Nomadic Communications 802.11n/ac: MIMO and Space Diversity

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http://disi.unitn.it/locigno/teaching-duties/nomadic-communications

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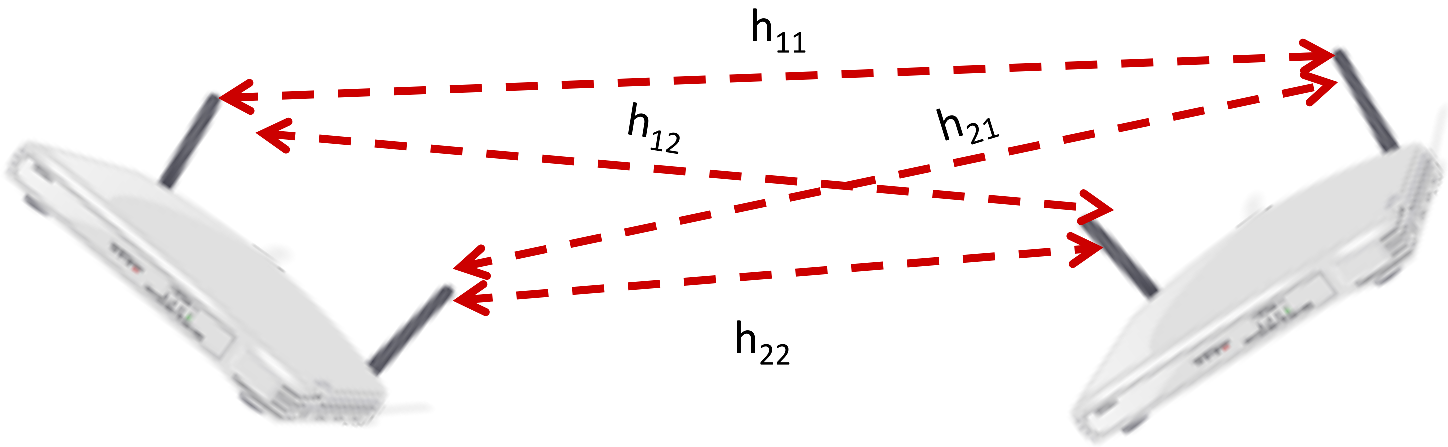
The goal

- 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 is working on this 802.11ad

The key ideas

- Leave flexibility on channel width 10, 20, but also 40 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 allows up to 4 antennas
  - STA have a minimum of 1
  - AP have a minimum of 2

Space Diversity

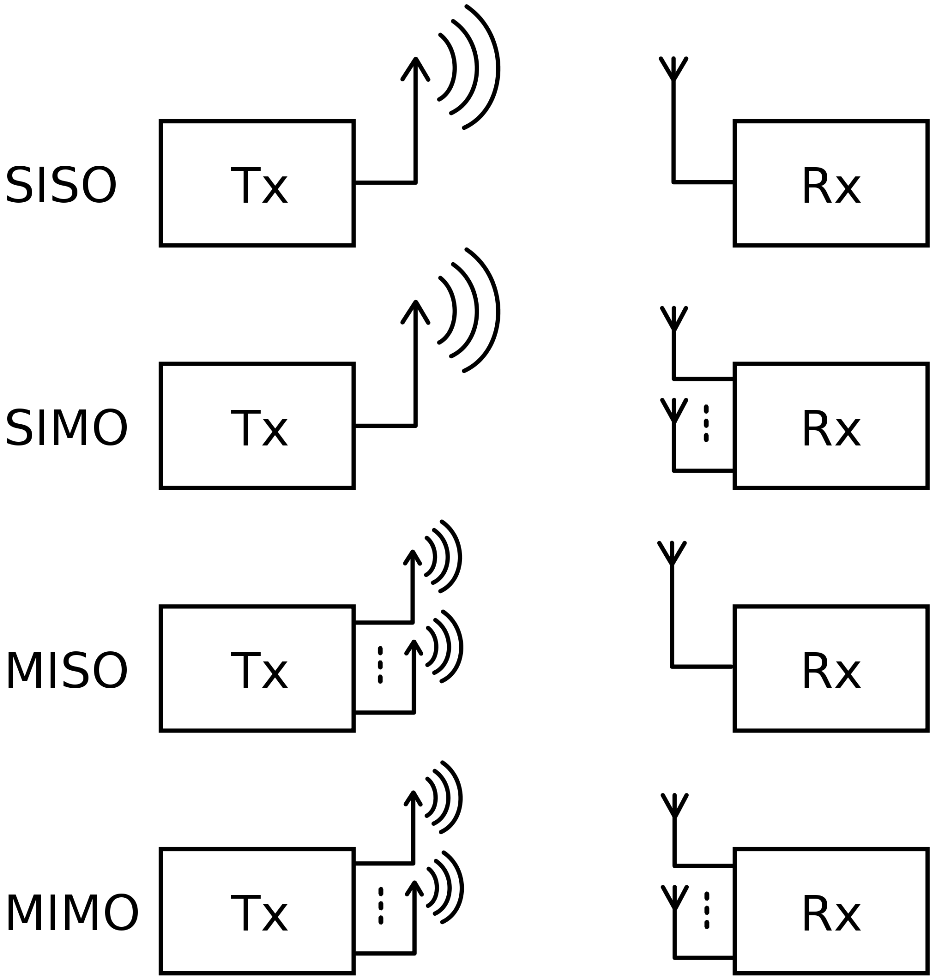
- A radio is characterized by the a 3-ple:

  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

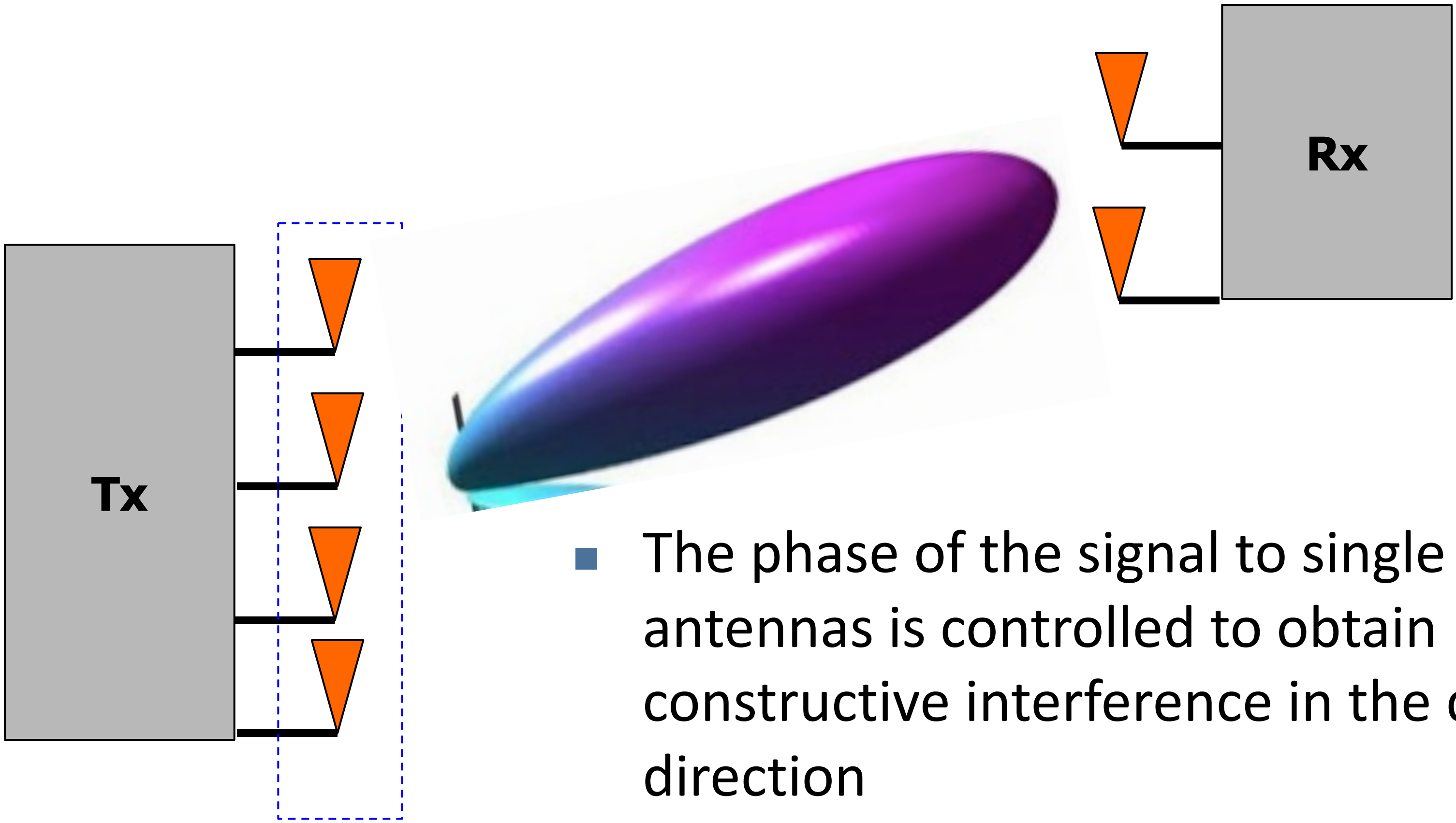
- The number of antennas at devices is independent
- Complexity and performance increase with the number of Tx and Rx antennas
- In principle different Tx can go to different devices



