EEENGM4221:
Broadband Wireless Communications

Challenges

Dr Simon Armour

Challenges

- The Wireless medium is convenient in many ways but places many challenges upon the wireless engineer
- We are required to design systems to operate over an at best challenging and often hostile channel
- Some challenges are familiar from previous courses
- We will consider another (perhaps) less familiar challenge in more detail here - Quality of Service

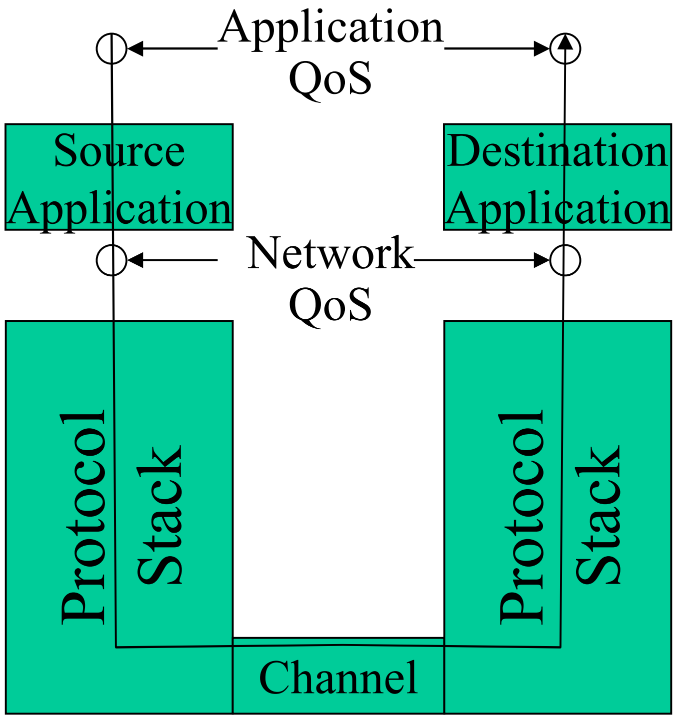
Familiar Challenges

- Spectral Efficiency (>1bit/s/Hz)
- Cost (a few dollars for a wireless modem chipset)
- Complexity (a ‘few million’ gates)
- Power Consumption (<10nJ per bit)
- Multiple Access (10s or 100s of nodes sharing a channel)
- etc

Ref:

Quality of Service

- QoS may be viewed from two perspectives:
  - The Quality of Service provided by the application to the User
  - The Quality of Service provided by the communication network to the application
  - We are concerned with the latter



Ref: GANZ 2, 3

QoS Parameters

- From a network perspective, QoS refers to the ability of the network to meet the needs of a given application
- This can be quantified by an ensemble of parameters:
  - Data Rate/Throughput
  - Delay
  - Loss/Error Rate

Ref:

QoS – Data Rate (1)

- Many applications have particular Data Rate Requirements
- The requirements vary widely depending upon application
- Some applications generate a constant bit rate, others a variable bit rate (CBR and VBR applications)
- Different applications react differently when the available bit rate provided by the network varies from the nominal bit rate of the application

QoS – Data Rate (2)

- Some applications may:
  - Fail completely if the bit rate provided by the network is less than that required (hard failure).
  - Cope with a data rate lower than that required, probably at some expense to the QoS perceived by the user.
  - Exploit a data rate greater than that required to improve the QoS perceived by the user.

QoS – Data Rate (3)

- One way to quantify the data rate provided by the network to the service is in terms of the mean data rate and the variation of data rate around that mean
  - Variation often referred to as jitter
- The amount of data rate jitter and the minimum data rate are likely to be important to some applications

QoS – Delay

- Some applications also have delay requirements
- Delay can be measured at various points in the communications stack.
- Here, it is easiest to consider it between the source application (input to the network) and the destination application (output of the network)
- Delay may be similarly evaluated in terms of mean, variation around the mean (jitter) and maximum.
- Requirements again vary with the application

QoS – Loss/Error Rate (1)

- Applications also have requirements in terms of the amount of lost/erroneous packets of data that they can tolerate
  - Many applications cannot tolerate any loss or error or at least begin to degrade the QoS to the user as soon as any loss or error occurs
  - For this reason, very intense error control is often implemented in the network often with multiple error control methods are each layer

Ref:

QoS – Loss/Error Rate (2)

- There can be a subtle difference between packet loss and packet error
- Packet loss implies a complete failure to transfer a packet across the network, the packet of data is a complete unknown at the destination application
- Packet error implies that some semblance of the packet is communicated but that it is not exactly the same as that generated at the source
  - Some applications will reject an erroneous packet making it more or less the same as a lost packet
  - Error Resilient Applications can make use of an erroneous packet – it may be more useful than no packet at all

