A Comparative Study of IEEE 802.11 family Protocols

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Summary
Wireless local area network (WLAN) is continuously developing since the emergence of base IEEE 802.11 protocol. Over the past twenty years, it has gone through continuous modification with the increasing demand for services it provided. This paper provides an extensive survey of protocols developed in 1999-2020. These protocols are compared based on their range, channel bandwidth, RF band, data rate, modulation type and other MAC and Physical layer parameters. It also summarizes the key technologies and amendments of all protocols in said timeline. It will help researchers to find research focus for all versions and assist to discover research gaps for next generation of IEEE 802.11 family.

Key words:
Wireless local area network (WLAN), IEEE 802.11 protocol, MAC and Physical layer

1. Introduction

WLANs are using IEEE 802.11 protocol for its deployment in public and private areas in recent years. The portable devices such as mobile phones use WLAN interfaces to access applications/services via WLANs [1]. The major issues with WLANs are; energy-consumption, limited bandwidth, hidden and exposed node problem. In 1997, the original IEEE 802.11 standard introduced basic service set (BSS) and networking in 2.4 GHz unlicensed bands. This standard sup-ports direct sequence spread spectrum (DSSS) and frequency-hopping spread spectrum (FHSS) in 2.4 GHz. Its MAC layer defines distributed coordination function (DCF) and point coordination function (PCF). This standard was revised in 1999. However, both versions or this standard are considered to be most primitive IEEE 802.11 standards. The family of the IEEE 802.11 standard includes its different versions namely IEEE 802.11a, IEEE 802.11b, IEEE 802.11g, IEEE 802.11e, 802.11n, 802.11p, 802.11ad, 802.11ac, 802.11ax and 802.11ah.

The IEEE 802.11a operated in 5GHz unlicensed band. Eight modulations and coding schemes are supported with a channel width 20 MHz. IEEE 802.11b has the same channel width as IEEE 802.11a but supports 2.4 GHz band. PHY layer adopts Direct sequence spread spectrum (DSSS) and complementary code keying (CCK) technology. OFDM technology was introduced in 2.4 GHz band first time in IEEE 802.11g in 1999.

The protection mechanism of its MAC layer is compatible to IEEE 802.11b. The next versions inherit many features from the initial versions of IEEE 802.11 standard. WiFi networks with physical (PHY) layer data rates up to 10-12 Gbps in the frequency band ranging to 60 GHz. In IEEE 802.11 protocol stack, MAC layer helps to determine quality-of-service (QoS) and channel efficiency for upper-layer applications. The IEEE 802.11e was introduced to improve security mechanisms and enhance quality of service at MAC level. To further increase data rates and throughput, IEEE 802.11n revised previous protocols at MAC/PHY layers to enable higher throughput. IEEE 802.11ad and IEEE 802.11ac again improved PHY/MAC layers to support 0.5-1 Gbps in 5Hz band and ≥ 1 Gbps in 60 GHz band. IEEE 802.11ax and IEEE 802.11ah supported 2.4-5 GHz frequency band with 10 Gbps and 40Mbps data rates respectively to focus on the standardization issues of next-generation WLANs. Many efforts have been performed to improve basic IEEE 802.11 protocols. Node throughput, channel utilization and network capacity is evaluated in [17], admission control mechanism is developed to provide QoS like in [31] [32] and [33], protocol parameter is optimized to achieve maximum performance in [32] and to solve unfairness problem caused by hidden nodes and heterogenous data rates is solved in [33]. All these modifications resulted in different versions of basic IEEE 802.11 protocol.

A thorough literature survey has been conducted to study different versions of IEEE 802.11 protocols from 1999 onwards. The evolution of all protocol is presented in Fig. 1. It indicates that the publish year for IEEE 802.11a is 1999, similarly other nine protocols and their release time shown in this figure. The graph in Fig. 2 shows the number of research articles included in our study related to each protocol's year wise. A clear transition can be noticed from older versions to recent versions as we move forward on x-axis. All protocols are indicated with different markers. IEEE 802.11a/b/g being the initial standards cover a long-time span for their credit in publications.

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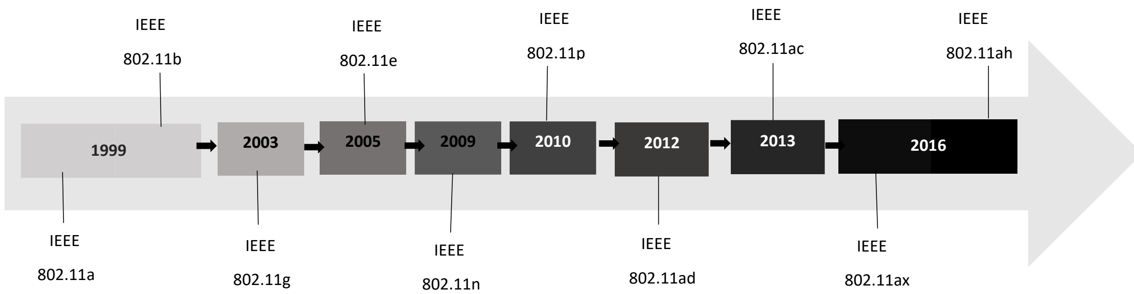

