Wireless Mesh and Vehicular Networks 802.11 PHY Layers

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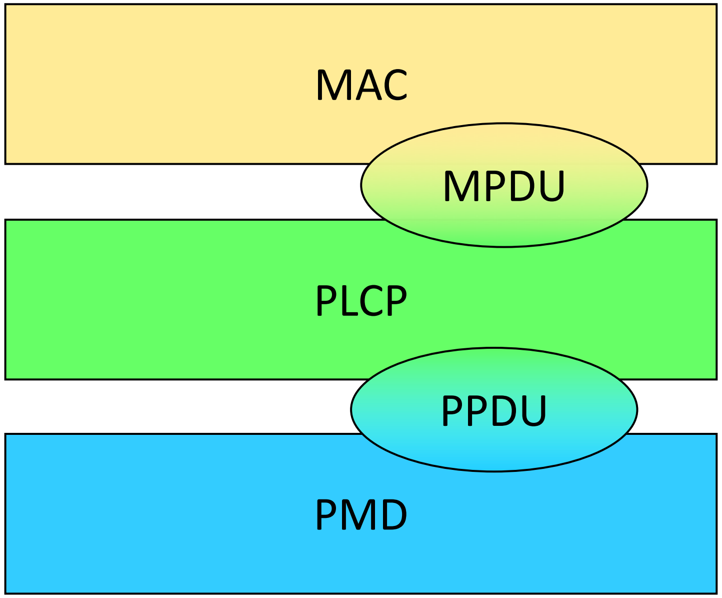
Copyright

- Details of the frame format and details of the MAC depends on details of the PHY layer
  - This is why in the end in 802 networks MAC and PHY are specified together while LLC and internetworking are in common
  - Both ISO/OSI and (to some extent) TCP/IP failed to recognize this
- There is an additional layer between MAC and PHY

PHY layer subdivision

- PLCP: Physical Layer Convergence Protocol
- PMD: Physical Medium Dependant
- PPDU contains the PHY layer headers stripped when the PDU is passed to the MAC
- PMD defines the specific electromagnetic characteristics used on different PHY means



- PLCP Header
  - Is actually already dependent on the PMD
  - Includes sync preambles and further info on the encoding of the remaining part of the MPDU

Goals of 802.11 PHY(s)

- Flexibility
  - Every standard allows multiple data-rates
- Robustness
  - Against multipath fading and impairments
  - Against heterogeneous channel conditions
- Preamble and “common” information header transmitted always at minimum speed
- Payload transmitted at the best rate (estimated by and at the transmitter)

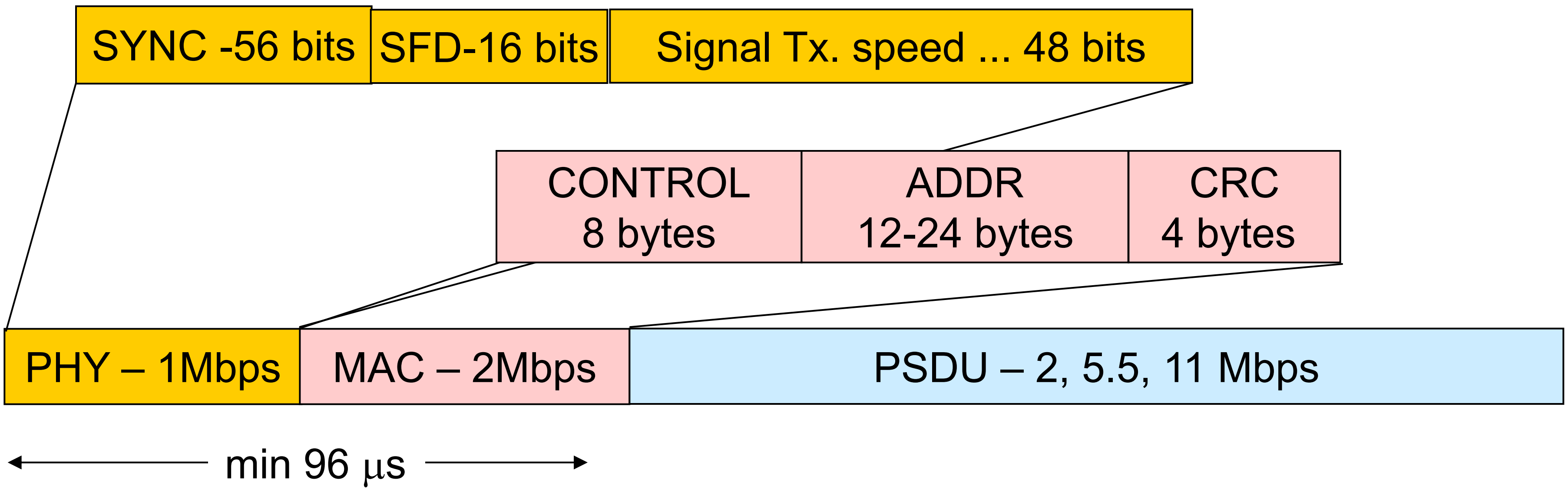
st—year	Freq/Bandw	Data Rates (Mbit/s)	SS technique	Max dist in—out
- —97	2.4GHz/20MHz	1,2	FHSS	20-100
- —97	THz/Baseband	1,2	none	10-??
b—99	2.4GHz/20MHz	5.5,11	DSSS	25-150
a/h—99	5.0GHz/20MHz	6,9,12,18,24,36,48,54	OFDM	20-150
g—03	2.4GHz/20MHz	6,9,12,18,24,36,48,54	OFDM	20-150

802.11 PHY: Current Standards & Evolution

st—year	Freq/Bandw	Data Rates (Mbit/s)	SS technique	Max dist in—out
n – 09	2.4 or 5 GHz/ 20-40MHz	15, 30, 45, 60, 90, 120, 135, 150 (40 MHz); divide by 2 for 20 MHz	OFDM	40-250
ac – 12+	5GHz / 160MHz	too many ... up to 1.69 Gbit/s	OFDM	40-250?
ad – 12+	60 GHz / 2.16 GHz	too many ... up to 7Gbit/s	UWB/OFDM	Meters
ah/ aj/ax/ay	900MHz / 60 GHz	Future standards	???	???

SFD – Start Frame Delimiter

PLPC – Physical Layer Convergence Protocol



Some Numerical Values…

802.11b

- PHY_{HDR}: 16 bytes, transmitted @ 1 Mbps
- MAC_{HDR}: 34 bytes, transmitted @ 1/2 Mbps
  - If slot=20µs, PHY_{HDR}+ MAC_{HDR}=20 slots
- ACK=PHY_{HDR}+14 bytes , transmitted @ 1/2 Mbps
  - If slot=20µs, ACK=12 slots

Detailed MAC Format (bytes)

Frame Control	Duration ID	Address1 (source)	Address2 (destination)	Address3 (rx node)
2	2	6	6	6

Sequence Control	Address4 (tx node)	Data	FCS
2	6	0 - 2,312	4

MAC Format fields

Field	Bits	Notes/Description
Frame Control	15 - 14	Protocol version. Currently 0
	13 - 12	Type
	11 - 8	Subtype
	7	To DS. 1 = to the distribution system.
	6	From DS. 1 = exit from the Distribution System.
	5	More Frag. 1 = more fragment frames to follow (last or unfragmented frame = 0)
	4	Retry. 1 = this is a re-transmission.
	3	Power Mgt. 1 = station in power save mode, 0 = active mode.
	2	More Data. 1 = additional frames buffered for the destination address (address x).
	1	WEP. 1 = data processed with WEP algorithm. 0 = no WEP.
	0	Order. 1 = frames must be strictly ordered.

MAC Format fields

Field	Bits	Notes/Description
Duration ID	15 - 0	For data frames = duration of frame. For Control Frames the associated identity of the transmitting station.
Address 1	47 - 0	Source address (6 bytes).
Address 2	47 - 0	Destination address (6 bytes).
Address 3	47 - 0	Receiving station address (destination wireless station)
Sequence Control	15 - 0	
Address 4	47 - 0	Transmitting wireless station.
Frame Body		0 - 2312 octets (bytes).
FCS	31 - 0	Frame Check Sequence (32 bit CRC).

A collection of different access techniques:

- Infrared (IR), never really used
- Frequency hopping spread spectrum (FHSS), 1-2 Mbit/s now obsolete
- Direct sequence spread spectrum (DSSS), 1,2,5.5 and 11 Mbit/s, the most diffused till 3-4 years ago
- Orthogonal Frequency Division Multiplexing (OFDM), nothing to do with FDM, this is a modulation technique 6 to 54 Mbit/s now the most used, and beyond
- Four different standards: 802.11; /b; /a/h/g; /n

Infrared

- Works in the regular IR LED range, i.e. 850-950 nm
- Used indoor only
- Employes diffusive transmissions, nodes can receive both scattered and line-of-sight signals
- Max output power: 2W
- Never really implemented ... tough can have “reasons” in some environments, and it is very cheap
- Tx uses a LED, Rx a Photodiode
- Wavelength between 850 and 950 nm

Infrared

- Modulation is “baseband” PPM (Pulse Position Modulation), similar to on-off keying with Manchester encoding to ensure constant sync transitions
- 1 Mbit/s: 16/4 PPM
  - 0000 → 0000000000000001
  - 0001 → 0000000000000010
  - 0010 → 0000000000000100
  - 0011 → 0000000000001000
  - 0100 → 0000000000010000
  - ...
- 2 Mbit/s: 4/2 PPM
  - 00 → 0001
  - 01 → 0010
  - 10 → 0100
  - 11 → 1000
- Pulses are 250 ns

IR PLCP frame

SYNC	SFD	DR	DCLA	LENGTH	CRC	PSDU

- SYNC: variable length, synchronization and optional fields on gain control and channel quality
- SFD (Start Frame Delimiter): 4 L-PPM slots with a hex symbol of 1001. This field indicates the start of the PLCP preample and performs bit and symbol synchronization
- DR (Data Rate): 3 L-PPM slots and indicates the speed used:
  - 1 Mbps: 000; 2 Mbps: 001
- DCLA (DC Level Adjustment): used for DC level stabilization, 32 L-PPM slot and looks like this:
  - 1 Mbps: 00000000100000000000000010000000
  - 2 Mbps: 00100010001000100010001000100010
- LENGTH: number of octets transmitted in the PSDU: 16-bit integer
- CRC: header protection – 16 bits
- PSDU: actual data coming from the MAC layer; Max 2500 octets, Min 0

- All radio-based PHY layers employ Spread Spectrum
- Frequency Hopping : transmit over random sequence of frequencies
- Direct Sequence: random sequence (known to both sender and receiver), called chipping code
- OFDM: spread the signal over many subcarriers with FFT based techniques

802.11 radios: Power

- Power radiation is limited to
  - 100mW EIRP in EU
  - 1000mW EIRP in USA
  - 10mW EIRP in Japan
- NIC cards are the same all over the world: changing power is just a matter of firmware config.
- EIRP: Equivalent Isotropic Radiated Power
  - In practice defines a power density on air and not a transmitted power
- Using high gain antennas (in Tx) can be (legally) done only by reducing the transmitted power or to compensate for losses on cables/electronics

