1.

a)

$$DR(S_1) = K(S_1) \cdot R = (+1, -1, +1, +1, +1, +1, -1, -1) \cdot (+1, +2, +2, +1, +1, +3, -1, -3)$$
$$= +10 \geq +3 = "1"$$

$$DR(S_2) = K(S_2) \cdot R = (-1, -1, +1, -1, +1, -1, +1, +1) \cdot (+1, +2, +2, +1, +1, +3, -1, -3)$$
$$= -8 \leq -3 = "0"$$

$$DR(S_3) = K(S_3) \cdot R = (-1, +1, +1, -1, +1, +1, +1, -1) \cdot (+1, +2, +2, +1, +1, +3, -1, -3)$$
$$= +8 \geq +3 = "1"$$

b)

$$R = 4 \cdot K(S_1) \cdot (+1) + K(S_2) \cdot (-1) + N = (+5, -2, +4, +5, +3, +5, -5, -5)$$

$$DR(S_2) = K(S_2) \cdot R$$
$$= (-1, -1, +1, -1, +1, -1, +1, +1) \cdot (+5, -2, +4, +5, +3, +5, -5, -5)$$
$$= -16 \leq -3 = "0"$$

c)

DSSS is a Spread Spectrum technique, which consists of multiplying a narrowband digital signal by a chip sequence of higher bandwidth, i.e. where each bit time corresponds to several chip times. CDMA is based on DSSS but assigns orthogonal or quasi-orthogonal chip sequences to different sender nodes, so that they can transmit at the same time using the same spectrum without causing significant interference to each other.

2.

a)

With QPSK modulation with $r = 0$ and $B = 300000\ Hz$, the bitrate can be calculated as follows:

$$B = \left(\frac{1+r}{log_2(M)}\right) \cdot R_b \Leftrightarrow R_b = B \cdot log_2(4) = 300000 \cdot 2 = 600\ kbit/s$$

The energy expended in a packet transmission is:

$$E_p = 1mW \times \frac{10 \cdot 8}{600000} = 0.133\mu J$$

Since these $0.133\mu J$ are accumulated in 6 seconds, the power generated by the solar panel is:

$$\boldsymbol{P_{charging}} = \frac{\mathbf{0}0.133\mu J}{\boldsymbol{6s}} \approx \mathbf{2.22 \cdot 10^{-8} \boldsymbol{W}}$$

b)

The receiver sensitivity must be lead to the given FER value of 0.01, taking into account QPSK modulation. The first step is to calculate the BER that leads to FER=0.01:

$$BER = 1 - (1 - FER)^{\frac{1}{10*8}} \approx 1.3 \times 10^{-4}$$

This is the output of the Q function in the BER expression for QPSK. We must now find the value of the argument of the function, $\sqrt{\frac{2 \cdot E_b}{N_0}}$ in the Q function table.

$$\sqrt{\frac{2 \cdot E_b}{N_0}} = Q^{-1}(1.3 \times 10^{-4}) \approx 3.7$$

We can now calculate E_b and then the receiver sensitivity:

$$E_b = \frac{N_0 \cdot (3.7)^2}{2} = \frac{\frac{10^{\frac{-140}{10}}}{1000} \cdot (3.7)^2}{2} \approx 6.85 \times 10^{-17}\ J$$

Now the receiver sensitivity:

$$\boldsymbol{P_r = R \cdot E_b = 600000 \cdot E_b \approx 4.11 \times 10^{-11}\ W \approx -73.9\ dBm}$$

c)

First, we have to calculate the maximum range. Assuming the two-ray model:

$$P_r = P_t \cdot \frac{G_t \cdot G_r \cdot (h_t \cdot h_r)^2}{d^4} \Leftrightarrow 4.11 \times 10^{-11} = 0.001 \cdot \frac{1 \cdot 1 \cdot (1 \cdot 1)^2}{d^4} \Leftrightarrow d \approx 70.2m$$

