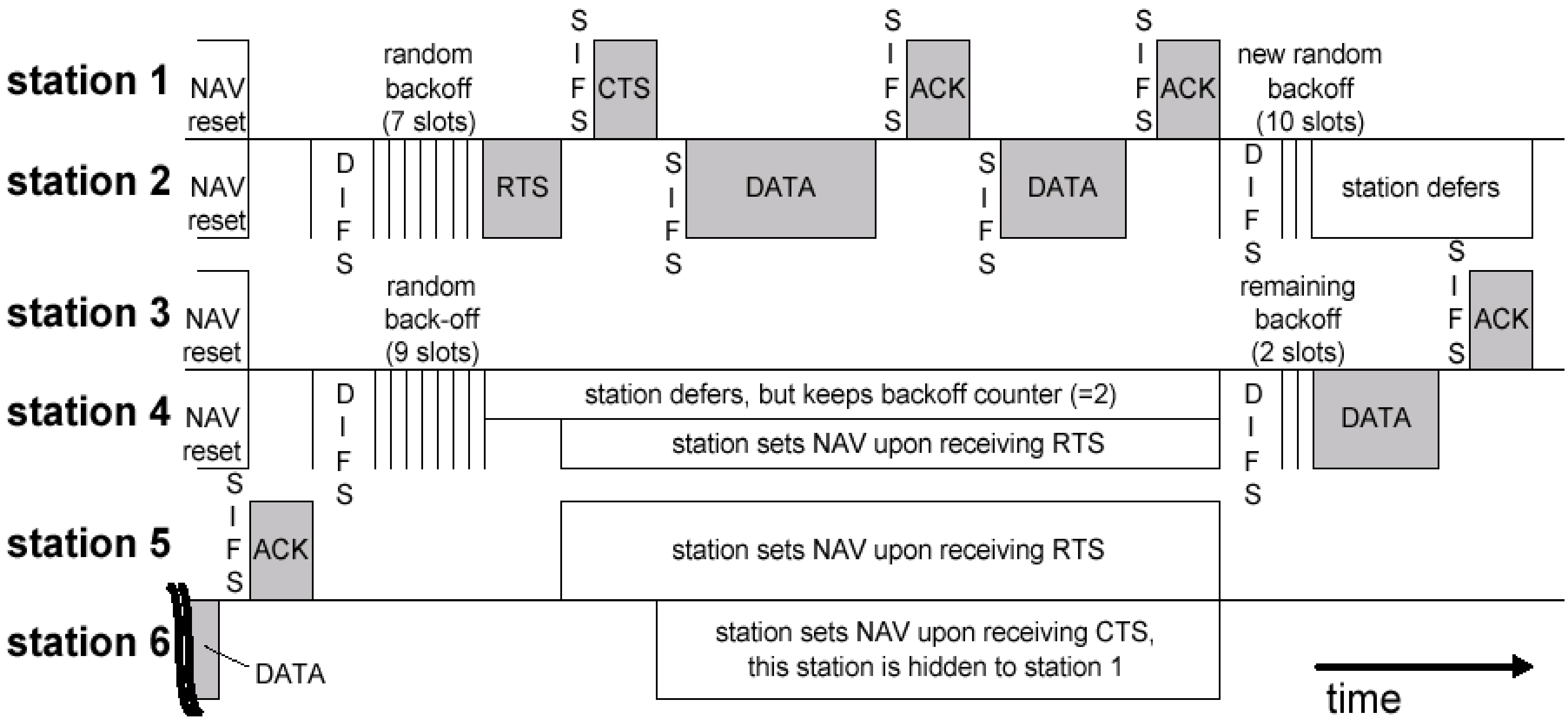
The IEEE 802.11 family of standards

continued

IEEE 802.11e Εξασφάλιση Ποιότητας Υπηρεσίας στα Ασύρματα Τοπικά Δίκτυα

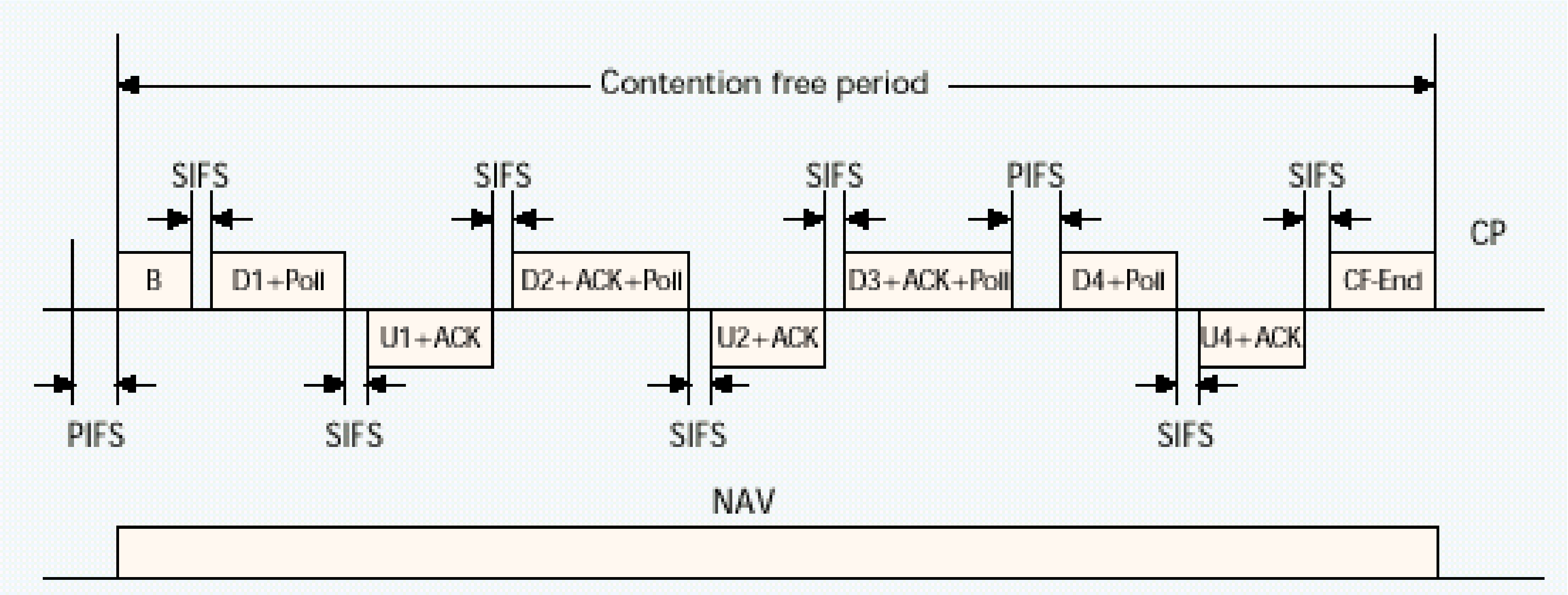
Περιορισμοί του 802.11 σε QoS

- Το DCF βασίζεται στον ανταγωνισμό και γι' αυτό το λόγο δεν παρέχει διαφοροποίηση της κίνησης και εγγυημένες καθυστερήσεις ή απώλειες πακέτων.



Περιορισμοί του 802.11 σε QoS

- Στο PCF δεν υπάρχει γνώση των απαιτήσεων των τερματικών ώστε το κανάλι να δίνεται στα πιο επείγοντα.
- Στο PCF είναι άγνωστη η περίοδος μετάδοσης ενός τερματικού στο οποίο δίνεται η άδεια μετάδοσης (polling).



Επεκτάσεις που εισάγει το 802.11e

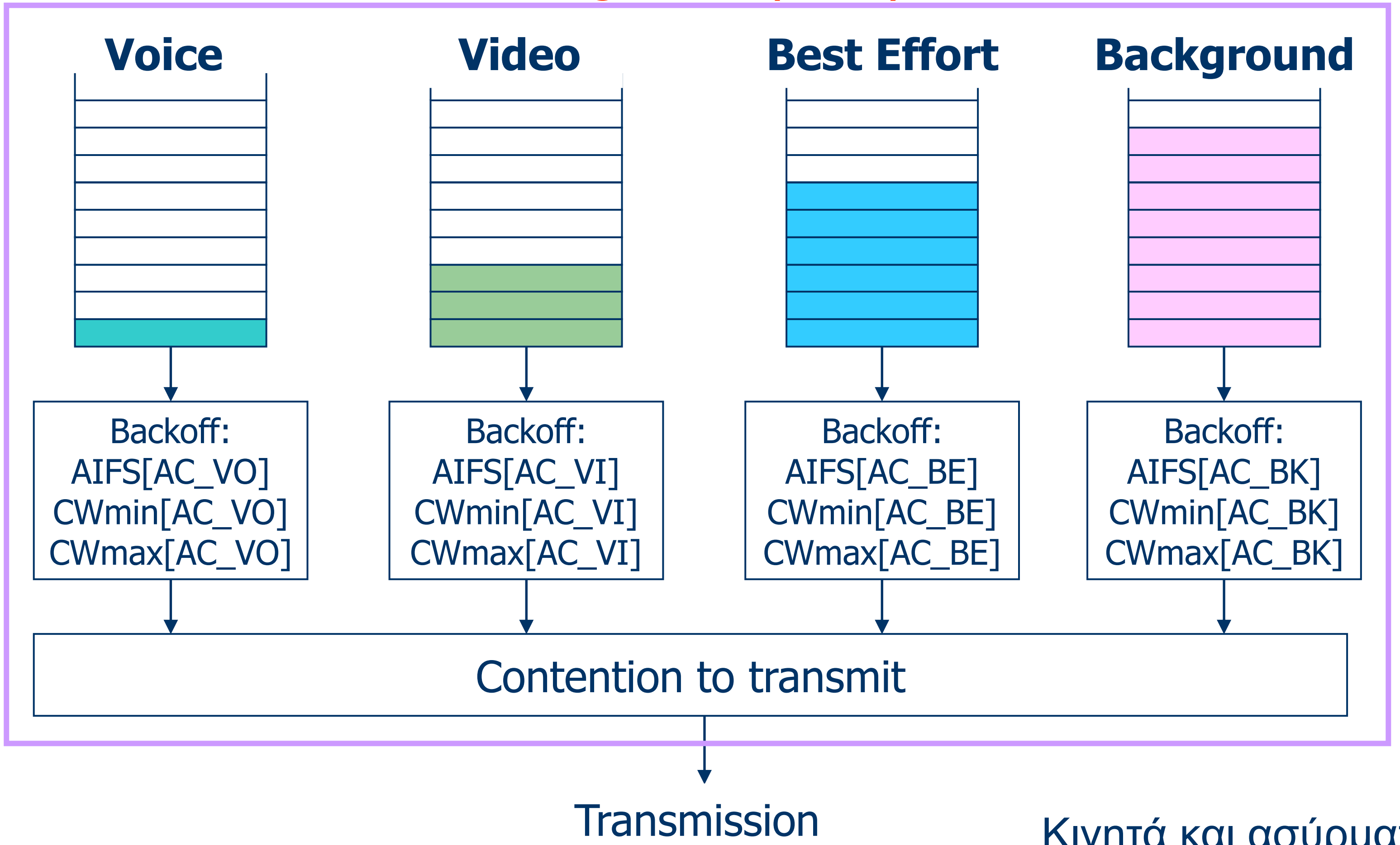
- Το AP ονομάζεται Hybrid Coordinator (HC) και υλοποιεί την Hybrid Coordination Function (HCF) η οποία περιλαμβάνει δύο τρόπους λειτουργίας:

- EDCA (Enhanced Distributed Coordination Access): Εισαγωγή διαφορετικών κλάσεων κίνησης στο DCF με διαφορετική συμπεριφορά και πιθανότητες πρόσβασης στο μέσο

- HCCA (HCF Control Channel Access): Βελτίωση των αδυναμιών του PCF (άμεση μετάδοση του beacon, ελεγχόμενος χρόνος δέσμευσης του καναλιού από τους σταθμούς)

EDCA
(Enhanced Distributed Coordination Access)

- CSMA/CA and Exponential Backoff
- Four Access Categories (ACs) within one station



EDCA
(Enhanced Distributed Coordination Access)