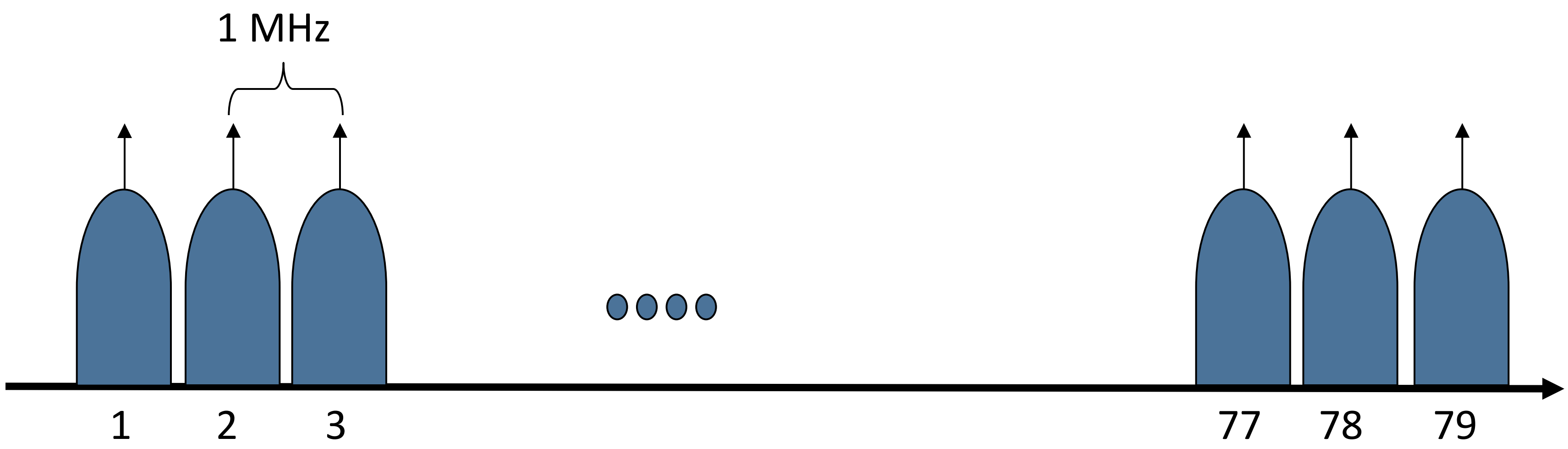
Band allocations

- ISM: Industrial Scientific Medical
  - Unlicenced bands for generic use
  - Normally not used for communications (cfr Cellular, TV, Radio, ...)
  - Law dictates limits in use, but do not guarantee interference-free operations
  - Similar to radio-amateurs bands ... but for the fact that those are only for study and not for commercial use

Band allocations

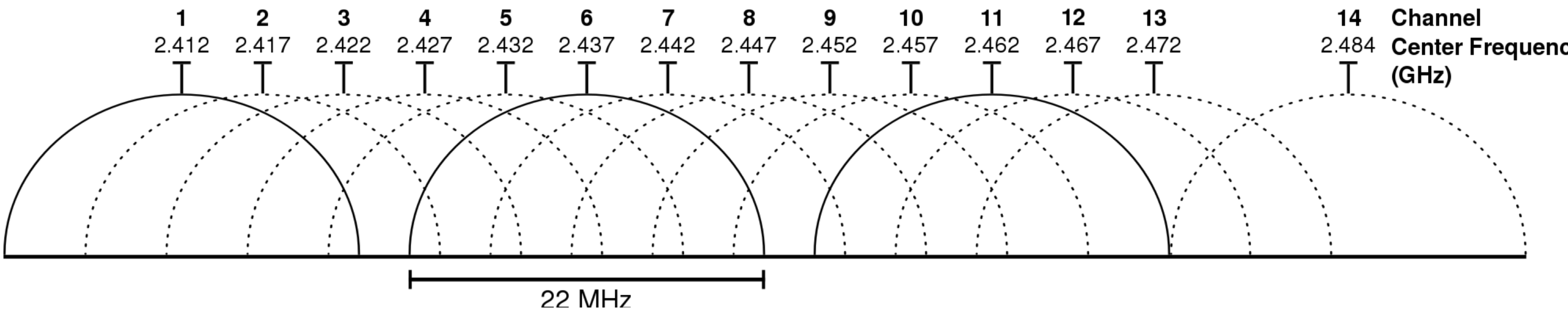
- 2.4—2.5 GHz
  - Actually 83.5 MHz of bandwidth in EU (13 channels) and 71.5 in US (11 channels)
- 4.9—5.9 GHz
  - Actual bandwidth assigned depends on countries, in US and EU there are normally 20-25 channels (about 120-150 MHz of bandwidth)
- 3.5 GHz
  - Currently allotted only in the US, very useful for extended range (up to 5km with 1W power)
- 60 GHz
  - Oxigen absorption, very small BSS ... a lot of bandwidth

2.4 GHz channels for 802.11 FHSS



- 79 1 MHz channels
- Limits Tx speed since Tx happens on one single channel at a time
- This scheme is also used by bluetooth

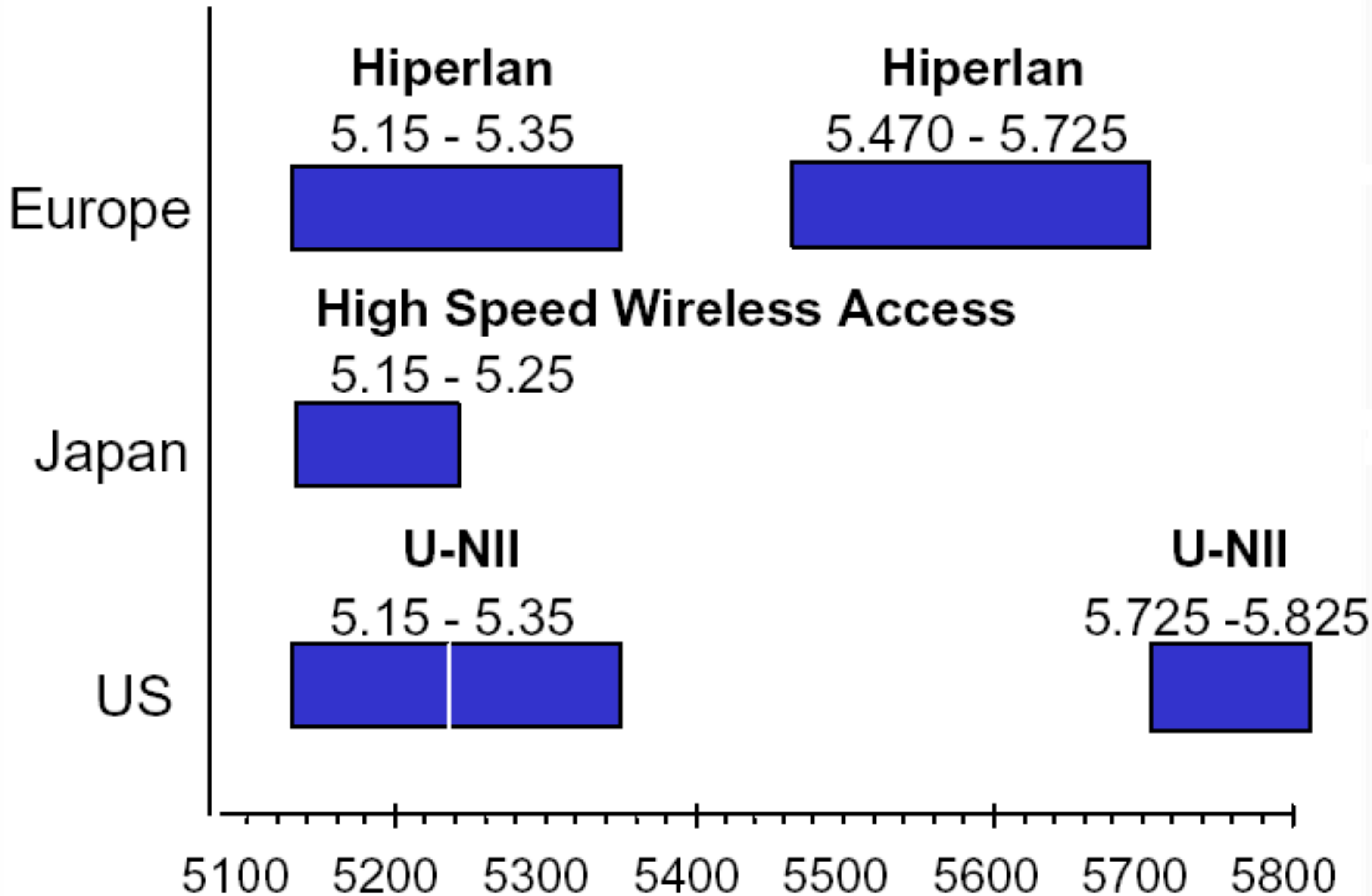
2.4 GHz channels for 802.11b/g



- At most 3 independent (orthogonal) FDM channels
  - 1,6,11; 1,7,12; 2,7,12; 1,7,13, ...
- Partially overlapping channels are noxious for Carrier Sensing → exposed and hidden terminals result

5 GHz channels for 802.11a

- Overlapping channels are avoided
  - in US 12 non-overlapping channels centered at
    - 5.180, 5.200, 5.220, 5.240, 5.260, 5.280, 5.300, 5.320
    - 5.745, 5.765. 5.785, 5.805
  - in EU the frequencies above are for hyperlan2 (licensed) thus intermediate frequencies are used
    - 5.35—5.47 GHz 6 non overlapping channels

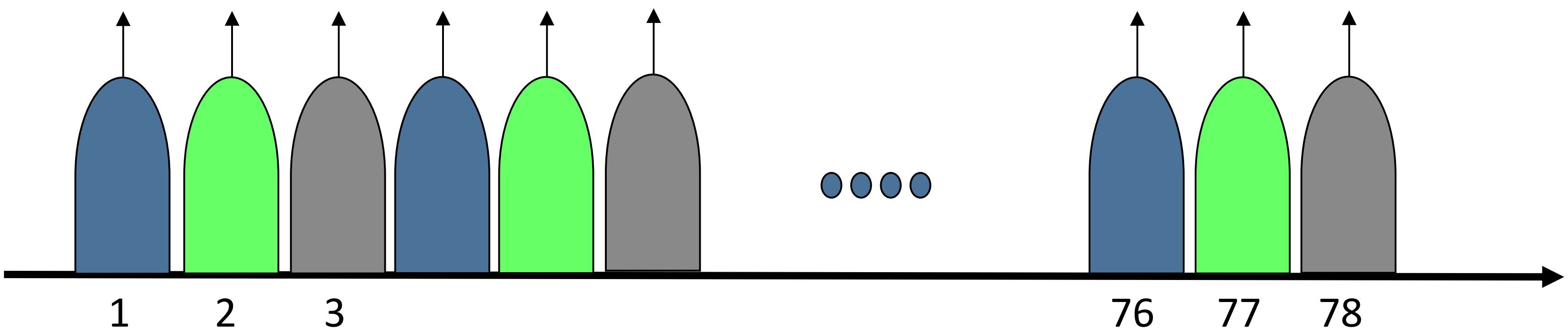


Original by Martin Johnsson: http://www.hiperlan2.com/presdocs/site/whitepaper.pdf

802.11 - FHSS

- 1 or 2 Mbit/s only @ 2.4 GHz
- GFSK modulation: base waveforms are gaussian shaped, bits are encoded shifting frequency, but the technique is such that it can also be interpreted as
- BPSK (2GFSK → 1Mbit/s)
- QPSK (4GFSK → 2Mbit/s)
- Slow Frequency Hopping SS
- 20 to 400 ms dwell time ⇒ max 50 hop/s, min 2.5 hop/s

- 1 channel is used as guard
- 78 channels are divided into 3 orthogonal channels of 26 subchannels each



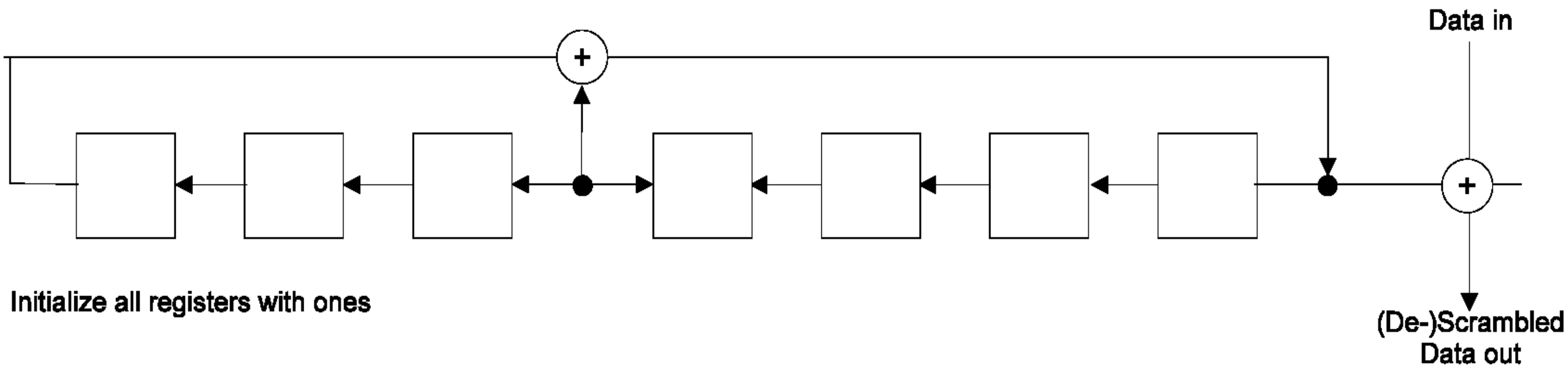
- Hopping is a PN sequence over the 26 channels
  - Tx and Rx must agree on the hopping sequence

