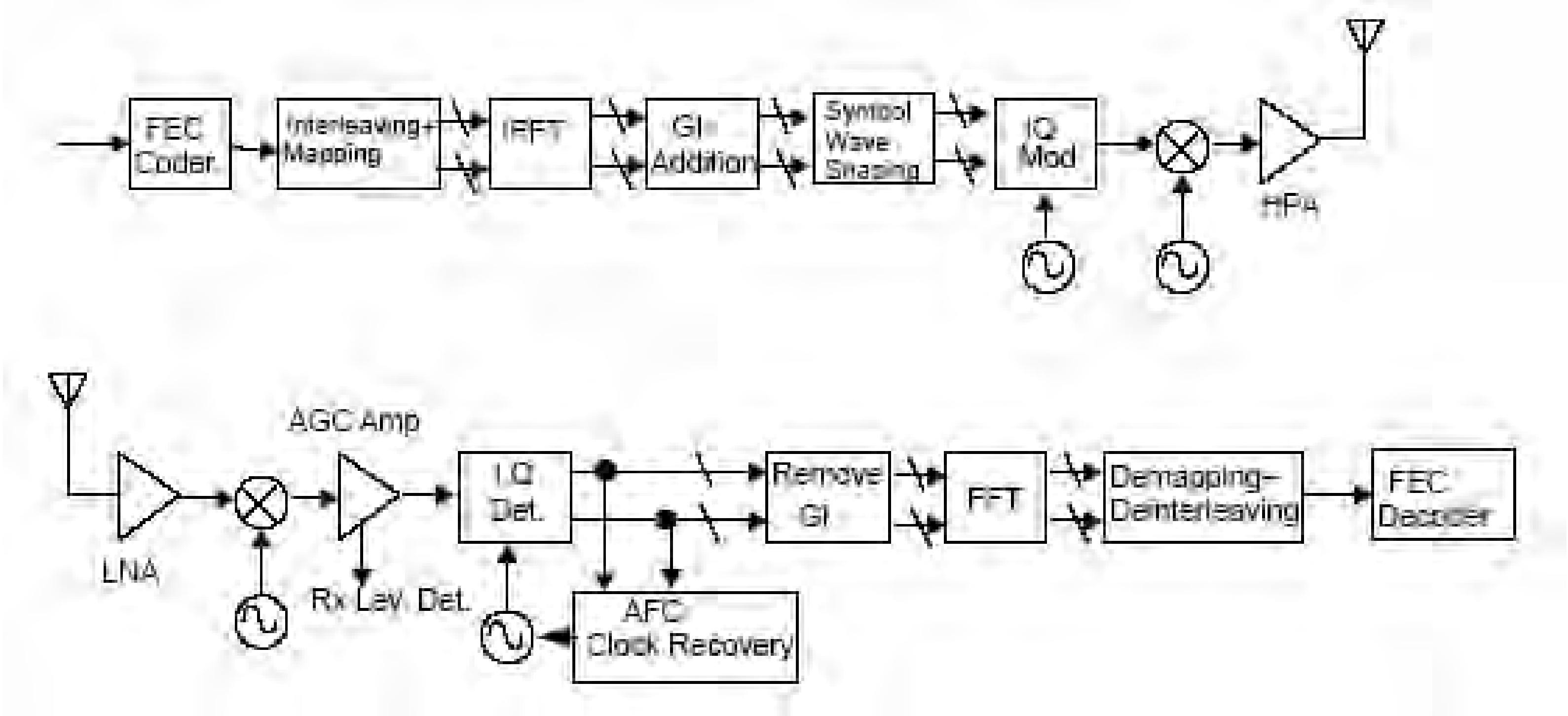
Wireless LANs
IEEE 802.11

History

- Wireless LANs became of interest in late 1990s
  - For laptops
  - For desktops when costs for laying cables should be saved
- Two competing standards
  - IEEE 802.11 and HIPERLAN
  - IEEE standard now dominates the marketplace
- The IEEE 802.11 family of standards
  - Original standard: 1 Mbit/s
  - 802.11b (WiFi, widespread after 2001): 11 Mbit/s
  - 802.11a (widespread after 2004): 54 Mbit/s
  - 802.11e: new MAC with quality of service
  - 802.11n: > 100 Mbit/s

