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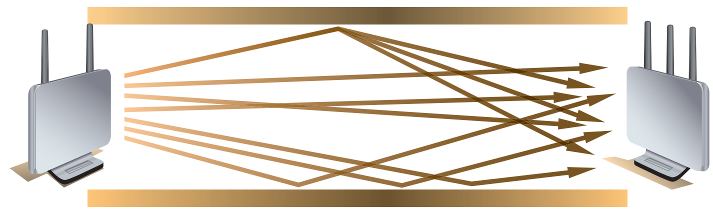
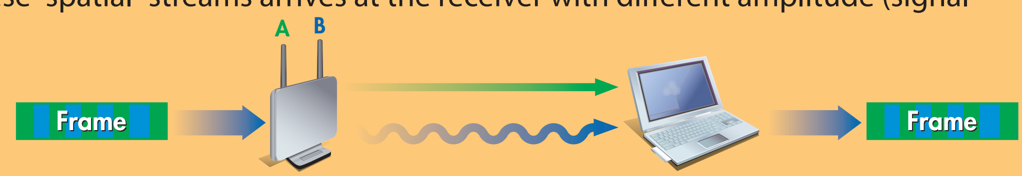
MIMO and Advanced Signaling Techniques

802.11n specifies several MIMO (Multiple-Input Multiple-Output) "M x N" configurations, where M is the number of transmit, and N is the number of receive antennas. The 802.11n standard defines configurations from "1 x 1," up to "4 x 4." Another commonly used naming convention is "M x N : S" where S is the number of spatial streams. Example: A "3 x 3 : 2" system indicates 3 transmit and 3 receive antennas along with 2 spatial streams.



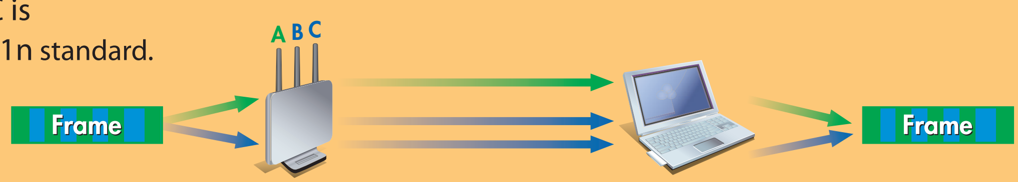
Spatial Multiplexing

A signal stream is broken down into multiple signal streams, each of which is transmitted from a different antenna. Each of these "spatial" streams arrives at the receiver with different amplitude (signal strength) and phase (delay).



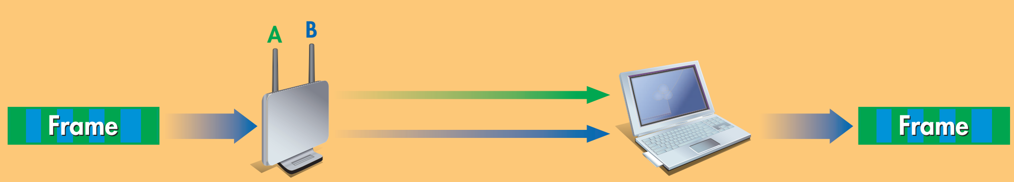
Space Time Block Coding (STBC)

A transmitter utilizes more antennas than spatial streams to redundantly transmit all (or part) of the transmit signal. This increases the reliability of the signal at the receiver, and reduces the error rate at a given Signal to Noise ratio. STBC is an optional feature in the 802.11n standard.



Transmit BeamForming

A transmitter uses multiple antennas to "concentrate" the signal energy in the direction of the receiver. The transmitter must know how the receiver will "see" the transmission ahead of time. Transmit Beam-forming is an optional feature in the 802.11n standard.

