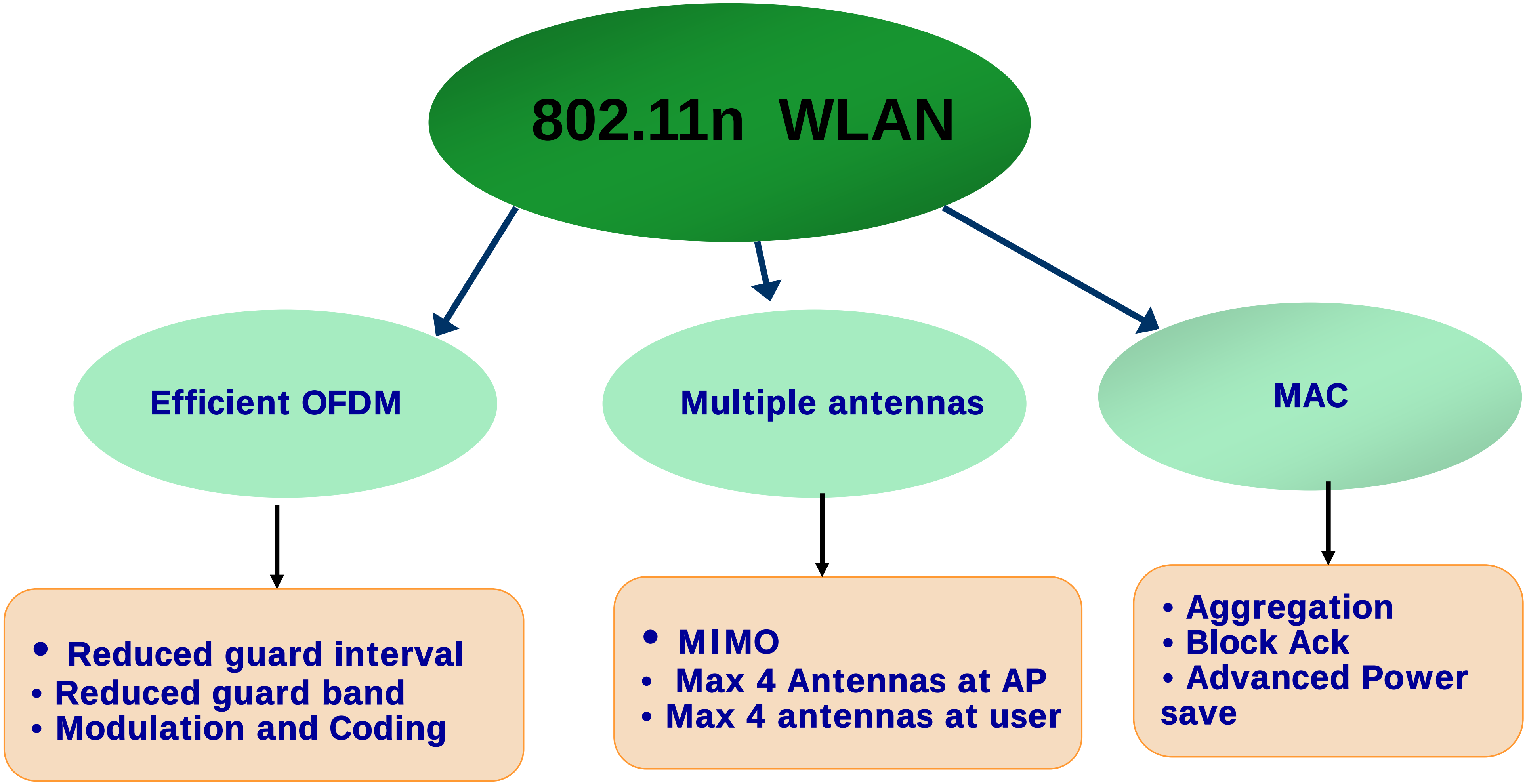
IEEE802.11n

- IEEE802.11n
- MIMO Technology

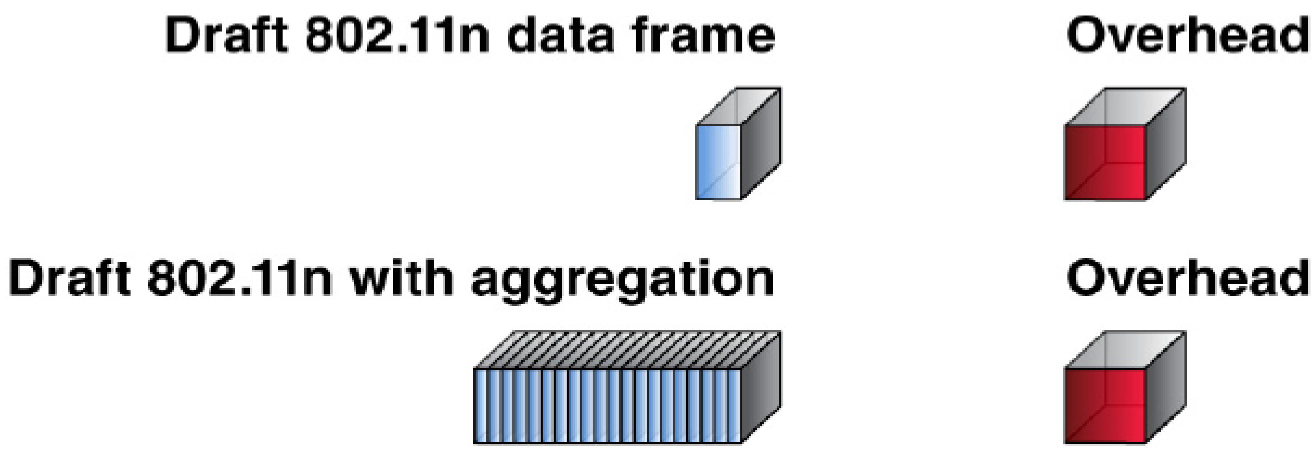
802.11n Explained

	802.11a	802.11b	802.11g	802.11n
Standard Approved	July 1999	July 1999	June 2003	Sept, 2009
Maximum Data Rate	54 Mbps	11 Mbps	54 Mbps	600 Mbps
Modulation	OFDM	DSSS or CCK	DSSS or CCK or OFDM	DSSS or CCK or OFDM
RF Band	5 GHz	2.4 GHz	2.4 GHz	2.4 GHz or 5 GHz
Number of Spatial Streams	1	1	1	1, 2, 3, or 4
Channel Width	20 MHz	20 MHz	20 MHz	20 MHz or 40 MHz

IEEE 802.11n – Main Features



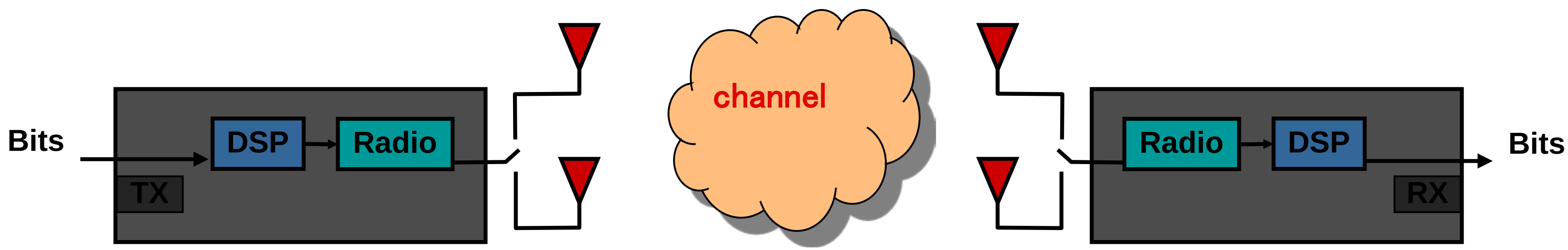
802.11n MAC Aggregation



MIMO System

- Multiple input, multiple output
- Represented as the number of transmit and receive antenna in a system e.g.
  - 2x3 = two transmit and three receive antennas
