WLAN New Technologies in IEEE 802.11

Dapeng Liu[1], Haiguang Wang[2], Xiaoming Peng[3], Stephen McCann[4], Ping Fang[5]*
Xiaodong Duan[6], Hui Deng[7], Lu Lu[8]

[1]China Mobile Research Institute, NO. 53, Xibianmennei Ave, Bejing, China, liudapeng@chinamobile.com[1], duanxiaodong@chinamobile.com[6], denghui@chinamobile.com[7], lulu@chinamobile.com[8]
[2]Huawei Technologies, China, Wang.Haiguang1@huawei.com[2], ping.fang@huawei.com[5]
[3]Institute for Infocomm Research, 1 Fusionopolis Way, Singapore, pengxm@i2r.a-star.edu.sg
[4]BlackBerry, 200 Bath Road, Berkshire, UK, smccann@blackberry.com

Abstract

Wireless Local Area Network (WLAN) technology has evolved very quickly in recent years. This paper introduces several new trends in the development of WLAN technology. Activities and progress in the standardization organization of WLAN, e.g. IEEE 802.11, are introduced. Next generation WLAN technology, a key enabling technology to make WLAN easy to use, together with low power and extended radio coverage are analyzed in this paper.

1. Introduction

WLAN has been widely deployed and has numberless applications. WLAN's PHY/MAC layer standard is specified by IEEE 802.11. The first release of the IEEE 802.11 specification was published in 1997 and several amendments were published afterwards. Recently, new trends of WLAN technology such as higher throughput, lower energy consumption, larger radio coverage, easy to use enhancement etc have appeared. Other organizations producing standards such as the Wi-Fi Alliance (WFA), Wireless Broadband Alliance (WBA) and the 3rd Generation Partnership Program (3GPP) also have activities related to WLAN. The WFA is an industry alliance to promote the industrial adoption of WLAN technology. It provides Wi-Fi™ certification services for the WLAN vendors. Recently, the WFA has developed several new WLAN certification programs such as Passpoint, Wi-Fi Direct etc. The WBA mainly works on the roaming specification for WLAN operators. In this paper, new trends of the development of WLAN technology are analyzed. The activities in IEEE 802.11, including IEEE 802.11ac, IEEE 802.11ad/aj, IEEE 802.11ai, IEEE 802.11ah, IEEE 802.11af and IEEE 802.11ax are reviewed.

2. Overview of WLAN New Technologies

The WLAN's throughput has been improved significantly in every generation of IEEE 802.11. The latest specification of IEEE 802.11ac was published in January 2014 with a throughput of 1Gbps. A new generation of WLAN technology which is aimed at the market requirement for the next five years is currently being studied within the IEEE 802.11ax (High Efficiency WLAN - HEW) group. IEEE 802.11ad operates at 60GHz frequency and can provide a theoretical almost 7Gbps throughput but has very limited radio coverage. Its typical use case includes high speed video connections between equipment inside a user's living room. There is another trend in the WLAN development which aims to provide greater radio coverage. IEEE 802.11af is the specification that defines this radio coverage enhancement feature. It re-uses television (TV) whitespace channels which are in the lower frequency bands, than typical WLAN, resulting in better radio coverage characteristics. Low power is another trend in the development of WLAN. IEEE 802.11ah provides low power consumption features and its use cases are primarily for wireless sensor networks. Another very important trend is the enhancement for ease of use. Such enhancement includes fast association optimization together with both network and service discovery. IEEE 802.11ai provides a fast initial link setup enhancement for WLAN and its use cases include very dense deployments, for example in subway stations. IEEE 802.11aq provides a new service discovery mechanism for WLAN and the external network. Use cases include the discovery of 3D Printers, VoIP services and other similar services. The terminal can determine whether a service is available in a WLAN before associating to it.

3. High Throughput and High Efficiency

978-1-4673-5225-3/14/$31.00 ©2014 IEEE

Among the various the IEEE 802.11 standard amendments, a few of them are focusing on improving the air interface throughput. These amendments are IEEE 802.11a/g/n/ac/ad and the most recent one, IEEE 802.11ax, which is still in the planning stage at the moment.

