1.

a)

In order to be used in a CDMA system, the keys should be perfectly or at least highly orthogonal. Since $K(A)$ fits two times within $K(B)$, in order to guarantee that A's data is correctly decoded, it must be guaranteed that $K(A)$ is orthogonal to each half of $K(B)$. If this is the case, then the orthogonality of $K(A)|K(A)$ with $K(B)$ is also true, where "|" means concatenation.

$$K(A) \cdot K_{1,1}(B) = (+1, +1, -1, -1) \cdot (+1, -1, +1, -1) = 0$$

$$K(A) \cdot K_{1,2}(B) = (+1, +1, -1, -1) \cdot (-1, +1, -1, +1) = 0$$

$K(A)$ and $K_1(B)$ are orthogonal.

$$K(A) \cdot K_{2,1}(B) = (+1, +1, -1, -1) \cdot (-1, -1, +1, +1) = -4$$

$$K(A) \cdot K_{2,2}(B) = (+1, +1, -1, -1) \cdot (-1, -1, +1, +1) = -4$$

$K(A)$ and $K_2(B)$ are not orthogonal.

Conclusion: $K_1(B)$ should be used.

b)

$$S(A) = +1 \cdot K(A)| - 1 \cdot K(A) = (+1, +1, -1, -1, -1, -1, +1, +1)$$

$$S(B) = -1 \cdot K(B) = (+1, -1, -1, +1, +1, -1, -1, +1)$$

$$R = S(A) + S(B) + N = (+4, -1, -2, 0, +1, -2, 0, +2)$$

$$DR_1(A) = K(A) \cdot R_1 = (+1, +1, -1, -1) \cdot (+4, -1, -2, 0) = +5 > +1 = \text{"0"}$$

$$DR_2(A) = K(A) \cdot R_2 = (+1, +1, -1, -1) \cdot (+1, -2, 0, +2) = -3 > -1 = \text{"1"}$$

c)

Since DSSS is being used, we are modulating chips and not bits. So, the same formula that relates the bitrate and bandwidth for 4-FSK will be applied, but now substituting R_c for R_b:

$$B = \left(\frac{(1+r) \cdot M}{log_2(M)}\right) \cdot R_c \Leftrightarrow R_c = B \cdot \frac{log_2(M)}{(1+r) \cdot M} = 2 \cdot \frac{log_2(4)}{2 \cdot 4} = 0.5\ Mchip/s$$

$$R_b(A) = \frac{R_c}{4} = 125\ kbit/s$$

$$R_b(B) = \frac{R_c}{8} = 62{,}5\ kbit/s$$

2.

a)

We know the path loss exponent ($\alpha = 4$) and we know the path loss at the reference distance ($PL(d_0) = PL_0 = 20\ dB$). The reference distance is $d_0 = 1m$. We know the antenna gains ($G_t = G_r = 1$). We also know the transmit power ($P_t = 20mW$) and the minimum received power ($P_r = -60\ dBm$). Consequently, we can apply the log-distance path loss model and calculate d.

$$P_r[dBm] = P_t[dBm] - PL_0 + G_t[dBi] + G_r[dBi] - 10 \cdot \alpha \cdot log_{10}\left(\frac{d}{d_0}\right)$$

Solving for d, we get $d \approx 21.1\ m$.

b)

The first step is to calculate the received power at $d = 12\ m$. We use the same formula as for a). The received power is then $P_r \approx -50.1\ dBm \approx 9.65 \times 10^{-6}\ mW$.

The next step is to calculate $E_b = \frac{P_r}{R_b}$. R_b can be easily calculated from the signal bandwidth, roll-off factor and the number of different symbols of the modulation ($M = 4$ for QPSK).

$$B = \left(\frac{1+r}{log_2(M)}\right) \cdot R_b \Leftrightarrow R_b = B \cdot \frac{log_2(M)}{(1+r)} = 100 \cdot \frac{log_2(4)}{(1+1)} = 100\ kbit/s$$

It is now possible to calculate E_b:

$$E_b = \frac{P_r}{R_b} = 9.65 \times 10^{-11}\ mJ$$

And then:

$$\frac{E_b}{N_0} = \frac{9.65 \times 10^{-10}}{10^{\frac{-110}{10}}} = 9.65$$

We are now in a position to calculate the BER:

$$BER_{QPSK} = Q\left(\sqrt{\frac{2 \cdot E_b}{N_0}}\right) \approx Q(4{,}39) \approx 5.41 \times 10^{-6}$$

Finally, knowing that each frame transmitted in a timeslot has $l = 40 \cdot 2 = 80$ bits in length (40 symbols per frame, with 2 bits per symbol in QPSK):

$$FER = 1 - \left(1 - BER_{QPSK}\right)^{l} \approx 4.33 \times 10^{-4}$$

c)

The effective throughput capacity measures the maximum received bitrate. Taking into account that each frame has a loss probability (i.e., probability of not being received) equal to FER. Since each robot can transmit only one frame per superframe time interval, the effective throughput capacity is calculated as follows:

$$Th = \frac{l}{sf} \cdot (1 - FER)$$

Where sf is the superframe length. We know $2 \times 44 = 88$ bits fit in each timeslot. Since we have a total of 5 timeslots in a superframe, the superframe length is:

$$sf = 5 \cdot \frac{88}{R_b} = 5 \cdot \frac{88}{100000} = 4.4\ ms$$

We can now calculate Th:

$$Th = \frac{80}{4.4} \cdot (1 - 0.1) \approx 16.4\ kbit/s$$

d)

The trick is to equate the log-distance received power equations with *d* plus unitary gain and *2d* plus non-unitary gain (which must be found). The received power must be the same and equal to the receiver sensitivity in both cases.

$$P_t[dBm] - PL_0 - 10 \cdot \alpha \cdot log_{10}\left(\frac{d}{d_0}\right) = P_t[dBm] - PL_0 + 2 \times G[dBi] - 10 \cdot \alpha \cdot log_{10}\left(\frac{2d}{d_0}\right) \Leftrightarrow$$

$$\Leftrightarrow G[dBi] = \frac{10 \cdot \alpha \cdot log_{10}\left(\frac{2d}{d_0}\right) - 10 \cdot \alpha \cdot log_{10}\left(\frac{d}{d_0}\right)}{2} \Leftrightarrow G[dBi] = \frac{10 \cdot \alpha \cdot log_{10}(2)}{2} \approx 6\ \ dBi$$

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.

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

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

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

b)

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

c)

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

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)

One must take into account that if more than one routing table entry matches the destination address, the longest match prevails. This rule must be considered when the packet is forwarded by R3. In this case, the packet goes to R4, where there is no entry matching the destination prefix. In this case, the packet is routed to R5 by default, which is directly connected to the destination subnet. The complete path is: R3_R4_R5_H2.

b)

Local routers can be found using the Router Discovery Protocol, which is based on ICMP. This same protocol, with specific extensions, constitutes the basis for agent discovery in Mobile IPv4.