Capabilities and Costs of COTS Network Components:

Optical Transport for e-VLBI, LOFAR, SKA

Hans Hinteregger
MIT Haystack Observatory

2nd e-VLBI Workshop
15-16 May 2003, Dwingeloo, Netherlands
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:**

  *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.
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 Tcwr (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 quoted $70/fkm ‘industry-norm’ in 2002 1st workshop. 
  
  Note: ($trench>$5K/km) = $fber 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).
Coarse WDM

- 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?
Dense WDM

- 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: ‘02Cisco 2.5 Gb/s line-card $50k → ‘03Extreme 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 $\rightarrow$ 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: $88M$