AUTHOR(S): Hareesh Babu and Paulosekutty Simon

802.11n: Next Generation WLAN

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Introduction

A wireless LAN (WLAN or WiFi) is a data communication system designed to provide location-independent wireless network access between devices by using radio transmission methods instead of a cable infrastructure as in the classical LAN. The original 802.11 standard for WLAN was ratified by the Institute of Electrical and Electronics Engineers (IEEE) in the year 1997. This version of 802.11 provides for 1 Mbps and 2 Mbps data rates and a set of fundamental signaling methods and other services. Subsequently, it has evolved into a series of standards through 802.11b, 802.11g, 802.11a and now 802.11n. Like any other IEEE 802 standard, the 802.11 series also focuses on the bottom two levels of the ISO model, the Physical Layer and the Data Link Layer.

The objective of the document is to provide an overview of the IEEE 802.11n WLAN technology, describe new techniques used to achieve greater throughput and range, and identify applications, products, and environments that will benefit from the technology. It also gives some insight into the implementations aspects based on the prior implementation exposure.

Overview and Architecture

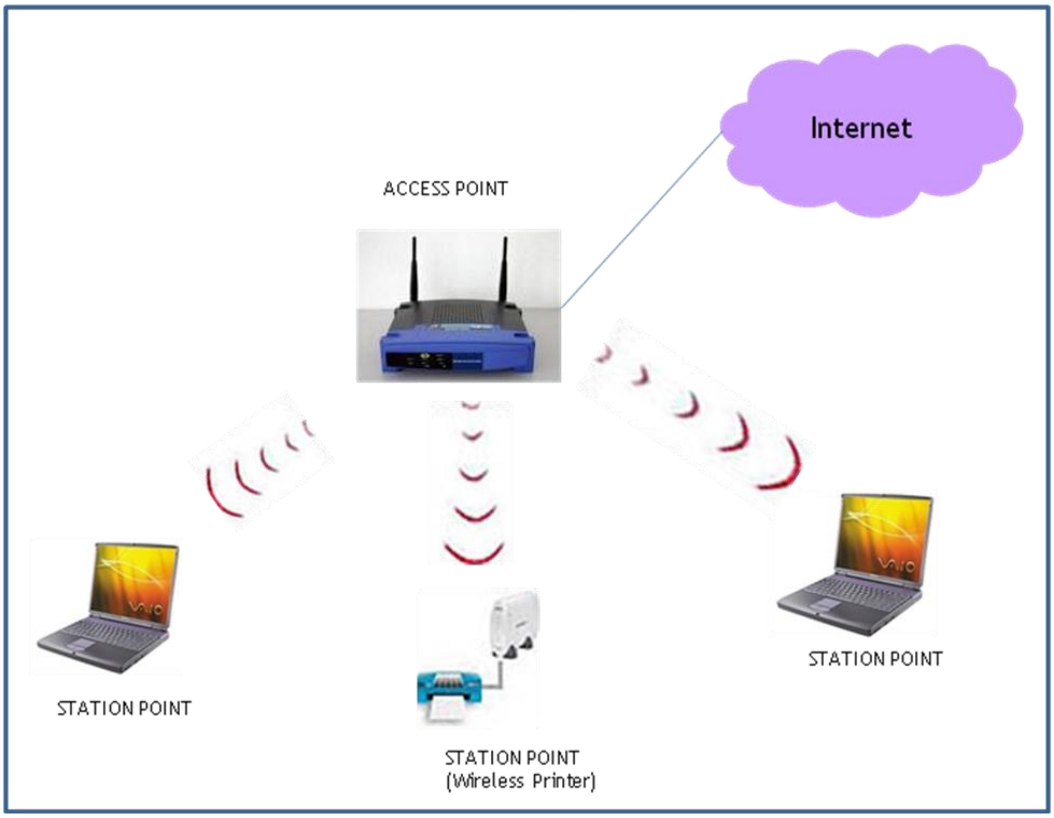


Fig: WLAN Network Diagram (Infrastructure Mode)

Demand for wireless LAN hardware has experienced phenomenal growth during the past several years, evolving quickly from a novelty into a necessity.