Fig. 1 Evolution of IEEE 802.11 protocols

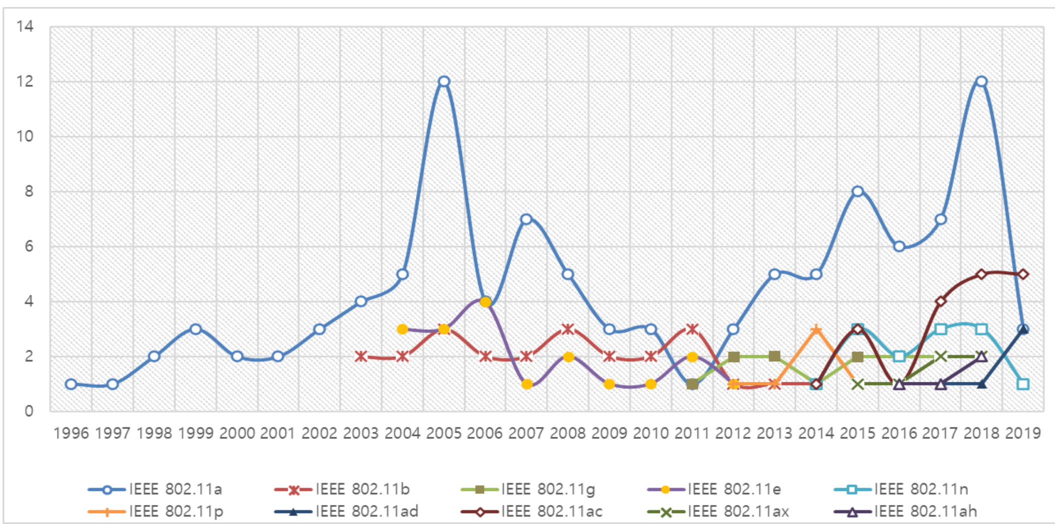

Fig. 2 The number of research articles related to each IEEE 802.11 Protocol in our survey

This article summarizes state of the art protocols for IEEE 802.11 and elaborates details of their MAC and physical layer parameters. It also provides a thorough understanding of the assumptions, techniques, approaches and assumptions that led to different versions of IEEE 802.11 protocols. Specifically, it includes all papers that modeled different versions of IEEE 802.11 such as: IEEE 802.11a, IEEE 802.11b, IEEE 802.11g, IEEE 802.11e, IEEE 802.11n, IEEE 802.11ac, IEEE 802.11ax, IEEE 802.11ah and IEEE 802.11ad.

The rest of the paper is organized as follows. We provide details of the IEEE 802.11 protocols in section 2. Section 3 provides a comparison of protocols. Section 4 is based on Discussion. Section 5 draws conclusions.

2. IEEE Protocols Detail

The MAC architecture of IEEE 802.11 a/b/g protocols has two main functions in MAC sub-layer of IEEE 802.11 a/b/g protocols namely Distributed Coordination Function (DCF) and Point Coordination Function (PCF). The first one is mandatory and the later one is optional. DCF supports synchronous transmission with CSMA/CA Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) access mechanism. A-synchronous transmission is provided by PCF using round-robin polling-based access mechanism. Fig. 4 provides insights to MAC architecture. It consists of point coordination function (PCF) and distributed coordination function (DCF). PCF and DCF are for centralized and distributed contention-free channel access respectively. Fig. 3 shows structure of MAC data frame for IEEE 802.11 a/b/g protocols. The data frame begins with MAC header which contains other fields. It contains MAC address of both source and destination, transmitter address and receiver address. Other than MAC header, the data frame has frame body and frame check sequence (FCS) field.

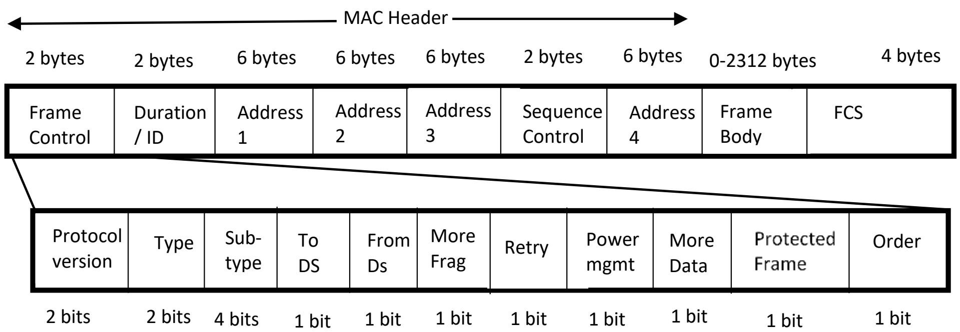

Fig. 3 Structure of IEEE 802.11 MAC Data Frame Format

The frame body contains encapsulated data from higher layer protocol. FCS is used for error detection purposes. The Duration/ID field is used either to check remaining duration between STA and AP in frame exchange or to retrieve buffer at a AP. Sequence control field identifies received frames at an STA. The frame control field has eleven sub-fields.

