ITS 323 – MORE DATA TRANSMISSION EXAMPLES

A few more examples that were used in the lectures.

1 Using Multiple signal Levels

Nyquist's theorem says the capacity is a function of the bandwidth (B) and the number of signal levels used (M). Increasing B or M will increase the capacity. But we know that there are practical limits: the bandwidth is normally restricted by the system being used (e.g. a telephone line only has a bandwidth of about 4kHz – we cannot increase it). Similarly, for the number of signals (M), *the more levels we use, the higher chance of errors*. Lets explain this with an example:

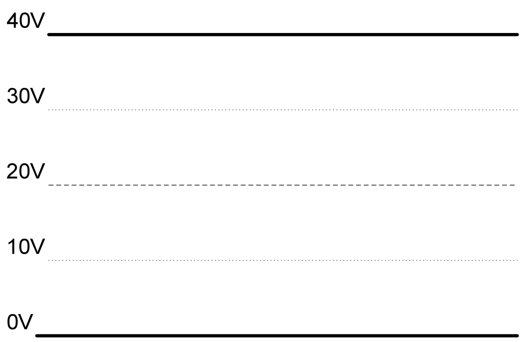
Assume we are using voltage levels to represent bits (the voltage levels used in this example are extreme, but I chose the numbers so it is easier to follow). If we use two levels (M=2), then we can say:

- To transmit a bit 0, we transmit at 10V
- To transmit a bit 1, we transmit at 30V

(Lets also assume the transmitter/receiver can only handle voltages from 0V to 40V).

The aim of the receiver is, given a received voltage level, determine the transmitted bit. We know that in practice, there is noise in our system. That is, the received voltage level may differ from the transmitted voltage. For example, if 10V is transmitted, 7V may be received.

We can visualise this as below:



From the receivers point of view, a signal received with voltage level *close to* 10V will be assumed to be bit 0. More precisely, a received signal level between 0V and 20V will be treated as bit 0 being transmitted. A received signal level between 20V and 40V will be treated as a bit 1 being transmitted. (If the signal level is *exactly* 20V, then lets just assume it is bit 0).

Lets say the transmitted voltage is T. The noise is N – that is the difference between the transmitted voltage and received voltage. So the received voltage is R = T + N.

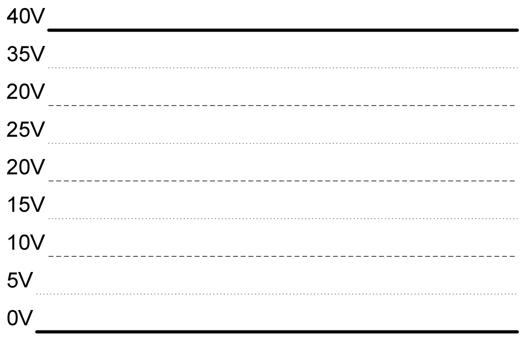
- For bit 0 transmitted, T = 10V.
  - If N is less than ±10V, then R will be between 0 and 20V. Therefore the receiver will *correctly* interpret the signal as bit 0.
  - But if N is greater than 10V, then R will be greater than 20V. Therefore the receiver will *incorrectly* interpret the signal as bit 1. THIS IS AN ERROR!
- We can do similar analysis for bit 1 transmitted at 30V. If the noise N is greater than 10V, then the receiver will incorrectly interpret the signal as bit 0.

So in our example with M = 2, we need a noise voltage of 10V or more to cause an error.

Now lets consider a case with M=4.

- To transmit the bits 00, we transmit at 5V
- To transmit the bits 01, we transmit at 15V
- To transmit the bits 10, we transmit at 25V
- To transmit the bits 11, we transmit at 35V

This is illustrated below.



If 5V is transmitted (that is bits 00), and the receiver receives between 0 and 10V, then it will correctly interpret the bits as 00. That is, the noise N is ±5V. But if N > 5V, then more than 10V will be received. The receiver will interpret this as bits 01 – THIS IS AN ERROR!

So with 4 levels (M=4), we need the noise voltage of 5V or more to cause an error. In other words, for M=4, we need a smaller amount of noise to cause an error at the receiver.

So in summary, Nyquist theorem says the more levels we use, the higher the data rate. But in practice we also know that the more levels we use, the more errors will occur. And errors will reduce our throughput (because we need to spend time fixing them)!

