Issues in λ Conversion in WDM Networks

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Agenda

- WDM Basics
- Basic Analysis of wavelength conversion
- Simulation Design
- Simulation Results
- Conclusion

The Problem!

- We need more bandwidth
  - Data traffic doubles every 4 (up to 12) months
  - More users connect to the Internet …
  - And stay connected for longer times …
  - And have better connection speeds (56kbps modem →DSL & Cable modem)
  - New applications (e.g. NAPSTER, GNUTELLA, KAZAA) require more bandwidth
  - The future brings numerous other bandwidth intensive applications
  - Data traffic >>> Voice traffic

Solution

- Optical Networking
  - Enormous bandwidth made available
    - WDM makes ~160 channels/wavelengths possible in a fiber
    - Each wavelength carries about 10 Gbps
    - Hence Tbps speeds become a reality
  - Low bit error rates
    - 10^{-9} as compared to 10^{-5} for copper wires
  - High speed transmission
  - Transparent to bit rates and modulation schemes
  - Reconfigurability
  - Made possible due to developments in hardware

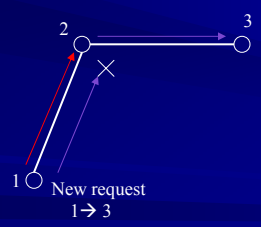
Hardware

- Fiber
  - reduced dispersion, non linearity and attenuation loss
- Lasers
  - reduced noise (both phase and intensity)
  - 2.5 Gbps, 10 Gbps , faster tunability
  - made from semiconductor or fiber
- Amplifiers (as opposed to regenerators)
  - make possible long distance transmissions
  - erbium-doped fiber amplifiers
  - transparent to bit rate and signal format
  - have large gain bandwidths (useful in WDM systems)
  - expensive (~$50K)

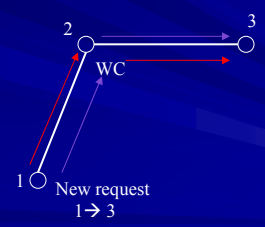
WDM Basics

- Utilizes the enormous bandwidth of the optical fiber
- Provides channels on a single mode fiber which can accommodate dissimilar data formats
- You can use the multi-THz capacity to provide 1-10Gbps channels compatible with current electronics speed
- all-optical WCs being developed
- greatly reduce blocking probabilities

Principle



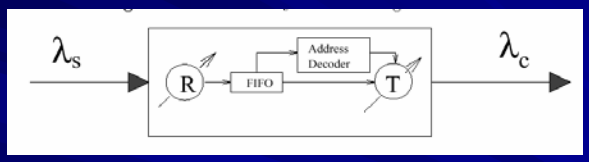
No Wavelength converters



With Wavelength converters

Wavelength Conversion Techniques

- Opto-Electronic Conversion



- Wave-mixing

Analytical Model

- Based on the Assumption that

Wavelength is used on successive links independent of its use on previous links

- Variables in the model
- L – interference length is expected number of links shared by two light-paths which share at least one link
- H – average hop distance

- G - gain in wavelength conversion defined as ratio of the link utilization with wavelength conversion to that without wavelength conversion for the same blocking probability
- H/L – effective path length
- W – number of wavelengths on a fiber
- ρ - probability that wavelength is used on any given link
- ρW = E[wavelengths used on any link]

- Blocking probability (P_b) : The probability that no wavelengths are available on all links in the H-link path.

- The probability with wavelength conversion:

$$P_{b,FC} = 1 - (1 - \rho^w)^H$$

- The probability without wavelength conversion:

$$P_{b,NC} = (1 - (1 - \rho)^H)^W$$

- Conversion gain :

$$\rho_{fc}/\rho_{nc} \sim H^{1-1/W}$$

Thus, for moderately large value of W the achievable link utilization is **higher** by approximately a factor of **H** when wavelength converters are used.