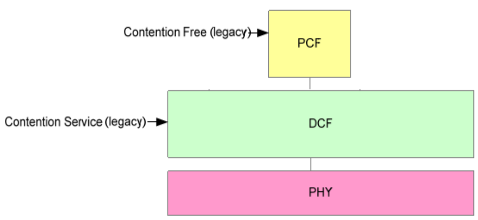

Fig. 4 MAC Architecture [3]

The physical layer of IEEE 802.11a works on orthogonal frequency division multiplexing (OFDM) principle. In this technology, the high-speed binary signal is divided in low rate bit streams which are modulated on individual sub-carriers from one of the channels in 5 GHz band. There are four pilot sub-carriers and 48 sub-carriers for actual data. These pilots help in coherent demodulation. In modulation, the data stream is translated into a sequence of symbols. The type of modulation determines the number of bits each symbol represents. There are eight different modes of modulation available in IEEE 802.11a including 16-QAM quadrature amplitude modulation (QAM), quadrature phase shift keying modulation (QPSK) and binary phase shift keying modulation (BPSK).

There are three different physical layers provided in IEEE 802.11b protocol. All these layers operate with different data rates. The three types of PHY layer includes Direct Sequence Spread Spectrum (DSSS), Frequency-hopping spread spectrum (FHSS) and infrared (IR) layer. The first two layers use ISM 2.4 GHz band. The FHSS adopts Gaussian Minimum Shift Keying (GMSK) with 79 channels separated at 1 or 2 MHz. The DSSS uses same frequency with differential quadrature phase shift keying (DQPSK) for 2 Mbps and differential binary phase shift keying (DBPSK) for the 1Mbps. The IR layer is specified for indoor applications. IEEE 802.11b uses 2.4 GHz frequency. Complementary Code Keying (CCK) is used as RF signal format for IEEE 802.11b. The IEEE 802.11g standard defines Extended Rate PHY (ERP) specification for DSSS implementation. There are four modulation schemes for this protocol namely DSSS-OFDM, coded ERP- packet binary convolutional (PBCC), ERP- DSSS/ CCK and ERP- OFDM. The first two schemes are optional whereas the later ones are mandatory. In IEEE 802.11g, the backward compatibility is preserved for all types of modulation except ERP-OFDM modulation scheme.

2.1 IEEE 802.11e

IEEE 802.11e [2], abbreviated as Enhanced Distributed Channel Access (EDCA), is an extension to IEEE 802.11standard, which provides QoS to the standard WLAN protocol. Each machine in EDCA can be divided up to four access categories (ACs). A transmission queue is associated with each AC. The channel access procedure is performed independently by a conceptual module in each AC inside same node of a station. In case of a conflict among two ACs of same node, the transmission of AC having higher priority is carried out first. This situation is considered as collision at the end of lower priority AC. Another scenario of conflict happens when multiple ACs are ready to transmit packet, it is referred as virtual collision because the AC having lower priority is not in collision. Different ACs are recognized by assigning different parameters to different ACs. These parameters include Arbitration Inter-Frame Space (AIFS), Transmission Opportunity (TXOP) and Contention Windows size (CW). Table. I shows parameter setting for IEEE 802.11e. The upper and lower limits of contention window and AIFSN are listed for four access categories. AIFS and Lower CW are assigned to higher priority classes. WLANs using IEEE 802.11e protocol usually operate between 5.75-5.850 GHz or 2.4-2.48 GHz frequency ranges.

Table 1: recommended parameter seting for IEEE 802.11e

Parameter	AC [3]	AC [2]	AC [1]	AC [0]
AIFSN	2	2	3	7
CW_{min}	8	16	32	32
CW_{max}	16	32	1024	1024

There are three main coordination functions namely PCF, DCF and HCF which are performed on MAC layer of this protocol. Hybrid coordination function (HCF) is an extension which is dedicated to controlled and contention-based channel access. MAC layer is responsible for fragmentation, aggregation, medium access control and error checking.