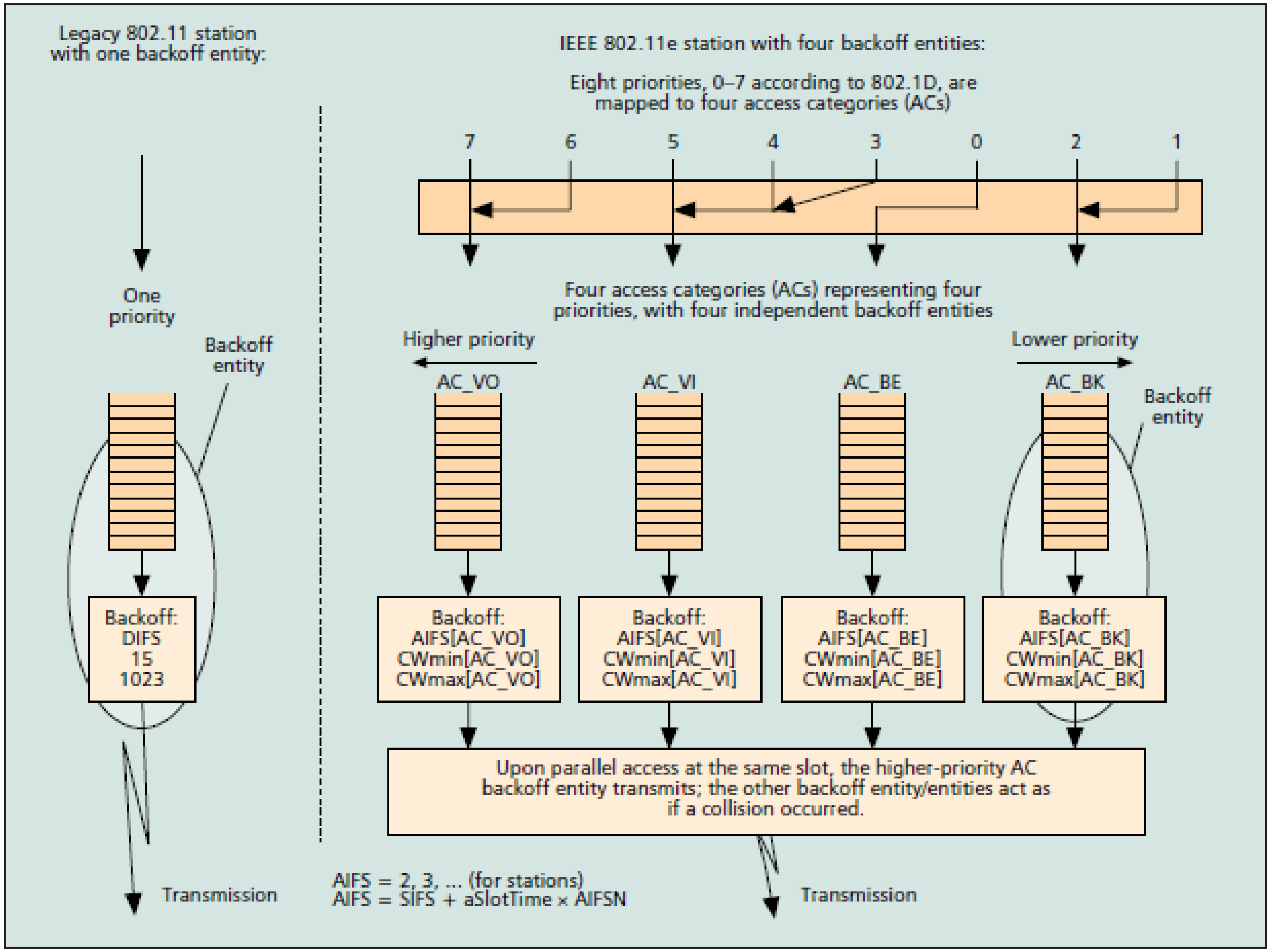
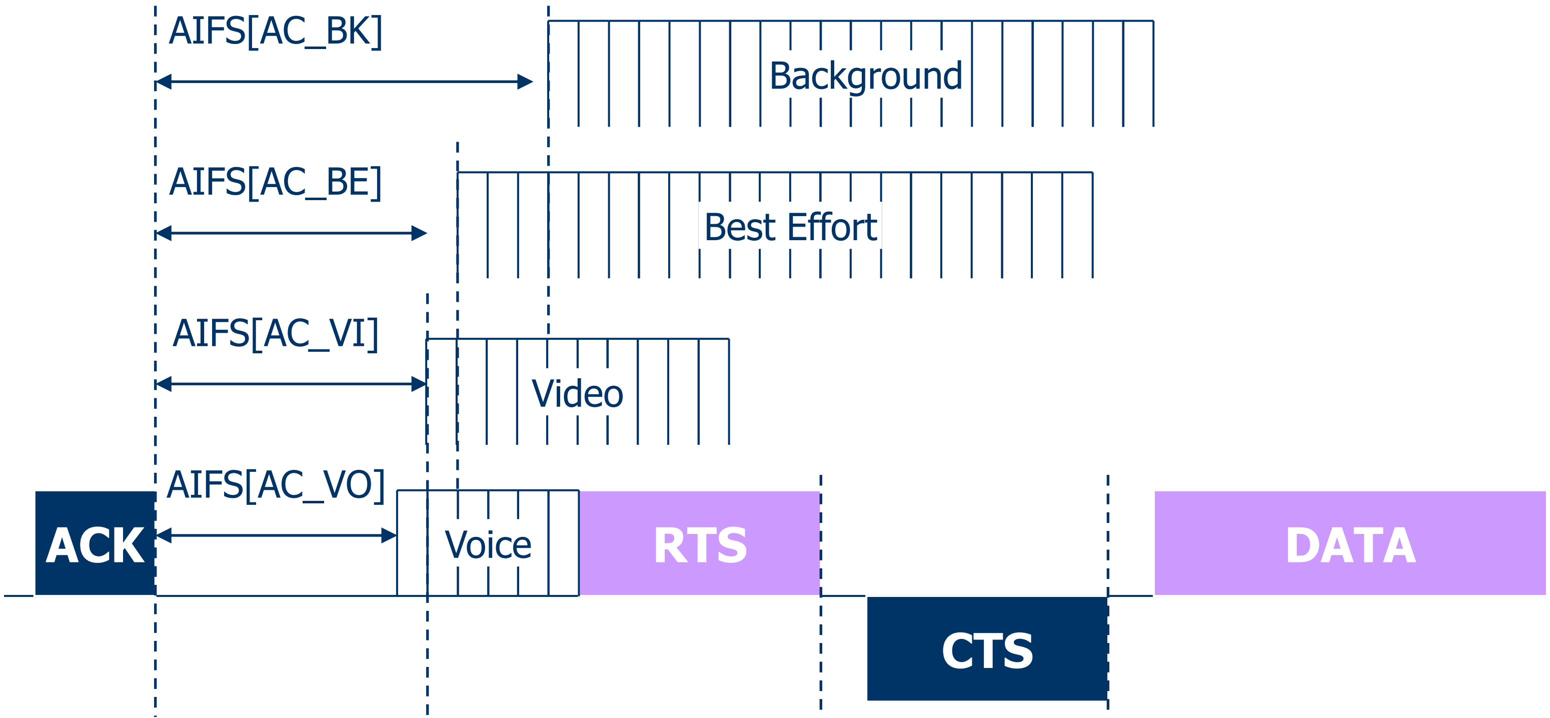
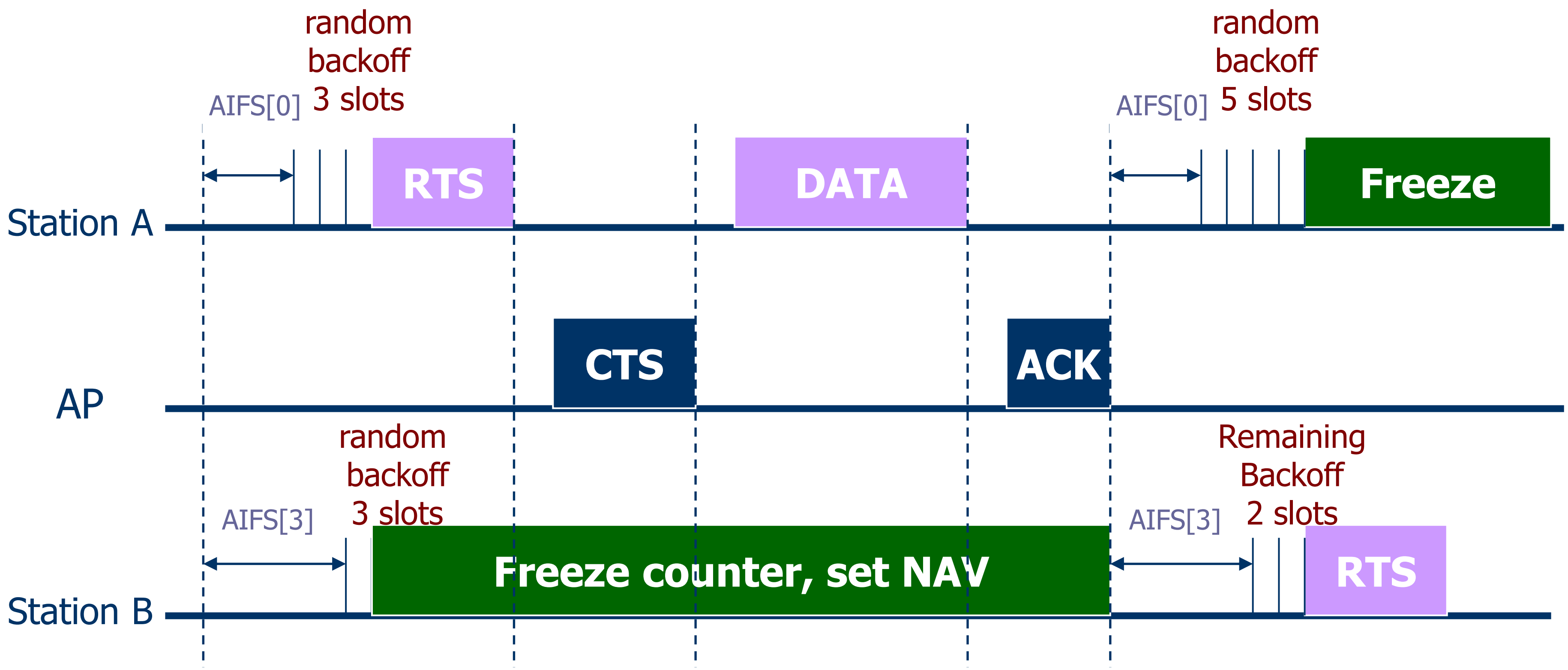


