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Digital Mobile Networks: Limitations and Possibilities

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Some energy fundamentals

$$BER = erfc\left(\sqrt{2E_b / N_0}\right)$$

The above is true for BPSK and QPSK

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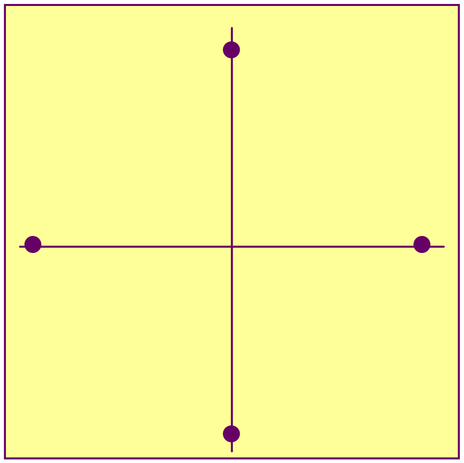
Modulation schemes



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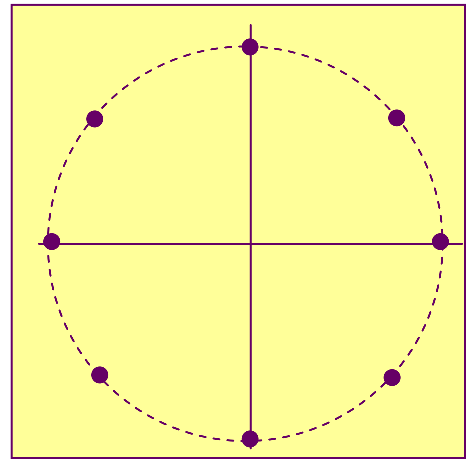

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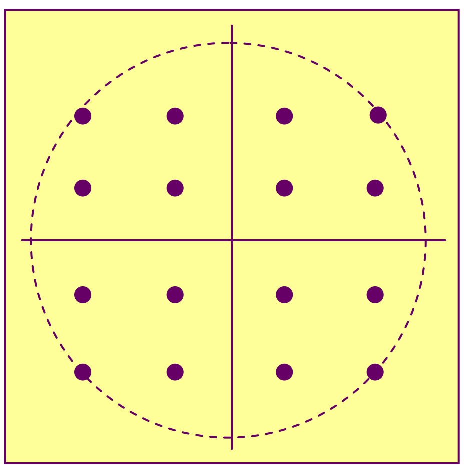

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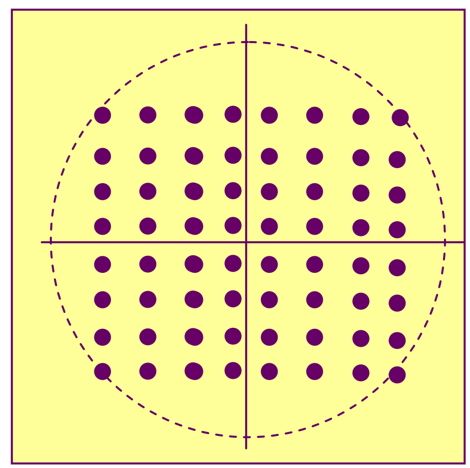

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BER performance

Higher order modulation schemes require a higher value of E_b/N_0 for a given BER.

