Telecom Network Systems

Friis Deep Space Com

1) 6 Gb/s (SATA 3) $= 6 \cdot 10^{9}$ b/s

1 bit $= \ln(2) \cdot kT = 2.87 \cdot 10^{-21}$ J/b $\times$

$= 1.7 \cdot 10^{-11}$ W

2) A 'point' antenna, or 'isotropic' antenna has a power-conversion efficiency that is depending on wavelength*. The output power of the antenna that is placed in a radiation field with density (W/m²) given by S, is given by

$$P_{R,iso} = S \cdot \frac{\lambda^2}{4\pi}$$

A real antenna has

$$P_{R,real} = S \cdot A_R$$

This defines an efficiency of receiving antenna

$$G_R \equiv \frac{P_{R,real}}{P_{R,iso}} = \frac{4\pi A_R}{\lambda^2}$$

*: see Wikipedia Free space path loss

or

$$P_{R,real} = P_{R,iso} \cdot G_R$$
$$= S \cdot \frac{\lambda^2}{4\pi} \cdot G_R$$

On the other side, the transmitting antenna also has an efficiency G_T. That means that the receiving antenna, at distance L sits in a power density

$$S = \frac{P_T \cdot G_T}{4\pi L^2}$$

$G_T \rightarrow \frac{4\pi A_T}{\lambda^2}$

$4\pi L^2 \rightarrow$ distance effect (sphere surface)

Then

$$P_{R,real} = S \cdot \frac{\lambda^2}{4\pi} G_R$$
$$= \frac{P_T G_T}{4\pi L^2} \cdot \frac{\lambda^2}{4\pi} G_R$$
$$= \frac{P_T}{4\pi L^2} \cdot \frac{4\pi A_T}{\lambda^2} \cdot \frac{\lambda^2}{4\pi} \cdot \frac{4\pi A_R}{\lambda^2}$$
$$= \frac{P_T A_R A_T}{\lambda^2 L^2} \qquad \text{q.e.d.}$$

3) $P_T = 10\ W$

$A_T = 10\ m^2$

$A_R = 1000\ m^2$

$\lambda = 1\ cm$

$L = 5 \cdot 10^{12}\ m$

$$P_R = \frac{P_T \cdot A_R \cdot A_T}{\lambda^2 L^2} = 4 \cdot 10^{-17}\ W$$

$T = 4\ K \Rightarrow \ln(2)\, kT = 3.83 \cdot 10^{-23}\ J/bit$

$$P_R / E_{bit} = 4 \cdot 10^{-17}\ \frac{J}{s} \Big/ 3.83 \cdot 10^{-23}\ J/bit$$

$$= 1.04\ Mb/s$$

4) $P_T = 10\ W$

$A_T = 1\ m^2$

$A_R = 100\ m^2$

$\lambda = 6 \cdot 10^{-7}\ m$

$L = 5 \cdot 10^{12}\ m$

$$P_R = \frac{P_T A_R A_T}{\lambda^2 L^2} = 1.11\ 10^{-10}\ W$$

$T = 350\ K \Rightarrow \ln(2)\, kT = 2.87 \cdot 10^{-21}\ J/bit$

$$P_R / E_{bit} = 1.11\ 10^{-10}\ \frac{J}{s} \Big/ 2.87 \cdot 10^{-21}\ \frac{J}{bit}$$

$$= 39\ Gb/s$$

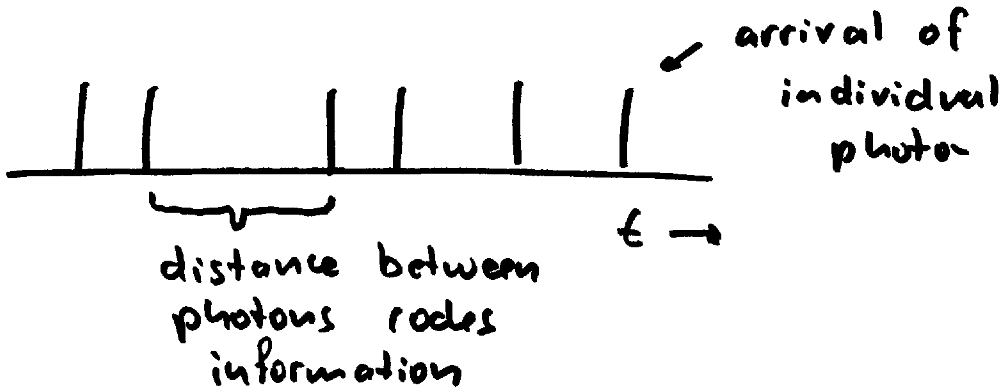
5) $P = 1.11 \; 10^{-10} \, W$

$$E_{phot} = h\nu = \frac{hc}{\lambda} = 3.31 \cdot 10^{-19} \; J$$

$$\text{flux} = \frac{P}{E_{phot}} = 3.36 \cdot 10^{8} \; \text{photons/s}$$

$$\text{bits/photon} = \frac{3.9 \; 10^{9}/s}{3.36 \; 10^{8} \; \text{phot/s.}} = 116 \; \text{bits/photon}$$

$\Rightarrow$ with time modulation we can have any number of bits per photon



6) $$I(\nu, T) = \frac{2h\nu^3}{c^2} \cdot \frac{1}{\exp\left(\frac{h\nu}{kT}\right) - 1}$$

See http://physics.info/planck/

Note: Wien already did the work for us: $\lambda_{max} = \frac{b}{T}$

b is Wien's constant $= 2.898 \; 10^{-3}$ mK

$T = 5800 \Rightarrow \lambda_{max} = 500$ nm