2.2 IEEE 802.11n

IEEE 802.11n operates in multiple frequency bands: 5GHz like 802.11a, 2.4 GHz same as 802.11g and 802.11b. It shows compatibility of IEEE 802.11n with previous versions. However, only one frequency can be utilized by one scheme. The main enhancement in IEEE 802.11n is the reduction in transmission overhead. For this purpose, frame aggregation is performed for maximum utilization. The global frames are combined with normal sub-frames and transmitted together as a single entity. IEEE 802.11n introduced Short Inter-Frame Space (SIFS) which is a space between packets. Its value is 10s for IEEE 802.11b and IEEE 802.11g and 16s for IEEE 802.11a. When a STA accesses the channel to transmit, it is not necessary to wait for a longer time to send a frames sequence. For this purpose, IEEE 802.11n added Reduced Inter Frame Space (RIFS), which is a smaller separation between transmissions. IEEE 802.11n operates in multiple frequency bands: 5GHz like 802.11a, 2.4 GHz same as 802.11g and 802.11b. It shows compatibility of IEEE 802.11n with previous versions. However, only one frequency can be utilized by one scheme.
The PHY layer enhancements include MIMO/Modulation and Coding Scheme (MCS), Duality of Frequency and Reduced Inter Frame Space (RIFS). MIMO helps to increase signal strength by combining different versions of transmitted signal generated by reflection and scattering. MIMO utilizes multiple spatial streams brought out by multiple antennas in transmission and reception. The state of transmission channel is estimated using feedback. MCS includes modulation, coding and number of spatial streams used by a STA. These are also called modes. There are 127 modes defined in IEEE 802.11n.
Some important parameters are summarized below:

- Frequency Band: 2.4 GHz or 5 GHz.
- Modulation Type: DSSS or OFDM.
- Maximum data rate: 600 Mbps.
- Channel width: 20 or 40 MHz.

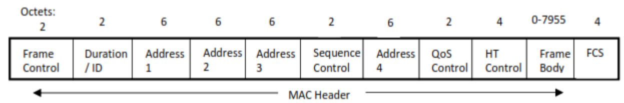

Fig. 3 IEEE 802.11n MAC frame format [7]

The frame format of MAC layer of IEEE 802.11n is shown in Fig. 5. There are three basic changes as compared to IEEE 802.11e version. It includes high throughput control field, frame check sequence field and frame body. The size
of first two fields is 4 bytes. The important PHY and MAC information regarding antenna selection/calibration and link adaptation is carried by HT control field. The results from MAC header and frame body are included in Frame check sequence. The frame body contains MSDU from higher layers. It is variable in length. May be as long as 7955bytes.

2.3 IEEE 802.11p

The design of PHY layer of this version is similar to IEEE 802.11a as it has seven channels (six service channels and one control channel) in 5.9 GHz band [5]. It uses 10MHZ bandwidth for all channels whereas IEEE 802.11a uses 20MHZ bandwidth. OFDM technology is used to overcome signal fading problem and to improve data transmission rate. It uses CSMA/CA to reduce collisions and provide fair channel access. MAC layer management entity (MLME) and physical layer management entity (PLME) are management functions associated with MAC and PHY layers. The MAC layer is based on IEEE 802.11e EDCA alongwith multichannel operation of WAVE architecture [4]. Each channel of EDCA has four different access categories. An independent queue is assigned to each category. The EDCA mechanism assigns different access parameters to access categories of each frame to ensure prioritization. It shows the importance of each message. These access categories are labeled as AC0-AC3. AC0 has lowest and AC3 has the highest priority to access medium.

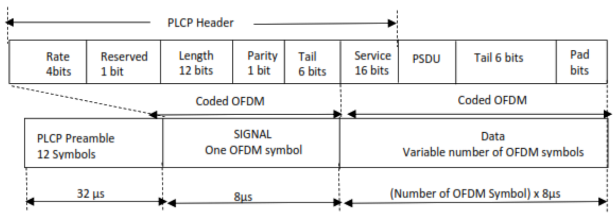

Fig. 4 The frame format of IEEE 802.11p [6]

The IEEE 802.11p uses 16 quadrature amplitude modulation 16-QAM. The frame format of IEEE 202.11p is shown in Fig. 6. It consists of preamble, signal and data sections. The preamble field has 12 training symbols. These symbols are used for gain control and coarse frequency offset estimation. The information about type of modulation and transmission data rate is present in header. In an OFDM symbol, PSDU is appended with pad bits and tail field to generate coded bits in data field.

2.4 IEEE 802.11 ad

IEEE 802.11ad is used in emerging technologies due to its multi-gigabit capability. This protocol faces some issues e.g complex antenna design and power consumption. To overcome these issue, four different versions of PHY layers are introduced; control PHY layer, mandatory control PHY layer, OFDM PHY layer and Low Power (LP-SC) PHY layer.

