COMP3310/6331 – #3

Media: Copper

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Why does it matter?

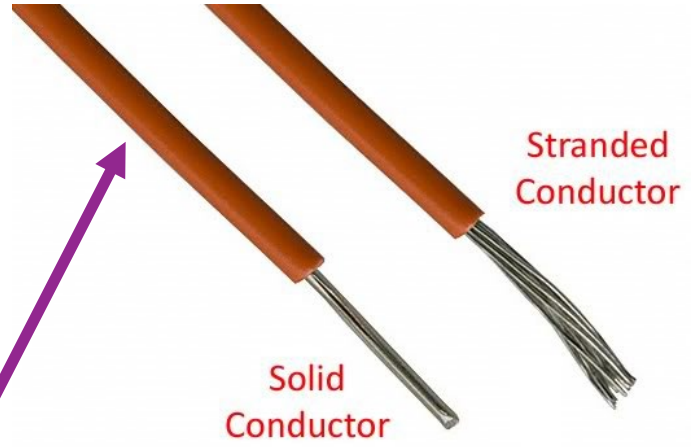
- Networks rely on analogue signals over/through physical media
- Many failure modes – and security challenges – are in the physical media
- Many weird behaviours in the physical media
  - And they vary by physical media
  - Dodgy CPUs, GPUs, RAM, HDD, etc. are fairly obvious – dodgy links are not.
    - Time dependant, weather dependant, wildlife dependant, …
- Good network design starts from physical media options
  - Costs (manufacture: materials and complexity/labour) – capital expenditure
  - Maintenance – operating expenditure
  - Benefits, risks

Putting those signals onto media

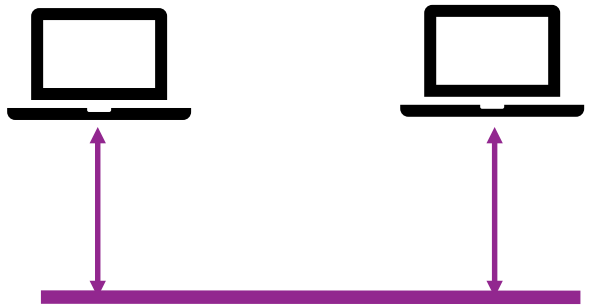
- Why wire, esp. copper?
  - Ubiquity, great conductor, cheap to work with, flexible, lots of experience
  - Can also be aluminium, steel, ceramics, wet string, …
- Used for electricity, so communications are easy
  - Data over power lines (power-line communications [PLC] …)
    - From ISP to homes, from devices to recorders
      - Low data rates (<1Mb/s) but long distances (km)
      - Developed in 1910's
    - Within a building
      - High data rates (100Mb/s) but short distances (10's m)
  - Data over fence lines, data over train tracks, …

Characteristics of copper

- Light, malleable, reasonably robust to oxidation – easy to connect
- Easy to make thin wires
  - Cross-section 0.2mm^2 solid, 0.02mm^2 stranded
  - = AWG 24 to AWG 33 – and lower
- Cheap? per kilo
- Tight bending radius
- Easy to add insulation and protection
  - cloth to rubber to plastic
  - And metal...

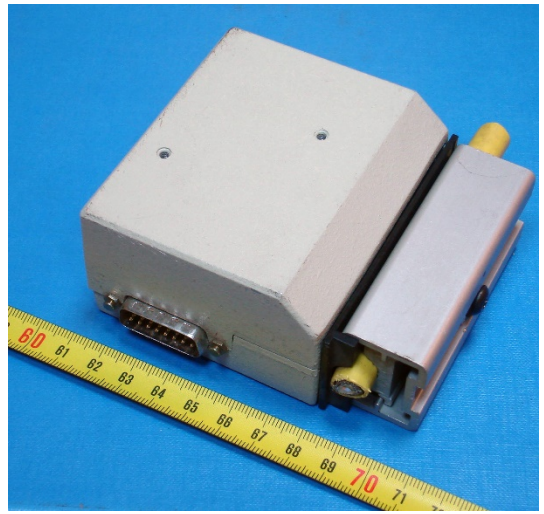


A shared medium



- One voltage over the whole wire(*eventually)
- Can (only) receive (RX) or transmit (TX) at a time?
  - Time or Frequency Division Multiplexing
  - TDM = Half-duplex = take turns
  - FDM = Electronics at each end to separate them
- Need a " common reference"
  - Where's zero?
  - So cables tend to have a "pair" of wires:

    RX/TX **and** Ground, or Reference,
    or Common, or Earth, or Shield, or …
- Some early networks: single cable and 'vampire taps'



Electrical characteristics of copper

- **Resistance**
  - Actually impedance (resistance, inductance, capacitance) – and others
  - Things that hate electrical signals going through metal
    - Some are frequency/change dependent, some are not
- **Attenuation** of a signal (aka "insertion loss") as heat, from resistance
  - And others

Resistance

- Resistance varies with length and cross-section

AWG	Diameter (mm)	Area (mm^2)	Resistance (Ω/km)
4	5	21	0.8
14	1.6	2	8.3
24	0.5	0.2	84
34	0.16	0.02	856

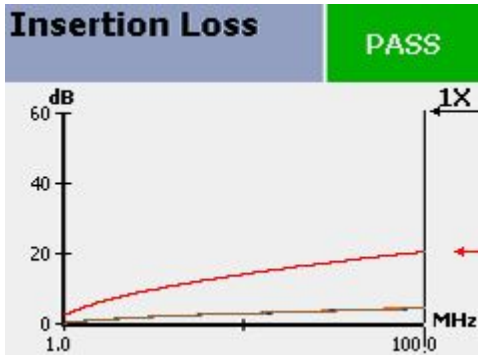
- Hence stranded cables aren't "as good" – effectively 5-10% thinner