802.11a PHY layer

- Transceiver block diagram



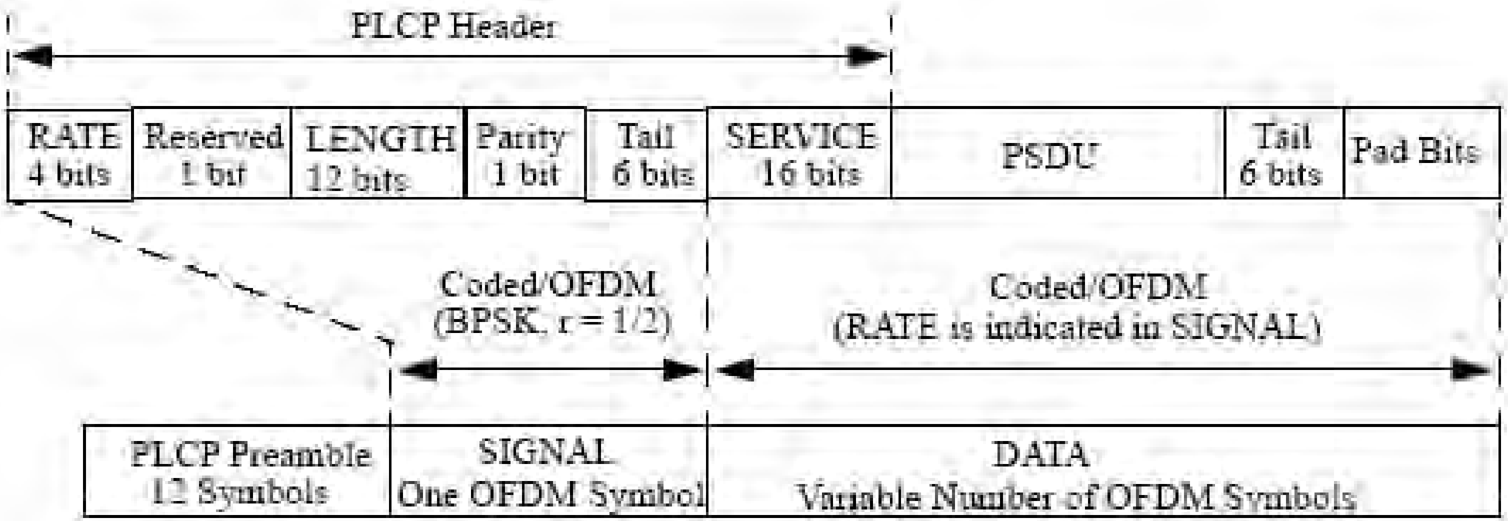
802.11a PHY layer

- The following data rates are supported:

Data rate (Mbit/s)	Modulation	coding rate	coded bits per subcarrier	coded bits per OFDM symbol	data bits per OFDM symbol
6	BPSK	1/2	1	48	24
9	BPSK	3/4	1	48	36
12	QPSK	1/2	2	96	48
18	QPSK	3/4	2	96	72
24	16-QAM	1/2	4	192	96
36	16-QAM	3/4	4	192	144
48	64-QAM	2/3	6	288	192
54	64-QAM	3/4	6	288	216

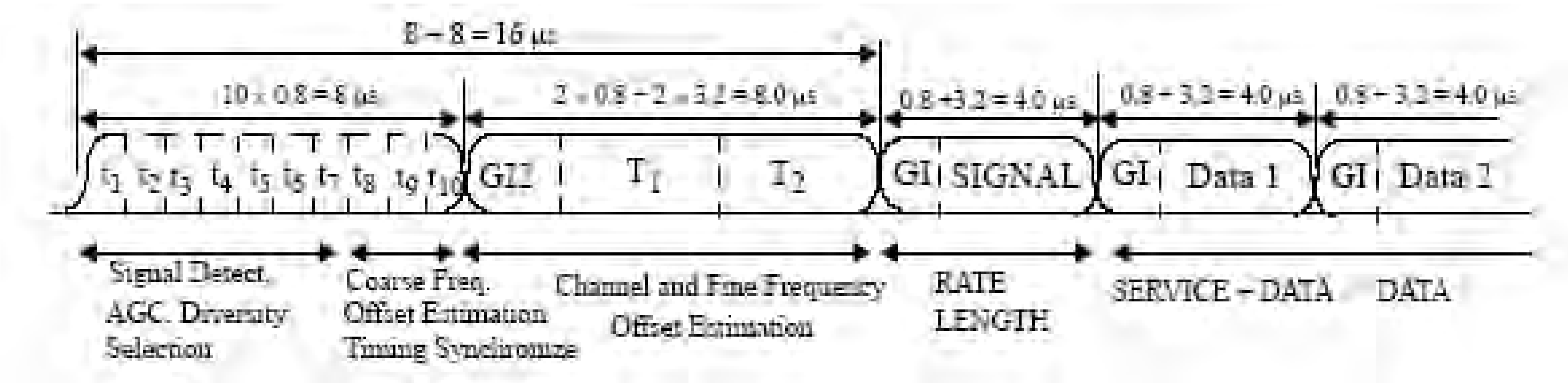
11a header and preamble

- Header conveys information about data rate, length of the data packet, and initialization of the scrambler



