pilot subcarriers	Total subcarriers, Data subcarriers
20MHz	-28 to -1 and +1 to +28	-21,-7,+7,+21	56 total,52 data
40MHz	-58 to -2 and +2 to +58	-53,-25,-11,+11,+25,+53	56 total,52 data
80MHz	-122 to -2 and +2 to +122	-103,-75,-39,-11,+11,+39,+75,+103	242 total, 234 data

160MHz	-250 to -130,-126 to -6, +6 to +126, +130 to +250	-231,-203,-167,-139,-117, -89,-53,-25,+25,+53,+89, +117,+139,+167,+203,+231	484 total,468 data

Table 3.1 802.11ac subcarriers

3.2 Modulation and Coding Set (MCS):

Modulation describes how many bits are included within one transmission time increment. Higher Modulations pack more data at a time into the transmission, therefore they require very high signal-to-noise ratios. 802.11ac uses an error-correcting code which adds redundant information in a proportion described by the code rate. In 802.11ac, modulation and coding are combined together to form a single number, the MCS index. Each of the MCS values lead to a wide range of speeds depending on the channel width, number of spatial streams, and the guard interval. Unlike 802.11n which uses 64-QAM, 802.11ac uses 256-QAM. The 256-QAM constellation has 16 phase shifts and 16 amplitude levels. Instead of transmitting a maximum of six bits on each subcarrier in the channel, a link which is encoded using 256-QAM transmits eight bits .This single feature alone represents a 33% rise in speed over its equivalent in 802.11n system. But for 256-QAM to be implemented reliably, the channel should contain very high signal to noise ratio. Practically the radio links in the real world are not perfect and therefore when a symbol is received, it does not necessarily line up exactly on the constellation point. The difference between the constellation point and the point which corresponds to the symbol received is measured by an error vector which represents a two dimensional space.

MCS	Modulation	Coding rate
0	BPSK	1/2
1	QPSK	1/2
2	QPSK	3/4
3	16-QAM	1/2
4	16-QAM	3/4
5	64-QAM	2/3
6	64-QAM	3/4
7	64-QAM	5/6
8	256-QAM	3/4
9	256-QAM	5/6

Table 3.2 MCS values for 802.11ac

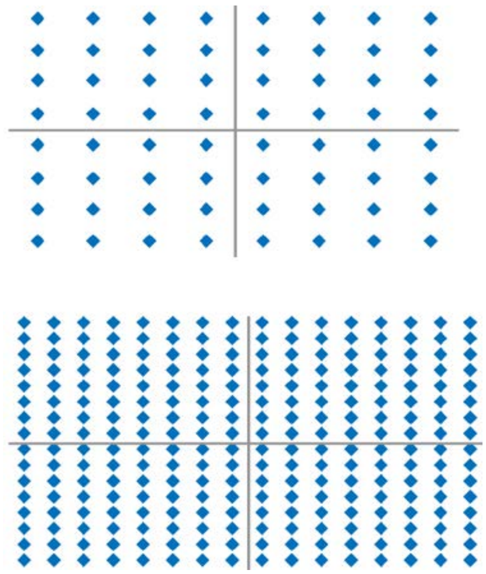

Figure 3.2 64-QAM vs 256-QAM

3.3 Functions of Physical Layer:

When a frame from MAC layer is received by the Physical layer, the following operations are performed

Preparation of service field: When the physical receives a MPDU from the MAC layer, it prepends a service field to it. The service field consists of the CRC calculated over the contents of VHT Signal B for error detection.

PHY Padding: Padding is done to make sure that the number of bits passed to the transmitter matches the number of bits required for a symbol.

Scrambling & FEC: Scrambling is performed on the data to make sure that there are no long strings of identical bits, because FEC works best on data that doesn't have long runs of identical bits. Scrambler output is then fed to a FEC which may be either BCC or LDPC encoder. To achieve higher data rates puncturing can be performed on the encoder's output.

Stream Parser: Output of FEC encoder is now fed to a stream parser which divides the encoded bits into multiple streams, each called as a spatial stream. These spatial streams are now fed to an Interleaver.

Segment Parser: Segment parsing is usually not done on 20, 40, 80MHz bandwidths. But for transmissions with 160MHz bandwidth, whether it is a contiguous 160MHz block or two 80MHz blocks, they will be mapped onto two 80MHz frequency segments.

Convolutional code interleaving: Usually the radio channels are noisy, so consecutive bits are affected when passed through a radio channel. So these consecutive bits are dispersed over different subcarriers to make the correction of the errors easier.

