EFM Copper Objective

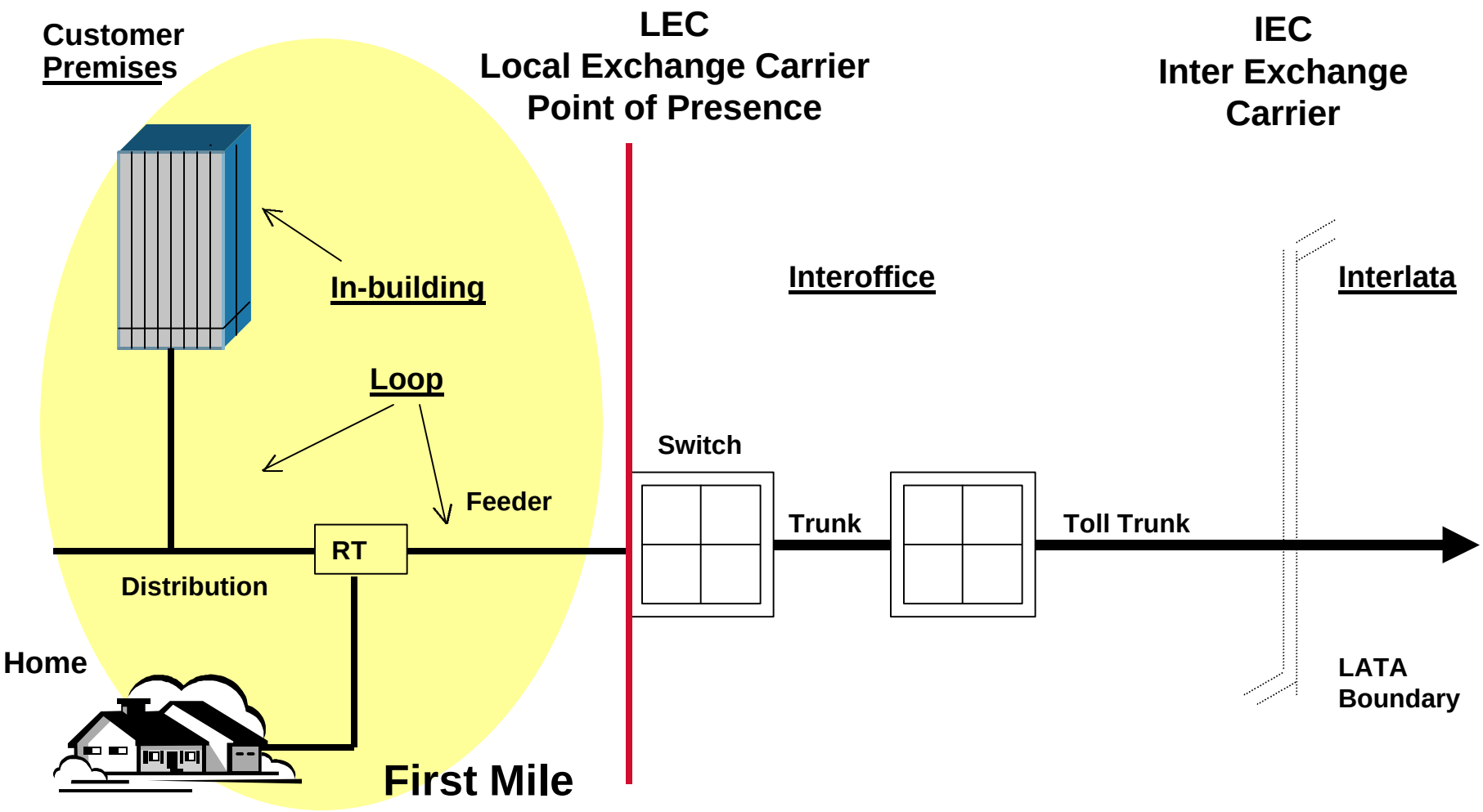
- **PHY for single pair non-loaded voice grade copper**