Ref:

QoS Requirements

- Sometimes it is possible to design a communications system with a particular service in mind
  - GSM designed for Voice
- However, increasingly communications systems must be flexible and support many different services with very different QoS requirements
  - WiMax is a good example
- So the challenge is not just to provide QoS but to provide flexible QoS

QoS - Priority

- Priority is another important issue relevant to QoS
- Inevitably, if demand is high enough, the network will not be able to provide QoS to all users
- It becomes necessary to decide what part of demand will be met:
  – Reduce QoS for all
  – Maintain QoS for some at the greater expense of others
  – Need to consider the implications of reducing QoS
    - Hard failure
    - Soft failure
- 'Controlled Unfairness'

Ref:

The Wireless Channel

- The Wireless Channel Creates Many Challenges as has been covered in other courses (EENG 22000, 32500):
  - Attenuation (Free Space)
  - Shadowing (Slow Fading)
  - Multipath (Fast Fading)
  - Delay Spread
  - Noise
  - Interference

Ref: STAL 5

A Tough Job

- As Wireless Engineers, we have to:
  - Achieve Spectral Efficiency, QoS, Multiple Access, etc
  - Keep costs and power consumption low
- And what are we given to do it?:
  - A channel which, attenuates, fades and adds noise and interference to our already pitifully small signal
- It's a tough job, but someone's got to do it…

Ref:

Free Space Attenuation

- A well known equation:

$$P_r = P_t \left(\frac{\lambda}{4\pi d} \right)^2$$

- So in a WWAN environment we could lose 100dB to free space loss

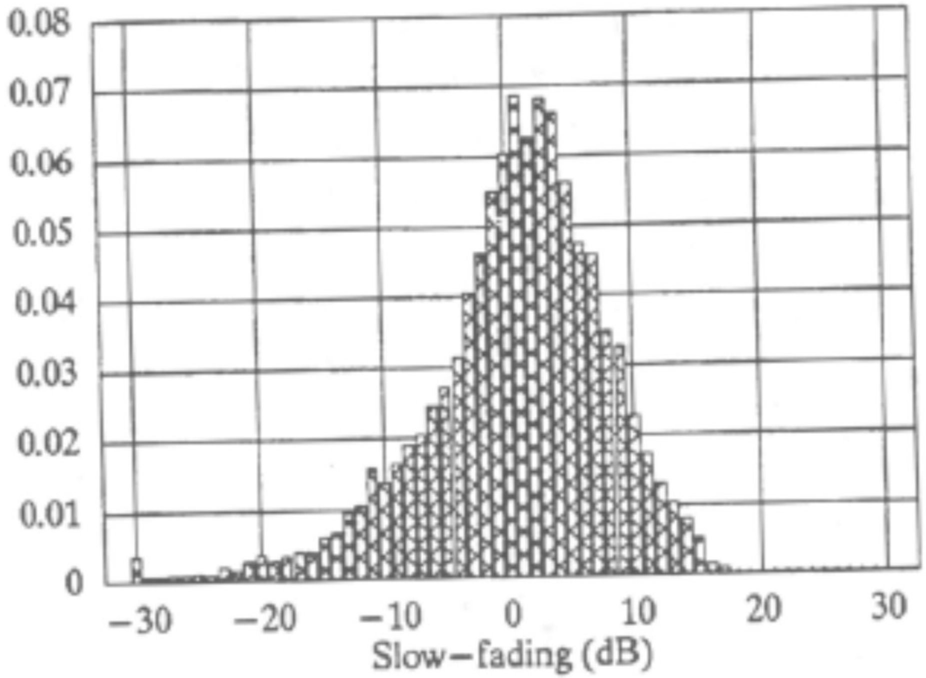
Shadowing (1)

- Shadowing introduces a random component to the loss.
- This may be characterised as a random function or is sometimes modelled as a simple change to the free space loss coefficient
- It is not just the possible additional loss that is a problem – variation of loss is also a problem
  - This variation may also be seen as an opportunity

Shadowing (2)

- Slow fading statistics have been the subject of many measurement campaigns.
- One example is as shown
- Note, often there is gain rather than attenuation
- Source: Hanzo & Keller, "Single and Multicarrier QAM"