Thus far, the demand has been driven primarily by users connecting notebook computers to networks at work and to the internet at home, coffee shops, airports, and other gathering places. As a result, Wi-Fi technology is most commonly found in notebook computers and internet access devices like routers and DSL/cable modems. In fact, more than 90 percent of all notebook computers are now shipped with built-in WLAN.

The increased use of Wifi among various users in "hot spots" as well as applications demanding higher data rates has pushed for systems with higher throughput, better coverage and more reliability. This has led to the development of the new standard 802.11n. These goals are addressed by 802.11n by improving the radio access technology at PHY level as well as by making the MAC more efficient by reducing the overheads.

The new generation of IEEE 802.11n-based Wi-Fi technology is expected to pick up significant market momentum in the coming years. Draft 2.0 of the 802.11n amendment to the standard is now widely considered stable, with only minor changes from draft 1.0.

Tests conducted by vendors and independent test labs show that draft 802.11n products reach up to twice as far and are as much as five times faster than the legacy 802.11a/b/g technology. The currently available draft 802.11n technology can comfortably cover a typical house with sufficient bandwidth to support video, gaming, data and voice applications.

In the enterprise environment, 802.11n is expected to support mission-critical applications with the throughput, QoS and security capabilities comparable to Ethernet.

Today, hardware that conforms to the 802.11n draft is becoming available, so consumers can begin building high-speed wireless networks in anticipation of the standard, while ensuring interoperability at high speeds and still supporting their existing WLAN hardware.

While the legacy networks operate in a 20 MHz channel, 802.11n additionally defines the use of 40 MHz channels with up to 4 spatial streams per channel. The IEEE 802.11n draft 2.0 certification program of WiFi Alliance presently confines the use of 40 MHz channels to the 5 GHz band. With 4 spatial streams in a 40 MHz channel, the maximum possible transmission data rate is 600 Mbps.

Current products can transmit at up to 300 Mbps using 2 spatial streams in a 40 MHz channel. Use of multiple spatial streams and 40 MHz channel is optional in 802.11n draft 2.0.

