1.

a)

$$\int(S1) = (-1,-1,+1,+1,+1,+1,-1,-1) \cdot (-1,0,+3,+3,+1,+1,-3,-5) = +17 > +2$$
$$\rightarrow "1"$$

$$\int(S2) = (-1,-1,-1,-1,+1,+1,+1,+1) \cdot (-1,0,+3,+3,+1,+1,-3,-5) = -11 < -2 \rightarrow "0"$$

b)

Without noise:

$$\begin{aligned} S(S1) &= 2 \times (-1,-1,+1,+1,+1,+1,-1,-1) * D(S1) \\ &= 2 \times (-1,-1,+1,+1,+1,+1,-1,-1) * (+1,+1,+1,+1,+1,+1,+1,+1) \\ &= (-2,-2,+2,+2,+2,+2,-2,-2) \end{aligned}$$

$$\begin{aligned} S(S2) &= (-1,-1,-1,-1,+1,+1,+1,+1) * D(S2) \\ &= (-1,-1,-1,-1,+1,+1,+1,+1) * (-1,-1,-1,-1,-1,-1,-1,-1) \\ &= (+1,+1,+1,+1,-1,-1,-1,-1) \end{aligned}$$

$$S_{N=0} = S(S1) + S(S2) = (-1,-1,+3,+3,+1,+1,-3,-3)$$

Noise:

$$\begin{aligned} N = S - S_{N=0} &= (-1,0,+3,+3,+1,+1,-3,-5) - (-1,-1,+3,+3,+1,+1,-3,-3) \\ &= (0,+1,0,0,0,0,0,-2) \end{aligned}$$

c)

$$\begin{aligned} S(S1) &= (-1,-1,+1,+1,+1,+1,-1,-1) * D(S1) \\ &= (-1,-1,+1,+1,+1,+1,-1,-1) * (+1,+1,+1,+1,+1,+1,+1,+1) \\ &= (-1,-1,+1,+1,+1,+1,-1,-1) \end{aligned}$$

$$S(S2) = (-1,-1,-1,-1,+1,+1,+1,+1) * D(S2)$$
$$= (-1,-1,-1,-1,+1,+1,+1,+1) * (-1,-1,-1,-1,-1,-1,-1,-1)$$
$$= (+1,+1,+1,+1,-1,-1,-1,-1)$$

$$S = S(S1) + S(S2) + N = (0,+1,+2,+2,0,0,-2,-4)$$

2.

a)

First, we need to calculate the radius of the first Fresnel zone.

$$r(F_1) = \sqrt{\frac{\lambda \cdot d_1 \cdot d_2}{d_1 + d_2}} = \sqrt{\frac{\frac{3 \times 10^8}{450 \times 10^6} \cdot 750^2}{1500}} \approx 15.8 \text{ m}$$

The height of the antennas should be enough to leave 80% of the diameter unobstructed (including by the ground). Since the terrain is flat, we just have to guarantee that the ground only blocks 20% of the Fresnel zone:

$$minimum\ height = 15.8 - 0.2 * 2 * 15.8 \approx 9.5m$$

The antenna height of 2m is lower than the minimum required to guarantee free space propagation characteristics. As such, the Two-Ray Model is more accurate.

b)

$$C = B \cdot log_2\left(1 + \frac{S}{N}\right) = B \cdot log_2\left(1 + \frac{S}{B \cdot N_0}\right) = 200000 \cdot log_2\left(1 + \frac{10^{\frac{-85}{10}}}{200000 \cdot 10^{\frac{-170}{10}}}\right)$$
$$\approx 2.1\ Mbit/s$$

c)

According to the Two-Ray model, the received power is calculated according to the Friis model if the distance between the endpoints is shorter than the crossover distance. In the considered scenario, the crossover distance is:

$$d_c = \frac{(4\pi \cdot h_t \cdot h_r)}{\lambda} \approx 75.4\ m$$

The distance between endpoints is 1500m, clearly beyond the crossover distance. Consequently, the Two-Ray reflection formula will be used:

$$P_r = P_t \cdot \frac{G_t \cdot G_r \cdot (h_t \cdot h_r)^2}{d^4} = 20 \cdot \frac{1 \cdot 1 \cdot (2 \cdot 2)^2}{1500^4} \approx 6.3 \times 10^{-11} \approx -102\ dBm$$

d)

In QPSK, one symbol represents 2 bits. Consequently:

$$t_{bit} = \frac{t_{symbol}}{2} = \frac{1}{B} \cdot \frac{1}{2} = \frac{1}{200000} \cdot \frac{1}{2} = 2.5\ \mu s$$

$$E_b = P_r \cdot t_{bit} = 1.58 \times 10^{-16} mJ$$

We can now calculate the BER for QPSK:

$$p = BER_{QPSK} = Q\left(\sqrt{\frac{2 \cdot E_b}{10^{-\frac{170}{10}}}}\right) \approx Q(5.6) \approx 1.07 \times 10^{-8}$$

Finally, we calculate the FER:

$$FER = 1 - (1-p)^{100\times 8} = 1 - (1 - 1.07 \times 10^{-8})^{800} = 8.6 \times 10^{-6}$$

3.

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 and by R2. The path is: R3_R1_R2_H2.

b) IP/MAC address translation is performed by the Address Resolution Protocol (ARP). The node that wishes to obtain the MAC address of the next hop node issues an ARP Request in broadcast. The destination node (if connected to the same link) or the next hop router (otherwise) will respond with an ARP Reply containing the requested MAC address.

4.

a)

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