3C5 Telecommunications

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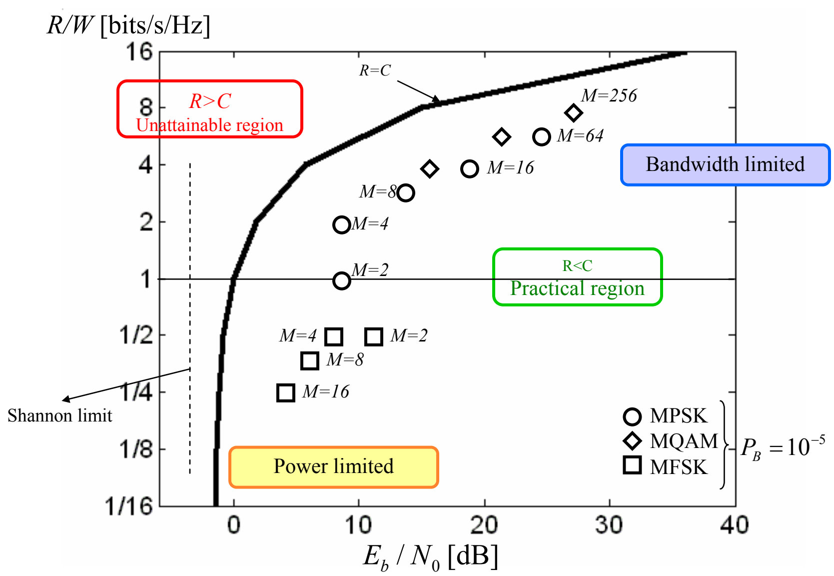
the last day

- we looked at performance of the system in a more holistic manner and focused on the probability error plane and the bandwidth efficiency plane as a means of doing so
- this all formed part of a discussion on trade-offs that need to be made when designing a system
- we discussed the concept of bandwidth-limited and power–limited systems and the different kinds of modulation schemes that suit each case



points we noted

- in bandwidth-limited systems spectrally efficient modulation schemes can be used at the expense of power
- in power-limited systems power efficient schemes can be used at the expense of bandwidth

some points

$$M = 2^k, \quad k = \log_2 M$$

$$R \ (bits/s) = \frac{k}{T_s} = \frac{\log_2 M}{T_s}$$

$$T_b = \frac{1}{R} = \frac{T_s}{k} = \frac{1}{kR_s}$$

$$R_s \ (symbols/s) = \frac{R}{\log_2 M}$$

bandwidth efficiency

$$\frac{R}{W} = \frac{\log_2 M R_s}{W} = \frac{\log_2 M}{T_s W} = \frac{1}{W T_b}$$

The smaller this product the more bandwidth efficient the modulation scheme!

so let's look at the bandwidth efficiency for different schemes

- start with MPSK
- we learned already that the theoretical minimum bandwidth required as per Nyquist is $R_s/2$
- this gives the bandwidth need to transmit the signal – i.e. number of Hertz in the carrier
- when a radio receives this RF signal it typically down converts this to a lower frequency at which to work – down to an intermediate frequency – we will look at this later
- and for MPSK systems we talk about double-sided bandwidth needed at IF an this is R_s.

bandwidth efficiency for MPSK

$$\frac{R}{W} = \frac{\log_2 M R_s}{R_s} = \log_2 M$$

This is how we place the R/W values for the various MPSK schemes on the bandwidth efficiency plane

so let's look at the bandwidth efficiency for different schemes

- let's now look at MFSK
- the minimum IF bandwidth for MFSK is $W = MR_s$
- this is because as mentioned the last day the bandwidth depends on the number of symbols in use

bandwidth efficiency for MFSK

$$\frac{R}{W} = \frac{\log_2 MR_s}{MR_s} = \frac{\log_2 M}{M}$$

This is how we place the R/W values for the various MFSK schemes on the bandwidth efficiency plane