  Distance >=2500ft and speed >= 10Mbps aggregate

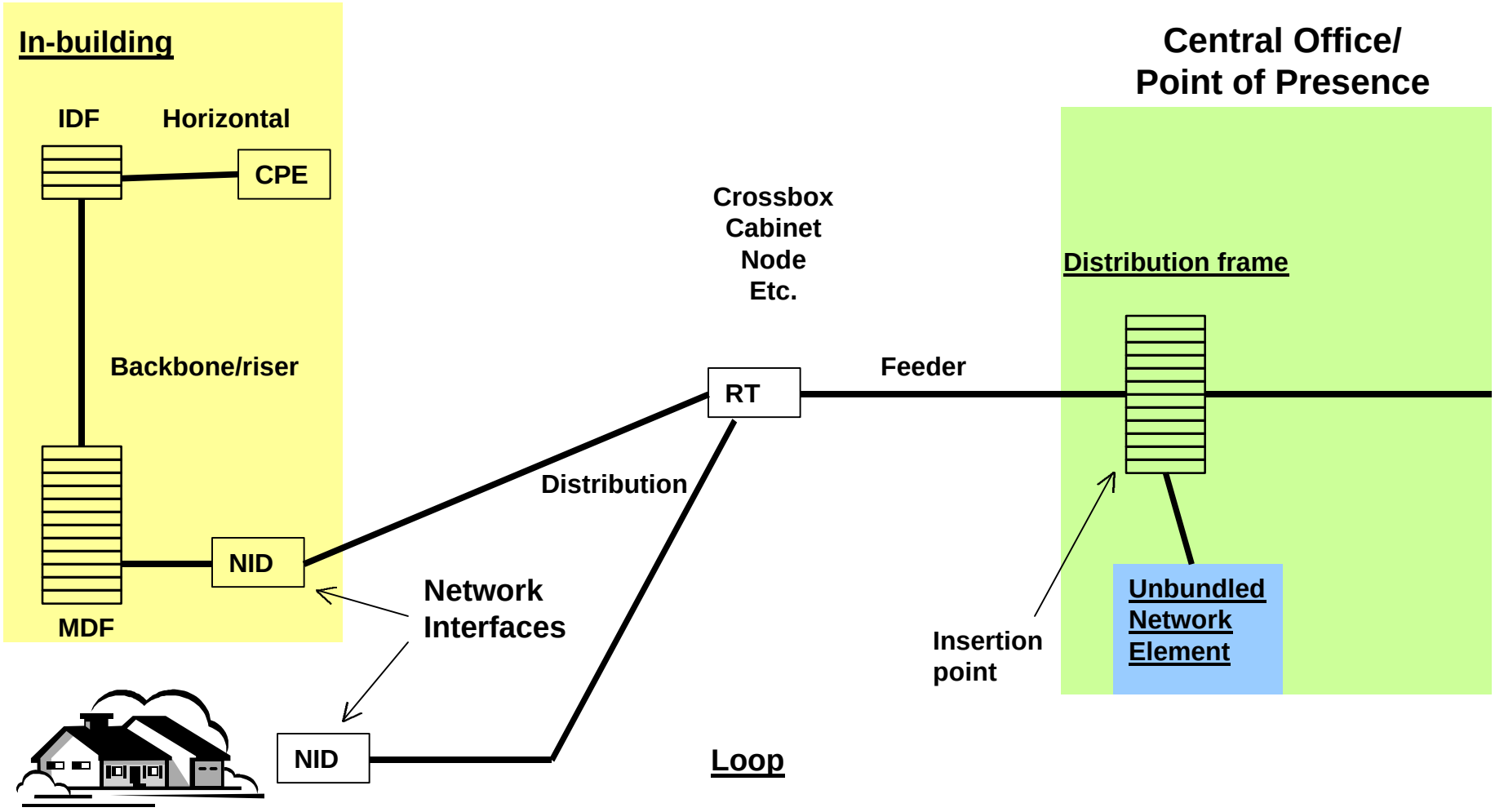
This means:

Single pair, bad wire, long wire

Where is EFM copper?



