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IEEE 802.11 WLAN and Advancements: A Review

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***Abstract*— For providing flexibility and mobility in accessing networks and services, wireless communication specifically Wireless Local Area Network (WLAN) has become popular in due to ease of installation and low cost. Due to increasing number of laptop users and increasing power of mobile phones, WLAN is becoming a viable option for everyone. WLAN is based on IEEE standard 802.11. With the advancements in wireless LAN standards and increasing data rate, mobile users can experience high levels of performance, reduced delay and high availability that make WLAN suitable for most of the applications. 802.11 working group has extended this standard from time to time by making some advancements and changes to the original IEEE standard. Most common extensions are 802.11a, 802.11b, 802.11g, 802.11n and work on 802.11ac is going on. Upcoming standards like 802.11ac can support various new applications. WLANs are on now becoming mainstream connectivity solution for a broad range of application areas and customers. At one time IEEE standard 802.11 was striving to achieve performance comparable to wired Ethernet, but with upcoming standards it may even surpass the benefits being offered by wired connectivity. In this paper we have presented basic architecture of IEEE standard 802.11, its history that is how it has reached from 802.11a to 802.11ac. We have also given details of advancements being done in 802.11ac and its target application areas.**

***Keywords*— WLAN, IEEE 802.11, PHY, MAC, OFDM, HDTV**

I. INTRODUCTION

In today's work scenario workforce is more mobile and organization has flatter structure. Employees are equipped with notebook computers and work in cross functional teams and have no geographic or organizational boundaries. Much of the time they work away from their desks. That is why they need access to the network and other resources beyond their desktops. Everyone wants the freedom to move and have access to the resources on the go. WLANs fit well in this kind of environment. With a wireless network, one can access information and other network resources from anywhere and anytime. Wireless LANs also provide a benefit for system managers.

This allows them to design, deploy, and enhance networks without regard to the availability of wiring, saving both effort and dollars. WLANs provide a throughput comparable to wired Ethernet, mobile access along with configuration flexibility. It also gives you the option to provide network access, where wired Ethernet cannot be laid such as older buildings, solid-wall structures or other such locations. This reduces cost of ownership and makes frequent modifications possible, without much of influence on other resources. It gives users anytime, anywhere network access. That is why WLAN has now become a standard interface on portable computers, tablets and smart phones. The applications used by these devices have continued to progress with increasing speeds and amendments in this standard.

IEEE 802.11 is PHY and MAC standard for wireless communication that keeps on evolving and is being defined by the Institute of Electrical and Electronic Engineers (IEEE). Now it is commonly referred to as Wi-Fi and it define an interface between a wireless client and an access point in case of infrastructure mode or between two or more wireless clients in case of ah-hoc mode. All IEEE 802.11 WLAN standards use unlicensed radio spectrum under 2.4 GHz and 5 GHz Industrial, Science and Medical (ISM) frequency bands. WLAN has now become part of every device; it has always remained backward compatible as it continuously advanced from 802.11 a/b/g/n and now 802.11ac. Every few years the industry has released amendments to this standard that has increased its data rates and capabilities. But even the latest WLAN systems ie 802.11n and 802.11ac are able to interoperate with equipment built to the previous standards. It has passed through various advancement stages that is IEEE 802a/b/g/n and now chipsets for 802.11ac are under development.

IEEE 802.11ac, also known as Gagabit Wi-Fi, is the latest WLAN standard that builds upon 802.11n by improving data rates, network robustness, reliability and RF bandwidth utilization efficiency[2]. This standard will be able to supply the wireless data rates and client capacity that are demanded by bandwidth intensive applications like HDTV and uncompressed video.

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IEEE 802.11n has enable 100 Mbps or 200 Mbps rates that puts it on a par with 10/100 Mbps Ethernet. Just a few years it seemed adequate for most of the emerging video applications. 802.11ac is designed to meet the requirements of high-definition video and wireless voice applications. Through data rate and range improvements this standard will make Wi-Fi equipments to transfer high definition TV (HDTV) and other video streams for advanced application in home and enterprise networks. It can help in reducing expenditure on IT by increasing the range and performance of hotspots, allowing connections to handle more clients. And it will improve overall user experience. It will provide data rates in excess of 1Gbps which will enable delivering HDTV or HD video to Smartphone's and portable computers. With more antennas, wider channels and more spatial streams, along with a number of new features to boost throughput and reliability 802.11ac will become de-facto standard for 5-GHz equipments in few years time[1]. 802.11ac can be considered the next step after 802.11n, along the path running from 802.11b, to 11a/g, then 11n, and now 802.11ac. In fig-1 and fig-2 we have shown Total WLAN chipsets sales forecast and WLAN chipsets sales forecast by technology standard respectively. It shows a clear trend of increasing sales and that too for higher speed and latest standards.