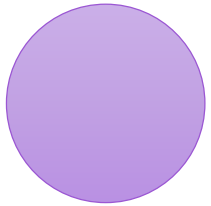
Resistance(f)

- Resistance varies with frequency

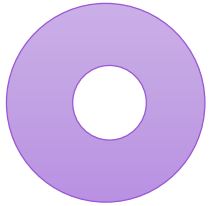
Skin-effect – changes cross-section
(6MHz, skin ~ 25µm)

Leads to **Frequency attenuation**

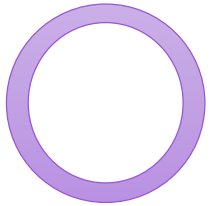




Wire end-on



Wire end-on
at low frequency



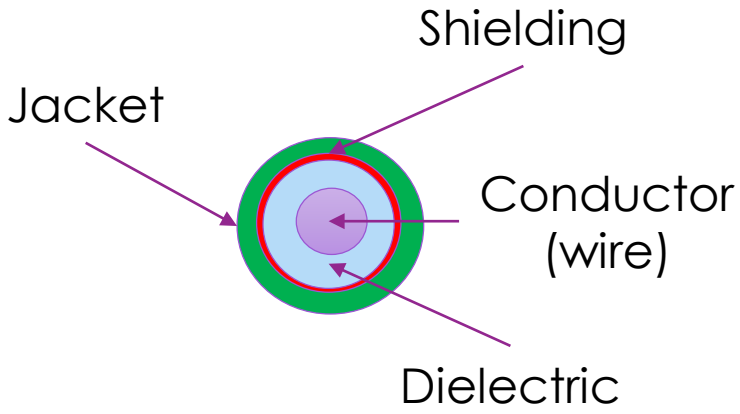
Wire end-on
at high frequency

Noise

- A straight wire is a great antenna
  - Can act as a receiver of other signals
  - Can act as a transmitter of its own signals
  - Electro-Magnetic Interference (EMI), Radio-Frequency Interference (RFI)
- Electrical "coupling" from adjacent wires
  - Leads to "cross-talk" (="XT")
    - Near end and Far end (NEXT, FEXT) mainly, but really all along the wire
- Impact goes up with distance

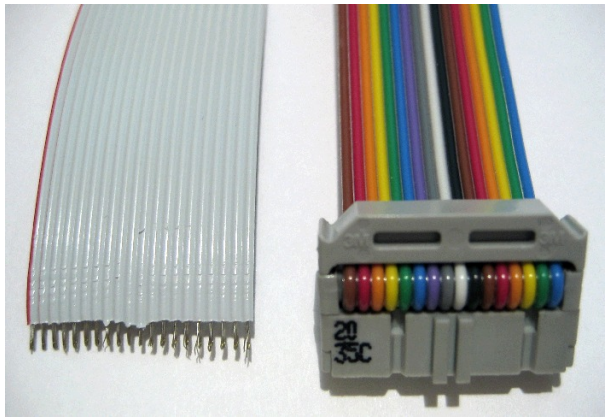
So how do we get around this?

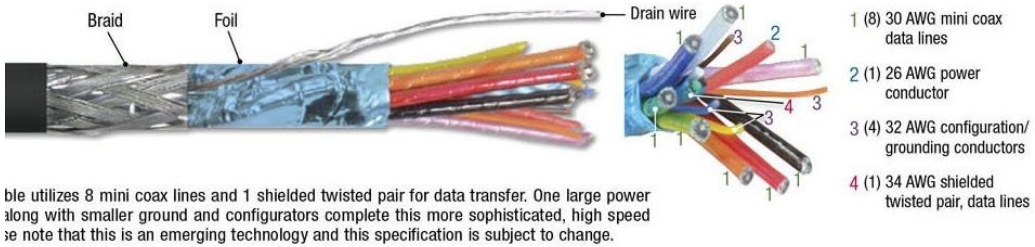
- Start with Good Cable Design!
- Take good copper and wrap it
  - "Coaxial" cables
  - Upside: Well shielded, robust
  - Downsides: single RX/TX – and pretty expensive
- Cables called 'RG-*nnn*' (RG-6, RG-58, …) (*)
  - No pattern in their characteristics
  - Varying attenuation, diameter, thickness, materials, solid/stranded, …



Another approach

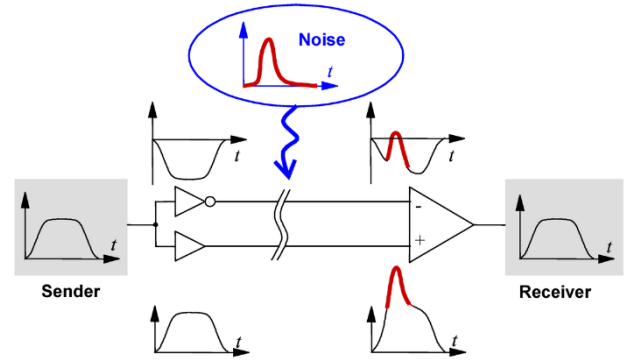
- Bring in Spatial Division Multiplexing
  - Aka – more wires in the cable
- USB, ATA, HDMI, Ribbon cables, …
- Upside:
  - Full duplex (RX, TX separately)
  - Multiple paths to share = **Inverse multiplexing** (one-to-many, to-one)
- Downside:
  - Lots of adjacent wires = crosstalk
  - Long, straight unshielded wires = antennas