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

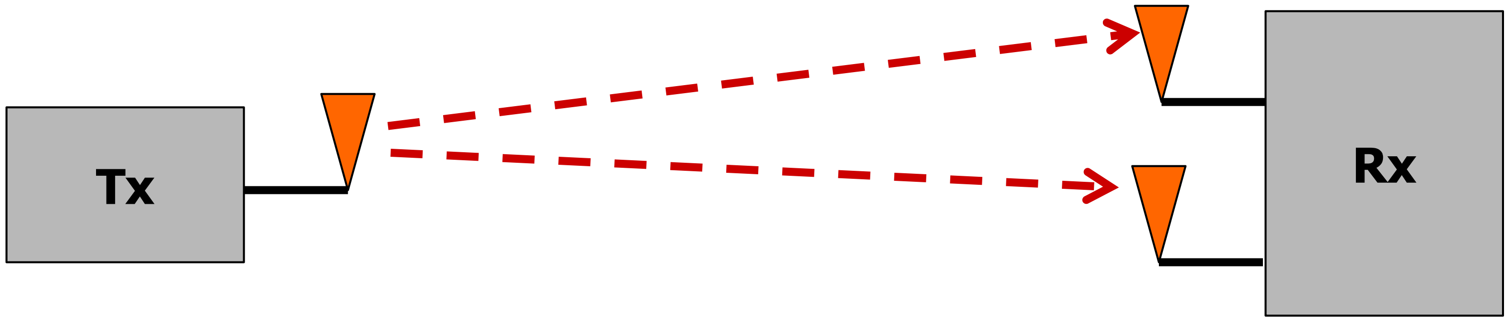


- The phase of the signal to single antennas is controlled to obtain constructive interference in the desired direction

MIMO - Beamforming

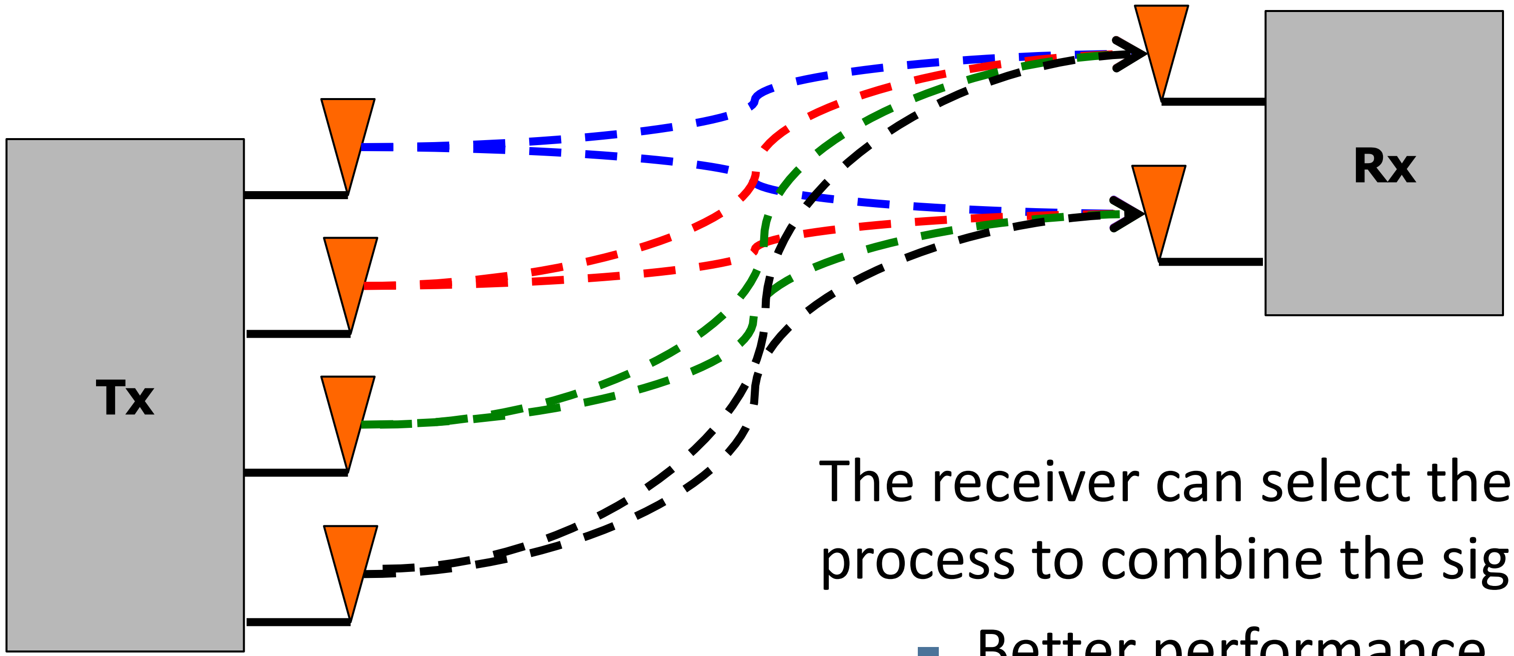
- Beamforming, i.e., using the Tx antennas as a single phase array is complex
- Requires full knowledge (estimation at the transmitter) of the channel state at the receiver: The CSI (Channel State Information)
- Signals must be pre-precessed to obtain the correct phase and amplitude at the antennas
- 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