As expected it has a lower bandwidth efficiency

A bandwidth-limited example

- Suppose we are given a bandwidth-limited AWGN channel of W= 4000 Hz. Suppose it turns out that we get a S/N_o value of 53dB-Hz to work with. We want to transmit at 9600 bits/s. We must design a system that can guarantee and P_b of less than 10^{-5}
- How do we do this?
- We can't transmit 9600 bits/s in 4000 Hz – not enough minimum bandwidth available – if we use one bit per symbol
- Hence we need to use a spectrally efficient modulation scheme
- MPSK with M = 8 is a good example
- This gives us 9600/3 =3200 symbols per second which would fit in a bandwidth of 4000 Hz
- We need to see if the system will meet the P_b requirements

The E_b/N_o conditions

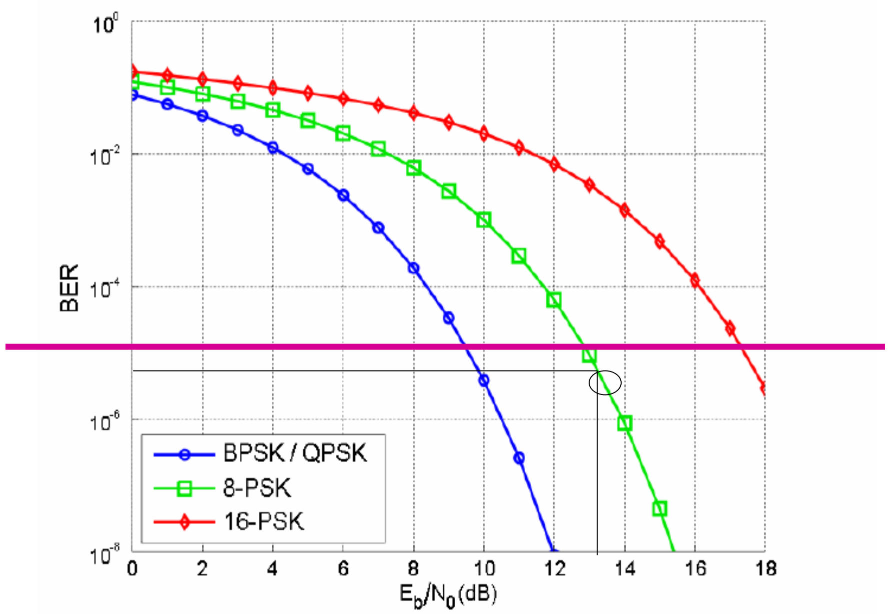
- so we need to translate the information we have about signal and noise to E_b/N_o as that is what we work with

$$\frac{S}{N_o} = \frac{E_b R}{N_o}$$

$$\frac{E_b}{N_o}(\mathrm{dB}) = \frac{S}{N_o}(\mathrm{dB-Hz}) - R(\mathrm{dB-bits/s})$$

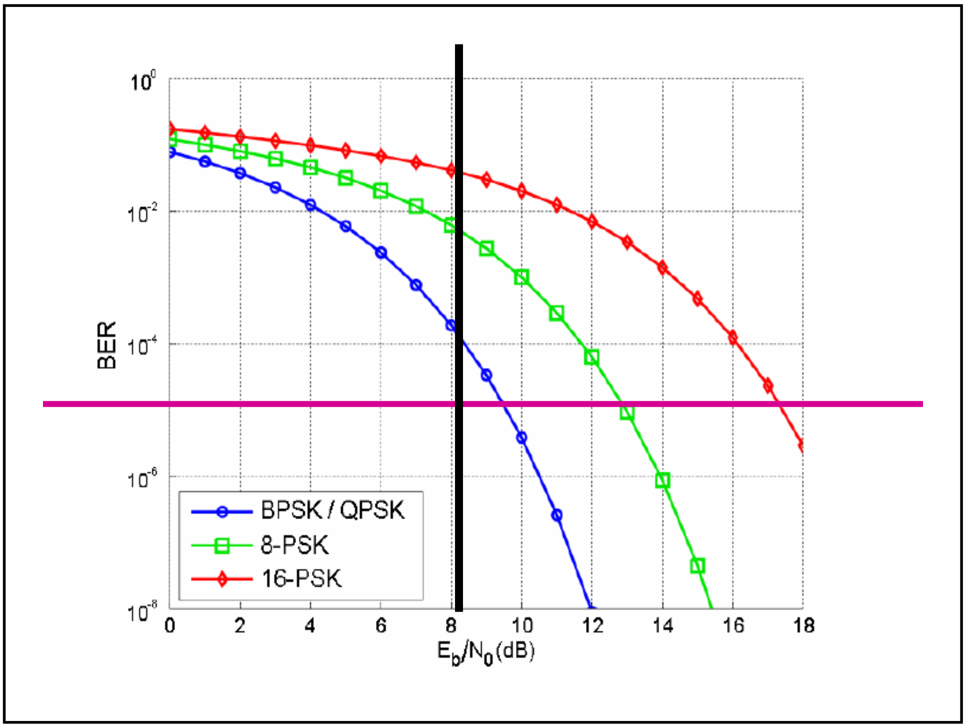
$$= 53 - (10\log_2 9600)\mathrm{dB-bits/s}$$