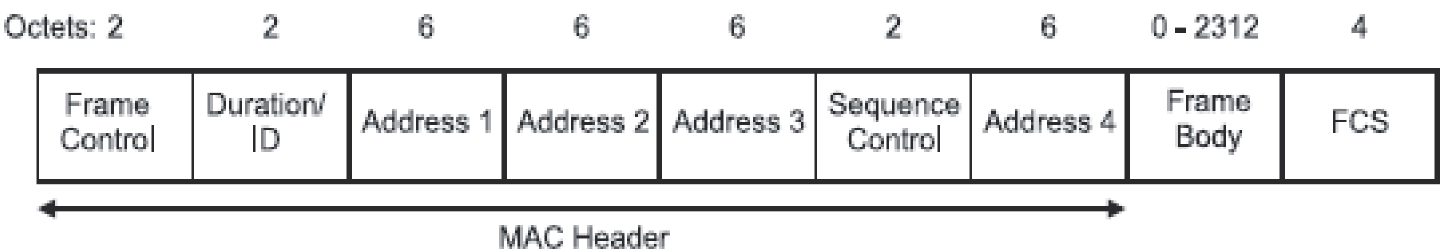
11a header and preamble

- PLCP preamble: for synchronization and channel estimation



MAC and multiple access

- Frame structure:
  - Contains payload data, address, and frame control into



- Multiple access: both contention-free and contention-based access

IEEE 802.11n standard

- Goals: > 100 Mbit/s on MAC SAP-to-SAP
  - Increased robustness to interference
  - Backwards compatibility
  - Improved flexibility for different applications

- Applications:
  - PC applications: increased data transfer rates at low costs
  - CE applications: even higher quality for high-end AV applications, cost less of an objective
  - HH applications: enable voice-over-IP transmission and other applications for mobile market

History (I)

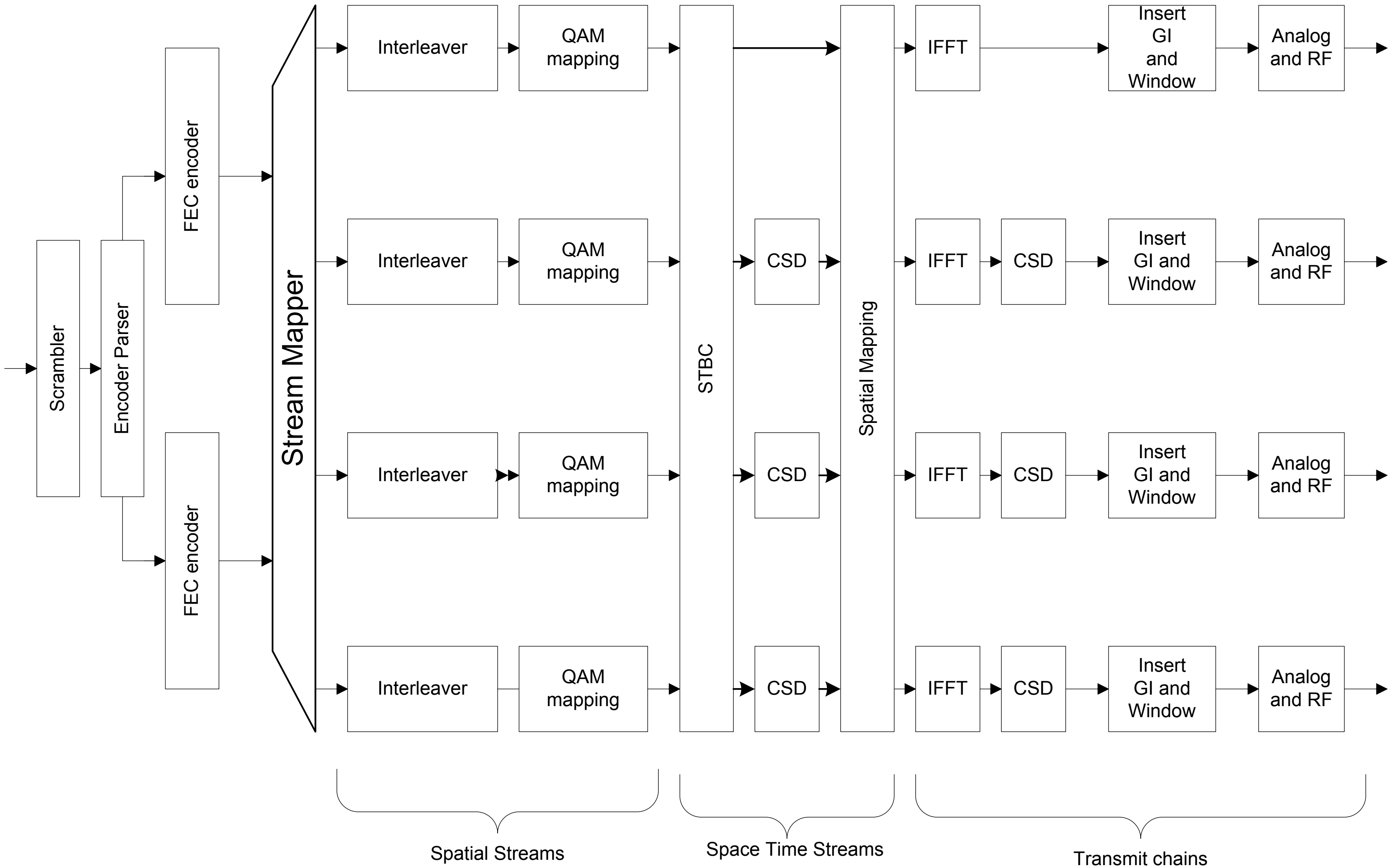
- 2002: IEEE establishes taskgroup 11n to create a high-throughput mode of 802.11 wireless LANs
- 2004:
  - presentation of more than 20 complete and partial technical proposals (meeting in Berlin September 2004)
  - Formation of 3 major alliances: TGnSync (Intel, Qualcomm), WWise (Broadcom, TI), MitMot (Motorola)
  - Downselection votes are deadlocked
- 2005:
  - Establishment of official “joint proposal” team that should establish compromise between the major alliances
  - Summer: emergence of a new group EWC (Intel, Broadcom,…): establishment and creation of new draft
  - Fall: EWC grow and attracts more and more participants
  - December: EWC finalizes its specifications