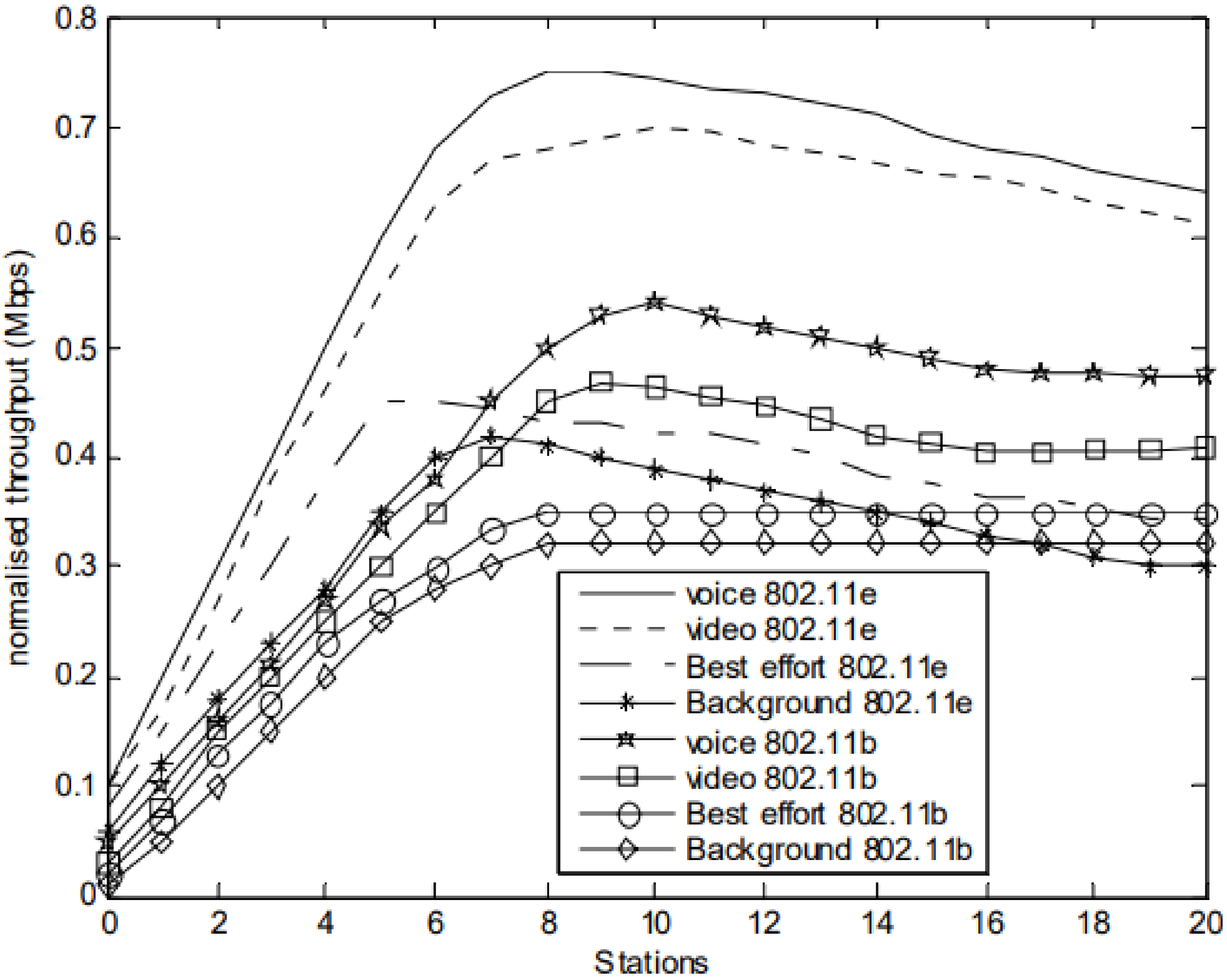
Figure 4. *[3] Legacy 802.11 station and 802.11e station with four ACs within one station.*

Inter Frame Space και Contention Window

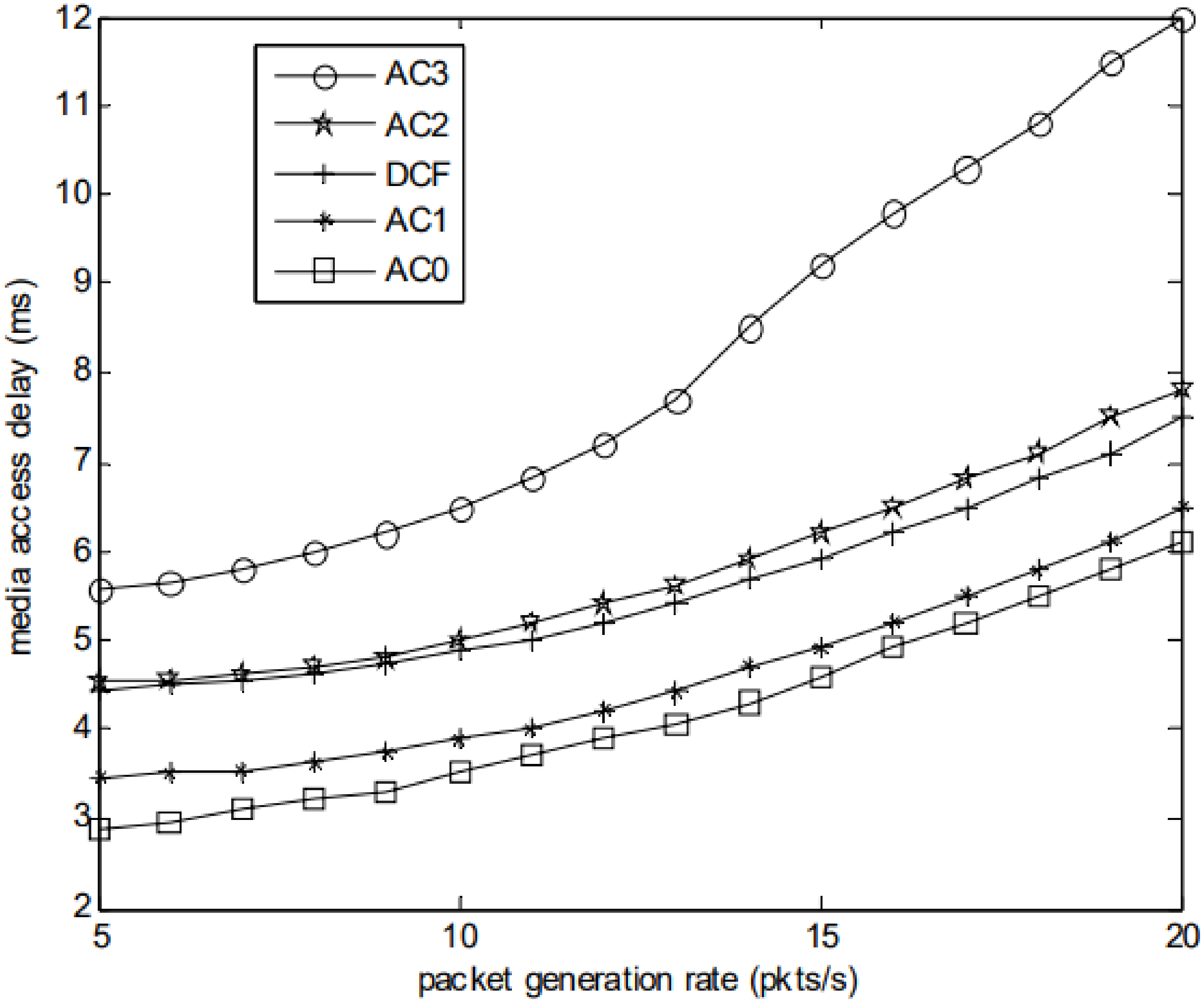


Διαδικασία Ανταγωνισμού με EDCA



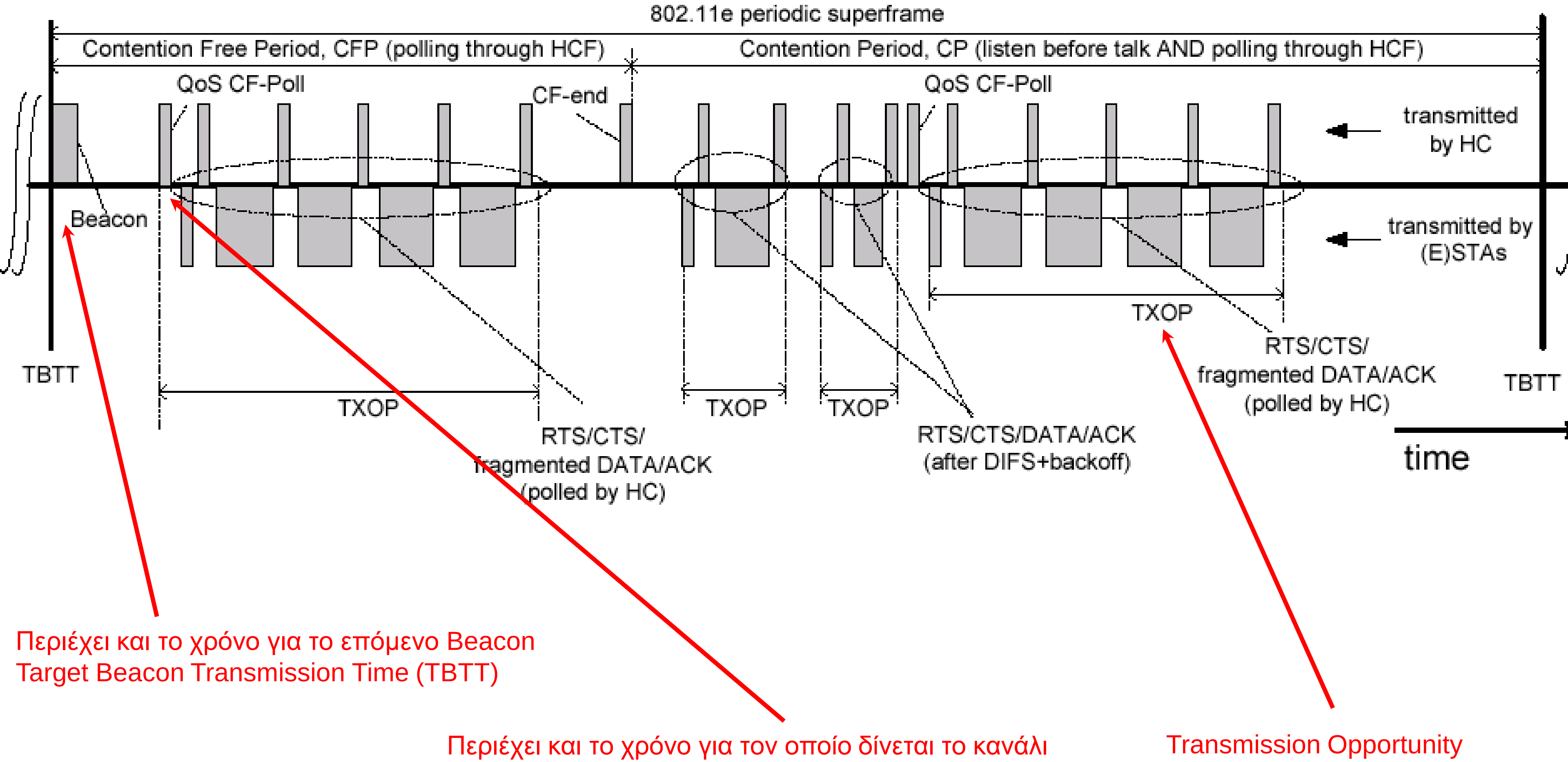


0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
normalised throughput (Mbps)
0
2
4
6
8
10
12
14
16
18
20
Stations
voice 802.11e
video 802.11e
Best effort 802.11e
Background 802.11e
voice 802.11b
video 802.11b
Best effort 802.11b
Background 802.11b