1) The control PHY layer helps to provide low throughput communication (27.5 Mbps) and low Signal-to Noise Ratio (SNR). To provide low SNR, it removes phase noise by using differential binary phase shift keying modulation. This protocol works in 60 GHz unlicensed band for short distance communication network but this link has blockage vulnerability. The channel bandwidth is 2.16 GHz.
2) The mandatory control PHY layer determines minimum rate to communicate. It is also used to deal with different operations on control and management frames e.g. information request/response, sector sweep/feedback and probe request/response.
3) OFDM PHY layer provides maximum throughput at the cost of energy intensive transceiver structure in multipath environments. It utilizes 64-QAM to achieve 6.75 Gb/s data rate.
4) Single Carrier (SC) PHY layer helps to provide a good trade-off between energy efficiency and average throughput suitable for mobile phones and tablet devices. Low Power SC PHY layer is an extension of SC PHY layer with more focus on power reduction.
5) The MAC layer adds contention-based access period (CBAP) access, association beam forming training (A-BFT) access, service period (SP) access and announcement transmission interval (ATI) access. Due to possible change in antenna direction, the link maintenance is vital while using IEEE 802.11ad. For this purpose, the IEEE 802.11ad standard defines the Fast Session Transfer (FST) protocol [15].

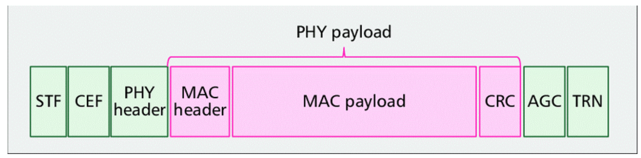

Fig. 5 IEEE 802.11ad packet structure [14]

Despite having different PHY layer designs, the packet structure is same with common preamble. IEEE 802.11ad uses 2.16 GHz bandwidth which is 14 and 50 times wider than IEEE 802.11ac and 802.11n respectively. Fig. 7 shows packet format for IEEE 802.11ad. The main elements are: short training field (STF), channel estimation field (CEF), PHY header, PHY payload and cyclic redundancy check (CRC). CEF can detect the type of PHY layer automatically. They might be appended by training and automatic gain control fields.

2.5 IEEE 802.11ac

There are three key features that makes very high through put (VHT) in IEEE 802.11ac possible [8]. Firstly, IEEE 802.11ac enhanced its service set to 8 at PHY layer. IEEE 802.11 WAVE-2 architecture enables an AP to send aggregated frames to multiple receivers by using multiple unit MIMO. Secondly, the data rate is enhanced significantly upto 33% by increasing number of bits to 8 from 6. The main disadvantage of this approach is requirement of higher Signal to Noise Ratio (SNR) for receivers to ensure reliable demodulation of symbols. This protocol uses 256 QAM modulation and with coding rates of 1/2, 2/3, 3/4, and 5/6. Thirdly, the bandwidth is increased with 5GHz. IEEE 802.11n have 20 MHz and 40MHz channels which is improved in IEEE 802.11ac with wider 80MHz and 160 MHz channels. Two 80MHz channels aggregate to define contiguous or non-contiguous 160MHz channels.

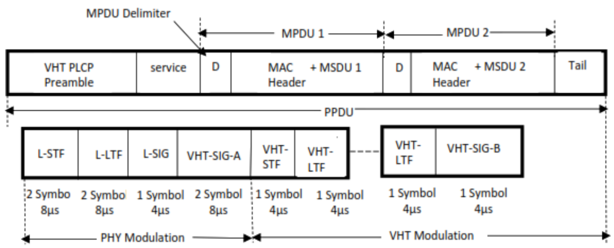

Fig. 6 PHY frame format of IEEE 802.11ac

- Data rate: 6.93 Gbps.
- Modulation formats: BPSK, QPSK, (16, 64, 256)
- QAM.
- Frequency band: 5.8 GHz ISM band.
- Transmission bandwidth: 20, 40 and 80 MHz.

The MAC frame format of IEEE 802.11ac is shown in Fig. 8. It includes MAC Protocol Data Unit (MPDU), Very High Throughput Physical Layer Convergence Protocol (VHT PLCP) and PLCP Protocol Data Unit (PPDU). The combination of PHY preamble and MPDUs makes PPDU. The PHY preamble consists of three address (L-STF, L-LTF and L-SIG) fields for the backward compatibility. Some newly introduced VHT fields are also part of this preamble.

2.6 IEEE 802.11 ax

This protocol adopts three main modifications to previous versions. Firstly, transmission rate is improved by using 1024QAM. The transmission rate is increased upto 9.6 Gbps theoretically. Secondly, robustness is enhanced in up-link transmission and outdoor scenarios by using dual carrier modulation. Thirdly, two coding schemes namely binary convolutional encoding (BCC) and low-density parity check (LPDC) are brought in [9].

In this protocol, 20MHz band is divided into 256 subcarriers and a sub-carrier division mechanism is also introduced. This mechanism improves spectrum efficiency and scheduling performance of OFDMA resources. This protocol enhances multiple access technology to ensure parallel transmission in spatial and frequency domain which provides a solid foundation to improve network efficiency. It improves channel utilization by enabling STAs and APs to transmit frames on non-continuous channels. The PPDU is enhances to support these PHY technologies.