FH PLCP frame

SYNC	SFD	PLW	PSF	HEC	PSDU

- Always transmitted at 1 Mbits/s
- SYNC: 80 bits alternating 01010101 . . .
- SFD: 16 bits (0000 1100 1011 1101)
- PLW: number of octets transmitted in the PSDU: 12-bit integer
- PSF: 4 bits, indicates the rate used in the PSDU
- HEC: CRC header protection – 16 bits
  - Generating Polinomial $G(x) = x^{16}+x^{12}+x^{5}+1$
- PSDU: actual data coming from the MAC layer; Max 4095 octets, Min 0
  - Scrambled to “whiten” it

- It is a simple feedback shift register generating a 127 bit long sequence XORed with data
  - $S(x) = x^7+x^4+1$

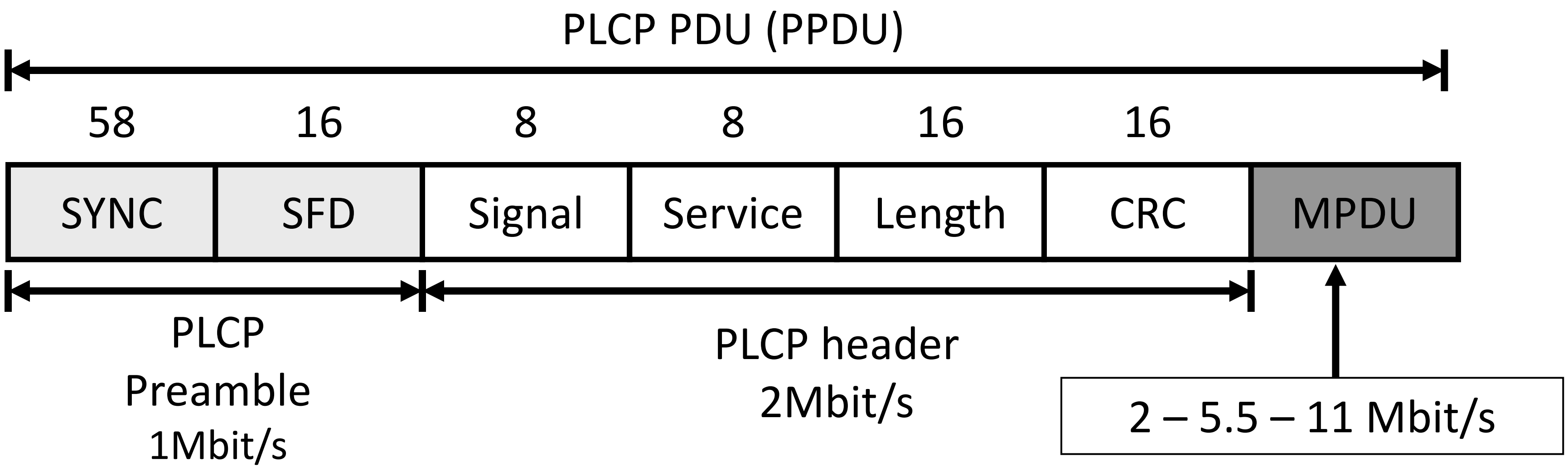


- Every 32 bits a 33-rd is inserted to suppress eventual biases

DSSS PHY

- Direct Spreading through digital multiplication with a chip sequence
- The scope is fading protection and not CDMA
- Max 3 FDM orthogonal channels
- Different specifications for the 1-2 and 5.5-11 PHY speeds
- Different headers
  - **Long** for 802.11 and 802.11b in compatibility mode (not used anymore)
  - **Short** for 802.11b High Rates only (5.5-11)

802.11b Short Preamble PLCP PDU



- Compatible with legacy IEEE 802.11 systems
- Preamble (SYNC + Start of Frame Delimiter) allows receiver to acquire the signal and synchronize itself with the transmitter
- Signal identifies the modulation scheme, transmission rate
- Length specifies the length of the MPDU (expressed in time to transmit it → NAV)
- CRC same as HEC of FHSS

- Spreading is obtained with an 11 bits Barker code
  - +1, –1, +1, +1, –1, +1, +1, +1, –1, –1, –1
- 1Mbit /s uses a binary differential PSK (DBPSK)
  - 0 → $j\omega = 0$; 1 → $j\omega = \pi$
- 2Mbit /s uses a quadrature differential PSK (DQPSK)
  - 00 → $j\omega = 0$; 01 → $j\omega = \pi/2$
  - 10 → $j\omega = \pi$; 11 → $j\omega = 3\pi/2$

- A sequence of +1 / -1 of length N such that

$$\left|\sum_{j=1}^{N-v} a_j a_{j+v}\right| \leq 1$$ for all 1<v<N

- Has very good autocorrelation function (i.e. 11 for t=0, <1 for 1<t<11
- Improves spectrum uniformity
- Increases reflection rejection (robustness to fading) because of the autocorrelation (up to 11 bit times delays!!)

- Uses a complex modulation technique based on Hadamard Transforms and known as Complementary Code Keying CCK
- It is a sequence of 8 PSK symbols with the following formula

$$c = \{e^{j(\varphi1 + \varphi2 + \varphi3 + \varphi4)}; e^{j(\varphi1 + \varphi3 + \varphi4)}; e^{j(\varphi1 + \varphi2 + \varphi4)}; -e^{j(\varphi1 + \varphi4)}; e^{j(\varphi1 + \varphi2 + \varphi3)}; e^{j(\varphi1 + \varphi3)}; -e^{j(\varphi1 + \varphi2)}; j^{\varphi1} \}$$

φi are defined differently for 5.5 and 11 Mbit/s

- The formula defines 8 different complex symbols at 11 Mchip/s
- At 11 Mbit/s 1 bit is mapped on 1 chip, at 5.5 the mapping is 1→2

Tx for 5.5 and 11 Mbit/s

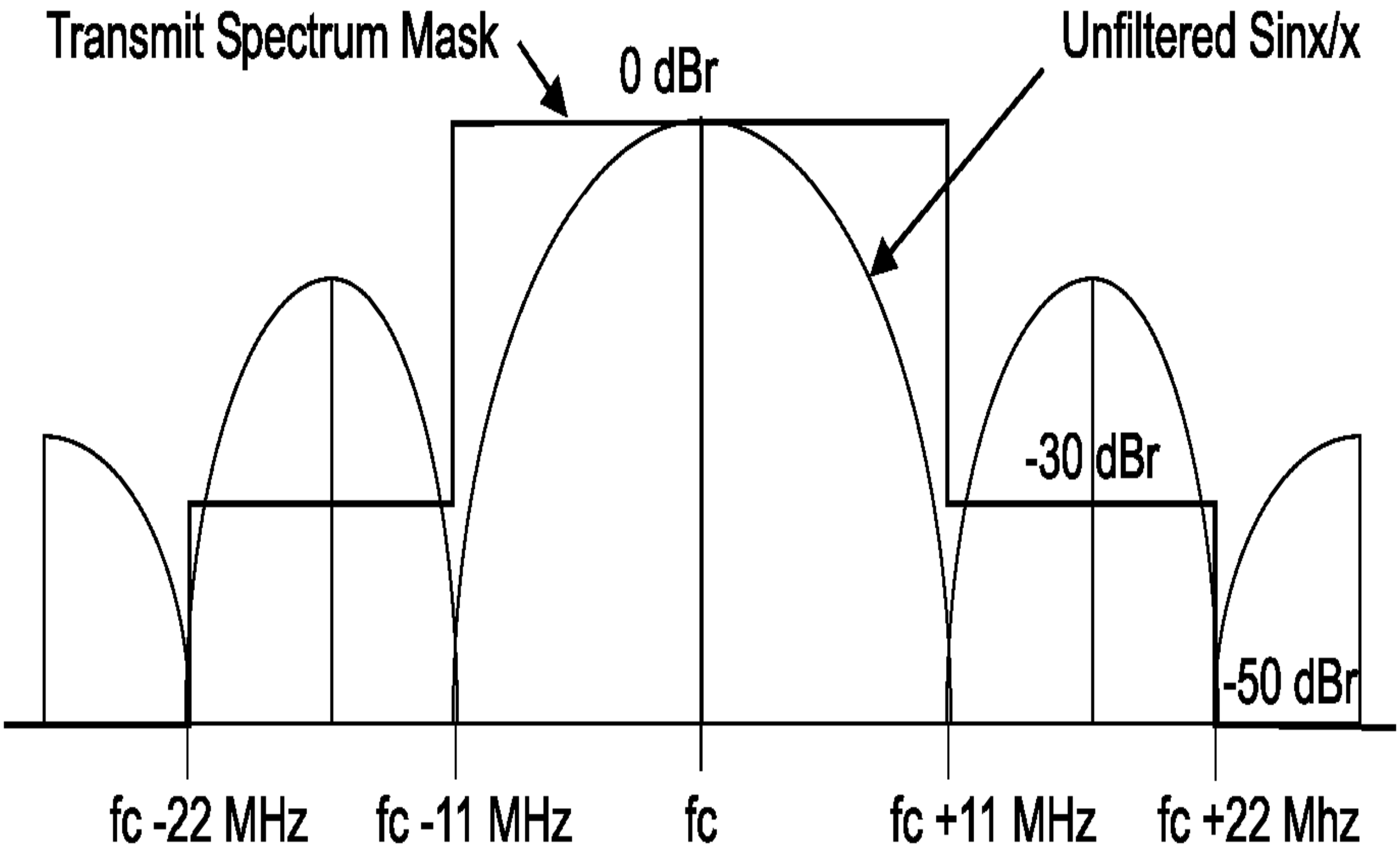
- In 5.5
  - φ1 and φ3 do not carry information
  - 4 bits are pairwise DQPSK encoded on φ2 and φ4
- In 11
  - 8 bits are pairwise DQPSK encoded on φ1, φ2, φ3 and φ4

- The resulting signal is a complex PSK modulation over single chips with correlated evolution over the CCK codes
- In practice there are 256 (2^8) possible codewords but only 32 (5.5 Mbit/s) or 64 (11 Mbit/s) are used
  - robustness to fading

Hadamard Encoding

- We can view them as extension to multiple dimensions of Barker codes
- A broad set of transformation techniques used in many fields
  - The base for the MPEG video encoding
  - Generalization of Fourier transforms
  - Quantum Computing
  - …