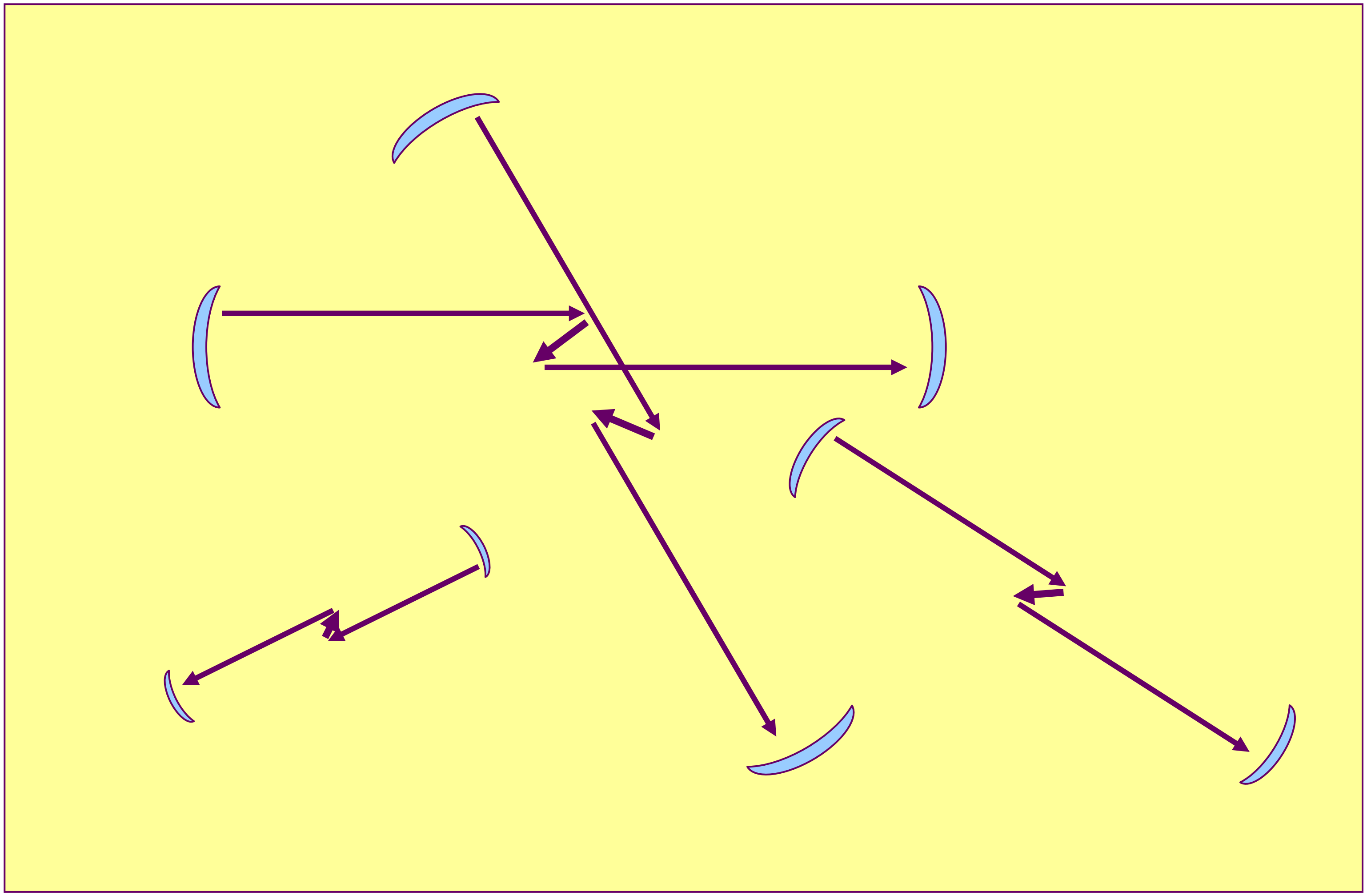
E.g. going from 16 QAM to 64 QAM requires 4 times as much energy per symbol but each symbol represents only 50% more bits.

An example from microwave systems.

A QPSK link delivers 8 Mbit/s in a 7 MHz bandwidth. SNR required is 12 dB.

An alternative 64 QAM system delivers 24 Mbit/s in a 7 MHz bandwidth. SNR required is 26 dB.

Which scheme is more efficient?



An example from microwave systems.

How far must an interferer be away in order to limit threshold degradation to 1 dB?

Because the difference in SNRs is 14 dB, the ratio of the distance for the two systems is $10^{(14/20)} = 5$.

Interferers must be 5 times further apart in the higher order system.

Site density can be 25 times higher in the lower order system. But the higher order system carries 3 times the bit rate per link.

Transferring this to digital mobile radio

In UMTS, “threshold degradation” is equivalent to “noise rise”.

Mutual interference is very direct in single frequency networks.

Capacity of a cell is inversely proportional to Eb/No (in linear units).

