1.

a)

$$D_{A,0} = (+1,+1,-1,-1) \cdot (+2,+1,-1,-2) = +6 \Rightarrow 1$$

$$D_{A,1} = (-1,-1,+1,+1) \cdot (+1,+2,-2,0) = -5 \Rightarrow 0$$

b)

$$D_{B,0} = (-1,+1,-1,+1) \cdot (+2,+1,-1,-2) = -2 \Rightarrow ?$$

$$D_{B,1} = (-1,+1,-1,+1) \cdot (+1,+2,-2,0) = +3 \Rightarrow 1$$

c)

Not enough data to know.

d)

The sequence (0, 0, 0, 0, -1, 0, 0, -1) is not a spreading code, and none of the other sequences is perfectly orthogonal with the spreading codes of both A and B.

2.

a)

Knowing the length of the frame in bits (l) and the target FER, it is easy to obtain the BER:

$$BER = 1 - (1 - FER)^{\frac{1}{l}} = 6{,}28 \times 10^{-5}$$

For QPSK modulation, the BER is calculated as follows:

$$BER_{QPSK} = \mathrm{Q}\left(\sqrt{\frac{\mathbf{2 \cdot E_b}}{\mathbf{N_0}}}\right)$$

One will have to calculate $Q^{-1}(BER) \approx 3.8$. Then, solving for $\frac{E_b}{N_0}$, we get $\frac{E_b}{N_0} = 7.22$.

Knowing that $\frac{E_b}{N_0} = \frac{P_r}{N} \cdot \frac{B}{R}$, and that $R_{QPSK} = \log_2(4) \cdot B = 2 \cdot B$, one can now solve the equation for P_r, reaching the final solution:

$$P_r = 1.44 \times 10^{-9}\, mW = -88\, dBm$$

b)

Two antennas transmitting over flat ground is a typical scenario to apply the Two-Ray Path Loss model:

$$P_r = P_t \cdot \frac{G_t \cdot G_r \cdot (h_t \cdot h_r)^2}{d^4}$$

The antenna gains can be calculated based on the effective aperture, which is a function of the physical aperture:

$$A_{eff} = \eta \cdot \mathrm{A}_{phy} = \frac{\lambda^2}{4\pi}\mathrm{G}$$

Solving for d, it results in $d \approx 46370{,}7\ m$.

One has to check whether this distance is greater than the crossover distance. In case it is not, the Friis Path Loss model should be used instead.

$$d_c = \frac{4 \cdot \pi \cdot h_t \cdot h_r}{\lambda} \approx 1047{,}2\ m$$

This confirms that the Two-Ray Path Loss model was the correct choice, since $d > d_c$.

c)

The BER expression is the same for BPSK and QPSK, but this does not mean that their error performance is the same. While each BPSK symbol corresponds to 1 bit, each QPSK symbol corresponds to two bits. As such, $E_{b(QPSK)} = 0{,}5 \cdot E_{b(BPSK)}$. Consequently, and since the Q()

function decreases as E_b increases, it can be concluded that BPSK is more robust (lower BER) than QPSK for the same receiver signal power.

d)

Applying Shannon's theorem, it is straightforward to calculate the maximum bandwidth efficiency ($\frac{C}{B}$):

$$\frac{C}{B} = \log_2\left(1 + \frac{S}{N_0 \cdot B}\right) \approx 3{,}45\ bit/s/Hz$$

3.

a)

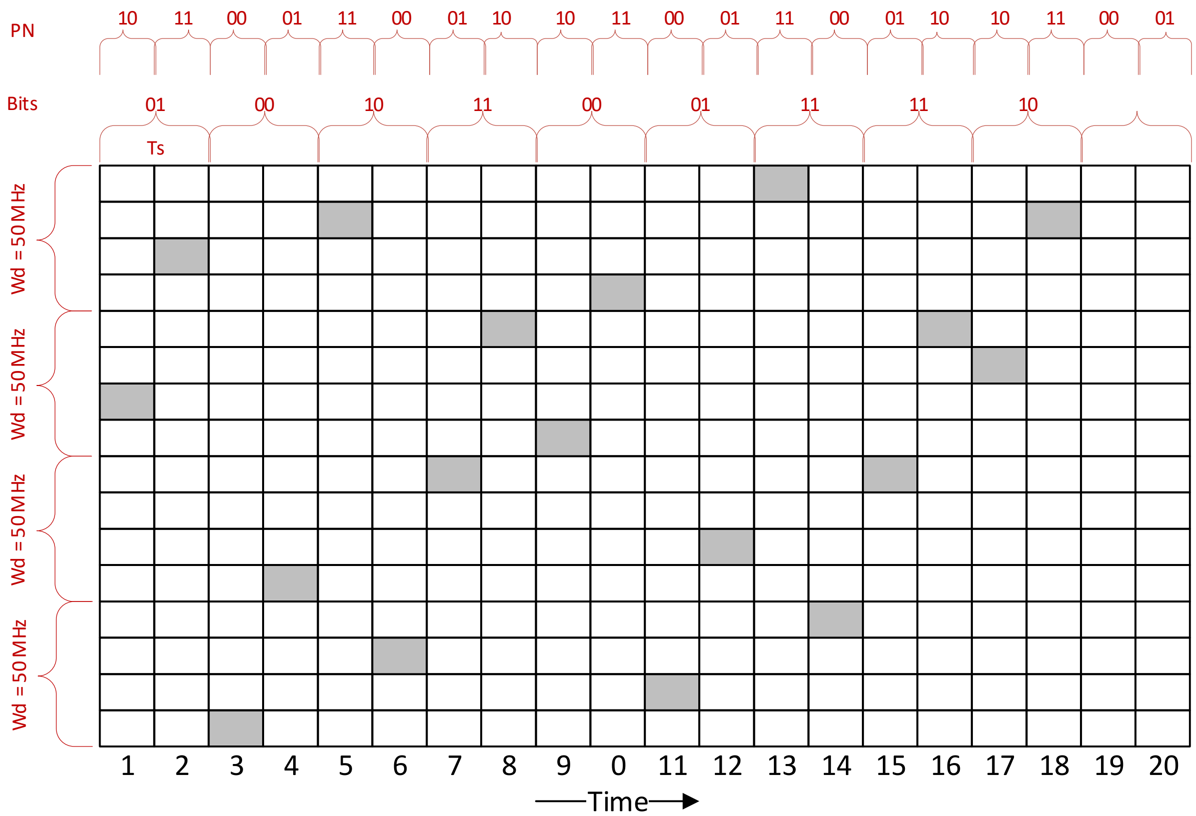
FHSS does not change the FSK symbol rate, and thus it also does not change the bitrate. Considering a sigle 4-FSK channel, $B = 50$ MHz.