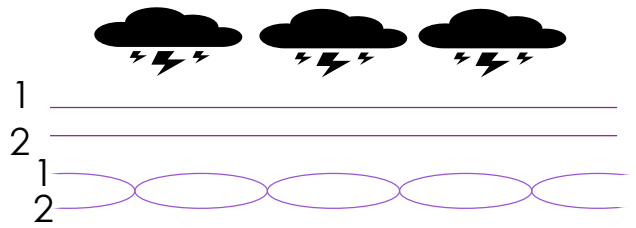




That antenna problem

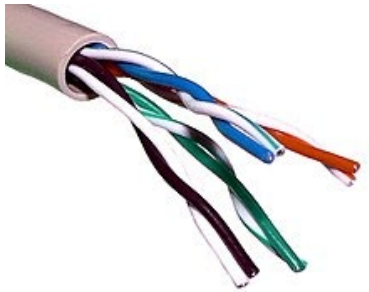
- What's the problem?
  - An antenna picks up/radiates every signal, unless it's well shielded
  - Shielding = materials = costs
- Can we avoid shielding? Yes, we can!
- First: Differential signalling
- Second: A noise source has a direction
  - Impacts one wire more than the other
  - Unless we add in **Twisting**

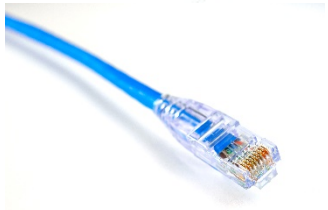


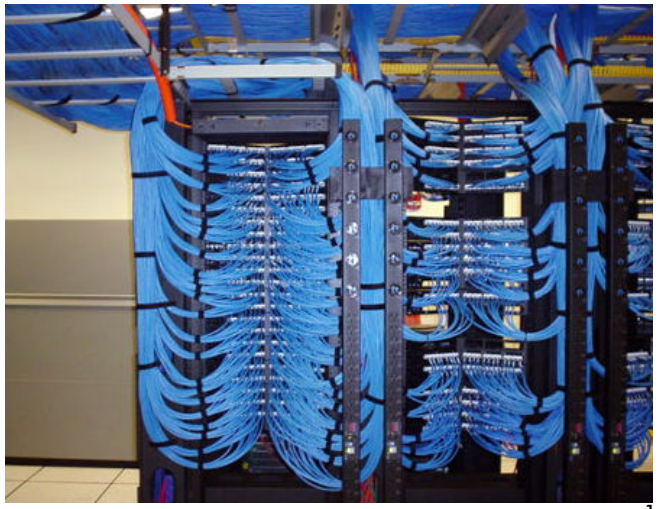


UTP Cables

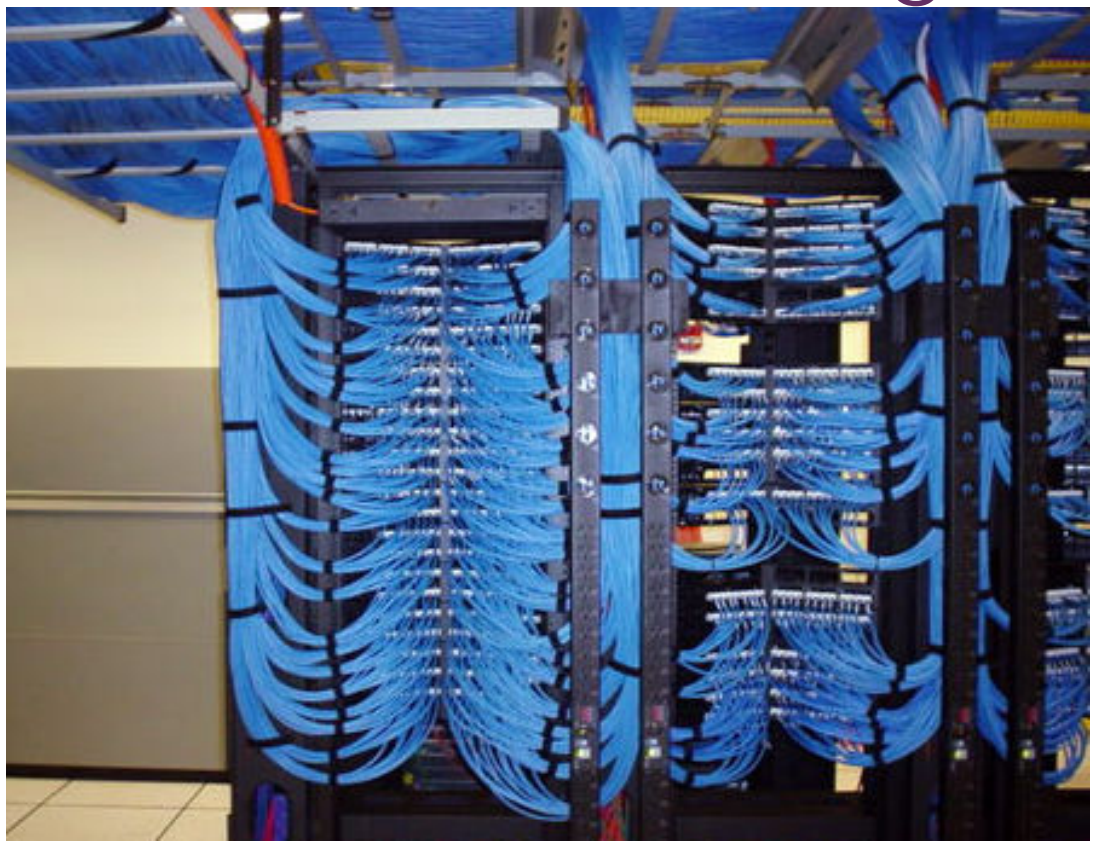
- Unshielded Twisted Pairs
- Comes in multiple Categories ("Cat1"-Cat8)
  - STANDARDISED: ISO/IEC 11801 (ed.3 2017)
  - And some not, industry makes stuff up – sigh.
- Standardised Connectors
  - A religious discussion with misused standards: RJ45 is common name (8P8C)
- "Structured Cabling"
  - Overarching design concept for a building
  - Run multiple functions over the same cables, colour-coded