  - 3x3 = three transmit and three receive antennas
- Enables significant increases in data throughput and link range without additional bandwidth or transmit power
- The 802.11n allows multiple MIMO configurations between 2x2 (minimum) and 4x4 (maximum)

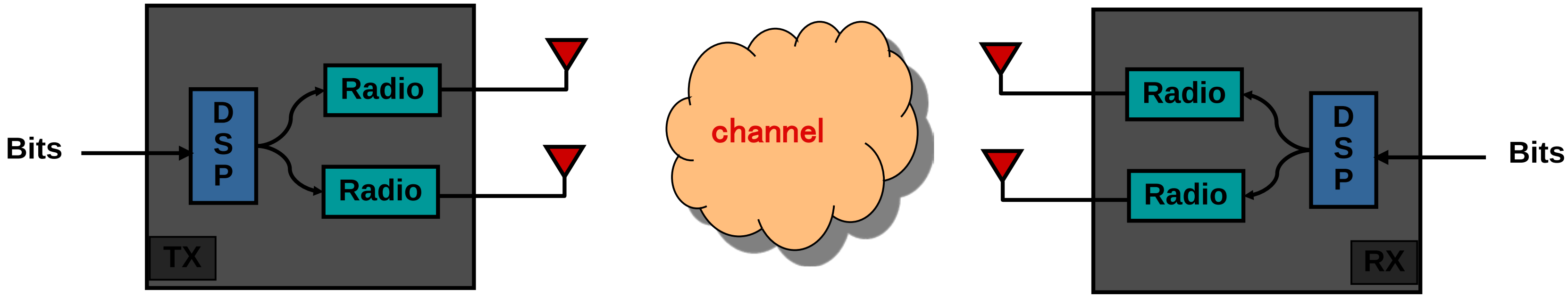
Conventional (SISO) Wireless Systems



Conventional “Single Input Single Output” (SISO) systems were favored for simplicity and low-cost but have some shortcomings:

- Outage occurs if antennas fall into null
  - » Switching between different antennas can help
- Energy is wasted by sending in all directions
  - » Can cause additional interference to others
- Sensitive to interference from all directions
- Output power limited by single power amplifier