History (II)

- 2006
  - January 13th: EWC specs are adopted (with some minor modifications) by the JP team
  - January 18^{th}: JP specs are approved (100 % confirmation) by 802.11n group
  - January 18^{th}: first products are announced
  - Internal review process within 802.11n starts
- 2007/2008
  - Comment resolution and standard “cleanup” continue
  - 2009: issuance of standard

Tx Block Diagram

OFDM symbols



Cyclic Shifts

- To prevent unintentional beam forming during the transmission
- Multiply OFDM symbol with diagonal matrix

$$\left[Q_k \right]_{i,i} = \exp(-j2\pi k \Delta_F \tau_{CS}^i)$$

corresponds to cyclic shift of symbols in time domain

Space-Time Coding (covered in Chapter 20 - Multiantenna Systems)
Overall concept (MIMO) is to transmit different versions of the data stream from different transmit antennas, i.e., delay diversity.
Space-Time Block Coding (STBC) introduces redundancy by sending from each transmit antenna a differently encoded version of the same signal which results in very high diversity

Spatial Expansion

- Allows the transmitter to use more antennas than space-time streams in a manner transparent to the receiver
  - a linear prec-coding matrix at the transmitter creates an "effective channel"

$$H_{effective} = H_{actual} \cdot V_{precoding}$$

- Three Types of Spatial Expansion:
  - CSD expansion
    - Uses cyclic shifts across the antenna array
  - CSD + Orthogonal Matrix
    - Orthogonal matrix may allow better isolation among the space-time streams
    - adding cyclic shifts mitigates beamforming artifacts and power fluctuation at the receiver
  - Beam forming Steering Matrix

STBC - Space Time Block Coding

- Increases rate at range for scenarios with more transmit chains than receive chains
- Useful especially for transmitting to single antenna devices
- Does not require closed-loop operations
- Based on 2x1orthogonal space-time coding
  - Nss = 1 → 2 x 1, 3 x 1, and 4 x 1
- Extended to scenarios with multiple spatial streams
  - Nss = 2 →4 x 2 and 3 x 2
  - Nss = 3 →4 x 3
- Asymmetric MCS sets may be applied
  - Useful when STBC protection is uneven, for e.g. 3 x 2 and 4 x 3
  - CSD + Orthogonal mapping used in the above two configurations
- STBC is fully optional