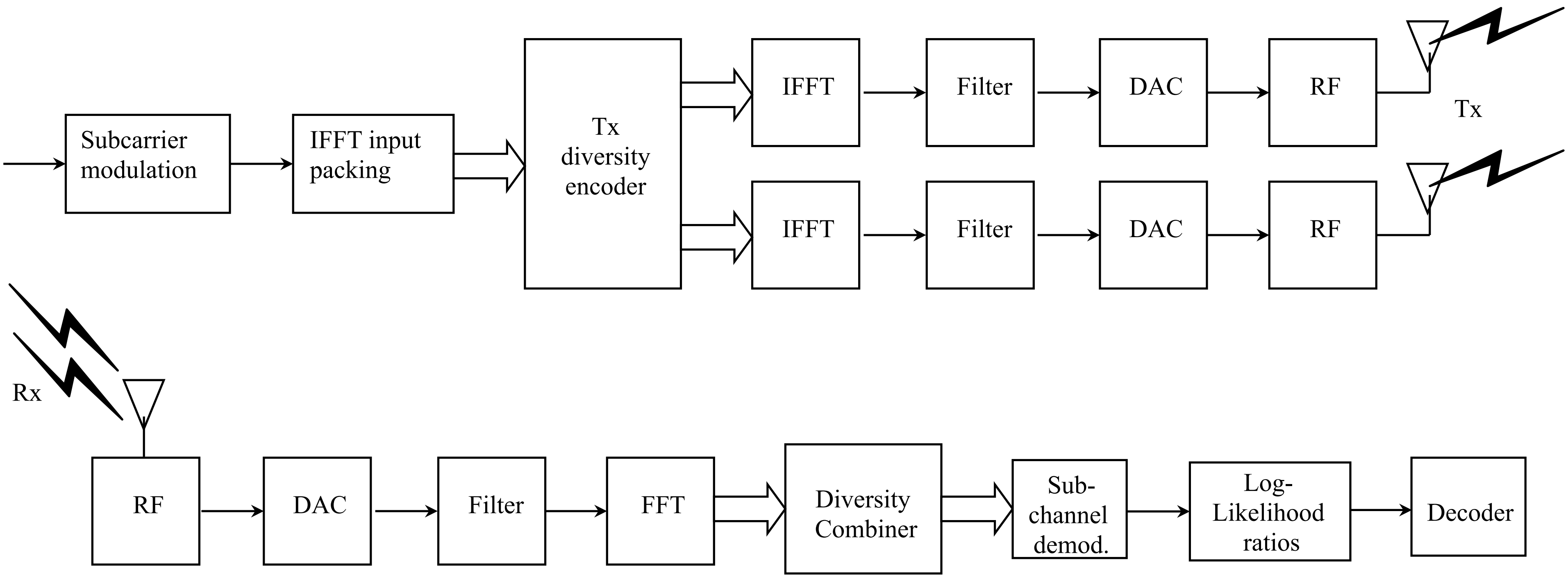


The receiver can select the best or process to combine the signals

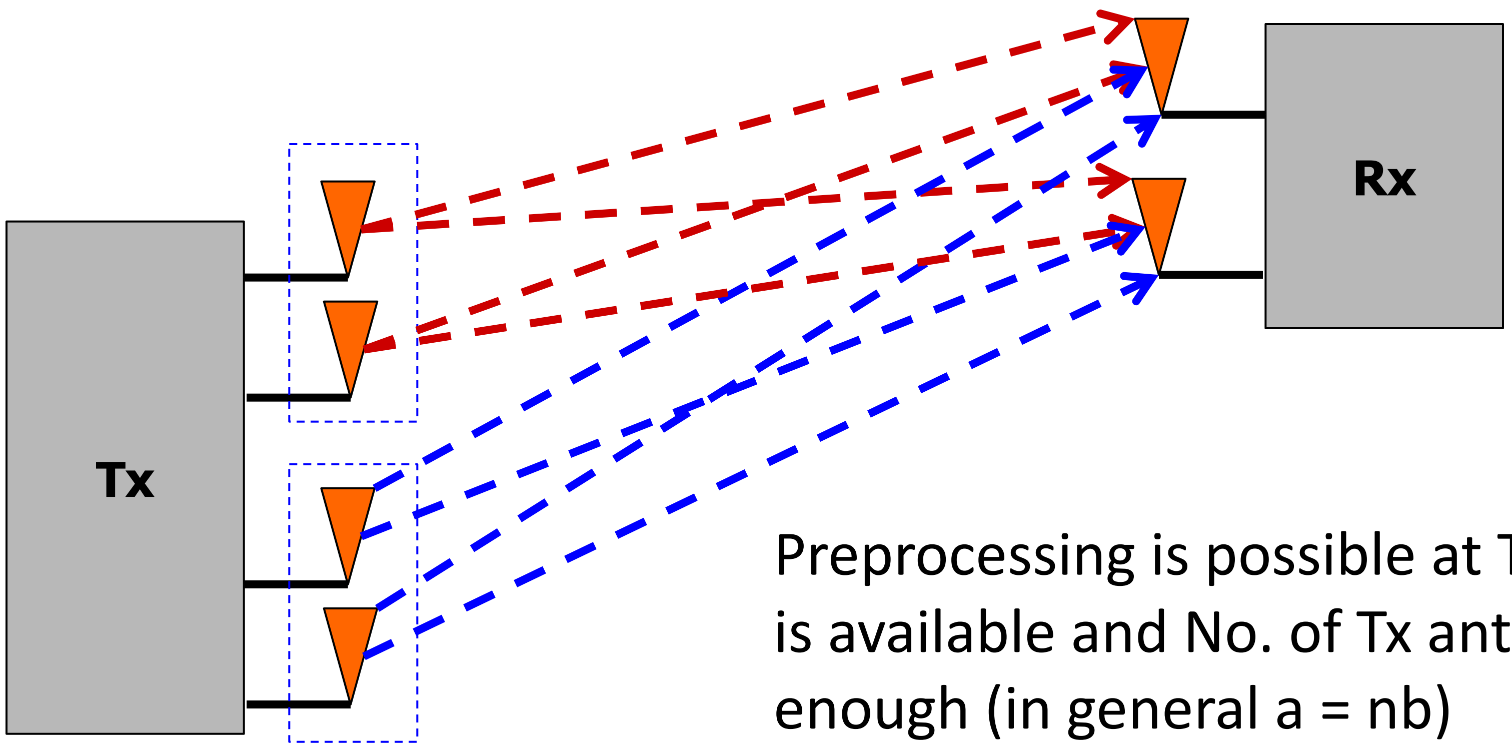
- Better performance
- More complexity

Example of Space Diversity use

- 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)