Constellation Mapping: Data bits are mapped onto the constellation points using the selected modulation scheme.

LDPC tone mapping: Constellation points are mapped onto OFDM subcarriers separated by sufficient distance to make sure that there is no interference between the successive bits. For example in 40MHz channel, there must be at least six subcarriers between two constellation points.

Segment deparsing: In 160MHz channels, the two frequency segments are brought back together for transforming them from constellation points to spatial streams suitable for transmission.

Space time block coding: This is an optional step which transmits one spatial stream across multiple antennas for more redundancy transforming spatial streams into space time streams.

Pilot insertion & CSD: Pilot subcarriers are inserted to make a complete data set for transmission. These pilot carriers are used for gathering channel measurements. Each space time stream is given a little phase shift to be identified at the receiver.

Spatial mapping: Space time streams are mapped onto the transmit chains using spatial mapping. For beamforming, these space time streams are shaped in such a way to be directed to a particular receiver.

Inverse Fourier transform: An inverse Fourier transform converts the frequency domain data from OFDM into time domain for transmission.

Guard insertion and Windowing: Guard Interval is inserted at the beginning of each symbol is windowed to improve the symbol quality.

Preamble Construction: VHT preamble is constructed and is added to the frame. Preamble is generally used for estimating the channel.

RF & Analog section: Here the digital data is converted to analog signal for transmission over an antenna at a frequency selected by the AP.

3.4 Physical layer frame formatting:

The format of the (very high throughput) VHT physical layer frame is same as the mixed-mode format used in 802.11n, and it begins with the same fields as 802.11a frames. A second difference is required to enable multi-user MIMO transmissions, i.e. the preamble should be able to define the number of spatial streams and enable multiple receivers to receive their frames. To meet this requirement, a new physical layer header was required.802.11ac physical layer frame uses a Signal field to describe the payload of the physical layer frame. The purpose of the signal field is to help the device at the receiver end in decoding the data payload, which is done by describing the parameters that are required for transmission. 802.11ac segregates the signal into two different fields, named as Signal A and Signal B fields. The Signal A is the part of the physical layer header which is identically received by all receivers; the Signal B belongs to the part of the physical layer header that is unique for every individual multi-user receiver.

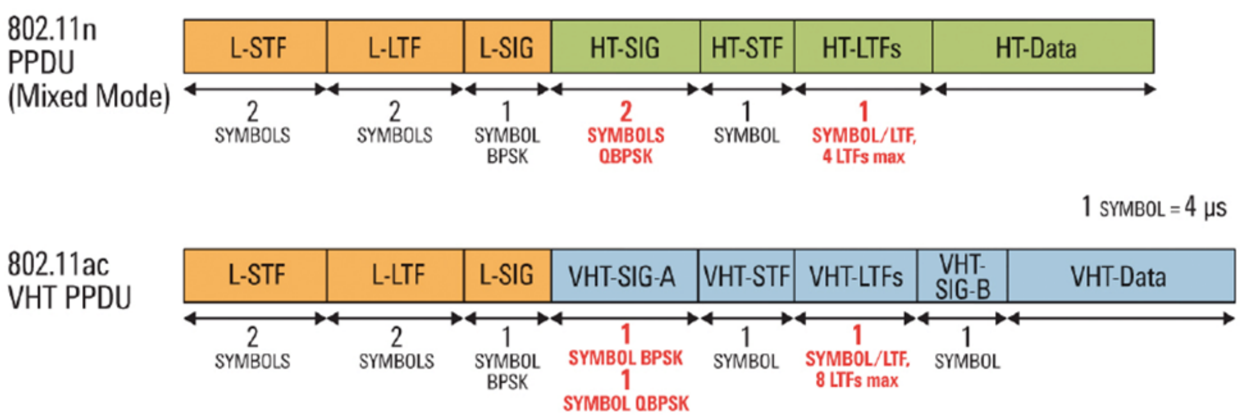

Figure 3.4 802.11ac VHT PPDU frame format

In the VHT PPDU Format, the first three fields are the same and are also compatible backwards with 802.11n and 802.11a. The remaining fields are specifically included in 802.11ac.

The first four fields for 802.11ac are received from non-VHT stations. The initial three fields are the same fields as in 802.11n, and the fourth field is used to distinguish the frame between 802.11n and 802.11ac. The remaining fields in the preamble are used exclusively only for VHT enabled devices.

