Requirements and Design of a Dynamic Grid Networking Layer

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Outline

- Introduction
- Fine Granularity Bandwidth Management
- Bandwidth Granularity and Network Capacity
- Coarse Granularity Bandwidth Management
- Conclusions

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Background

- Grid computing has fundamental “on demand” aspects
- On demand processing and storage resources have always been an integral part of grid computing
- On demand networking resources can enable a much wider range of grid computing services
  - Enables services that use large and/or sporadic bandwidth usage between sites
  - Enables adaptive sharing and more efficient use of computing resources
- The technology is emerging to make Bandwidth on Demand (BoD) feasible:
  - GMPLS (IETF), ASTN/ASON (ITU-T), and UNI/NNI (OIF)

The Key questions are:

- **When is BoD used?**
- **How can BoD be provided in a cost efficient manner?**

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Bandwidth Networking Model

- We envision the grid networking layer to be a hybrid optical and packet infrastructure (HOPI)
  - The networking layer will provide various levels of bandwidth granularity for bandwidth management
  - Granularity ranges from very fine best-effort IP packet networking to very coarse granularity of a single or group of wavelengths.
- This is the networking model that is emerging from the R&E community
- We consider two levels of bandwidth granularity
  - Fine Granularity:
    - connections established with IP/MPLS paths or SONET/SDH channels using virtual concatenation (1 – 150 Mbps channels).
  - Coarse Granularity:
    - Connections established with full wavelengths (1 –10 Gbps channels)

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Fine Granularity Bandwidth Management

Goals of the Fine Granularity BoD Analysis

- Identify the key parameters that affect decisions on using fine granularity BoD.
- Identify the key parameters that affect the design and implementation of BoD capabilities.
- In short, identify the **fundamental forces** that will drive grid networking BoD deployment decisions and network design.

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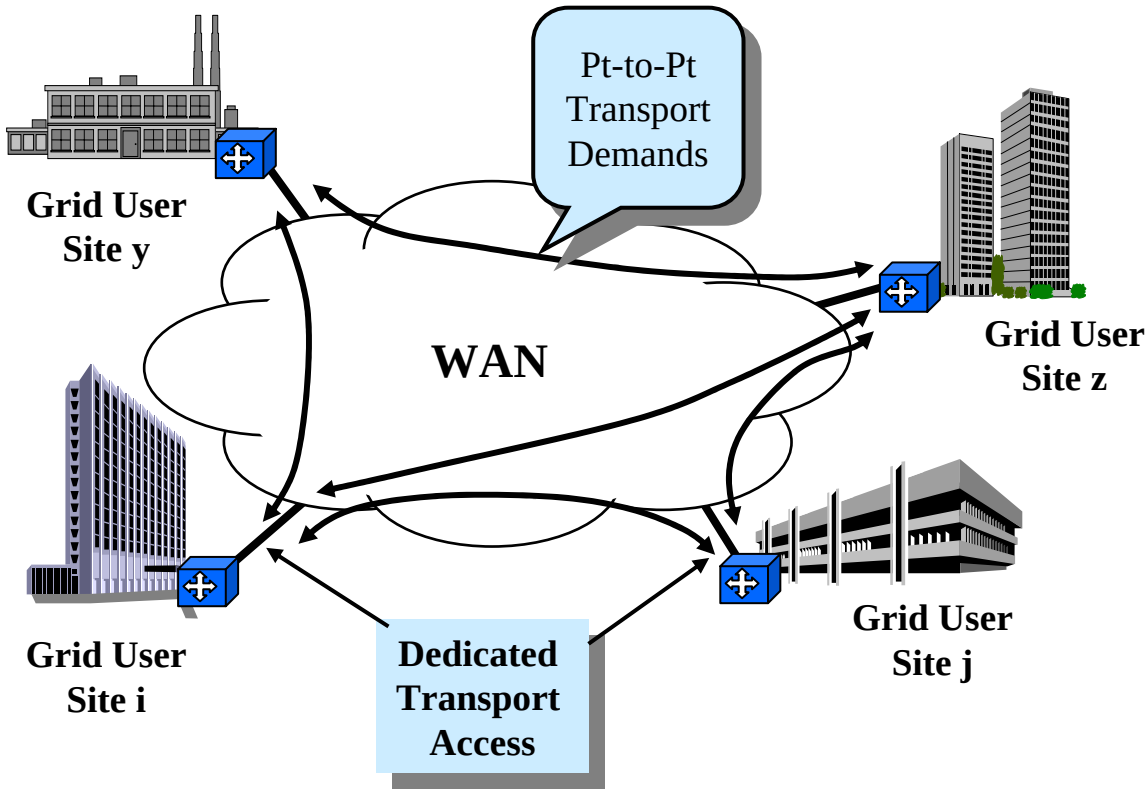
Network Model



How do you decide between using BoD or Dedicated Bandwidth between grid sites?