16 QAM (as in HSDPA) requires a higher Eb/No than QPSK (as in “normal” UMTS transmission).

Lessons

Short-distance, high-speed communications in a low-interference environment is readily achievable.

Long-distance, high-speed communications in a high-interference environment poses a big challenge.

Ensure that your expectations of HSDPA are realistic.

And another thing….

UMTS is referred to as a “spread spectrum” technology.

This refers to a high bandwidth being used for a low-ish bit rate.

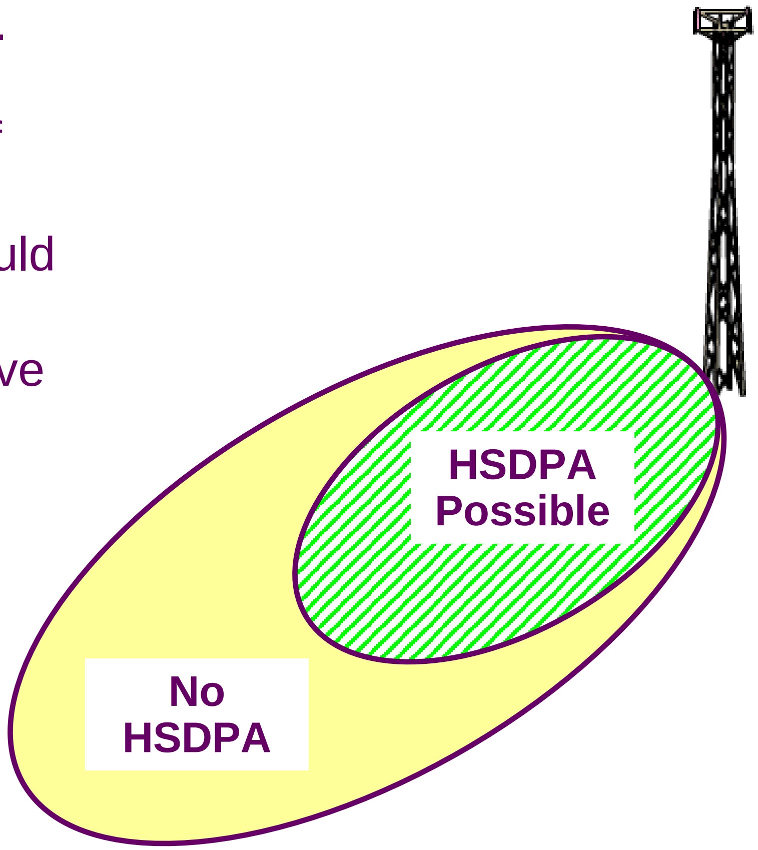
This is essential for negative signal-to-noise ratio operation and single frequency networks.

As bit rates rise, not much spreading goes on and single frequency networks are not realistically possible.

HSDPA must share spectrum with “normal” services, causing further problems.

Likely deployment - HSDPA

- HSDPA is not a “magic” solution.
- Interference limitations still exist.
- HSDPA only possible in areas of low interference.
- Aggregate network capacity should be increased.
- HSDPA likely to be highly effective in isolated environments (e.g. indoors).



Some good news for HSDPA

All five UMTS operators in the United Kingdom have some HSDPA deployment.

But this is probably for short-distance communication in low-interference environments (often indoors).

Further questions

What can improve the situation?

- **MIMO?**
- **Interference cancellation?**

What are the implications for WiMax? For 4G?

MIMO (multiple input, multiple output)

Capacity (and coverage) will be increased if you can reduce interference or reduce the Eb/No requirement.

MIMO can do both the above.

Multiple antennas can direct transmitted energy, reducing the power requirement and minimising energy in unwanted directions (thus reducing interference).

In receivers, multiple antennas give diversity gain, that helps the link budget, but also allows for maximal gain receivers to be implemented, providing an Eb/No gain.