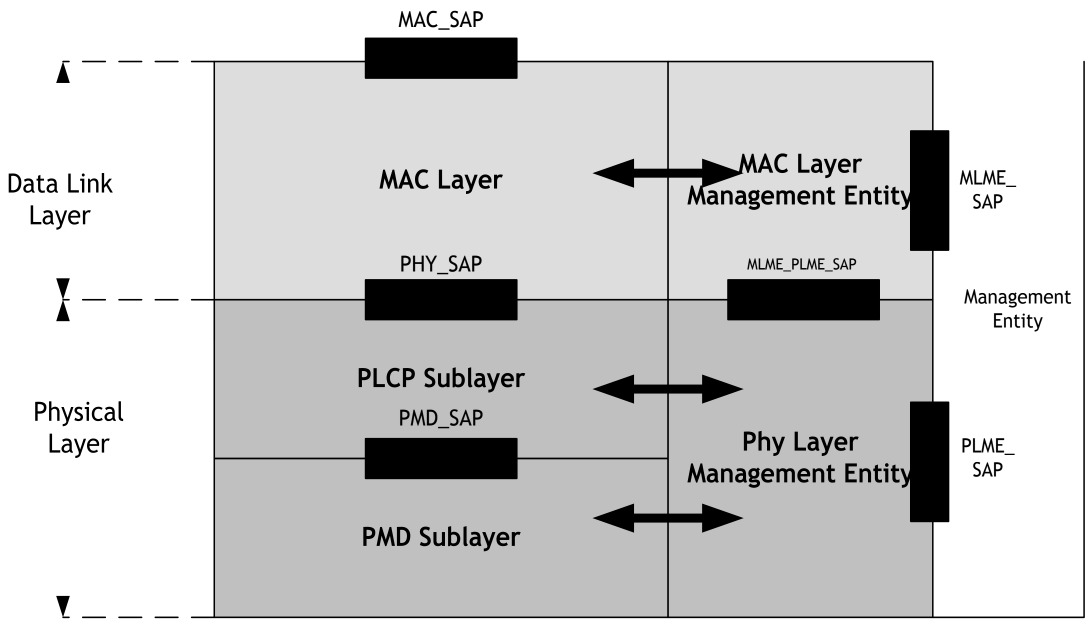


Fig: IEEE 802.11 Protocol Stack

Key Features and Benefits of 802.11n

The emerging 802.11n specification differs from its earlier standards in that it provides for many optional modes and configurations that dictate different maximum data rates. This enables the standard to provide baseline performance parameters for all 802.11n devices, while allowing manufacturers to enhance the capabilities to accommodate different applications. With all options enabled, 802.11n could offer data rates up to 600 Mbps. But WLAN hardware does not need to support all options to be compliant with the standard.

In comparison, every 802.11b-compliant product must support data rates up to 11 Mbps, and all 802.11a and 802.11g hardware must support data rates up to 54 Mbps.

Overall enhancements can be broadly divided into Radio/PHY enhancements and MAC enhancements.

Radio/PHY Enhancements

Radio enhancements is primarily centered around diversity and the related MIMO technology. The idea is to improve the SNR at the receiver and translate this into higher throughput and range.

MIMO Improves Performance

One of the most significant components of the draft specification is Multiple Input Multiple Output, or MIMO. MIMO makes use of a radio-wave phenomenon called *multipath*. Transmitted signals reflects off various objects, finally reaching the receiving antenna multiple times through different routes/paths and at slightly different times. If uncontrolled, multipath actually distorts the original signal at the receiver side, causing Inter Symbol Interference (ISI), making it more difficult to decode the information and thus degrading the performance. MIMO harnesses the multipath with a technique known as *space-division multiplexing*. ie. MIMO makes use of the multipath in a constructive way. The transmitting WLAN device splits a data stream into multiple parts, called spatial streams, and transmits each spatial stream through separate antennas to corresponding antennas on the receiving end. The current 802.11n draft provides for up to four spatial streams, even though compliant hardware is not required to support four.

Doubling the number of spatial streams from one to two effectively doubles the raw data rate. There are trade-offs, however, such as increased power consumption and, to a lesser extent, cost. The draft-n specification includes a MIMO power-save mode, which mitigates power consumption by using multiple paths only when communication would benefit from the additional performance. The MIMO power-save mode is a mandatory feature in the draft-n specification.

MIMO Enhancements

There are two features in the draft-n specification that focus on improving MIMO performance: *Beam-forming* and *Diversity.*

Beam-forming is a technique that focuses radio signals directly on the target antenna, thus improving the SNR at the receiver. This translates to higher range and/or higher radio data rates. It also helps to improve the overall system performance by limiting the interference. Beam-forming is achieved by means of smart antenna system with an array of antenna elements. By controlling the transmit signal at each of these elements, it is possible to direct/focus most of the radiated signal towards the intended target.

Diversity exploits multiple antennas by combining the outputs or selecting the best subset of a larger number of antennas than required to receive a number of spatial streams. This is important because the draft-n specification supports up to four antennas, so devices will probably encounter access points built with a different number of antennas. A notebook computer with two antennas, for example, might connect to an access point with three antennas. In this case, only two spatial streams can be used even though the access point itself may be capable of three spatial streams. With diversity, surplus antennas are put to good use. The device with more antennas uses the extra ones to operate at longer range. For example, the outputs of two antennas may be combined to receive one spatial stream to achieve a longer link range. The concept may be extended to combine the outputs of three antennas to receive two spatial streams for higher data rate and range.

Diversity is not restricted to 802.11n or WLAN as such. It can be used to improve any type of radio communication. In fact, diversity has typically been implemented in some existing 802.11a/b/g systems through selection of the better of two antennas.

Increased Channel Size

802.11n draft defines the use of both 20MHz and 40MHz Channels. Data rate is straightaway doubled by using the doubled channel size. In fact it achieves better than double by making use of the fact that the channel is no longer two 20MHz channel, but a single 40 MHz channel. This meansthat there is no need to provide huge guard band at the bottom of the top 20 MHz channel and top of the bottom 20MHz channel to avoid interference. Instead these otherwise reserved areas can be used to send more information, thus achieving more than just the double rate.