The various fields within the frame structure:

- ***L-STF (Short Training Field):*** This field is two symbols in length and it is used when backward compatibility with previous versions of 802.11 is required. For every 20 MHz sub-band, the field is duplicated with phase rotation. The subcarriers are rotated by 90° or 180° in some sub-bands to reduce the ratio of peak and average power.
- ***L-LTF (Long Training Field):*** This is a legacy long training field, and it is two symbols in length. Its properties are similar to that of L-STF which includes the criteria employed for transmission, being transmitted in sub-bands and those of phase rotation.
- ***L-SIG:*** It is also a legacy field with a length of one symbol and BPSK is used for transmission.
- ***VHT-SIG-A:*** This is a new field used in 802.11ac and consists of two symbols in which one symbol is transmitted in BPSK and a second in QBPSK (BPSK rotated by 90°). This type of transmission ensures that there is auto-detection of a VHT transmission. The field contains information to make the receiver correctly interpret the upcoming data packets. Information including the bandwidth, number of MIMO streams, Space-Time Block Code (STBC) used, guard interval (GI), Binary Convolution Code (BCC) or Low Density Parity Check (LDPC) coding, Modulation and Coding Set (MCS), and beam-forming information.
- ***VHT-STF - VHT Short Training Field:*** This 802.11ac field is one symbol long and is it used to increase the gain control estimation for MIMO operation.
- ***VHT-LTF - VHT Long Training Field:*** The long training fields may include minimum of 1 and maximum of 8 (1, 2, 4, 6, 8) VHT-LTFs. The mapping matrix for 1, 2, or 4 VHT-LTFs is the same as in 802.11n whereas the 6 and 8 VHT-LTF combinations have been added for 802.11ac.
- ***VHT-SIG-B:*** This field gives the details about data in payload which includes the length of data and modulation coding scheme that is being used for multi-user mode. We notice repetition of bits for every 20 MHz sub-band

4. MAC LAYER

4.1 Medium access procedures

In the view of the evolutionary nature of 802.11ac protocol there are no significant new changes to the way devices access the medium. However, with new channel bandwidth comes new rules for determining whether the medium is clear. Also in order to increase the effective utilization of bandwidth and to avoid collisions due to different protocols used by devices CTS/RTS frames have started including the intended bandwidth consumption.

4.2 Dynamic Bandwidth Operation

802.11ac uses bandwidths from 20 MHz to 160 MHz range, which brings challenges to channel management. So proper procedure must be used to ensure the effective utilization of the channels

So 802.11ac defines a modified CTS/RTS mechanism to determine whether channels are available. The mechanism is:

1) The 802.11ac device sends a RTS which in 20 MHz, it is replicated three times for 80 MHz or another 7 times for 160MHz. Each receiver which receives the RTS sets the respective virtual channels in busy state.

2) The receiver devices of RTS checks the primary or secondary channels of the requested bandwidth are busy. If some of the bandwidth is used the receiver replies with CTS which specifies the available bandwidth.

3) CTS is sent over each 20 MHz sub-channel.

