Capabilities and Costs of COTS Network Components:

Optical Transport for e-VLBI, LOFAR, SKA

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Outline

- **Opto-Electronic Costs Plummeting:**
  Switch, Transceiver examples
- **Trench Cost 'Tall Pole':** but as low as **$5K/km** in WA
- COFON, Customer Owned Fiber Optic Network, opportunities:
  Buy 'stranded' US intercity 'dark fiber' for < $1000/km per pair!
- **Fiber Cost Low: $60/km** per fiber in AU
- **SFP to XFP:** Small Form Pluggable, *low-cost* Transceivers, going from (gigE-2.5Gb/s) to X=10Gb/s
- **SpaceDM+CoarseWDM, DenseWDM:** tradeoffs
- **e-VLBI, LOFAR, SKA:** hardware/budget strawmen

Opto-Electronic Costs Plummet

- **GigE Switch**:
  Extreme Summit 5i **$ 15,000 in 2001** ➡
  Dell PowerConnect 5212 **$ 1,200 in 2003**
- **GigE LX** (non-CWDM) **Transceiver**:

  Finisar GBIC **$ 750 in 2001** ➡ SFP **$180 in 2002**.

  Fabry-Perot laser, used for ~20 km reach at ~1310 nm, is *least expensive*, but *not CWDM-capable* due to poor wavelength control.

  CWDM (multi-rate 0.1-2.7 Gb/s) **Transceiver**:

  DFB laser Tx for 16 wavelengths spaced 20 nm, 1310 to 1610 nm.

  PIN diode (APD) '03 SFPs ~ **$400, 600, 800 for 50, 70, 100** km reach.

Trench Cost: 'Tall Pole'

- **EU: > $20/m** (or in any populous wide-area)
- **US: > $ 10/m** (in simplest desert environment with government right-of-way, 2002 est.)
- **WA: ~ $ 5/m** (Telstra 2003, maybe $4/m)
  So, expect to spend $5 (15) million for 1000 (3000) km of long trenches for LOFAR (SKA) in Australia.
- ***Elsewhere, > double $$ cost.***

(Stranded Fiber Lure in US)