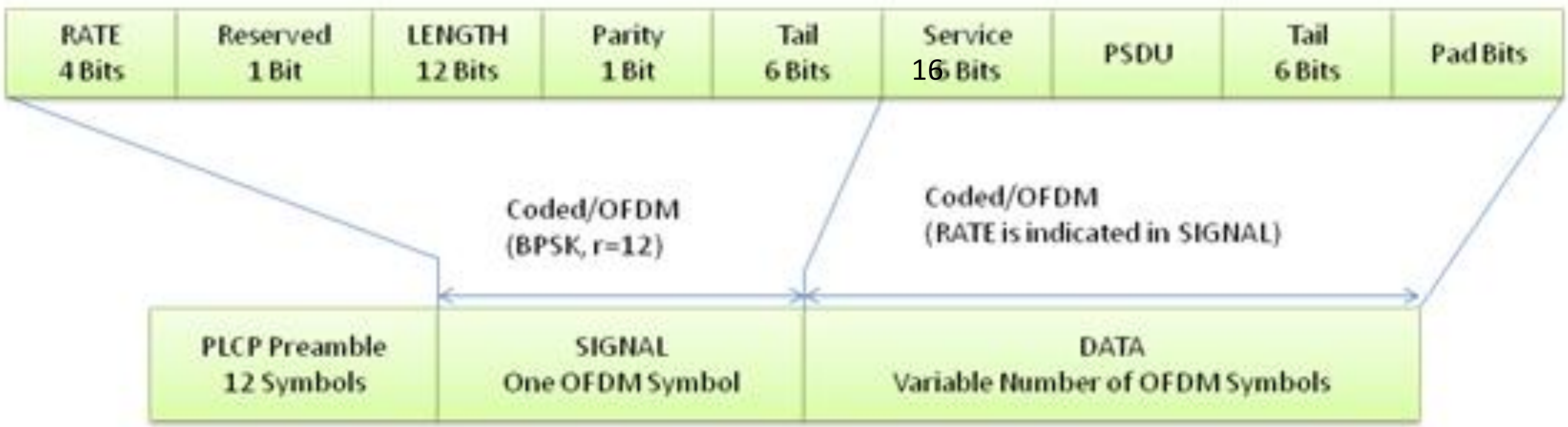
Transmission Power Mask



802.11a/g OFDM PHY

- 6, 9, 12, 18, 24, 36, 48, and 54 Mb/s
- 6, 12, 24 mandatory
- 52 subcarriers over 20 MHz, 312.5 kHz apart
- Adaptive BPSK, QPSK, 16-QAM, 64-QAM
- OFDM symbol duration 4 μs
- Provides also "halfed" and "quarter" over 10 and 5 MHz by doubling (X 4) the OFDM symbol time
- Convolutional encoding with different rates for error protection
  – Encoding is embedded within the OFDM MoDem

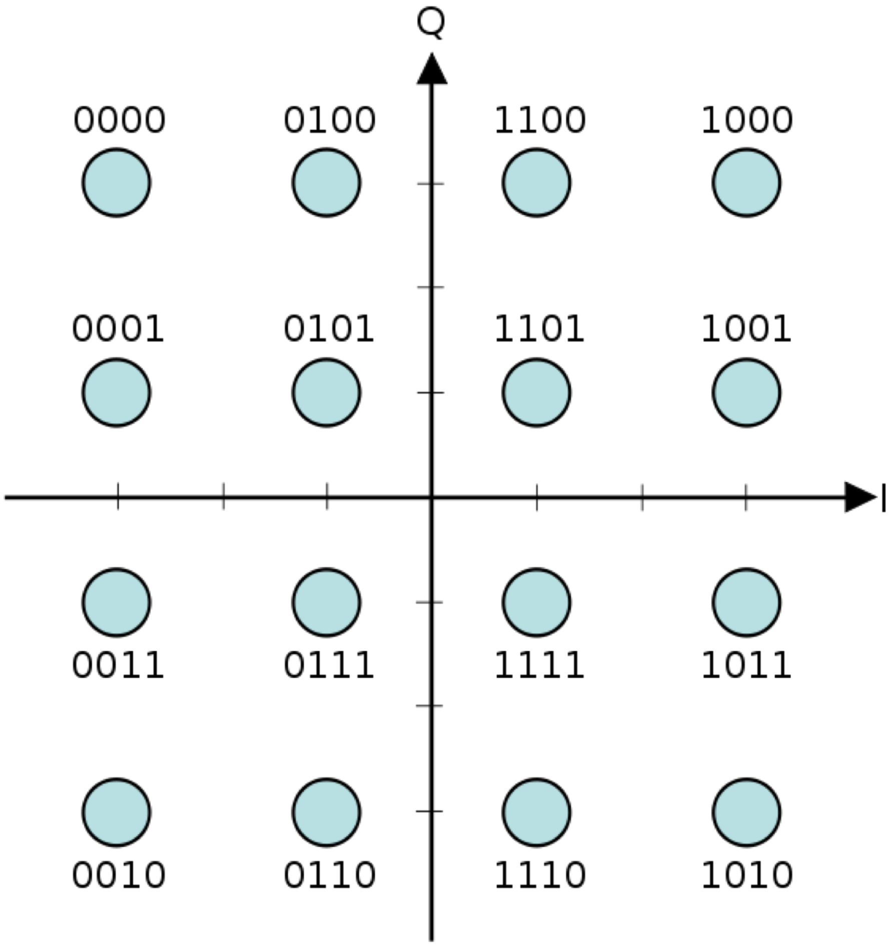
OFDM PPDU



- PLPC is 12 OFDM symbols corresponding to 48 μs
- Rate defines the DATA rate
- Service is always 0 and enables scrambling synchronization
- SIGNAL is protected with a r=1/2 convolutional code

Sample 16-QAM with gray bit encoding

- Adjacent symbols differs by one bit only
- Makes multi-bit errors less probable
- Associated with interleaving and convolutional encoding greatly reduces BER and hence FER



Data rates, Slot time and BW

• 802.11a achieves data rates 6,9,12,18,24,36,48, and 54 MB/s.
• One OFDM symbol is sent every 4us, of which 0.8μs is the cyclic prefix (guard time)

Bandwidth
• One OFDM is 20 MHz and inludes 64 carriers:
=> One carrier = 20MHz/64 = 312 kHz.

SLOT TIME
• Slot time = RX-to-TX turnaround time + MAC processing delay + CCA < 9μs where CCA = clear channel assessment

Typical times:
• RX-to-TX turnaround time < 2μs
• MAC processing delay < 2μs
• CCA < 4μs

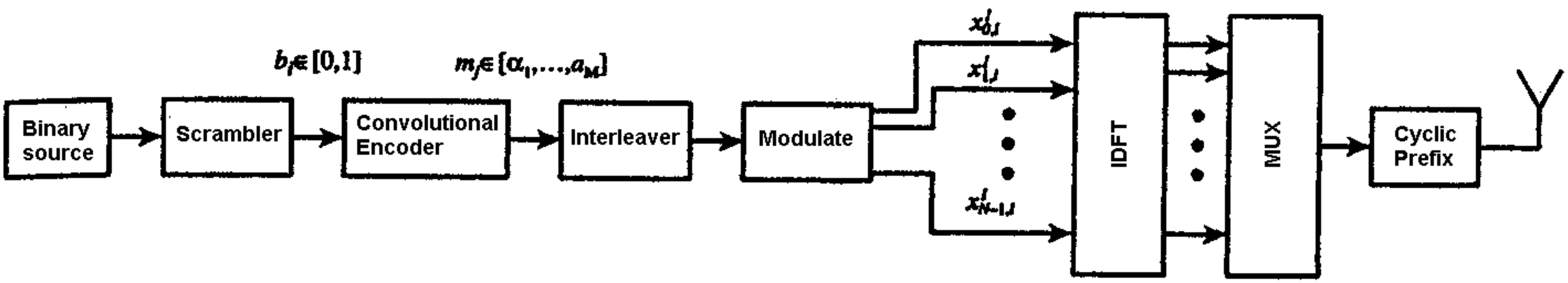
BPSK example:
• 250k symbols sent every second.
• One symbol uses 48 data carriers.
• BPSK modulation with a convolutional code of rate 1/2
48 * 0.5 * 250k = 6 Mb/s

64-QAM example:
• 250ksymbols/s, 48 data carriers.
• 64-QAM modulation = 64 = 2^6
• a convolutional code of rate 3/4
48 * 0.75 * 250k *6 = 54 Mbit/s

802.11a/g modulations

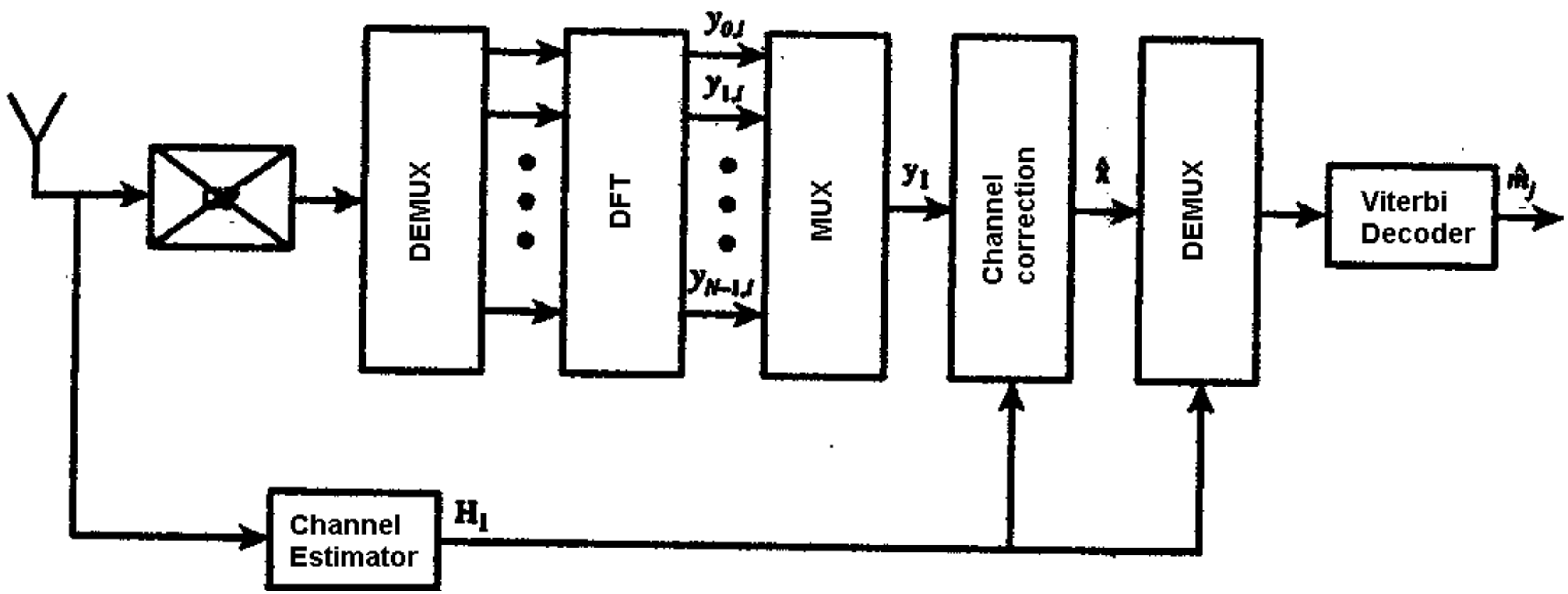
Mod.	Net (Mbit/s)	Gross (Mbit/s)	FEC rate	Efficiency (bit/sym.)	$T_{1472\ B}$ (μs)
BPSK	6	12	1/2	24	2012
BPSK	9	12	3/4	36	1344
QPSK	12	24	1/2	48	1008
QPSK	18	24	3/4	72	672
16-QAM	24	48	1/2	96	504
16-QAM	36	48	3/4	144	336
64-QAM	48	72	2/3	192	252
64-QAM	54	72	3/4	216	224