Some terminology



What is “voice grade” copper

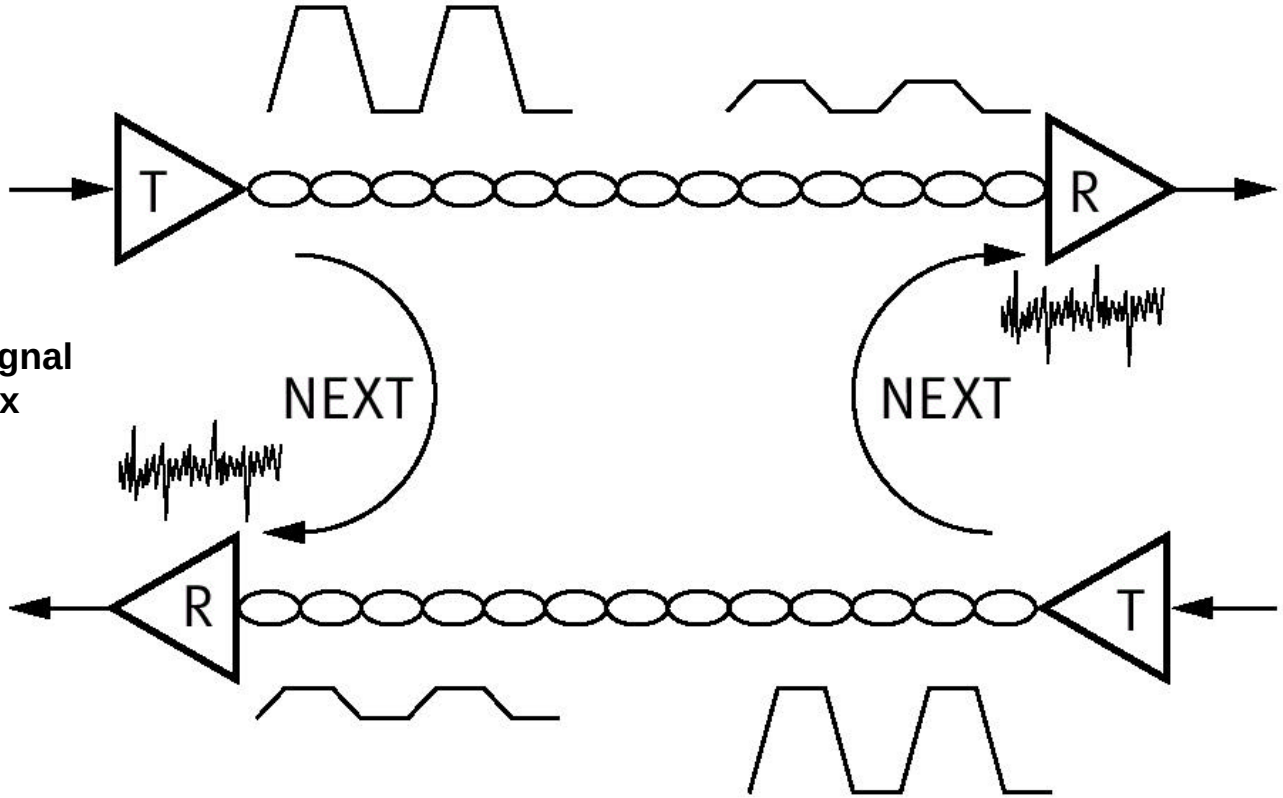
- **Voice grade**
  - Suitable for transmitting voice, “voiceband” = 300Hz – 3.3kHz
- **Non-loaded**
  - Load coil improves attenuation 0-3kHz (kills signals >3kHz!)
- **Local loop**
  - Path between Central Office (DF) and Network Interface
- **In building**
  - Un-structured cabling – does not meet TIA 568 etc.
- **Many types of cable**
  - Cat-3, Cat-1 (aka “voicegrade”) in local loop
  - Type-1, Type-2, 24AWG – in building
  - Typically 1 twist per foot - 6 twist per foot
  - 25 pair – 3600 pair (25-50 pair binder groups in cable)
- **Installed sometime between 1876 and 2001**
- **Anything that conducts!**