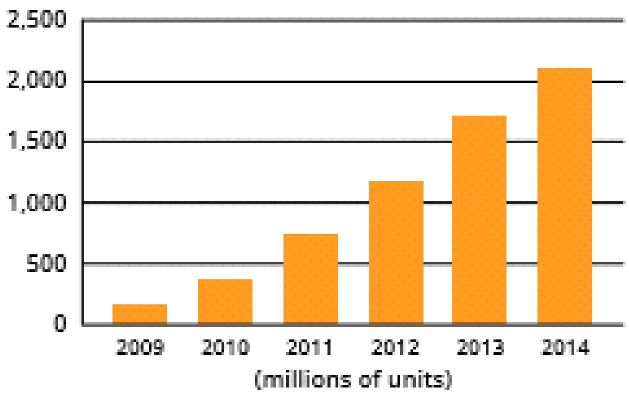

Fig- 1. Global shipment forecast for WLAN Chipsets[8]

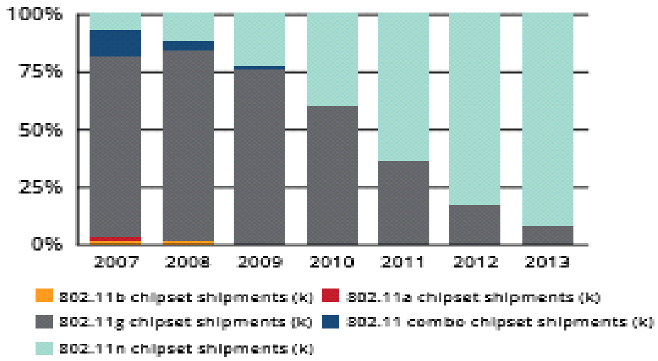

Fig- 2. WLAN chipset forecast by Technology Standard[8]

This paper explains the latest advance in Wi-Fi, 802.11ac along with basic architecture and history of 802.11. In Section-2 we have given history of IEEE 802.11. How it has reached to 802.11ac from 802.11a in 1999. In section-3 brief architecture of IEEE802.11 is given. Given detail of standard components of WLAN and how they work. In section-4 IEEE 802.11ac is explained in detail. Finally we conclude the paper in section-5.

II. HISTORY OF IEEE 802.11

With the emergence of cable modems and enhancements in mobile communication like 3G, 4G internet speed has increased manifold. Easy availability of network resources on the go has made notebook computers, tablets and Smartphone's very popular. So now there is large interest in providing high-speed wireless network access. Initially, many companies started developing wireless products, but they achieved little success because these products suffered from many issues, including high manufacturing costs and low production volume, as well as product incompatibility between vendors. Then IEEE developed first 802.11 standard which was completed in 1997. It provided specifications for PHY. One was frequency hopping spread spectrum (FHSS) and the other was a direct-sequence spread spectrum (DSSS). They also provided specification for an infra-red (IR) PHY.

These specifications for PHY were designed to support 1Mbps and 2Mbps rates. Radio-based PHYs were designed to operate at 2.4 GHz. By 1999, two amendments were made to this standard. The IEEE 802.11b is an extension to the previously-defined PHY with DSSS and used complementary-code keying(CCK) modulation scheme. It supports data rate of 11Mbps. IEEE 802.11a specified a new radio-based PHY at that operates in different frequency band i.e. 5.2 GHz and used Orthogonal Frequency-Division Multiplexing (OFDM) transmission which allows data rates up to 54 Mbps. Although 802.11b may appear to be the older standard but the amendment for 802.11a was proposed before 802.11b. IEEE 802.11b PHY is capable of giving throughput of 11 Mbps but it does not exceed 5 Mbps due to various overhead. This speed is insufficient for many application like video streaming etc. Therefore companies shown interest in developing 802.11a based chipsets, capable of providing throughput in excess of 20Mbps. Usage of 5.2 GHz as carrier by IEEE 802.11a allowed for coexistence of 11b and 11a networks without interference, but the production cost of manufacturing devices capable of supporting both 2.4 GHz and 5.2 GHz (to support both standards) became a barrier preventing the transition from 802.11b to 802.11a products in the marketplace. Then in the year 2002 a new amendment to 802.11 is done i.e. 802.11g, to cope up with all these problems. This standard also used OFDM as being used in IEEE 802.11a and supported data rates up to 54 Mbps, but it used 2.4 GHz as carrier as used in 802.11b. The main challenge of this standard was backward compatibility with 802.11b network. Although IEEE 802.11g provides good performance, but throughput given by this standard is not good enough to application like video streaming and establishing multiple video conferencing sessions. That leads to the next amendment to this standard to support higher throughput i.e. 802.11n. IEEE 802.11n specifications were released in 2007 and it improved the range of operation and quality-of-service (QoS). Initial goal of this standard was to allow data rates of at least 100 Mbps. For improving throughput multiple transmit and receive antennas or MIMO is being used and it allowed the access point can use 40 MHz channel and more sophisticated processing techniques.