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Fine Granularity Bandwidth Requirement Model

- Users create demand for aggregate bandwidth between each pair of grid sites
  - required bandwidth varies statistically over time (described later)
  - required aggregate bandwidth reflects bandwidth needed to meet QoS objectives
- BoD capacity is provisioned in a fixed bandwidth unit
  - e.g., 1 Mbps, DS-1 (1.5 Mbps), STS-1 (50 Mbps)

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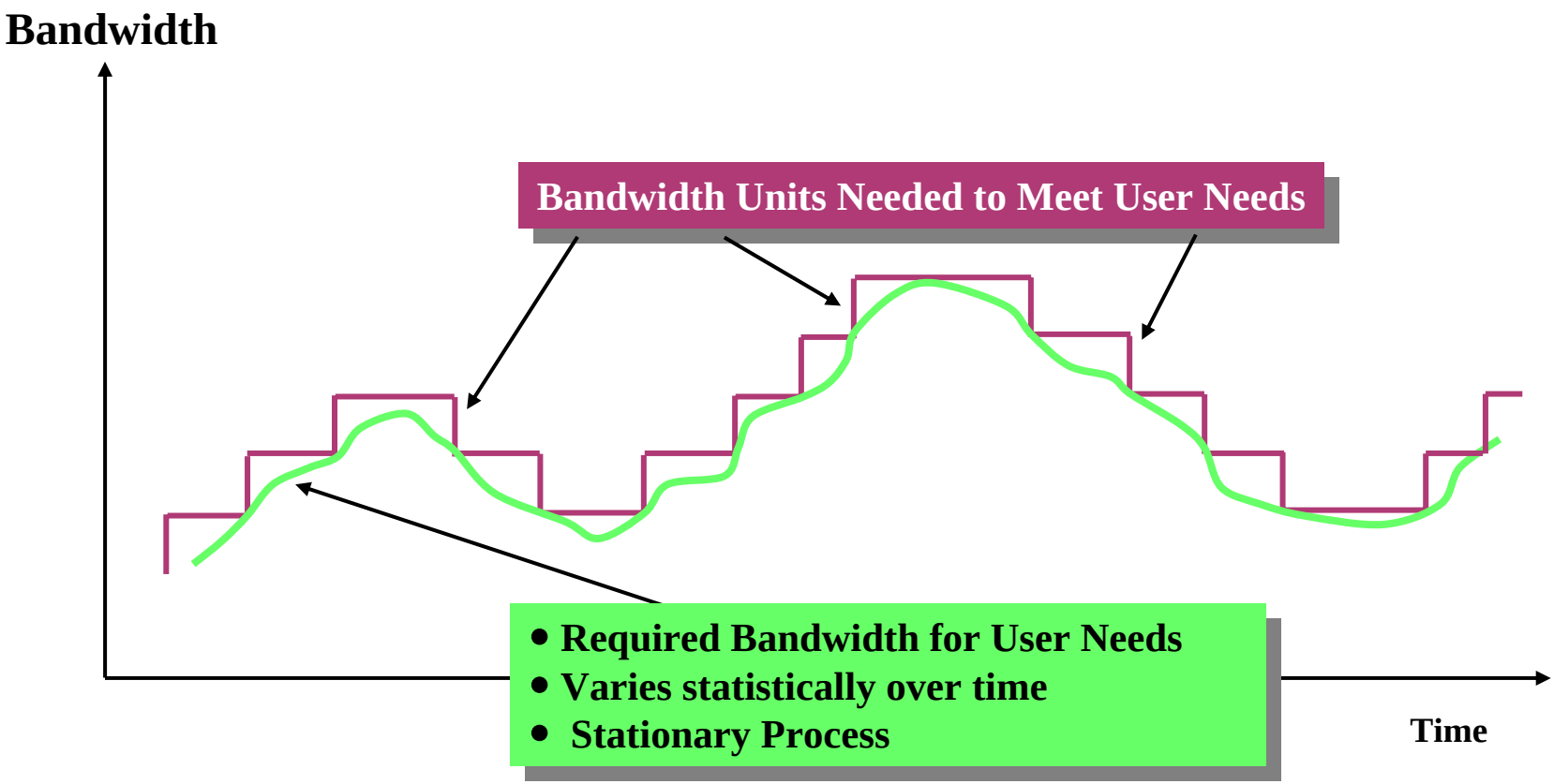
Bandwidth Units Needed to Meet Pt-Pt User Load