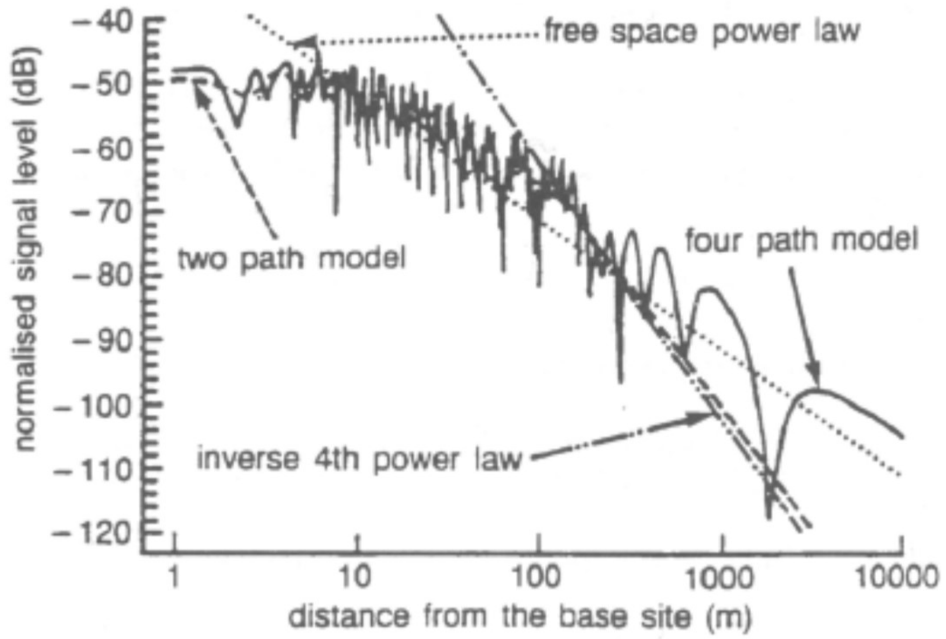
pdf of slow fading



Ref:

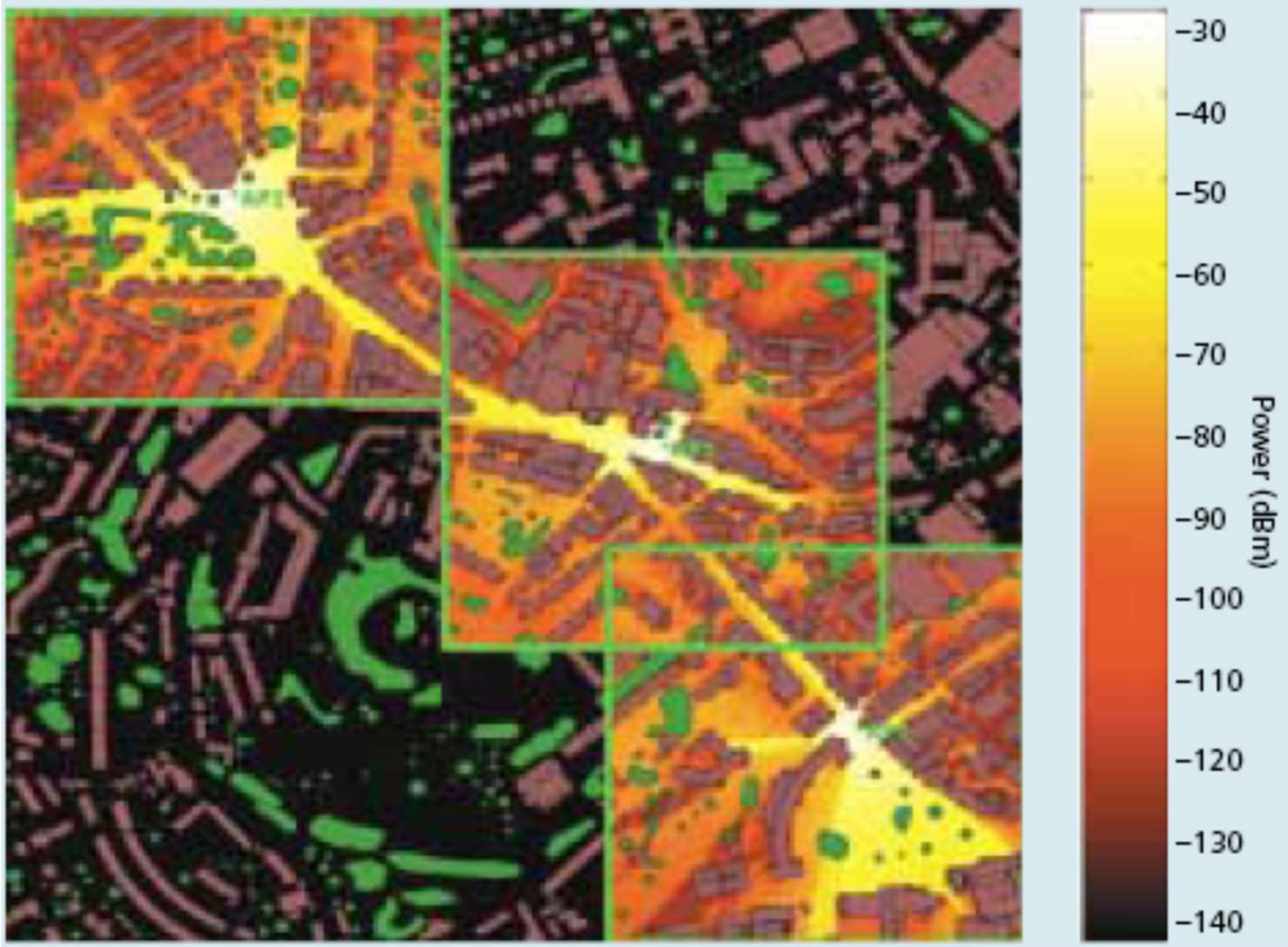
Shadowing (3)