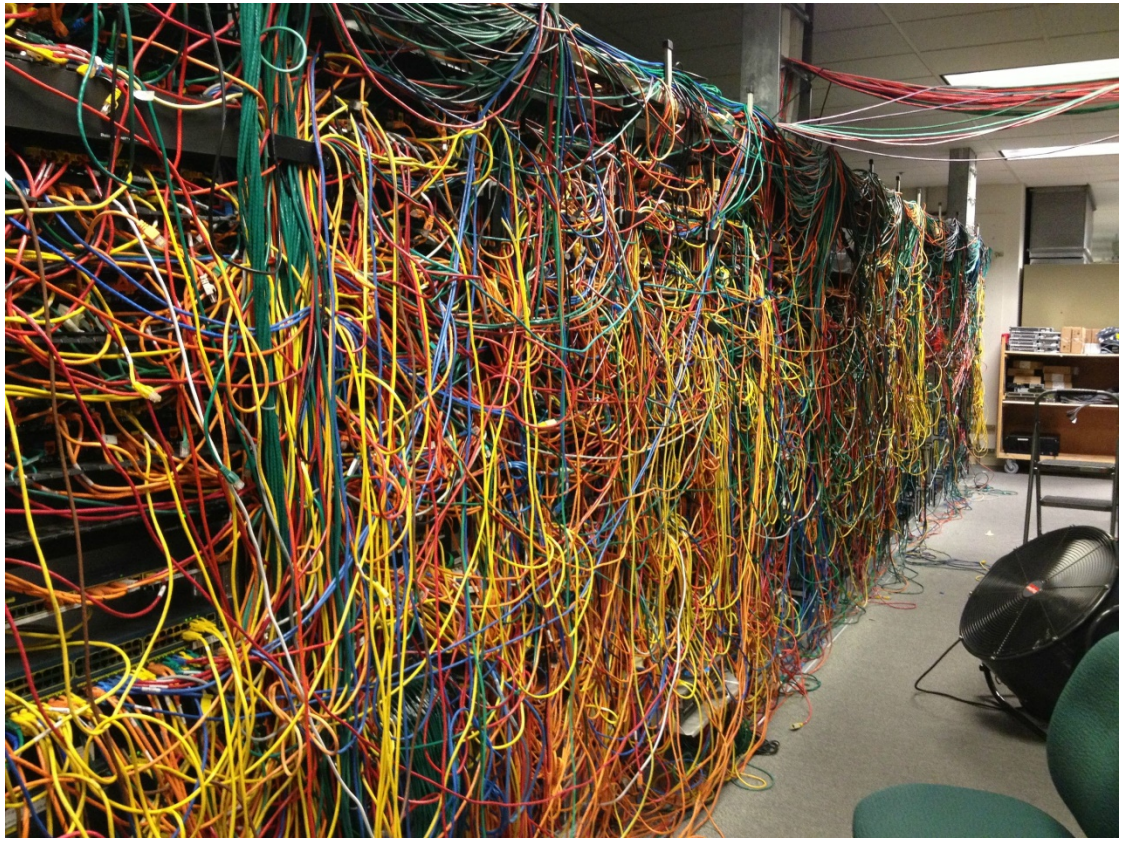




Structured cabling…



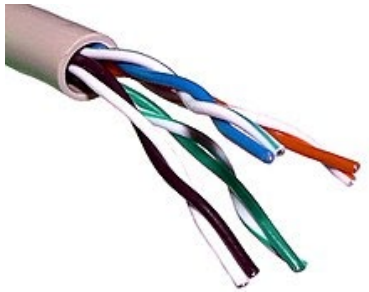
What you want…



What you get…

UTP Cables

- Standardised wiring within the plug
  - STRICT rules about terminating cables
    - Amount of insulation removed (XT)
    - Amount of untwisting (Noise)
    - Plenty of great youtube videos



- (Actually, if one standard is good, two (or more) are better!
  - *TIA/EIA-568 A and B – and others*
  - So not totally standardised.)

- And … bring back some shielding??

UTP -> SF/FTP ??

- (U/)UTP:
- Add Foil: U/FTP and F/UTP
- Add Braided Shielding: S – only on outside
- Up to SF/FTP…
  - Nearly every combination is sold somewhere
- Take home messages:
  - More F and S is great for performance
  - More F and S is a pain for making cables.
    - Makes them really expensive and stiff, too

Do not memorise, just get the taste of it

UTP cables by category

Category	Cable	Bandwidth	Data rates
3	UTP	16MHz	10-100Mb/s
4	UTP	20MHz	
5	UTP	100MHz	100-1000Mb/s
5e	UTP	100MHz	
6	UTP	250MHz	10Gb/s
6A	UTP, F/UTP, U/FTP	500MHz	
7	S/FTP, F/FTP	600MHz	10Gb/s + stuff
7A	S/FTP, F/FTP	1000MHz	
8/8.1	F/UTP, U/FTP	1600-2000MHz	40Gb/s
8.2	S/FTP, F/FTP	1600-2000MHz	

Time

- Speed of electricity in copper is not infinite = ~ 2/3 c = 0.3 µsec/100m
  - **Propagation delay** – takes time for everyone to get the signal
  - Which leads to **collisions**
    - @1Gb/s => 100bits
  - And leads to **skew** across multiple pairs
    - UTP: 2+ pairs have to be the same length, within tolerance
- Reflections
  - "Impedance mismatch"
  - Send a signal, it comes back to you, later
    - Used on landline phones for positive feedback!
    - Otherwise it's a real nuisance.

