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)

Single hop:

$$P_t^{1-hop}[dBm] = P_r\ [dBm] + PL_0 - G_t\ [dBi] - G_r\ [dBi] + 10 \cdot \alpha \cdot log_{10}\left(\frac{2d}{d_0}\right)$$

$$P_t^{1-hop} = \frac{P_r \cdot 10^{\frac{PL_0}{10}} \cdot \left(\frac{2d}{d_0}\right)^{\alpha}}{G_t \cdot G_r} = \frac{P_r \cdot 10^{\frac{PL_0}{10}} \cdot (2d)^3}{G_t \cdot G_r}$$

With two hops we have, for each hop:

$$P_t^{2-hop} = \frac{P_r \cdot 10^{\frac{PL_0}{10}} \cdot d^3}{G_t \cdot G_r}$$

We can now divide the power used for one hop by the power used for two hops:

$$\frac{P_t^{1-hop}}{2 \cdot P_t^{2-hop}} = \frac{\frac{P_r \cdot 10^{\frac{PL_0}{10}} \cdot 2^3 \cdot d^3}{G_t \cdot G_r}}{2\frac{P_r \cdot 10^{\frac{PL_0}{10}} \cdot d^3}{G_t \cdot G_r}} = \frac{2^3 \cdot d^3}{2 \cdot d^3} = 4 > 1$$

b)
There will be two concurrent signals at C, plus termal noise. The signal from B constitutes the useful signal, while the signal from A will constitute interference. The first step is to calculate the power received for each of these signals. Since the transmit power corresponds to the minimum, the received power from B is equal to the receiver sensitivity: -80 dBm. We only have to calculate the received power from A. We know that at 100 m from A, the power is -80 dBm. We can use this reference distance and power and proceed to calculate the received power at C, which is located at 200 m from A:

$$P_r^A[dBm] = P_t\ [dBm] - PL_0 - 10 \cdot \alpha \cdot log_{10}\left(\frac{d}{d_0}\right) = -80 - 10 \cdot 3 \cdot log_{10}\left(\frac{200}{100}\right) \approx -89.0\ dBm$$

The interference plus noise power is thus:

$$I + N = 10^{\frac{-89}{10}} + 2000000 \times 10^{\frac{-20}{10}}\ mW \approx -89.0\ dBm$$

The SINR is then:

$$P_r^B[dBm] - (I + N)[dBm] \approx 9.0\ dB = 8.0$$

c)
We must first calculate the BER, which requires the Q function. Knowing that $R = B$ (since $r = 0$):

$$BER_{BPSK} = Q\left(\sqrt{\frac{2 \cdot E_b}{N_0}}\right) = Q\left(\sqrt{\frac{2 \cdot SINR \cdot B}{R}}\right) = Q\left(\sqrt{\frac{2 \cdot 8.0 \cdot 2000000}{2000000}}\right) \approx 3.17 \times 10^{-5}$$

Now, we can calculate the FER:

$$FER = 1 - (1 - BER_{BPSK})^{20 \times 8} \approx 4.94 \times 10^{-2}$$

3.

a)

$$Packet\ size\ (l)\ =\ 64\ kbps\ \times\ 40\ ms\ =\ 2560\ bits\ =\ 320\ bytes$$

$$T_{packet}\ =\ DIFS\ +\ Backoff\ +\ PHo + \frac{(MACh\ +\ RTP/UDP/IP\ +\ data)}{R}$$
$$+\ SIFS\ +\ PHo + \frac{ACK}{R}\ =$$
$$=\ 0.034\ +\ 0.067\ +\ \left(0.096\ + \frac{34 \times 8\ +\ 40 \times 8\ +\ 320 \times 8}{2000}\right) + \ 0.016\ +\ 0.096$$
$$+ \frac{14 \times 8}{2000} \approx 1.94\ ms$$

$$Throughput\ =\ \frac{320 \times 8}{1.94}\ kbps \approx 1320\ kbit/s$$

b)

$N = \lfloor 1320/64 \rfloor = 21\ streams$ → Since each call is bi-directional → 10 telephones

c)

$FER_{MAC} = (FER_{PHY})^{1+4} = 0.03^5 = 2.43 \times 10^{-8}$

4.

a)

$$\frac{R}{W} = 4 \Leftrightarrow W = \frac{R}{4} \Leftrightarrow W = \frac{12000000}{4} = 3\ MHz$$

b)

The provided bitrate value is a diversion, since we can always trade-off bandwidth for capacity. We just have to apply the Shannon-Heartley theorem, taking into account that $\frac{C}{W} \approx 10$ for $\frac{E_b}{N_0} = 20$:

$$C = W \cdot (1 + SNR) \Leftrightarrow \frac{C}{W} = (1 + SNR) \Leftrightarrow SNR = 2^{10} - 1 = 1023$$

c)

1 symbol = 2 bits

$$1 - P_M = (1 - BER)^2 \Leftrightarrow BER \approx 5 \times 10^{-6}$$