Problems for EFM copper

- **Attenuation – increases with frequency**
  - **10 Mbps needs > 1 MHz (higher speeds desirable)**
- **Impedance mis-matches, out of balance and other line impediments (particularly for unstructured)**
  - **Signalling above 12 MHz problematic because of emissions**
- **Bridged taps for in building wiring**
- **Wet/dry pairs - requirement to share the line with existing service**
- **Background noise**
  - **ANSI T1E1.4 defines AWGN –140dBm/Hz**
- **Noise sources in binder**
  - **Services regulated by spectral planning**
  - **Other noise: ringing, on/off hook, in-building noise – bursty and LOUD!**

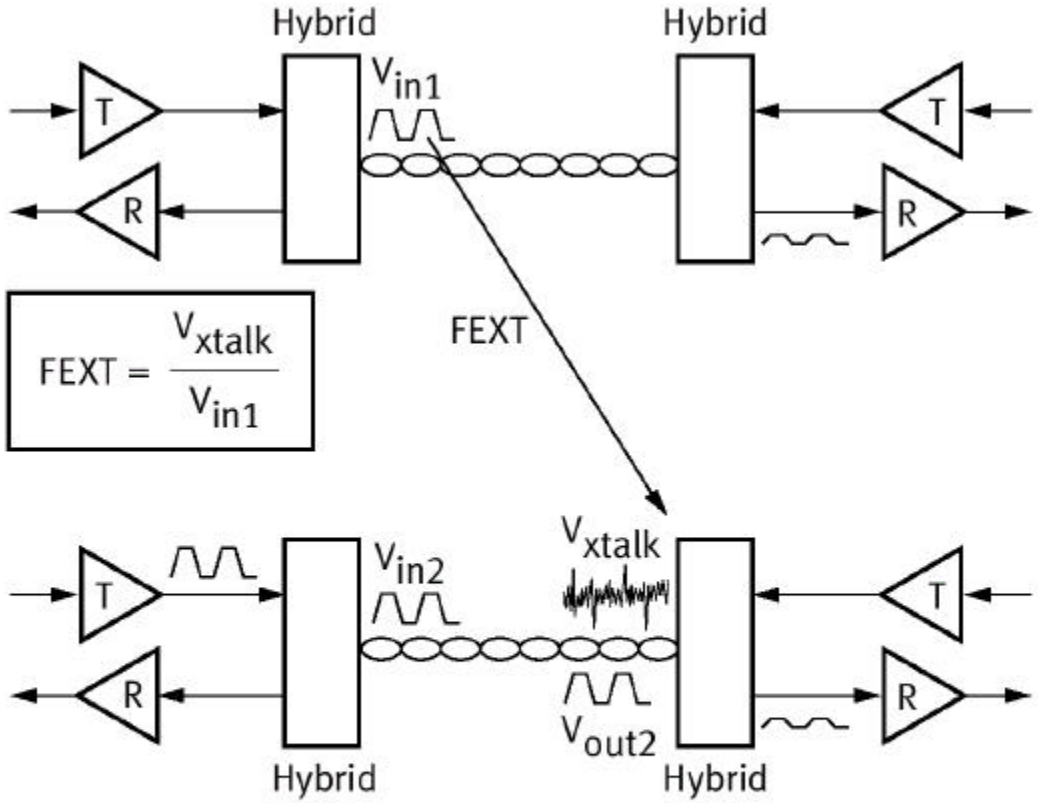
Near-End Crosstalk (NEXT)

Strong Tx signal
Kills weak Rx



- **Attenuation to Crosstalk Ratio (ACR) gives measure of SNR**
- **ACR approaches 0 for many EFM cable types at 3kft, 2MHz**

Far-End Crosstalk (FEXT) and Equal-Level Far-End Crosstalk (ELFEXT)



