WLAN 802.11a Spec. (Physical Layer)

周信亨

2005/04/28

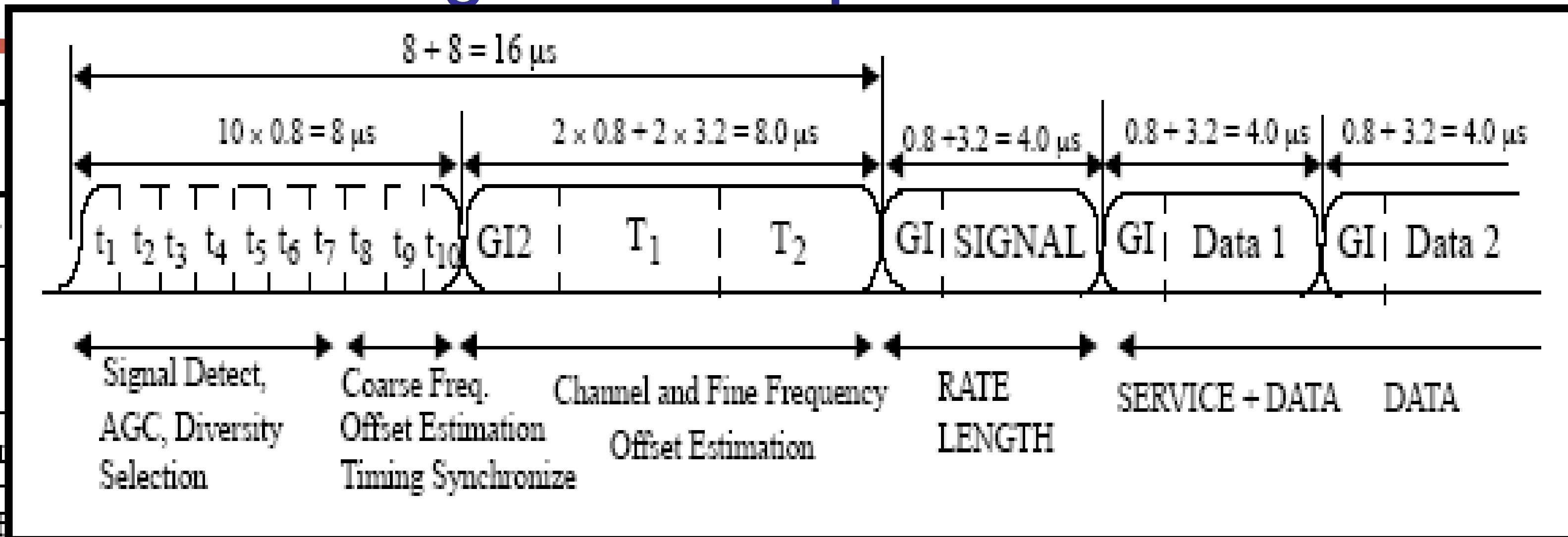
802.11a PHY SPEC. for the 5GHz band

- Introduction
  - The radio frequency LAN system is initially aimed for the 5.15-5.25, 5.25-5.35 GHz, & 5.725-5.825 GHz unlicensed national information infrastructure (U-NII) band.
  - The support of transmitting & receiving at data rates of 6, 12, 24 Mbit/s is mandatory. (9, 18, 36, 48, 54Mbit/s)
  - The system uses 52 subcarriers that are modulated using binary or quadrature phase shift keying (BPSK/QPSK), 16-quadrature amplitude modulation (QAM), or 64-QAM.
  - Forward error correction coding (convolutional coding) is used with a coding rate of 1/2, 2/3, or 3/4

RATE-dependent parameters

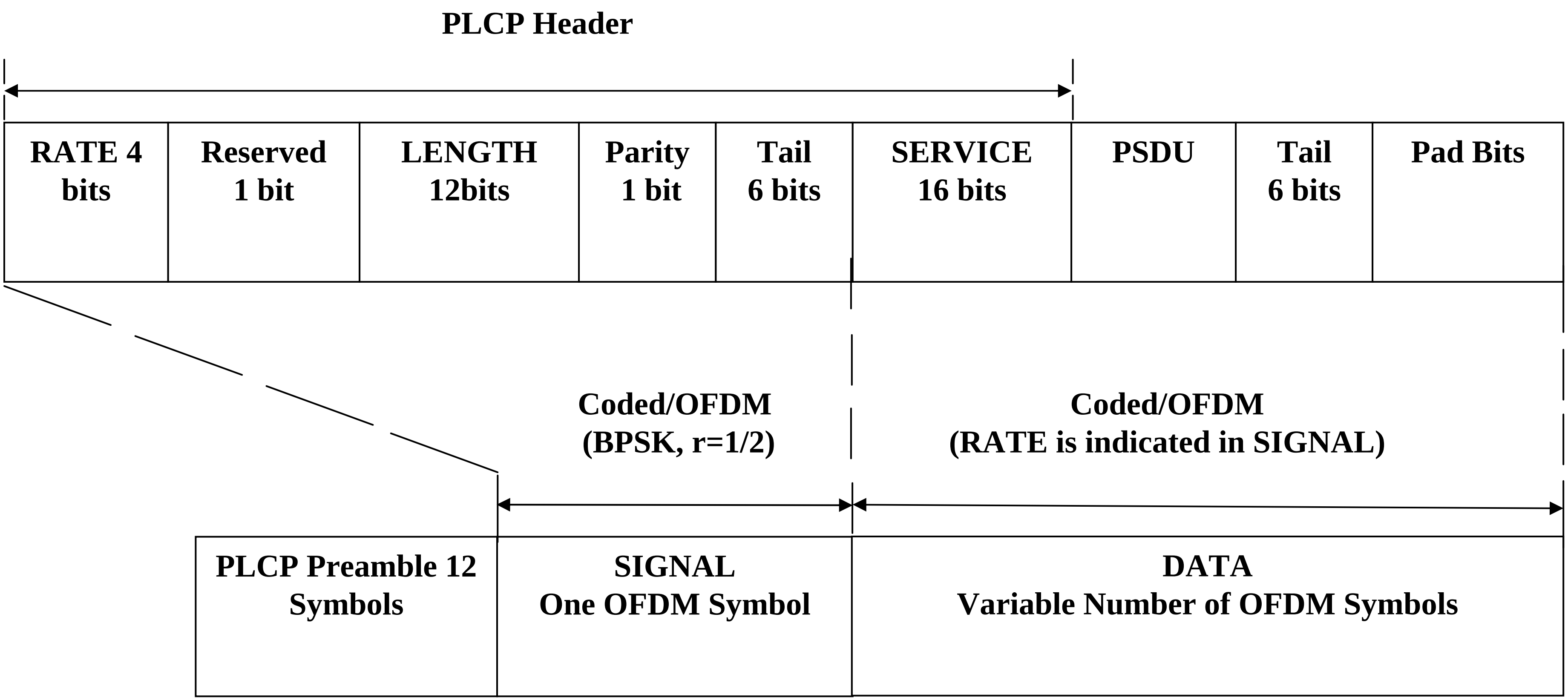
Data rate (Mbits/s)	Modulation	Coding rate (R)	Coded bits per subcarrier (N_{BPSC})	Coded bits per OFDM symbol (N_{CBPS})	Data bits per OFDM symbol (N_{DBPS})
6	BPSK	1/2	1	48	24
9	BPSK	3/4	1	48	36
12	QPSK	1/2	2	96	48
18	QPSK	3/4	2	96	72
24	16-QAM	1/2	4	192	96
36	16-QAM	3/4	4	192	144
48	64-QAM	2/3	6	288	192
54	64-QAM	3/4	6	288	216