Fig-3 shows amendments done to IEEE 802.11 from time to time.

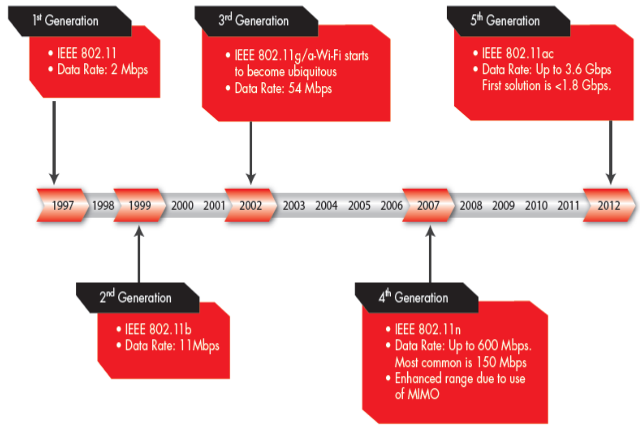

Fig-3: IEEE 802.11 Amendments[3]

802.11ac is the next amendment to the IEEE 802.11 specification for Wireless Local Area Networks (WLANs)[4]. The main goal of this amendment was to achieve throughput in order of 1Gbps within the Basic Service Set (BSS). The official target rates, as defined at the start of the project, are a maximum Multi-Station (Multi-STA) throughput of at least 1 Gbps and a maximum single link throughput of at least 500 Mbps. Devices and application are continuously moving from fixed to wireless environment that increased the throughput requirements. Existing 802.11 technologies operate in the 2.4 GHz band (802.11b, 802.11g), the 5 GHz band (802.11a), or both (802.11n). 802.11ac operates strictly in the 5GHz band, but supports backwards compatibility[4] with other 802.11 technologies operating in the same band (most notably 802.11n). In Figure-2 we have shown the amendments done to 802.11 from time to time, and the trend towards increasing speed and video based application. We can have the basic idea about the amendments and changes done to IEEE 802.11 from the Table-1, which shows the data rate they support, frequency band in which they work, nominal range, channel bandwidth and modulation type.

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TABLE I
IEEE 802.11 SPECIFICATIONS

Standard	802.11a	802.11b	802.11g	802.11n	802.11 ac
Frequency Band	5 GHz	2.4 GHz	2.4 GHz	2.4 GHz, 5 GHz	5GHz
Maximum Throughput	54 Mbps	11 Mbps	54 Mbps	600 Mbps	1.3 Gbps
Nominal Range	120m	140m	140m	250m	250m
Channel bandwidth	20MHz	20MHz	20MHz	20, 40 MHz	20, 40, 80 MHz(mandatory) 160 MHz(optional)
Maximum Spatial Streams	1	1	1	4	8
Modulation Type	QPSK, BPSK	CCK	OFDM, 64-QAM	OFDM, 64-QAM	64-QAM, 256-QAM

III. IEEE 802.11 ARCHITECTURE

An 802.11 LAN is based on cellular architecture where the system is subdivided into cells, where each cell(called Basic Service Set or BSS)[5] is controlled by a base station called Access Point or AP. WLAN can be formed by a single cell, with a single Access Point, but most installations are being formed by several access points being connected through some kind of backbone called Distribution System. The whole interconnected Wireless LAN including the different cells, their respective Access Points and Distribution System is seen by the upper layers of OSI model as single 802 network and is called Extended Service Set(ESS). Fig-1 shows a typical 802.11 WLAN. It's main components are shown in fig- 4 and explained in following paragraphs.