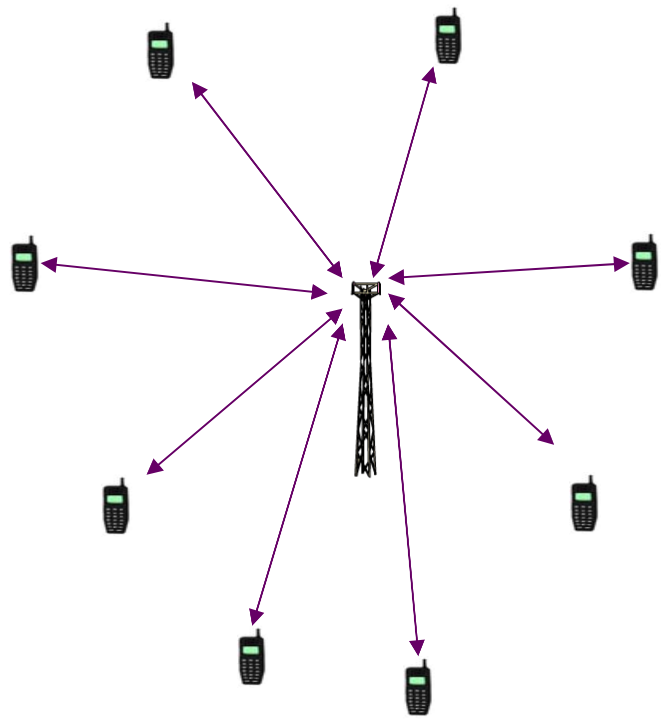
MIMO Improvements

Laptop mobiles can provide greater separation than handhelds leading to improved diversity gains.

Even a simple four-antenna array at the base station only can give dramatic air-interface capacity improvements (e.g. by a factor of two or more). True MIMO at both terminals can yield much greater improvements.

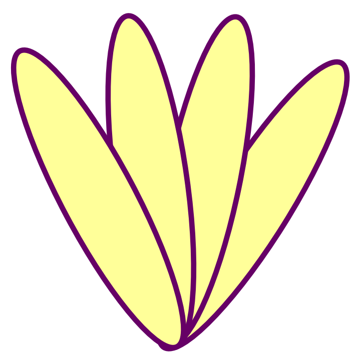
The larger physical size of a laptop computer gives it an inherent advantage regarding achievable MIMO gain.

MIMO Improvements



- The ultimate outcome is for each mobile terminal to establish a near-isolated channel to the base station.

- Even a simple four-beam base station antenna can double air interface capacity.



Noise and Interference

The fundamental limitation on any telecommunications system is that imposed by the presence of thermal noise.

$$C = B\log_2\left(1 + S/N\right)$$

Shannon's theorem makes no mention of BER nor of the effect of interference.

There is no theoretical limit to the efficacy of interference cancelling techniques.

Noise and Interference

The effect of thermal noise can be overcome by increasing the signal power.

In an interference-limited network, this will become self-defeating.

How good are interference cancelling systems?

The best approach is always to minimise the amount of interference generated in the first place.

UMTS, FDD and fast power control

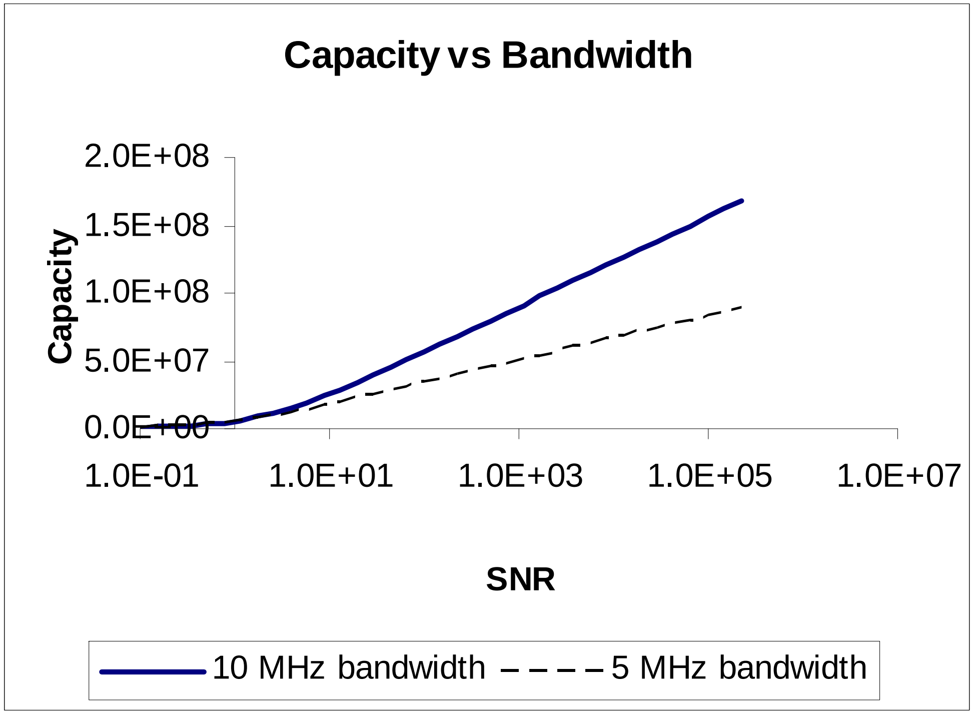
Fast power control on FDD UMTS leads to the amount of power being transmitted being just sufficient to provide the required service.