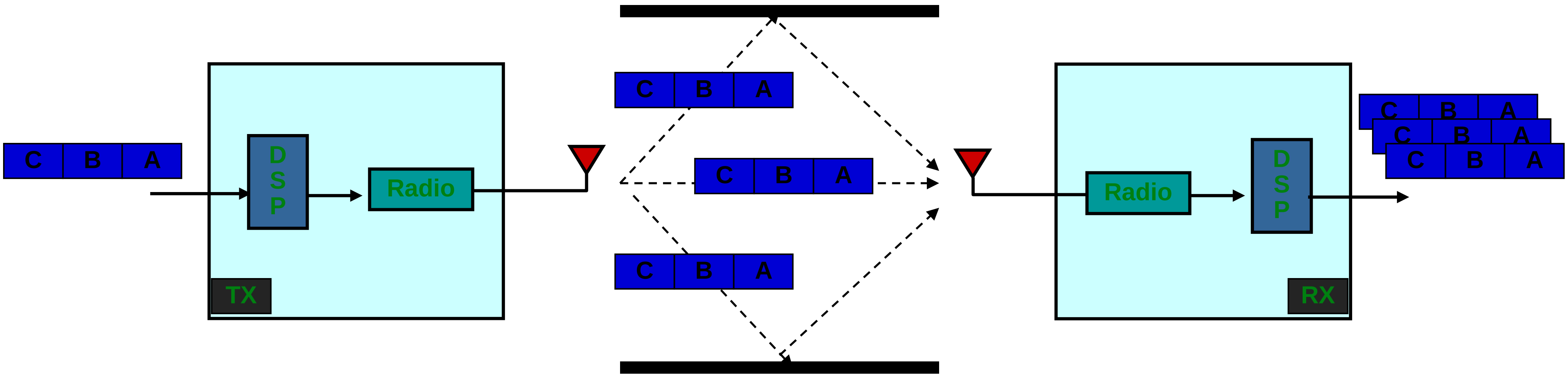
MIMO Wireless Systems



Multiple Input Multiple Output (MIMO) systems with multiple parallel radios improve the following:

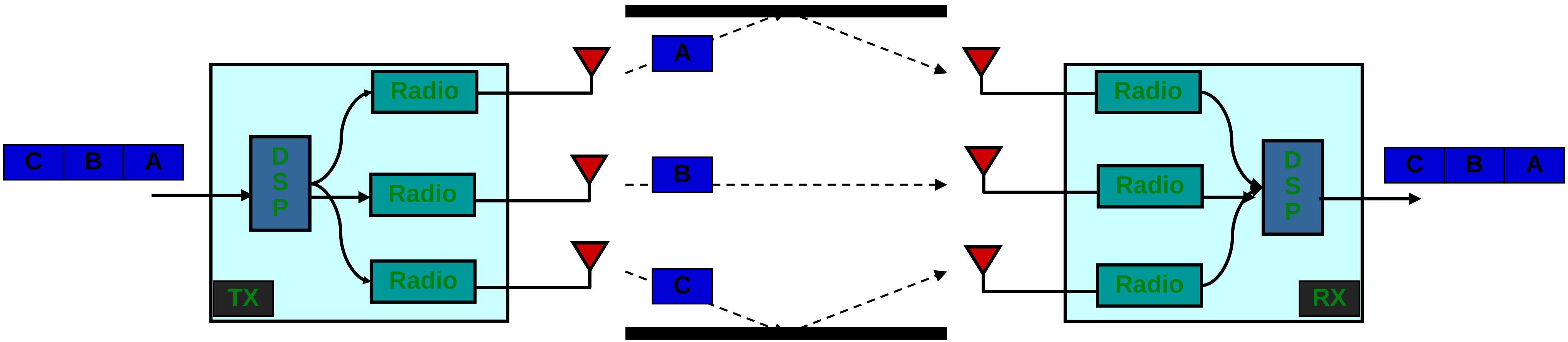
- **Outages reduced by using information from multiple antennas**
- **Transmit power can be increased via multiple power amplifiers**
- **Higher throughputs possible**
- **Transmit and receive interference limited by some techniques**

Multi-path propagation in a/b/g systems



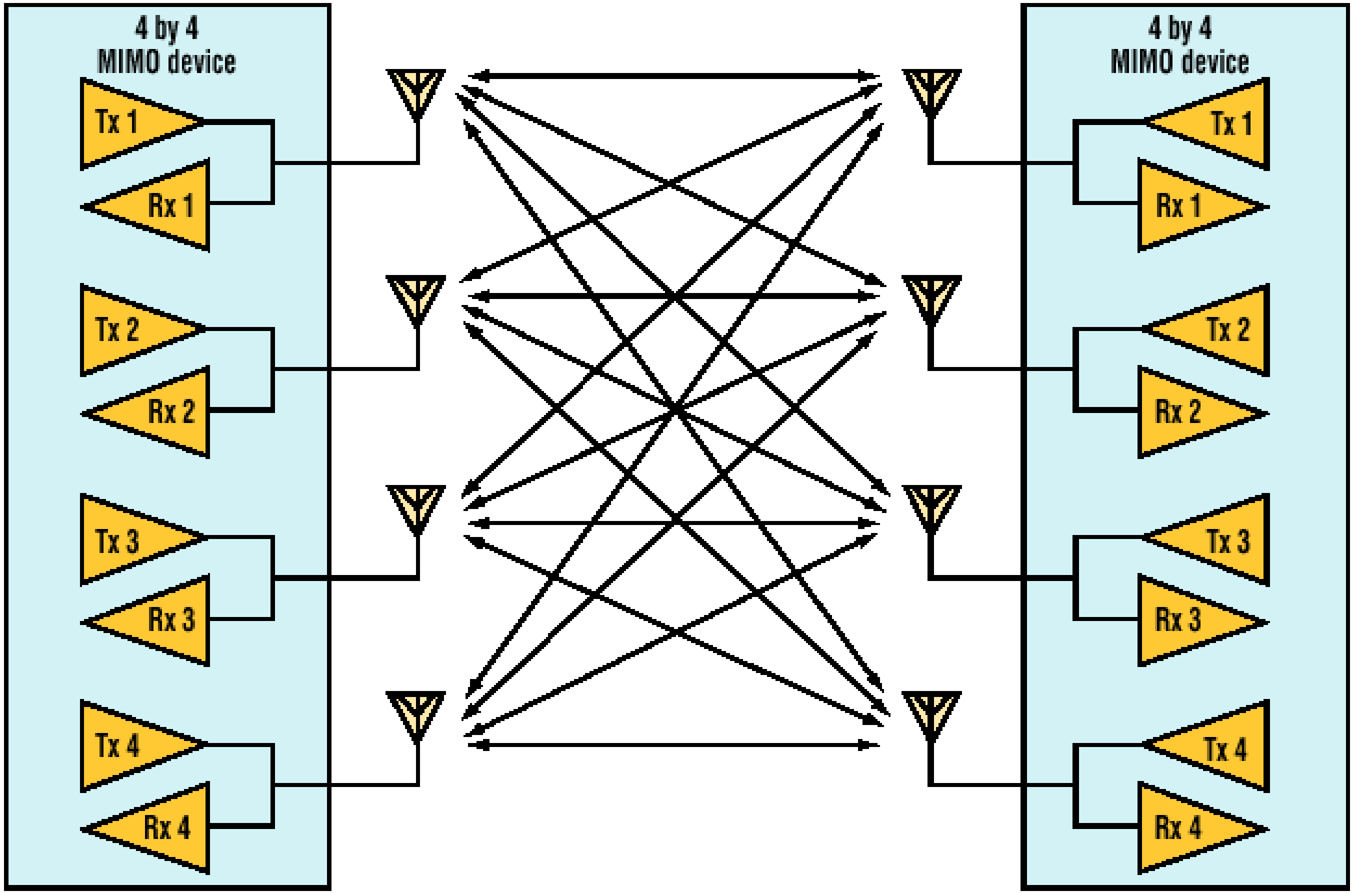
- **Multi-path propagation causes inter-symbol interference (ISI) impacting throughput and range.**