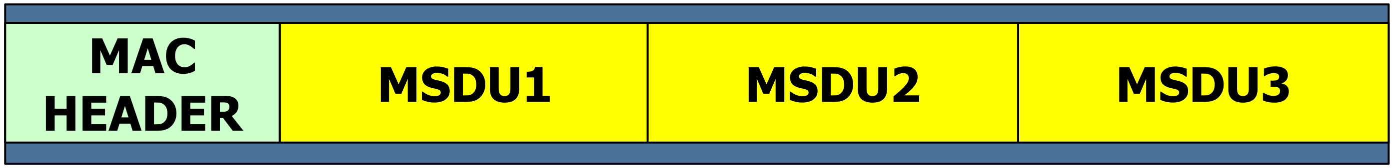
Modulation and Coding

- 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



MPDU Aggregation – A-MPDU

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

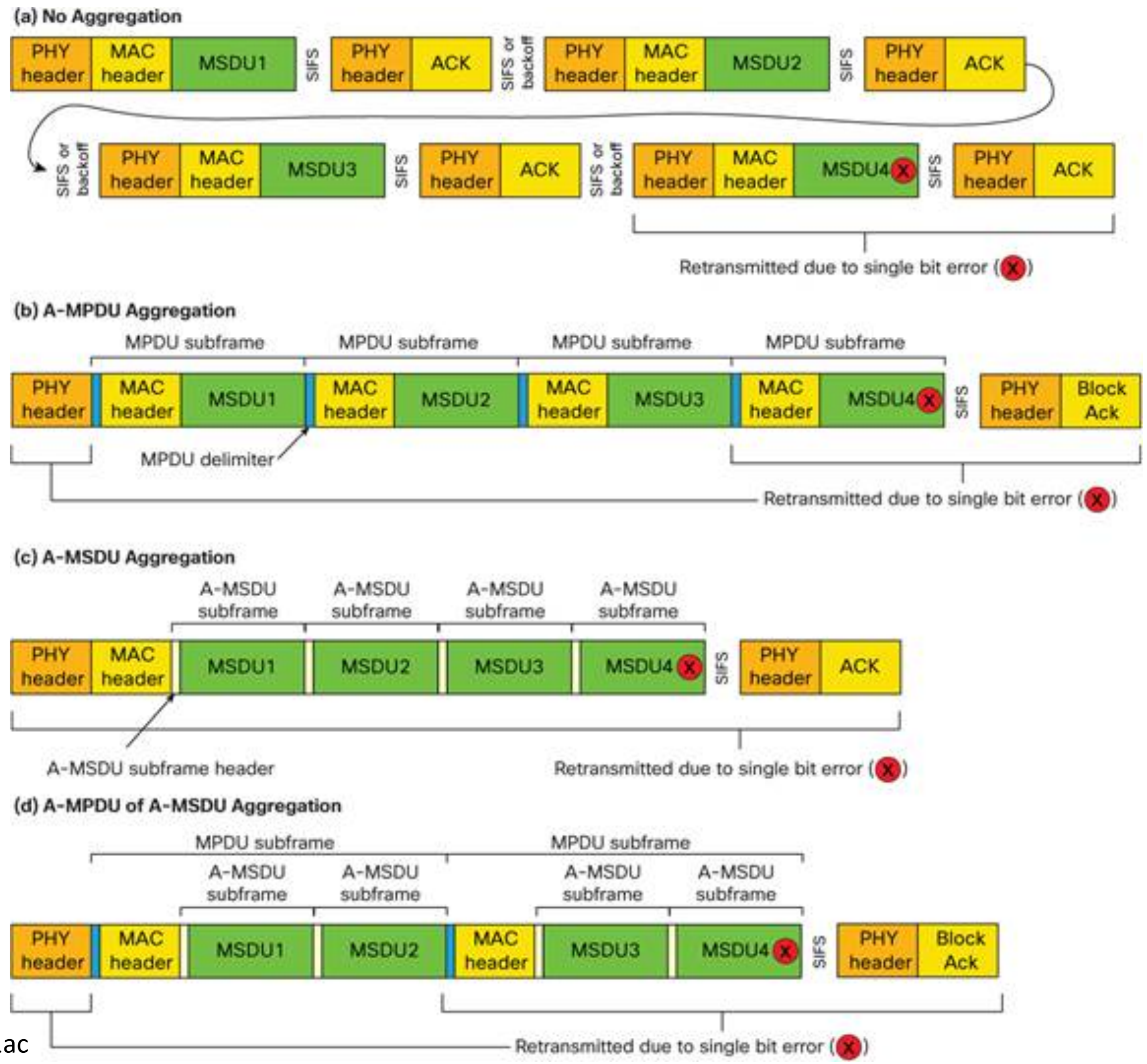
PLPC HEADER	MAC HEADER	MSDU1	MAC HEADER	MSDU2