The trade off here is that fewer channels will be available for other devices. In the case of the 2.4-GHz band, there is enough room for three non-overlapping 20-MHz channels. But a 40-MHz channel does not leave much room for other devices to join the network or transmit in the same airspace. This calls for more intelligent and dynamic management of the resources to ensure that the 40-MHz channel option improves overall WLAN performance by balancing the high bandwidth demands of some users with the basic need of other users to remain connected to the network.

Improved OFDM

802.11n defines more subcarriers within 20MHz channel compared to 802.11g/a. 802.11n has 52 sub-carriers instead of 48. This improves the maximum attainable data rate from 54 Mbps to 65 Mbps for a single stream in 20MHz.That means, for 40 MHz, 802.11n will have 108 sub-carriers, considering the reuse of guard band of the adjoint 20 MHz channels, giving further advantage.

Another improvement done in the OFDM system is to reduce the guard interval between OFDM symbols. Guard interval is used to manage the effect of ISI due to multipath. Typically 800ns is the defined guard interval. 802.11 has defined an optional mode for a reduced guard interval of 400ns for environments that doesn't have severe multipath issues. This means the useful symbol time is reduced from 4 microseconds to 3.6 microseconds. This again translates to a higher data rate.

MAC Enhancements

The PHY level improvements discussed so far has increased the possible data rates to some level. In practice, the effective throughput is also a function of the efficiency of the MAC protocol like contention process. Also there are overheads like interframe spacing, ack mechanism etc.

Aggregation

To reduce the fixed overheads in every frame, such as radio preamble, radio header and MAC header, 802.11n introduced the concept of frame aggregation. Using this, two or more frames can be put together in one frame for transmission. Two types of aggregations are defined, MSDU aggregation and MPDU aggregation. While both have advantages,to accommodate these large aggregated frames, the maximum allowed frame size is increased to 64KB.

One limitationor constraint for frame aggregation is that all the constituent frames aggregated into one single transmission should be intended for the same target, ie the same mobile client or the same access point.

To support the aggregation feature, a block acknowledgement mechanism is also defined and optimised in 802.11n. This also opens up a selective retransmission mechanism that can provide some improvement in the effective throughput.

Reduced Interframe Spacing

802.11n also provides an efficient mechanism to transmit a stream of frames to different destinations by reducing the interframe spacing. A new value, RIFS reduces the dead time between frames significantly thus increasing the effective utlilization of the transmit opportunity. A burst of frames can be transmitted within a transmit opportunity, the frames separated by this basic RIFS, without the need to perform the random backoff between transmissions.

Apart from these major features, 802.11n also defines an additional mechanism for power saving like Spatial Multiplexing Power save and Power Save Multi-Poll.