Timing related parameters

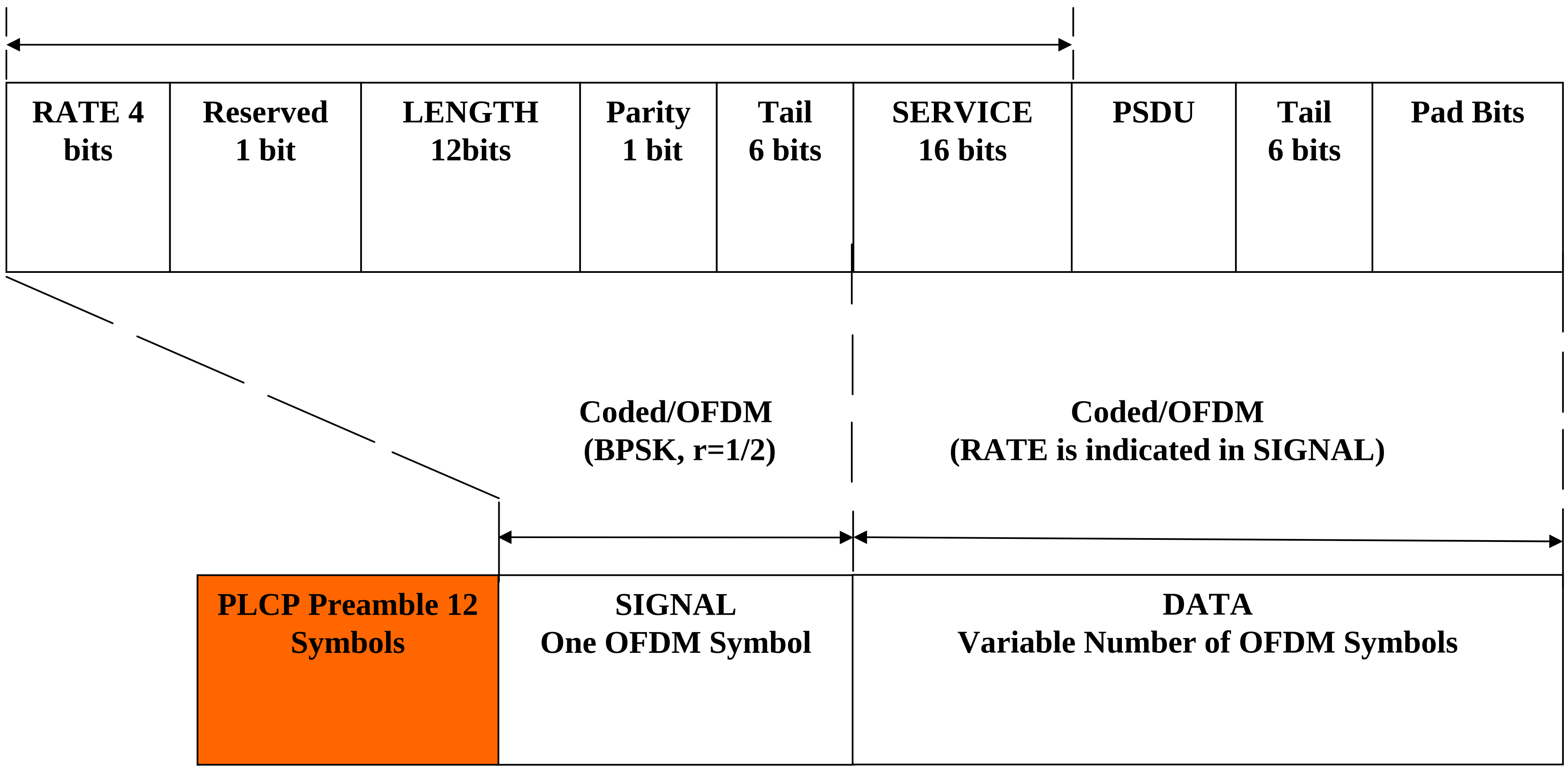


N_{SD}: Number	
N_{SP}: Number	
N_{ST}: Number	
Δ_F: Subcarrier	
T_{FFT}: IFFT/FF	
$T_{PREAMBLE}$: PLCP preamble duration	16 μs ($T_{SHORT} + T_{LONG}$)
T_{SIGNAL}: Duration of the SIGNAL BPSK-OFDM symbol	4.0 μs ($T_{GI} + T_{FFT}$)
T_{GI}: GI duration	0.8 μs (T_{FFT}/4)
T_{GI2}: Training symbol GI duration	1.6 μs (T_{FFT}/2)
T_{SYM}: Symbol interval	4 μs ($T_{GI} + T_{FFT}$)
T_{SHORT}: Short training sequence duration	8 μs (10 × T_{FFT} /4)
T_{LONG}: Long training sequence duration	8 μs (T_{GI2} + 2 × T_{FFT})

PLCP sublayer

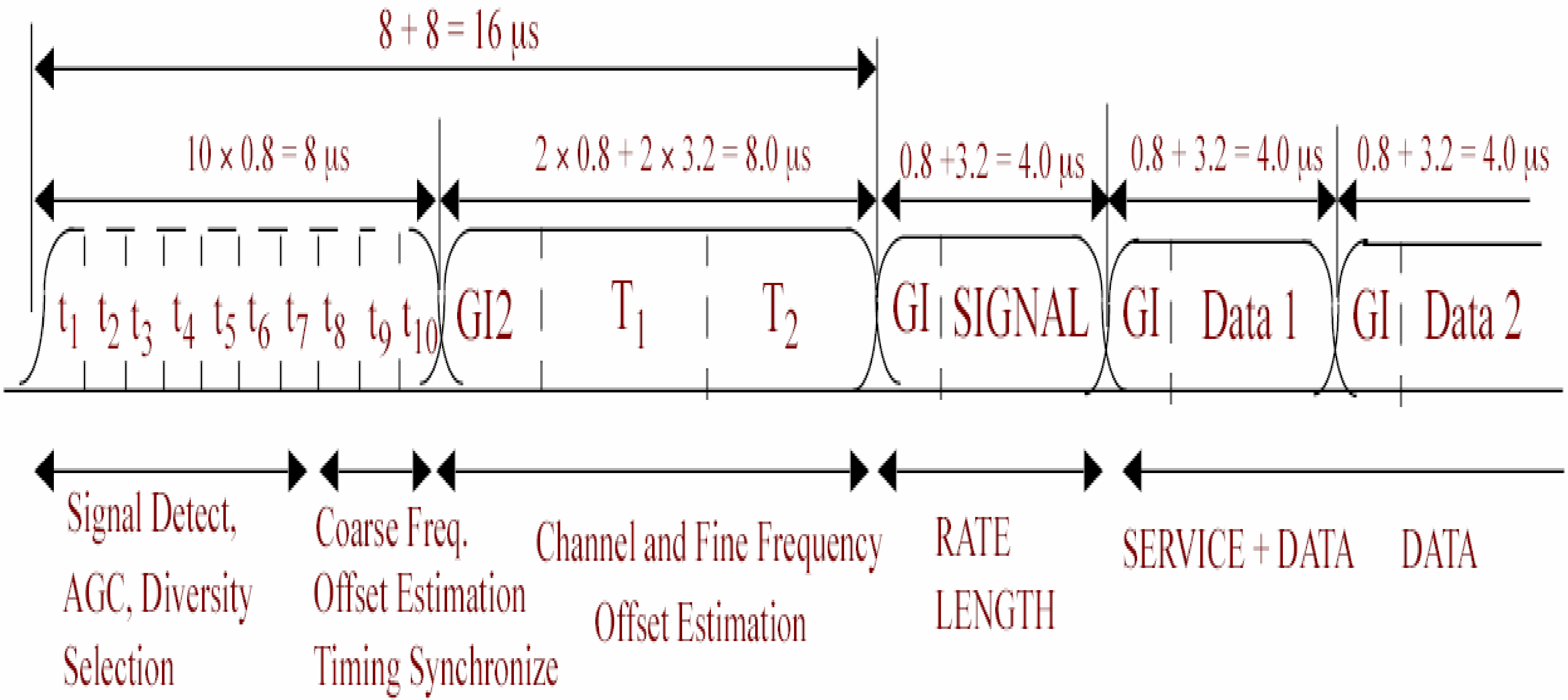


PLCP preamble (SYNC)



PLCP preamble (SYNC)

- It consists of 10 short training symbols & 2 long training symbols



WiTS Lab
Inst. of Comm. Engr.

PLCP preamble (SYNC)

- In the PLCP (Physical Layer Convergence Procedure) preamble field
  - Composed of 10 repetitions of a "shorting training sequence",used for
    - AGC (Automatic Gain Control) convergence
    - Diversity selection
    - Timing acquisition
    - Coarse frequency acquisition in the receiver
  - Two repetitions of a "long training sequence",used for
    - Channel estimation
    - Fine frequency acquisition in the receiver

Short training symbol

- A short OFDM training symbol consists of 12 subcarriers, which are modulated by the elements of the sequence S, given by

$$
\begin{aligned}
S_{-26,26} = \sqrt{13/6} \times \{&0,\ 0,\ \overset{-24}{1+j},\ 0,\ 0,\ 0,\ \overset{-20}{-1-j},\ 0,\ 0,\ 0,\ \overset{-16}{1+j},\ 0,\ 0,\ 0,\ \overset{-12}{-1-j},\ 0,\ 0,\ 0,\\
&\overset{-8}{-1+j},\ 0,\ 0,\ 0,\ \overset{-4}{1+j},\ 0,\ 0,\ 0,\ \overset{0}{0},\ 0,\ 0,\ 0,\ \overset{4}{-1-j},\ 0,\ 0,\ 0,\ \overset{8}{-1-j},\\
&0,\ 0,\ 0,\ \overset{12}{1+j},\ 0,\ 0,\ 0,\ \overset{16}{1+j},\ 0,\ 0,\ 0,\ \overset{20}{1+j},\ 0,\ 0,\ 0,\ \overset{24}{1+j},\ 0,\ 0\}
\end{aligned}
$$

- The multiplication by a factor of $\sqrt{13/6}$ is in order to normalize the average power of the resulting OFDM symbol, which utilizes 12 out of 52 subcarriers.
- The fact that only spectral lines of $S_{-26:26}$ with indices that are a multiple of 4 have nonzero amplitude results in a periodicity of 0.8 us.

Short training symbol

- The signal shall be generated according to the following equation:

$$r_{SHORT}(t) = w_{TSHORT}(t) \sum_{k=-N_{ST}/2}^{N_{ST}/2} S_k \exp(j2\pi k \Delta_F t)$$

Long training symbol

- A long training symbol consists of 53 subcarriers (including a zero value at dc), which are modulated by the elements of the sequence L, given by

$$L_{-26,26} = \{1, 1, -1, -1, 1, 1, -1, 1, -1, 1, 1, 1, 1, 1, 1, -1, -1, 1, 1, -1, 1, -1, 1, 1, 1, 1, 0, \\ 1, -1, -1, 1, 1, -1, 1, -1, 1, -1, -1, -1, -1, -1, 1, 1, -1, -1, 1, -1, 1, -1, 1, 1, 1, 1\}$$

- A long OFDM training symbol shall be generated according to the following equation:

$$r_{LONG}(t) = w_{TLONG}(t) \sum_{k=-N_{ST}/2}^{N_{ST}/2} L_k \exp(j2\pi k\Delta_F (t - T_{GI2}))$$