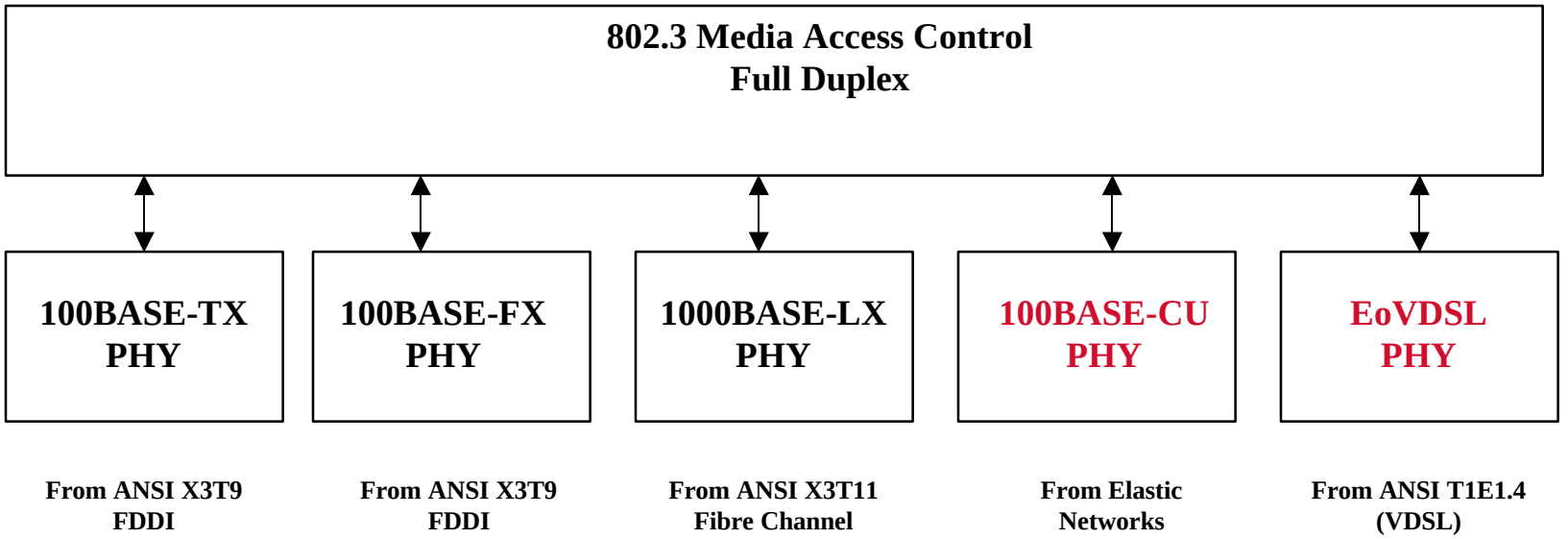
$$FEXT = \frac{V_{xtalk}}{V_{in1}}$$

$$ELFEXT = \frac{V_{xtalk}}{V_{out2}}$$

- **FEXT less limiting than NEXT at EFM frequencies**
- **ELFEXT determines rate available for most EFM**
- **Difficult to measure**
- **Power back off crucial**