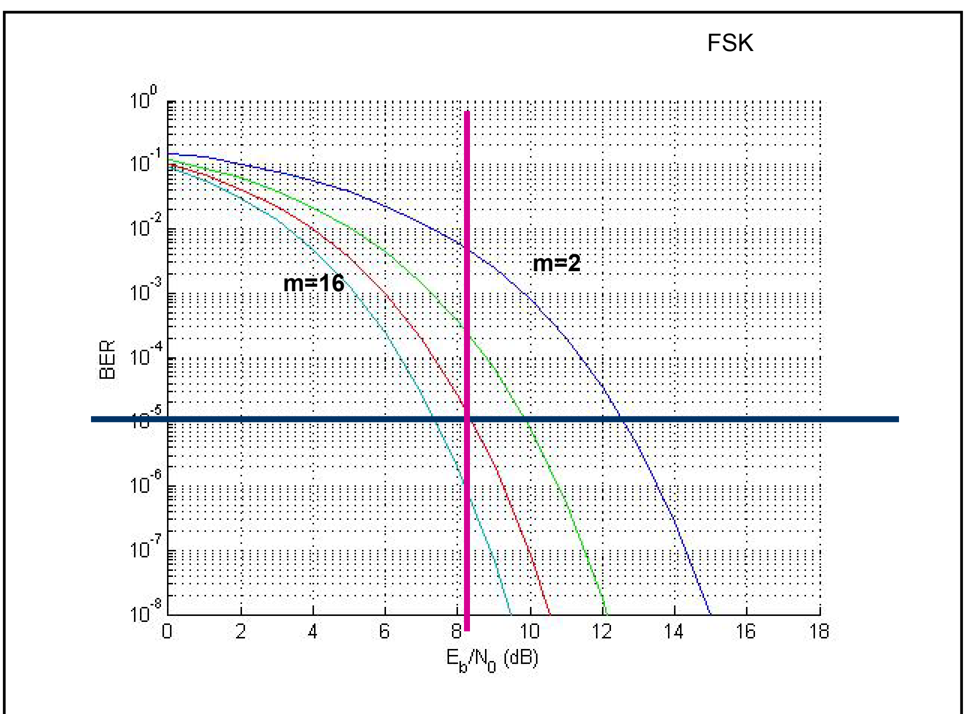
$$= 13.2\mathrm{dB} \ \ (\mathrm{or}\ \ 20.89)$$



A power-limited example

- we have same data requirements as last time and same error requirements but now have lots of bandwidth with W=45kHz and S/N_o = 48dB-Hz
- When we work from the 48dB-Hz figure as before we get an E_b/N_o or 8.2dB
- This is quite a poor E_b/N_o and we can not get our desired performance with PSK
- Hence we look to MFSK as bandwidth is not a problem
- We look at 16 FSK


BPSK / QPSK
8-PSK
16-PSK
BER
E_b/N_0 (dB)

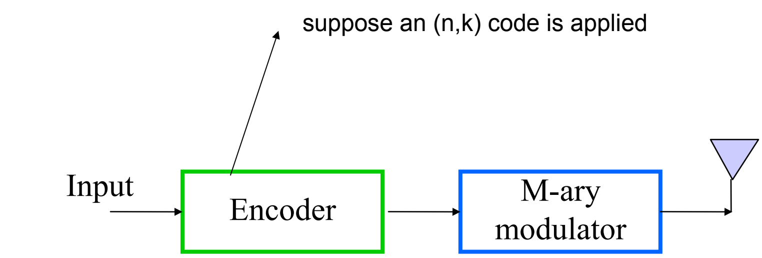

FSK
m=16
m=2
BER
E_b/N_0 (dB)