Transmit Beamforming

- Closed loop Tx BF support
  - Increase rate at range by applying a steering matrix at the transmitter
  - Most useful when more transmit chains than space-time streams
- Support in PHY –
  - Support for sounding the channel
  - Support for asymmetric MCSs (modulation coding schemes)
  - Channel state information feedback support
    - Calibration for implicit-feedback beamforming using reciprocity
    - Steering matrix feedback for explicit-feedback beamforming
      - compressed and uncompressed
    - Channel matrix feedback for explicit feedback, calibration, and rate adaptation
- All beam forming and rate adaptation support is optional

Modulation Coding Scheme (MCS)

- Mandatory Symmetrical Sets
  - 8 MCS sets for 20 MHz, 1 spatial stream
  - Range from BPSK rate ½ to 64-QAM rate 5/6
  - Data rates range from 6.5 Mbps to 65 Mbps (72.2 Mbps with short GI)

Index	Modulation	Code Rate	Data Rate (MBPS)
0	BPSK	½	6.5
1	QPSK	½	13
2	QPSK	¾	19.5
3	16-QAM	½	26
4	16-QAM	¾	39
5	64-QAM	2/3	52
6	64-QAM	¾	58.5
7	64-QAM	5/6	65

Modulation Coding Scheme (MCS)

- Option extension of Symmetric MCSs
  - 40 MHz bandwidth expansion
  - 2, 3, and 4 spatial streams
  - Extension to 32 symmetric MCSs
  - Data rate up to 540 Mbps (600 Mbps with short GI)
- Optional HT duplicate mode in 40 MHz
  - Modulation is duplicated in upper and lower bands (with rotation)
  - BPSK, code rate ½
  - 6 Mbps (6.7 Mbps with short GI)
  - Provides a very robust communications mechanism
- Total of 33 symmetric MCSs

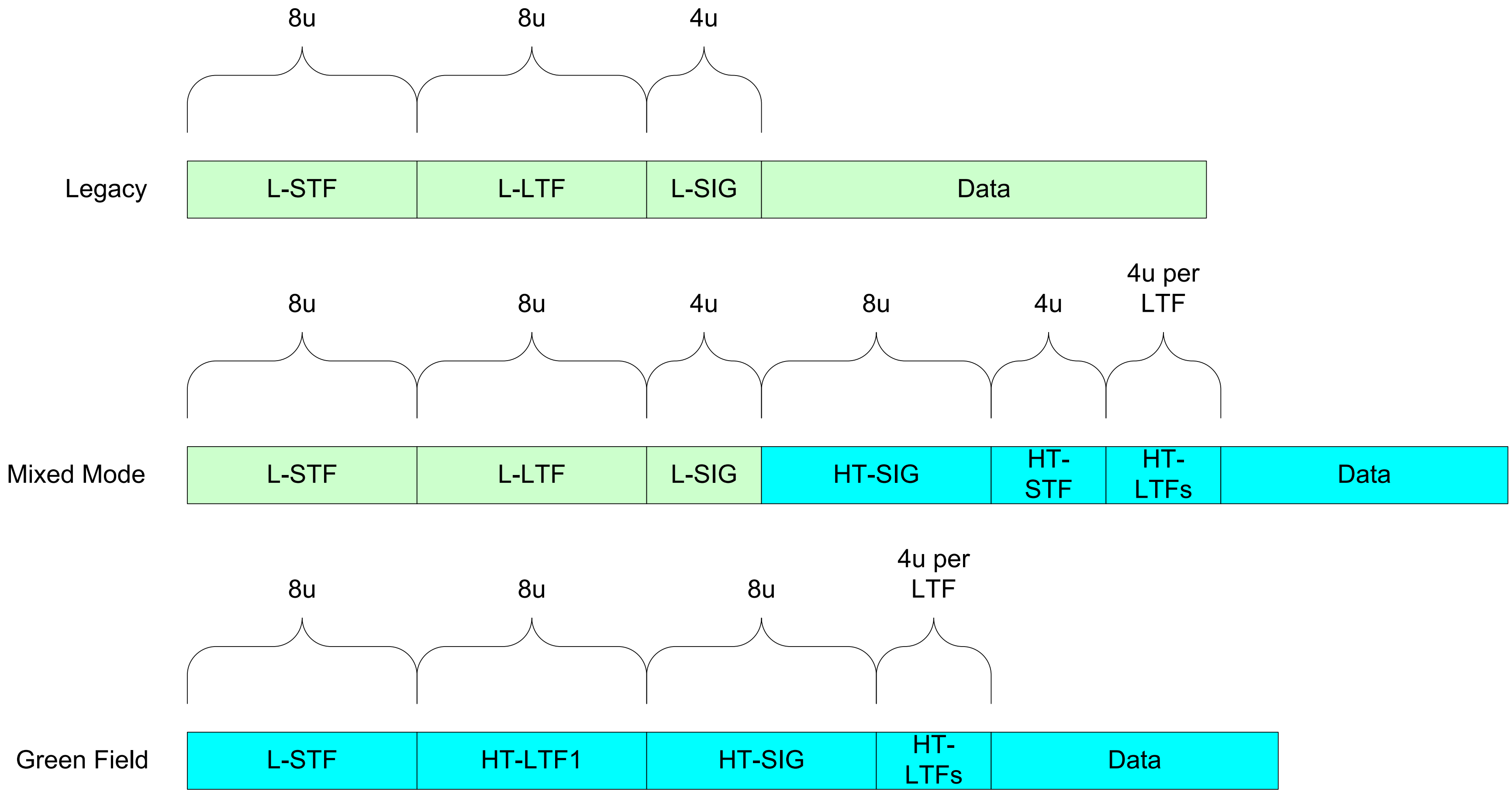
Modulation Coding Scheme (MCS)