802.11/802.11n MAC: Implementation Aspects

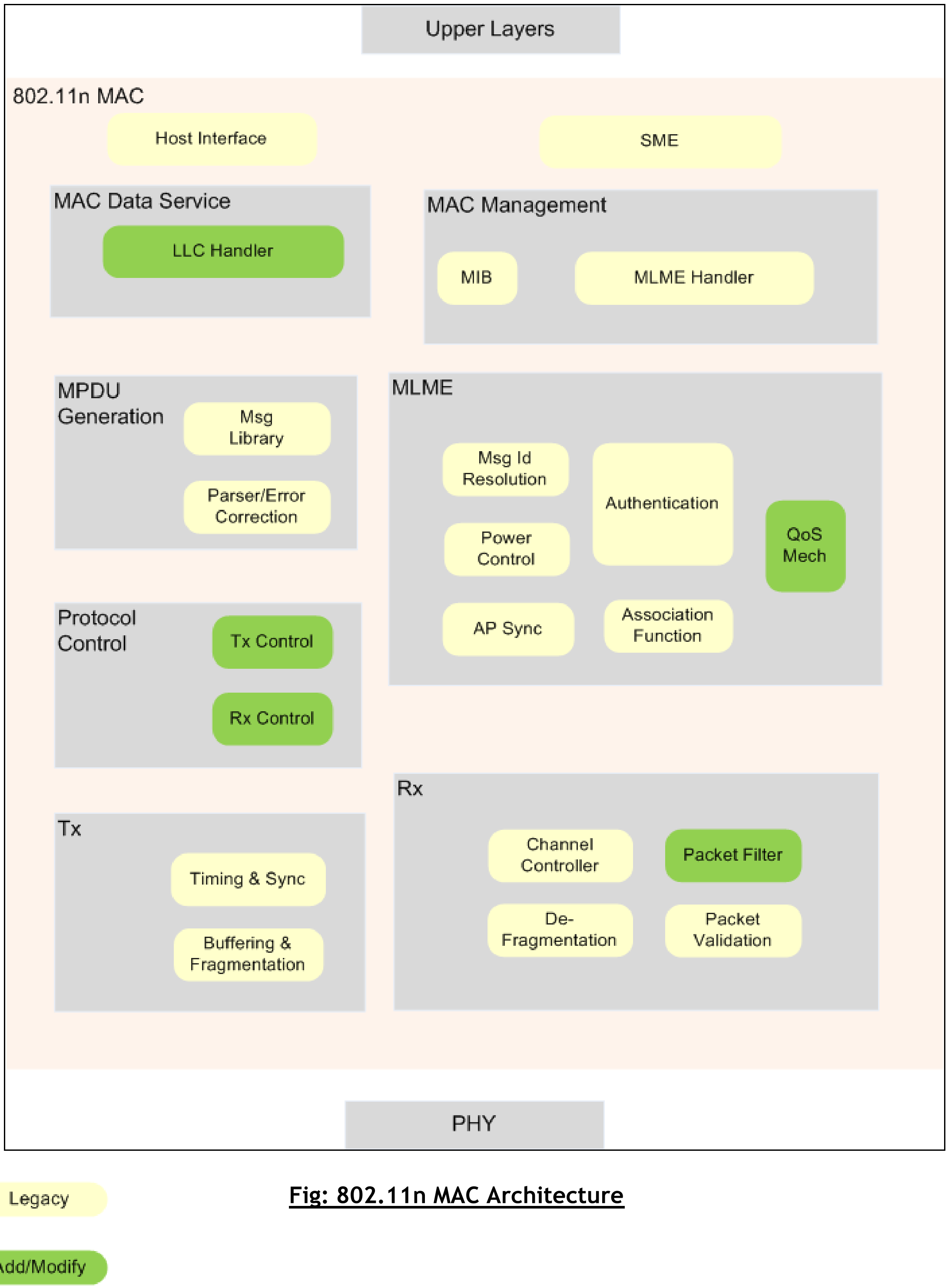


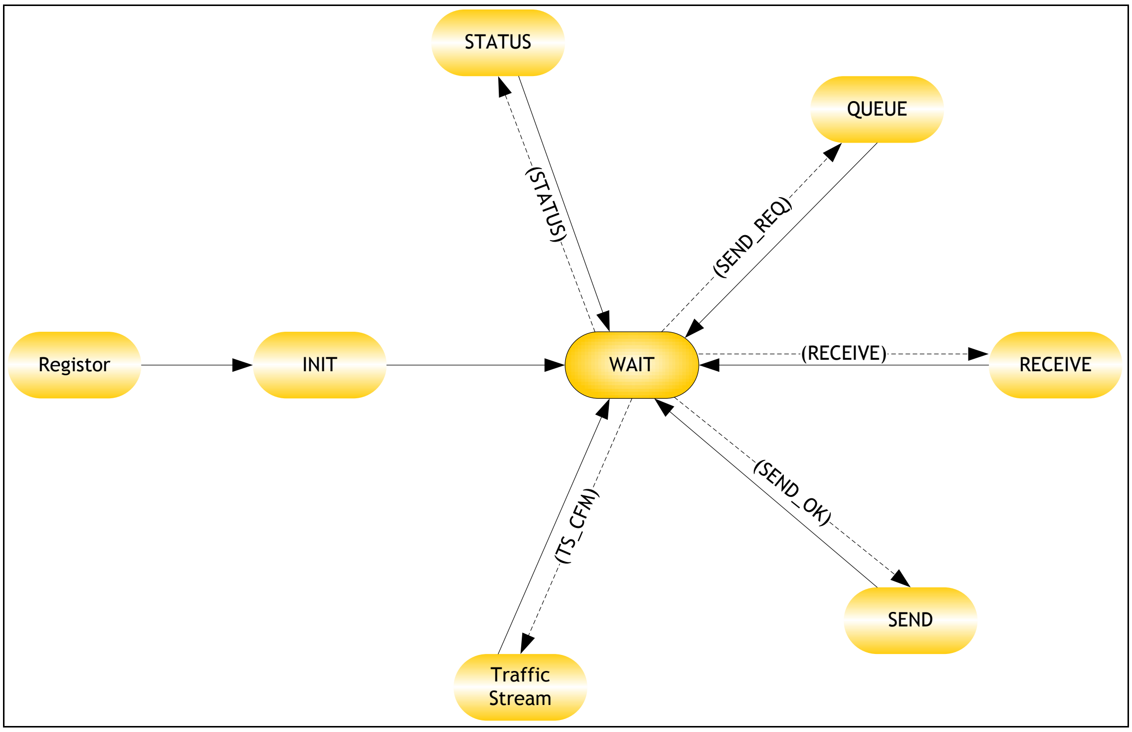
Fig: 802.11n MAC Architecture

Note: Modules Indicated in green are either new or modified functionalities to support the added features in 802.11n.

LLC (Logical Link Control) Handler

A-MSDU aggregation allows several MAC Service Data Units (MSDU) to be aggregated into a single A-MSDU. LLC Handler transfers the QoS Data to/from upper layer and stores it in priority queues.

Through A-MSDU aggregation, the performance of 802.11n achieves high throughput and high channel utilization. But, in a noisy environment, the performance of A-MSDU aggregation gets degraded for high data rates.



<u>**Fig: Typical LLC Handler State Machine**</u>

QoS Mechanism

QoS (EDCA) supports the CSMA/CA-based medium access scheme by introducing priority based medium access for different traffic categories. In order to allow prioritized and separate handling of traffic, 802.11n QoS mechanism uses the eight IEEE 802.1D User Priorities (UP). Traffic from these 8 UPs is mapped to 4 different Access Categories (AC): for Voice (AC_VO), Video (AC_VI), Best-Effort (AC_BE), and Background (AC_BK) traffic. Each Access Category is assigned a single transmit queue.

To achieve the prioritized QoS guarantee, the 802.11n EDCAF (Enhanced Distributed Channel Access Function) provides the distinguished services by configuring the different QoS parameters (AIFSN, CWmin, CWmax, TXOP_Limit, PF) to different access categories (ACs).

AIFSN is the number of time slots allotted to a given AC that defines the waiting period before starting the back-off procedure. CWmin and CWmax are the values for the contention window for the back-off procedure. PF (Persistence Factor) determines how to increase the contention window after collision. Txop is the duration of each AC transmission.