Finally we look at a situation where more is need ……

- Suppose we are given a bandwidth-limited AWGN channel of W= 4000 Hz. Suppose it turns out that we get a S/N_o value of 53dB-Hz to work with. We want to transmit at 9600 bits/s. We must design a system that can guarantee and **P_b of less than 10^{-9}**
- We saw already to meet the bandwidth requirements we need PSK but we also saw from previous calculations it will not deliver the require P_b.
- Hence we have a bandwidth-limited AND power-limited situation.

solution?

- The solution here is to code the signal
- **A coding gain will result-** i.e. the signal will experience a better probability of error
- We have not studied coding in enough detail to look at the coding gain properly but the concept should be clear
- The 8PSK generates 3200 symbols per second and we have 4000 to play with so if we encode in such a manner so as not to increase the bandwidth by no more than 25% all is ok.



R [bits/s]

$$R_c = \left(\frac{n}{k}\right) R \text{ [bits/s]}$$

$$R_s = \frac{R_c}{\log_2 M} \text{ [symbols/s]}$$

coding gain

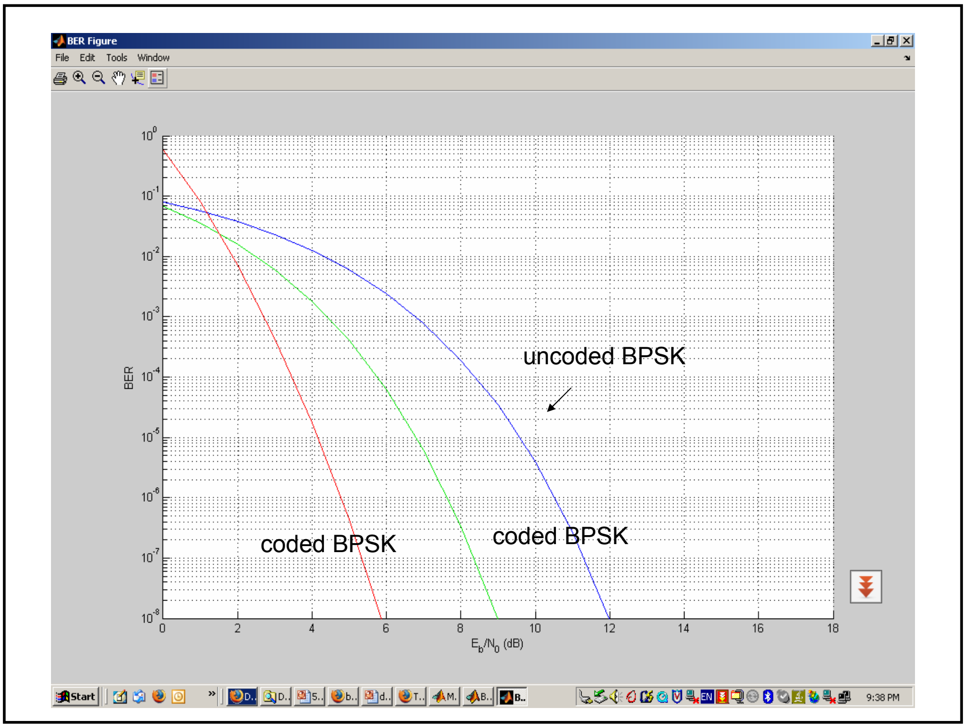
$$G = \left(\frac{E_b}{N_o}\right)_{\text{uncoded}} - \left(\frac{E_b}{N_o}\right)_{\text{coded}}$$