The most important enhancement at MAC layer is an high efficient multiple access mechanism MU-MAC which enables multiple users (MU) to transmit UL (Up-link) or DL (Down-link) data concurrently. These mechanisms are also referred as UL MU-MAC and DL MU-MAC respectively. This mechanism has some rules to obey and depends time, space and frequency domain resources. The MU-MAC rely on MUMIMO and OFDMA based multiple access processes of this protocol. Previously, IEEE 802.11ac only supported DL MUMIMO. Another enhancement is cascaded MU MAC, which allows all transmissions to take place alternatively to improve efficiency. These enhancements reduce MAC layer overhead and improve spectrum efficiency.

The IEEE 802.11ax addresses frequency bands between 1 GHz and 6 GHz. It will also work in unlicensed 2.4 GHz band unlike IEEE 802.11ax. IEEE 802.11ax uses OFDMA instead of OFDM to allocate resources within given bandwidth. The PPDU frame format is shown in Fig. 9 for IEEE 802.11ax. IEEE 802.11ax introduced few changes in frame format to improve frequency, channel and medium utilization. It keeps the legacy preambles for backward compatibility. The L-LTF field is used to detect channel state information (CSI) in IEEE 802.11ax IoT devices. The frame is sent for SU or MU transmission if the modulo result is 1 or 2 respectively. A null data packet (NDP) frame is reserved for CSI exchange.

2.7 IEEE 802.1ah

The IEEE 802.11ah PHY layer inherits characteristics from IEEE 802.11ac [11]. Its channel bandwidth supports 1-2 MHZ as mandatory and 1-16 MHz normally. It can transmit upto one km or more due to low operating frequency and narrow bandwidth. It consumes less power as compared to state-of-the art wi-fi technologies. IEEE 802.11ah utilizes multiple coding and modulation schemes. BCC is mandatory coding scheme whereas LDPC is optional.

The MAC layer of IEEE 802.11ah meets the requirements of IoT networks such as target wake time (TWT), traffic indication map (TIM) segmentation, restricted access window (RAW) and fast association/authentication. TWT is the specific time or set of times defined by an AP for individual stations to access the medium. TIM places all stations in hierarchy in a well-defined manner. This structure reduces contention, conserves energy and manages large number of stations in effective way. RAW divides stations within basic services set into different groups and restricts channel access to a specific group of stations at a given time. It reduces contention.

There is possibility of collisions when power outage take place or an AP is deployed and multiple stations are trying

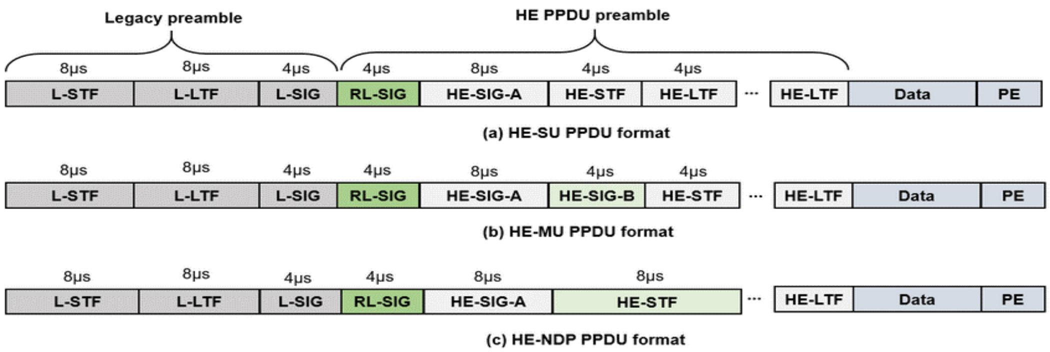

Fig. 7 IEEE 802.11ax PPDU frame format [10]

to associate simultaneously. The RAW mechanism improves throughput and reduce delay caused by collisions in this scenario. In power saving mechanisms, beacons trigger power saving (PS) station for the channel to wake up and be ready for transmission. TIM segmentation mechanism is introduced in IEEE 802.11ah to split information into several segments and transmit them separately. The power consumption reduces further for stations transmitting data rarely. APs can stay in power saving mode for longer time if TWT stations negotiate for time interval when AP should wake up to transmit. The long-distance communication network application for outdoor scenarios, supporting the IoT scenarios and works in a frequency band below 1 GHz. The physical layer defines the OFDM transmission for the 1 MHz channel to 16 MHz channel using CB technology, supporting MIMO and DL MU-MIMO technology. The MAC layer introduced the concept of Relay AP, TWT mechanism, energy saving mechanism based on Traffic Indication Map (TIM)STA, and non-TIM STA, and sectorized BSS technology.

Fig. 10 differentiates among legacy and short MAC headers. There are four fields in short frames. The duration, ID field, Quality of Service (QoS) and throughput fields are not included in short frame.