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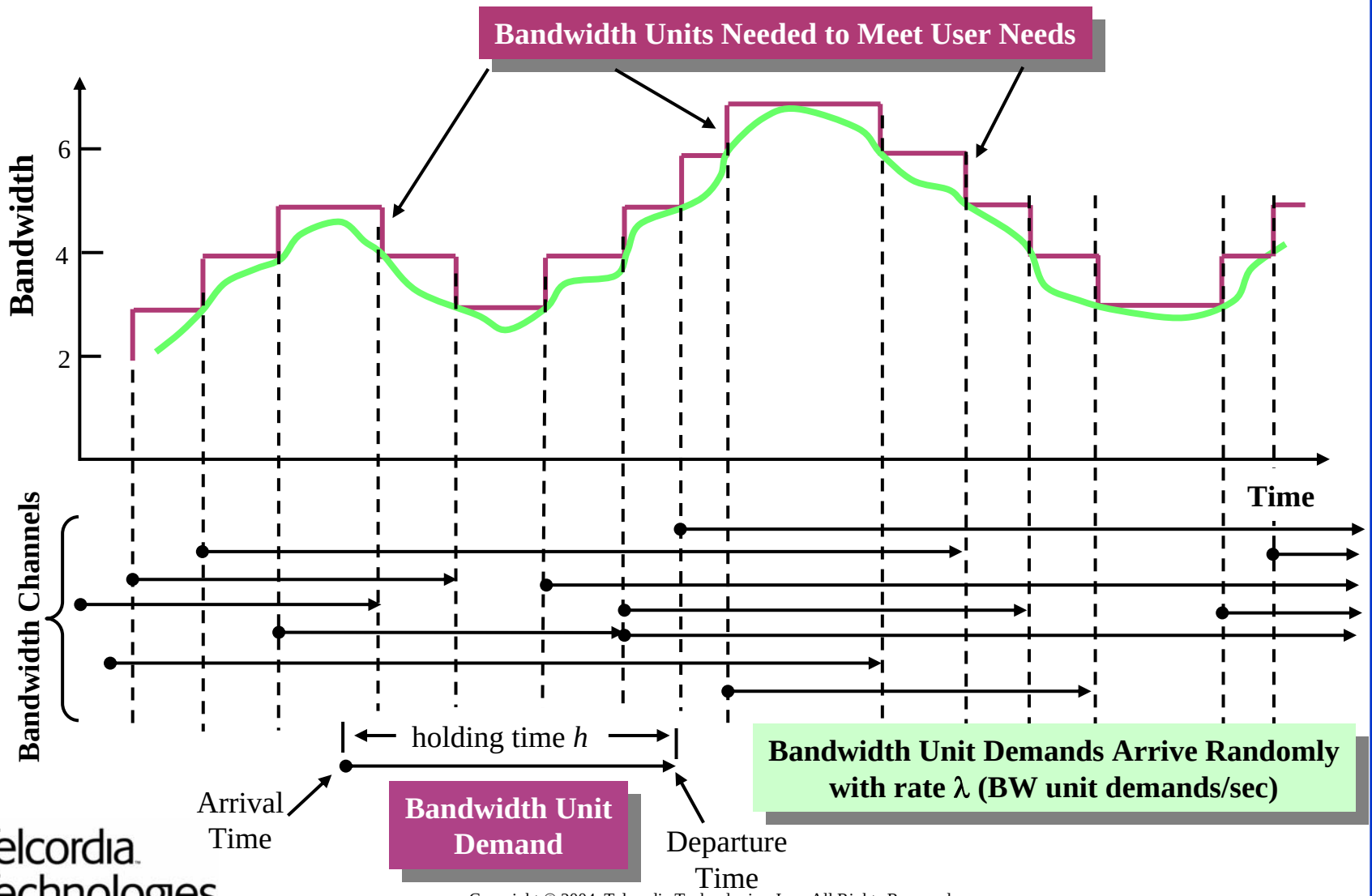
Statistical Model of Bandwidth Unit Demand Arrival/Departure Process (1)