Multi-path propagation in 802.11n systems



- **Spatial multiplexing turns multi-path propagation into a benefit yielding significant improvements in throughput and range.**

802.11n at the maximum



2. Compared to SISO systems,which rely on one transmitter and receiver, MIMO systems use multiple transmitters and receivers. The draft 802.11n specification allows up to four transmitters and four receivers (4 by 4) per AP/client device, providing multiple transmission paths for each signal.

MIMO Alternatives

There are two basic types of MIMO technology:

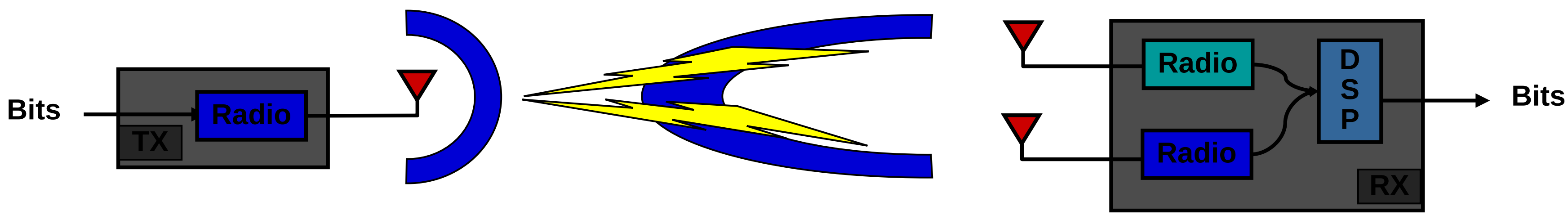
- **Beamforming MIMO**
  - » **Standards-compatible techniques to improve the range of existing data rates using transmit and receive beamforming**
  - » **Also reduces transmit interference and improves receive interference tolerance**
- **Spatial-multiplexing MIMO**
  - » **Allows even higher data rates by transmitting parallel data streams in the same frequency spectrum**
  - » **Fundamentally changes the on-air format of signals**
    - **Requires new standard (11n) for standards-based operation**
    - **Proprietary modes possible but cannot help legacy devices**

Beamforming MIMO Overview

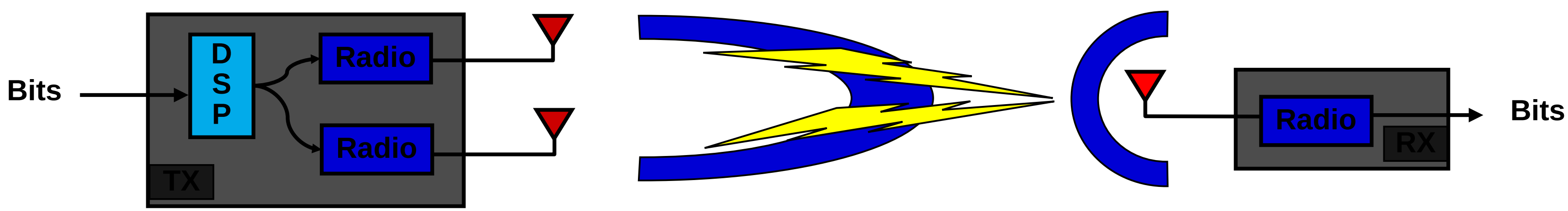
Consists of two parts to make standard 802.11 signals "better

Uses multiple transmit and/or receive radios to form coherent 802.11a/b/g compatible signals