  - where $T_{GI2} = 1.6\mu s$

Long training symbol

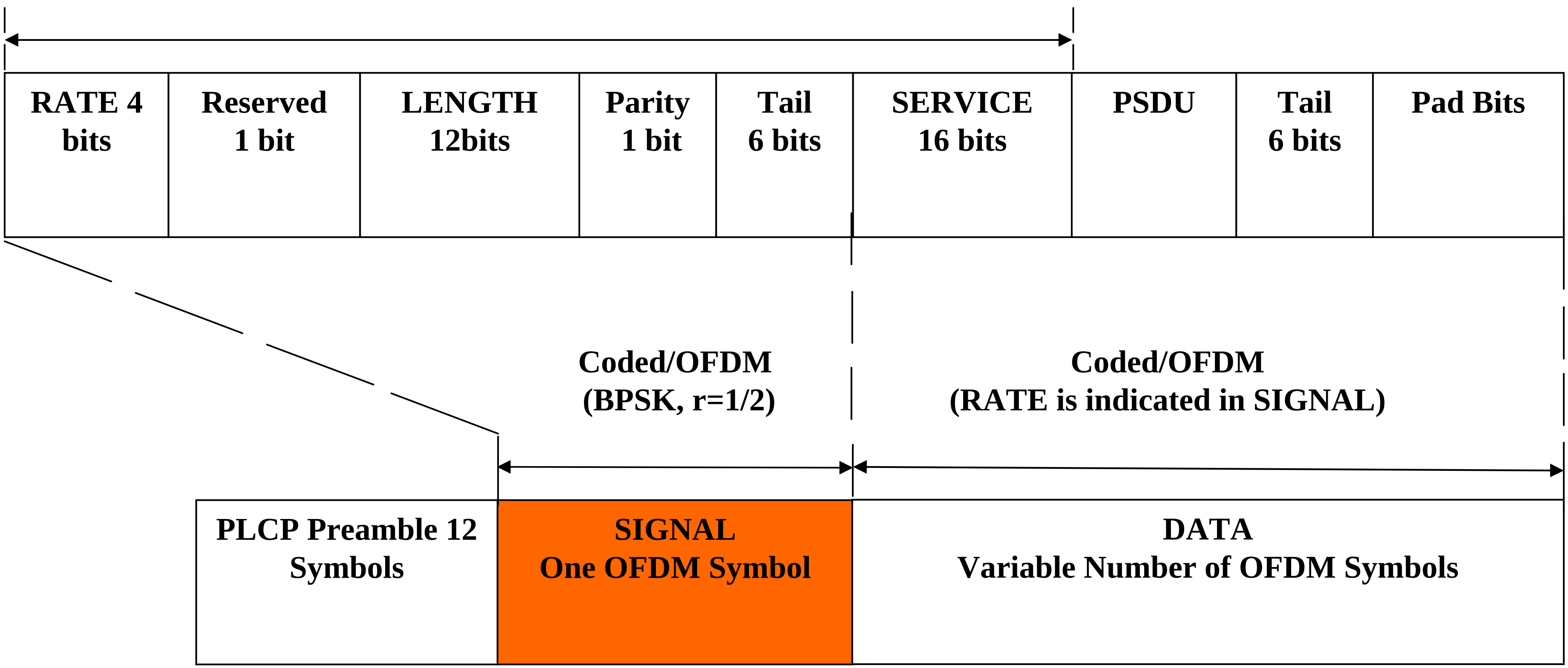
- Two period of the long sequence are transmitted for improved channel estimation accuracy, yielding

$$T_{LONG} = 1.6 + 2 \times 3.2 = 8 \mu s$$

- The sections of short repetitions and long repetitions shall be concatenated to form the preamble

$$r_{PREAMBLE}(t) = r_{SHORT}(t) + r_{LONG}(t - T_{SHORT})$$

Signal field (SIGNAL)



Signal field (SIGNAL)

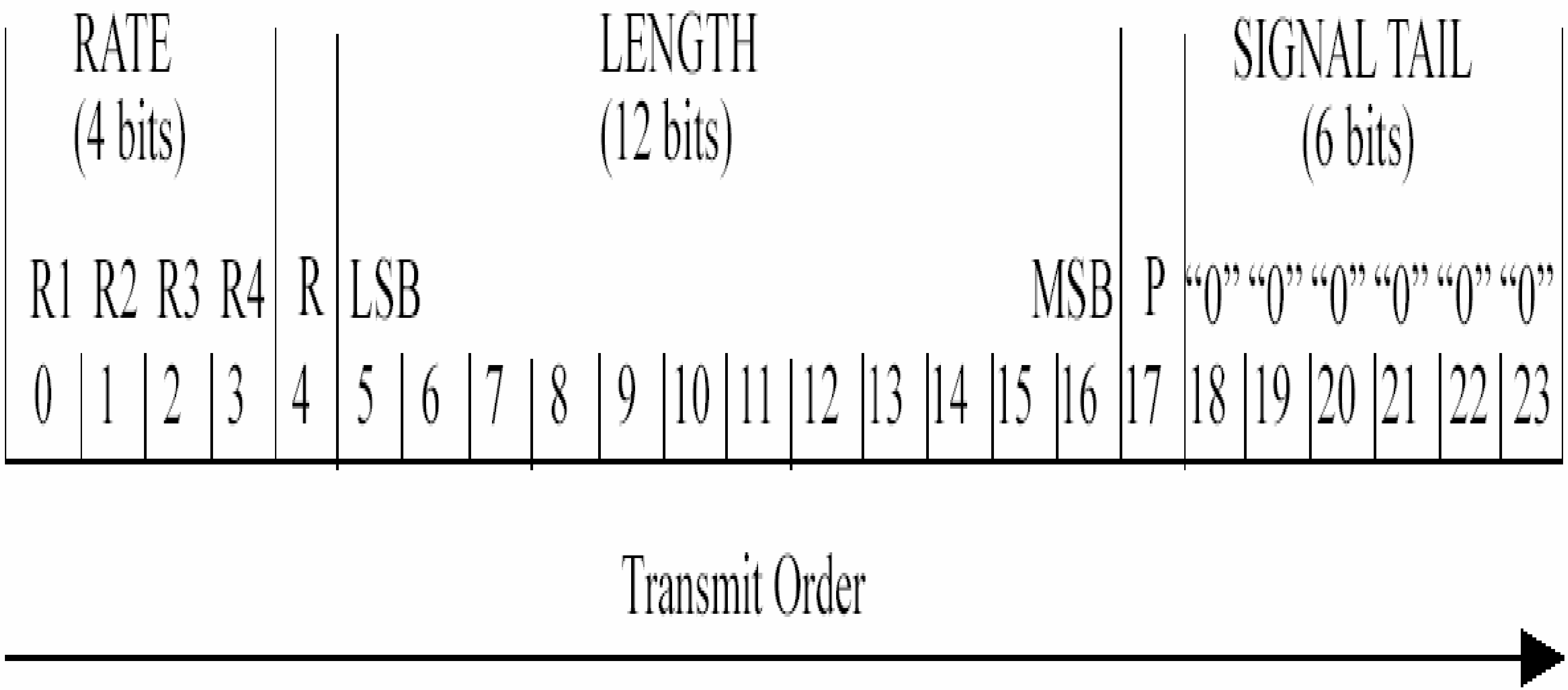


Figure 111—SIGNAL field bit assignment

Signal field (SIGNAL)

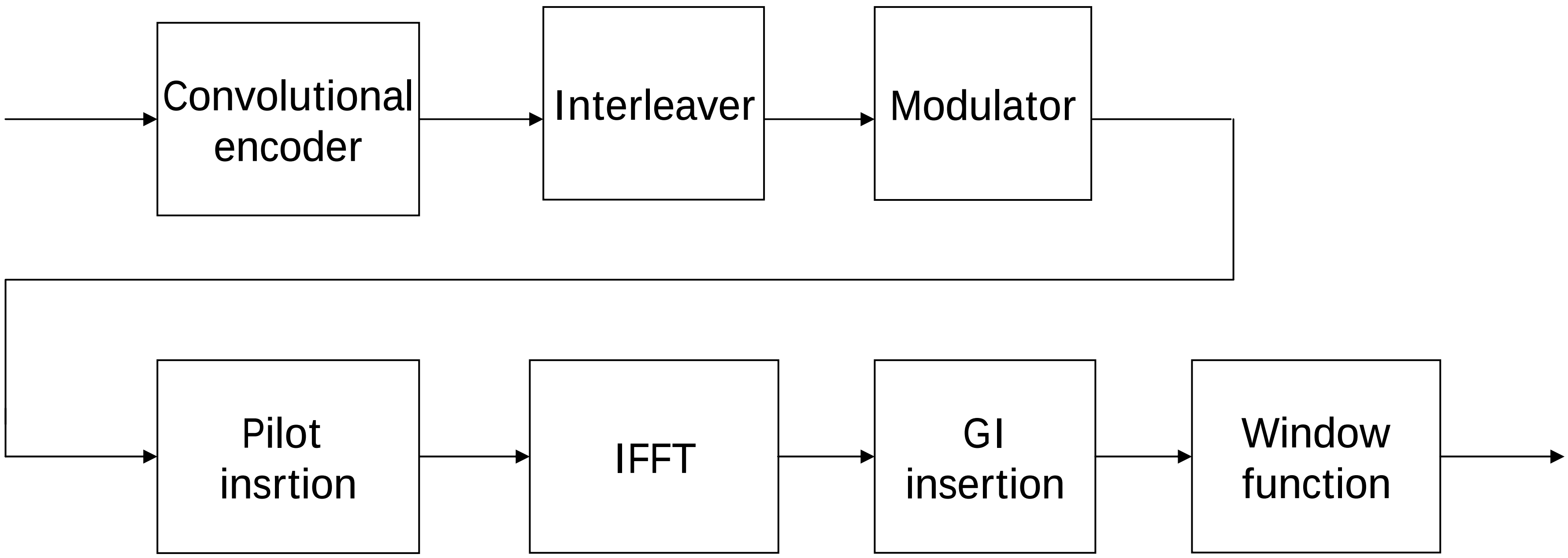
- Bit 4 : shall be reserved for future use
- Bit 17: shall be positive parity (even parity) bit for bit 0~16
- Bit 18~23 : all 6 bits shall be set to zero
- Data rate

Rate (Mbits/s)	R1–R4
6	1101
9	1111
12	0101
18	0111
24	1001
36	1011
48	0001
54	0011