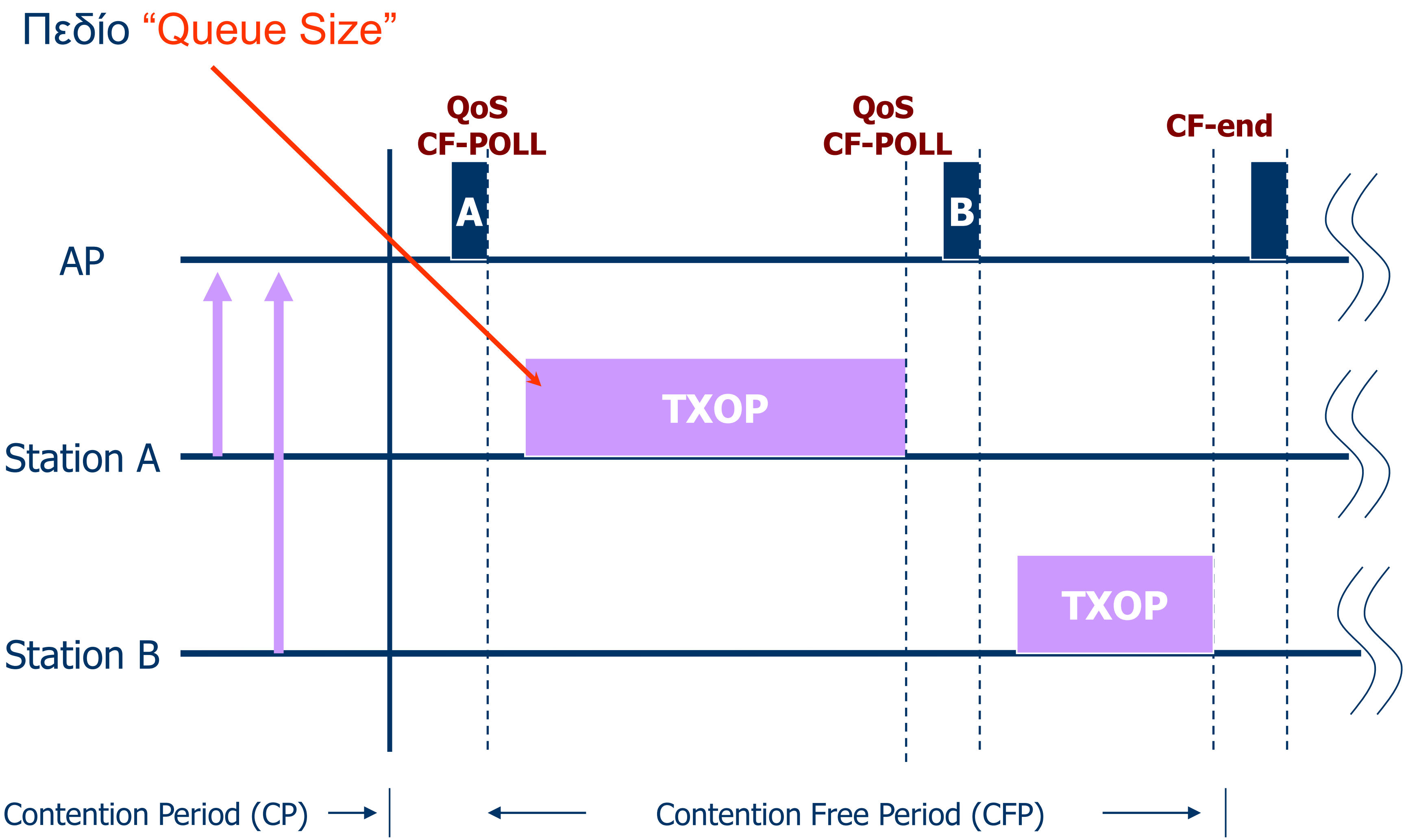


AC3
AC2
DCF
AC1
AC0
media access delay (ms)
packet generation rate (pkts/s)

HCCA
(HCF Control Channel Access)



Διαδικασία Δέσμευσης με HCCA



Factors Affecting Wireless QoS

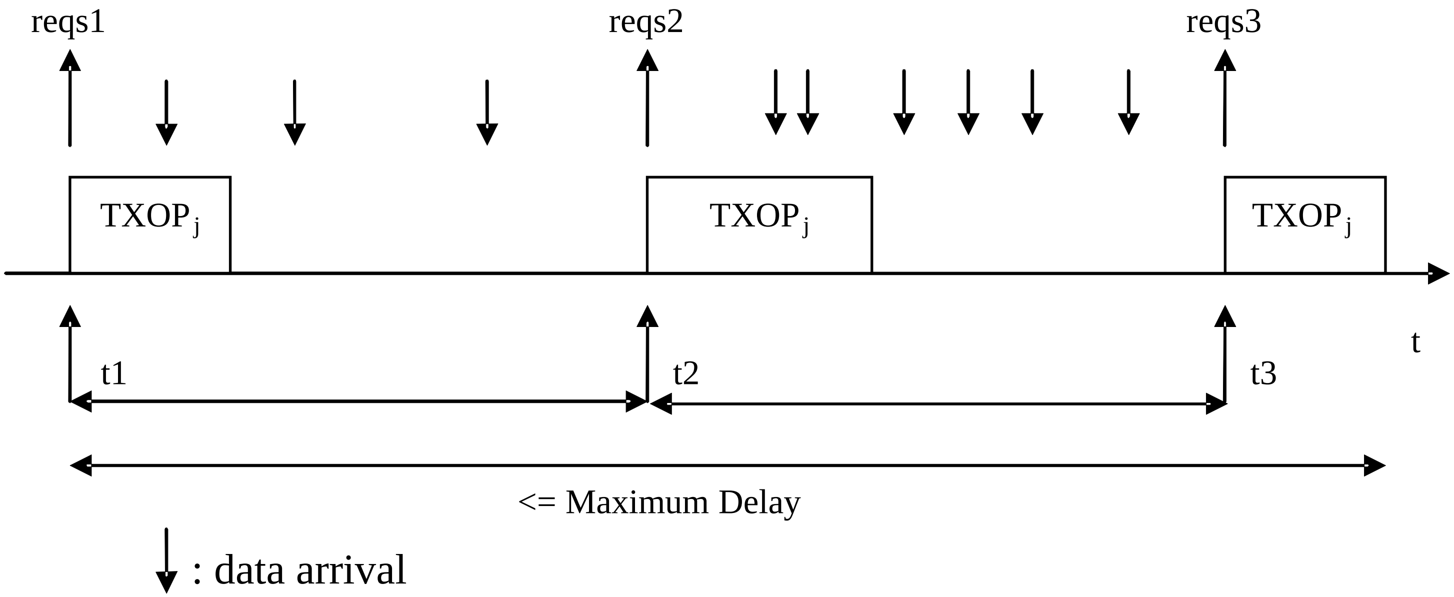
- QoS of wireless network is affected by the following:
  - Attenuation,
  - Multi-path interference,
  - Spectrum interference: for example interferences from neighboring cells,
  - Noise: Noise sources can be natural and man-made such as radio, TV and other radio-frequency transmission,
  - Mobility: affects hand-over and resource utilization, management,
  - Limited capacity: resources are costly.
- Higher error rates are typical

Core Network QoS Components

- **Admission Control**: Limits number of flows admitted into the network so that each individual flow obtains its desired QoS.

- **Scheduling**:
  - Scheduling affects delay, jitter and loss rate.
  - Allows protection against misbehaving flows.
  - Takes into account traffic and channel conditions

Traffic Scheduling in 802.11e

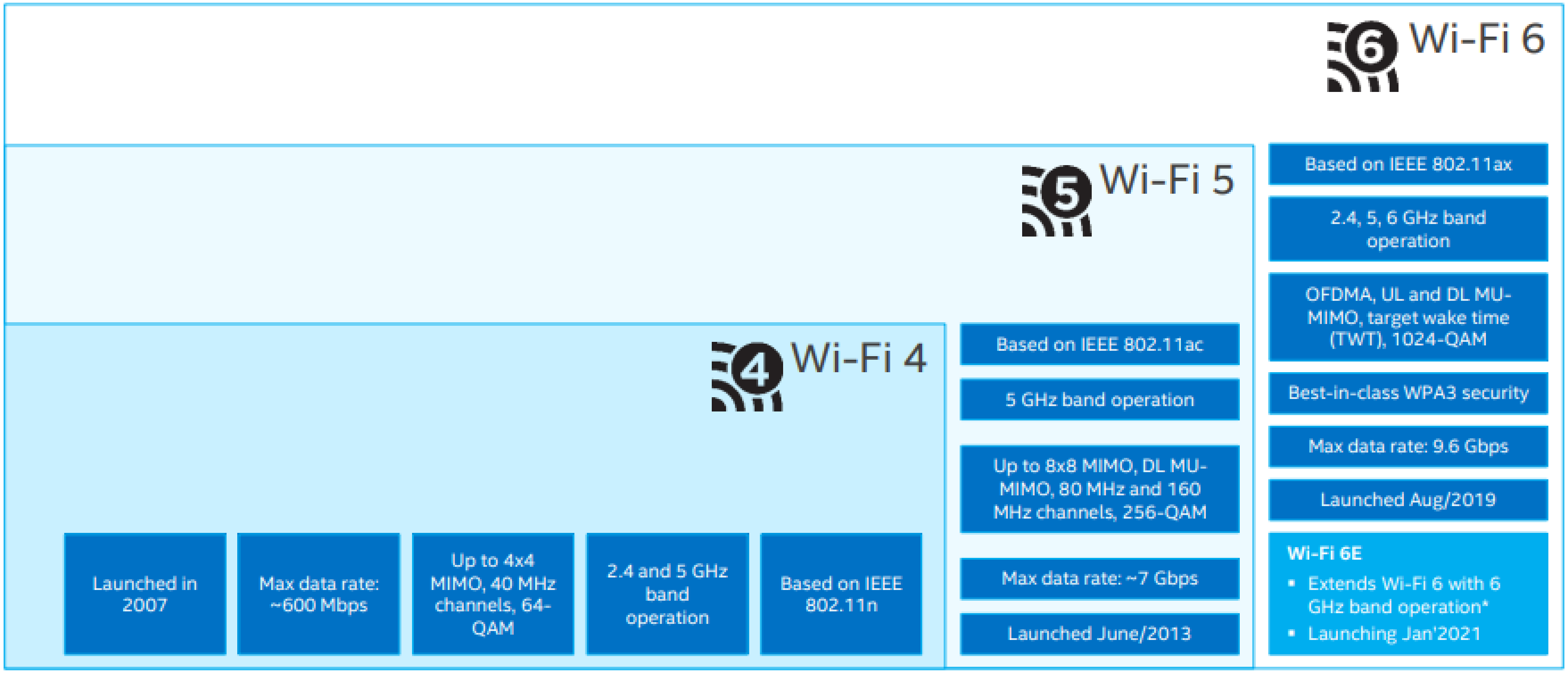


IEEE 802.11
Physical Layer Enhancements

802.11 PHY enhancements

	Wi-Fi 4	Wi-Fi 5	Wi-Fi 6	Wi-Fi 6E	Wi-Fi 7
Launch date	2007	2013	2019	2021	2024 (expected)
IEEE standard	802.11n	802.11ac	802.11ax		802.11be
Max data rate	1.2 Gbps	3.5 Gbps	9.6 Gbps		46 Gbps
Bands	2.4 GHz, 5 GHz	5 GHz	2.4 GHz, 5 GHz	6 GHz	2.4 GHz, 5 GHz, 6 Hz
Channel size	20, 40 MHz	20, 40, 80 80+80, 160 MHz	20, 40, 80 80+80, 160 MHz		Up to 320 MHz
Modulation	64-QAM	256-QAM	1024-QAM		4096-QAM
MIMO	4×4 MIMO	4×4 MIMO, DL MU-MIMO	8×8 UL/DL MU-MIMO		16×16 UL/DL MU-MIMO

802.11 PHY enhancements



802.11 PHY and MAC

	802.11b	802.11a	802.11g	802.11n	802.11ac
Frequency	2.4 GHz	5 GHz	2.4 GHz	2.4/5 GHz	5 GHz
Channel width	20 MHz	20 MHz	20 MHz	20/40 MHz	20/40/80/ 160 MHz
PHY	DSSS	OFDM	OFDM, DSSS	OFDM	OFDM
MIMO & beamforming	No	No	No	Yes	Yes
Max. data rate	**11 Mbps**	**54 Mbps**	**54 Mbps**	**600 Mbps**	**~6933 Mbps**