Transmission block scheme



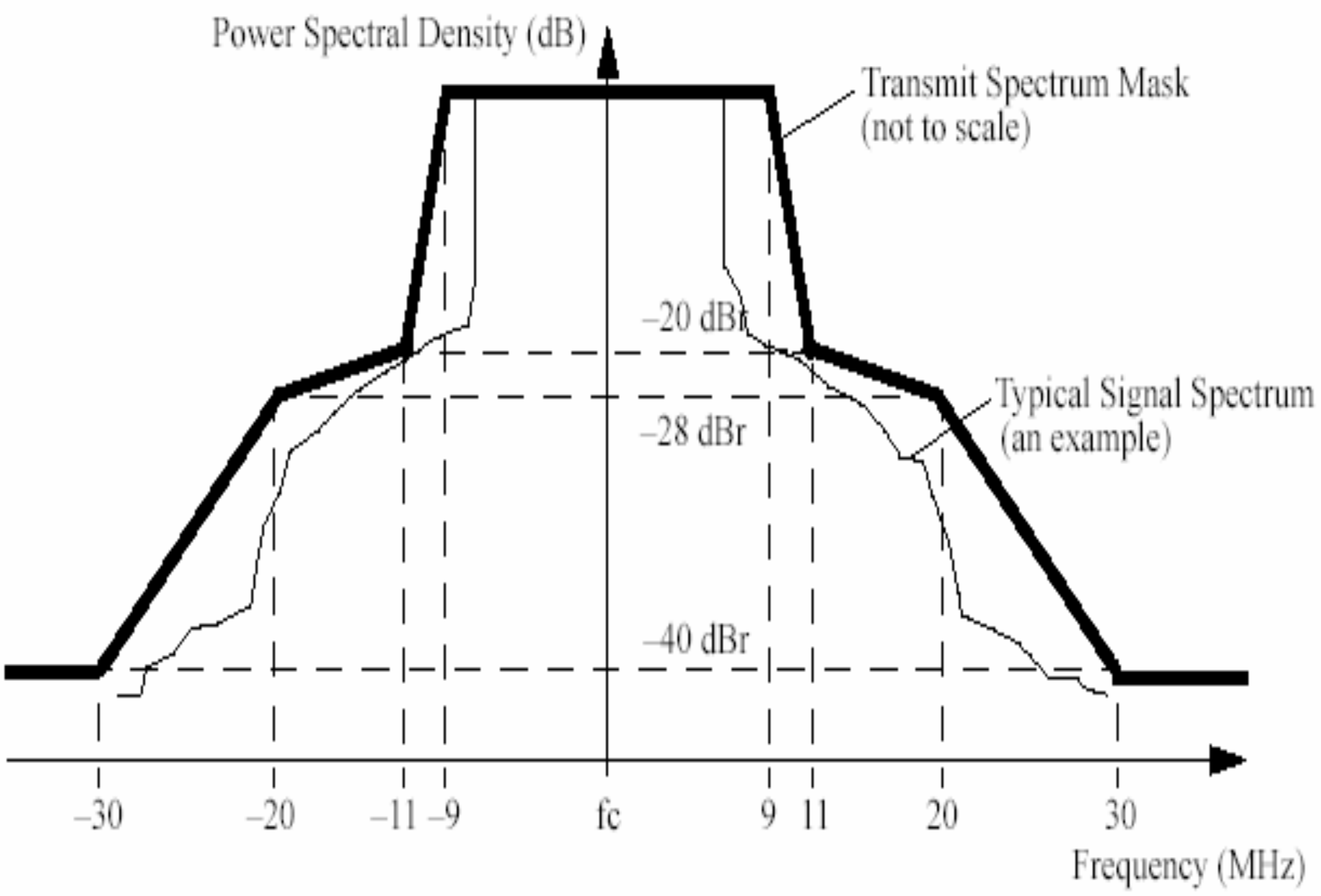
- The modulation is done in the digital domain with an IFFT
- Interleaving distributes (at the receiver) evenly errors avoiding bursts
- Convolutional coding corrects most of the “noise” errors
  - This justifies the “observation” that modern 802.11 tends to have an on-off behavior

Receiver block scheme



- Channel estimation enables distortion correction
- Viterbi decoding is an ML decoder for convolutional codes

OFDM transmission power mask



802.11g specifics

- Defines the use of 802.11a OFDM techniques in the 2.4 GHz band
- Mandates backward compatibility with 802.11b
- Introduces some inefficiency for backward compatibility
- Many PPDU formats
  - Long/sort preambles
  - All OFDM (pure g) or CCK/DSSS Headers with OFDM PSDU (compatibility mode or b/g)

802.11n/ac:
MIMO and Space Diversity

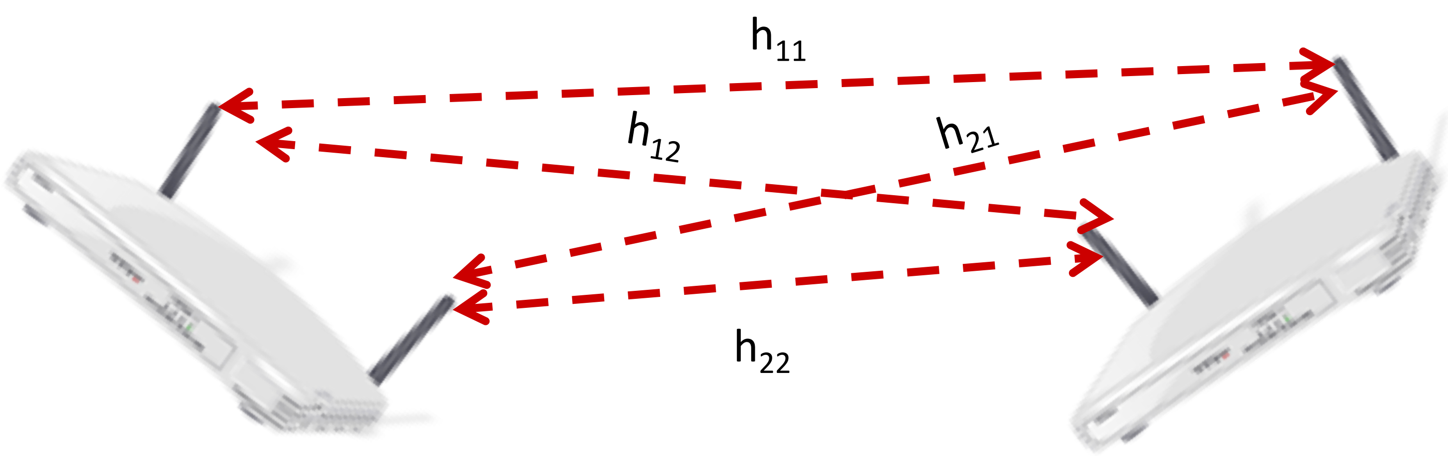
The goal

- The IEEE 802.11 WG on "high throughput" set out with the following goals
  - Achieve PHY rate speeds > 300Mbit/s
  - Achieve App-level throughputs > 100Mbit/s
- Stick to the ISM bands
- Remain reasonably compliant and compatible with existing systems
  - Similar PHY channel use
  - Basic CSMA capabilities for DCF
- OFDM derived from 802.11a as a work baseline
  - Ultra Wide Band techniques are not considered → another WG standardized 802.11ad at 60 GHz

The key ideas

- Leave flexibility on channel width 10, 20, 40, 80, 160 MHz
  - The duration of OFDM symbols reduces linearly with the channel bandwidth, increasing PHY speed
- Use space diversity techniques either to improve reliability or to increase throughput (more later)
- Make the most out of TXOPs and Block ACK techniques developed in 802.11e
- Further “trim” PHY layer possibilities
  - E.g., reduce ODFM symbol Guard Time (GI) to 400ns instead of 800ns as symbol spreading due to multipath is normally below 200ns

- Exploit multiple Tx and Rx antennas with a reasonable independent transmission path combining the different signals



Space Diversity

- h_{ij} are the (time varying) channel characterizations between Tx antenna i and Rx antenna j
- The scheme is known as MIMO (Multiple In Multiple Out)
- The multiple flows can be used to
  - Increase throughput
  - Increase data reliability
  - Perform Beamforming
- 802.11n/ac allows up to 4 antennas
  - STA have a minimum of 1
  - AP have a minimum of 2

Space Diversity

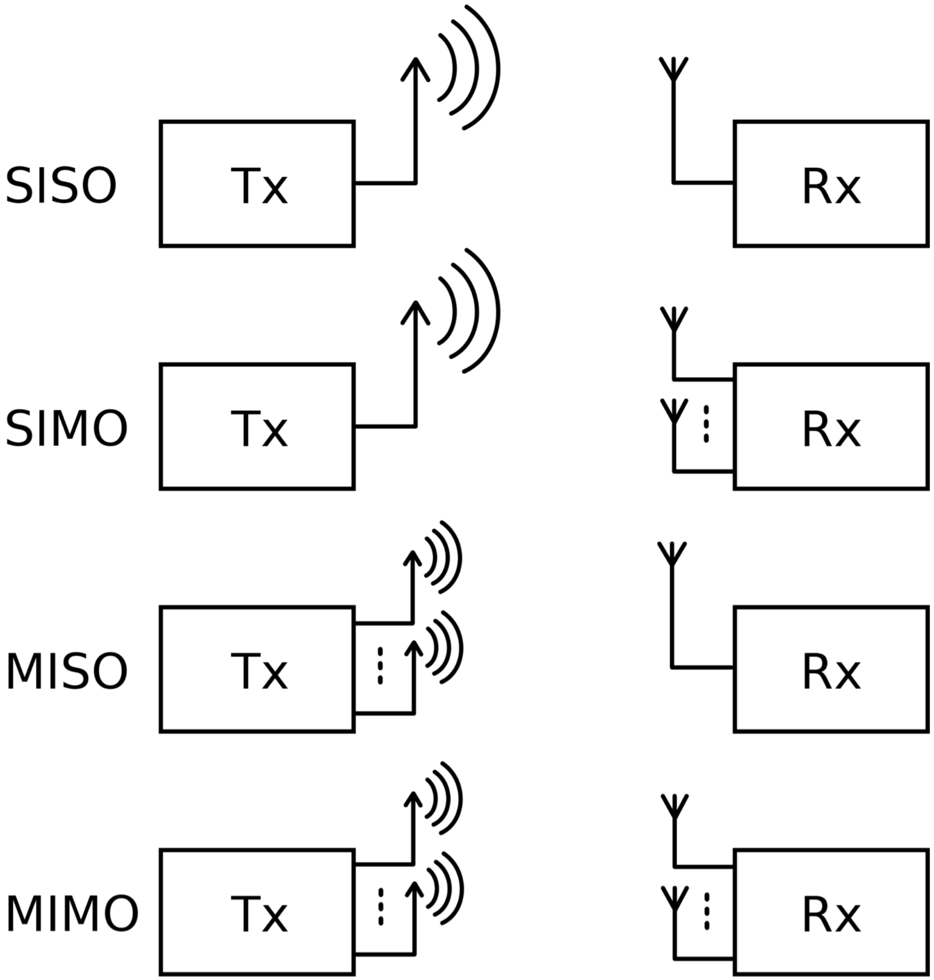
- A radio is characterized by the a 3-ple:

  a x b : c

  – a=max No. of Tx "chains"
  – b=max No. of Rx "chains"
  – c=max No. of independent spatial data streams
  – c<=a,b ; a,b <= No. of antennas
  – **a "chain" means the ability of processing an independent data flow**
- 2 x 3 : 2 identify a device with 3 antennas that can send at most 2 independent data flow, but receive with 3
- 2 x 2 : 1 has 2 antennas, but cannot use the diversity to increase throughput, only to improve reliability

SISO, MISO, SIMO, MIMO

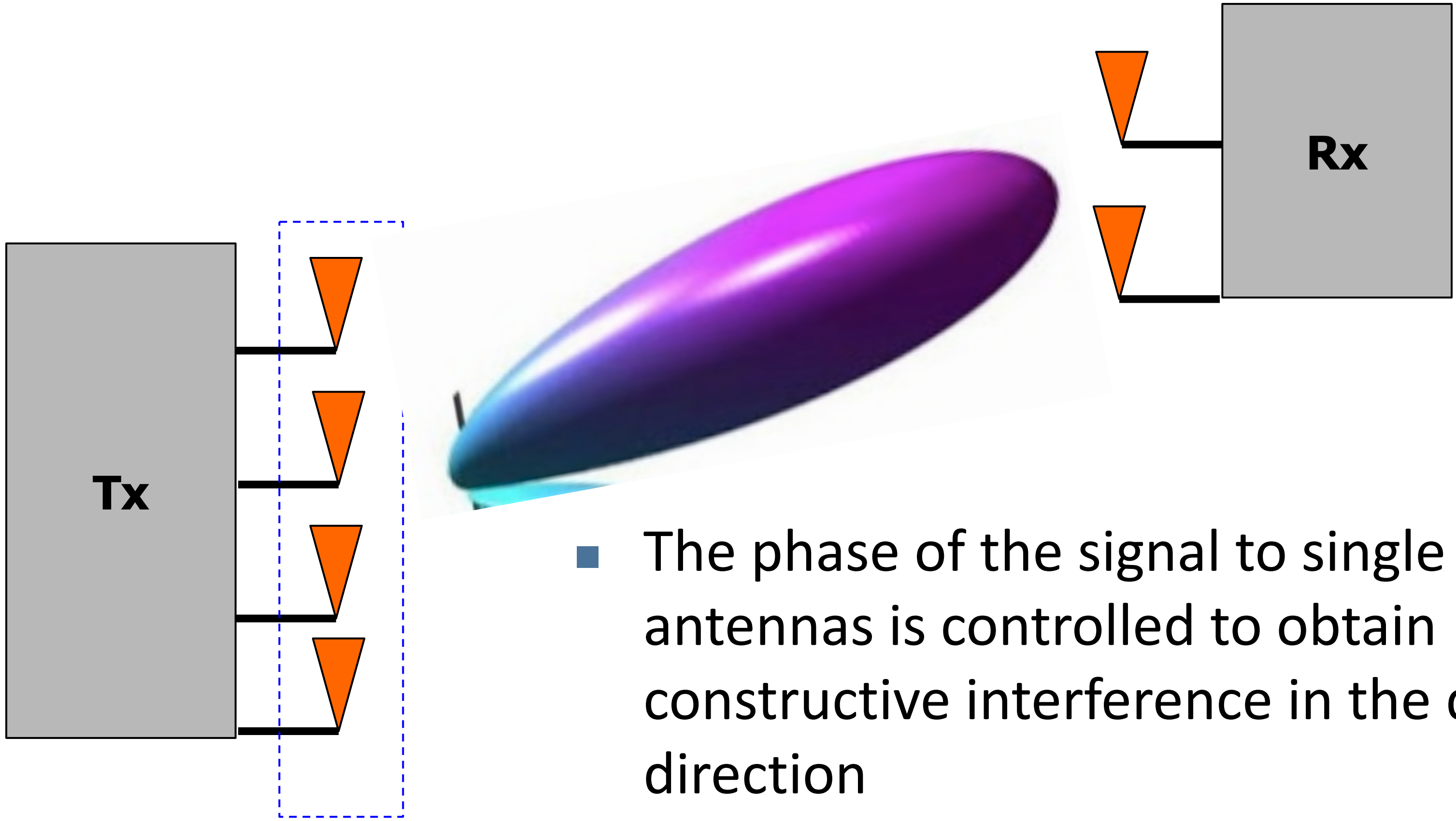
- The number of antennas at devices is independent
- Complexity and performance increase with the number of Tx and Rx antennas
- In principle different Tx can go to different devices