Capital and Operating costs

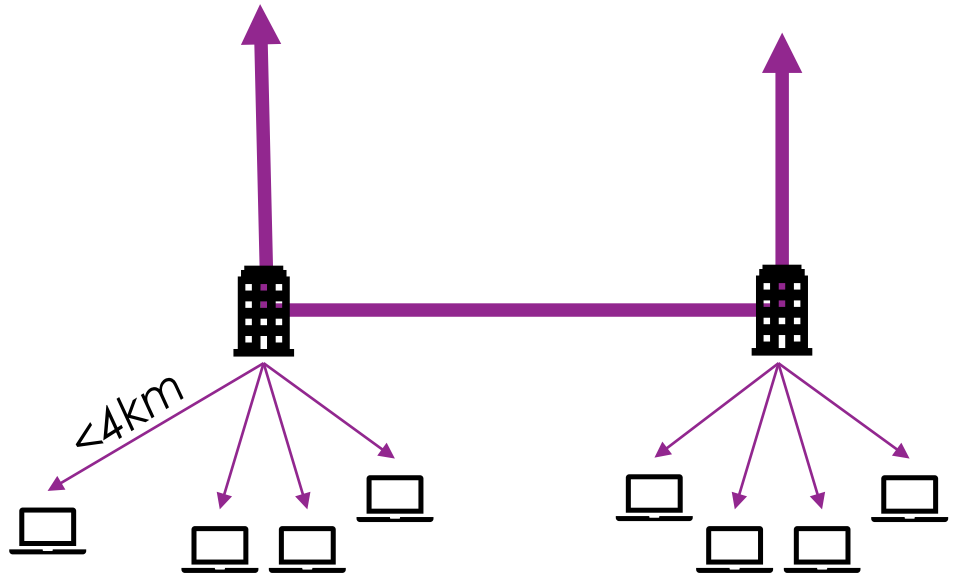
- Everything costs (materials, equipment, labour)
- Capital and operational costs
  - Buying the stuff
  - Putting it in
  - Taking care of it
- What happens?
  - Trenching ($-$$$$), then ducting/pulling, or direct burial
    - But metal rusts, junctions leak, ducts collapse, insulation perishes
    - Insects/rodent get hungry, excavators get sloppy
  - Aerial cables?
    - Antennas, lightning, birds/mammals, flying excavators, cable thieves

The great outdoors…

The Last Mile

- Easy to make a shared backbone – you only need one.
- From the backbone (exchange), get to every house…

- Trade-off costs vs performance:
  - How much does an exchange cost
  - How long is that final cable run
  - What's the cost to make and deploy
  - What can you get through it



- Quick scaling calculation:
  - 10M houses/offices in Australia,
  - Up to ~4km from their exchange… (can't go much further!)

Putting Bits on Copper Cables: DSL

- Digital Subscriber Line
  - Based on PSTN cables = 1 pair of wires to your home
- Telco standards = International Telecommunications Union
  - ITU-T (with names like G.992, H.264, …)
  - Many flavours, mostly asymmetric

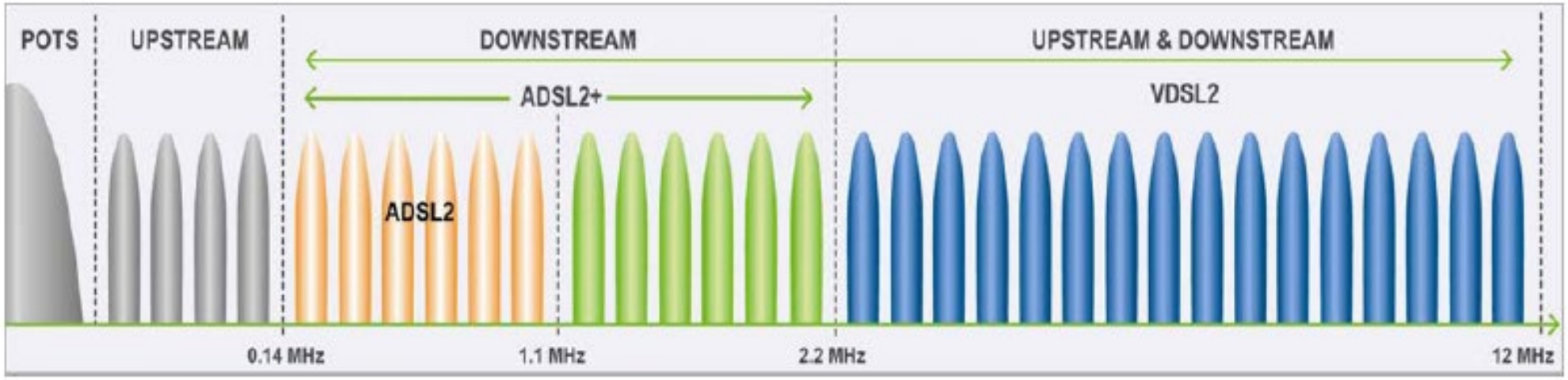
DSL	ITU	Down	Up
ADSL	G.992.1	10Mb/s	1Mb/s
ADSL 2	G.992.3	12Mb/s	3.5Mb/s
ADSL 2+	G.992.5	24Mb/s	3.5Mb/s
VDSL	G.993.1	52Mb/s	16Mb/s
VDSL 2	G.993.2	200Mb/s down+up	
S(H)DSL	G.991.2	5.7Mb/s per pair, up to four	

When living next to the exchange!