Next step is to calculate the received power at one half of the maximum range, using the same formula:

$$P_r = 0.001 \cdot \frac{1 \cdot 1 \cdot (1 \cdot 1)^2}{\left(\frac{70.2}{2}\right)^2} \approx 6.57 \times 10^{-10}$$

In order to obtain the same performance $\frac{E_b}{N_0+I_0}$at half the maximum range, must be the same as $\frac{E_b}{N_0}$at maximum range. From this equation, we can calculate I_0.

$$\frac{E_b(d/2)}{N_0 + I_0} = \frac{E_b(d)}{N_0} \Leftrightarrow \frac{6.57 \times 10^{-10} \cdot \frac{1}{600000}}{\frac{10^{\frac{-140}{10}}}{1000} + I_0} = \frac{4.11 \times 10^{-11} \cdot \frac{1}{600000}}{\frac{10^{\frac{-140}{10}}}{1000}} \Leftrightarrow I_0 \approx 1.5 \times 10^{-16}$$

Based on I_0, we can now calculate the interfering power I:

$$\boldsymbol{I = I_0 \cdot B = 4.5 \times 10^{-11}\ W \approx -73.5\ dBm}$$

3.

a)

In this scheme, we need one minislot per ground station. In its minislot, theground station will declare how many of its uplink slots will be actually used. Consequently, in our scenario we need 10 minislots.

b)

The duration of the superframe must take into account the reservation minislots, uplink slots, downlink slots and all the guard intervals:

$$\boldsymbol{T_{super} = 10 \cdot \left(\frac{8 \cdot 8}{300} + 1\right) + 20 \cdot \left(\frac{500 \cdot 8}{300} + 1\right) + 20 \cdot \left(\frac{500 \cdot 8}{300} + 1\right) = 585.5\, ms}$$

c)

When all the uplink slots are being used by the respective owner, each ground station can transmit on 2 uplink data slots. In each of these slots, we have to discount the header of 8 bytes. The throughput can now be calculated in the usual way:

$$\boldsymbol{Th_{up} = \frac{2 \times (500 - 8) \cdot 8}{T_{super}} = \frac{7872}{585.5 \times 10^{-3}} \approx 13.4\, kbit/s}$$

d)

Our target ground station is able to successfully use the free slot (besides its own uplink slots) whenever it chooses to compete (40%), since there are no other competing ground stations.

We can now calculate the average throughput:

$$\boldsymbol{Th_{up} = (1 - 0.4) \cdot \frac{2 \times (500 - 8) \cdot 8}{T_{super}} + 0.4 \cdot \frac{3 \times (500 - 8) \cdot 8}{T_{super}} \approx 16.1\, kbit/s}$$

4.

a)

One must not forget that although the total effective bandwidth is 20 MHz, the system hops through a sequence of 4 independent frequency channels, which means that in each T_c interval, only ¼ of the bandwidth is being used for MFSK transmission.

$$\boldsymbol{T_s = 2 \times T_b = 2 \times \frac{1}{R_b} = 2 \times \frac{1}{B/4}\left(\frac{(1+r)\cdot M}{log_2(M)}\right) = 2 \times \frac{1}{\frac{20 \times 10^6}{4}} \cdot \left(\frac{(1+1)\cdot 4}{2}\right) = 1.6\mu s}$$

$$\boldsymbol{T_c = 2 \times T_s = 3.2\mu s}$$

b)

The system employs slow FHSS, since $T_c \geq T_s$.

c)

Flat Fading, since $B_{coherence} > 10 \cdot B$.

Fast Fading, since $T_{coherence} < 10 \cdot T_b$.

d)

We apply the Shannon-Heartley Theorem:

$$\boldsymbol{C = B \cdot \log_2\left(1 + \frac{S}{N}\right) = 20 \times 10^6 \cdot \log_2\left(1 + 10^{\frac{10}{10}}\right) \approx 69.2\ Mbit/s}$$