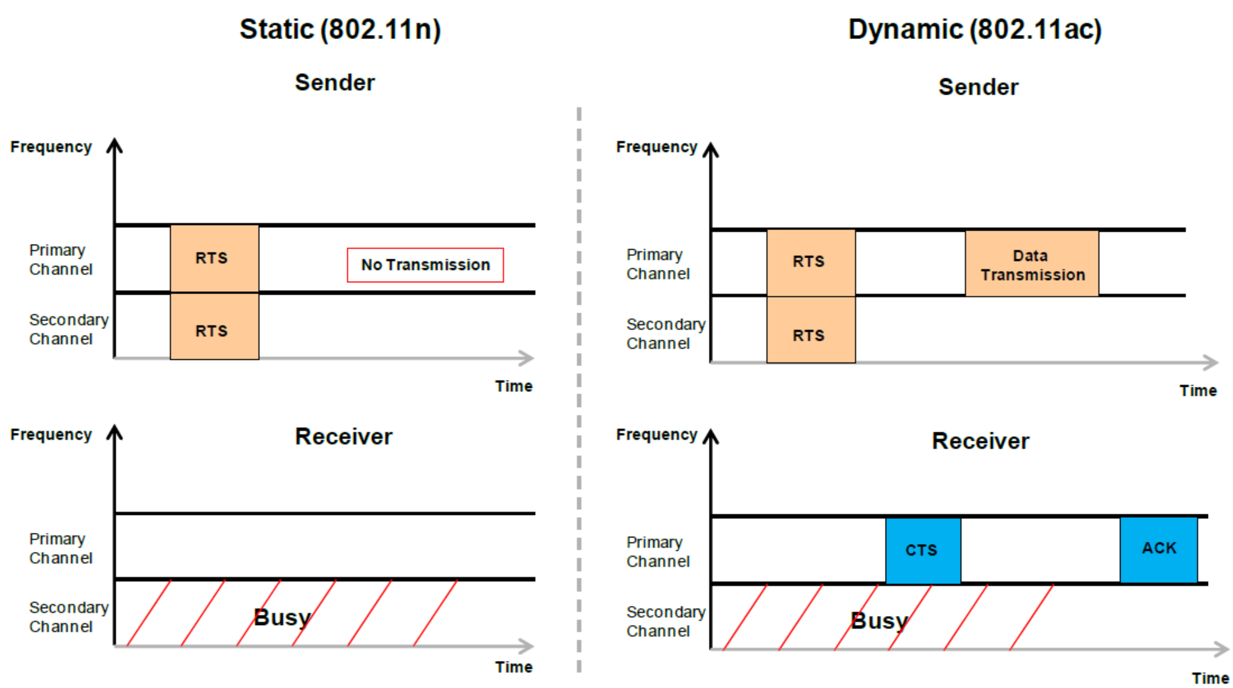

Figure 4.2(a) Comparison of channels in 802.11n and 802.11ac

Figure 4.2(a) compares 802.11n and 802.11ac. In 802.11n if a sub-channel is unavailable then whole transmission is stopped whereas in 802.11ac if some of the sub-channels are unused remaining channels will be used.

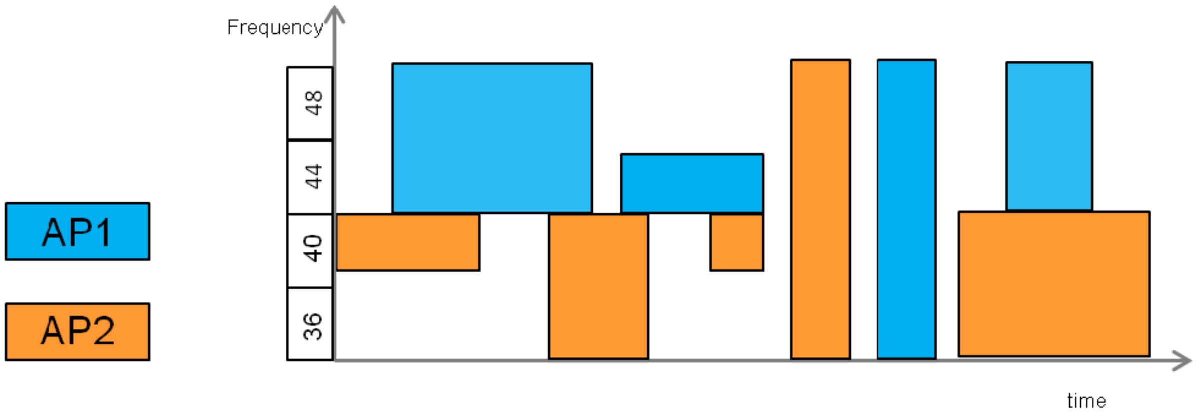

Figure 4.2(b) Access points in 802.11ac accessing 80MHz

Figure 4.2(b) shows how two AP's in 802.11ac utilize the 80 MHz bandwidth. Dynamic bandwidth management is designed for effective utilization of the bandwidth. In this type of bandwidth management both AP's can utilize the same bandwidth simultaneously.

4.3 Beamforming and channel state information (CSI)

Beamforming is a technique in which a transmitter transmits a series of symbols to all the receivers and receivers in turn reply to transmitter with feedback about the received signals. This feedback is called channel state information (CSI). CSI is used for optimizing amplitude-phase relation for maximum reception.