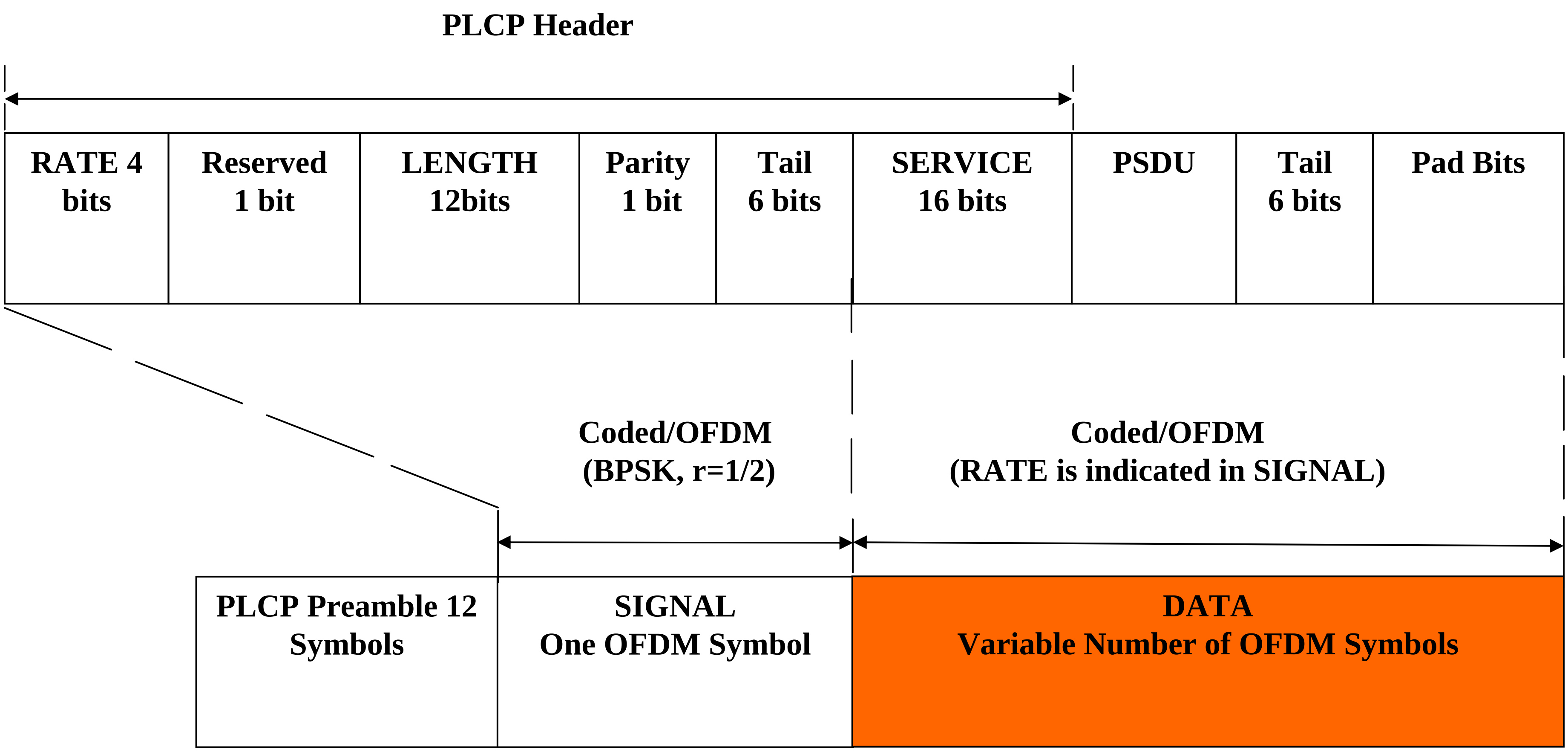
Signal field (SIGNAL)

- The SIGNAL field contains the RATE & the LENGTH field of the TXVECTOR
- The RATE field conveys information about the type of modulation & the coding rate as used in the rest of the packet
- The LENGTH field indicates the number of octets in the PSDU
- The encoding procedure, which includes convolutional encoding, interleaving, modulation mapping processes, pilot insertion, & OFDM modulation as used for a transmission of data at a 6 Mbit/s rate

Block diagram (SIGNAL)

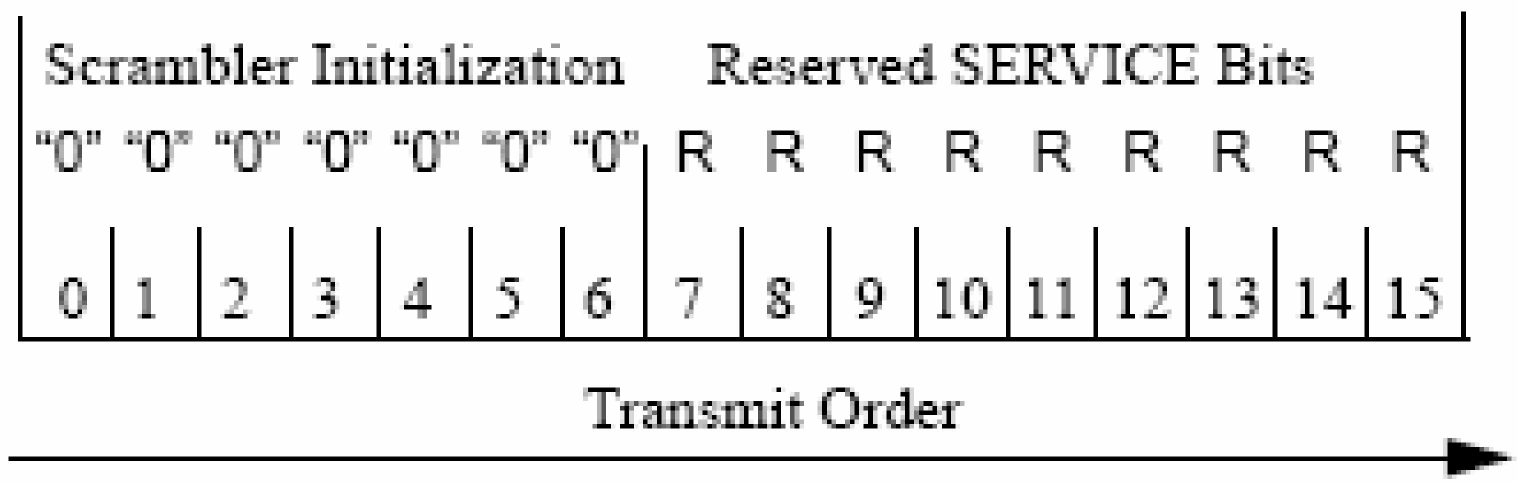


Data field (DATA)



Service field

- The 0 ~ 6 bits are set to zeros and are used to synchronize the descrambler in the receiver



Tail bit field

- The tail bit field shall be six bits of “0,” required to return the convolutional encoder to the “zero state.”

- This procedure improves the error probability of the convolutional decoder, which relies on future bits when decoding and which may not be available past the end of the message.

Pad bits

- The number of bits in the DATA field shall be a multiple of N_{CBPS} (the number of coded bits in an OFDM symbol)

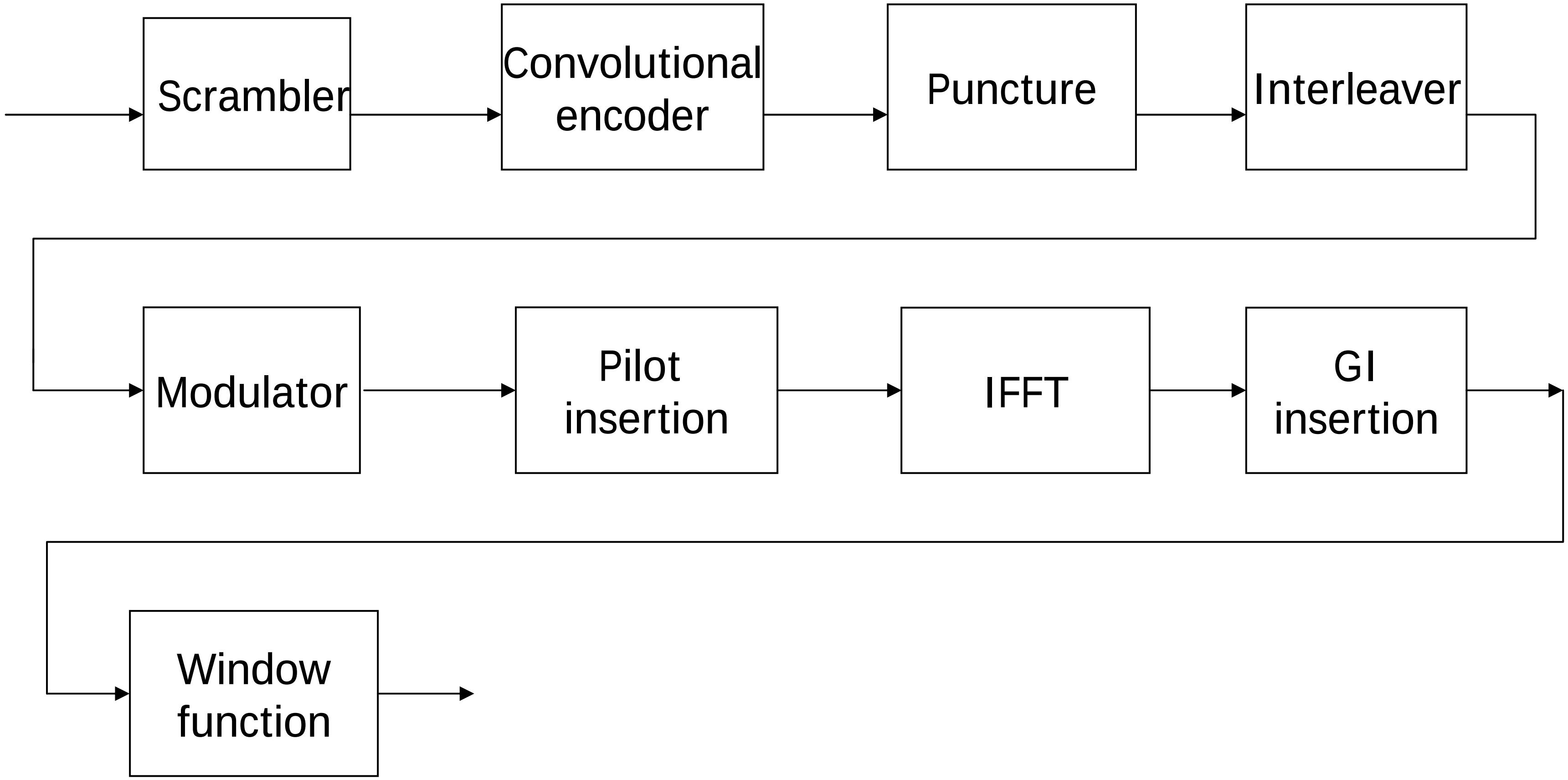
- To achieve that, the length of the message is extended so that it becomes a multiple of N_{DBPS} (the number of data bits per OFDM symbol)