MIMO

- Based on the coordinated processing of the data flows and signals to the antennas
- Many different ways to use the redundancy and increased processing power
  - Directional beams
  - Interference reduction
  - Multiple parallel data flows
- Moreover the behavior is as if antennas had a larger cross-section
  - More energy from the signal can be collected at the receiver

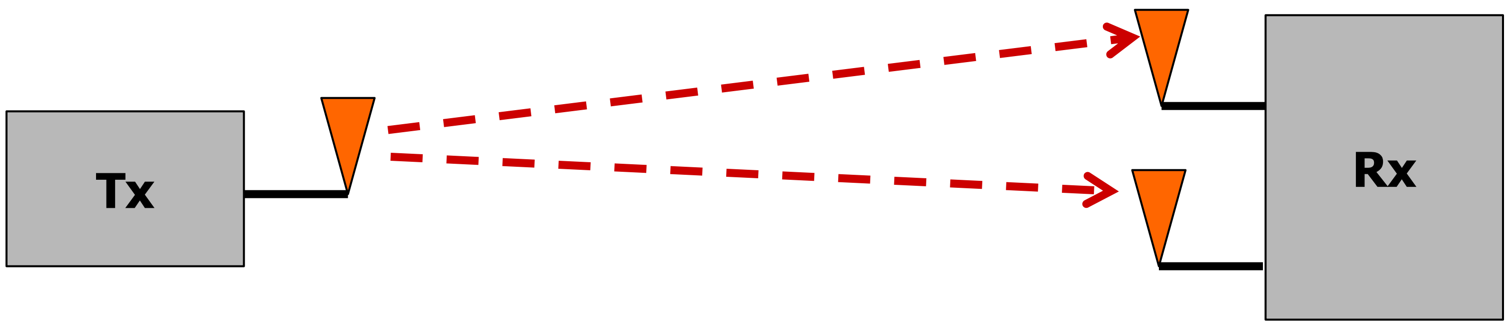
- Tx antennas are used as a single phase-array antenna to obtain directionality



  - The phase of the signal to single antennas is controlled to obtain constructive interference in the desired direction

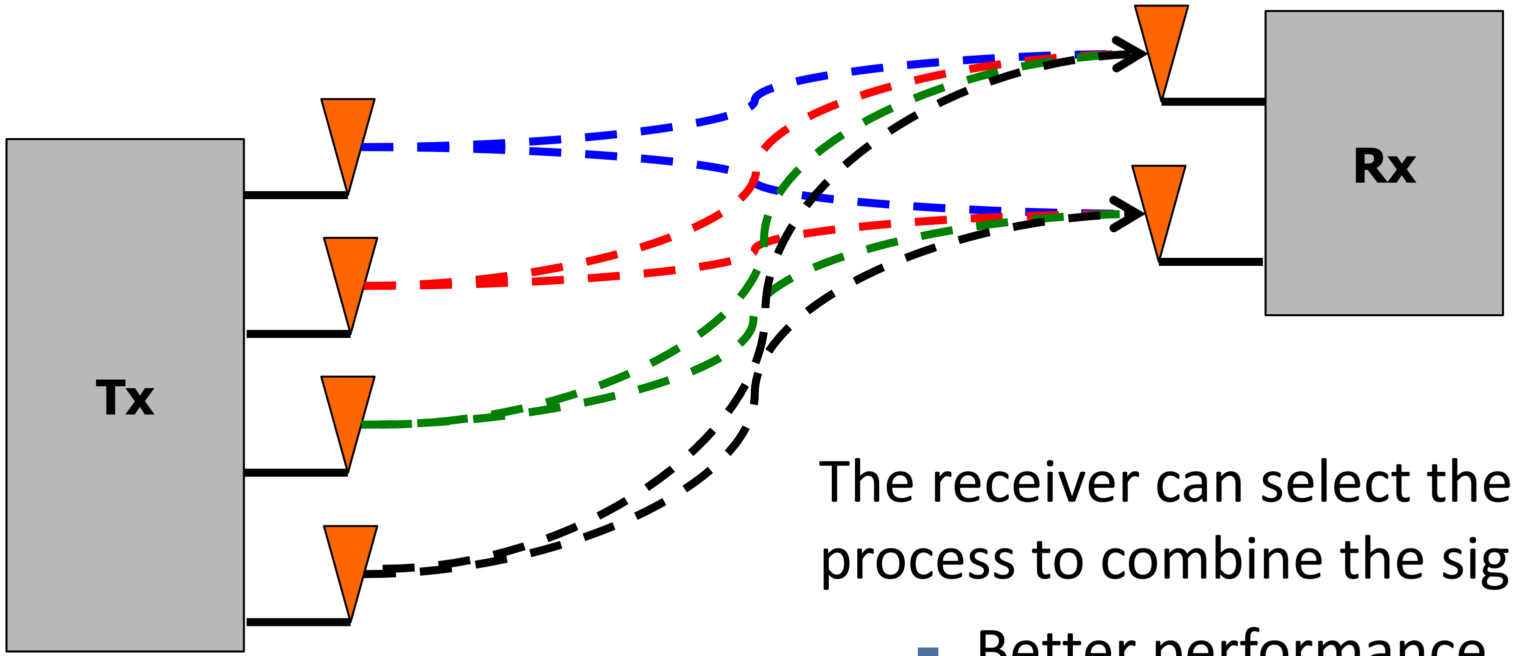
- Beamforming, i.e., using the Tx antennas as a single phase array is complex
- Requires full knowledge (estimation at the transmitter) of the channel state at the receiver: The CSI (Channel State Information)
- Signals must be pre-precessed to obtain the correct phase and amplitude at the antennas
- 802.11n can use beamforming, but often it is done with the “switched array technique”
  - Antennas are selectively switched on and off changing the antenna pattern
  - Patterns are limited and not “well formed”
  - They cannot be used to process received signals

If the receiver antennas are more than $\lambda/2$ apart (the more the better) the received signals have roughly independent fading and can be combined



The phase of the signal to single antennas is controlled to obtain constructive interference in the desired direction

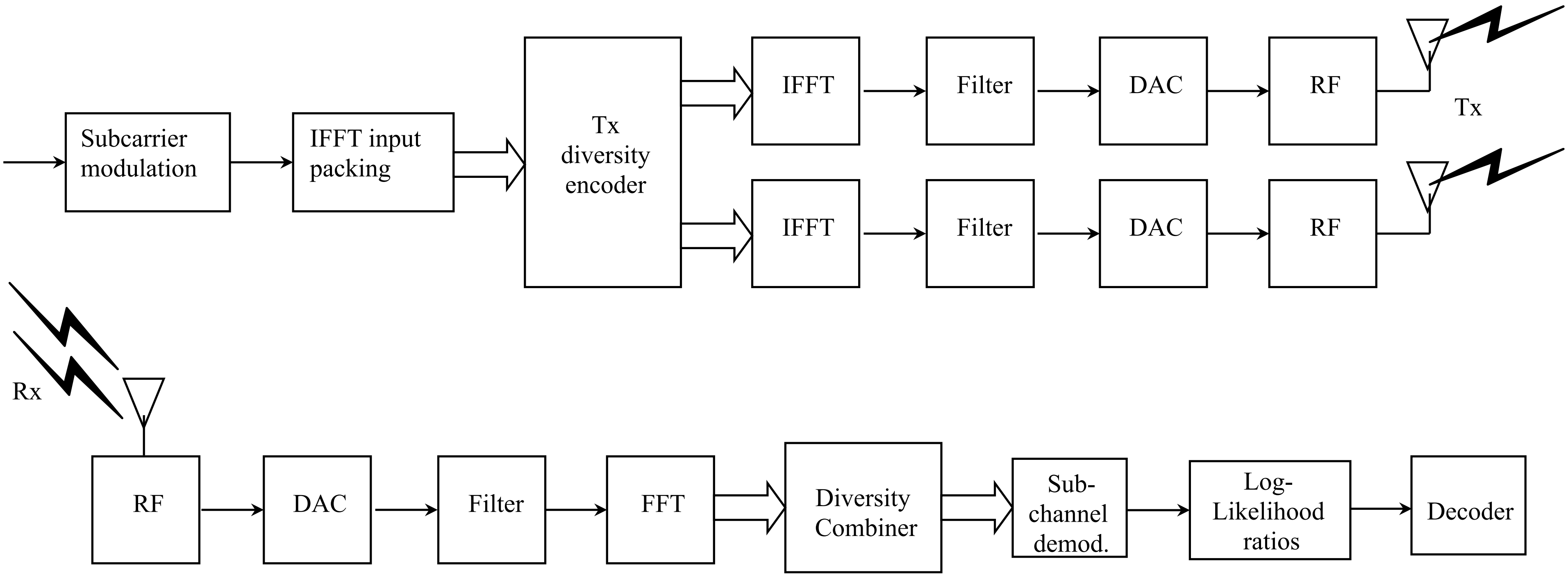
Tx antennas are used independently, transmitting multiple-orthogonally-encoded version of the same information