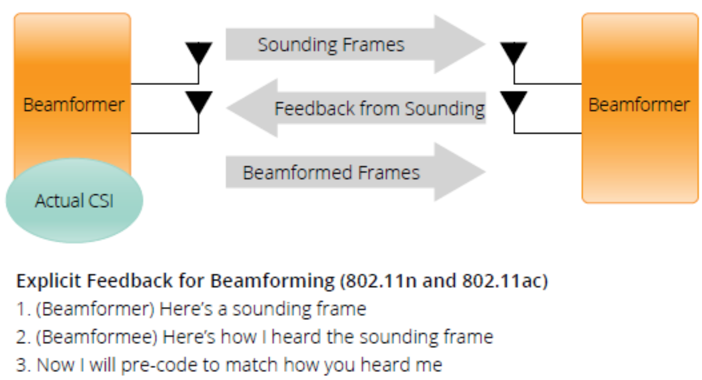

Figure 4.3(a) beamforming sounding frames

In 802.11ac the protocol in generating CSI relies on sounding or null data frames (NDP), together with announcement and response frames. Firstly, the receiver sends the null data packet announcement frame (NDPA) frame which has the information that identifies the stations participating in beamforming. This is followed by the NDP frame, then the beamforming respond to the NDP frame with beamforming report.

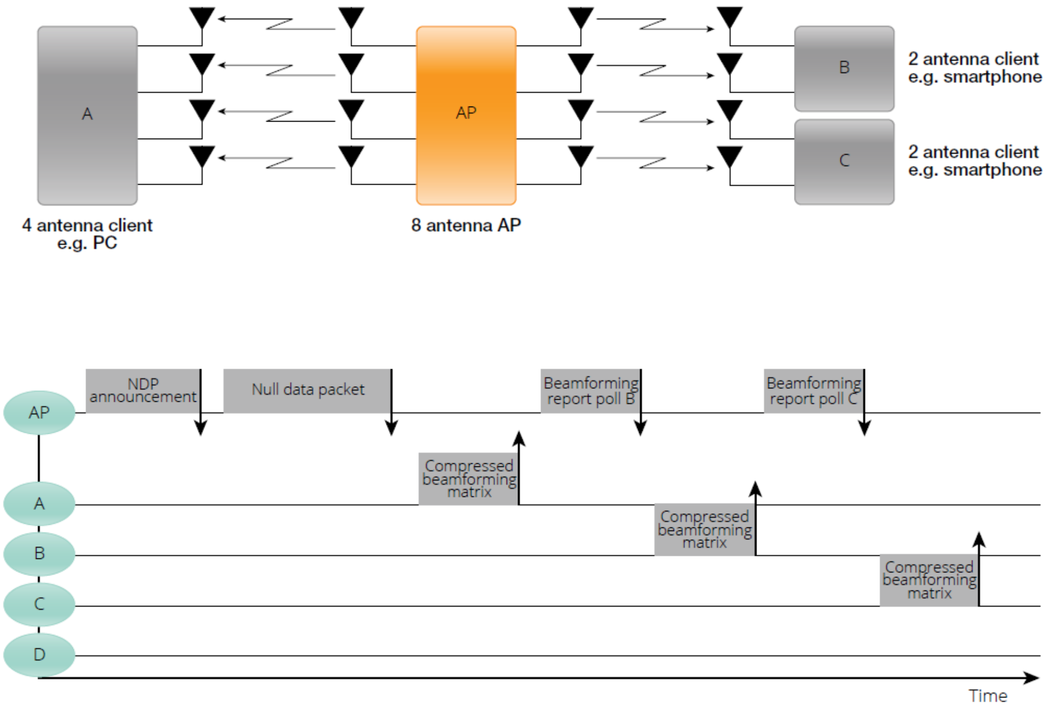

Figure 4.3(b) Beam forming feedback

4.4 Multi-user MIMO

The most significant throughput gains in 802.11ac are achieved by Multi-user MIMO. In Multi-user MIMO multiple antennas send separate streams of data independently even when the transmissions occupy same space and time. Multi-user MIMO technique is also called as spatial diversity multiple access (SDMA).

802.11ac assumes that access points (AP's) are different from the client devices and have more transmitting antennas than clients. As the number of spatially diverse paths depends on the number of antennas, and the number of opportunities depends on the volume of traffic buffered for transmission, the AP's are allowed to transmit to several clients.