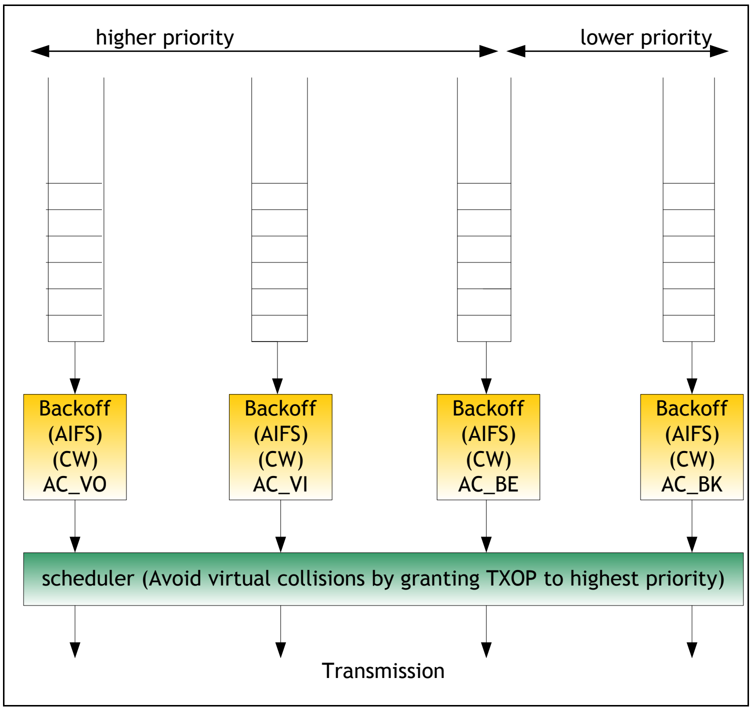


Fig: QoS Based Queue Management

TX Control /Rx Control / Packet Filter

This block is the heart of the MAC. All the control functions in 802.11n DCF are implemented in this block. It has two processes, one for the transmit path (Tx Control) and one for the receive path (Rx Control).

Tx Control controls the sequence of events involved in initiating a session. If the the packet size (MPDU/A-MPDU) is extremely long (more than RTS threshold value set by MIB), then Tx Control will send the RTS and wait for the CTS from the destination. When the CTS is received within the specified interval, Tx Control waits for SIFS seconds and sends the actual data and waits for the ACK. If the ACK is received within the specified time, the session is completed and Tx Control goes to back-off before handling the next packet in the queue.

Rx Control is responsible for the sequence of events in responding to a session. When the RTS packet is received, Rx Control sends the CTS packet back after SIFS seconds if NAV is zero. When the data packet is received, the ACK packet will be sent back after SIFS seconds.

In 802.11n, when A-MPDU packet is received, either immediate or delayed Block-ACK will be sent. In case of Block- ACK Setup, ADDBA response will be sent for ADDBA request. DelBA response will be sent for DelBA request frame. In Case of Direct Link Setup, DLS response will be sent for DLS request frame and DLS Teardown will be sent for DLS delete frame.

Packet Filer is responsible for removing duplicate packets in case of A-MPDU. It uses tuple cache to store the destination addresses, sequence numbers and fragment numbers of A-MPDU packets for constructing compressed block ACK. The packet filter de-aggregates the packet and forwards it to the upper layers based on sequence number. If there is an error in the MPDU /A-MPDU packets, those packets will be dropped and the Tx Control process will be notified after EIFS seconds.

Market Projections

802.11 (WiFi) solutions have achieved both interest and critical success around the globe in a relatively short period of time. Its resounding success in terms of equipment sales and usage has led to numerous incarnations aimed at improving throughput and reach for both consumers and enterprises. WiFi is now positioned to reach even higher throughput levels and wider reach with the upcoming 802.11n standard.

The 802.11n standard that is being supplied by vendors also enjoys significant user demand as content and applications require more robust pipes and larger footprints. Form factors from traditional laptop computers and cell phones are moving to TV sets and other appliances in households and business tools in enterprises.

According to research firms, 802.11n Wi-Fi technology will dominate the wireless HD video market, at least for the next several years. Three other technologies competing in this space are Wireless Home Digital Interface (WHDI), Wireless HD (WiHD) and Ultra Wide Band (UWB).

WHDI and WiHD are being promoted by various consumer electronics manufactures through special interest groups. But they are relatively new, expensive, and power-hungry, which is generally not an attractive scenario for quick market success.

The primary drawback of 802.11n in this space is that it requires codec technology on both ends to transmit HD video, whereas, neither of its primary competitors, WHDI and WiHD, requires codec.

802.11n Expertise at L&T Infotech

- Very good exposure to WLAN development and testing
- Expertise in driver (NIC/CF/SD/PCMCIA) development and porting across various OS like Linux, windows, Windows Mobile, Android etc.
- Expertise in Atheros, Marvell, Intel and Broadcom platforms and MadWiFi drivers
- In-house VoWiFi test lab for interoperability testing of WiFi enabled handsets

Focus Area:

- WLAN Stack & Driver development for
  - Access Point
  - Station / Mobile / Customized devices
- Enhancements and Feature additions based on latest IEEE 802.11n drafts and releases
- Development of Test Cases, Test Automation suites and IOT
- Integration and testing of 802.11i RADIUS Authentication for Wi-Fi Topology.
- Development of Simulators on various operating systems.