- Optional Asymmetric MCS Sets
  - Mix of 64-QAM, 16-QAM, and QPSK
  - Asymmetric MCSs useful for transmit beam forming (TxBF) and STBC situations where some streams are more reliable than others
  - 44 Assymetric MCSs
- Total of 77 MCSs

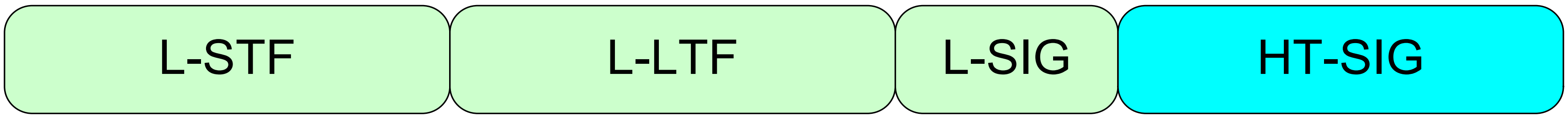
Three Frame Formats in .11n

- Legacy (Mandatory)
- Mixed Mode (Mandatory)
  - Legacy portion of the preamble provides built in PHY protection
    - Allows mixture of legacy and 11n packets in one network
    - Avoids hidden node issues when beamforming
  - However, the preamble length is increased
- Green Field (Optional)
  - Very efficient preamble

Frame formats



MM Preamble First Part

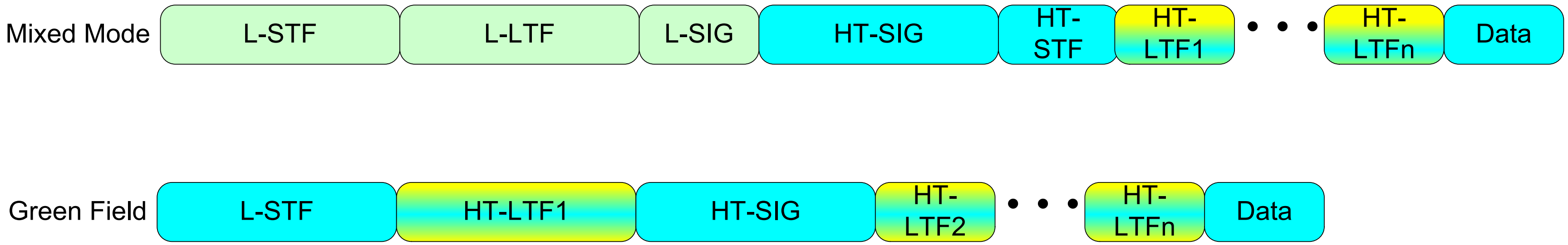


- Transmitted as a single stream expanded to up to four streams as explained above.
- The HT-SIG is transmitted on two OFDM symbols.
  - The modulation is BPSK rotated by +90°.
- Provides very robust built-in legacy PHY and beam forming-related PHY protection

HT-STF

- HT-STF – High Throughput Short Training Field.
- Used to set the AGC and for acquisition tasks in GF
- Based on the .11a sequence with CSD of -400, -200, -600ns) between channels:
- 4μsec long