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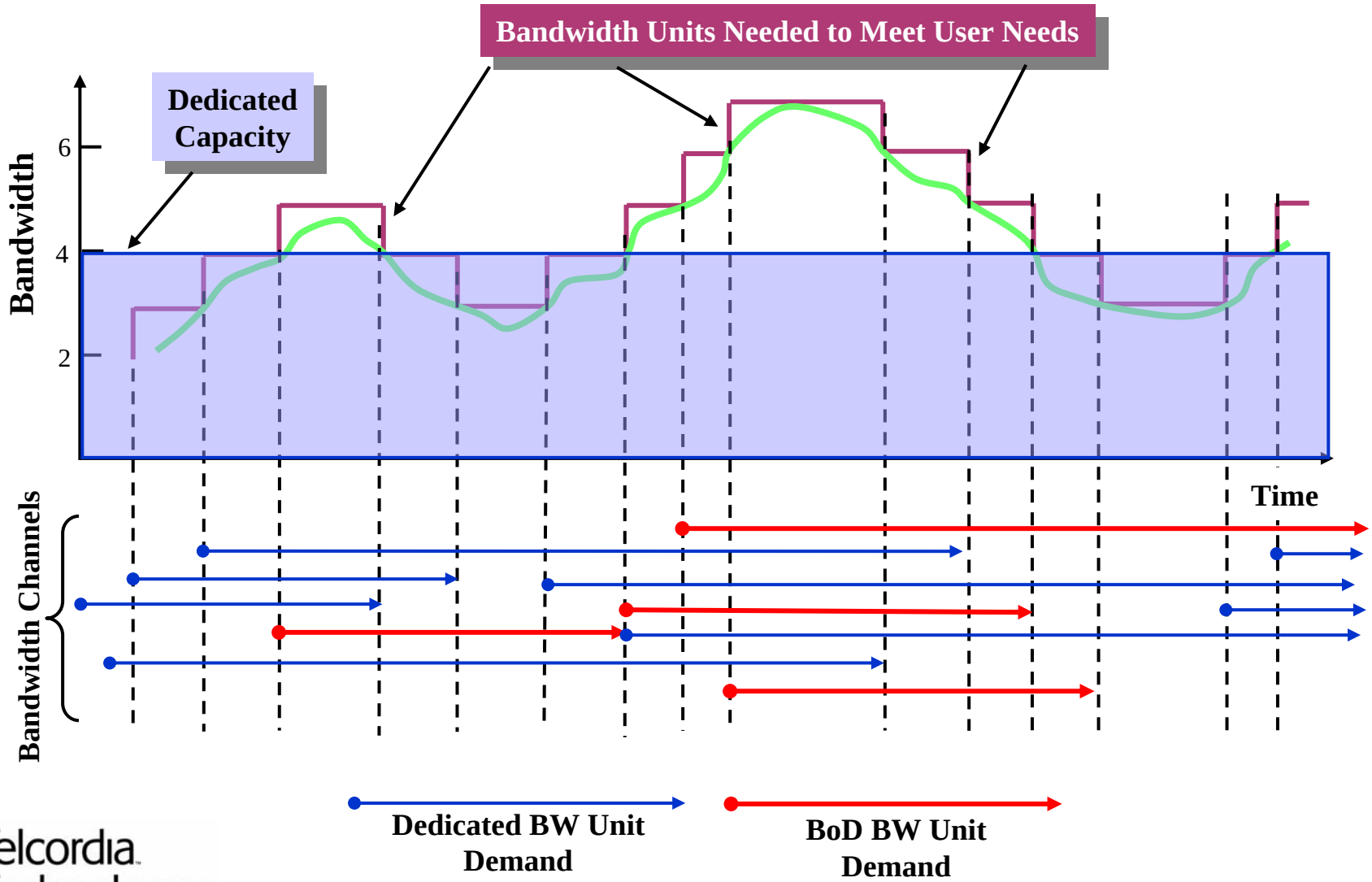
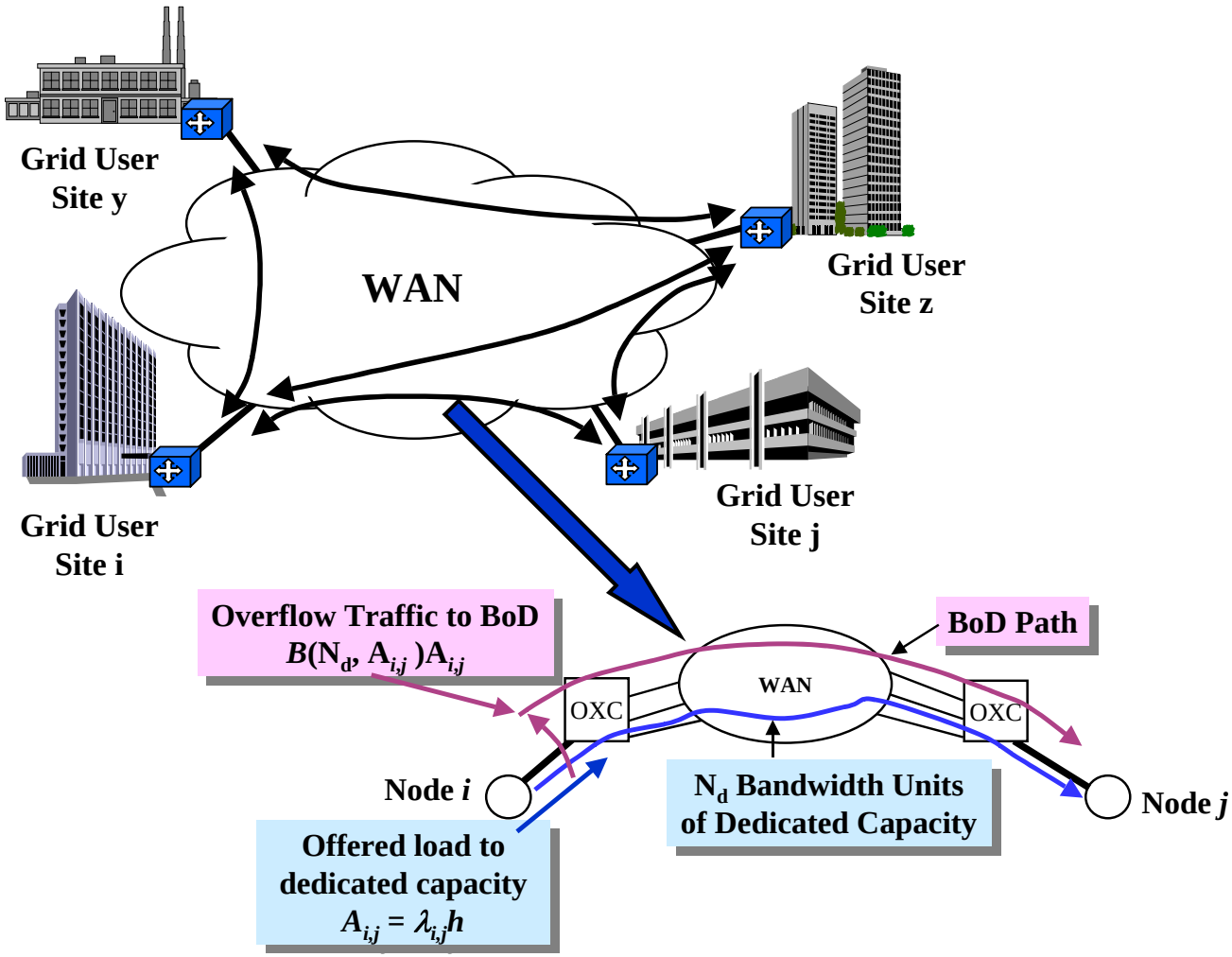