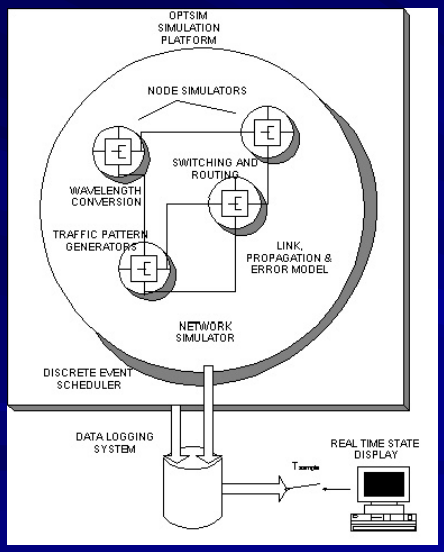
- With the assumption of wavelength independence dropped, we have conversion gain:

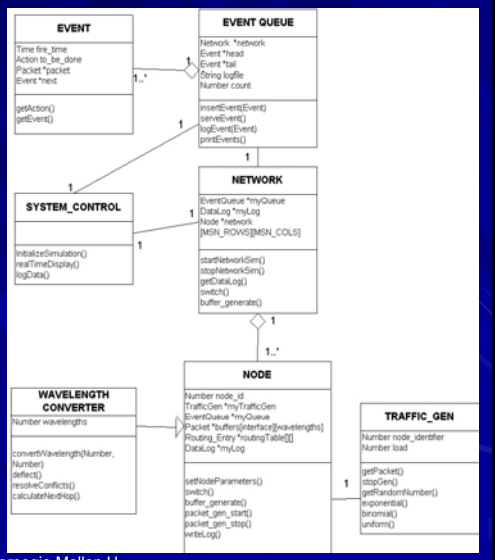
$$\rho_{fc}/\rho_{nc} \sim (H^{1-1/W}) \text{ mixing probability}$$

OptSim Simulator

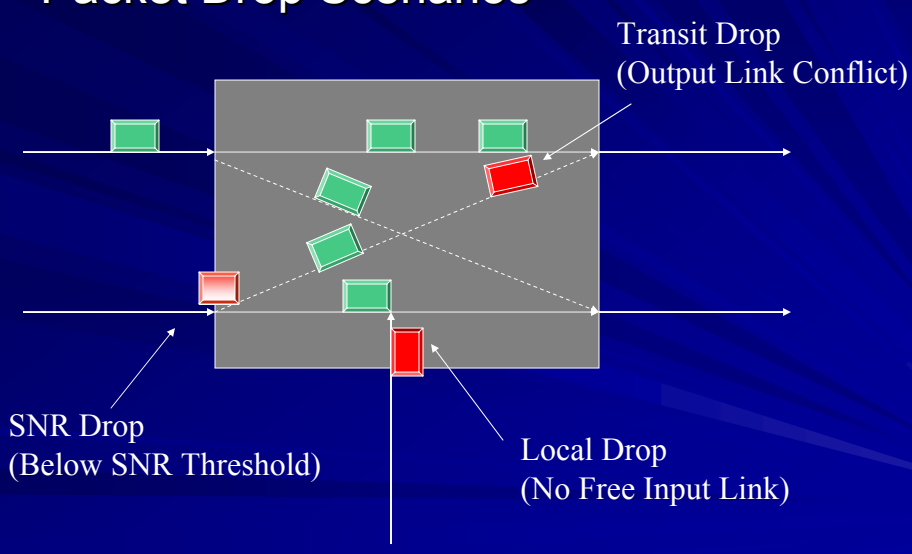
- Language – C++ on Solaris
- DES Architecture, >3000 lines
- Highly modular and reusable
- Node Models Included
  - Full wavelength conversion
  - Full wavelength conversion with wavelength deflection
  - no wavelength conversion
- Traffic and Packet generation
  - Packets generation: E[packet] = load*W <Binomial>
  - Destination selection: Dest ~ Uniform(1,N), N = no of dest.
- Network Architecture Models
  - Mesh-torus – 4x4 , 5x5 support for NxN if your processor can handle it (above 100x100 you need to go to PSC)
  - Irregular: NSFNET Backbone