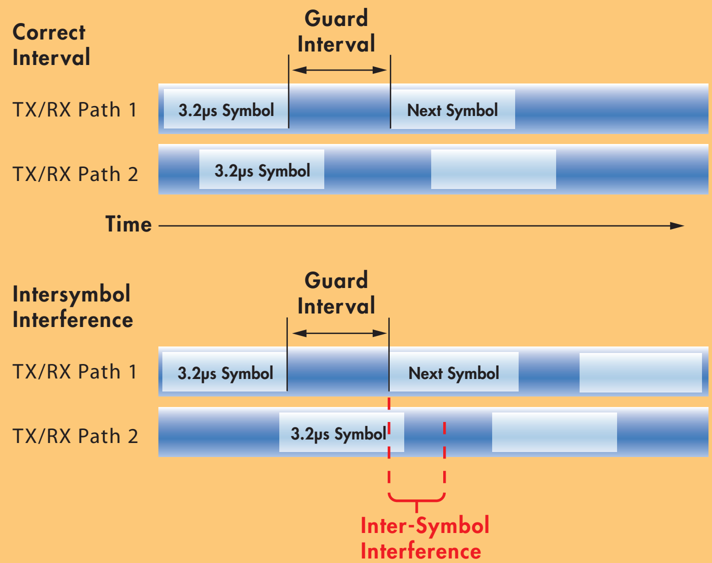


Short Guard Interval (SGI)

Guard Interval is the period of time in between symbols (the smallest unit of data transmitted at one time), used to reduce the Inter-Symbol Interference which occurs when multiple copies of a signal arrive at the receiver at different times, due to multipath.

Things to remember

- Legacy 802.11a/b/g devices use an 800 nanoseconds guard interval, but 802.11n devices have the option of using a shorter Guard Interval of 400 nanoseconds.
- An OFDM data symbol is 3.2 microseconds long, so the total symbol time is 4 microseconds long when using an 800 nanosecond Guard Interval or 3.6 microseconds when using the 400 nanosecond Guard Interval.
- Using the Short Guard Interval gives a raw data rate improvement of just over 11%, while still maintaining enough Inter-Symbol Interference protection for most typical environments.



Modulation and Coding Scheme

802.11n defines MCS (Modulation and Coding Scheme) which is an integer value (0 through 76) which determines the modulation, coding rate and number of spatial streams for transmission. *Refer to the table on page 3.*

Things to remember

- 802.11n access points are required to support at least MCS values 0 through 15 in the 20 MHz (non Short Guard Interval) mode.
- 802.11n stations must support MCS values 0 through 7 in the 20 MHz (non Short Guard Interval) mode.
- MCS values 33 through 77 describe mixed combinations (For e.g. MCS 33 includes 16-QAM on stream 1 and QPSK on another) that can be used to modulate two to four streams.
- All other MCS values, including those associated with 40 MHz channels, Short Guard Interval, and unequal modulation, are optional as defined in the standard.