DSL+

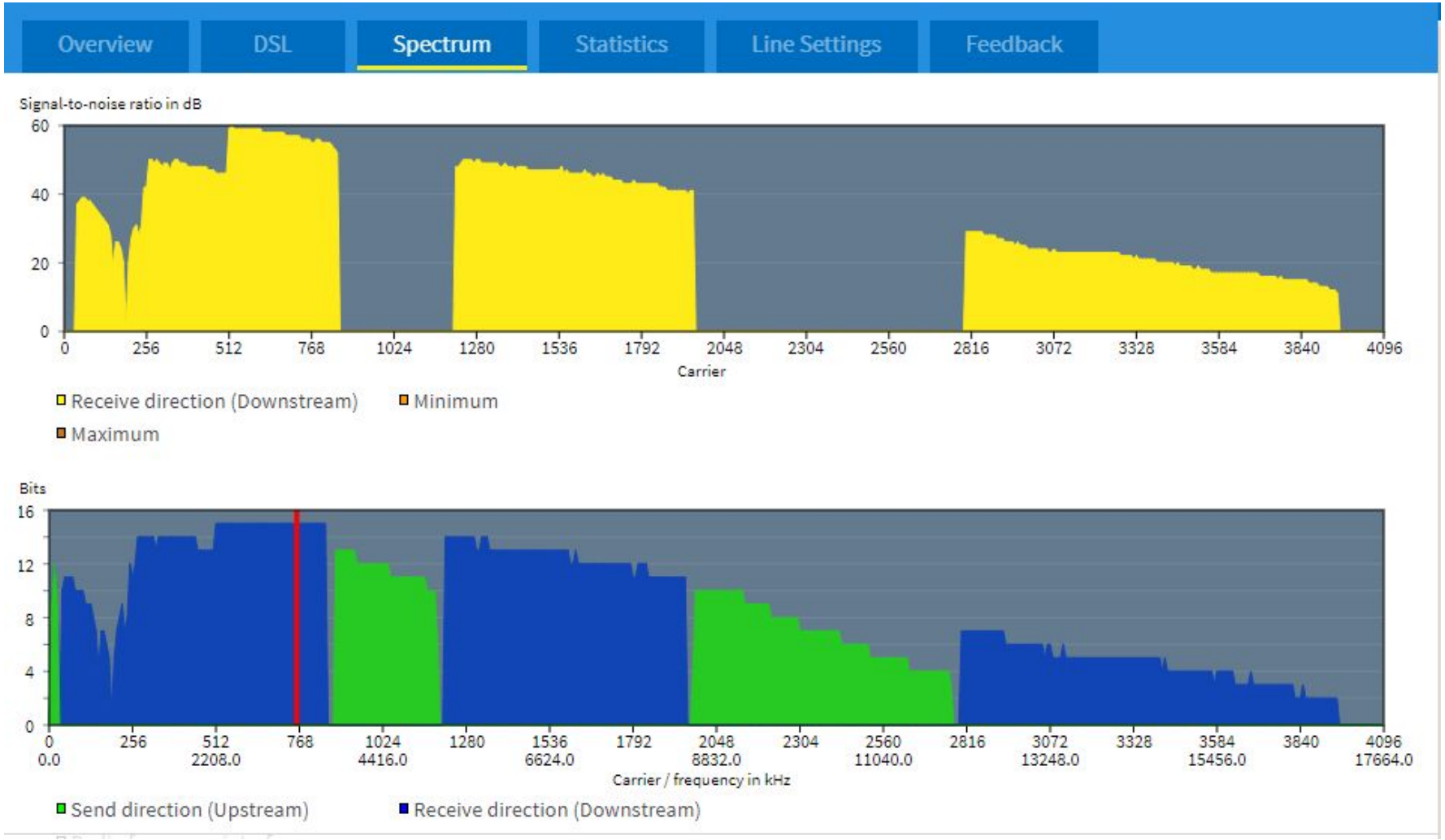
- DSL based on
  - 65536 QAM with FDM
  - With increasing number of overlaid features
  - *G.inp = reduce impact of external noise, error-correction (profile 17a)*
  - *G.vector = reduce impact of crosstalk = 100Mb/s at 500m*
  - *G.fast = 1Gb/s to 100Mb/s (down+up) at 500m*
  - *XG.fast = 10Gb/s at 130m*
- Need a DSL modem at home, maybe a filter for the phone
- Need a DSL Access Multiplexer (DSLAM) at the exchange/node