– Receive beamforming / combining boosts reception of standard 802.11 signals



- Phased array transmit beamforming to focus energy to each receiver

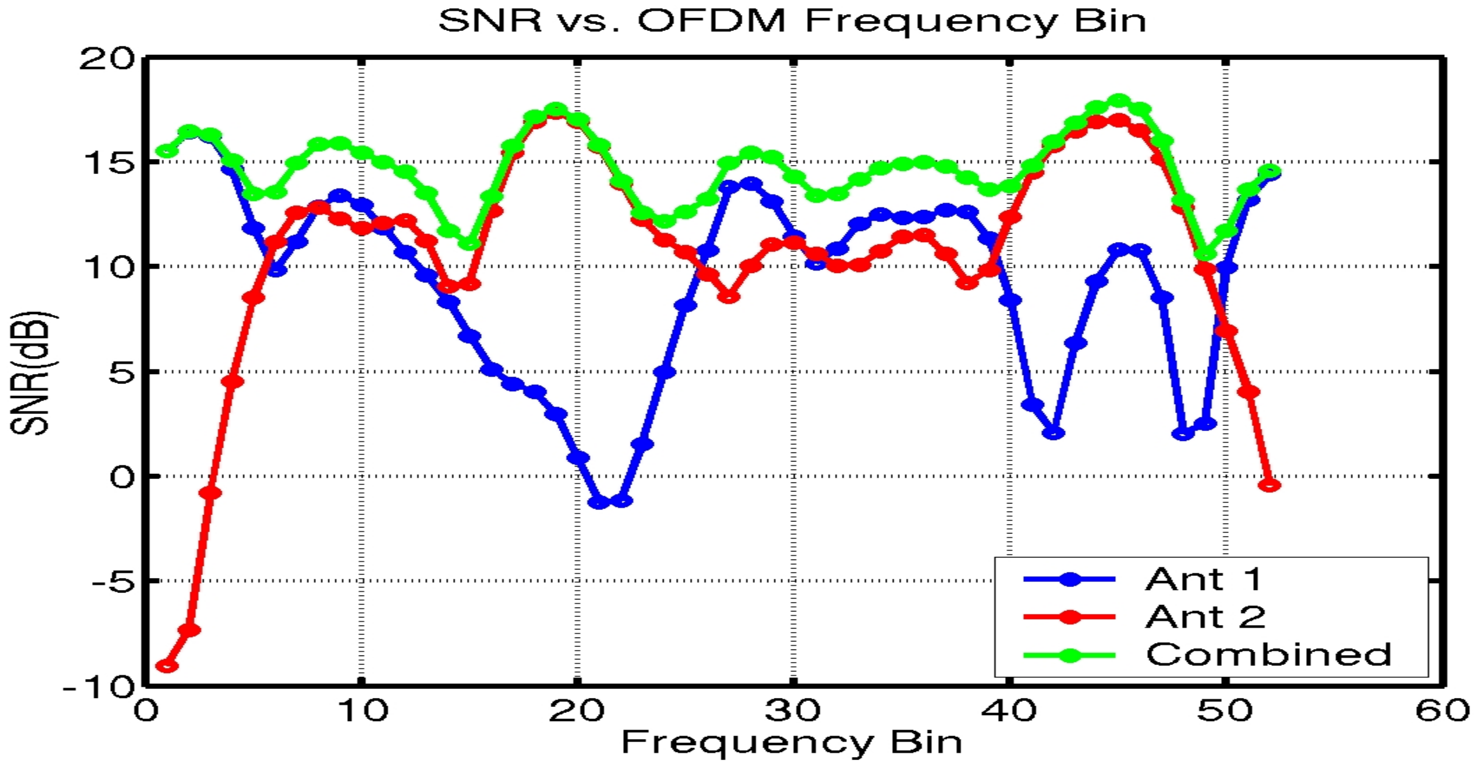


Benefits of Beamforming

Benefits

- **Power gain (applicable only to transmit beamforming)**
  - » **Power from multiple PA's simultaneously (up to regulatory limits)**
  - » **Relaxes PA requirements, increases total output power delivered**
- **Array gain: "dynamic high-gain antenna"**
- **Interference reduction**
  - » **Reduce co-channel inter-cell interference**
- **Diversity gain: combats fading effects**
- **Multipath mitigation**
  - » **Per- subcarrier beamforming to reduce spectral nulls**

Multipath Mitigation

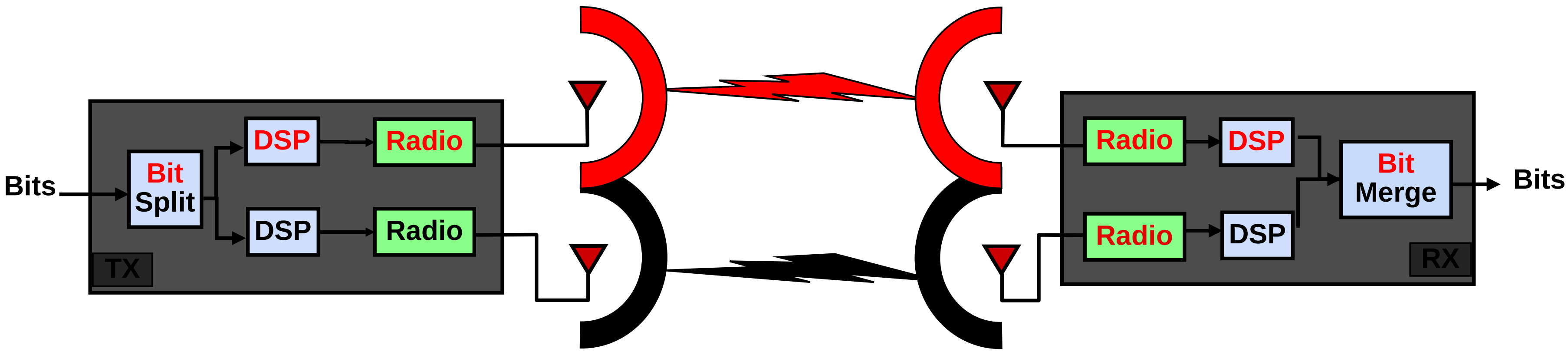


- Multiple transmit and receive radios allow compensation of notches on one channel by non-notches in the other
- Same performance gains with *either* multiple tx or rx radios and greater gains with *both* multiple tx and rx radios