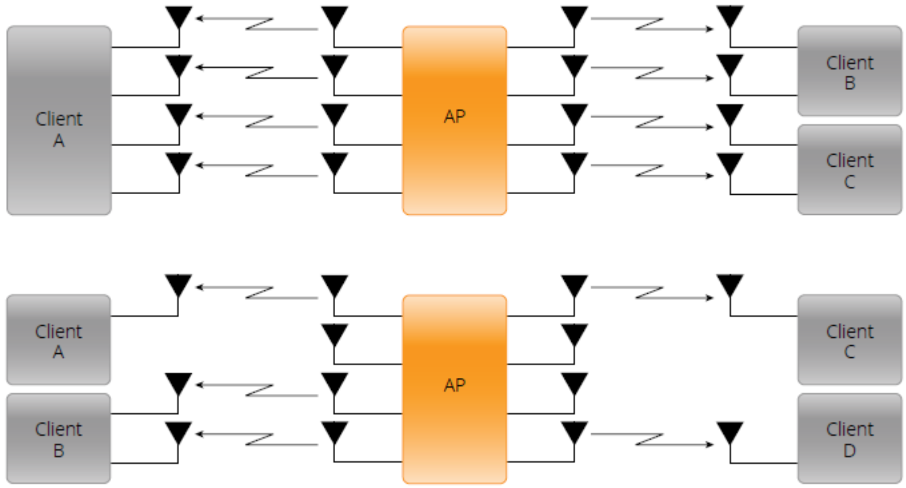

Figure 4.4 Downlink MU-MIMO transmission options

There is no downlink Multiple-user MIMO in 802.11ac since it will add more complexity to the protocol and it will not be useful because of the amount of traffic. In 802.11ac it is expected that clients consume more data than what they generate.

4.5 Frame Aggregation

Frame aggregation was introduced in 802.11n with a goal to increase network efficiency. By using aggregation the amount of overhead is decreased by allowing a device to the radio channel and then the same channel is used to transmit multiple frames. But, implementing aggregation requires the device to look ahead at its transmit queue to find frames to coalesce into a single aggregate frame.

802.11ac, however, adds an interesting feature to aggregation: all frames that are being transmitted use the aggregate MPDU (A-MPDU: Aggregate MAC Protocol Data Unit) format. Even if there is only a single frame to be transmitted, it is transmitted as an aggregate frame. This type of transmission model implies that, 802.11ac MAC must take over all the framing responsibility, and the physical layer works only with the entire length of what is actually transported.

Figure 4.5(a) shows the format of the A-MPDU aggregation type. The maximum length of an A-MPDU is controlled by the value of a field named Maximum A-MPDU Length Exponent, which defines the maximum length of an A-MPDU by the formula $2^{13+\text{Exponent}}-1$ bytes. 802.11ac allows the exponent value to vary from 0 to 7, which means that the maximum A-MPDU length is between 8 KB and 1 MB.

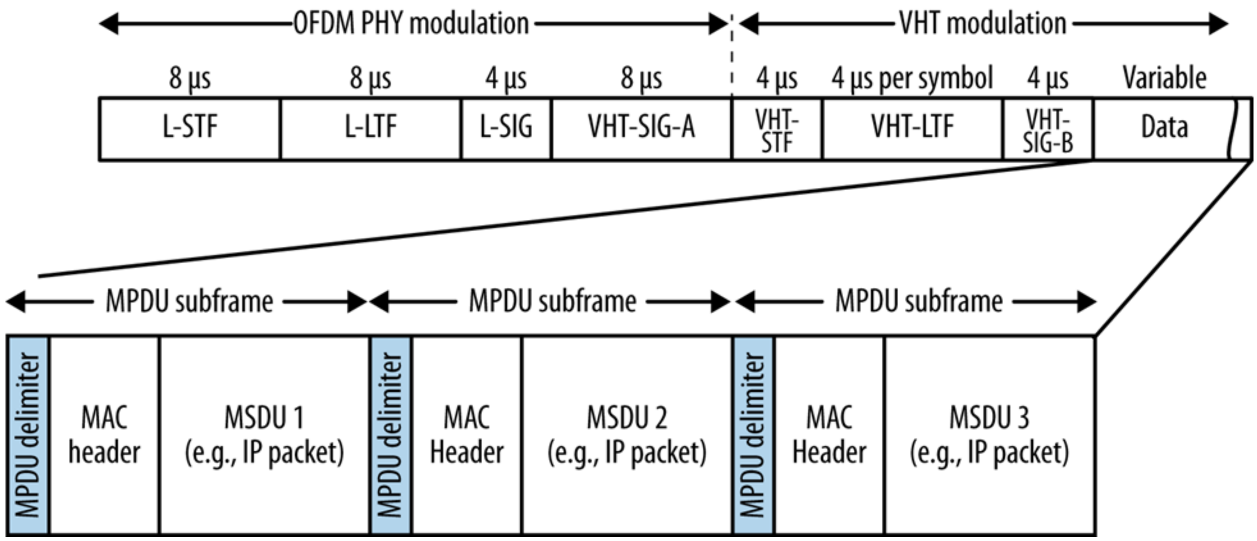

Figure 4.5(a) A-MPDU frame aggregation

What is A-MSDU and A-MPDU?