The magic inside DSL

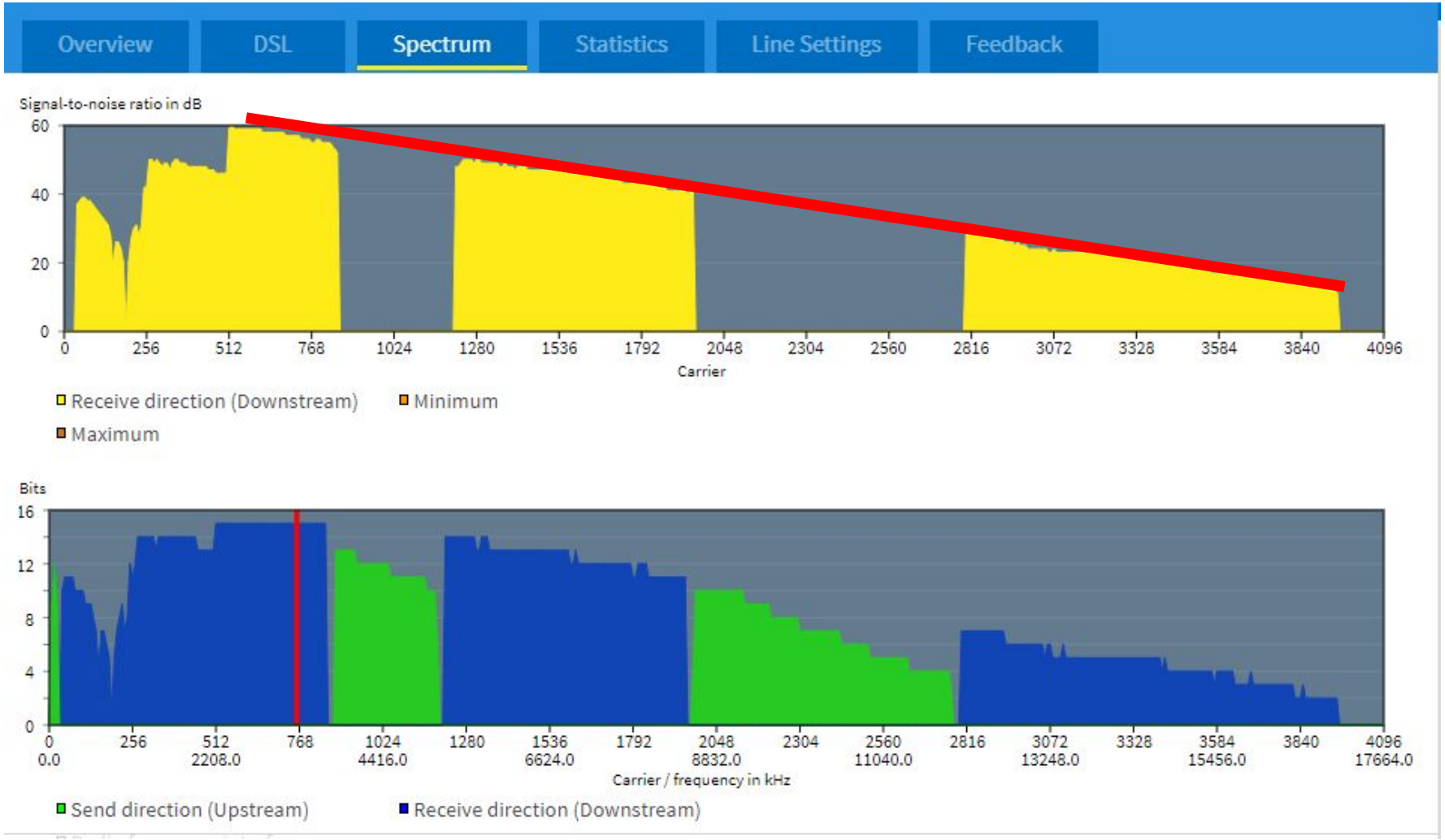


- Multiple (4kHz) frequency carriers – some up, some down
- Each carrier can take 2-16bits/symbol
- Each version of DSL adds more channels = more bandwidth