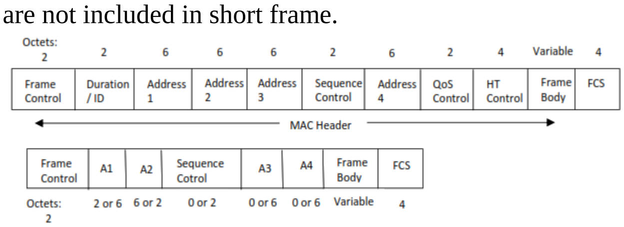

Fig. 8 Legacy MAC header (top) [13] and short MAC header (bottom) [12]

3. Comparison Of Ieee 802.11 Protocols

The evolution of IEEE 802.11 protocols is shown in Fig.11. It shows how the data rate, bandwidth and range changed in different versions of protocols. A detailed comparison of these protocols is provided in Table. II based on a MAC and physical layer parameters. The Short Interframe Space (SIFS) is time taken by wireless interface to receive frame and send back acknowledgment as a frame. It can be calculated as the difference in time when first symbol is received till the last symbol of response frame. SIFS and DIFS both are measured in microseconds. DIFS is acronym for DCF (Distributed Coordination Function) Inter-frame spacing.

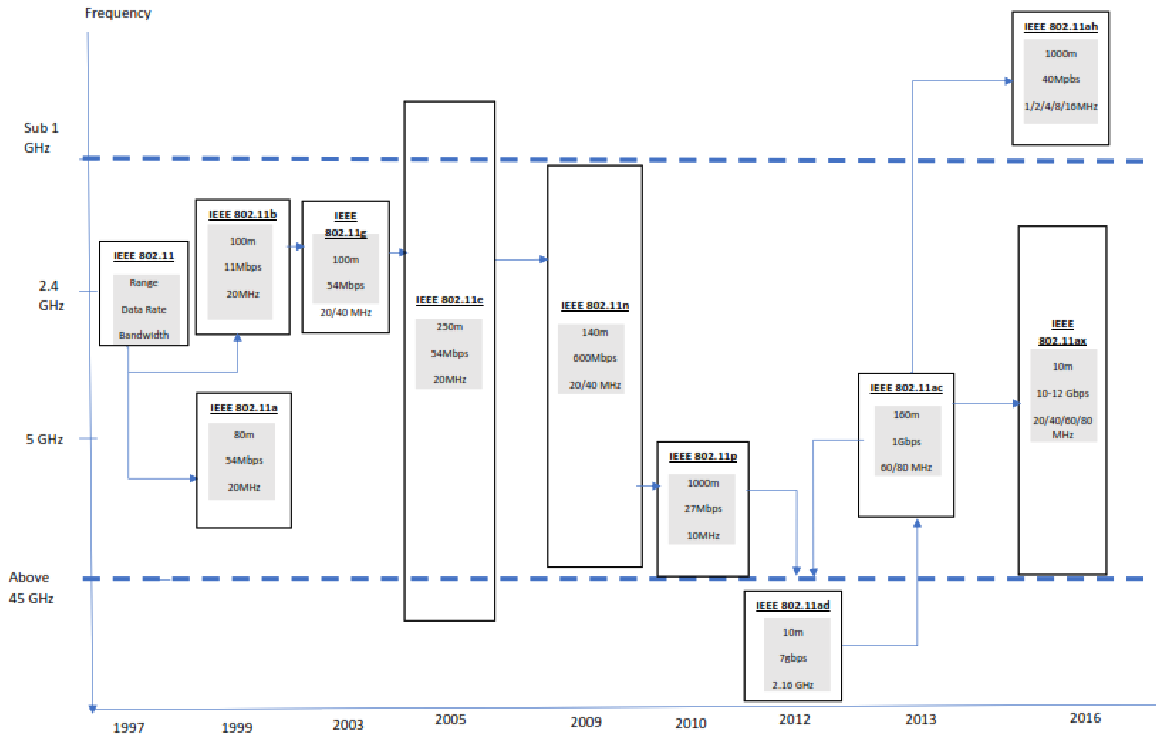

Fig. 9 The Enhancements in IEEE protocol parameters over years

Table 2: Comparision of IEEE 802.11 protocols

Parameters	IEEE 802.11e	IEEE 802.11n	IEEE 802.11p	IEEE 802.11ad	IEEE 802.11ac	IEEE 802.11ax	IEEE 802.11ah
SIFS (μs)	20	16	32	10	16	16	160
DIFS (μs)	60	34	58	50	34	60	264
Slot time σ (μs)	20	9	13	20	9	9	52
PHY header length	24 bytes	24 bytes	24 bytes	24 bytes	20 bytes	36bytes	30bytes
MAC header length	28 bytes	34 bytes	28bytes	28 bytes	36 bytes	24 bytes	14 bytes
CWmin	32	16	8	16	16	32	16
CWmax	1024	1024	1024	1024	1024	1024	1024
Propagation delay δ (μs)	1	1	1	2	1	1	1
PHY rate (Mbps)	36 Mbps	54.k (k=2, 3)	12 Mbps	385-4620 Mbps	6.9 Gbps	54 Mbps	650 Kbps
Retry limit	7	4	4	11	7	7	4-7
Modulation technique	OFDM	OFDM & MIMO	MIMO/frame Aggregation	OFDM	OFDM	OFDM	SC, OFDM
Max. Data Rate	54 Mbps	600 Mbps	27 Mbps	7 Gbps	1 Gbps	10-12 Gbps	40 Mbps
RF band	2.4 GHz, 5 GHz and 6 GHz	2.4 and 5 GHz	5.9 GHz	60 GHz	5 GHz	2.4 & 5 GHz	900 MHz
Channel bandwidth	20MHz	20 or 40 MHz	10MHz	2.16GHz	60 or 80 MHz	20,40,80,160 MHz	1,2,4,8 and 16 MHz
Range	250m	140m	1000m	10m	160m	10m	1km
Priority-based	✓	×	✓	×	×	×	×
Application	Real-time industrial environments without tight timing constraints	Video/voice streaming with wireless VoIP	Intelligent Transportation Systems (ITS) via cars	Cloud-enabled surveillance	Distribution of HDTV	Internet of Things (IoT) & Multimedia	Multimedia, smart/e-Health, IoT and M2M

It is the time delay for which sender wait after completing its back off, before sending RTS (Request to Send) package. Slot time is usually twice the time an electronic pulse takes to travel between two nodes. In each access category, upper CWmax and lower CWmin limits are set according to expected traffic flow. A wider window is needed heavier traffic. Propagation delay is time taken for signal head to travel from the sender to the receiver. It is calculated as the ratio between the link length and the propagation speed. MAC layer data header has information about type of frame and source/destination address of the frame whereas PHY header indicates start of frame, size and its sequence. The physical layer (PHY) rate is maximum speed at which data can move between a client and wireless router. The retry limit is the number of times the signal can re-try to send data to sender. The packet drop probability increases rapidly for small values of the retry limit and a large network size.