Pad bits

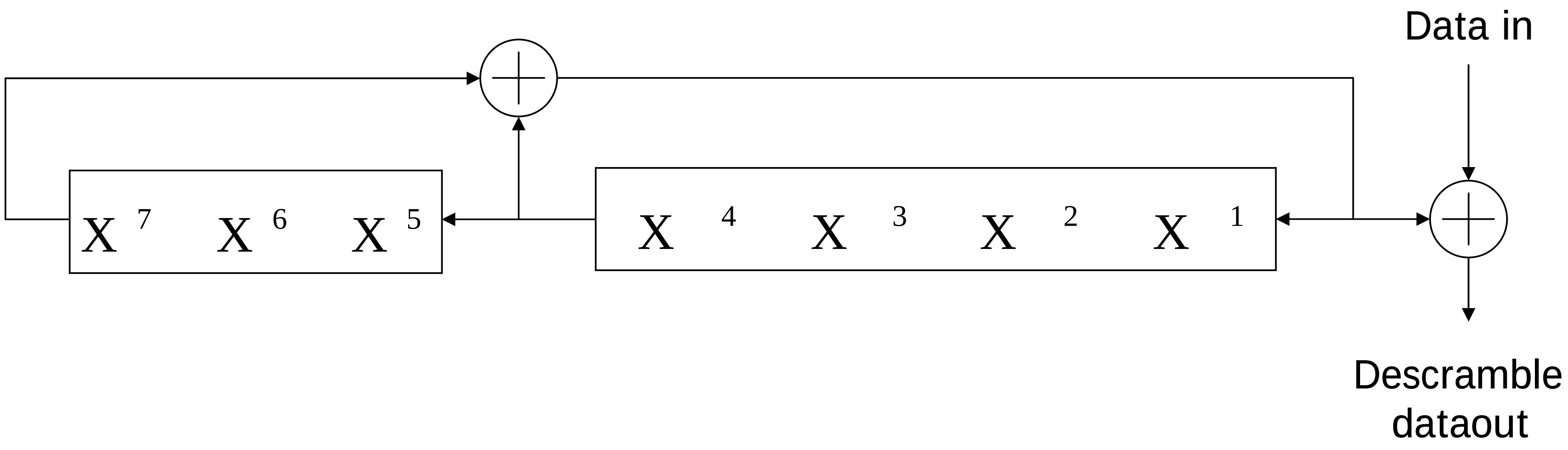
- $N_{SYM} = \text{Ceiling}((16 + 8 \times \text{LENGTH} + 6)/N_{DBPS})$
- $N_{DATA} = N_{SYM} \times N_{DBPS}$
- $N_{PAD} = N_{DATA} - (16 + 8 \times \text{LENGTH} + 6)$

- where
  - N_{SYM} ：The number of OFDM symbols
  - N_{DATA} : The number of bits in the DATA field
  - N_{PAD} : The number of pad bits
  - LENGTH : The length of the PSDU

Block diagram



Scrambler and descrambler



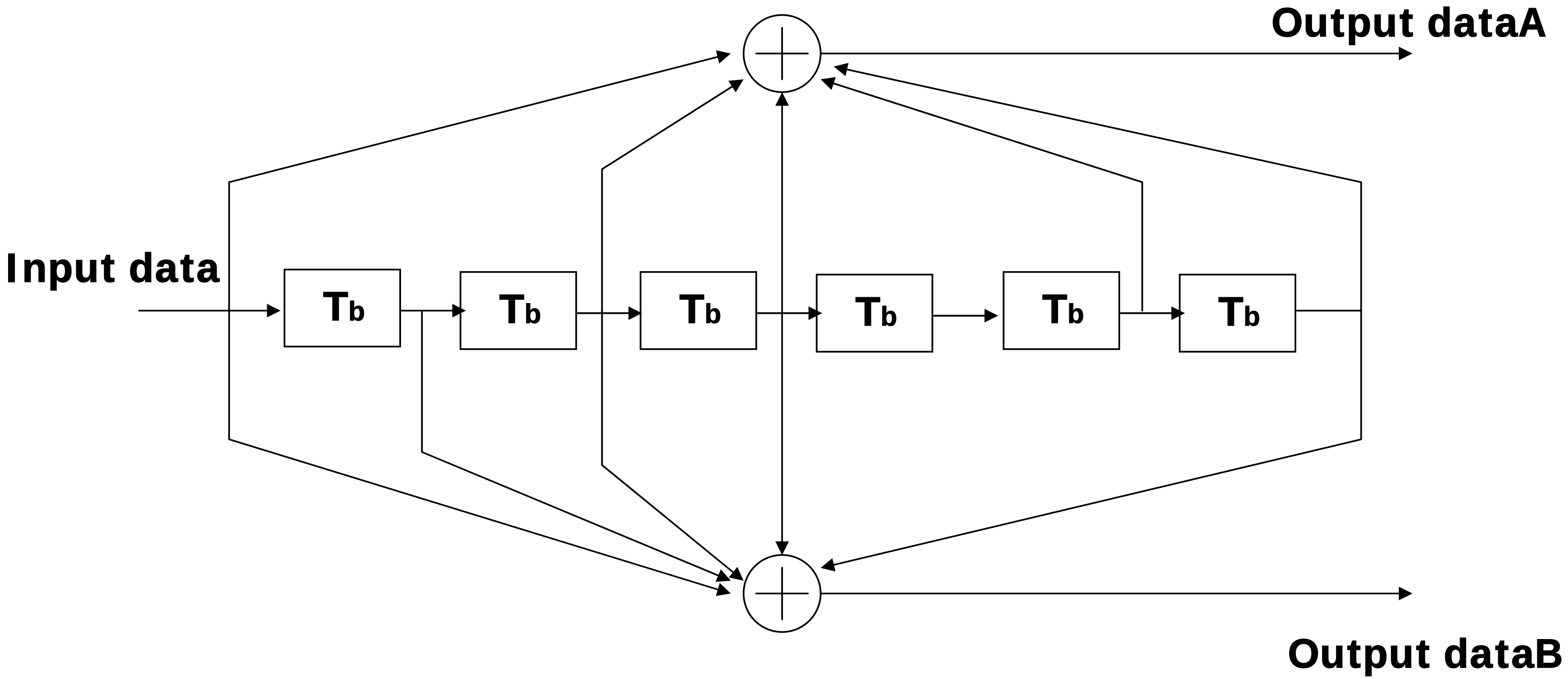
PLCP DATA scrambler and descrambler

- The frame scrambler uses the generator polynomial $S(x)$ is
$$S(x) = x^7 + x^4 + 1$$

- The 127-bit sequence generated repeatedly by the scrambler shall be (leftmost used first),00001110 11110010 11001001 00000010 00100110 00101110 10110110 00001100 11010100 11100111 10110100 00101010 11111010 01010001 10111000 1111111,when the all ones initial state is used.

Convolutional encoder

- The DATA field shall be coded with a convolutional encoder of coding rate R = 1/2