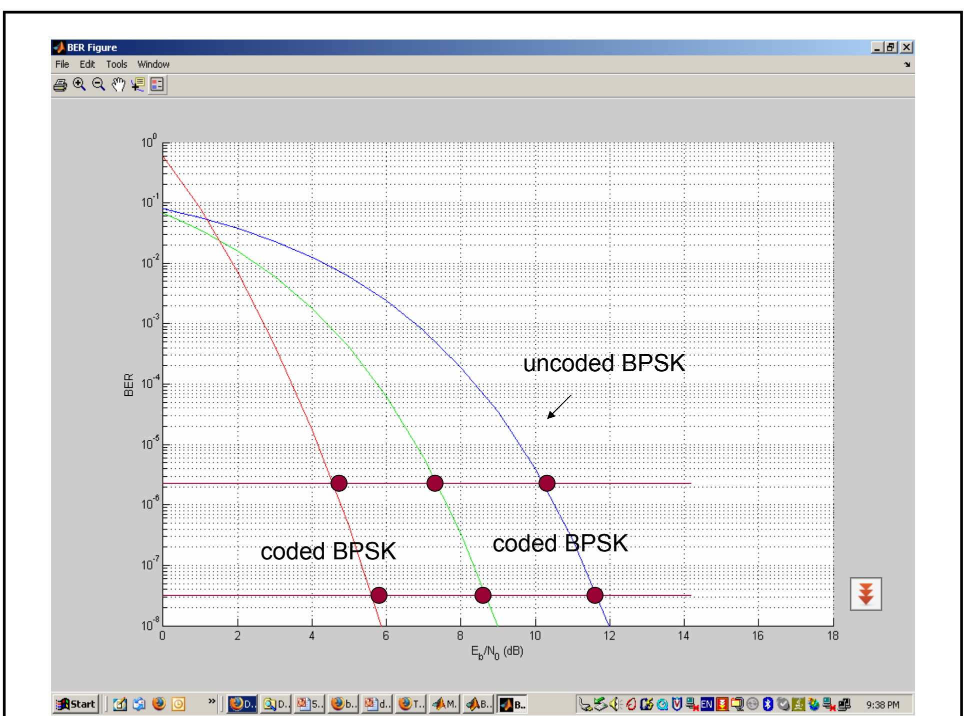
The gain is a function of the modulation type used and the probability of error

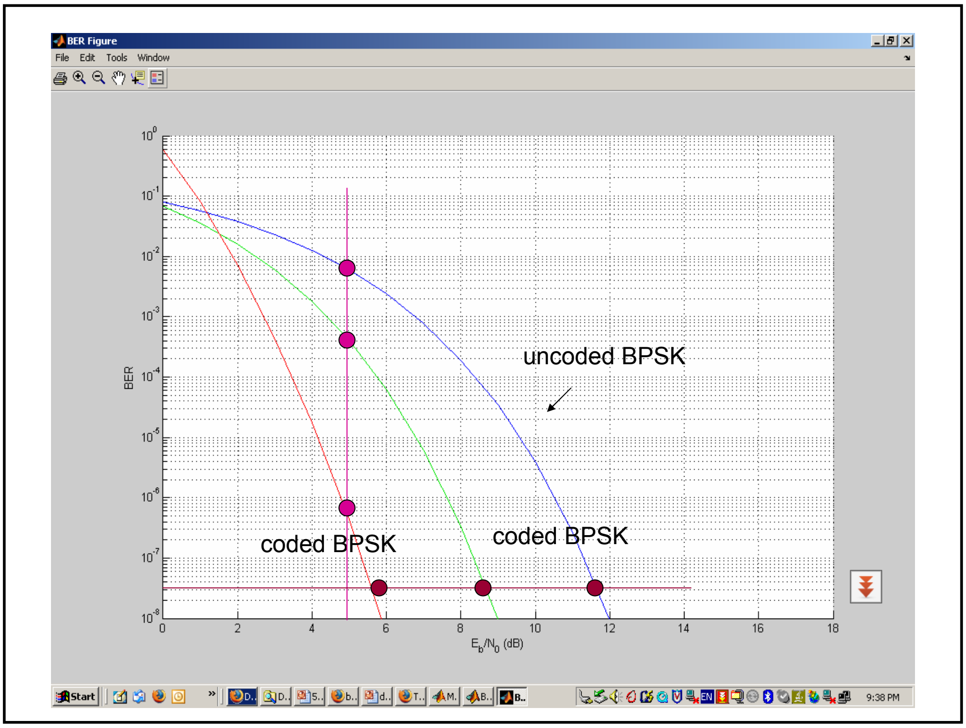
We can find the uncoded E_b/N_o that will give us the required P_b and it turns out to be 40.22 dB