- 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



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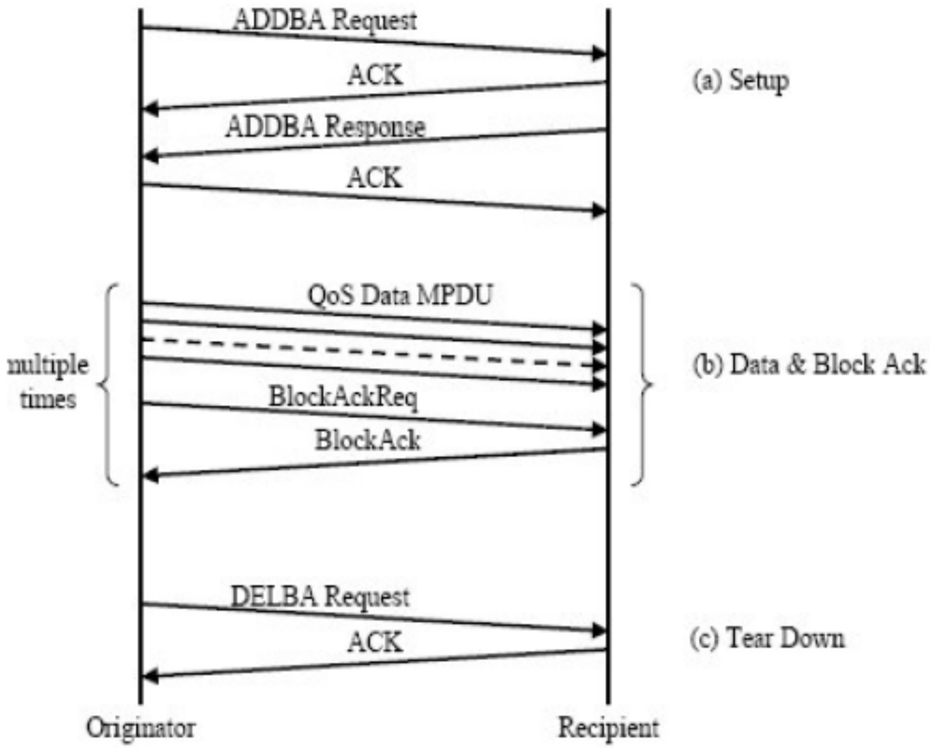
Block ACK Usage