$$B = \left(\frac{(1+r)\cdot M}{log_2(M)}\right)\cdot R_b \Leftrightarrow R_b = B\cdot\frac{log_2(M)}{(1+r)\cdot M} = 50\cdot\frac{log_2(4)}{(1+0)\cdot 4} = 25\ Mbit/s$$

b)

Fast FHSS, since $T_c < T_s$.

c)



4.

a)

If the cyclic prefix were not used, the duration of an OFDM symbol would be equal to $1/f_b$, where f_b is the subcarrier separation. The the cyclic prefix is used must be added to obtain the total duration. As such, we have:

$$T_{OFDM} = \frac{1}{f_b} + t_{cyclic\_prefix} = \frac{1}{312500} + 0.0000008 = 4\ \mu s$$

b)

Each OFDM symbol corresponds to N modulation symbols, each transmitted in a different subcarrier. Consequently, in each subcarrier, the modulation symbol rate is the same as the OFDM symbol rate, R_{OFDM}, which is the inverse of the symbol duration:

$$R_{OFDM} = \frac{1}{0.000004} = 250000\ sym/s$$

The net bitrate is the sum of the net bitrates of all data subcarriers. The net bitrate of a single subcarrier is calculated as follows:

$$R_b^{sc} = R_{OFDM} \times L \times CR,$$

Where L is the number of bits per modulation symbol (equal to $log_2(M)$, where M is the number of different symbols available in the modulation), and CR is the code rate of the FEC (i.e. $\frac{k}{n}$, where k is the number of useful bits transmitted, and n is the total number of bits transmitted).

We have that:

$$R_b^{sc} = \frac{R_b}{N} = \frac{18000000}{48} = 375000\ bit/s.$$

Knowing that $L = 2$ for QPSK, we can calculate CR:

$R_b^{sc} = R_{OFDM} \times L \times CR \Leftrightarrow CR = \frac{375000}{2 \times 250000}$=3/4

Since 3 useful bits require the transmission of 4 bits, 6 useful bits require the transmission of 8 bits.

c)

The useful PHY bitrate of IEEE 802.11ac without carrier aggregation can be calculated as follows:

$$R_b = N_{MIMO_{streams}} \times N_{subcarriers} \times R_{OFDM} \times L \times CR$$

Under the given conditions, the result is the following:

$$R_b = 2 \times 52 \times 250000 \times 8 \times \frac{3}{4} = 156\ Mbit/s$$

d)

IEEE 802.11ax supports OFDMA with spatial reuse, 1024-QAM, uplink MU-MIMO, longer OFDM symbols, more scheduled power-saving, enhanced spread protection guard intervals.

5.

a)

L3

b)

i)

Since $R = 500\ m$ and $D = 1{,}5\ km$, we can calculate the cluster size:

$$G = \frac{\left(\frac{D}{R}\right)^2}{3} = 3$$

Since the total bandwidth is 36 MHz, and each channel has 3 MHz, the total number of channels is $N_c = \frac{36}{3} = 12$. The number of channels per cell is $N_c^{cell} = \frac{N_c}{G} = 4$.

The number of RBs per channel is 15, so the number of RBs per cell is $N_{RB}^{cell} = N_c^{cell} \times 15 = 60$.

ii))

We can assign different numbers of channels per cell, placing more channels in the cell with highest density. Since the density of the latter is twice that of the others, and the objective is to keep the same average resources per user, a likely rule of thumb is to assign twice the number of channels to the highest density cell, compared with the others. Let x be the number of channels in one of the lowest density cells. We can obtain x as follows:

$$N_c = x + x + 2x \Leftrightarrow x = \frac{N_c}{4} = 3$$

So, the highest density cell has 6 channels and the others have 3 channels each.

c)

The total length of the packet, including UDP and IP headers is $L = 8 \times (28 + 1500) = 12224$ bits. The code rate of the FEC is $CR = \frac{120}{1024} \approx 0.1172$. The total number of transmitted bits is thus:

$$CR = \frac{k}{n} \Leftrightarrow n = \frac{k}{CR} = \frac{12224}{0.1172} \approx 104300$$

Since in QPSK each symbol encodes 2 bits, the required number of symbols is 52150. Since each RB has 72 symbols (extended cyclic prefix), the total number of RBs is:

$$N_{RB} = \left\lceil \frac{52150}{72} \right\rceil = 725$$