Spatial Multiplexing MIMO Concept

Spatial multiplexing concept:

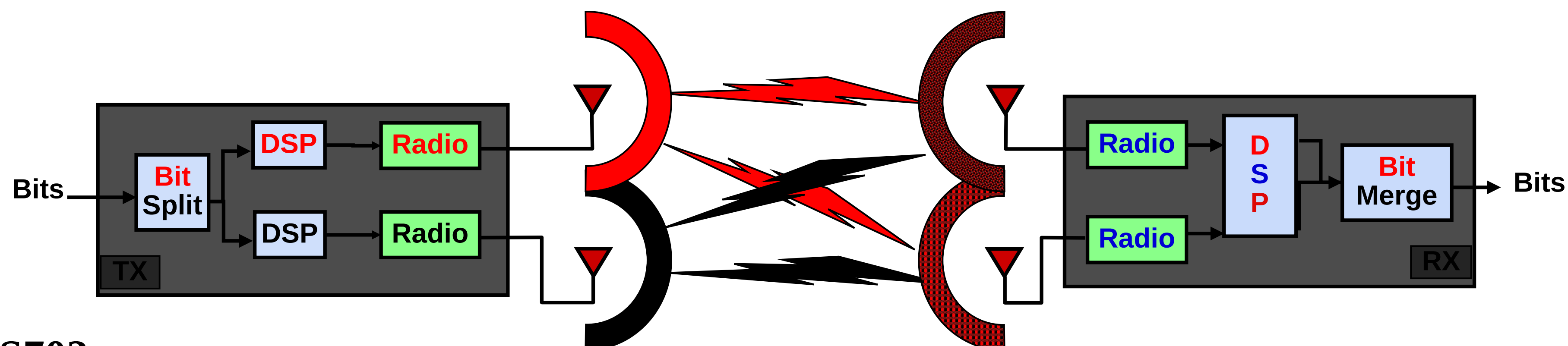
- Form multiple independent links (on same channel) between transmitter and receiver to communicate at higher total data rates



Spatial Multiplexing MIMO Reality

Spatial multiplexing concept:

- Form multiple independent links (on same channel) between transmitter and receiver to communicate at higher total data rates
- However, there are cross-paths between antennas
- The correlation must be decoupled by digital signal processing algorithms



Break the Shannon's Limit

Shannon's formula: $$C / W = \log_2(1 + S / N)$$

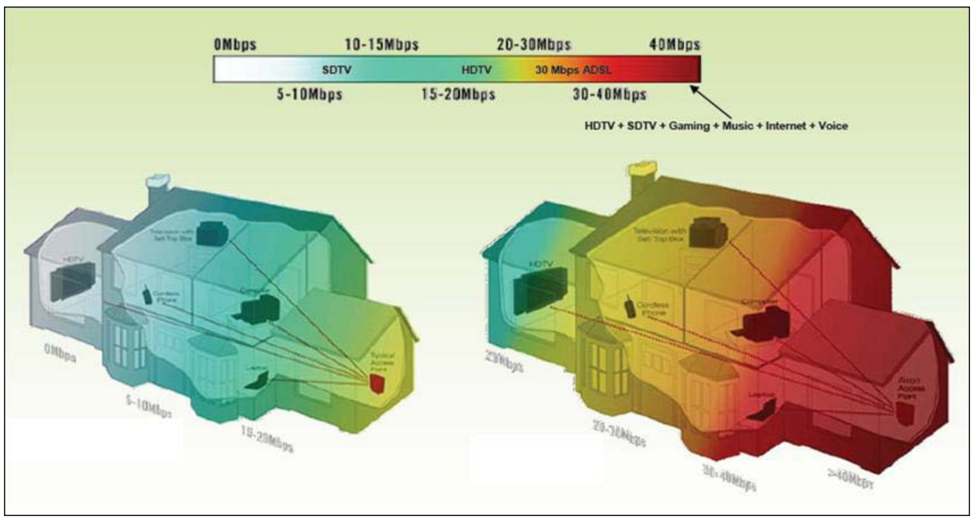
MIMO system: $$C = \sum_{i=1}^{m} \log_2\left[1 + \frac{p_i \lambda_i}{\sigma^2}\right]$$