HT-LTFs

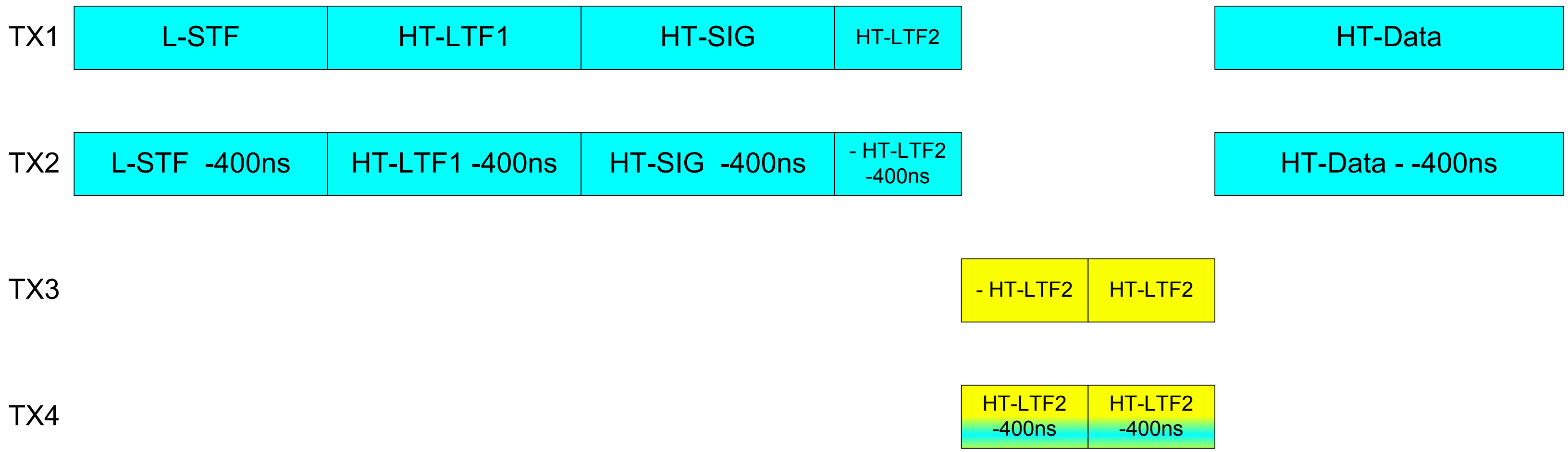


- Used to train the receiver to the MIMO channel.
- The sequence transmitted is based on the 11a long training field sequence –
  - Extended to 56 tones by adding 4 tones in 20MHz
  - In 40MHz, extended to 114 tones first moving the sequence up and down 32 tones, then adding tones between the two channels and in the DC subcarriers
  - In 40MHz the upper channel is +90° rotated compared to the lower channel.
  - In the Green Field format, HT-LTF1 has a duration of 8 μsec. (with GI2).
  - All other HT-LTFs have a duration of 4 μsec. (with GI of 800 nsec.).

Channel Sounding

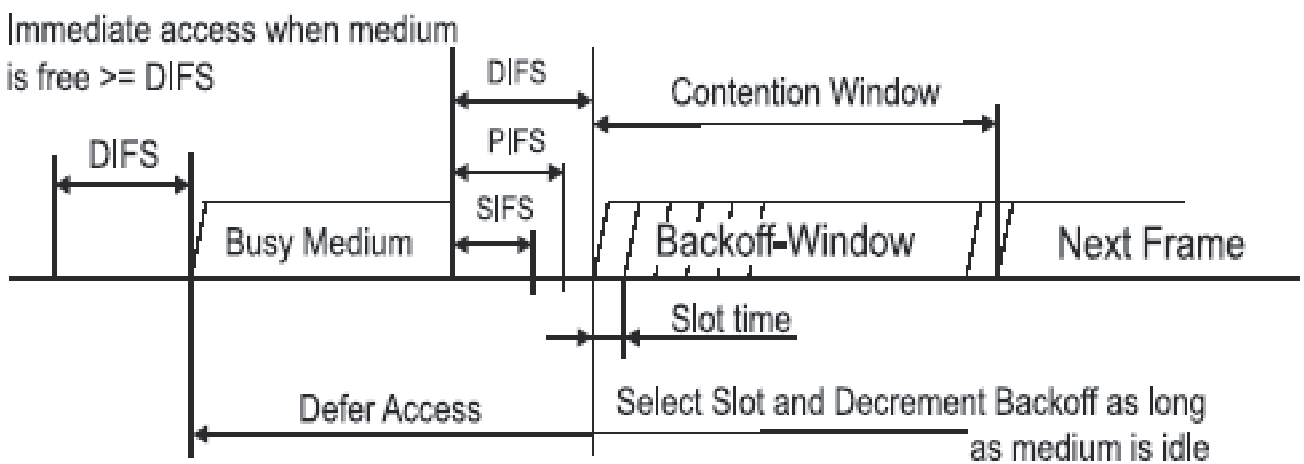
- Channel sounding is useful for link adaptation and transmit beam forming
- Three sounding methods
  - Standard packet
    - Limited by need to extract data from packet
    - Channel is sounded using preamble
  - Segmented LTF
    - Allows sounding of spatial dimensions not present in data
    - First the spatial streams in the data are trained, then the “NULL” streams are trained.
  - Zero Length Packet (renamed No Data Frame)
    - Allows sounding of any spatial dimensions (as there is no data)
    - Training is done like a usual packet with the number of streams indicated by the MCS