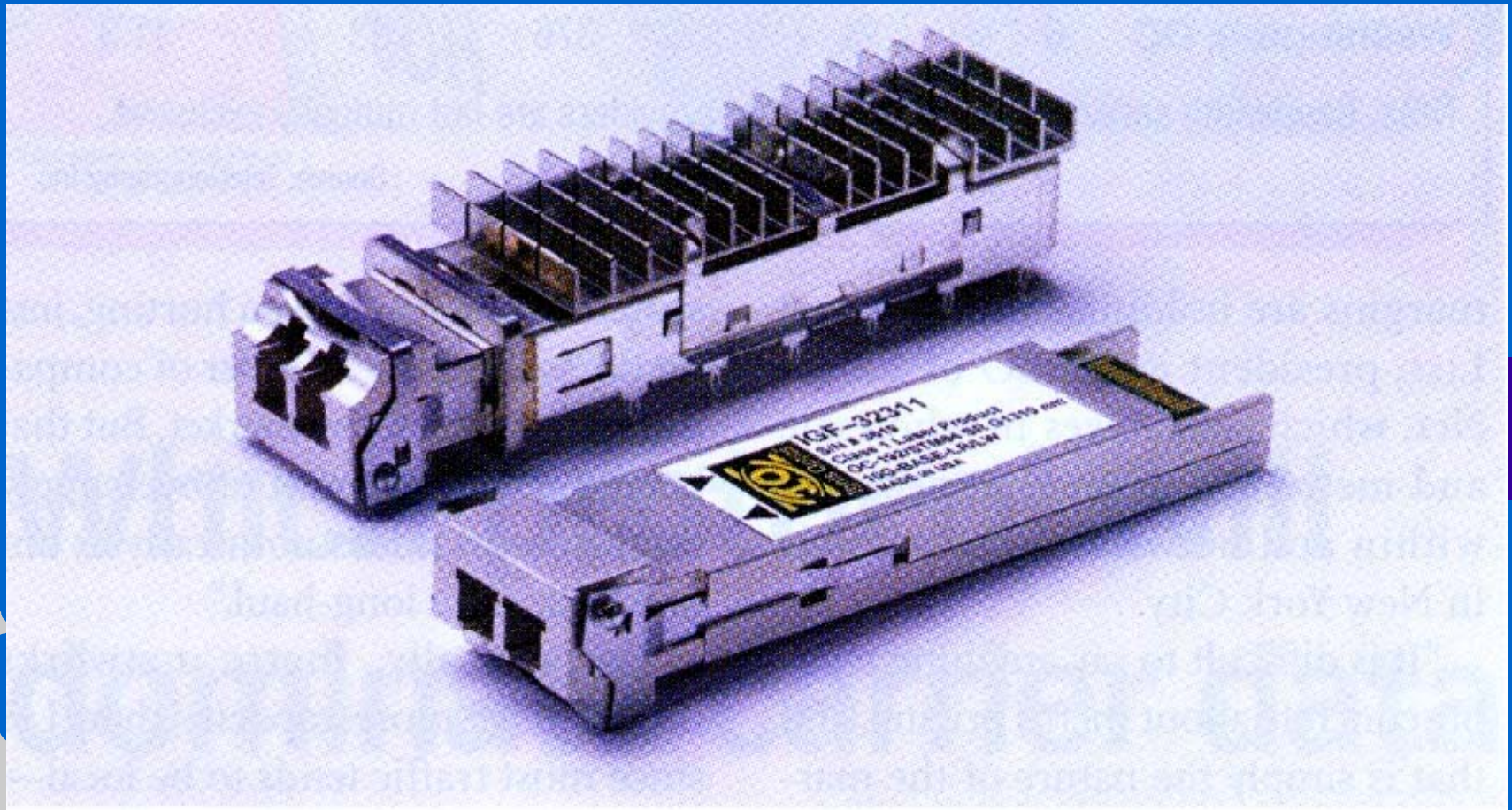
- COFON, Customer Owned Fiber Optic Network, targets of opportunity in US:
- Much 'stranded' intercity dark fiber is in place, due to overbuilds in *Bubble*, bankruptcies in *Bust* ➡
  So, can now **BUY** *stranded fiber-pair for* **< $1000/km!**
- COFON WANs affordable! National Light Rail, e-VLBA? *Can* **SPAN 5000 km USA** *for* **< $5 million** *per fiber-pair!*
- *Can* **LIGHT** *fiber-pair for* **< $1.6 million** *to* **40 (160) Gb/s** *using 16-lambda CWDM!* Generous budget 16x100 Tcvrs: $1000 per Tcvr (repeater) with > 50 km reach.
  2.5 (10) Gb/s per lambda in **'03 SFP ('05 XFP)** package.

Low Cost of Fiber

- ***$60/fiber-km*** (Telstra 2003) Can it go lower? I
  I quoted $70/fkm 'industry-norm' in 2002 1st workshop.
  Note: ($trench>$5K/km) = $fiber for >80 fibers/trench.
- $300 incremental cost of CWDM (DFB laser+Mux+Demux)
  ~ equals cost of 5 fiber-km. ➡
  So, pure SDM (more fibers, no WDM) costs less than CWDM for < 5 km reach (in a new trench).
  Applies, for example, to central 50% of LOFAR stations.
- Must use *suppressed-H2O-absorption-peak type of fiber for 16-lambda* CWDM capability. Otherwise, at most 12.

SFP Transceivers

- **SFP: Small Form Pluggable** standard package small 2.24”x 0.54”x 0.33”, duplex LC connector, hot-pluggable, low-power 700 mw typical.
- **Fixed & multi-rate versions:** 0.1-2.7 (3.2=XAUI) Gb/s
  SX (1 km typ, MM, 850 nm **VCSEL**, $70),
  LX (20 km typical reach, SM, ~1310 nm **FP laser**, $180),
  ZX-CWDM (40, 80, 120 km, SM, $400, 600, 800)
  InP for 1310,1330, … 1590,1610 nm **DFB lasers**,
  DFB, DFB, DFB Tx (graded output power), and
  PIN, PIN, A(valanche) PD Rx with graded sensitivity.



The XFP transceiver shows every sign of soon eclipsing its 10-Gbit/sec siblings for many applications. To hasten this event, developers have demonstrated modules capable of supporting 40-km transmission distances. *Photo courtesy of Ignis Optics*

XFP

- XFP: X=10Gb/s small Form Pluggable standard
- Form is close to SFP, also hot-pluggable.
- Introduces XFI, serial 10Gb/s electrical interface: Can use <$100 bridge-chip to XAUI or XGMII. ***Xilinx*** V2ProX to support XFI directly in 2H03.
- XFP 3Q03 intro: 10+km reach, 1310 nm DFB ***Finisar, Intel, Luminent, etc.*** ~$500 by end'03!
- XFP 80km CWDM version <$1000 by 3Q05? ***Finisar*** demo'd 40km DWDM! When low-cost?