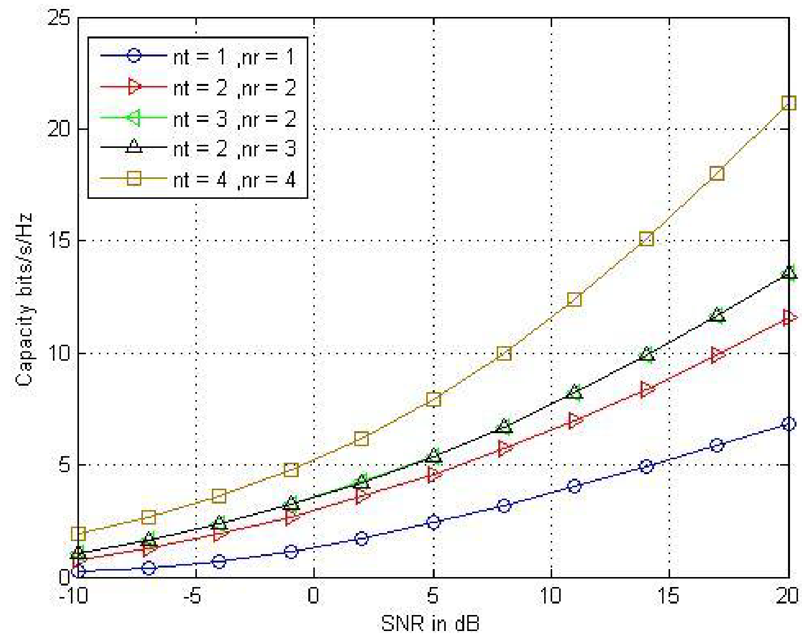
Performance of Bell Lab BLAST system:

Number of transmit antennas at base	**1**	**2**	**4**
Number of receive antennas at each mobile	**1**	**2**	**4**
Peak data rate	7.2Mbps	14.4Mbps	28.8Mbps
Average sector throughput*	3.6Mbps	5.4Mbps	8.1Mbps

MIMO Channel Capacity and Range

- **Increased Capacity and Data Throughput**
- **Increased Range**

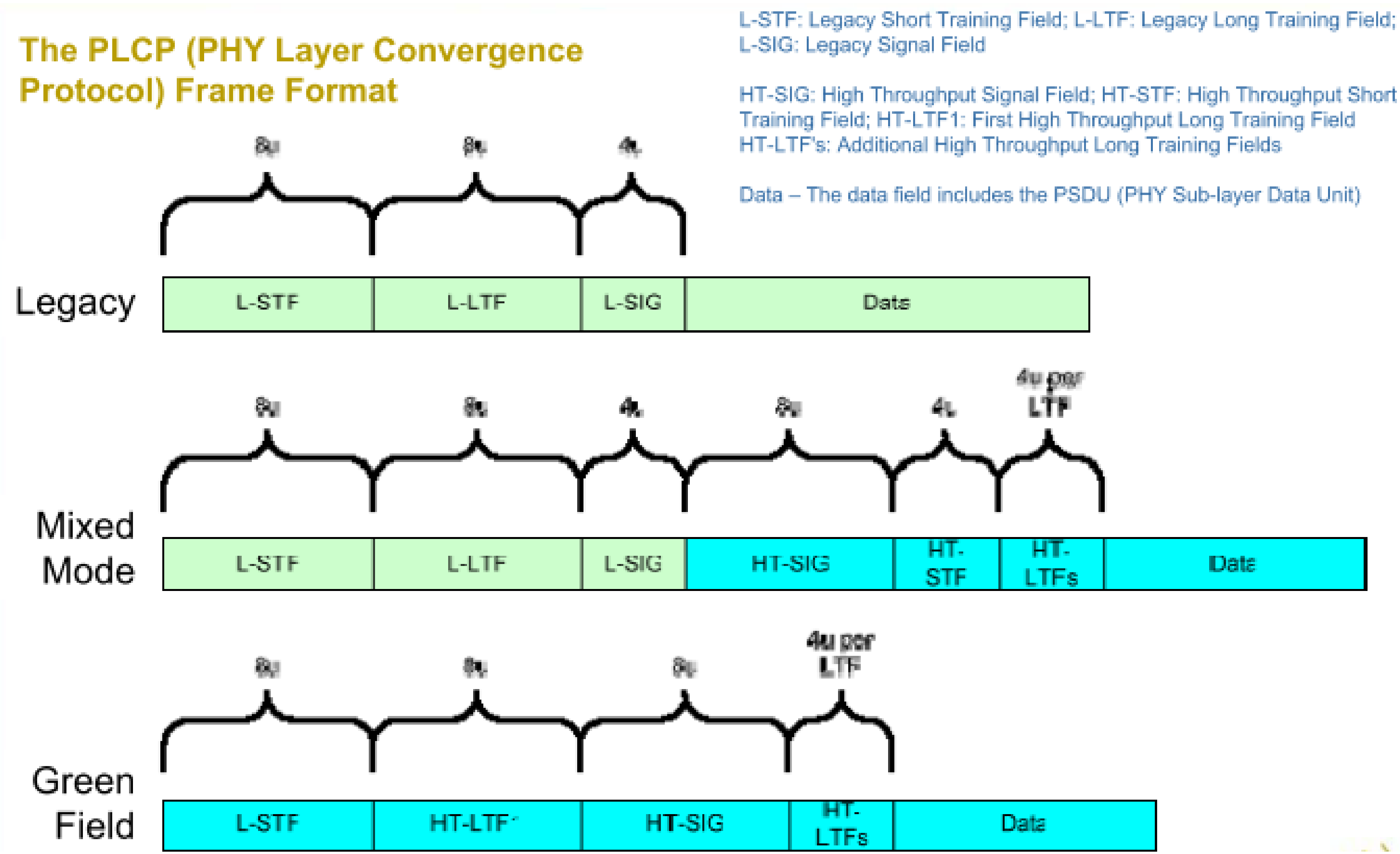




IEEE 802.11n Operating Modes

- There are three basic 802.11n operating modes
  - 802.11na
  - 802.11ng
  - Greenfield
- When configured as 802.11na or 802.11ng, an AP will accept connections from a and g client respectively
- Greenfield mode is a ‘pure’ n mode and will not accept connections from legacy clients
  - Defaults to 40MHz channels and enables a short guard interval (SGI) of 400ns to maximize performance