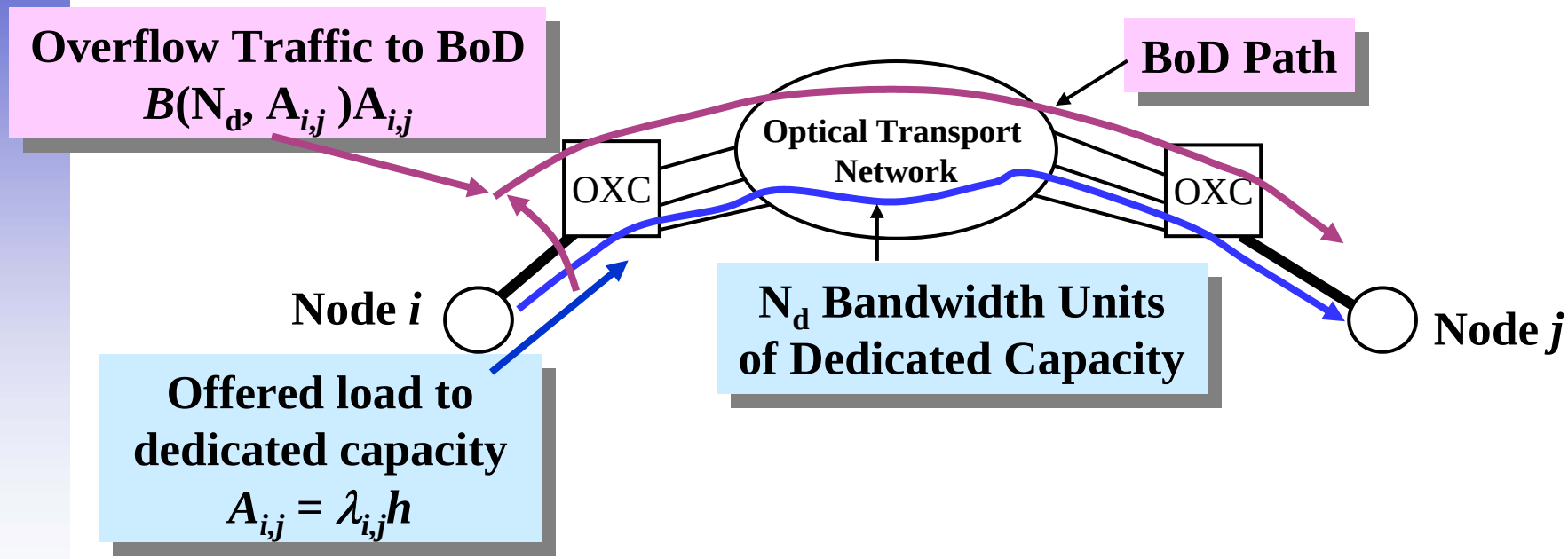
Statistical Model of Bandwidth Unit Arrival/Departure Process (2)