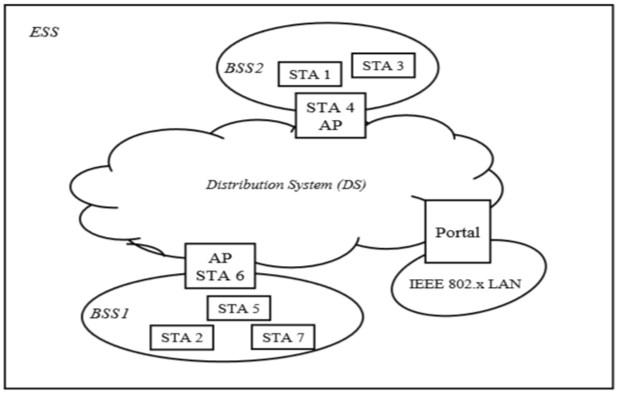

Fig- 4: IEEE 802.11 WLAN Architecture[7]

A. Components

Basic Service Set[5]: A BSS is a set of stations that communicate with one another through wireless medium. It is called IBSS, if all the stations are mobile and are not connected to a wired network. It can be shot lived, just to form an ad-hoc network. When it includes an access point (AP), it is called infrastructure BSS. In an infrastructure based WLAN, if one mobile station want to communicate with other, it needs to send it to AP and then AP sends it to other station. This consume double the bandwidth. It appears to be a significant cost, but the benefits given by the AP far outweigh this cost. One of them is, AP buffers the traffic of mobile while that station is operating in a very low power state.

Extended Service Set (ESS)[5]: A ESS is a set of infrastructure BSSs, where the APs communicate among themselves to forward traffic from one BSS to another and to facilitate the movement of mobile stations from one BSS to another. The APs perform this communication via an abstract medium called the distribution system (DS). To network equipment outside of the ESS, the ESS and all of its mobile stations appears to be a single MAC-layer network where all stations are physically stationary. Thus, the ESS hides the mobility of the mobile stations from everything outside the ESS.

Distribution System[5]: the distribution system (DS) is the mechanism by which one AP communicates with another to exchange frames for stations in their BSSs, forward frames to follow mobile stations from one BSS to another, and exchange frames with wired network.

International Journal of Recent Development in Engineering and Technology
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B. Services

Station Services: Authentication, De-authentication, privacy, delivery of data. Similar functions to those that are expected of a wired network. The wired network function of physically connecting to the network cable is similar to the authentication and de-authentication services. Privacy is for data security. Data delivery is the reliable delivery of data frames from the MAC in one station to the MAC in one or more other station, with minimal duplication and minimal ordering[5].

Distribution Services: Association, Disassociation, Reassociation, Distribution, Integration. This allows mobile stations to roam freely within an ESS and allow an IEEE 802.11 WLAN to connect with the wired LAN infrastructure. A thin layer between MAC and LLC sublayer that are invoked to determine how to forward frames within the IEEE 802.11 WLAN and also how to deliver frames from the IEEE 802.11 WLAN to network destinations outside of the WLAN[5].

C. Mode of Operation

Wireless networks can have to distinct modes of operation: Ad-hoc and infrastructure based. In an infrastructure based wireless network, there is always some kind base station or access point(AP) that acts as a central node to connects the wireless stations. The base station is usually provided in order to enable access to the Internet, an intranet or other network resources. Base stations usually have a fixed location, but sometimes we may have mobile base stations. The disadvantage over ad-hoc networks is that the base station is a central point of communication. If it fails or stops working none of the wireless stations can communicate with each other. Ad-hoc networks can be formed “on the fly”, they don't need a base station. Self organization is the key to forming an ad-hoc network because initially there is no central node to talk to. In ad hoc networks the wireless stations talk to each other directly, and they also forward the packets meant for the other stations. Mobile stations establish routes as well to forward the packets to a node that is not directly in range. They use hop based approach. Packet passes through multiple stations before reaching its destination. These are two different modes of operation that can support different set of applications. In fig- 5 and fig- 6, we have shown basic architecture of a WLAN in infrastructure mode and Ad-hoc mode respectively.