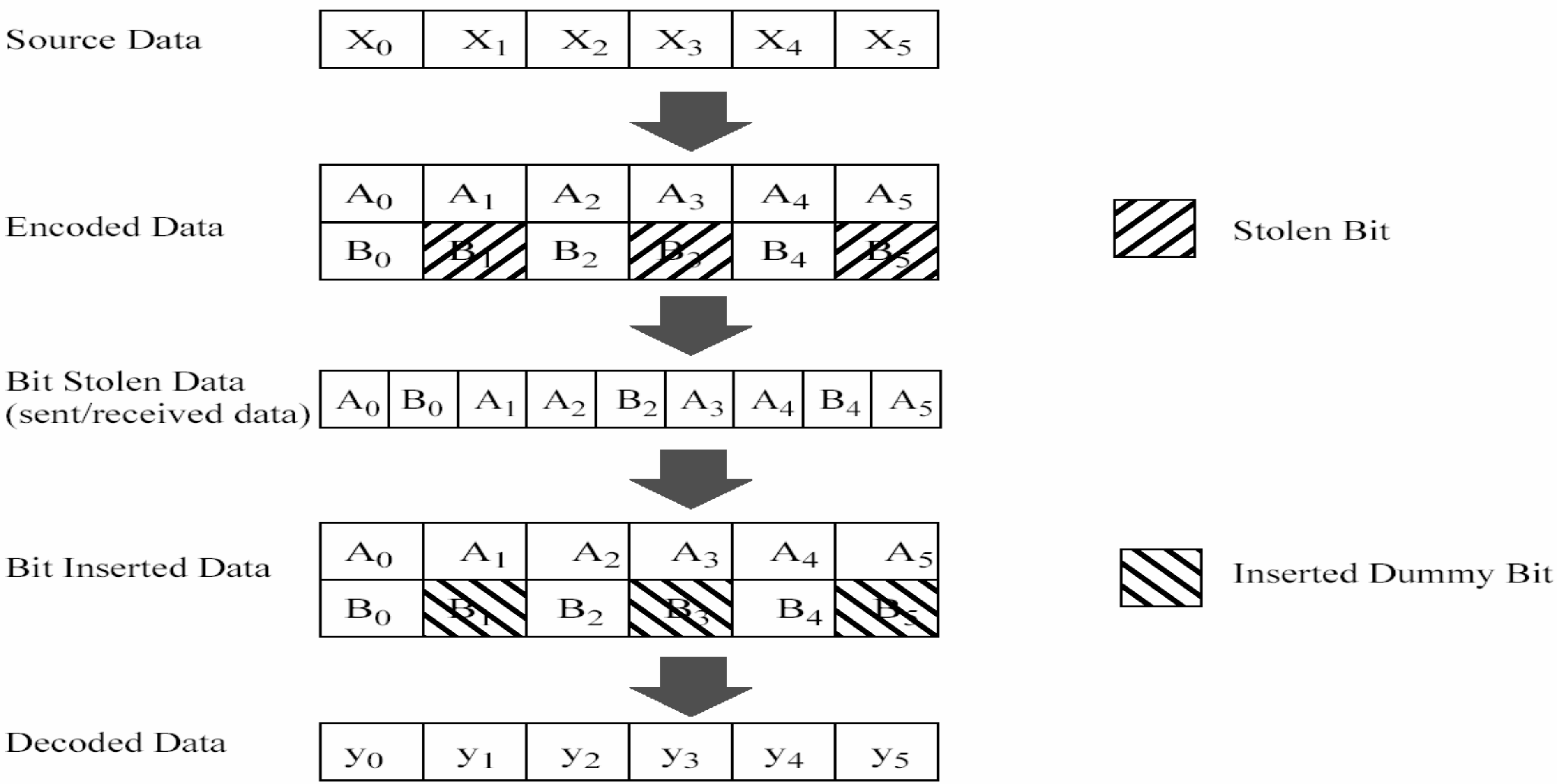
Convolutional encoder

- Higher code rate: 2/3, or 3/4
- Puncturing is a procedure for omitting some of the encoded bits in the transmitter (thus reducing the number of transmitted bits and increasing the coding rate)
- Increasing the BW efficiency
- Increasing the bit error rate (BER)

WiTS Lab — Inst. of Comm. Engr.

Puncturing

Punctured Coding (r = 2/3)



Data interleaving

- In order to avoid the presence of deep fade
- The interleaver is defined by a two-step permutation
- The permutation ensures that adjacent coded bits are mapped on to nonadjacent subcarriers
- We shall denote by
  - *k* the index of the coded bit before the first permutation
  - Permutation *i* shall be the index after the first and before the second permutation
  - Second permutation *j* shall be the index after the second permutation

Data interleaving

- first permutation

$$i = (\mathrm{N_{CBPS}}/16)(k \bmod 16) + \mathrm{floor}(\mathrm{k}/16) \qquad \mathrm{k} = 0,1,\ldots,\mathrm{N_{CBPS}} - 1$$

- second permutation

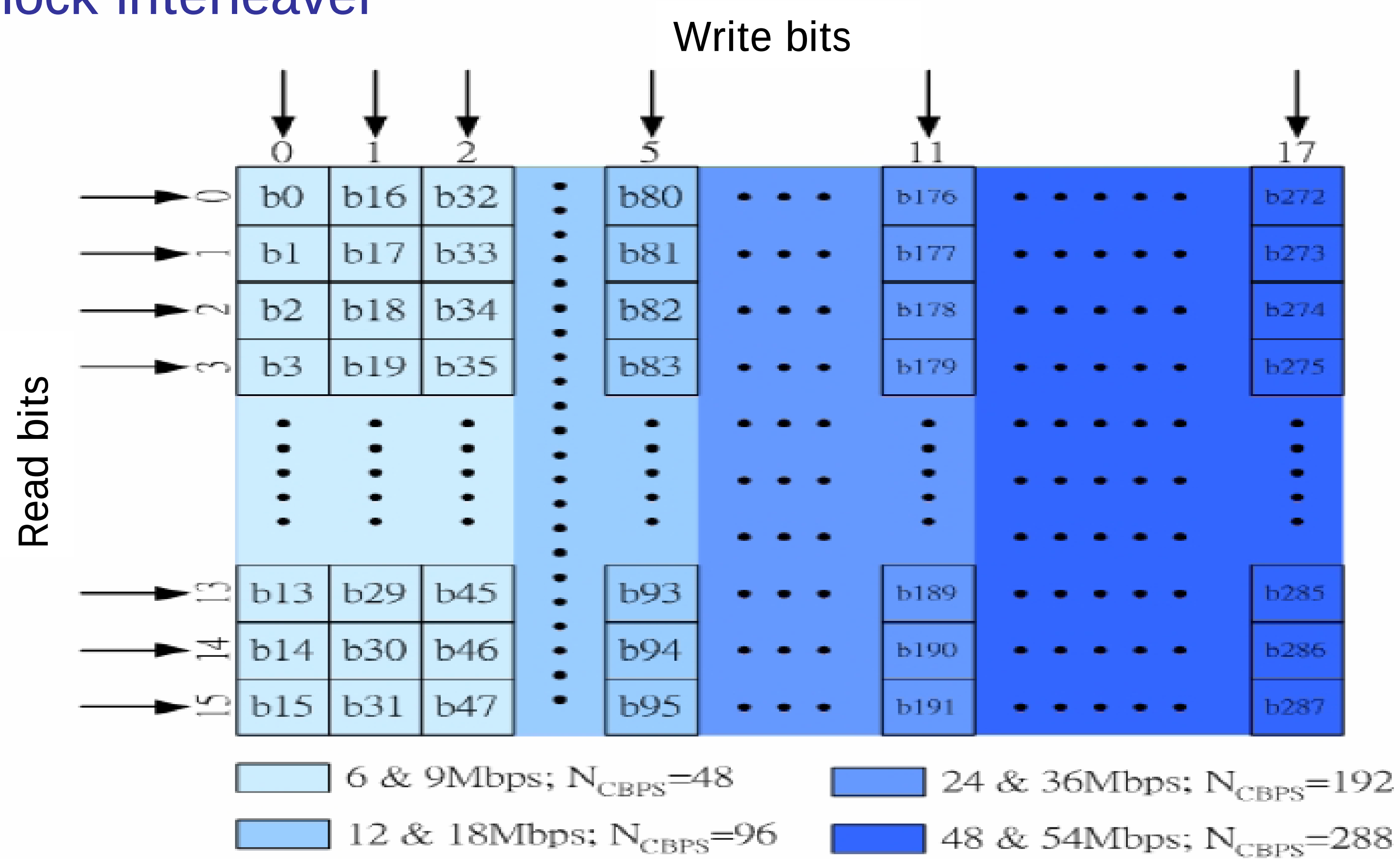
$$j = s \times \mathrm{floor}(i/\mathrm{s}) + (i + \mathrm{N_{CBPS}} - \mathrm{floor}(16 \times i/\mathrm{N_{CBPS}})) \bmod \mathrm{s}$$

$$i = 0,1,\ldots,\ \mathrm{N_{CBPS}} - 1$$

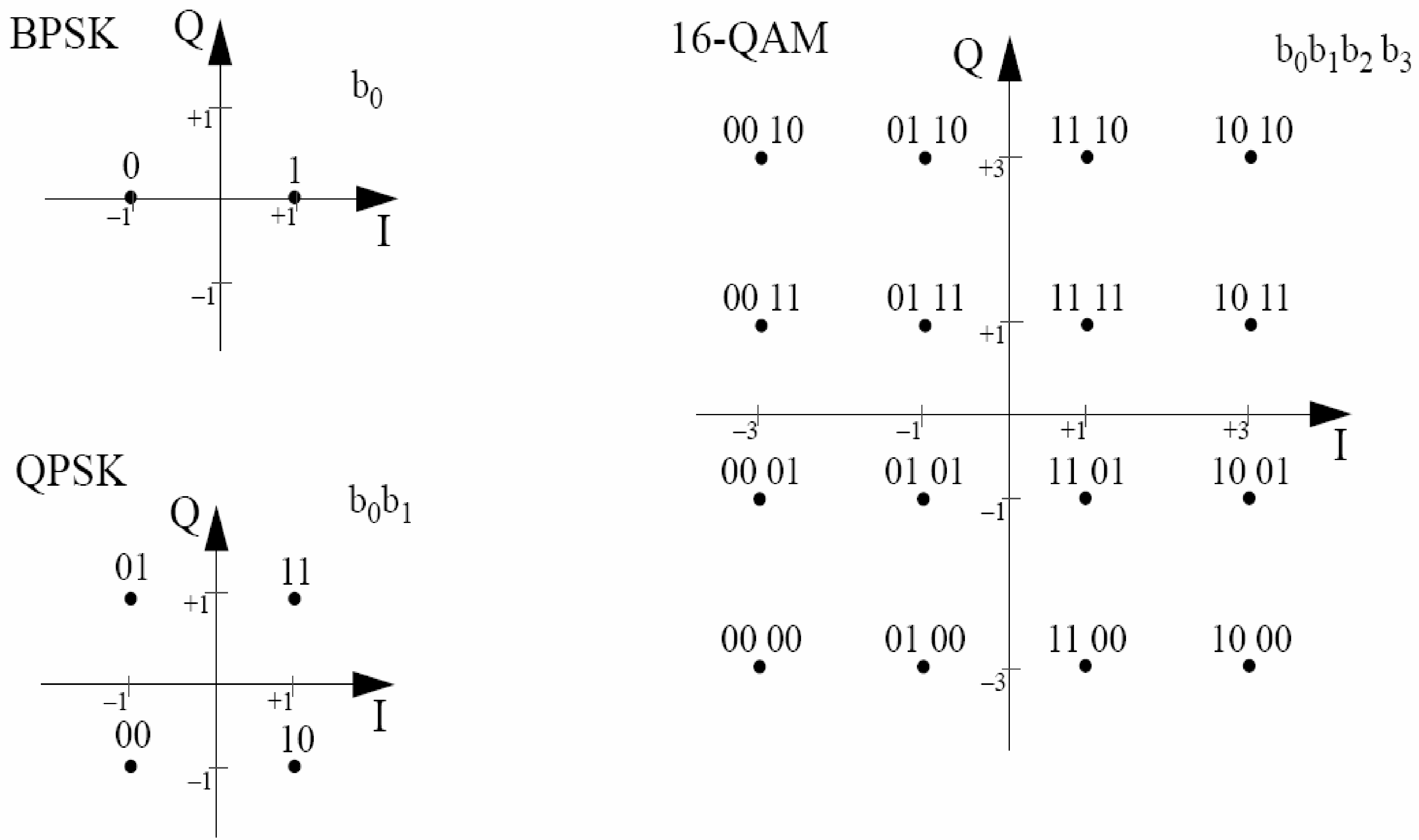
$$\mathrm{s} = \max(\mathrm{N_{BPSC}}/2, 1)$$