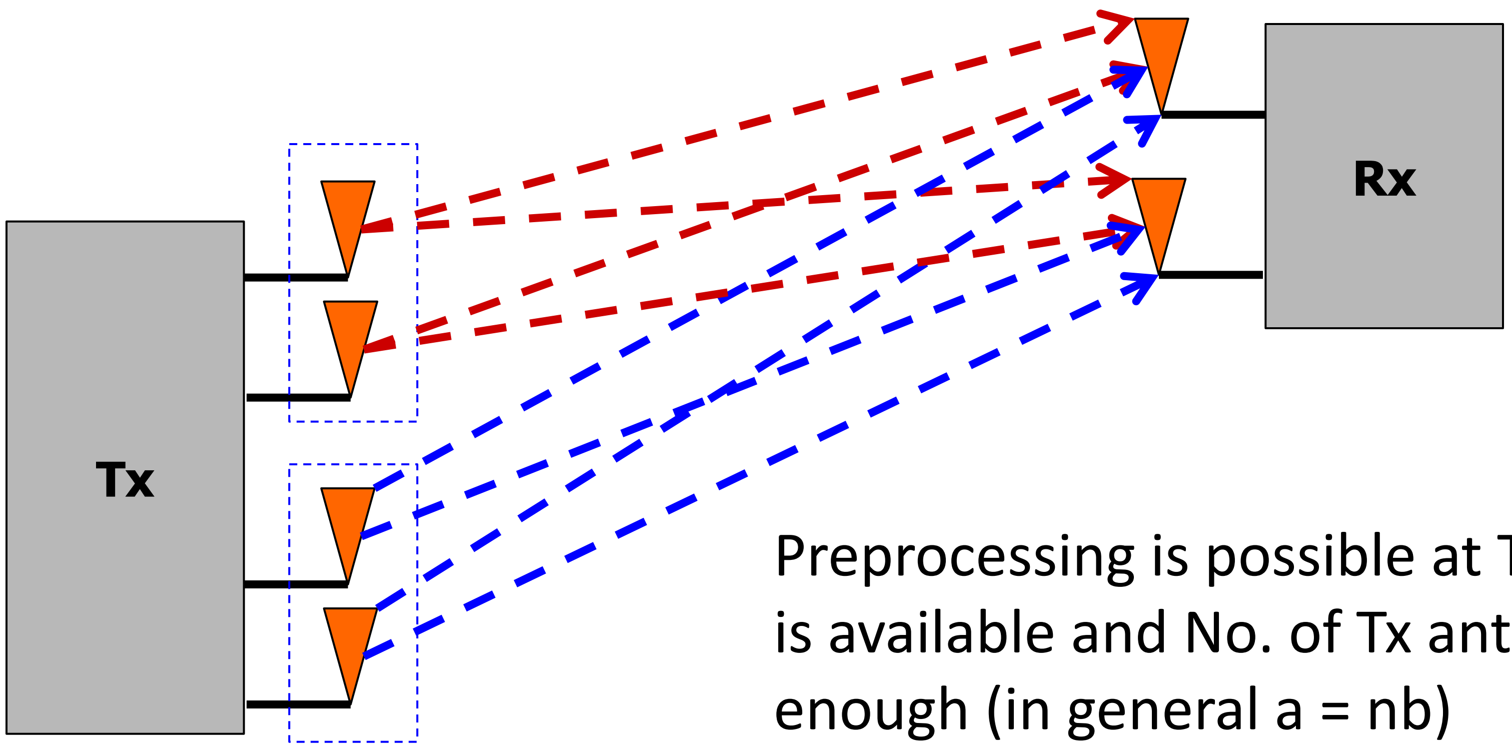
The receiver can select the best or process to combine the signals

- Better performance
- More complexity

- 2 Tx antennas, 1 Rx antenna
- Two chains are needed for the transmission



max(c) = min(a,b) → No. of streams is limited by the smallest number of antennas



Preprocessing is possible at Tx if CSI is available and No. of Tx antennas is enough (in general a = nb)

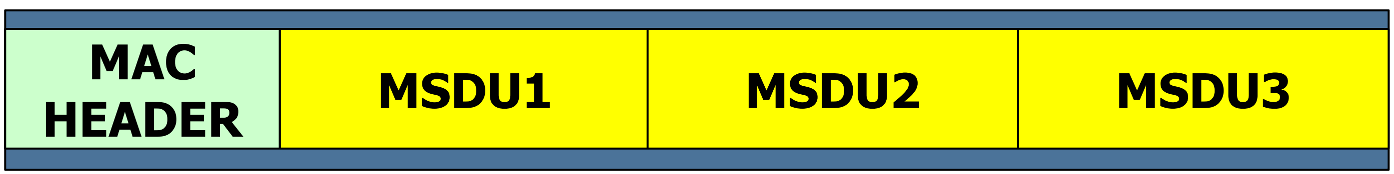
Modulation and Coding

- Very similar to 802.11a but ...
- 20 and 40 MHz channels
- Up to 4 streams
- Overall 124 (31x2x2) possible schemes exist
  - 8 mandatory modulation schemes
  - Define basic/required rates
- Up to 600 Mbit/s,
  - with 400 ns GI
  - 4 spatial streams
  - 64-QAM modulation, 5/6 Convolutional encoding
- Data rate table ... is too large for a slide ☺ see wikipedia http://en.wikipedia.org/wiki/IEEE_802.11n-2009#Number_of_antennas

What MAC for MIMO?

- CSMA is not well adapted to MIMO and space diversity
- However there is not viable alternative for a DCF
  - TXOPs help
  - Block ACKs help
- MPDUs can be aggregated using Block ACKs
  - Can work also across multiple streams
- MSDUs can be aggregated within the same MPDU
  - MPDU size is now 64 kbytes! (up from 2.3kB)
- Block ACKs can refer to MPDUs on multiple streams

- Multiple SDU within the same frame
  - One single MAC header



- Multiple PDU within the same physical communication
  - One single PLPC header
  - Multiple (one per MSDU) MAC headers

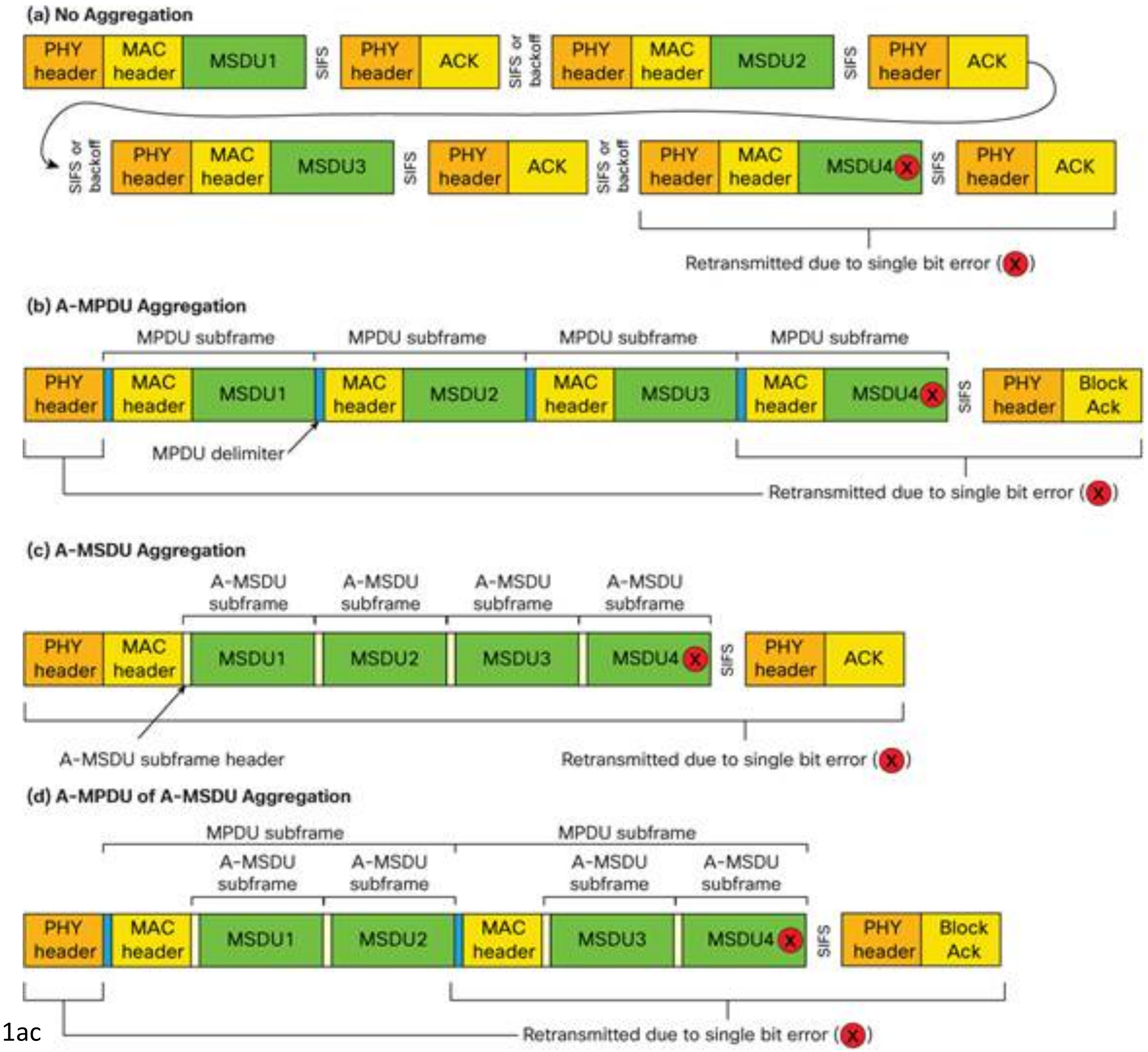
PLPC HEADER	**MAC HEADER**	**MSDU1**	**MAC HEADER**	**MSDU2**

- A-MSDU and A-MPDU can be nested
- Large gains for sustained transfers, STA/AP accumulate traffic for block transmission

Comparison of aggregation

A-MSDU Aggregation is the most efficient , but also incurs the most overhead if channel errors occur.

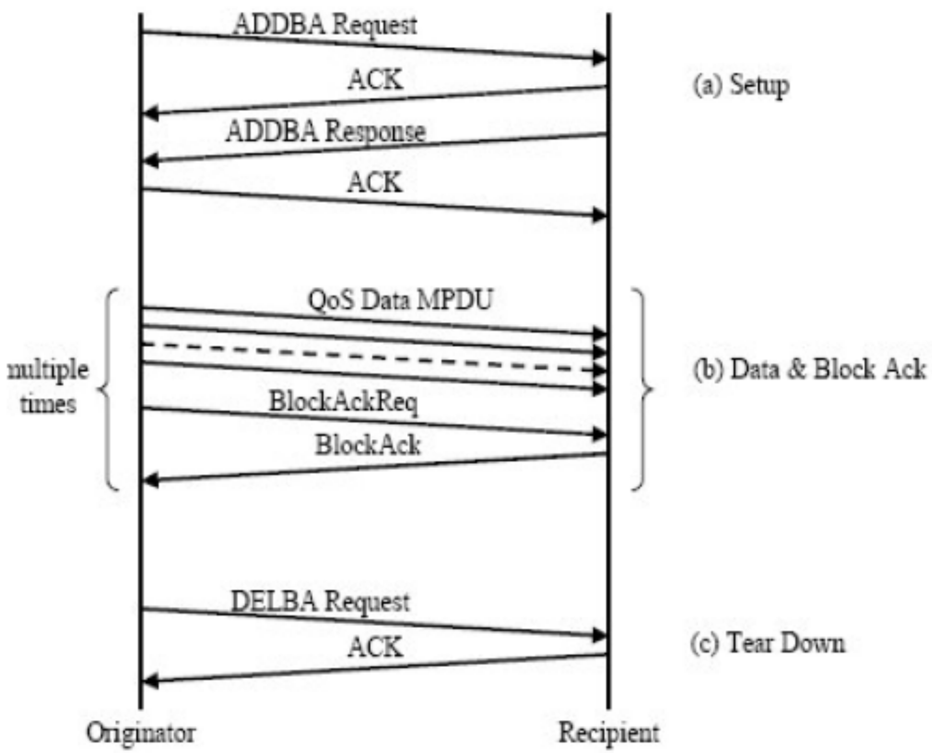
Mixing A-PPDU and A-MSDU Aggregation offers flexibility in choosing the optimal mix of efficiency when there are no errors and retransmission overheads



courtesy of Cisco System: white paper on 802.11ac

Block ACK Usage

- Block ACK procedure is not trivial
- Must be initiated and terminated



ADDBA Request used to initiate BA session

ADDBA Response confirms/rejects the sessions

Frames of a session need NOT be sent consecutively
- They can be mixed with other frames of a station
- They can be interleaved with packets from other stations
- They can be sent in multiple .11e TXOPs

BlockAckReq used to solicit a BlockACK response frame

DELBA used to terminate a BA session

Compressed Block ACKs

- Block ACK message in 802.11e contains Block ACK field with 64 × 2 bytes
  – 2 bytes for each MSDU fragment to be acknowledged)
- Fragmentation of MSDU is not allowed in 802.11n A-MPDU
- 2 bytes reduced to 1 byte, and the block ACK bitmap is compressed to 64 bytes
  – Maximum number of MPDUs in 1 A-MPDU is limited to 64
- The TX STA can request one block ACK for all frames instead of using legacy acknowledgments to each frame
- Gain is in the reduction of SIFS