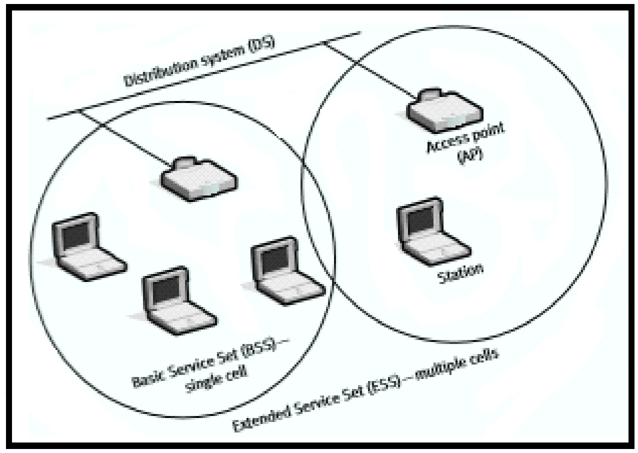

Fig-5: Infrastructure Mode

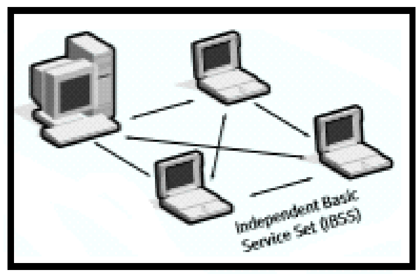

Fig- 6: Ad-hoc Mode

IV. IEEE 802.11AC

802.11ac is the name of a next amendment to the IEEE 802.11 specification for WLANs. The main goal of the new 802.11ac amendment was to significantly increase the throughput within the Basic Service Set (BSS). The official target rates, as defined at the start of the project, are a maximum Multi-Station (Multi-STA) throughput of at least 1 Gbps and a maximum single link throughput of at least 500 Mbps. These higher rates are motivated by the continuing trend to transition devices and applications from fixed links to wireless links and by the emergence of new applications with ever higher throughput requirements[6]. Existing 802.11 technologies operate in the 2.4 GHz band (802.11b, 802.11g), the 5 GHz band (802.11a), or both (802.11n). 802.11ac operates strictly in the 5GHz band, but supports backwards compatibility with other 802.11 technologies operating in the same band (most notably 802.11n)[4].

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To achieve its goals, 802.11ac has allowed up to 8 spatial channels and optional 160 MHz channel bandwidth. In addition to these, 802.11ac also supports a number of advanced digital communication concepts, such as space division multiplexing, Low-Density Parity Check (LDPC) coding, shortened guard interval (short GI), Space-Time Block Coding (STBC), and explicitfeedback transmit beamforming (Tx BF).

A. Major improvements

Data rate: APs may transmit at a maximum of 6.93Gbps and single clients such as laptops may reach up to 1.73Gbps. These speeds depend on the use of up to eight antennas, along with a corresponding number of radio transmitter/ receivers. It should be noted that many mobile clients, including smartphones and tablets normally don't use multiple antennas and are unlikely to operate beyond 433Mbps. 802.11ac products, first available in consumer products support 80MHz channels and up to 3 data streams for a maximum data rate of 1.3Gbps[9]. Future products will add 160MHz channels and up to 8 streams, for a maximum data rate of 6.93Gbps.

Rate at range: Maximum distance that a Wi-Fi signal can reach will remain unchanged with 802.11ac, but multiple antennas will extend the data rate at every distance. Three antenna 802.11ac AP increases data rate at all distances compared to 802.11n APs with one and three antennas.

Multi-user performance: 802.11ac uses multiple antennas to simultaneously transmit to multiple clients. This alleviates congestion delays, where one client needs to wait [9] for another to complete – much like being delayed behind a slow driver on a single-lane road.

It's clear that the goal of 802.11ac is to extend data rates and throughput. The IEEE identified a set of use models or scenarios in which 802.11ac will enable us improve the performance of existing tasks. This aims at supporting applications that include video streaming, HD digital video, HDTV etc that consumes much more bandwidth than voice communication or other applications. It has already changed the cellular industry, With increasing number and popularity of smartphones and tablets, increased the bandwidth demand. Consumption of Streaming video, movies, HDTV and video based applications like video conferencing is driving significant increases in Internet traffic. Consumers increasingly prefer bandwidth-hungry HDTV over standard definition TV.