The IEEE 802.11a/g/n air interface amendments have been in use for many years and now are being gradually phased out and are being replaced by the most recent very high throughput amendment, IEEE 802.11ac. It was natural evolving step to further improve the throughput by expanding the channel bandwidth from 40Mhz to up to 160MHz in the 5GHz carrier frequency. Compared to 11n, not only the throughput has been improved to 1Gbps, but also the Access Point (AP) is capable of support multiple users simultaneously through Multi-User MIMO.

Comparing the legacy IEEE 802.11a/g/n technologies, the improvement of the IEEE 802.11ac peak rate is achieved by integrating various advanced technology at the physical (PHY) layer. This paper will explain each of them in turn. Firstly, IEEE 802.11ac expands the maximum supported bandwidth by four times, from 40 MHz to 160 MHz. Comparing it to the legacy 20 and 40 MHz channel supported by a station (STA), with IEEE 802.11ac, the STA can now support 20, 40, 80 and 160 MHz channels. This expansion of the supported maximum channel bandwidth allows IEEE 802.11ac to increase the transmission rate by 4 times without even considering other technologies. Secondly, the IEEE 802.11ac physical layer further includes two more high order modulation and coding rates: 256 QAM with a 3/4 coding rate and 256 QAM with a 5/6 coding rate. The highest modulation and coding rate supported previously was 64 QAM with a coding rate of 5/6. Therefore the highest achieved modulation and coding rate is improved by 33%. Multiple Input Multiple Output (MIMO) plays an important role in improving the transmission rate of IEEE 802.11 devices. MIMO was introduced in the IEEE 802.11 system by the IEEE 802.11n amendment, for which a maximum of four antennas are supported. With IEEE 802.11ac, the maximum number of antennas supported by a STA is 8. For a pair of communicating STAs, the maximum antenna configuration supported is 8x4 while in IEEE 802.11n, the number was 4x4. Another new feature introduced to the IEEE 802.11 system by the IEEE 802.11ac amendment is the downlink multi-user MIMO (MU-MIMO). With this new technology, an access point (AP) is able to transmit to a few devices, up to four, at the same time. It is the first time that an IEEE 802.11 system can support one to many unicast communications simultaneously.

The IEEE 802.11ac amendment has been formally approved by the IEEE Standards Association (IEEE-SA) in the 2013 and now it is public available. Chip-sets and products that support IEEE 802.11ac were already available off the shelf, even before the amendment had been approved by the IEEE-SA. Gradually, more and more notebook and mobile devices supporting IEEE 802.11ac have been shipped to end users since last year.

As the IEEE 802.11ac amendment has been completed successfully and now receives an overwhelming welcome from the market, its success story encourages the chip-set vendors and the technical gurus from various parties, such as telecom equipment manufacturers, vendors, mobile device makers, service providers and academic researchers, to commence the next IEEE 802.11 air interface technology following on from IEEE 802.11ac. Starting in May 2013, a group for next generation WLAN technology (HEW) has been setup within the IEEE 802.11 working group, which is now called IEEE 802.11ax. The major topic faced by this group is how to further improve the air interface transmission rate to meet the rapid increase of mobile internet traffic, the majority of which is video traffic, and in addition to also consider the large scale and high density deployment of APs in sites such as stadia or airports. The group has discussed various technologies such as OFDMA, simultaneous transmission and reception, HARQ, massive MIMO, and the better support of multicast transmission.

Different from 802.11ac amendment, IEEE 802.11ad is another amendment to provide an even higher air interface throughput up to almost 7Gbps at 60GHz millimeter wave band (from 57GHz to 66GHz). 802.11ad was published in January 2013. Due to the high frequency characteristic of 60GHz, IEEE 802.11ad has short-range radio coverage typically around several meters. Its main applications focus on data synchronization among laptop and personal devices, wireless display and wireless I/O. Like all other IEEE 802.11 amendments, the IEEE 802.11ad amendment also has backward capability which means it can seamlessly switch traffic to the 2.4GHz and 5GHz bands when it is necessary. Another key difference is that 11ad MAC enhancement creates a new mode called Personal BSS (PBSS) mode. This mode allows ad hoc network similar to the IBSS, in which a STA assumes the role of the PBSS central point (PCP) and only the PCP transmits beacon frame. Furthermore, 11ad amendment creates reservation-based service which is not available for 11n/ac amendment, but critical for real-time video streaming type of applications.