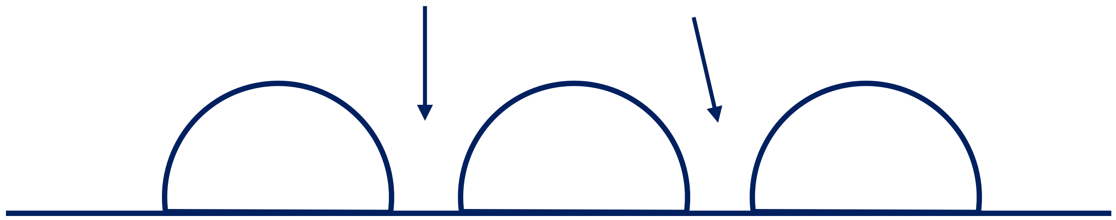
MAC:
CSMA/CA and wideband medium access

PHY-I:
OFDM and modulation

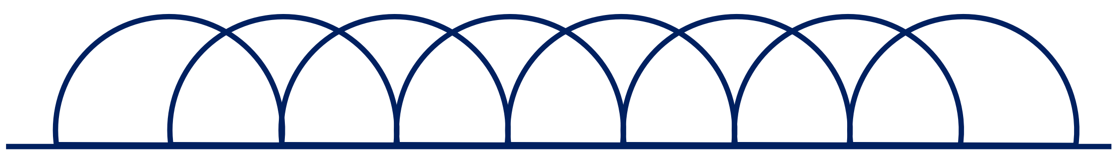
PHY-II:
MIMO and beamforming

OFDM vs FDM

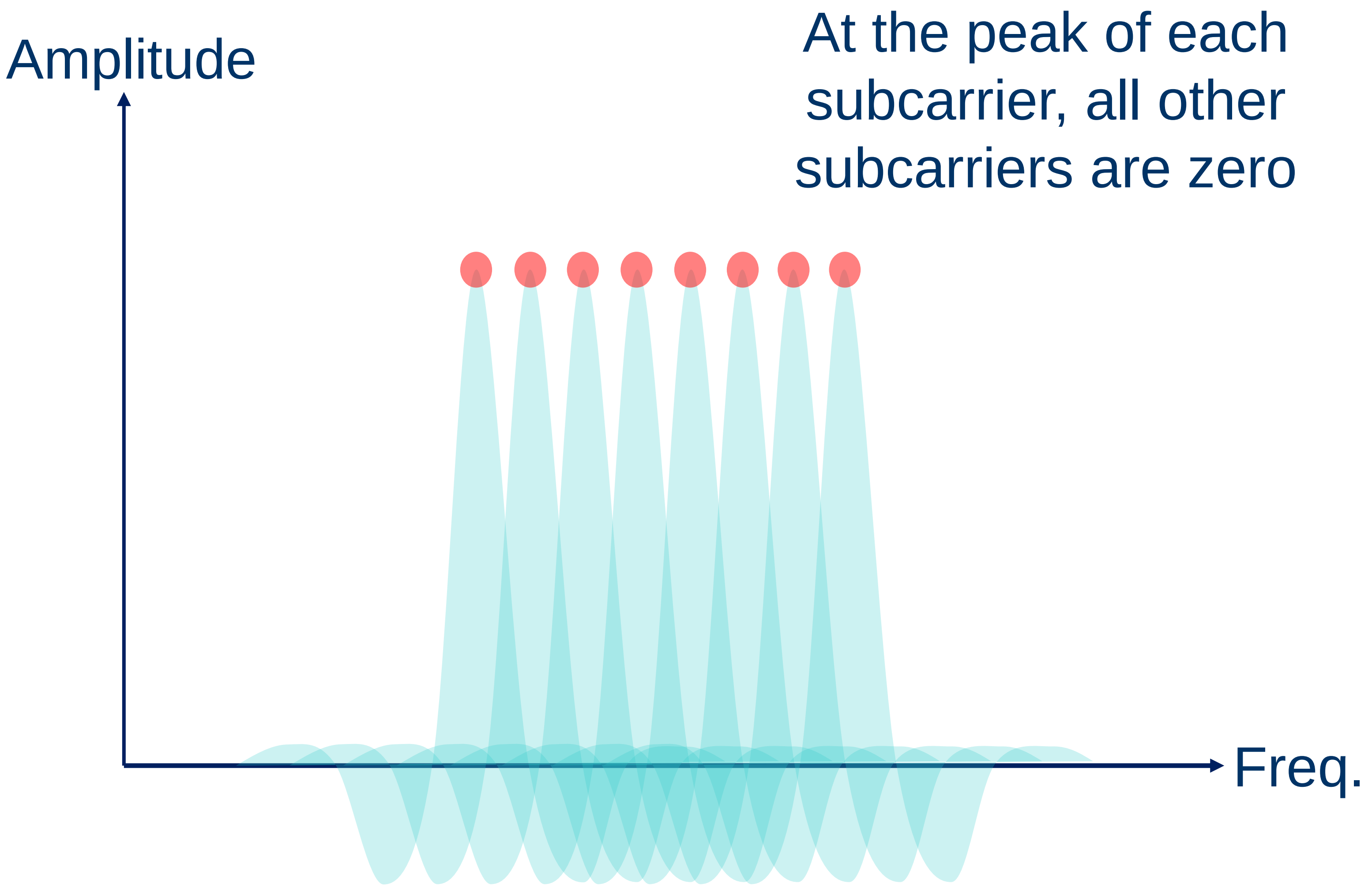
- FDM
  - Non-overlapping subchannels
  - Wastage of bandwidth necessary to separate subchannels



- OFDM
  - Overlapping but orthogonal subchannels
  - Carefully chosen subchannels – at the peak of each subcarrier, all other subcarriers are zero

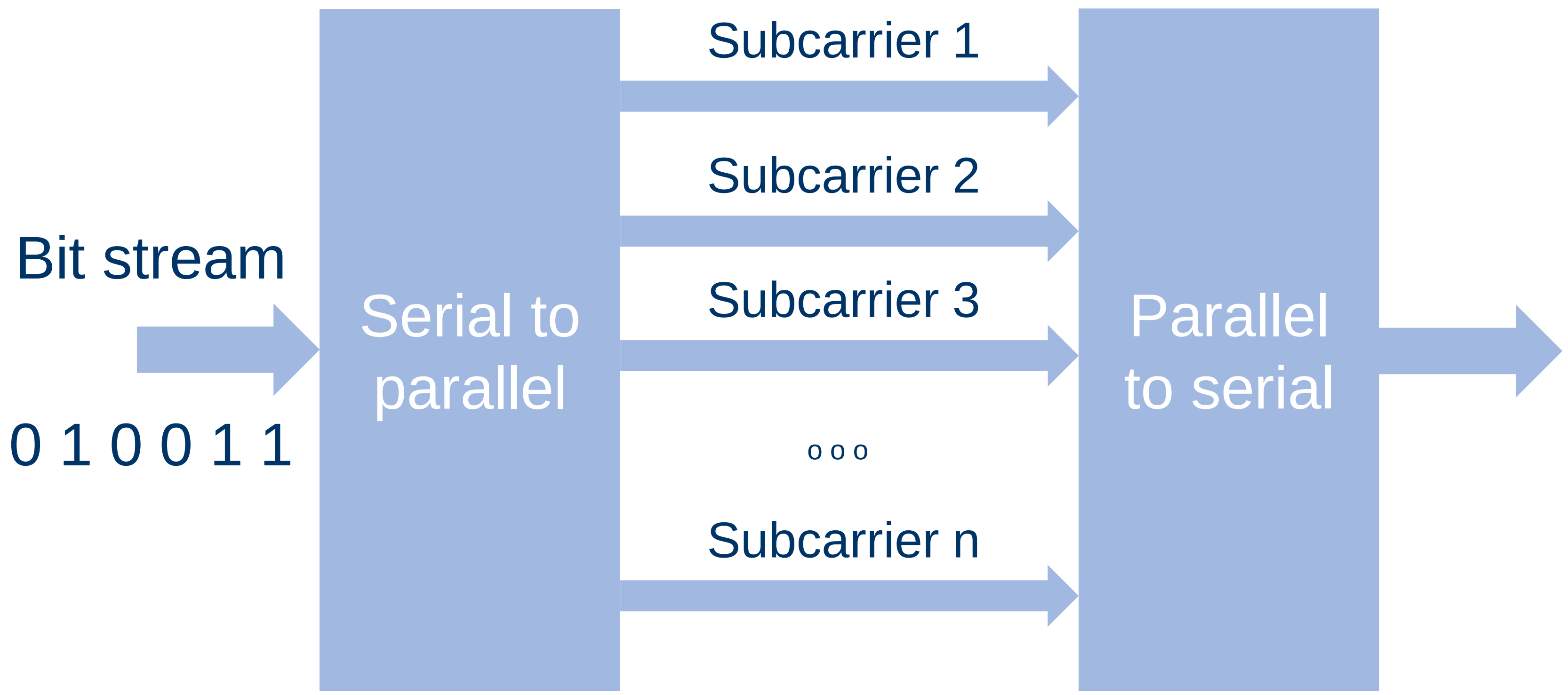


OFDM subcarriers



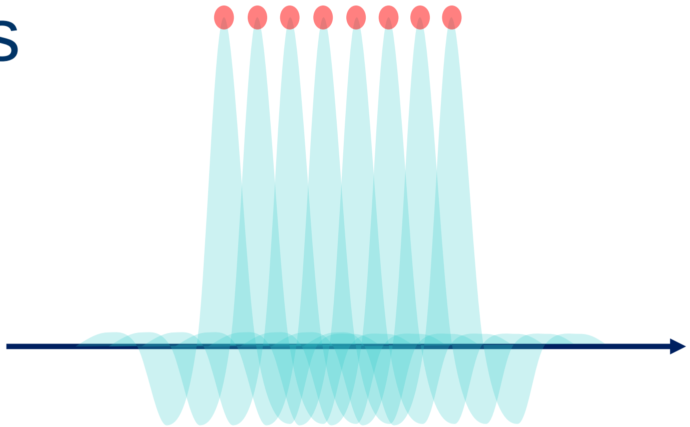
OFDM

➢ How to spread information over the subcarriers?



OFDM

- Example with 8 subcarriers



0 1 0 0 1 1 0 1 1 0 0 1 0 1 0 1

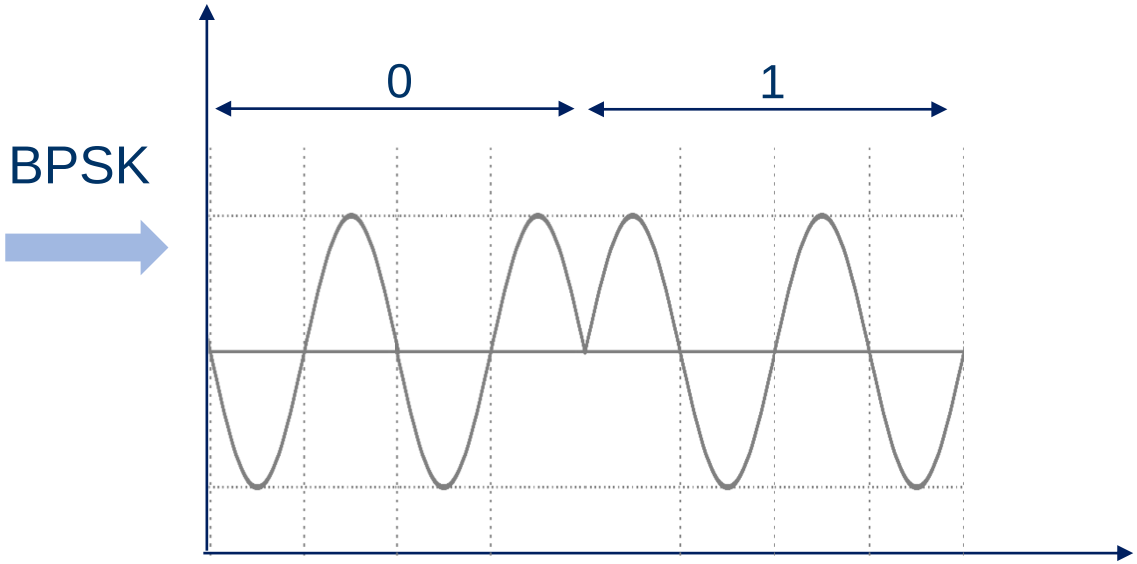
Sub 1	0	1
Sub 2	1	0
Sub 3	0	0
Sub 4	0	1
Sub 5	1	0
Sub 6	1	1
Sub 7	0	0
Sub 8	1	1