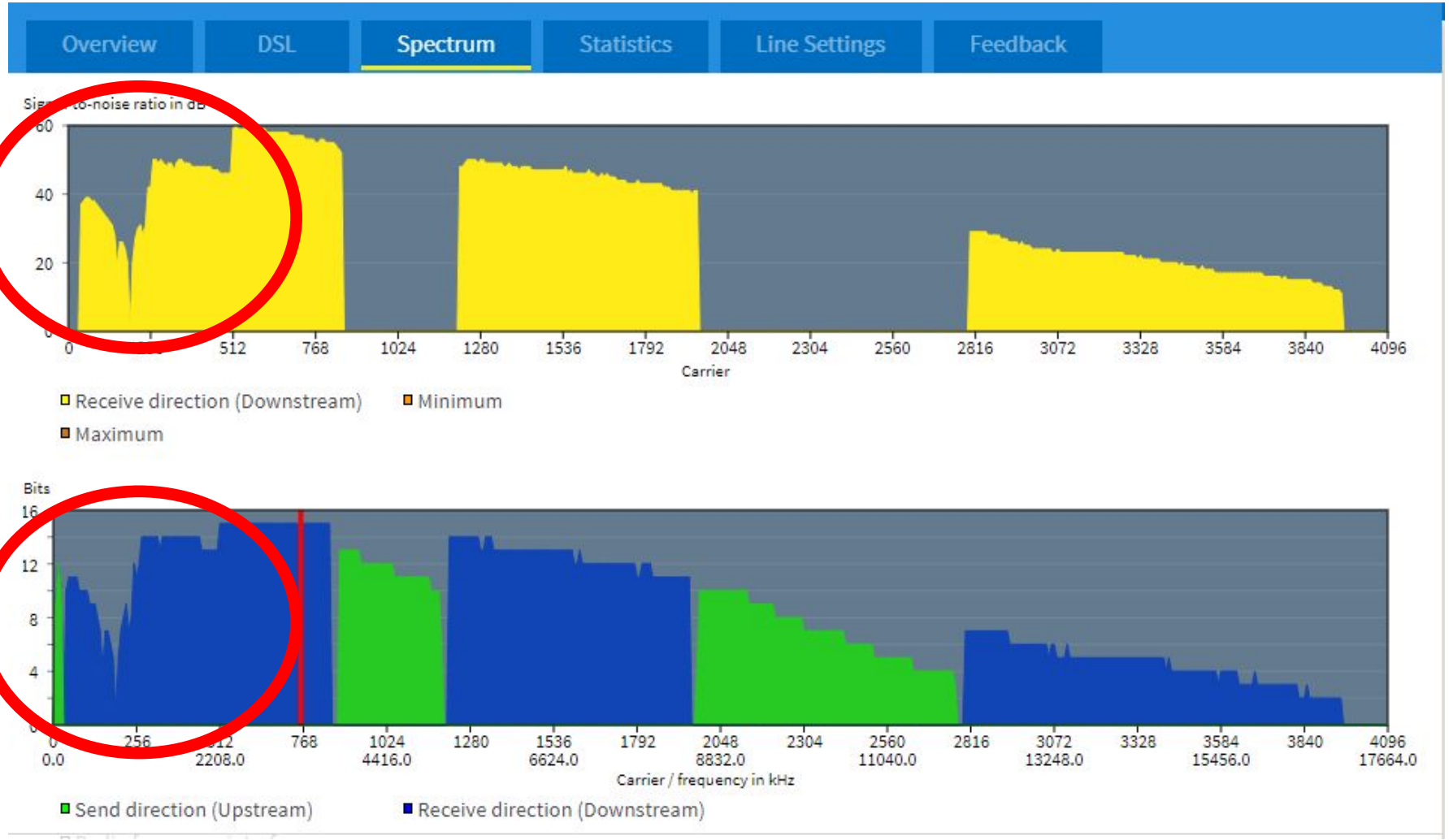
The NBN today – VDSL2



Frequency Attenuation

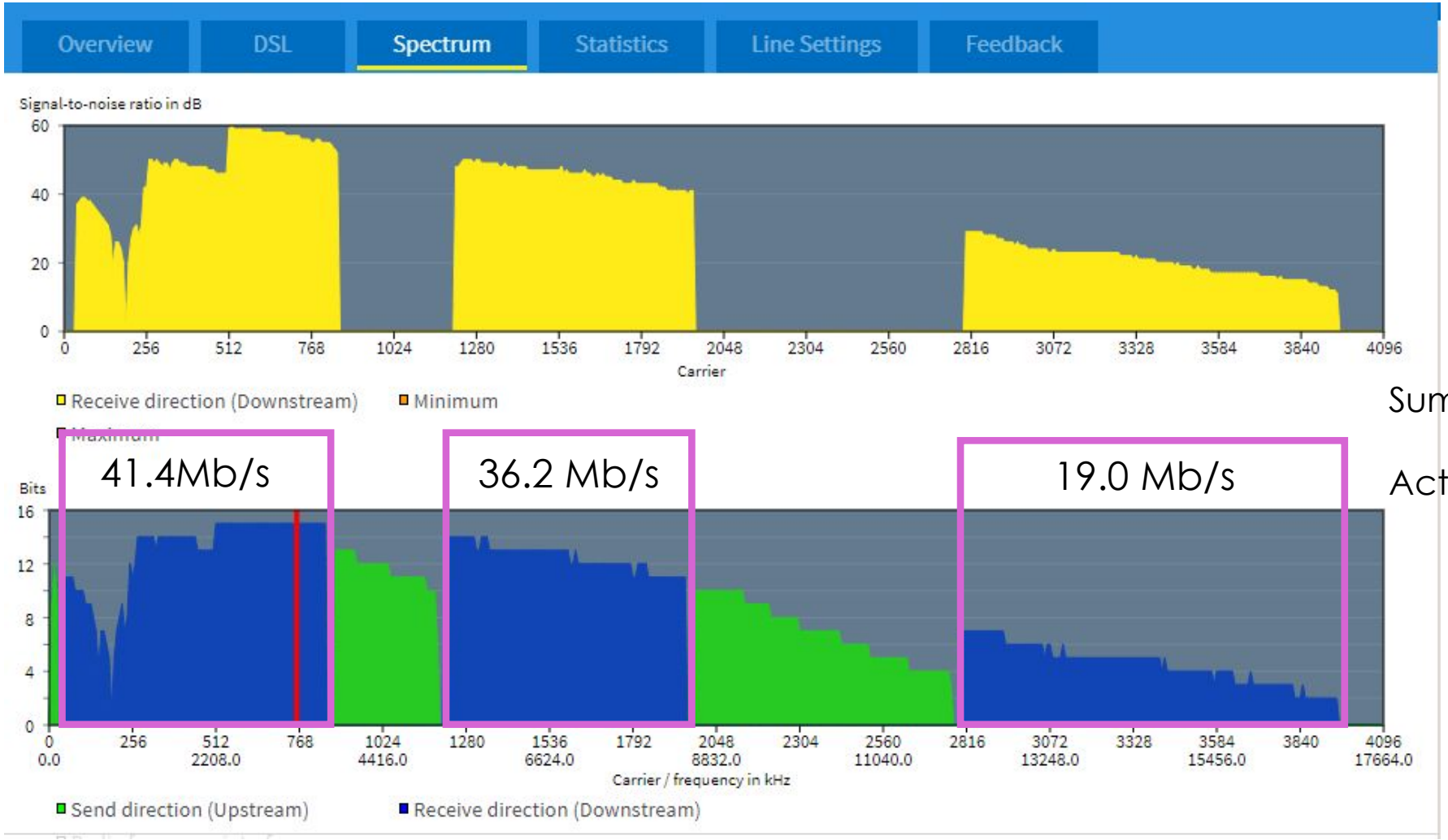


What's going on here?



Downstream Data rate?

- Each channel carries N bits per symbol
- Each channel is ~4.3kHz
- So datarate = #channels * N * 4.3kHz



Sum = 96.6Mb/s

Actual = 94.3Mb/s

Moving on: Some (copper) alternatives

- Power-line carrier:
  - Note earlier performance limitations in wide area.
  - Shared medium; transformers block it, not every circuit in a house is joined up, maybe seen by your neighbour, can be a transmitter, can be an antenna

- Mixed-Technology approaches
  - NBN FTTx
  - Hybrid Fibre Coax [HFC, cable networks]
    - Coax cable, shared medium, …
  - After we've discussed optical fibre…