802.11ac

5-th generation WiFi OFDM-MIMO technology to its (current??) limit

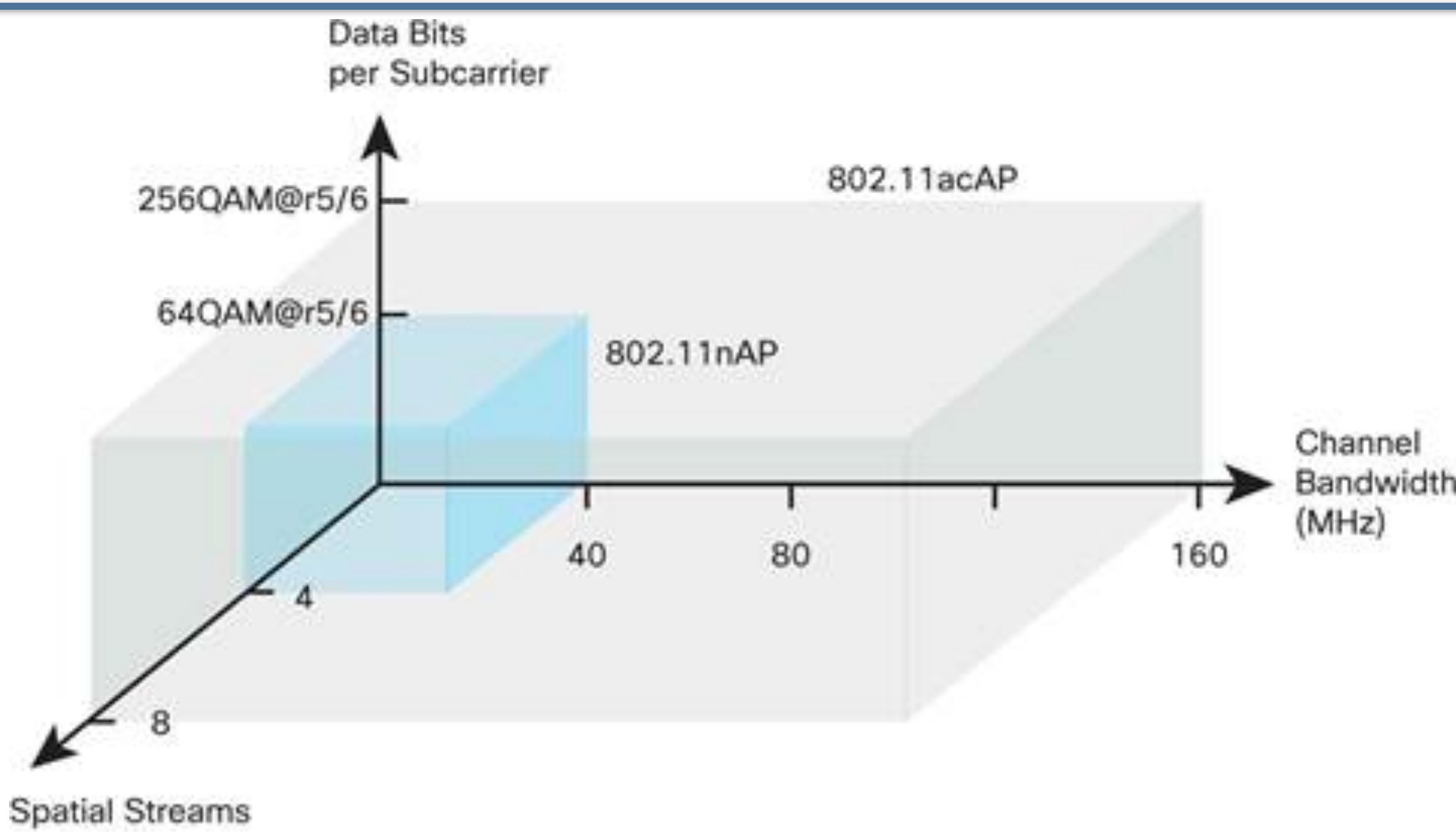
Gbit Transmission Speed – Large Bandwidth, 256 QAM Modulations

Wireless “switching” – MU-MIMO

802.11ac features

- Available only in the 5GHz band
- Channel aggregation: 20, 40, 80, 160 MHz
- Dynamic use of aggregated channels
- 256 QAM modulation if channel conditions permits (more levels more noise/interference sensitivity)
- Standardized and interoperable beamforming
- Mandatory frame aggregation in A-MPDUs
  - All PSDs (even single ones) are sent as if aggregated
- Explicit avoidance of 802.11n features resulted useless (less backward compatibility problems)

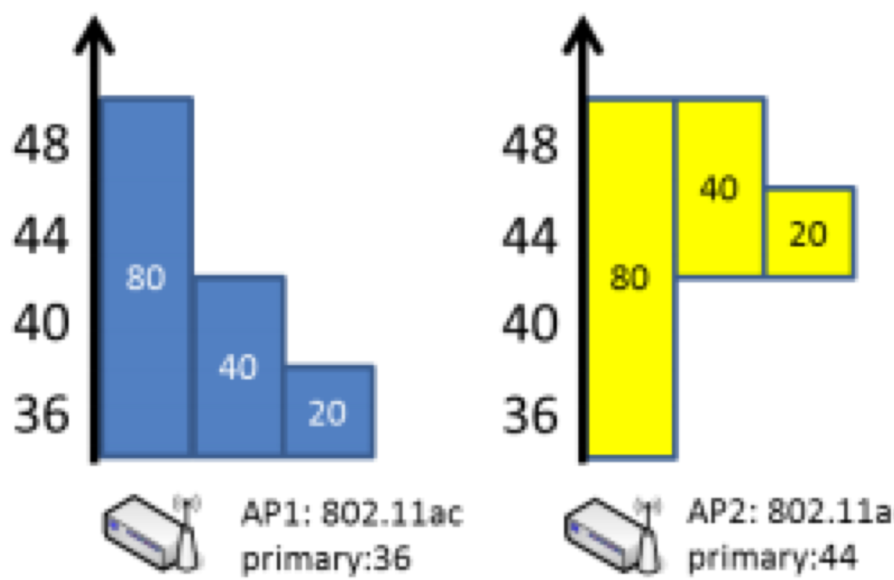
/ac vs /n enhancement space



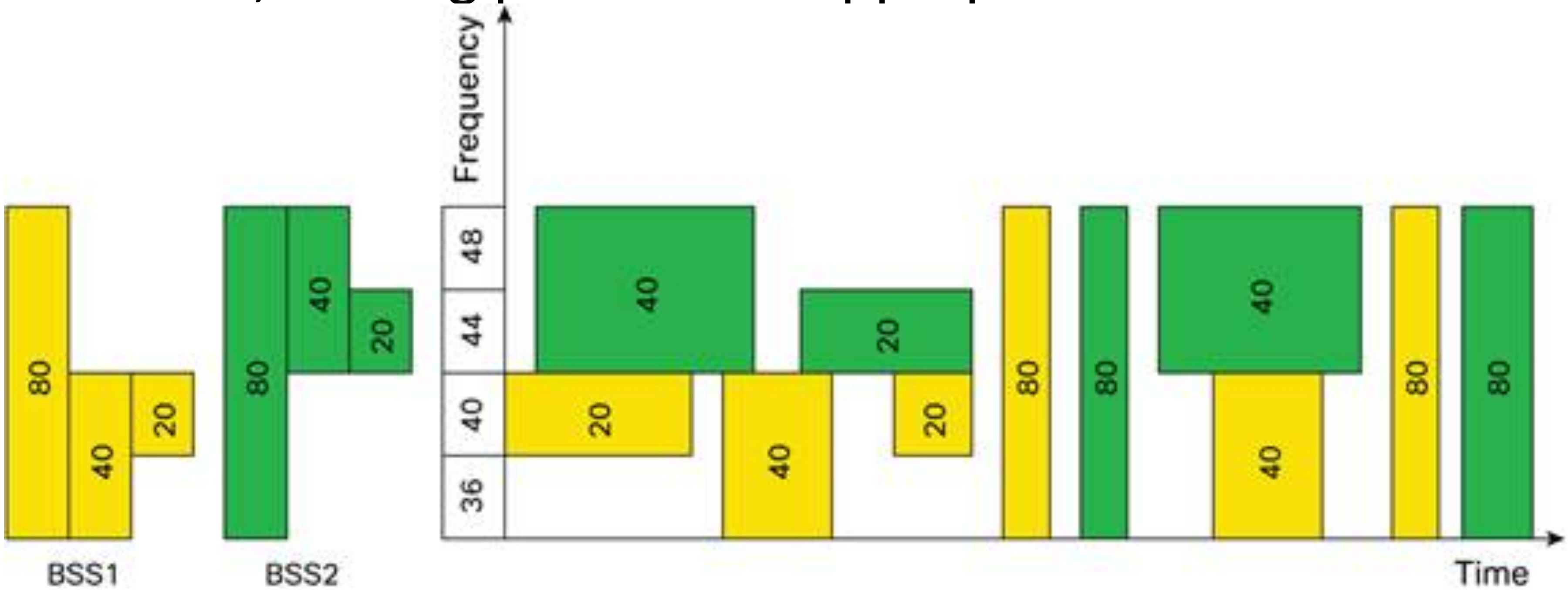
courtesy of Cisco System: white paper on 802.11ac

Channel selection

- The choice of the transmission bandwidth (20—160 MHz) is done on a per-frame (aggregated) basis
- CCA is performed in parallel on all the 20 MHz channels where transmission occurs
- If one is occupied the STA desist from transmitting on it
- A concept of primary-secondary channels is defined to enhance planning of ESS



- Two BSS can dynamically use the same (wideband) channel, sharing part of it as appropriate



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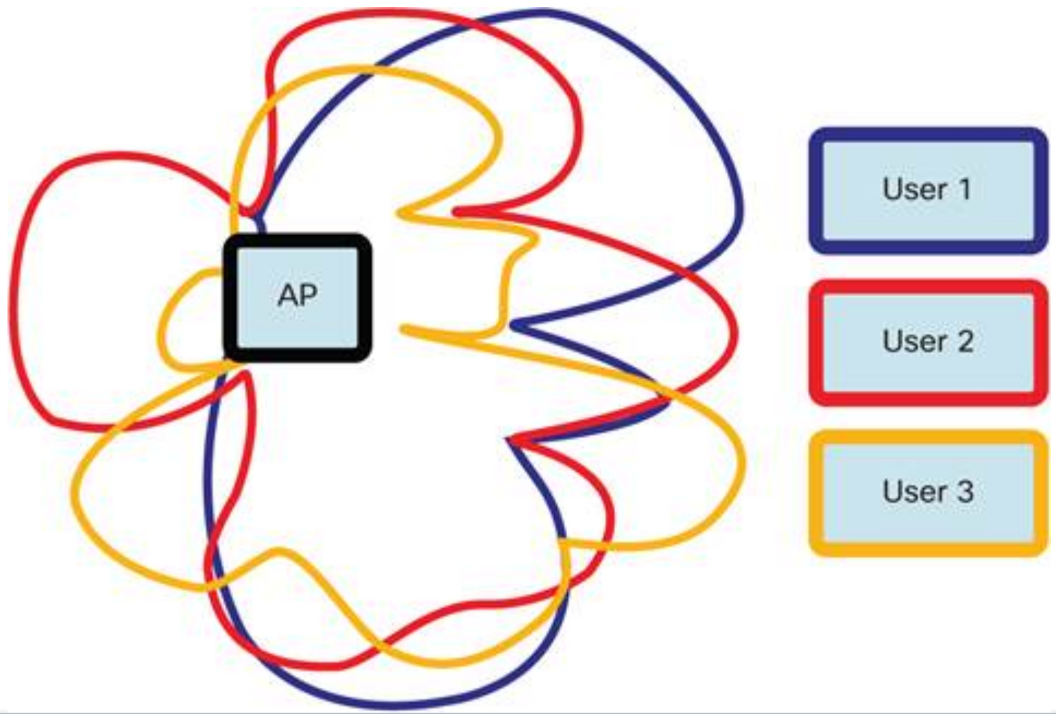
MU-MIMO

- 802.11n defines MIMO, but its use is limited to communications between the same pair of stations
- 802.11ac allows the AP to do beamforming so as to transmit to different users in parallel at the same time



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