Step 1: Serial to parallel

OFDM

- Step 2: Modulate bits on each subcarrier

Sub 1	0	1
Sub 2	1	0
Sub 3	0	0
Sub 4	0	1
Sub 5	1	0
Sub 6	1	1
Sub 7	0	0
Sub 8	1	1

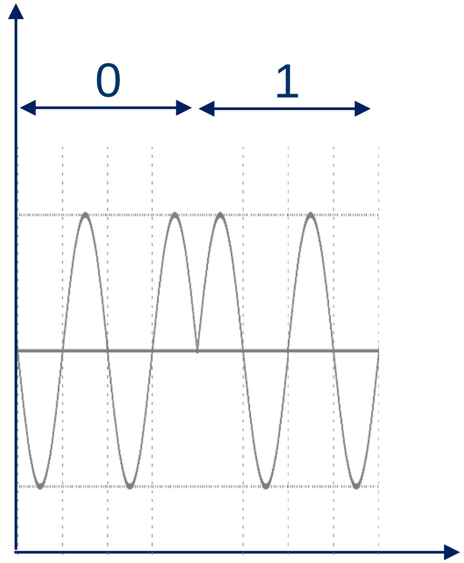


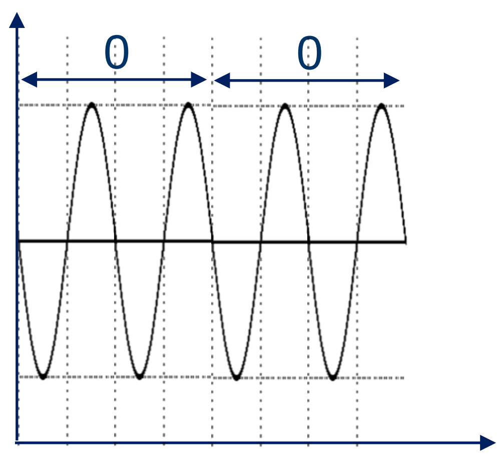
OFDM

- Step 2: Modulate bits on each subcarrier

Sub 1	0	1
Sub 2	1	0
Sub 3	0	0
Sub 4	0	1
Sub 5	1	0
Sub 6	1	1
Sub 7	0	0
Sub 8	1	1

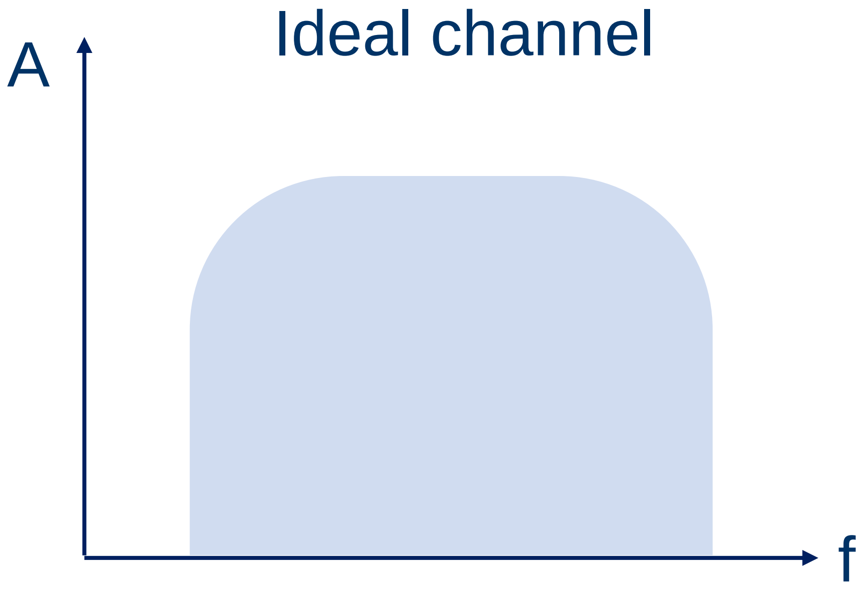
BPSK

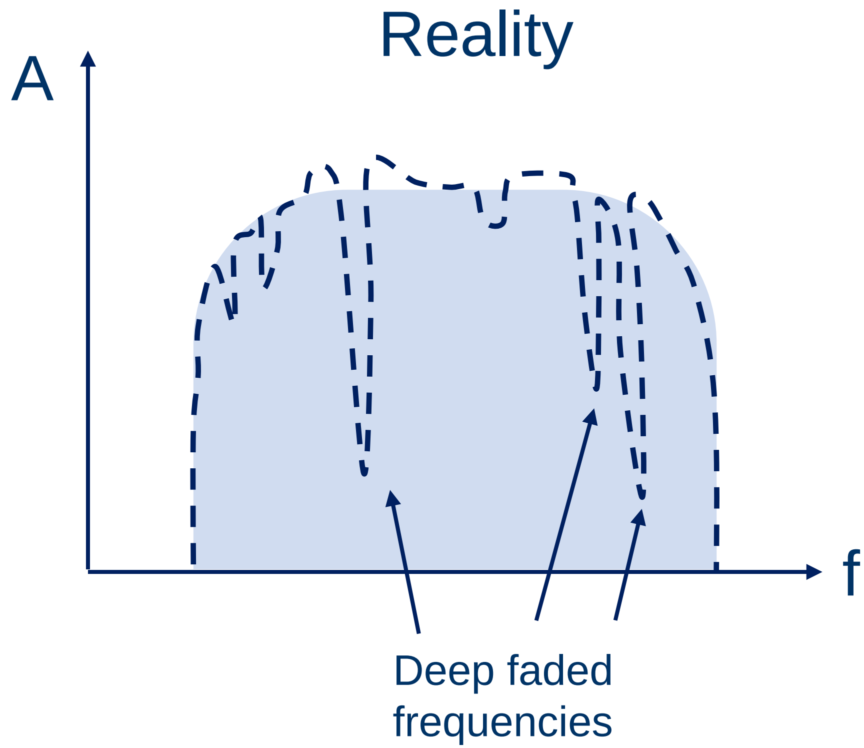




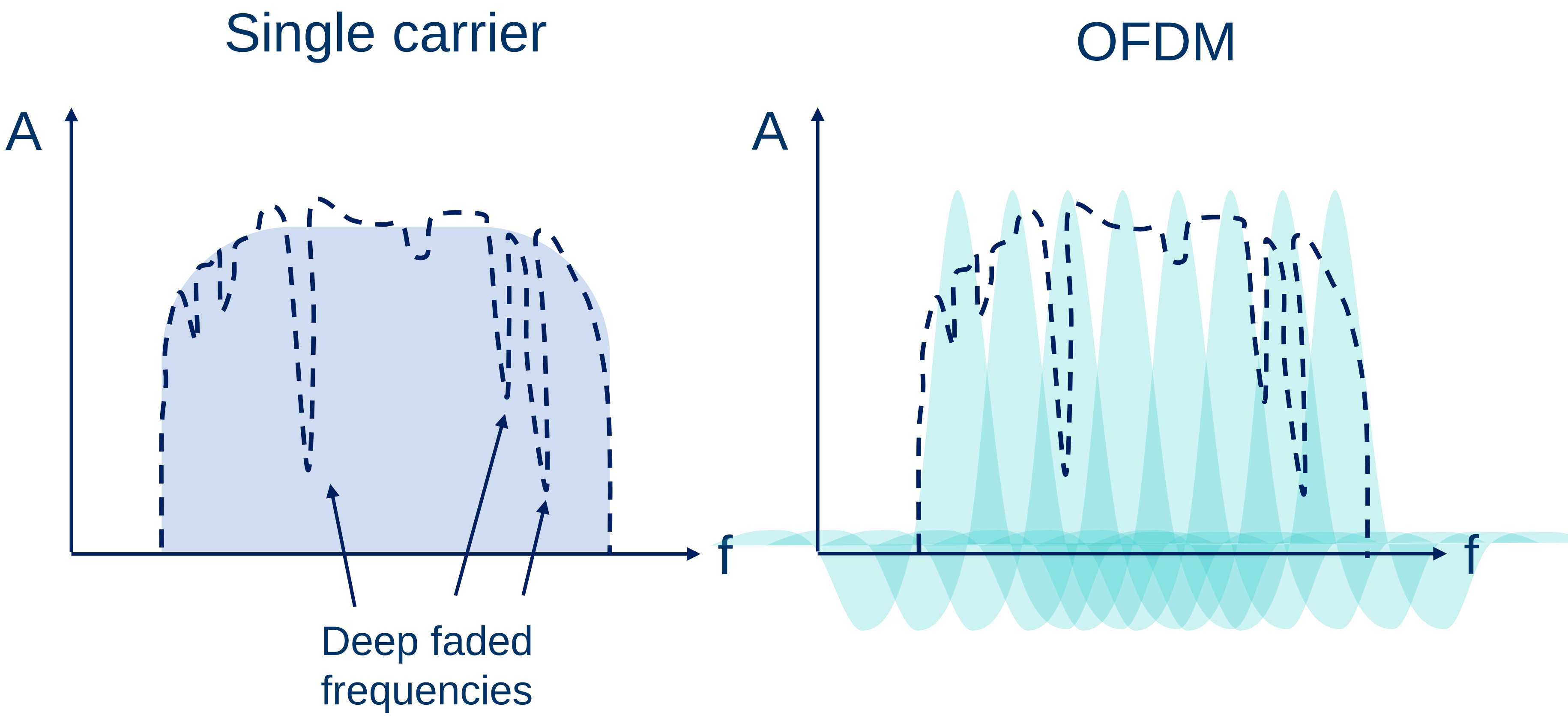
Why OFDM?

- Frequency selective fading
  - Some frequencies within the channel fade severely
  - These frequencies are uncorrelated



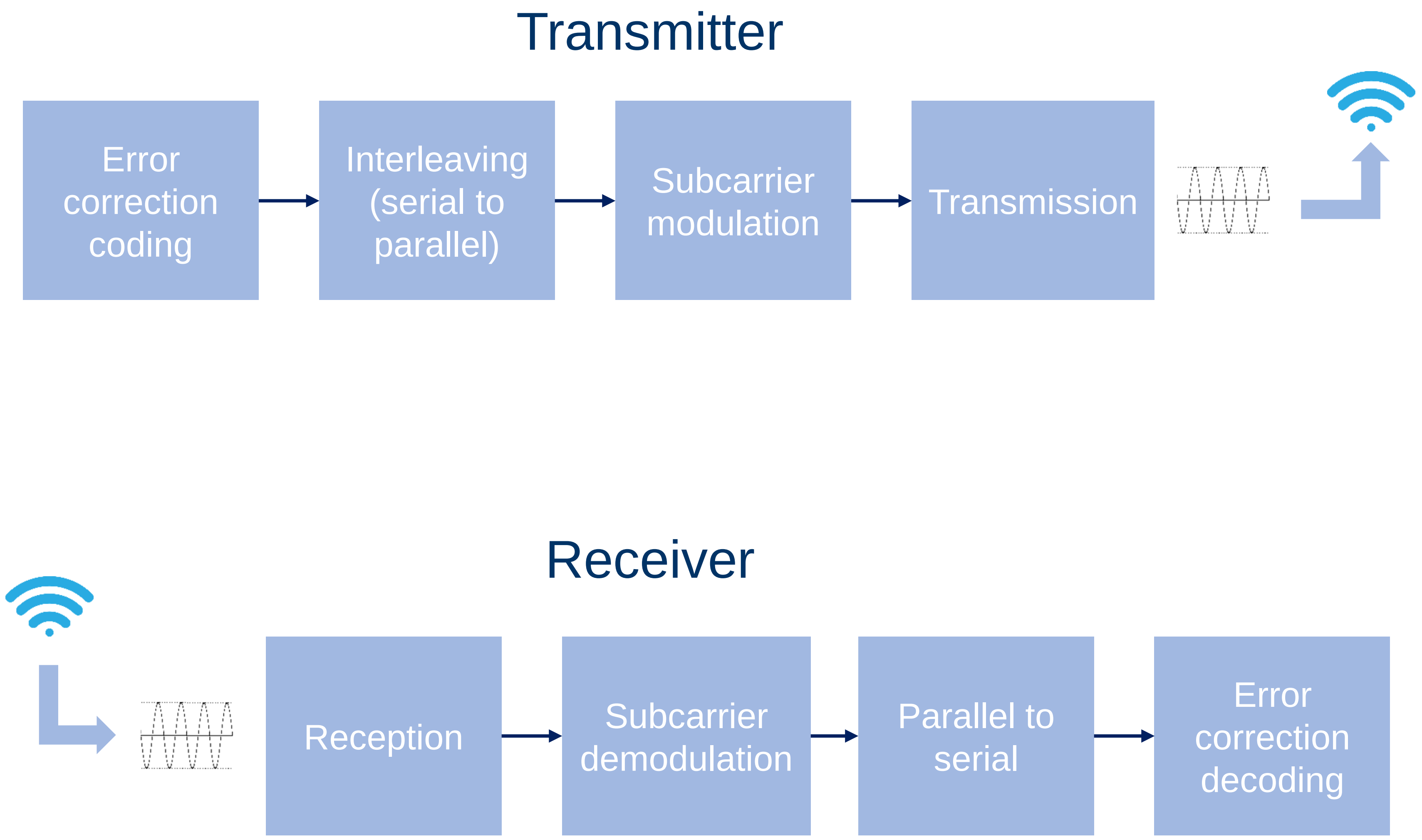


Why OFDM?