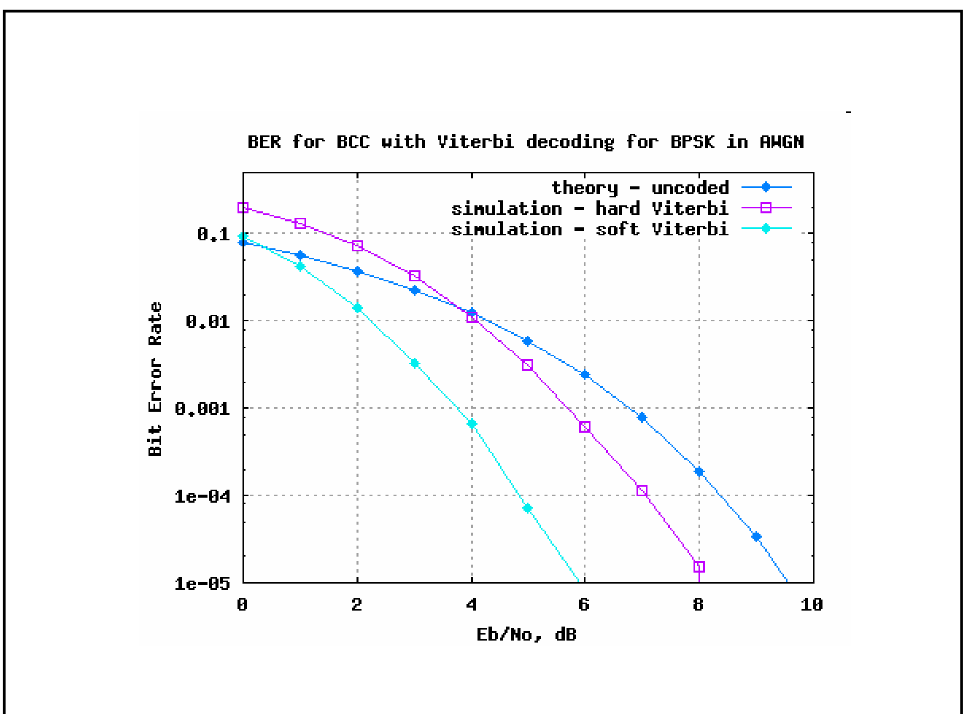
We know already that we need an E_b/N_o after coding of 13.2 dB from the first example – hence we need a gain of 2.8 dB

Suffice to say it is possible to find codes that can deliver this gain and that satisfy the bandwidth requirements


BER Figure
File Edit Tools Window
BER
E_b/N_0 (dB)
uncoded BPSK
coded BPSK
coded BPSK


BER Figure
File Edit Tools Window
BER
E_b/N_0 (dB)
uncoded BPSK
coded BPSK
coded BPSK


BER Figure
File Edit Tools Window
uncoded BPSK
coded BPSK
coded BPSK
BER
E_b/N_0 (dB)
9:38 PM


BER for BCC with Viterbi decoding for BPSK in AWGN
theory - uncoded
simulation - hard Viterbi
simulation - soft Viterbi
Bit Error Rate
Eb/No, dB

summary activity

everybody can now take a turn to explain some concept they grasped about digital modulation and a concept they find difficult

summary modulation

1. reliably detectable characteristic of the carrier wave used
2. PSK/FSK/QAM key schemes
3. I,Q format most convenient
4. constellation diagrams and scatterplots offer insight to what happens when errors occur – distance concepts
5. error probability plane all important – learned how to plot BER curves for different modulation schemes
6. bandwidth-efficiency plane all important – analysed some plots
7. tradeoffs between different modulation techniques depend on resource availability - power and bandwidth two key resources
8. Shannon-Hartley needed as dealing with capacity now of a continuous channel
9. Error coding can add to performance and needs to be considered in overall calculation of transmission rate

where we are….

- intro to wireless and waves in general
- intro to information theory
- compression
- error coding
- digital modulation

- visit to lab
- receiver characteristics
- a complete system