Simulation Architecture





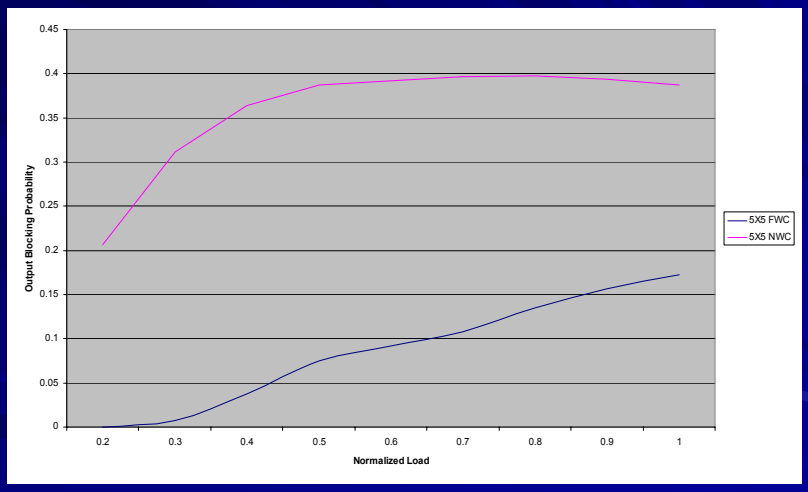
Packet Drop Scenarios



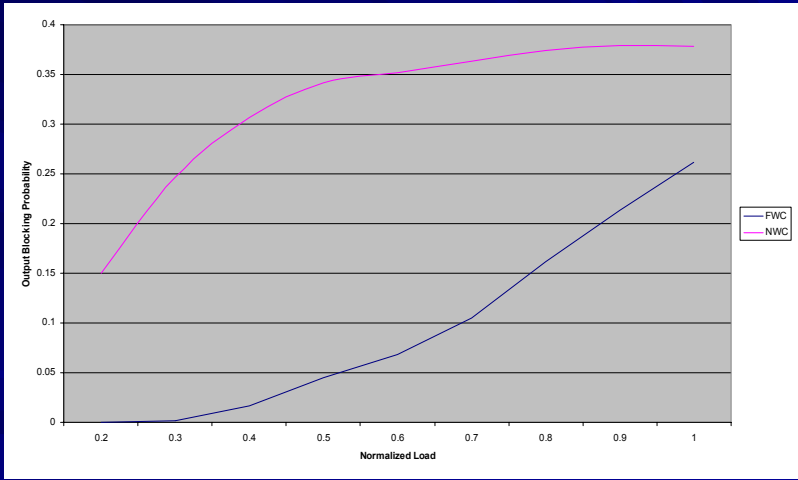
System Parameters

- Packet size : 53 bytes
- Line Speed : 10 Gbps (OC - 192)
- Switching time : 42 ns
- MSN Size : NxN
- Link Length : 5000 m
- Speed of light in fiber : 0.2 m/ns
- Link attenuation : 0.2 dB/km
- SNR drop per hop : 3 dB

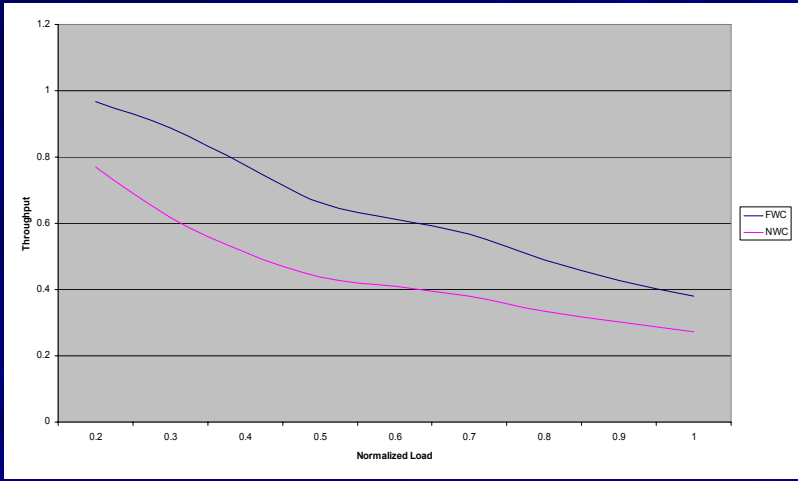
Comparison of Blocking Probabilities in a 5X5 MSN with and without λ-Conversion