2 Signal to Noise Ratio (SNR)

SNR, as the same suggests, is a ratio of the strength of the signal we want transmitted versus the strength of noise in the system. Our signal is good, noise is bad! The higher the SNR, the better. Why? Because receivers can only correctly interpret information if it is received with a certain threshold SNR.

Consider the example of the class lecture. The lecturer is the transmitter. The students listening to the lecture are receivers. The students talking in class are noise.

The lecturer talks with a microphone – lets assume the signal strength created is 10 (the units do not matter, it could be measured as volts or watts). Lets assume every student in the room creates noise if they talk. And the noise strength is 1 per student (since the students do not have a microphone, and talk quieter than the lecturer). So if 2 students talk at the same time, the total noise is 2. The SNR is 10/2 = 5.

Now lets assume that the students in the class can successfully hear and understand the lecturer if the SNR is greater than 3 (SNRthreshold). So if 2 students are talking, the class can still understand the lecturer. (Since SNR = 5 is greater than SNRthreshold).

Now what if 5 students are talking in class? The total noise is 5, and the SNR is now 10/5 = 2. Now SNR = 2 is *less than* the SNRthreshold of 3 – so with this amount of noise, the class CANNOT understand the lecturer.

Lets look at another example. Only two students talking (noise = 2), but the lecturer turns off the microphone – the signal level is now 5 (instead of 10). The SNR is 5/2 = 2.5 which again is less than SNRthreshold - the class CANNOT understand the lecturer.

So in summary, the ability to understand (or to successfully communicate data from transmitter to receiver) depends on three things:

- Transmitted signal strength (S)
- Amount of noise (N)
- Threshold of SNR at which receiver can successfully understand.

Mathematically, for successful communication we need SNR > SNRthreshold. In practice, SNRthreshold is usually a characteristic of a receiver. For example, a wireless LAN access point may have a SNRthreshold of -71dBm. And a wireless LAN client might have a signal strength of 17dBm. Therefore the client can successfully communicate with the access point of the noise is less than .

3 Decibels and Power

Some useful equations on dB.

Decibel is a measure of the ratio between two signals:

Decibel gain, $G_{dB} = 10 \log_{10} (P_{out}/P_{in})$

Where

- G_{dB} is the gain, in decibels
- P_{in} is the input power level
- P_{out} is the output power level

When talking about communication transmission, often we talk about Watts. So the power can be given as decibel-Watts or dBW.

$Power_{dBW} = 10 \log (Power_{W} / 1W)$

If the power in Watts is 1000 W, then it is equivalent to 30dBW. A power of 1mW is equivalent to -30dBW.

Another term often used is decibel-milliWatts or dBm.

$Power_{dBm} = 10 \log (Power_{mW} / 1mW)$

So 1mW = 0dBm and 100mW = 20dBm.

Lets look at the example used for SNR of wireless LANs in the previous section. We said SNRthreshold = -71dBm.

So to convert dBm to mW:

$Power_{mW} = 10^{(Power_{dBm}/10)}$

$10^{(-71/10)} = 10^{-7.1} = 7.94 \times 10^{-8}$ mW

And we said the signal strength was 17dBm = 50.11mW

So if we transmit at 50.11mW, the minimum strength signal that can be successfully received is 7.94×10^{-8} mW.

Now lets see what distance this corresponds to. Lets assume Free Space Loss:

$P_t/P_r = (4\pi d)^2 / (G_t G_r \lambda^2)$

If we assume the gains of the antennas G_t and G_r are both 1. And the frequency is 2.4GHz. Therefore the wavelength λ is v/f (where v is the speed of light, 3×10^8 m/s). So λ is:

$$3 \times 10^8 / 2.4 \times 10^9 = 3/24 = 0.125\text{m}$$

Therefore:

$(50.11 / 7.94 \times 10^{-8}) = (4\pi d)^2 / (0.125^2)$

If you re-arrange, you can calculate d = 250m

[Most people that have used Wireless LAN know that it is hard to get connectivity at 25m, let alone 250m. But our calculation assumed *free-space loss* – which does not consider walls, the ground, people blocking signals, which all reduce the transmission distance. Also the figures quoted are for the lowest data rate of 6Mb/s – if you want the full 54Mb/s data rate, then the distance will be much lower].