1.

a)

Two bits were received from each mobile station, which must be decoded separately.

$$R_{S1}^{1} = K_{S1} \cdot R_{BS}^{1} = (+1,+1,-1,+1) \cdot (0,0,+3,-2) = -5 \rightarrow "0"$$
$$R_{S1}^{2} = K_{S1} \cdot R_{BS}^{2}(+1,+1,-1,+1) \cdot (+2,0,-2,+2) = +6 \rightarrow "1"$$

$$R_{S2}^{1} = K_{S2} \cdot R_{BS}^{1} = (+1,+1,+1,-1) \cdot (0,0,+3,-2) = +5 \rightarrow "1"$$
$$R_{S2}^{2} = K_{S2} \cdot R_{BS}^{2}(+1,+1,+1,-1) \cdot (+2,0,-2,+2) = -2 \rightarrow "0"$$

b)

Without noise:

$$\begin{aligned} R_{BS}^{1} &= D_{S1}^{1} \times K_{S1} + D_{S2}^{1} \times K_{S2} \\ &= (-1) \times (+1,+1,-1,+1) + (+1) \times (+1,+1,+1,-1) \\ &= (0,0,+2,-2) \\ R_{BS}^{1} &= D_{S1}^{2} \times K_{S1} + D_{S2}^{2} \times K_{S2} \\ &= (+1) \times (+1,+1,-1,+1) + (-1) \times (+1,+1,+1,-1) \\ &= (0,0,-2,+2) \end{aligned}$$
$$R_{BS} = R_{BS}^{1} | R_{BS}^{2} = (0,0,+2,-2,0,0,-2,+2)$$

Now we must only subtract from the actually received sequence in order to get the noise:

$$\begin{aligned} N &= (0,0,+3,-2,+2,0,-2,+2) - (0,0,+2,-2,0,0,-2,+2) \\ &= (0,0,+1,0,+2,0,0,0) \end{aligned}$$

c)

In order to present good characteristics against multipath fading, a key must be significantly orthogonal to rotated versions of itelf. Regarding K_{S1}:

$$K_{S1} \cdot (K_{S1} \gg 1) = (+1,+1,-1,+1) \cdot (+1,+1,+1,-1) = 0$$
$$K_{S1} \cdot (K_{S1} \gg 2) = (+1,+1,-1,+1) \cdot (-1,+1,+1,+1) = 0$$
$$K_{S1} \cdot (K_{S1} \gg 3) = (+1,+1,-1,+1) \cdot (+1,-1,+1,+1) = 0$$

As such, signals from S1 can endure a delay spread up to 3 chip times. Similar results can be obtained for K_{S2}.

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:

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

b)

The receiver sensitivity must 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, $\sqrt{\frac{\mathbf{2 \cdot E_b}}{\mathbf{N_0}}}$ 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. Since one half of the maximum distance now falls within the crossover distance ($d_c \approx 36{,}4$), we have to use the Friis Model:

$$P_r = 0.001 \cdot \frac{1 \cdot 1 \cdot \lambda^2}{\left(4\pi \cdot \frac{70.2}{2}\right)^2} \approx 6.13 \times 10^{-10}\ W$$

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.

$$\frac{E_b(d/2)}{N_0 + I_0} = \frac{E_b(d)}{N_0} \Leftrightarrow \frac{6.13 \times 10^{-1} \cdot \frac{1}{600000}}{\frac{10^{\frac{-140}{10}}}{1000} + I_0} \Leftrightarrow I_0 \approx 1.4 \times 10^{-16}$$

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

$$\boldsymbol{I = I_0 \cdot B = 4.5 \times 10^{-11}\, W \approx -73.8\, dBm}$$

3.

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. From the point of view of the baseband MFSK modulation, only ¼ of the bandwidth is being used.

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

$$\boldsymbol{= 1.6 \mu s}$$

$$\boldsymbol{T_c = \frac{T_s}{2} = 0.8 \mu s}$$

$$\boldsymbol{T_b = T_c = 0.8 \mu s}$$

b)

The system employs fast FHSS, since $T_c < T_s$.

c)

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

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

d)

We apply the Shannon-Heartley Theorem:

$$\boldsymbol{\frac{C}{B} = \log_2\left(1 + \frac{S}{N}\right) = \log_2\left(1 + 10^{\frac{10}{10}}\right) \approx 3.46\ [bit/s]/Hz}$$

4.

a)

Since the Skype session is bidirectional, the paths CN→MN and MN→CN must be analyzed separately and both must be feasible:

- CN->MN: An IP packet issued by CN is initialized with TTL=100 in the header. Remind that the tunnel between the HA and FA counts only 1 hop from the perspective of the inner IP packet (i.e., the original IP packet). The packet must follow the segments CN→HA (30 hops), HA→FA (1), FA→MN (7). This gives a total of 38 hops, which is less than 100. Consequently, this direction does not present any obstacles.
- MN→CN: The IP packet issued by the MN is directly routed to the CN. This corresponds to 90 hops, which is also less than the initial TTL. Consequently, there are no problems in this direction.

Conclusion: It is possible to establish a Skype session between the MN and the CN.

b)

Packet	**Outer Source Address**	**Outer Destination address**	**Inner Source Address**	**Inner Destination address**
CN→HA	146.64.4.6	193.154.3.10	N/A	N/A
HA→FA	193.154.3.1	195.137.10.2	146.64.4.6	193.154.3.10
FA→MN	146.64.4.6	193.154.3.10	N/A	N/A
MN→CN	193.154.3.10	146.64.4.6	N/A	N/A