This approach leads to the minimisation of network interference.

TDD networks may have technologies that are superior to the RAKE receiver but, without fast power control, interference is going to be higher.

Another look at Shannon

$$C = B\log_2\left(1+S/N\right)$$



To get high bit rates, we need low interference and lots of bandwidth.

What are the challenges?

High speed communication over short distances in a low-interference environment is relatively straightforward.

High speed communication over long distances in a high-interference environment poses significant challenges.

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What about 4G?

If “4G” means networks providing continuous coverage at 4G bit rates that it is some way off.

If high bit rates available in only particular environments is deemed to constitute 4G then it could be argued that it is already here.

Interestingly, landline-based broadband has similar problems: “Up to 8 Mbit/s” sales pitches only materialise if you live sufficiently close to a hub.

Where does this leave WiMax?

Wi-Fi has been a success, delivering high bit rates to lap top computers via a radio interface.

WiMax has a allowed the idea that the same can be achieved with continuous coverage over large areas to disseminate.

But Wi-Fi requires interference to be low. Evidence from apartment blocks suggests that performance is severely compromised when many transmitters are located in close proximity of each other.

WiMax will face the same challenges as UMTS. Further, it is a TDD-based technology that prevents the use of fast power control.

Where does this leave WiMax?

OFDMA technology is an appropriate technology for wideband mobile offering, amongst other things, diversity against multi-path.

The standard bandwidth would appear to be 10 MHz, giving an advantage over UMTS.

WiMax will not generally be a single frequency network, requiring perhaps a block of 50 MHz of spectrum to be made available to deliver necessarily low interference for high speed data.

WiMax is not a “magic bullet” to provide “WiFi” performance in a mobile, outdoor environment without overcoming significant obstacles.

Can we reduce BER requirements?

Any value of Eb/No that is required can be matched to a BER. If we can reduce our required BER then we can reduce Eb/No requirements and hence increase capacity.

Packet-based traffic can tolerate higher error rates if it is able to wait for a re-transmission. If voice can be sent via a packet channel (e.g. VoIP) then the capacity of a mobile network can increase significantly (by a factor of 2 or more).

A Snapshot of the Situation in the UK

Mobile penetration (including GSM) is at 115%
No operator has more than 30% market share
Five UMTS operators use 12, 5 MHz FDD pairs.
Four of these also have one (virtually unused) 5 MHz TDD channel
UMTS penetration is 15%
Mobile internet use increasing – typical fee $12 per month
All five operators deploy some HSDPA-based services

Likely that some 900 MHz GSM spectrum is taken away from current users and reallocated.

Conclusions

An appreciation of the fundamental laws governing capacity on radio links is essential to predicting radio network performance.

Technologies such as MIMO can reduce interference and transmit powers thus increasing network capacity.

Using packet channels for voice services should increase air-interface capacity.

"4G" bitrates only likely to be possible in preferred areas for some time yet.

WiMax is a strong candidate technology but offers no magic solution to the fundamental problems.