- Slow fading and free space loss effects may be compounded as illustrated here.
- Source: Hanzo & Keller, “Single and Multicarrier QAM”



Shadowing (4)

- Source: CCR



Ref:

Multipath (Fast Fading)

- Multipath effects may further attenuate the signal according to Rayleigh or Rician statistics
  - E.g. 20dB fade 1% of the time or 10dB fade 10% of the time under Rayleigh conditions (See EENG32500)
- Multipath fading may be wideband in which case:
  - It creates complications for modem design
    - We will not consider this further (See EENGM2510 re wideband modems)
  - It can also be seen as a source of diversity – not all of the signal will be attenuated at any one time.

Ref:

Noise and Interference

- After being faded, a wireless signal is subject to noise and interference
- Noise, whilst random, typically conforms to a reliable statistical model
  - Its ever present but at least we can expect it to have a consistent effect
- Interference is a bit more of an unknown:
  - It may vary with the band of operation
  - It may be bursty in nature

The Design Problem

- Often as Engineers we must resign ourselves to having to deal with the compound effects of fading, noise and interference
- There is an engineering trade-off to consider here. Do we:
  - Design for the worst case and accept that we don't get the best out of our channel sometimes
  - Design for the best case and accept that communication fails sometimes
  - Or more likely, find a compromise somewhere in the middle?
- OR do we consider an adaptive system…. more later!

Ref:

Medium Access Control (1)

- A suitable Multiple Access strategy gives us a method for dividing the channel up for use by multiple users
  – There is no definitive term for these ‘parts of the resource’
    - Time-slots, sub-bands, codes, etc
  – They may also be of fixed or variable size
- Even with a suitable Multiple Access strategy in any domain (time/frequency/code/space) or combination of domains, the problem remains how these fractions of the overall resource are allocated for communications purposes

Medium Access Control (2)

- It is perhaps intuitively easiest to consider the problem in time
  - Essentially: ‘Whose turn is it to transmit’
  - Extension to other domains just requires a little extra thought
- It is the job of the MAC protocol to:
  - Decide who’s ‘turn’ it is
  - Make sure everyone knows who’s turn it is
- If the MAC protocol fails, there is a risk of communications failure

Medium Access Control (3)

- The PHY layer has the task of dealing with the challenges of the channel and providing a service to the layers above it.
- The challenges in designing a MAC protocol are:
- Provision of QoS
  - If the resource is oversubscribed, ensure that it is shared appropriately
    - Fairness
    - Provision of priority – ‘controlled unfairness’

Medium Access Control (4)

- Efficiency
  - Don't let the resource go unused if it is needed
  - Minimise Overhead's (deadtime, signalling, etc)
- Flexibility
  - Can the MAC protocol support Mesh, multihop, ad-hoc, etc
- Most MAC protocols only achieve a fraction of the above!

Wireless Medium Access Control

- Wireless MACs face additional challenges compared to the generic MAC tasks:
  - Collision Detection
  - Time Varying Channels
  - Errors, Error Bursts
  - Signal Attenuation:
    - Hidden Nodes
    - Exposed Nodes
    - Capture
  - Power Efficiency

Ref: Gummalla, et. Al. “Wireless Medium Access Control Protocols,” IEEE Communications Magazine 2000.