- Frequency selective affects only some subcarriers in OFDM
  - Lower bit error rate

OFDM Block Diagram

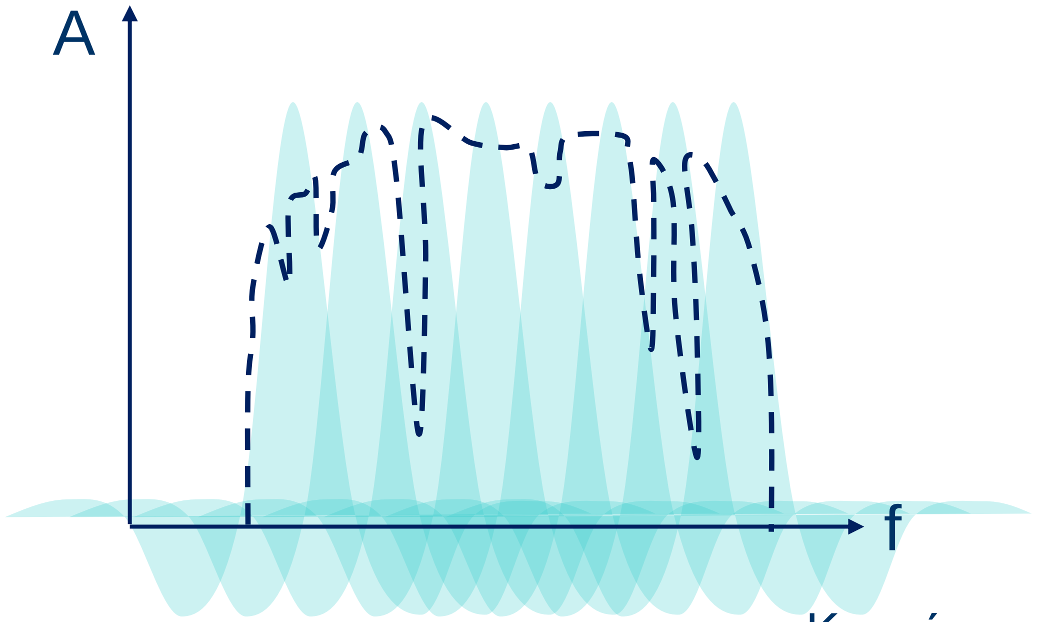


Interleaving

- Process of mapping the incoming data bits to subcarriers
  - In practice, serial to parallel interleaving is not round-robin

- General rule
  - Map the consecutive bits to subcarriers far away from each other
  - Reduces the probability of consecutive bits being dropped due to fading in nearby subcarriers – improves FEC performance

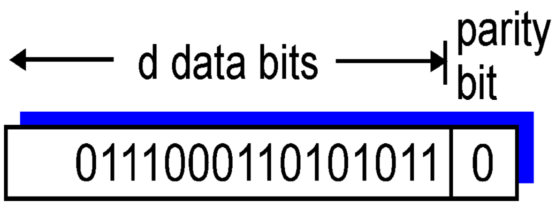
0 1 0 0 1 1 0



Error control - Parity checking

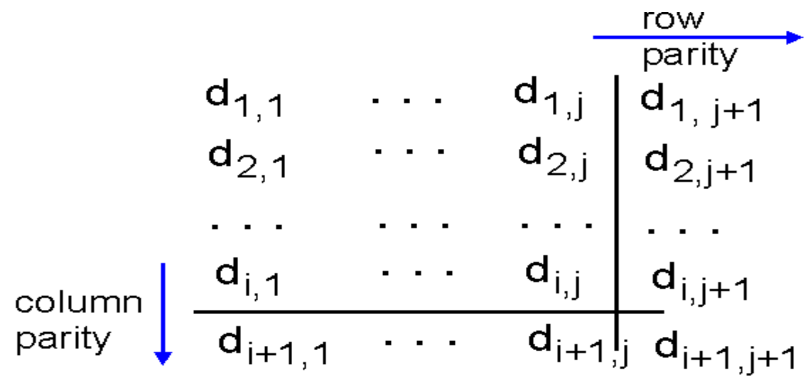
single bit parity:

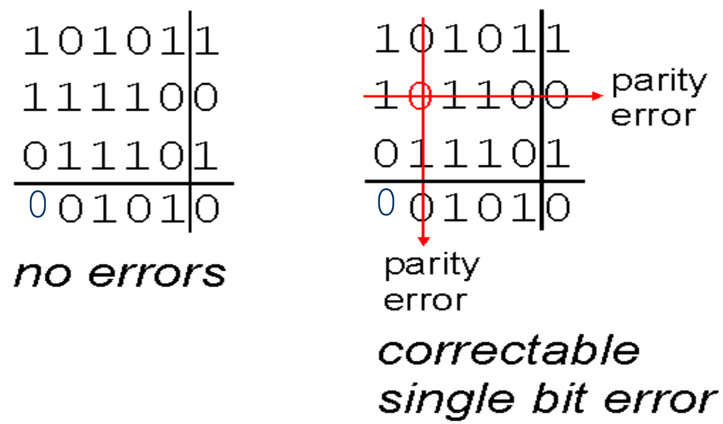
- *d*etect single bit errors



two-dimensional bit parity:

- detect and correct single bit errors





Modulation

- 802.11a supports following modulation schemes

Modulation	Bits per symbol
BPSK	1
QPSK	2
16-QAM	4
64-QAM	6

Block Interleaving

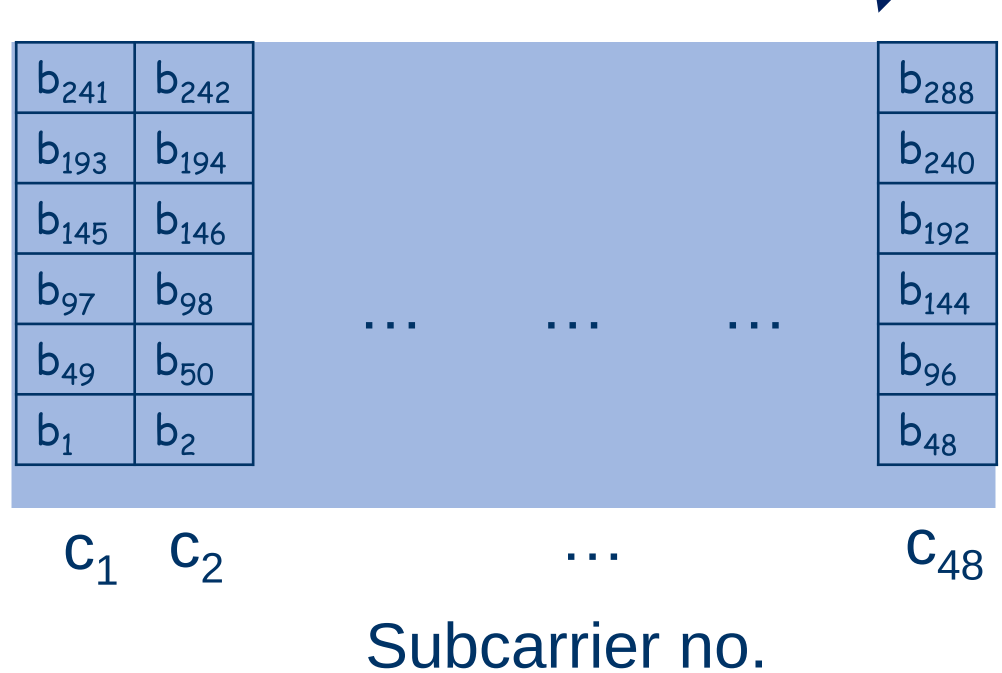
- 802.11a example
  - 48 subcarriers
  - Modulation chosen - 64 QAM (6 bits per symbol)