Data interleaving

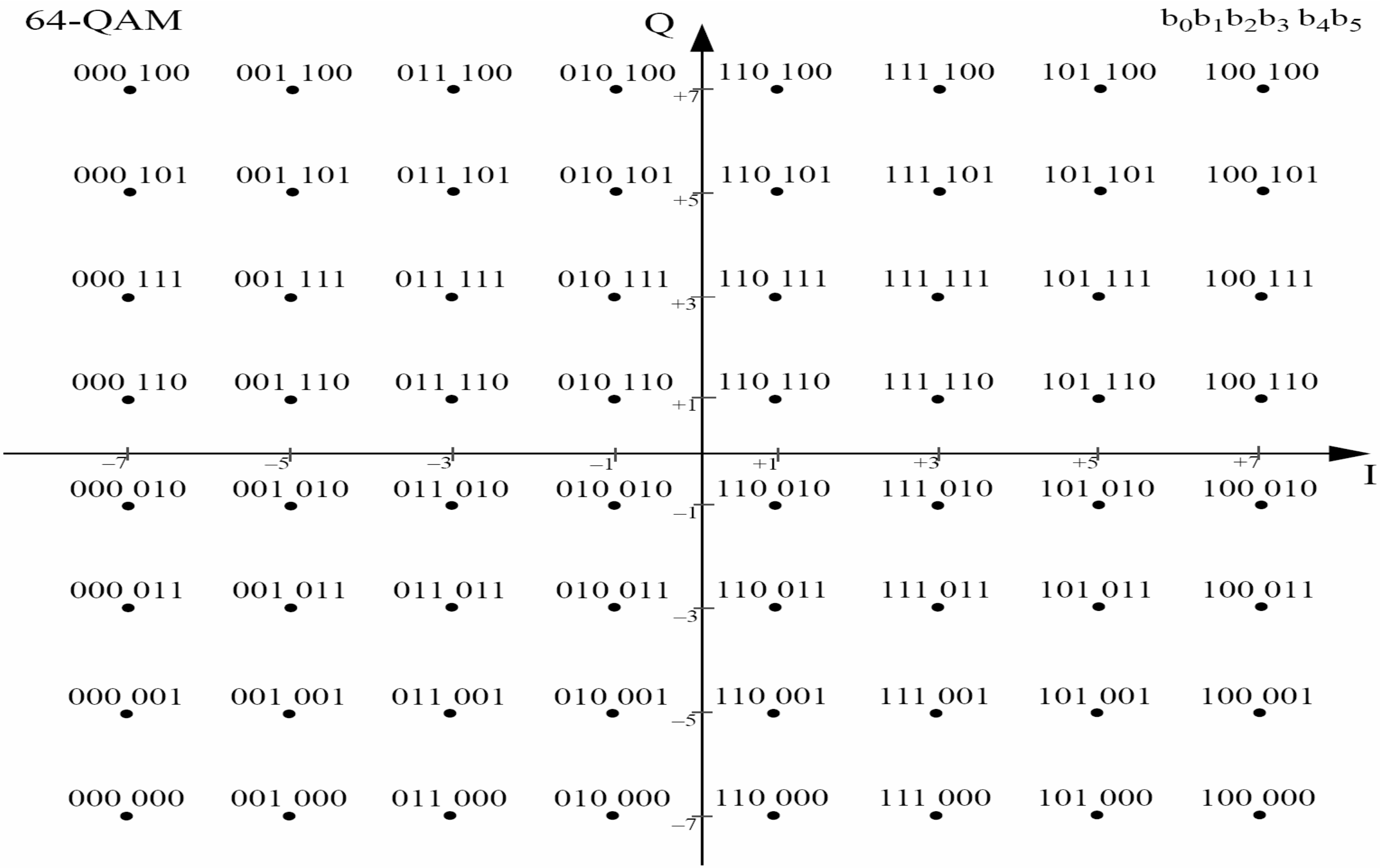
Block interleaver



Modulator


BPSK
Q
b_0
+1
0
1
–1
+1
I
–1
QPSK
Q
b_0b_1
01
11
+1
–1
+1
I
00
10
–1
16-QAM
Q
$b_0b_1b_2\,b_3$
00 10
01 10
11 10
10 10
+3
00 11
01 11
11 11
10 11
+1
–3
–1
+1
+3
I
00 01
01 01
11 01
10 01
–1
00 00
01 00
11 00
10 00
–3

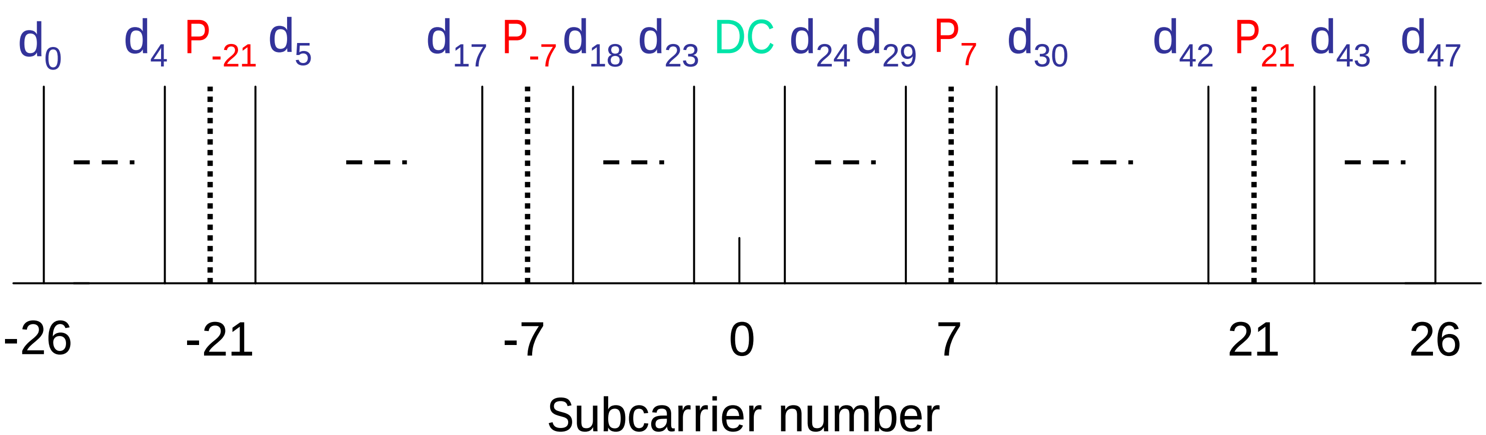
Modulator


64-QAM
Q
$b_0b_1b_2b_3\ b_4b_5$
000 100
001 100
011 100
010 100
110 100
111 100
101 100
100 100
+7
000 101
001 101
011 101
010 101
110 101
111 101
101 101
100 101
+5
000 111
001 111
011 111
010 111
110 111
111 111
101 111
100 111
+3
000 110
001 110
011 110
010 110
110 110
111 110
101 110
100 110
+1
−7
−5
−3
−1
+1
+3
+5
+7
I
000 010
001 010
011 010
010 010
110 010
111 010
101 010
100 010
−1
000 011
001 011
011 011
010 011
110 011
111 011
101 011
100 011
−3
000 001
001 001
011 001
010 001
110 001
111 001
101 001
100 001
−5
000 000
001 000
011 000
010 000
110 000
111 000
101 000
100 000
−7

Pilot subcarriers

- In each OFDM symbol, four of the subcarriers are dedicated to pilot signals in order to make the coherent detection robust against frequency offsets and phase noise.

- These pilot signals shall be put in subcarriers ***–21, –7, 7 and 21***. The pilots shall be BPSK modulated by a pseudo binary sequence to prevent the generation of spectral lines.



Pilot subcarriers

- The polarity of the pilot subcarriers is controlled by the P_n sequence (i.e. the output sequence of the scrambler)
- Replacing all 1's with -1 and all 0's with 1
- Each sequence element is used for one OFDM symbol
- In the sequence of the pilot polarity, the first element, p_0, multiplies the pilot subcarriers of the SIGNAL symbol, the others p_n are used for the DATA symbols

Pilot subcarriers

The 127-bit sequence generated repeatedly by the scrambler shall be (leftmost used first), 00001110 11110010 11001001 00000010 00100110 00101110 10110110 00001100 11010100 11100111 10110100 00101010 11111010 01010001 10111000 1111111, when the "all ones" initial state is used.