- 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

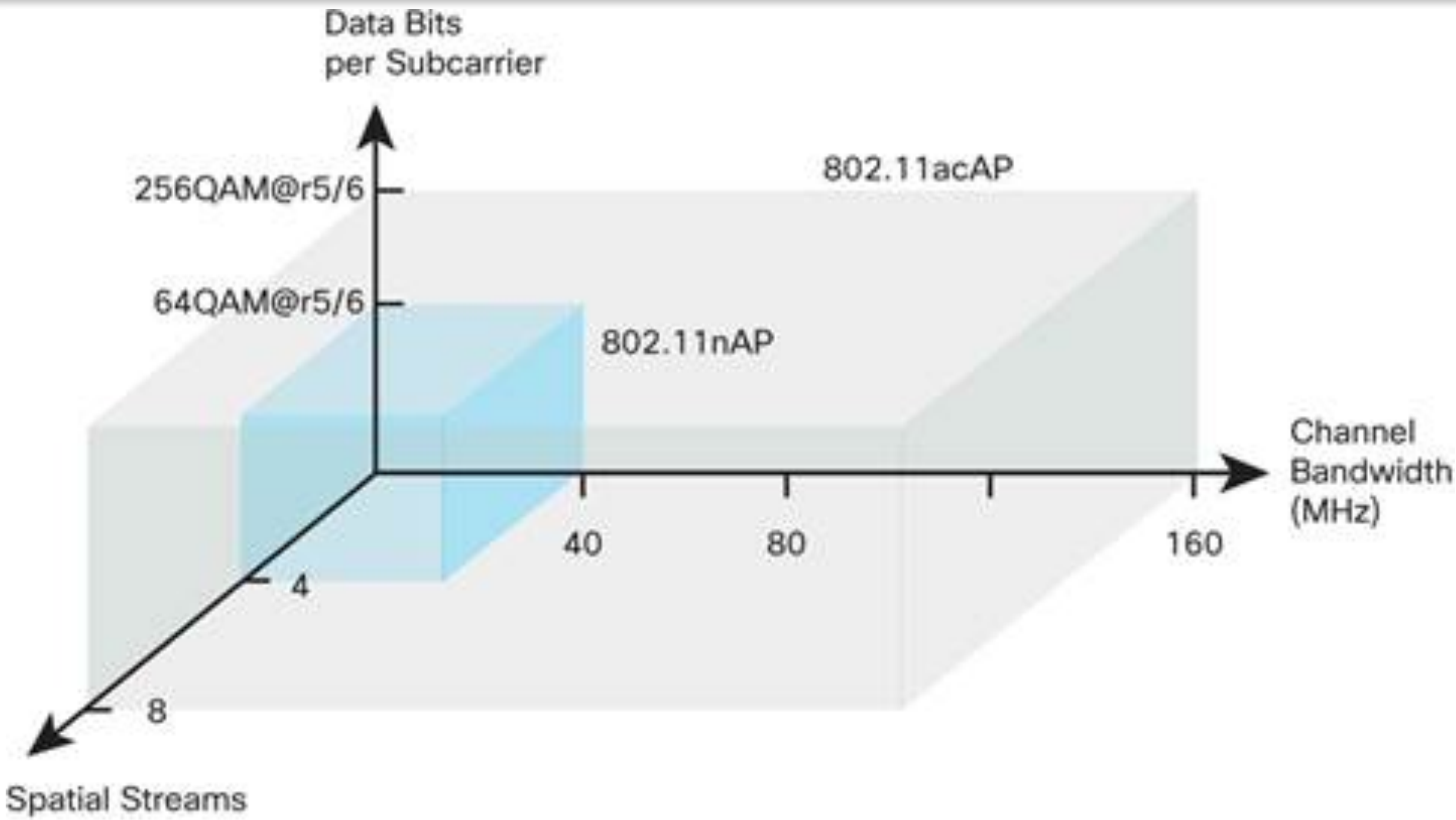
Gbit Transmission Speed – Large Bandwidth, 256 QAM Modulations

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



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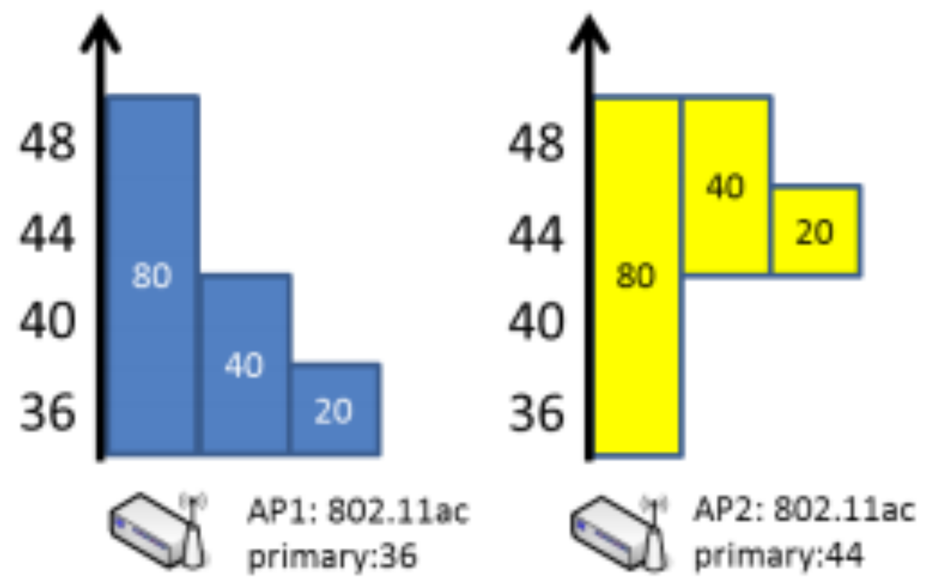
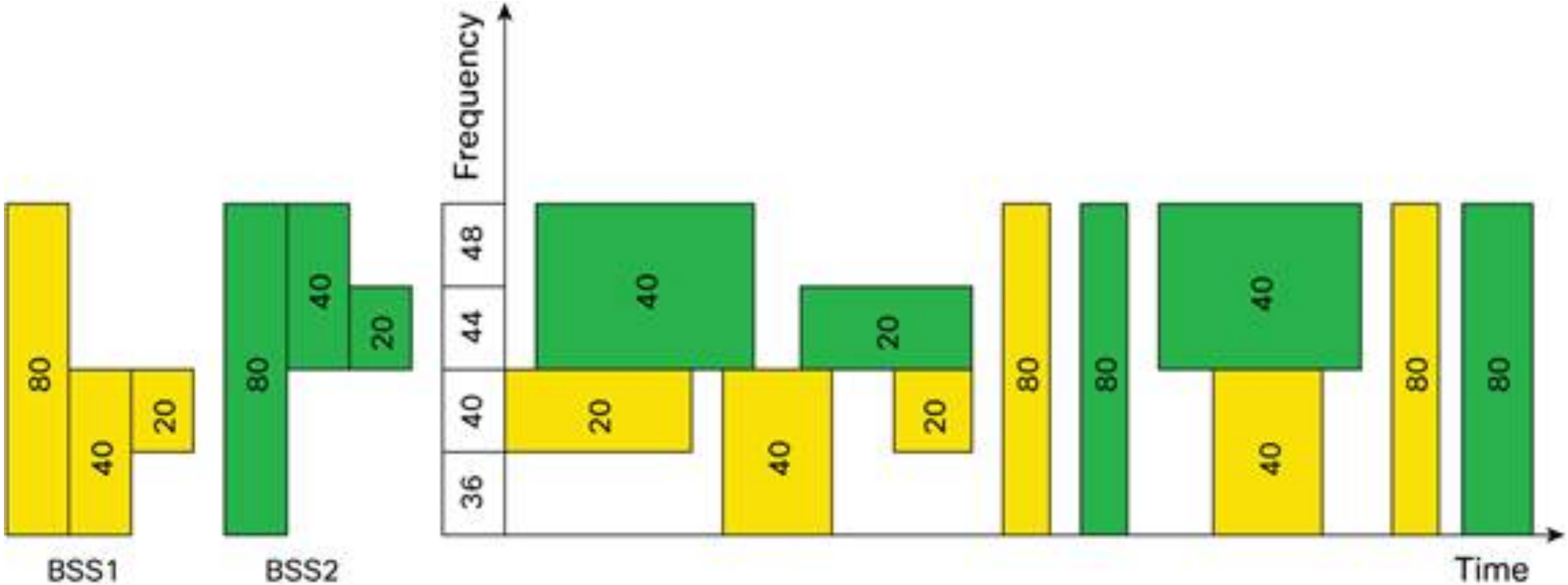
Channel selection