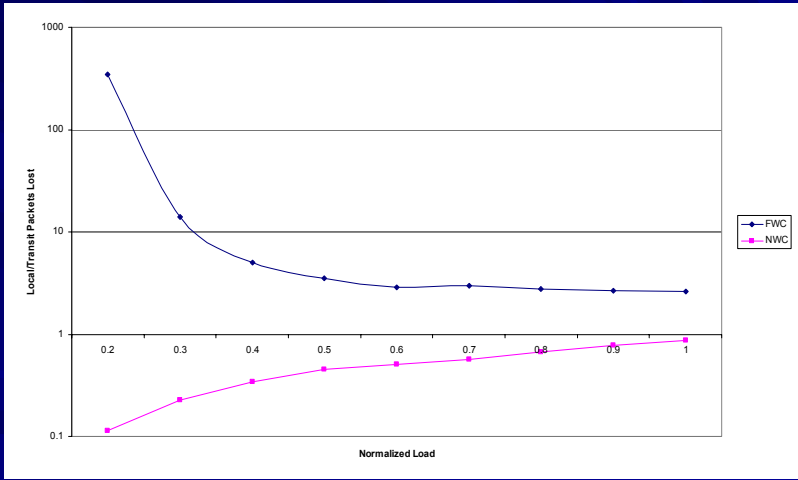
Comparison of Blocking Probabilities in a 4X4 MSN with and without λ-Conversion



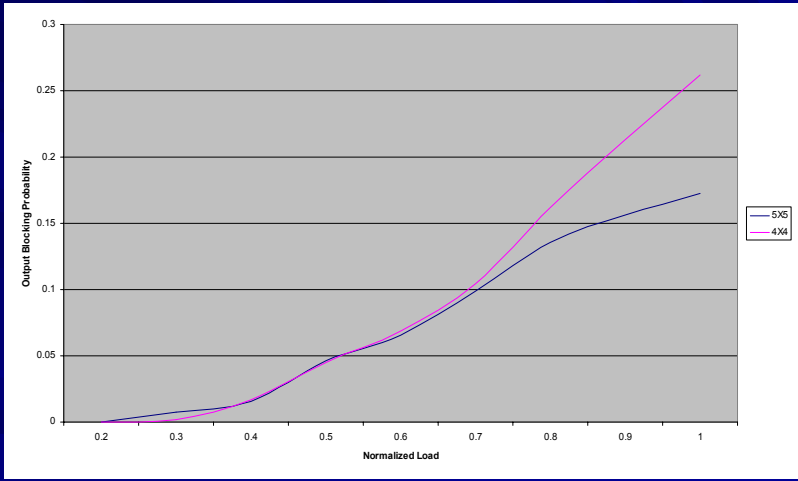
Improvement in Throughput due to λ-Conversion in 5x5 MSN



Local/Transit Packets Lost v/s Normalized Load in a 5X5 MSN



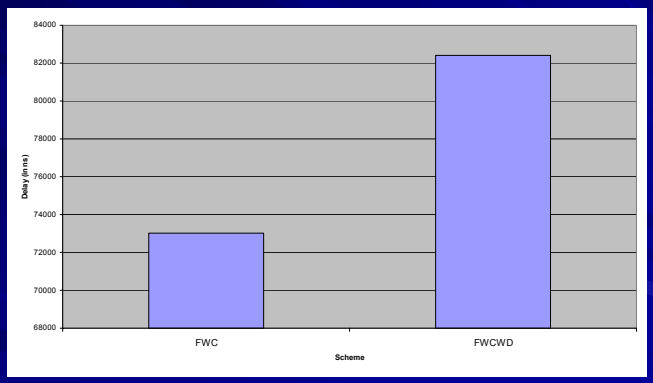
Improvement in Blocking Probability as a function of Network Size