Due to the specific spectrum regulation of the 60GHz (from 59GHz to 64GHz) and new spectrum allocation at the 45GHz (from 42.3-47GHz and 47.2-48.4GHz) in China, the IEEE 802.11aj group was formed in Sept 2012 to define a

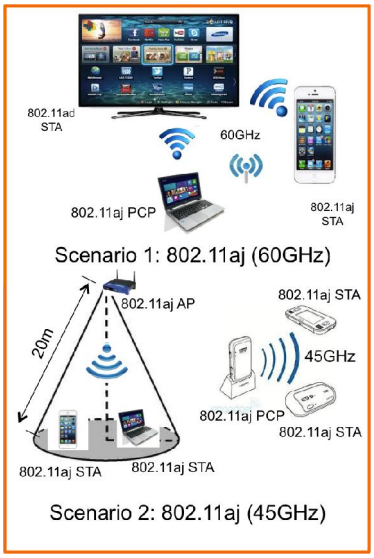

Figure 1 802.11aj Scenario

further amendment to enable wider range of application scenarios that requires larger coverage area and lower-power consumption, e.g. mobile phone and Tablet (figure 1). Similarly, the amendment maintains the 802.11 user experience.

4. Ease of Use

WLAN has cost-effective benefits compared to a cellular network, but from the user experience perspective, the cellular network provides an automatic and seamless network connection experience, in other words the user does not need to manually select cellular network. For a WLAN however, the user normally needs to manually select an SSID to connect to a WLAN. IEEE 802.11u was developed to solve this problem by providing a network discovery mechanism before association. IEEE 802.11u becomes the key technology of WFA's Passpoint program. Together with other enhancements, Passpoint can provide a cellular like automatic network discovery experience. Furthermore, WLAN service discovery enhancement is currently being developed by the IEEE 802.11aq working group. As an example of WLAN service discovery, the WLAN terminal can discover that a 3D printing service is available in a WLAN even before actually association to that WLAN.

Another aspect of WLANs that affect the user experience is the association time delay. The station needs to scan the channel first to determine which channel it will use. After that, it will need to do authentication and also request an IP address, together with other configuration parameters. These steps normally will involve several message roundtrips and increases the link set up time. Reducing the link set up time will improve the user experience especially in a dense deployment scenario. One typical use case example is the crowded subway station where lots of users are trying to associate with the subway's WLAN access point simultaneously. The IEEE 802.11ai working group was formed to tackle this problem. The working group's goal is to reduce the link setup latency to less than100 milliseconds. With this optimization, many novel applications become feasible. For example, the uses who sit in a bus can quickly connect to the WLAN access point in the road side to refresh his/her social network. IEEE 802.11ai optimizes the link set up time in several ways, the first of which is to reduce the scan time whereby both passive and active scan times are optimized. The second aspect of IEEE 802.11ai to reduce the link set up time is to reduce the authentication and higher layer protocol setup delay. A new authentication mechanism called FILS (Fast Initial Link Setup) is introduced. In the current IEEE 802.11 standards, higher layer protocol set up, such as IP address allocation is typically done after association. However with IEEE 802.11ai, the higher layer protocol set up occurs during the association and/or re-association, so that the link set up time is reduced.

5. Low Power and Enhanced Radio Coverage

IEEE 802.11 technology is not just being developed to achieve high data transmission rates. It is also customized to meet various requirements for applications. Recently in 2011, a new group was set up to define a standard amendment for low power and low rate wireless sensor networks. As the target transmission frequency is below 1 GHz the group is also named as Sub-1GHz group. The channelization is different from that of the 2.4 GHz and 5GHz bands, due to the fact that spectrum resources below 1 GHz are scarce and precious, since with the same transmission power the radio signal can reach further compared to the conventional WLAN higher bands. The available Sub-1GHz channels are very narrow, varying from a few MHz to about 26 MHz. Considering the scarcity of available spectrum and the low rate of transmission required by sensor networks, together with service provider requirements for data offloading, the channel bandwidths supported by Sub-1GHz technology are 1, 2, 4, 8 and 16 MHz. With such a channelization scheme, low power sensor networks can use a narrow band channel bandwidth such as 1 MHz. On the other hand, high speed throughput channel users can use a 16 MHz bandwidth. To support the required features such as large scale sensor networks, a long transmission range (up to 1 kilometer), and support for low power devices etc, a few new features have been introduced at both the PHY and medium access control (MAC) layer.