Modulation and Coding Scheme Index Table

MCS Index	Number of Streams	Modulation and Coding Rate	PHY Data Rate (in Mbps) 20 MHz Channel		PHY Data Rate (in Mbps) 40 MHz Channel	
			No SGI	SGI	No SGI	SGI
0	1	BPSK 1/2	6.50	7.20	13.50	15.00
1	1	QPSK 1/2	13.00	14.40	27.00	30.00
2	1	QPSK 3/4	19.50	21.70	40.50	45.00
3	1	16-QAM 1/2	26.00	28.90	54.00	60.00
4	1	16-QAM 3/4	39.00	43.30	81.00	90.00
5	1	64-QAM 2/3	52.00	57.80	108.00	120.00
6	1	64-QAM 3/4	58.50	65.00	121.50	135.00
7	1	64-QAM 5/6	65.00	72.20	135.00	150.00
8	2	BPSK 1/2	13.00	14.40	27.00	30.00
9	2	QPSK 1/2	26.00	28.90	54.00	60.00
10	2	QPSK 3/4	39.00	43.30	81.00	90.00
11	2	16-QAM 1/2	52.00	57.80	108.00	120.00
12	2	16-QAM 3/4	78.00	86.70	162.00	180.00
13	2	64-QAM 2/3	104.00	115.60	216.00	240.00
14	2	64-QAM 3/4	117.00	130.00	243.00	270.00
15	2	64-QAM 5/6	130.00	144.40	270.00	300.00
16	3	BPSK 1/2	19.50	21.70	40.50	45.00
17	3	QPSK 1/2	39.00	43.30	81.00	90.00
18	3	QPSK 3/4	58.50	65.00	121.50	135.00
19	3	16-QAM 1/2	78.00	86.70	162.00	180.00
20	3	16-QAM 3/4	117.00	130.00	243.00	270.00
21	3	64-QAM 2/3	156.00	173.30	324.00	360.00
22	3	64-QAM 3/4	175.50	195.00	364.00	405.00
23	3	64-QAM 5/6	195.00	216.70	405.00	450.00
24	4	BPSK 1/2	26.00	28.90	54.00	60.00
25	4	QPSK 1/2	52.00	57.80	108.00	120.00
26	4	QPSK 3/4	78.00	86.70	162.00	180.00
27	4	16-QAM 1/2	104.00	115.60	216.00	240.00
28	4	16-QAM 3/4	156.00	173.30	324.00	360.00
29	4	64-QAM 2/3	208.00	231.10	432.00	480.00
30	4	64-QAM 3/4	234.00	260.00	486.00	540.00
31	4	64-QAM 5/6	260.00	288.90	540.00	600.00

Mandatory MCS indicies for stations (MCS 0–7, 20 MHz No SGI, shaded green)

Mandatory MCS indicies for APs (MCS 8–15, 20 MHz No SGI, shaded teal)

40 MHz Channel Mode

The 802.11n standard defines both 20 MHz and 40 MHz wide channel operation. In the 40 MHz mode, the capacity of the channel is effectively double that of legacy systems.

Things to remember

- 802.11 APs and STAs exchange information about what channel widths are supported using HT Information Element and HT Capabilities Element frame fields.
- APs operating a 40 MHz BSS must continuously monitor the environment for legacy or non-40 MHz capable HT STAs in both the primary and secondary channels.
- There are 11 non-overlapping 40 MHz Channels possible in the 5 GHz band.

Channel #	36	40	44	48
Center Freq (Mhz)	5180	5200	5220	5240
Bands	UNII-1 Band (Indoor)			

Channel #	52	56	60	64	100	104	108	112	116	120	124	128	132	136	140
Center Freq (Mhz)	5260	5280	5300	5320	5500	5520	5540	5560	5580	5600	5620	5640	5660	5680	5700
Bands	UNII-2 Band (Indoor/Outdoor)				ETSI Band/ UNII-2 Extended (Indoor/Outdoor)										

Channel #	149	153	157	161	165
Center Freq (Mhz)	5745	5765	5785	5805	5825
Bands	UNII-3 Band (Outdoor)				ISM

Potential non-overlapping channels

Different colors denote potential non-overlapping 40 Mhz channel width combinations

MAC Layer Enhancements

MAC layer enhancements such as Frame Aggregation and Block ACK are key components to achieving HT (high throughput) data rates. For every 802.11 packet transmitted, there is overhead in the form of interframe space, radio preambles and ACK (acknowledgement) frames.

MSDU Aggregation

- Smaller sized frames transported between the MAC and LLC layers are combined.
- Aggregate MSDUs (A-MSDU) includes Ethernet frames for a single destination.
- All constituent frames must be of same QoS level.