Some of the IEEE 802.11 Wireless LAN projects L&T Infotech has been involved:

- Design and development of Rear View Wi-Fi camera for Japanese Tier 1 automobile company for their SUV.
- 802.11n draft 2.0 compliant MAC development on Marvell platform.
- Test Suite development for complete automation of Wi-Fi Alliance certification.
- Development of WLAN GUI Connect manager for a Fab-less chipset vendor

Conclusion

As we have seen, 802.11n is focusing on improving the throughput, reliability and coverage by addressing both the radio transmission technology as well as the MAC protocols. While the radio improvements are primarily around MIMO and related techniques, the MAC improvements are focused on the minimizing the fixed overheads.

With all the optional modes and all the possible combinations of features, the corresponding data rates are quite impressive. The current 802.11n draft provides for 576 possible data rate configurations. In comparison, 802.11g and 802.11a provides for 12 possible data rates, while 802.11b provides only four. With four spatial streams in a 40 MHz channel, the maximum possible transmission data rate in 802.11n is 600 Mbps.

To achieve maximum throughput, a pure 802.11n 5 GHz network is recommended. The five GHz band has substantial capacity due to many non-overlapping radio channels and less radio interference as compared to the 2.4 GHz band.

Abbreviations and Acronyms

WLAN	Wireless LAN
MAC	Medium Access Control
PHY	Physical Layer
MIMO	Multiple Input Multiple Output
ISI	Inter Symbol Interference
OFDM	Orthogonal Frequency Division Multiplexing
MSDU	MAC Service Data Unit
MPDU	MAC Protocol Data Unit
A-MSDU	Aggregated MAC Service Data Unit
A-MPDU	Aggregated MAC Protocol Data Unit
QoS	Quality of Service
AIFS	Arbitration Inter-Frame Space
RIFS	Reduced Inter-Frame Space
SIFS	Short Inter-Frame Space
EIFS	Extended Inter-Frame Space
EDCA	Enhanced Distributed Channel Access
HCF	Hybrid Co-ordinator Function
HC	Hybrid Co-ordinator
DCF	Distributed Co-ordinator Function
CSMA	Carrier Sense Mulpiple Access
EDCAF	Enhanced Distributed Channel Access Function
UP	User Priority
AC	Access Category
PF	Persistence Factor
RTS	Request To Send
CTS	Clear To Send
NAV	Network Allocation Vector
ADDBA	Add Block-Ack
DelBA	Delete Block-Ack
DLS	Direct-Link Setup
MIB	Management Information Base
CW	Contention Window

References

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About the author(s)

Hareesh Babu has over a decade of experience in the Wireless and Network device driver domain. His key expertise and special focus lies is in the area of Wifi/WLAN technology in the MAC and the MAC-PHY interface. He is also well experienced in the mobile technologies such as GPRS, EDGE LTE as well as L2 swtiching and Routing protocols.

Paulosekutty Simon has over 18 years of experience in telecom product development. His experience ranges from designing point to multipoint radios, GSM base station feature development and maintenance, Layer 1 controller for UMTS Base station, WiMax and LTE Base Station WLAN AP development. Paulose has a specific interest in physical layer implementation.

About L&T Infotech

Larsen & Toubro Infotech Ltd. (L&T Infotech), one of the fastest growing IT Services companies, is ranked 5th globally among the Best IT Services Providers by Global Media Services in 2009, ranked 11th by NASSCOM among the top software and services exporters from India and also ranked among the 'Leaders' category in the prestigious Global 100 list released by the International Association of Outsourcing Professionals (IAOP). A wholly-owned subsidiary of USD 9.8 billion Larsen & Toubro, India's largest technology-driven engineering organization, L&T Infotech is differentiated by the unique Business-to-IT Connect, which is a result of our rich corporate heritage.

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For more information, visit us at www.Lntinfotech.com or email us at info@Lntinfotech.com