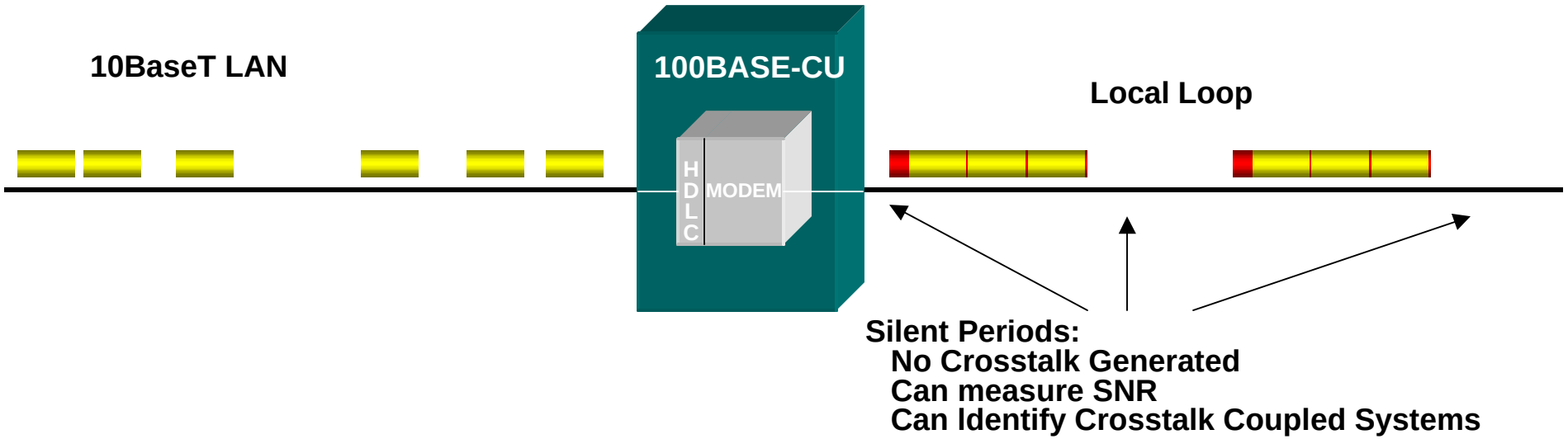
How to solve…

Historical precedent – use existing PHY



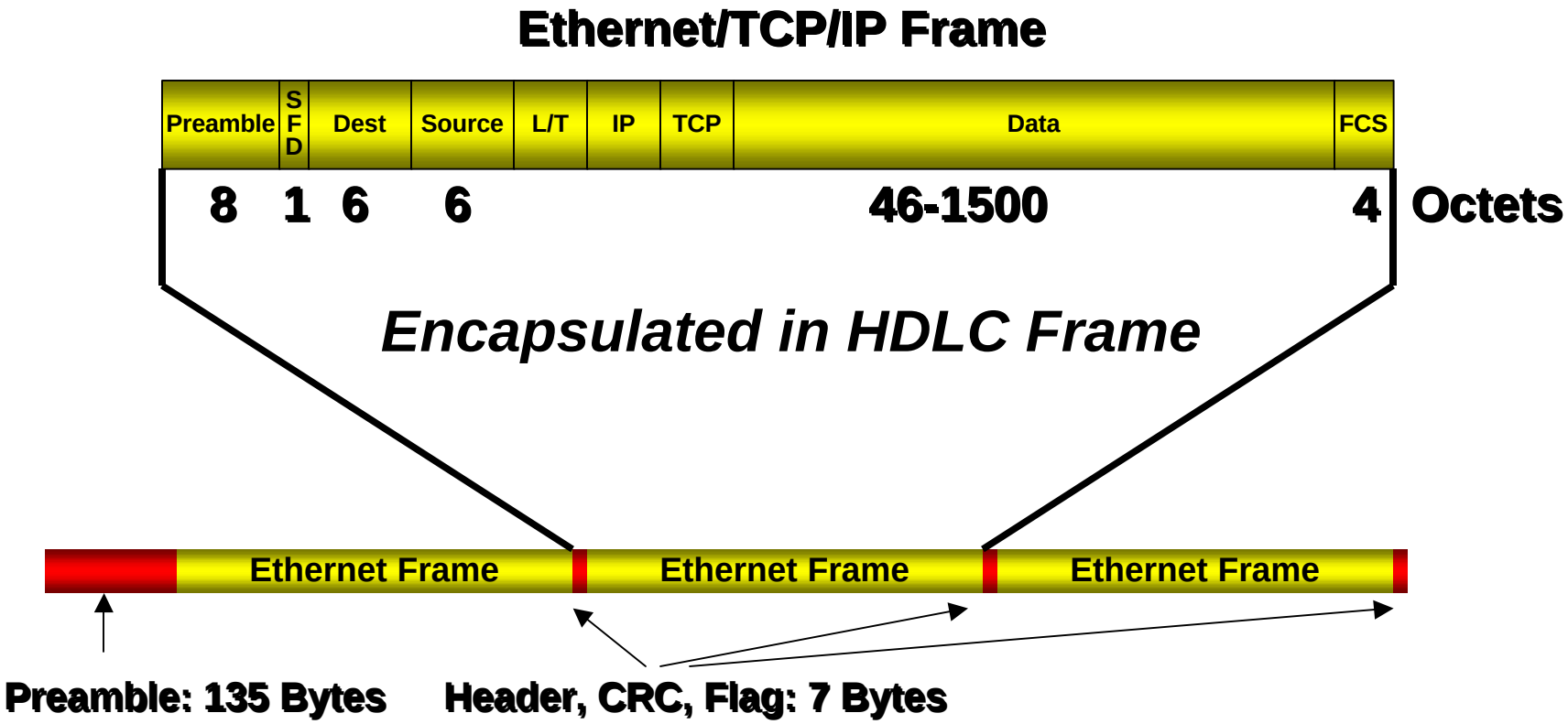
- Builds on known working Physical Layer (historical precedent)
- Ethernet “value add” – simple & low cost