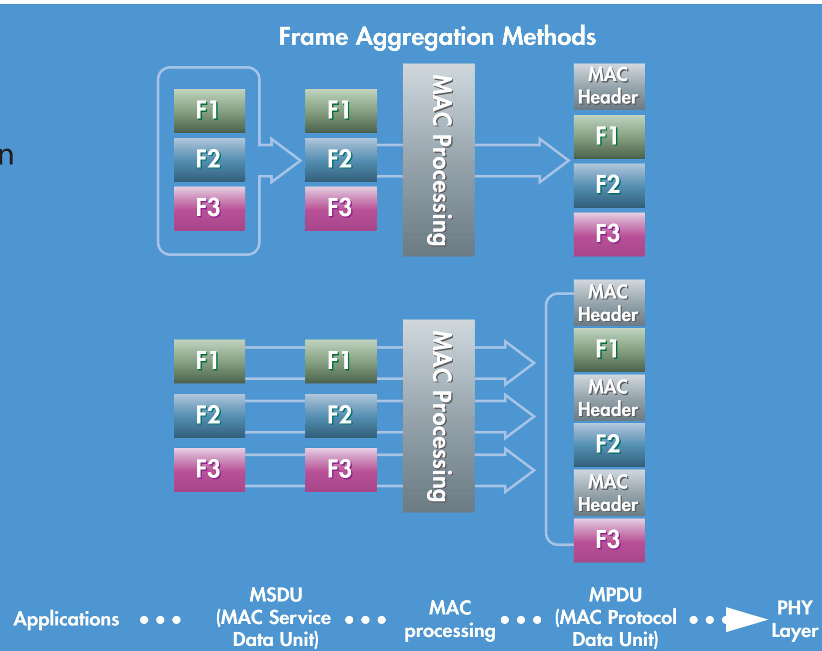
MPDU Aggregation

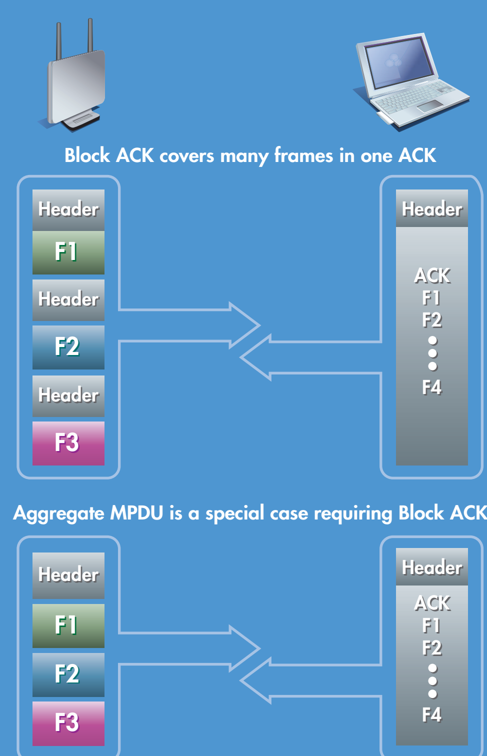
- Aggregate MPDUs (A-MPDUs) are multiple MPDUs combined into a single MAC frame, each retaining its own MAC header.
- All constituent frames must be of same QoS level.

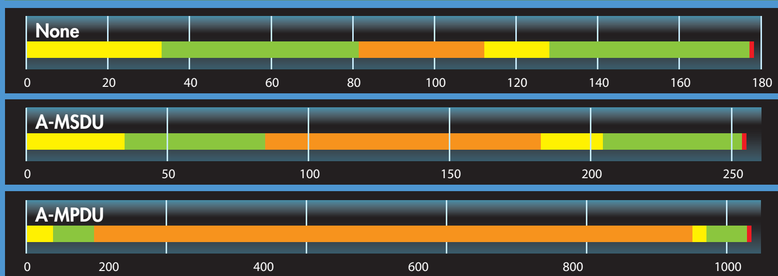
Block Acknowledgement

Things to remember

- Block Acknowledgement allows more than one frame to be acknowledged by a receiver, within a single ACK frame.
- A-MSDU frame may be acknowledged using a normal legacy ACK.
- A-MPDU frame requires acknowledgement of each MAC subframe.