At the PHY layer, besides the new channelization scheme, a new modulation and coding scheme (MCS10) with repetition 2, has been introduced. The legacy BPSK with 1/2 code rate is further repeated one more time at the PHY layer, as this helps to increase the receiving gain by about 3dB and thus increase the transmission range. Another significant change at the PHY layer is that the symbol duration becomes 40 µs, 10 times the duration of symbols defined for IEEE 802.11a/g/n/ac. Various MAC and PHY layer timing parameters have been extended too, for example, the Short Interframe Space (SIFS) has been increased by 10 times to 40 µs.

IEEE 802.11ah technology is required to support up to 6000 stations per network. To meet this requirement at the MAC layer, the Traffic Indication Bitmap (TIM) has been extended to support more than 6000 nodes. To solve the problem that many stations may try to access the network at the same time, a Time Division Multiple Access (TDMA) based channel access mechanism is supported by the IEEE 802.11ah MAC layer. Channel access is not just based on a simple contention scheme. Channel access now needs to follow a certain schedule arranged by the AP. The scheduling

information is contained in the Restricted Access Window (RAW) element and broadcasted to all devices within the network via a beacon. The TDMA method can reduce contention among a large number of stations significantly. Another challenge issue faced by IEEE 802.11ah technology is the uncontrolled contention of many authentication requests as a large scale network boots up, which cannot be solved by the RAW as it can only be used by a station after association. Two authentication control mechanisms, one centralized and one distributed, have been introduced to solve the issue.

Many sensor nodes are low power devices utilizing battery power as an energy resource. To cut down the energy consumption, the sensor nodes within the IEEE 802.11ah network are allowed to sleep for a few days before waking up and receiving signals from an AP, which is a much longer time than that allowed by legacy systems. As the transmission rate can be very low (for example, 150 Kbps using the lowest rate), the transmission time incurred by management and control frames become significant, so that to cut down signaling overhead, many control and management frames are being reduced to a Null Data Packet (NDP). That is, much of the information previously contained in MAC frames is now put into a PHY layer signaling field, for example, the acknowledgement (ACK) frame. The IEEE 802.11ah standard amendment is expected to be finished in the 2016 and many chip-set vendors are now planning to develop the chip-sets for smart home devices, metering devices or mobile phones with data offloading.

IEEE 802.11af is another amendment that can provide larger radio coverage. It allows the secondary re-use of the TV whitespace spectrum (typically below 1 GHz) and can provide long-range radio coverage. Due to the long-range feature of IEEE 802.11af, it is also referred to as Super Wi-Fi. TV whitespace are the unused channels of the TV broadcasting service in any specific geographic location. To identify available TV whitespace channels in a location, IEEE 802.11af defines an interface to a TV whitespace database, which is coordinated on a regional basis. It also defines a secured signaling protocol between an access point and a station to protect any primary services on the channel.

6. Conclusions

This paper introduces the current trends in the development of WLAN technology. In summary, the WLAN's usage scenario has been extended and the corresponding PHY/MAC layer optimization is being developed to meet the requirement of this scenario. The extended usage scenario includes wireless sensor networks and short-range high-speed transmission for multimedia traffic. In the meantime, long-range radio enhancements are being developed for cellular traffic offloading and better radio coverage. Further more, the optimization for ease of use features is also being developed to provide a smoother and a better user experience. In addition, from the spectrum utilization perspective, there are two different trends: the first is the increase in WLAN frequency operation from 2.4GHz to 5GHz then to 60GHz and the other is the decrease in WLAN frequency operation to sub 1 GHz frequencies for extended radio coverage. WLAN has experienced very successful development in the past years and will continue to evolve in the future.

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