Sounding with Segmented LTF



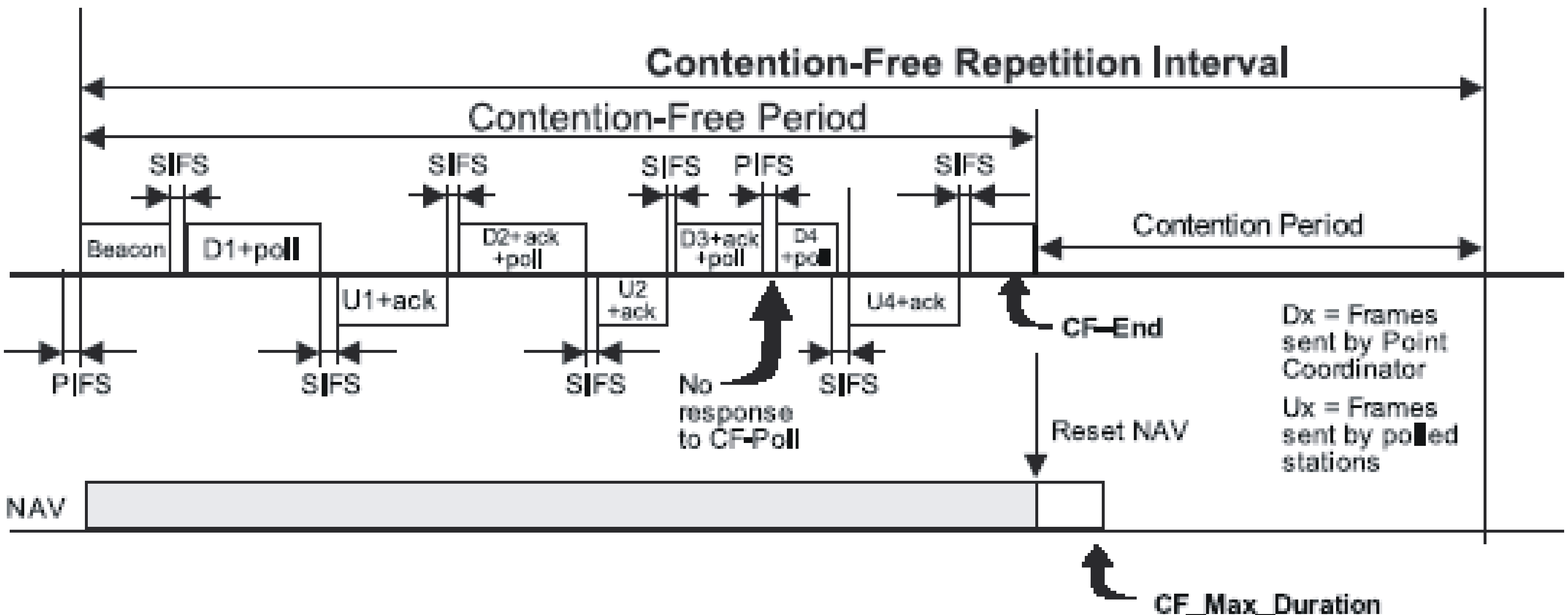
Contention-based access

- CSMA (carrier-sense multiple access):



Contention-free access

- Polling:



Further improvements

- 802.11e: improvements in the MAC; provides quality of service
  - CSMA/CA-based Enhanced Distributed Channel Access (EDCA) manages medium access during CP.
  - Polling-based HCF (Hybrid Coordination Function) Controlled Channel Access (HCCA) handles medium access during CFP.
  - BlockACK and delayed blockACK reduce overhead
  - Contention Free Burst (CFB) and Direct Link Protocol (DLP) improve channel efficiency.