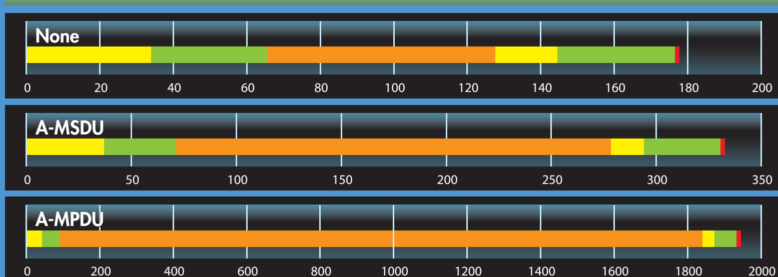




Aggregation Method	Aggregated Frame Size (Bytes)	Overhead	Maximum Throughput (Mbps)
None	*2304*	*83%*	*104.19*
A-MSDU	*7935*	*58%*	*251.92*
A-MPDU	*65535*	*14%*	*514.01*

Data Rate Improvement With Frame Aggregation Transmitting at 600 Mbps

IFS | Preamble | Payload | ACK



Aggregation Method	Aggregated Frame Size (Bytes)	Overhead	Maximum Throughput (Mbps)
None	*2304*	*65%*	*104.84*
A-MSDU	*7935*	*35%*	*194.74*
A-MPDU	*65535*	*6%*	*281.57*

Data Rate Improvement With Frame Aggregation Transmitting at 300 Mbps

IFS | Preamble | Payload | ACK

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Co-existance with Legacy Devices

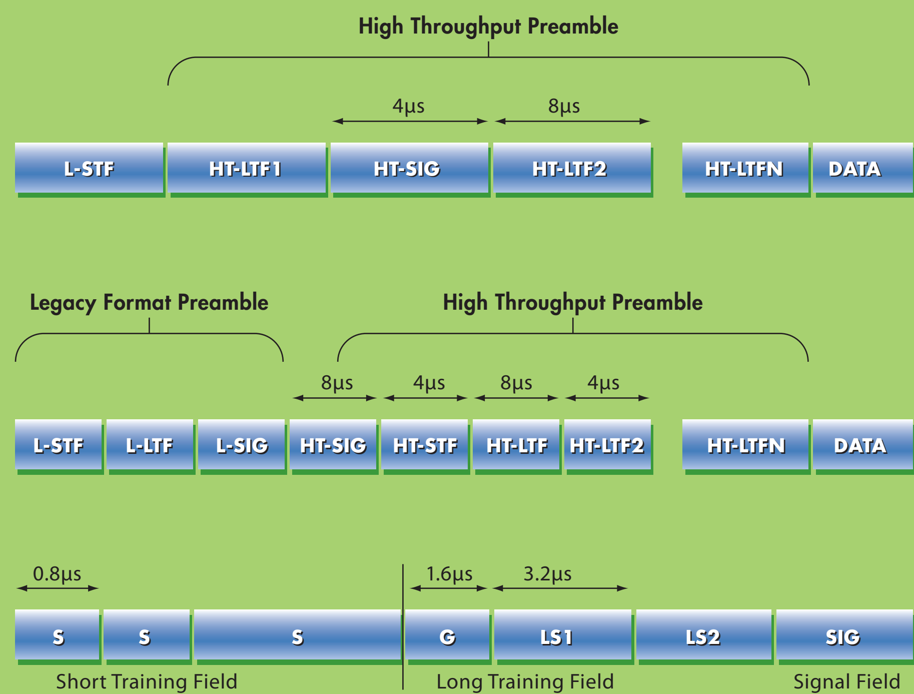
802.11n networks can co-exist with the now legacy 802.11a/b/g networks. An 802.11n Greenfield deployment is an 802.11n network deployed and operating in such a way that backwards compatibility with legacy 802.11a/b/g devices is not required. In a 802.11n mixed mode deployment, 802.11n devices operate in the presence of legacy 802.11a/b/ g devices.