Candidates – 100BASE-CU



- Burst mode Time Domain Duplexed – reduced NEXT
- Adjustable symmetry
- Flexible spectrum – avoids interference
- Decision Feedback Equalizer and Forward Error Correction
- Flexible corner frequency for deployment over wet pairs

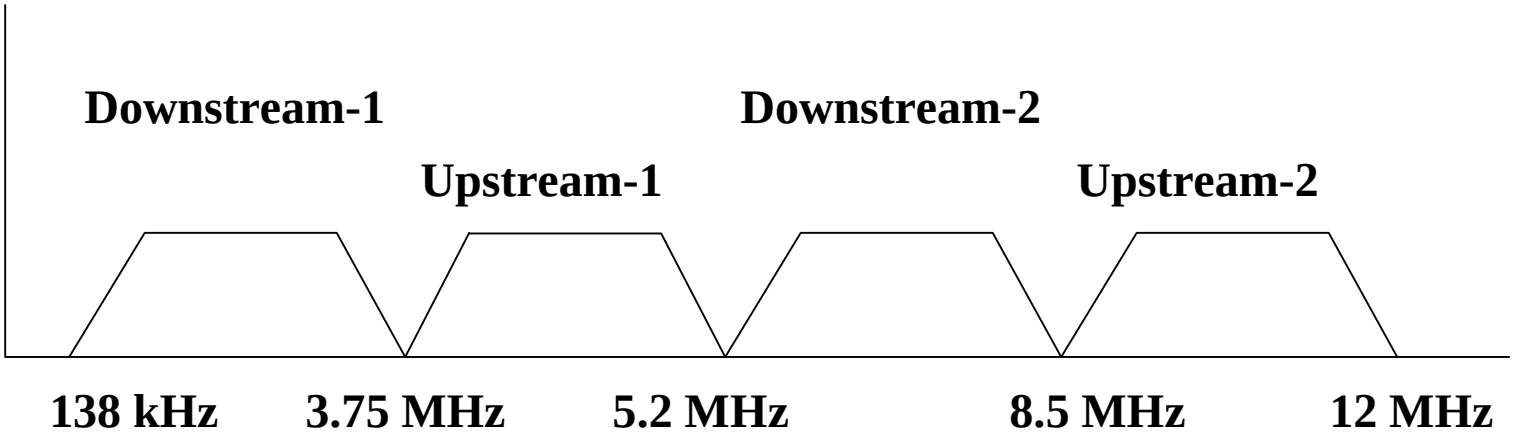
100BASE-CU encapsulation



Ex: 100BASE-CU Burst:

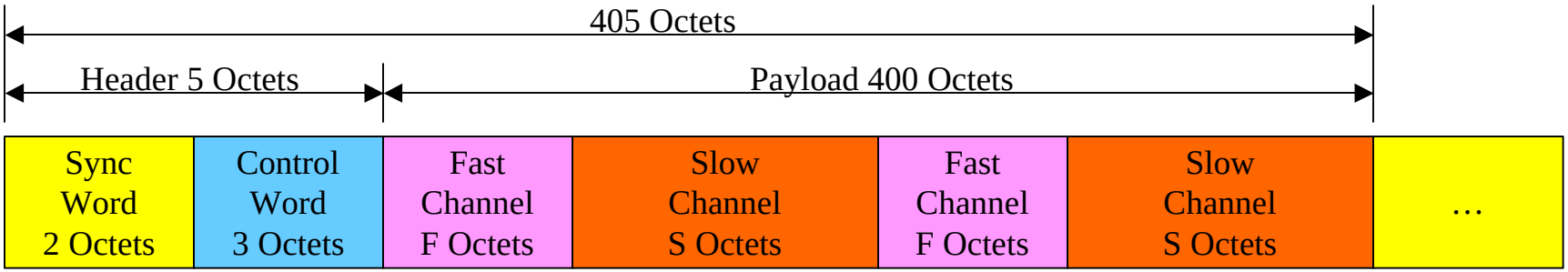
31 1518 Byte Frames per Burst

Candidates – EoVDSL

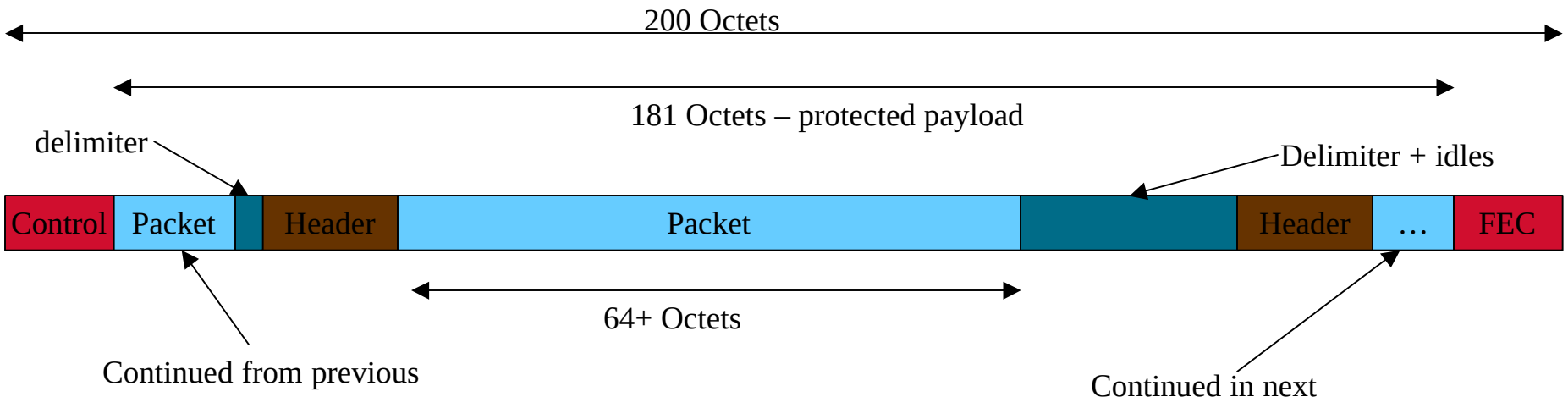


- Frequency division duplexed – no NEXT
- 4 bands (instead of 2) gives more flexibility for performance vs reach
- Decision Feedback Equalizer and Forward Error Correction (interleaved)
- PHY specification from ANSI T1E1.4 (leverage 4 years of work)
- Multiple silicon vendors

EoVDSL Encapsulation



- **Standard VDSL frame has fast and slow parts**
  - **Fast channel is optional**
  - **F=0, S=200 for 802.3 compatible operation**
- **Continuous transmission**
  - **Ethernet packets encapsulated and stuffed into bitstream**



Summary

Ethernet over Point to Point Copper meets the 5 Criteria