802.11n PLCP Frame Format



Impact of spatial streams on throughput

	Maximum connect rate (40MHz channels)		
No of unique streams*	Legacy mode	Greenfield mode	Effective throughput
2	270Mbps	300Mbps	Up to 150Mbps
3	405Mbps	450Mbps	Up to 225Mbps
4	540Mbps	600Mbps	Up to 300Mbps

***The number of unique streams cannot be greater than the number of transmit antennas**

Wireless LAN router
3x3 MIMO by Aruba Networks

Increased range

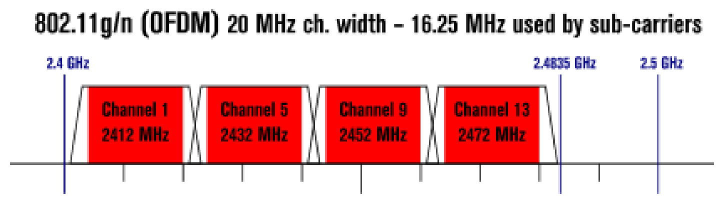
- **A technique called *spatial beamforming* drives further increases the effective range of 802.11n**
- **Transmit beamforming is used to control the directionality of the radiation pattern**
  - **Improves the received signal quality at the decoding stage**

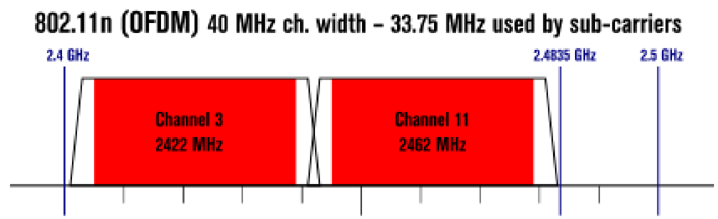
Protocol	Range (Radius Indoor) Depends on type and number of walls	Range (Radius Outdoor) Loss includes one wall
802.11a	~35m	~120m
812.11b/g	~38m	~140m
802.11n	~70m	~250m

Source: Wikipedia, 802.11n

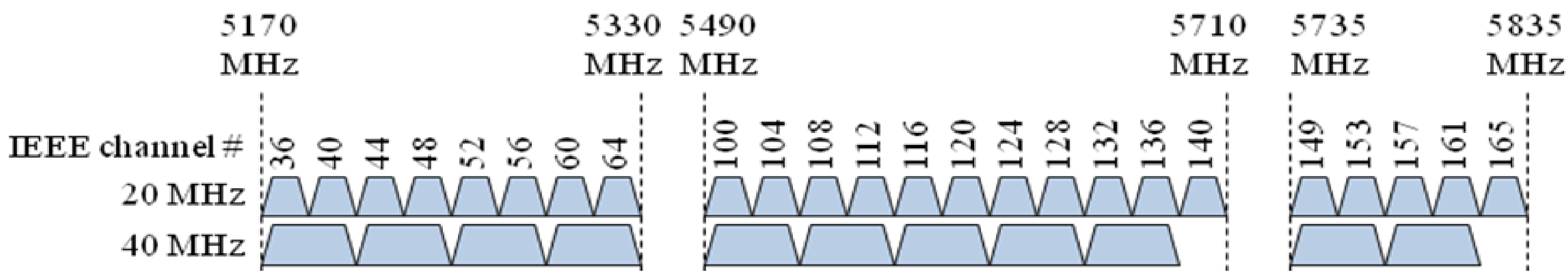
Availability of channels in IEEE802.11n

- **In 2.4GHz band, 4x20MHz channels or 2x40 MHz channels**





- **In the 5GHz band, any allowable channel can be designated as a 40MHz channel but..**
  - » **…each channel can only bond up or down e.g. Ch36 (+1), Ch40 (-1)**
  - » **There will be eleven 40MHz channels in the 5GHz band in the US**



802.11n Summary

- Better OFDM
- Space-Division Multiplexing
- Diversity
- MIMO Power save
- 40 MHz channels
- Aggregation
- Reduced Inter-Frame Spacing
- Greenfield mode

Feature	Definition	Specification Status
Better OFDM	Supports wider bandwidth & higher code rate to bring maximum data rate to 65 Mbps	Mandatory
Space-Division Multiplexing	Improves performance by parsing data into multiple streams transmitted through multiple antennas	Optional for up to four spatial streams
Diversity	Exploits the existence of multiple antennas to improve range and reliability. Typically employed when the number of antennas on the receiving end is higher than the number of streams being transmitted.	Optional for up to four antennas
MIMO Power Save	Limits power consumption penalty of MIMO by utilizing multiple antennas only on as-needed basis	Required
40 MHz Channels	Effectively doubles data rates by doubling channel width from 20 MHz to 40 MHz	Optional
Aggregation	Improves efficiency by allowing transmission bursts of multiple data packets between overhead communication	Required
Reduced Inter-frame Spacing (RIFS)	One of several draft-n features designed to improve efficiency. Provides a shorter delay between OFDM transmissions than in 802.11a or g.	Required
Greenfield Mode	Improves efficiency by eliminating support for 802.11a/b/g devices in an all draft-n network	Currently optional

Class Quiz

- What are the two schemes in MIMO technology?
- What is the spatial multiplexing?
- What are the main improvements in IEEE802.11n?