802.11n Preambles

Preambles are used by the receiver to fine tune the manner in which it will receive the transmission. It allows the receiver to intelligently adjust gain settings, and apply frequency and timing correction algorithms, such that the frame will be processed as accurately as possible.

Things to remember

- The Greenfield preamble is optional, and may be used when all STAs present support (HT) Greenfield operation.
- The HT (High Throughput) Mixed Format preamble is mandatory; and is used whenever there are non-HT stations present.
- The non-HT preamble is mandatory to provided support for legacy 802.11 a/b/g operation.



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HT Information Element

HT STA advertises information about what types of STAs are observed to be present, using the Beacon and Probe Response frames. These frames carry the Information Element.

B0 B1	B2	B3	B4	B5 B15
Operating Mode	Non-Greenfield STAs Present	Transmit Burst Limit	OBSS Non-HT STAs Present	Reserved

Use of Fields Within the HT Information Field

Indication from overlapping BSS		Indication to associated STAs		Indication to overlapping BSS		
OBSS Non-HT STAs present from overlapping BSS	ERP IE is present and Non-ERP_present equals 1 from overlapping BSS	Operating Mode	ERP IE is present and Use_protection equals 1	OBSS Non-HT STAs Present	ERP IE is present and Non-ERP_present equals 1	Typical use
0	0	1	0	0	0	Non-HT STAs may be present in both the primary and the secondary channel, but protection by overlapping BSS is determined to **not be** necessary.
0	0	3	0,1	0	0	Non-HT STAs are associated to and protected by the BSS, but protection by overlapping BSS is determined to **not be** necessary.
0	0	3	0,1	0	0,1	Non-HT STAs are associated to and protected by the BSS and protection by overlapping BSS is determined to **be** necessary.
1	0	3	0	1	0	Both the BSS and an overlapping BSS have determined that protection by the BSS **is necessary**, and protection by overlapping BSS is determined to **be** necessary.
	0		0		1	
	1		0		1	
	1		1		1	
0	0,1	1	0	0	0	An overlapping BSS **has** determined that protection by the BSS **is necessary**, but the BSS is advising that there may be non-HT STAs, rather than requiring protection.
0	0,1	3	0,1	0	0	An overlapping BSS **has** determined that protection by the BSS **is necessary**, the BSS has **no** associated non-ERP STAs, and the BSS **is** requiring **determined** protection.
0	0,1	3	1	0	0	An overlapping BSS **has** determined that protection by the BSS **is necessary**, the BSS **has** associated non-ERP STAs, and the BSS **is requiring** protection.
0	0	0,2	0	0	0	No non-HT STAs **are** present. (Layer 3)
Other combinations of values						*None or unusual*

IEEE P802.11n™/D2.00 February 2007 Draft STANDARD for Information Technology-Telecommunications and information exchange between systems – Local and metropolitan area networks.

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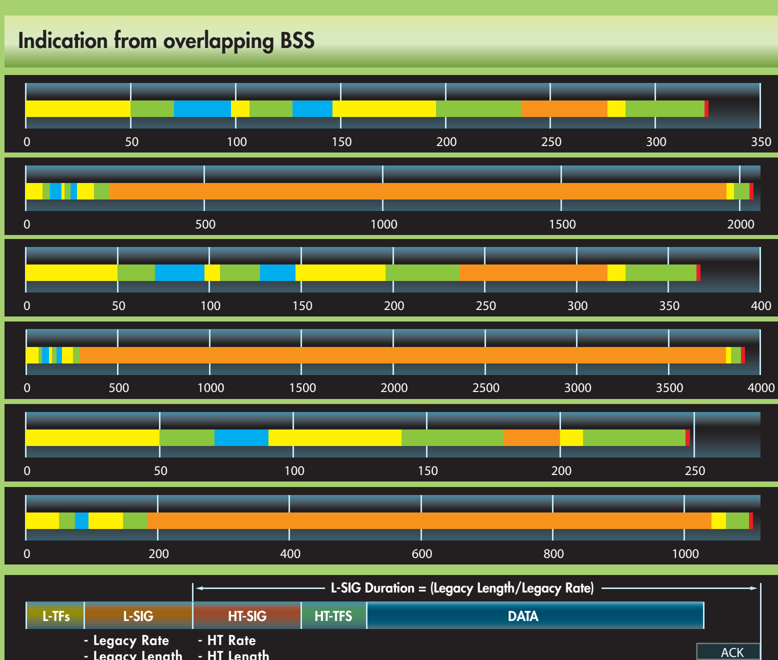
Protection Mechanisms