Every frame transmitted by an 802.11 device has a significant amount of overhead because it includes radio level headers, Media Access Control (MAC) frame fields, interframe spacing and acknowledgment of transmitted frames. At the maximum data rates, this overhead can lead to significant consumption of bandwidth when compared to the actual payload data frame. To deal with this issue, the 802.11n standard defined two types of frame aggregation: MAC Service Data Unit (MSDU) aggregation and MAC Protocol Data Unit (MPDU) aggregation. Both of these types group many number of data frames into one large integrated frame. Because management information needs to be specified only once per frame, this improves the throughput as the ratio of payload data to the total volume of data is higher.

In 802.11n standard, Frame Aggregation was the most significant MAC enhancement proposed which maximize throughput and efficiency. There are two methods to perform frame aggregation:

- Aggregate MAC Service Data Unit (A-MSDU)
- Aggregate MAC Protocol Data Unit (A-MPDU)

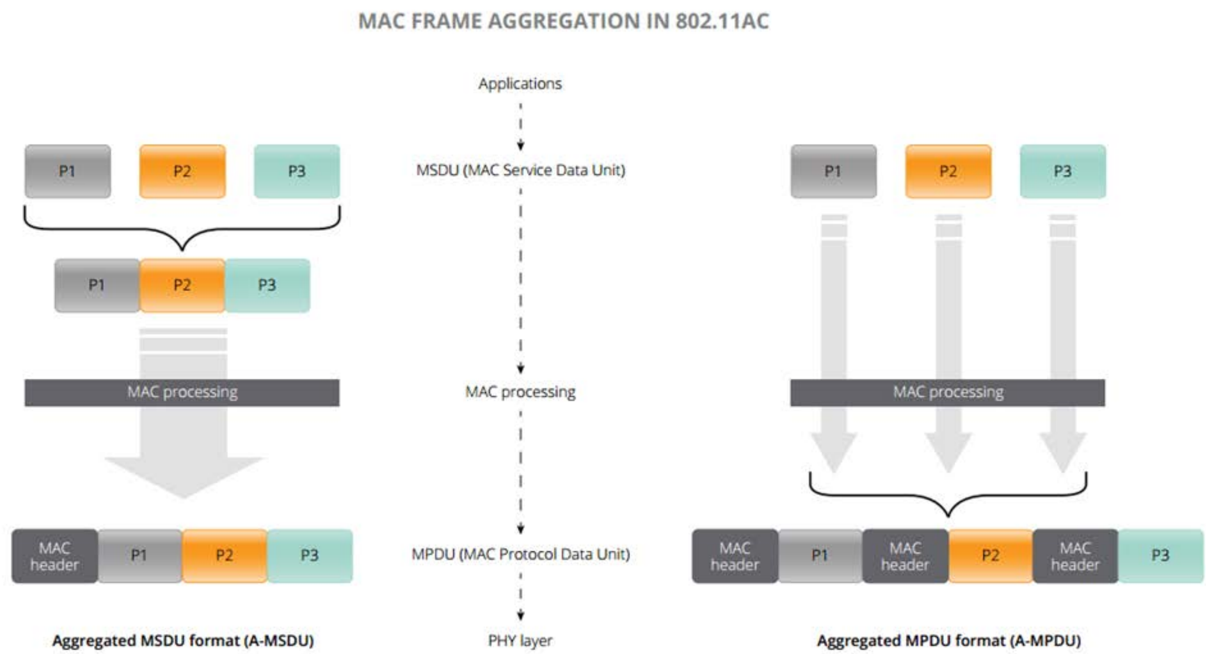

Figure 4.5(b) MAC frame aggregation in 802.11ac

A-MSDU: The main feature of A-MSDU is to allow multiple MSDUs (MAC Service Data Units) to be sent to the same receiver which is merged in a single MPDU. This supporting function for A-MSDU within 802.11n is mandatory at the receiver. As to Destination Address (DA) and sender Address (SA) in the sub-frame header should match with the same receiver address (RA) and the transmitter address (TA) in the MAC header, A-MSDU cannot be used for broadcast & multicast.
A-MPDU: The characteristic of A-MPDU aggregation is to combine Multiple MPDU sub frames with a single leading PHY header. A key difference from A-MSDU aggregation is that an A-MPDU functions when MAC header encapsulation process is completed. This method usually offers higher MAC throughput when compared to A-MSDU.