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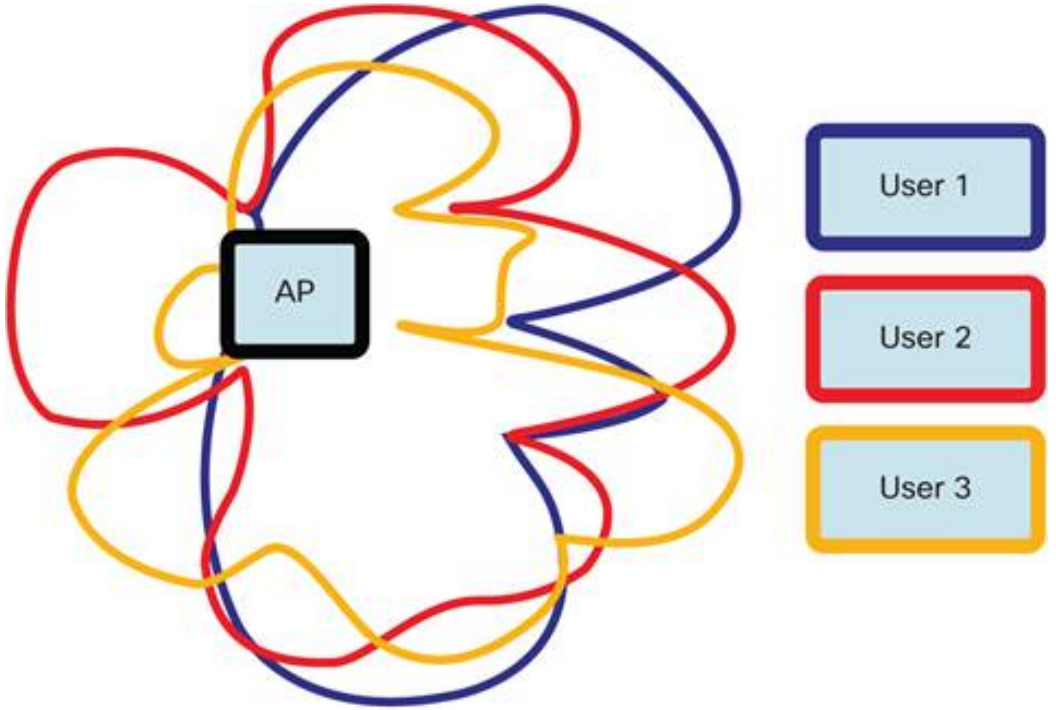
- 802.11n defines MIMO, but its use is limited to communications between the same pair of stations
- 802.11ac allows the AP to do beamforming so as to transmit to different users in parallel at the same time



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