$0 \rightarrow 1$
$1 \rightarrow -1$

$$p_{0..126v} = \{1,1,1,1,\ -1,-1,-1,1,\ -1,-1,-1,-1,\ 1,1,-1,1,\ -1,-1,1,1,\ -1,1,1,-1,\ 1,1,1,1,\ 1,1,-1,1,$$
$$1,1,-1,1,\ 1,-1,-1,1,\ 1,1,-1,1,\ -1,-1,-1,1,\ -1,1,-1,-1,\ 1,-1,-1,1,\ 1,1,1,1,\ -1,-1,1,1,$$
$$-1,-1,1,-1,\ 1,-1,1,1,\ -1,-1,-1,1,\ 1,-1,-1,-1,\ -1,1,-1,-1,\ 1,-1,1,1,\ 1,1,-1,1,\ -1,1,-1,1,$$
$$-1,-1,-1,-1,\ -1,1,-1,1,\ 1,-1,1,-1,\ 1,1,1,-1,\ -1,1,-1,-1,\ -1,1,1,1,\ -1,-1,-1,-1,\ -1,-1,-1\}$$

Pilot subcarriers

Polarity of the pilot subcarriers

$$
\begin{aligned}
p_{0..126v} = \{ & 1,1,1,1,\ -1,-1,-1,1,\ -1,-1,-1,-1,\ 1,1,-1,1,\ -1,-1,1,1,\ -1,1,1,-1,\ 1,1,1,1,\ 1,1,-1,1, \\
& 1,1,-1,1,\ 1,-1,-1,1,\ 1,1,-1,1,\ -1,-1,-1,1,\ -1,1,-1,-1,\ 1,-1,-1,1,\ 1,1,1,1,\ -1,-1,1,1, \\
& -1,-1,1,-1,\ 1,-1,1,1,\ -1,-1,-1,1,\ 1,-1,-1,-1,\ -1,1,-1,-1,\ 1,-1,1,1,\ 1,1,-1,1,\ -1,1,-1,1, \\
& -1,-1,-1,-1,\ -1,1,-1,1,\ 1,-1,1,-1,\ 1,1,1,-1,\ -1,1,-1,-1,\ -1,1,1,1,\ -1,-1,-1,-1,\ -1,-1,-1 \}
\end{aligned}
$$

i	OFDM symbol	Element of p_i	Pilot at #-21	Pilot at #-7	Pilot at #7	Pilot at #21
0	SIGNAL	1	1.0 +0 j	1.0 +0 j	1.0 +0 j	–1.0 +0 j
1	DATA 1	1	1.0 +0 j	1.0 +0 j	1.0 +0 j	–1.0 +0 j
2	DATA 2	1	1.0 +0 j	1.0 +0 j	1.0 +0 j	–1.0 +0 j
3	DATA 3	1	1.0 +0 j	1.0 +0 j	1.0 +0 j	–1.0 +0 j
4	DATA 4	–1	–1.0 +0 j	–1.0 +0 j	–1.0 +0 j	1.0 +0 j
5	DATA 5	–1	–1.0 +0 j	–1.0 +0 j	–1.0 +0 j	1.0 +0 j
6	DATA 6	–1	–1.0 +0 j	–1.0 +0 j	–1.0 +0 j	1.0 +0 j

IFFT

- An OFDMsymbol, $r_{DATA,n}(t)$,is defined as N_{SD}:

$$r_{DATA,n}(t) = w_{TSYM}(t)\left(\sum_{k=0}^{N_{SD}-1} d_{k,n} \exp\left(j2\pi M(k)\Delta_F (t - T_{GI})\right) + p_{n+1} \sum_{k=-N_{ST}/2}^{N_{ST}/2} p_k \exp\left(j2\pi\Delta_F (t - T_{GI})\right) \right)$$

N_{SD}: the number of modulated data symbols
N_{ST}: the number of pilot symbols

IFFT

- The common way to implement the inverse Fourier transform is by an Inverse Fast Fourier Transform (IFFT) algorithm
- An example, a 64-point IFFT is used, the coefficient
  - 1~26 are mapped to the same numbered IFFT inputs
  - -26~-1 are copied into the IFFT inputs 38~63
  - The rest of the input are set to zero

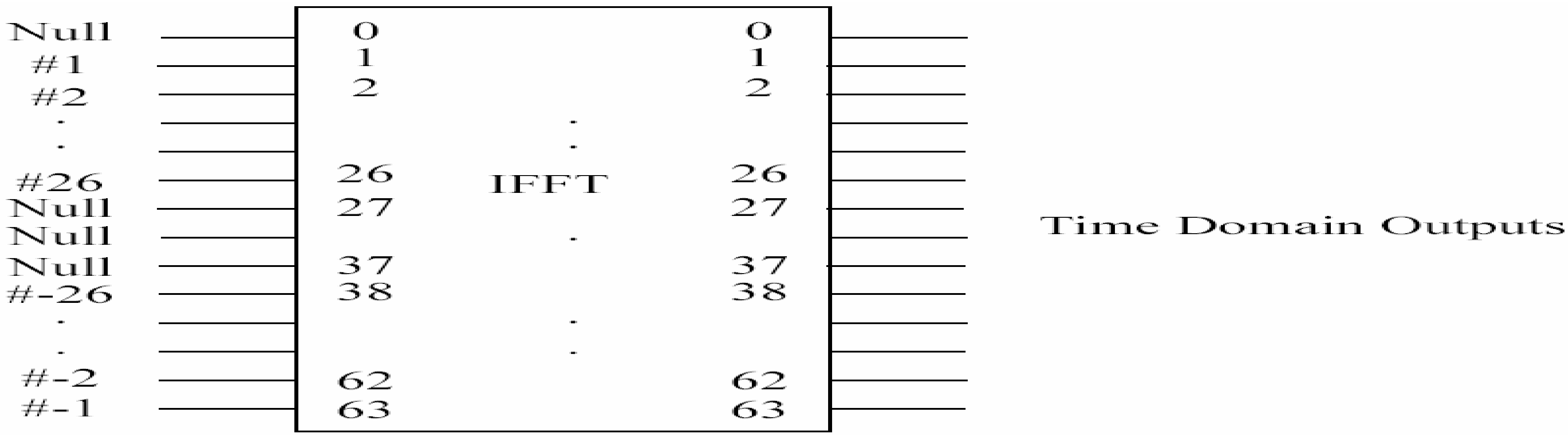
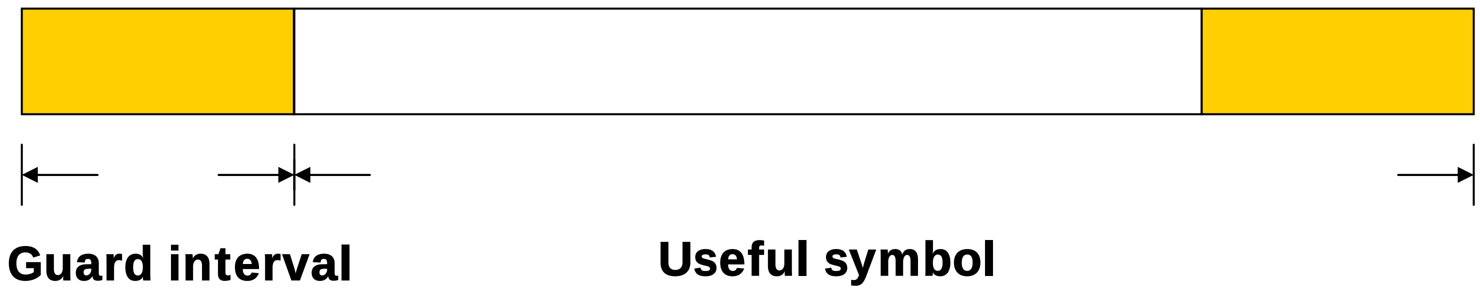


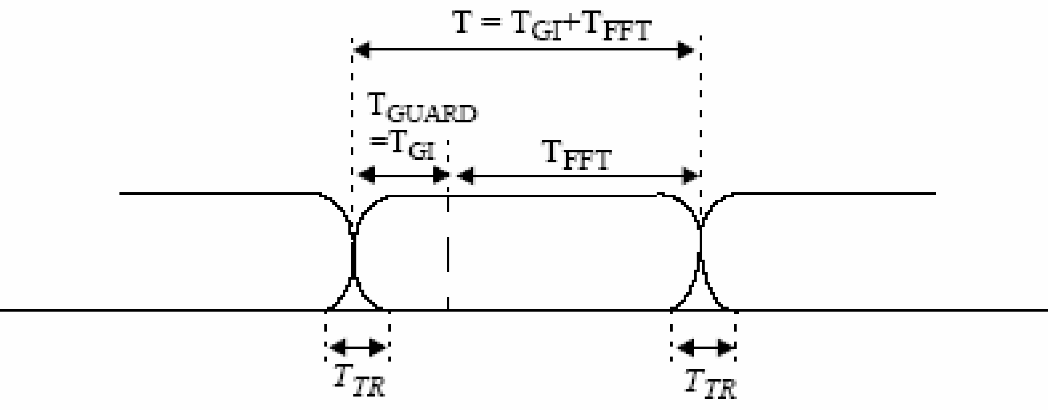
Figure 109—Inputs and outputs of IDFT

Guard Interval

- Shifting the time by T_{GUARD} creates the "cyclic prefix" used in OFDM to avoid ISI from the previous frame
- Three kinds of T_{GUARD} are defined
  - For the short training sequence (0 μs)
  - For the long training sequence (T_{GI2} = 1.6 μs)
  - For the data OFDM symbols (T_{GI} = 0.8 μs)



Windowing function



T:Time-windowing function duration

T_{FFT}:IFFT/FFT period

TGI : GI duration

$$w_t(t) = \begin{cases} \sin^2\left(\frac{\pi}{2}\left(0.5 + t/T_{TR}\right)\right) & \left(-T_{TR}/2 < t < T_{TR}/2\right) \\ 1 & \left(T_{TR}/2 < t < T - T_{TR}/2\right) \\ \sin^2\left(\frac{\pi}{2}\left(0.5 - \left(t - T\right)/T_{TR}\right)\right) & \left(T - T_{TR}/2 < t < T + T_{TR}/2\right) \end{cases}$$

T_{TR} : Transition time is the transition time between two consecutive periods of FFT (about 100ns), smooth the transition is required in order to reduce the spectral sidelobes of the transmitted waveform