SpaceDM

- SDM: Space Division Multiplexing is use of || fibers. One optical channel per fiber without WDM.
- Use pure SDM (without WDM) if you have access to #fibers > #channels needed.
- For <5km reach, it's cheaper to install pure SDM (cable with #fibers >= #channels needed).
- For >5 km reach, SDM-CWDM combo with 8-16 wavelengths/fiber is cheaper. So, install cable with #fibers >= #channels/(wavelengths/fiber).

CoarseWDM

- CWDM: ***Coarse*** Wavelength Division Multiplexing
- ***CWDM order-of-magnitude lower-cost than DWDM.***
- CWDM std: 16 lambdas, 20 nm spacing, 1310-1610 nm
- ***Only DFB lasers are currently CWDM-capable: lambda accurate to +/- 5 nm (0-70C), 0.1nm/C typ***
- WDM needs Mux after Tx, Demux before Rx: ***TSUNAMI*** 16channel Mx or Dx, $2400(1200) in '03('04), ***$75/ch.***
- Q1: Denser cheap CWDM, 10 or 5 nm spacing? When?
  Q2: Mux/Demux cost reduction to ~ $30/channel? When?
  Q3: (C)WDM VCSEL cheaper than DFB laser? When?

DenseWDM

- Dense DWDM: Wavelength Division Multiplexing
- DWDM transceiver (traditional telecom):
  Complex, Expensive (~10x), Power-, and Space-hungry!
- But DWDM supports 0.8nm (100GHz) standard channel spacing, versus 20nm for CWDM. Ultra-DWDM, with < 0.1 nm (12.5GHz) spacing, has been demonstrated.
- Mux/Dmux for DWDM costs ~ same as for CWDM.
  DWDM and CWDM can be mixed in a fiber-scarce path.
- When cheap DWDM? ***Finisar*** has demo'd DWDM-XFP!
  I guess: (Ultra)-DWDM in time for SKA, not LOFAR.

Control e-VLBI Cost

- Use RNs for transoceanic/wide-area links, for 99% of way!
  (RN = research network, donated links: I2, IEEAF, etc.)
  e-VLBI = scavenger ➡ low port-fees at RNPOPs.
- Install / Buy / Lease & Light fiber, for 1% rest of way
  (Antenna-to-1st-RNPOP link, Last-RNPOP-to-correlator link).
  Local Lambda-Service costs too high: >10x fiber-lease!
  Owning costs < leasing fiber for high-duty long-term use.
  Light local fiber: $1200 GigE switch + $500 per lambda.
- RNPOP Terminal Equipment, TE, update costs falling fast:
  '02 ***Cisco*** 2.5 Gb/s line-card $50k ➡ '03 ***Extreme*** 6x10Gb/s card $48k

LOFAR Transport

- Trench, 3x300 = 900 km, $5(4-6) K/km in WA: $4.5M
- Fiber, 75000 fkm if 12 fibers/station, $6/fkm: 4.6M
- Light 1st km, 33 x 96 = 3168 antennas x $180 Tcvr: .6M
  Light 1-6 km, same (SDM, one fiber per antenna): .6M
  Light 6-36 km, 3168 x $450 CWDM Tcvr: 1.4M
  Light 36-300 km 11x3=33 stations, use 80+km max-reach CWDM. Outer 6x3 stations need 11x3 repeaters. Budget 3168 ant x 2(repeaters) x $600 Transceiver: 3.8M
- 2.5(10)Gb/s per antenna SFP(XFP) '03('06) Total: $15.5M

SKA: 6-year projection ~2009

- SKA: 1000 stations x 25 antennas x 40 sqm = 10^6 sqm
- 8 GHz bandwidth x 2 polarizations = 32 GS/s per antenna, (after FIR/FFT, RFI exc) 2 bits/S ➡ 64 Gb/s per antenna.
- UDWDM: 160x0.2=32 nm span -- 100 x CWDM density!
- 0.2nm (25GHz) UDWDM: mature = $250 per 10Gb/s channel, *160 channels = 1.6 Tb/s, $40K per station*: $40M
- Average 6 x $500 C-band EDFA, $3K per station: 3M
- Fiber, 1000 fibers incl. DCF, ave. 500 km, $60/km: 30M
- Trench, 3x1000 km, $5K/km: 15M
- Total 1.6 Pb/s data transport infrastructure: $88M