802.11n defines several mechanisms by which HT and non-HT STAs can coexist with each other. Depending on the type of HT transmission and the values contained in the HT and ERP Information Elements, several protection frame exchanges are allowed: RTS/CTS, CTS-to-Self, L-SIG TXOP or the use of a legacy or mixed mode format preamble to transmit a frame which requires a response frame.

Things to remember

- CTS frame must be transmitted using legacy data rates.
- Legacy devices on neighboring access points operating onthe same channel will cause protection mechanisms to be invoked.
- L-SIG TXOP protection is achieved by "spoofing" the legacy format portion of the PLCP, such that its duration covers the HT exchange.
- An HT STA transmitting using L-SIG TXOP protection will prepend its HT transmission with a mixed mode format preamble, with the legacy rate field set to 6 Mbps and the legacy length field set to duration of the HT exchange.
- The 802.11n standard recommends that device manufacturers include a NAV-based fallback mechanism (such as CTS-to-self), if it is determined that L-SIG TXOP protection fails to effectively suppress non-HT transmissions.
- Phase Co-existance Operation (PCO) is an AP-coordinated method of dividing time into alternating 20 MHz and 40 MHz phases for PCO-capable STAs, and at the same time, alerting legacy STAs to defer the medium.



Protection Mechanism	Channel Bandwidth	Aggregated Frame Size	PHY Frame Size	Link Layer Throughput	Protection Overhead
RTS-CTS	40 MHz	1500 bytes	300Mbps	36.84 Mbps	88%
RTS-CTS	40 MHz	65535 bytes	300Mbps	258Mbps	14%
RTS-CTS	20 MHz	1500 bytes	144Mbps	32.5Mbps	77%
RTS-CTS	20 MHz	65535 bytes	144Mbps	133.9Mbps	07%
CTS-to-Self	40 MHz	1500 bytes	600Mbps	48.22Mbps	92%
CTS-to-Self	40 MHz	65535 bytes	600Mbps	475.47Mbps	21%
L-SIG TXOP					<0.01%

IFS | Preamble | Protection Frame | Data | ACK

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Acronyms

AGC Automatic Gain Control

A-MPDU Aggregate MAC Protocol Data Unit

A-MSDU Aggregate MAC Service Data Unit

ASEL Antenna Selection

CSD Cyclic Shift Diversity

HT High Throughput

HT-GF-STF High Throughput Greenfield Short Training Symbol

HT-LTF High Throughput Long Training Field

HT-SIG High Throughput SIGNAL Field

HT-STF High Throughput Short Training Field

LDPC Low Density Parity Check

L-LTF Non-HT Long Training Field

L-SIG Non-HT SIGNAL Field

L-STF Non-HT Short Training Field

LTF Long Training Field

MCS Modulation Coding Scheme

MIMO Multiple Input, Multiple Output

PCO Phased Coexistence Operation

PSMP Power Save Multi-Poll

RIFS Reduced Interframe Spacing

SISO Single Input, Single Output

SM Spatial Multiplexing

STBC Space-Time Block Code

STBC/SM Space-Time Block Code/Spatial Multiplexing

TxBF Transmit Beamforming

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