5. COMPATIBILITY

5.1 Compatibility basics

802.11ac is carefully designed to be backwards compatible with 802.11a/n devices. In fact 802.11ac design is simpler and more through in compatibility with 802.11a and 802.11n. 802.11ac defines 2 preamble formats: Greenfield and Mixed. Because Greenfield do not consider compatibility, 802.11ac does not use this format.

802.11ac devices detect the preamble and pilot of the access devices to differentiate the 802.11 used by the access devices and adapt to the access device. This leads to the co-existence of 802.11a/n/ac which is key requirement to meet in developing the new requirement

5.2 Compatibility between transmitters and receivers of frames

The introduction of the 802.11ac extends the compatibility matrix in 5 GHz band from two concurrent technologies to three concurrent technologies. Also compatibility is not only limited to intended receiver but also to every receiver. Compatibility between transmitter and receiver can be summed up by the table 5.2

Transmitter type	802.11a receiver	802.11n receiver	802.11ac receiver
802.11a	Designed operation	802.11n devices receive 802.11a frames	802.11ac devices receive 802.11a frames
802.11n	802.11n devices transmit 802.11a frames(backwards compatibility)	Designed operation	802.11ac devices receive 802.11n frames
802.11ac	802.11ac device transmits 802.11a frames(backwards compatibility)	802.11ac device transmits 802.11n frames	Designed operation

Table 5.2 compatibility between transmitter and receiver

5.3 Compatibility between transmitters and listening devices

The interesting feature of co-existence is that any device may listen to the frame. When two 802.11ac devices are communicating old 802.11a device is not left behind or harmed it can still participate in the sharing of the medium. This is achieved by the using the same type of OFDM preamble which is used in earlier versions of 802.11, thus the earlier versions of 802.11 can estimate the time where the channel is busy and avoid collisions. Table 5.3 will explain how different types of devices listening will react.

Transmitter type	802.11a listener	802.11n listener	802.11ac listener
802.11a	Designed operation	802.11n devices listen to 802.11a frames and defer medium access to avoid collisions	802.11ac devices listen to 802.11a frames and defer medium access to avoid collisions

802.11n	802.11n greenfield frames require RTS/CTS or CTS-to-self-protection; 802.11n mixed-mode frames require no specific protection	Designed operation	802.11ac devices listen to 802.11n frames and defer medium access to avoid collisions
802.11ac	802.11ac uses a compatible physical preamble, allowing 802.11a devices to read the medium as busy and avoid collisions	802.11ac uses a compatible preamble, allowing 802.11n devices to read the medium as busy and avoid collisions	Designed operation

Table 5.3 Comparison of response of receiving end devices

6. CONCLUSION

802.11ac is an excellent evolutionary step in Wi-Fi technology which has potential to provide high throughput to next generations. To make complete usage of this potential, 802.11ac systems have to go beyond a minimal implementation that simply misuse the wider bandwidth channels available to this technology.

As 802.11n systems are already available which implement MIMO processing with space-division multiplexing, LDPC, STBC, beamforming, multiple streams and a variety of other PHY, MAC and also coexistence enhancements, any new systems will be measured with respect to 802.11n. Therefore, 802.11c which is a next generation amendment has MU-MIMO and wider bandwidths in addition to the available features.

The bandwidth increase of 11ac is currently a concern in situations with limited bandwidth resources. As frequency is a scarce resource that needs to be used as efficiently as possible, exploiting channel diversity with the usage of higher number of spatial streams allows more efficient spectrum use than simply doubling the bandwidth of the transmission. Therefore channel and antenna diversity remain important requirements, even for wider bandwidth systems.

It is understood that a 4x4 system with a maximum number of spatial streams and MU-MIMO will be requiring, at a minimum, in order for 11ac to fully realize it’s capacity.

Is 802.11ac the last word in Wi-Fi, at least at the physical layer? There is certainly a case for accepting that it pushes most features to the limit – channel bandwidth, modulation, number of antennas and spatial streams, beamforming.

There is some opportunity in MU-MIMO but it is difficult to see where necessary improvements can be made in existing spectrum without some new invention. Nevertheless, 802.11ac provides plenty of scope. It might take many years before chips and devices catch up with all the features in the standard, and by that time there will not many new developments signaling where the next wave of innovation should be directed.

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