More complex versions of block interleavers used

- Interleaver buffer size = 48 x 6 = 288 bits

0, 1, 0, … , 1

$b_1, b_2, b_3, \dots, b_{288}$

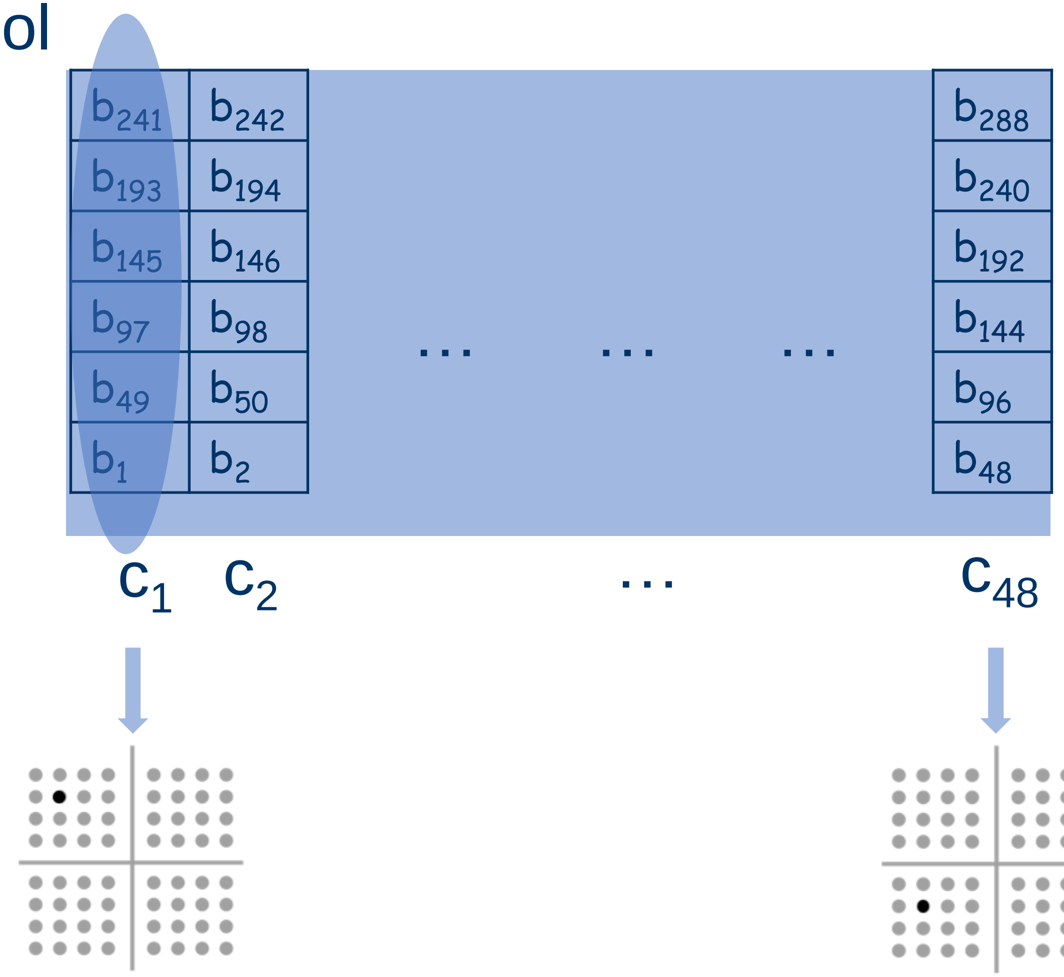


Subcarrier Modulation

- Subcarrier symbol

0, 1, 0, … , 1

$b_1, b_2, b_3, \ldots, b_{288}$

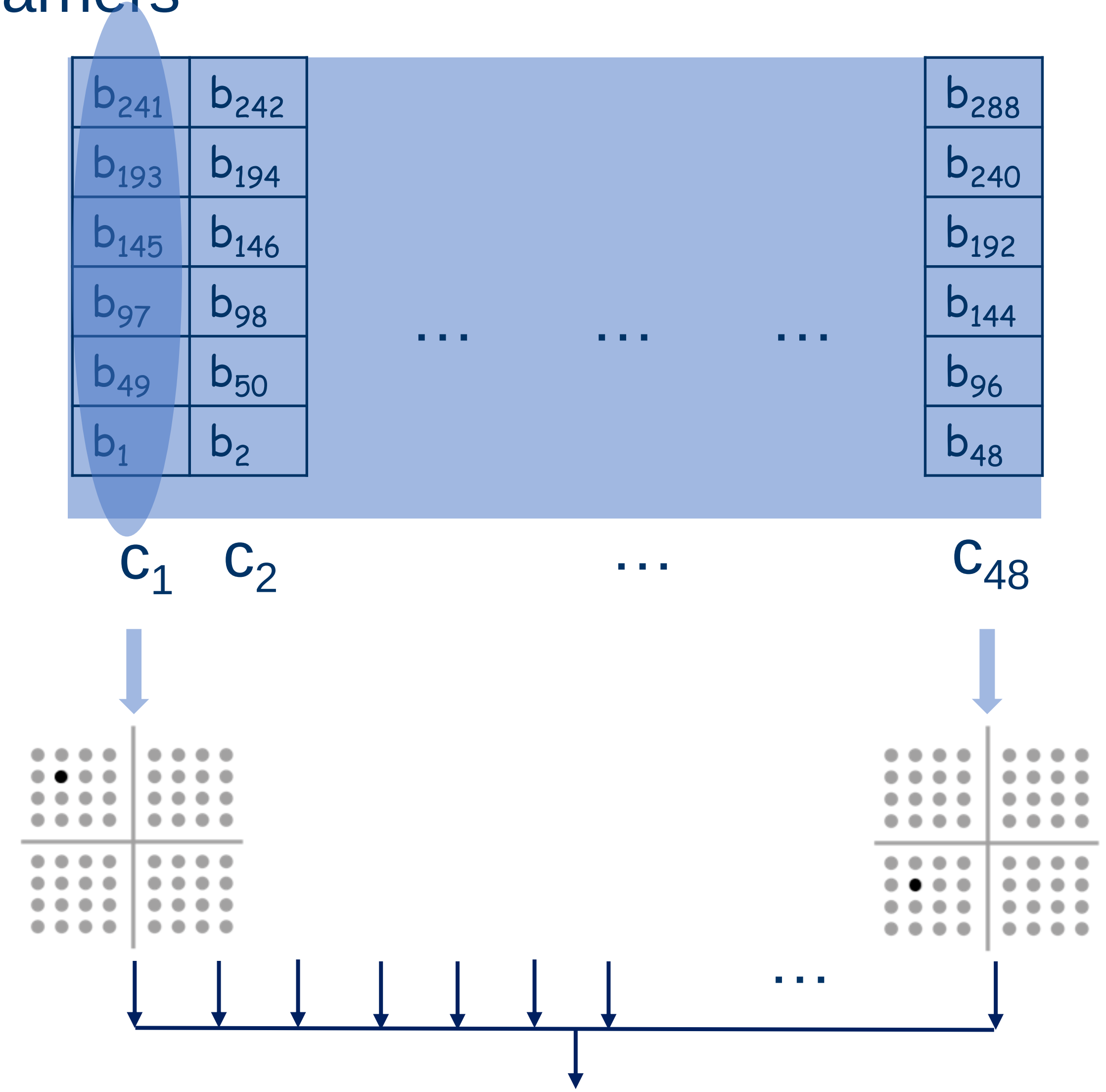


Final transmission

- Combine subcarriers

0, 1, 0, … , 1

$b_1, b_2, b_3, \ldots, b_{288}$



802.11a OFDM PHY

Modulation	Coding rate	Coded bits per subcarrier symbol	Coded bits per OFDM symbol	Data bits per OFDM symbol	Data rate (Mbps)
BPSK	1/2				
BPSK	3/4				
QPSK	1/2				
QPSK	3/4				
16-QAM	1/2				
16-QAM	3/4				
64-QAM	2/3				
64-QAM	3/4				

802.11a OFDM PHY

Modulation	Coding rate	Coded bits per subcarrier symbol	Coded bits per OFDM symbol	Data bits per OFDM symbol	Data rate (Mbps)
BPSK	1/2	1			
BPSK	3/4	1			
QPSK	1/2	2			
QPSK	3/4	2			
16-QAM	1/2	4			
16-QAM	3/4	4			
64-QAM	2/3	6			
64-QAM	3/4	6			

802.11a OFDM PHY

Modulation	Coding rate	Coded bits per subcarrier symbol	Coded bits per OFDM symbol	Data bits per OFDM symbol	Data rate (Mbps)
BPSK	1/2	1	48		
BPSK	3/4	1	48		
QPSK	1/2	2	96		
QPSK	3/4	2	96		
16-QAM	1/2	4	192		
16-QAM	3/4	4	192		
64-QAM	2/3	6	288		
64-QAM	3/4	6	288		

802.11a OFDM PHY

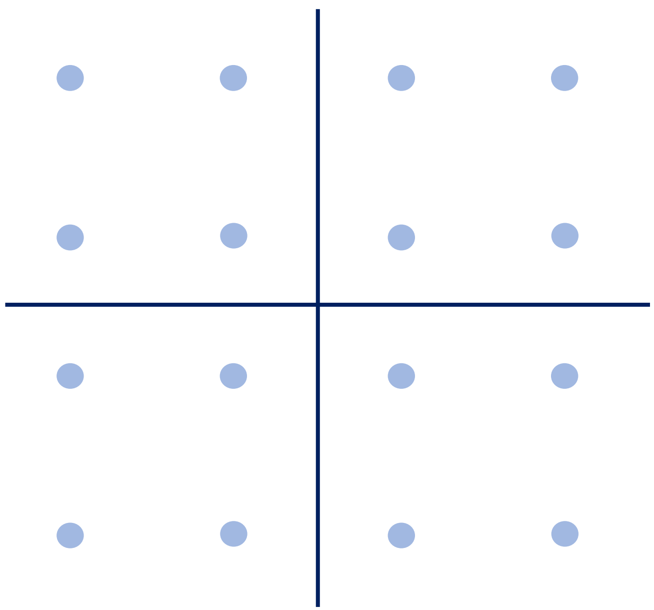
Modulation	Coding rate	Coded bits per subcarrier symbol	Coded bits per OFDM symbol	Data bits per OFDM symbol	Data rate (Mbps)
BPSK	1/2	1	48	24	
BPSK	3/4	1	48	36	
QPSK	1/2	2	96	48	
QPSK	3/4	2	96	72	
16-QAM	1/2	4	192	96	
16-QAM	3/4	4	192	144	
64-QAM	2/3	6	288	192	
64-QAM	3/4	6	288	216	

802.11a OFDM PHY

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

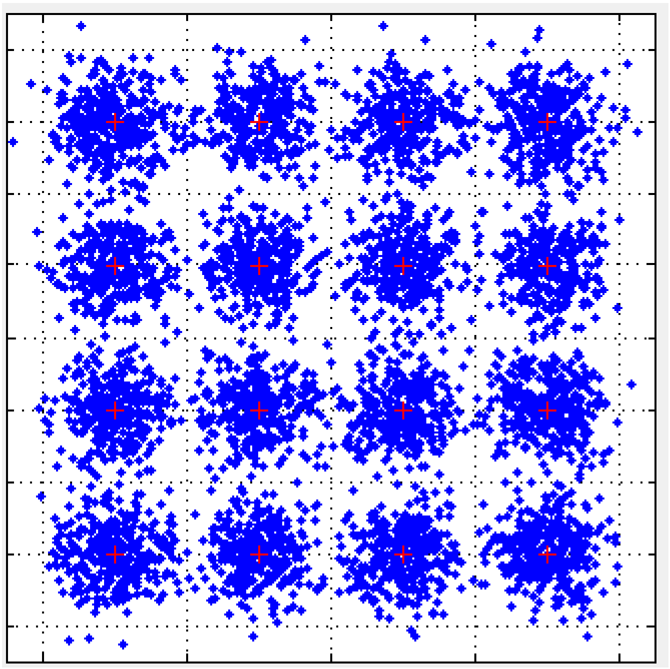
Demodulation

- Received symbols depend on channel variations
  - Multi-path – common reason behind amplitude and phase changes



Transmitter

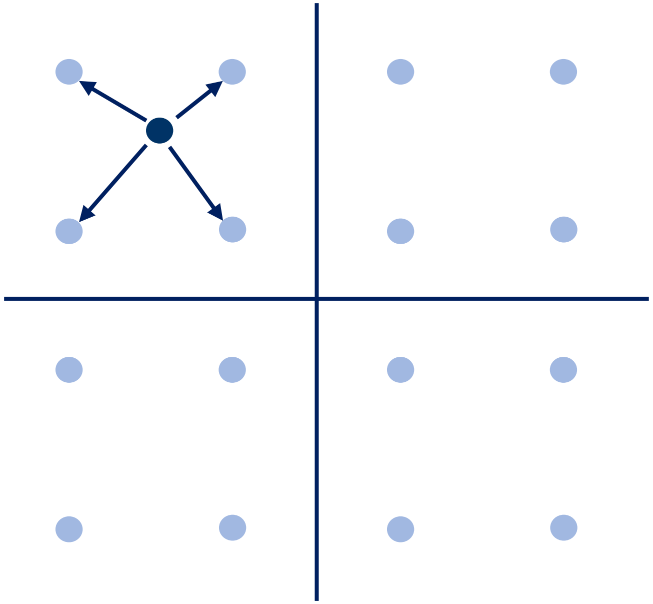
Inter-symbol interference



Receiver

Demodulation

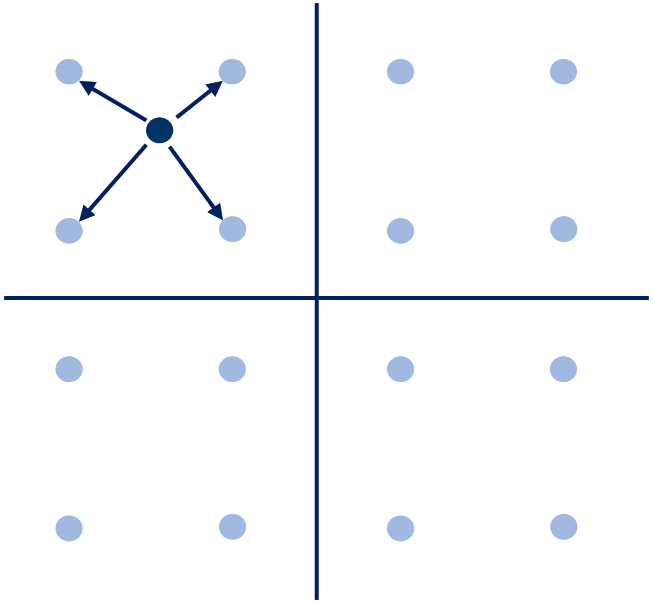
- Hard decision
  - Calculate the distance to the constellation points, pick the one with the lowest distance
  - Can be overly conservative



Receiver

Demodulation

- Soft decision
  - For the received symbol, calculate its distance to the nearby constellation points
  - Use the distance to associate a probability to the constellation point
  - Combine the probabilities with FEC decoding to minimize errors



Receiver

RSS, SNR and SINR

- Commonly used measures of channel quality

- RSS – Received Signal Strength
  - Measured in dBm
  - Often available through RSSI register on WiFi chipsets

- SNR – Signal to Noise Ratio (S/N)
  - Measured in dB
  - Ratio of RSS and measured noise, available or can be derived

- SINR – Signal to Noise and Interference Ratio (S/I+N)
  - Measured in dB
  - Considers how much interference is caused by other transmissions
  - Very useful metric but difficult to measure

Receiver sensitivity

- Better signal strength (higher SNR) ensures lower inter-symbol interference (ISI)

- 802.11 standards associate a receiver sensitivity with each modulation and data rate

802.11a

Modulation	Data rate (Mbps)	Receiver sensitivity (dBm)
BPSK	6	-82
BPSK	9	-81
QPSK	12	-79
QPSK	18	-77
16-QAM	24	-74
16-QAM	36	-70
64-QAM	48	-66
64-QAM	54	-65

OFDM in 802.11ac

- 802.11ac introduces the use of 256 QAM
  - 256 QAM – 8 bits per symbol

Modulation	Coding rate	Receiver sensitivity (dBm)
BPSK	1/2	-82
QPSK	1/2	-79
QPSK	3/4	-77
16-QAM	1/2	-74
16-QAM	3/4	-70
64-QAM	2/3	-66
64-QAM	3/4	-65
64-QAM	5/6	-64
256-QAM	3/4	-59
256-QAM	5/6	-57

OFDM in 802.11ac

- 802.11ac uses wider channel widths
  - 20, 40, 80 and 160 MHz
  - More subcarriers for OFDM

Channel width (MHz)	OFDM subcarriers
20	52
40	108
80	234
160	468

- For higher data rates, 160 MHz channel width and 256 QAM modulation can be used