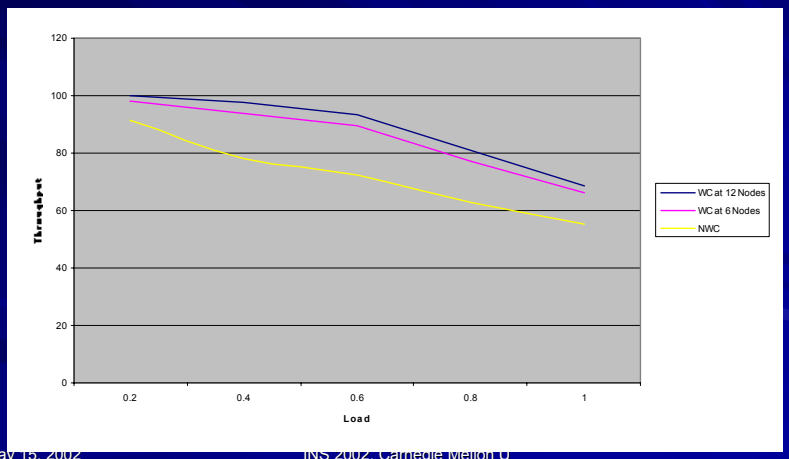
Effect of 3R Regeneration

- Wavelength deflection uses deflection to resolve conflicts
- 3R regeneration to boost SNR of packets was simulated
- Benefits seen
  - Minimizes packet drops due to low SNR
- Problems
  - Overall link utilization comes down since E[packet life] increases
  - Performance is not greatly improved
  - Average packet latency increases

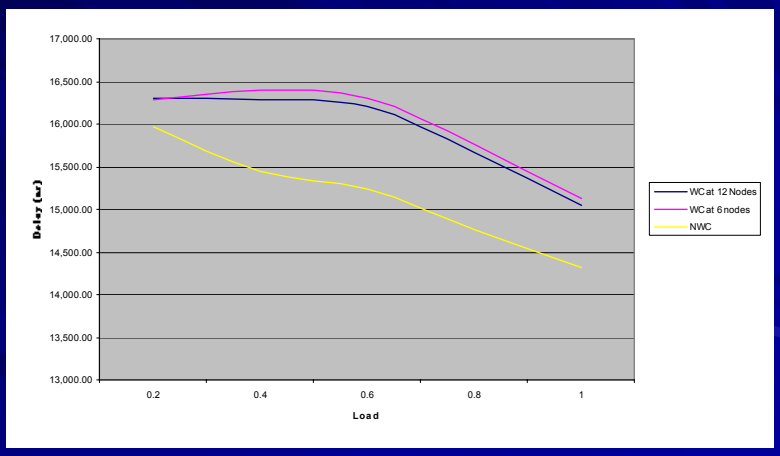
λ-Deflection Eliminates Output Blocking at the Cost of Increased Delay (No free dinner…except tonite!)



Throughput Comparison for Different Wavelength Densities in the NSF Backbone



Delay Comparison for different converter densities in the NSF Backbone



Conclusions

- Low Connectivity → High Load Correlation → Effectiveness of Wavelength Conversion is Less
- Very High Connectivity → Short Hop-Lengths →Effectiveness of Wavelength Conversion is Less
- In such networks, wavelength converters don't help at hot spots as much as additional wavelengths. Thus *Sparse Wavelength Conversion* is almost as effective.
- Mesh – torus networks do not fall into the above categories and show remarkable performance improvement with extensive wavelength conversion