Radio frequency is any frequency within the electromagnetic spectrum associated with radio wave propagation. The channel bandwidth is the data rate of signal. A fast connection can be established using higher channel bandwidth. The other parameters included are modulation technique, maximum data rate, network range, applications and whether protocol is based on priority or not.

From Table. II, it is found that IEEE 802.11p and IEEE 802.11ah have highest range among other protocols. The physical header is longest for IEEE 802.11ax and length of MAC header is maximum for IEEE 802.11ac. The lower limit for contention window varies among 8-32 and its higher limit is 1024 for all protocols. The propagation delay is 1_s for all protocols except for IEEE 802.11ad where it is double. Almost all protocols supports OFDM modulation except IEEE 802.11p which supports MIMO only. IEEE 802.11ax and IEEE 802.11ad have high frequency bandwidth channels which consequently provides high data rates.

IEEE 802.11e was the first amendment to IEEE 802.11a/g to support delay-sensitive applications such as voice and video. It had more focus to allow laptop and cellular phones to join WLANs. IEEE 802.11n solved frame aggregation and security related issues. It has high throughput to handle even more stations. To support multi-stations throughput, IEEE 802.11ac was introduced having very high throughput WLAN with high density modulation to support high density of users. Next, IEEE 802.11ah allows the creation of large groups of sensors/stations and supports Internet of Things (IoT). It helps to achieve wider coverage range and higher data rates. IEEE 802.11ax is highly efficient and can operate in all ISM bands in 1-6 GHz range. The throughput speeds are 4 higher than IEEE 802.11ac for dense deployments. The new version introduces better power control to improve spectrum utilization.

The applications which involve thousands of devices per access point such as smart grid, environmental/agricultural monitoring sensors and lightning control, 802.11ah is a better choice for its extended range. IEEE 802.11ah perform better than IEEE 802.11ac and IEEE 802.11n due to its long transmission range and high throughput. For voice over WiFi applications of cellular networks, it is found that release n has the best throughput packets amounts, little delay time and lowest period of time for packet drop and retransmission attempts as compared to IEEE 802.11 standards ac/ad. For indoor environments based applications, IEEE 802.11ac performs better than IEEE 802.11n.

4. Conclusion

The IEEE 802.11 wireless LAN (WLAN) is the predominant technology for wireless access in local areas. To meet the increasing demand of technical world, there is a need to improve and revise standard IEEE 802.11 protocol. This survey provides overview of several standard IEEE 802.11 protocols. We have presented details of each protocols, its technical approach and a comparison between them based on a number of related parameters. It is noticed that earlier efforts focused on improving data rate at PHY layer and the trend eventually shifts to reduce the overhead in MAC layer. Both approaches increase overall efficiency.

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