The intent of IEEE 802.11ac is to replace the cables between set-top boxes, game consoles, PCs and TV monitors where the requirement is for very high data rates but relatively short distances. Most consumer electronics companies see 802.11ac as the first viable wireless technologies for video, especially uncompressed video[1]. Some of the usage areas for IEEE 802.11ac are shown in Table-II

TABLE II
802.11AC USAGE MODELS[1]

Category	Usage Model
1.Wireless Display	1a. Desktop storage & display
	1b. Projection on TV or projector in conference room
	1c. in-room gaming
	1d. Streaming from camcorder to display
	1e. Broadcast TV field pick up
2. Distribution of HDTV	2a. Lightly compressed video streaming around the home
	2b. Compressed video streaming around the home
	2c. Intra-large vehicle(e.g. airplane) applications
	2d. Wireless networking for small office
	2e. Remote medical assistance
3. Rapid Upload/ Download	3a. Rapid sync-n-go file transfer
	3b. Picture by picture viewing
	3c. Airplane docking
	3d. Movie content download to car
	3e. Police/surveillance car upload
4.Backhaul	4a. Multi-media mesh backhaul
	4b. Point-to-point backhaul
5.Outdoor Campus/ auditorium	5a. Video demos/telepresence in auditorium
	5b. Public safely mesh
6.Manufacturing floor	6a. Manufacturing floor automation

B. Technological Advancements

Modulation Enhancements: IEEE 802.11ac also uses OFDM(Orthogonal Frequency Division Multiplexing) like the other IEEE standards for wireless transmission. But this standard optionally allows use of 256 QAM along with QPSK, BPSK , 16 QAM and 64 QAM modulations. 256 QAM increases PHY rate by 33% as it allows 6-8 bits per sub-carrier.

But 256 QAM can only be considered in very favorable channel conditions. 256 QAM can increase PHY rate, but it doesn't increase the reach of the service. This technique also requires the design of transmitter and receiver in such a way to accommodate higher constellation.

Wider RF channel bandwidths: The most prominent feature of this standard is wider bandwidth of channels. 802.11ac supports 20, 40 and 80 MHz channels, while it was 20 and 40 MHz only in case of 802.11n. It optionally allows 160MHz or 80+80 MHz channels. also allowed. By doubling the bandwidth of RF channel it will double the throughput. 80 MHZ and 160 MHz are both defined, but use of 160 MHz is optional

More spatial streams: 802.11ac supports 8 spatial streams, while it was only 4 in 802.11n. With this APs size will increase, as few more antennas will be added and Clients will become more capable by implementing multiple spatial streams and beam forming features behind a smaller number of antennas. This will create opportunities for multi-user MIMO, where a high-capacity AP can communicate with multiple, lower-throughput clients simultaneously[1].

Multi-user MIMO (MU-MIMO): Till now all communication in 802.11 was one-to-one or one-to-all. Now 802.11ac allows an AP to transmit different streams to several targeted clients simultaneously. This is a good technique to use surplus antennas in AP to simultaneously communicate with clients. It uses Space Division Multiple Access (SDMA) i.e. streams not separated by frequency or time, instead resolved in space like MIMO. MU-MIMO doesn't increase the performance of individual clients, but it increases the utilization of the network by simultaneously communicating with multiple clients

MAC Improvements: The maximum size of an A-MPDU can optionally be increased to a maximum of 1,048,575 octets (compared to a maximum of 65,535 octets in 802.11n). The RTS/CTS mechanism has been updated to address hidden nodes problem on secondary channels. It arises because 802.11ac uses wider bandwidth. To this end, both RTS and CTS (optionally) support a "dynamic bandwidth" mode. Reduced Inter-Frame Spacing (RIFS) is a deprecated feature of the 802.11n specification whose purpose was to increase MAC efficiency by reducing the gap between successive transmissions. 802.11 used RIFS[4] to reduce gap between successive transmissions. 802.11ac uses aggregation in place of RIFS, as it is more efficient way for MAC.

V. CONCLUSIONS

802.11 WLANs are already very common due to large penetration of portable computers, tablets and Smartphone's. IEEE 802.11 is a robust and reliable way of providing wireless connectivity with good data rate. IEEE 802.11 has been amended from time to time to provide better throughput and better performance along with better security features. It has started it's journey in 1999, supporting throughput of 11Mbps and now with 802.11ac it has crossed 1Gbps mark. 802.11ac has the potential to support next generation of application, that are more bandwidth intensive and video oriented. This will offer more freedom and flexibility to choose interoperable solutions, since it is backward compatible with most IEEE 802.11 standards. This new standard provides opportunities to expand the horizon of wireless network computing.

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