Network Traffic Model



Model to Determine use of Dedicated vs BoD



Dedicated bandwidth costs C_d per unit time

BoD costs C_{BoD} per unit time

Cost Ratio = $C_d/C_{BoD} < 1$

N_d is chosen to minimize total cost

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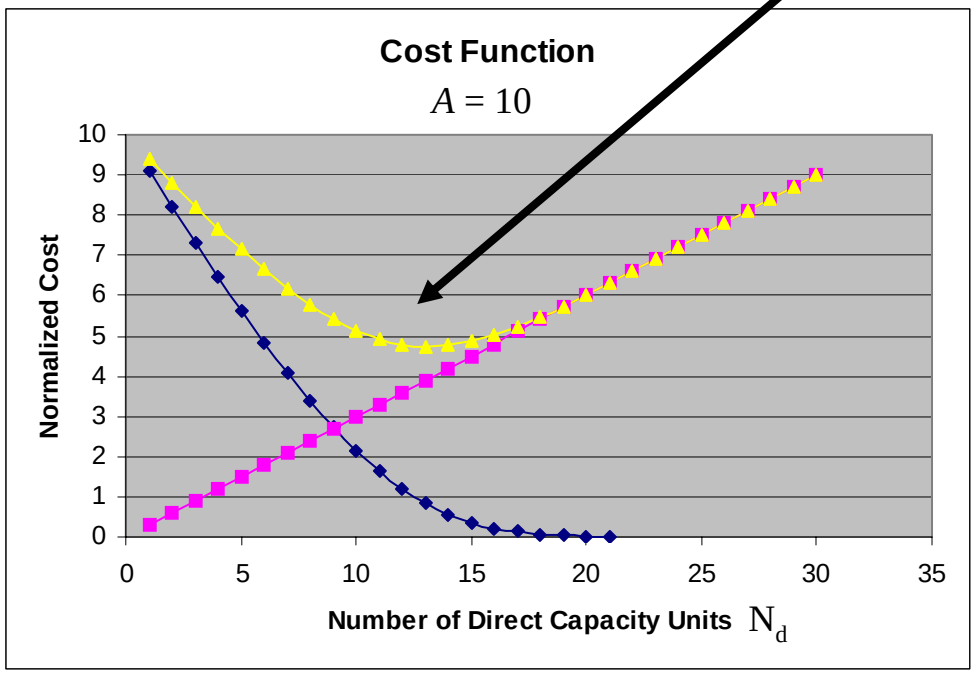
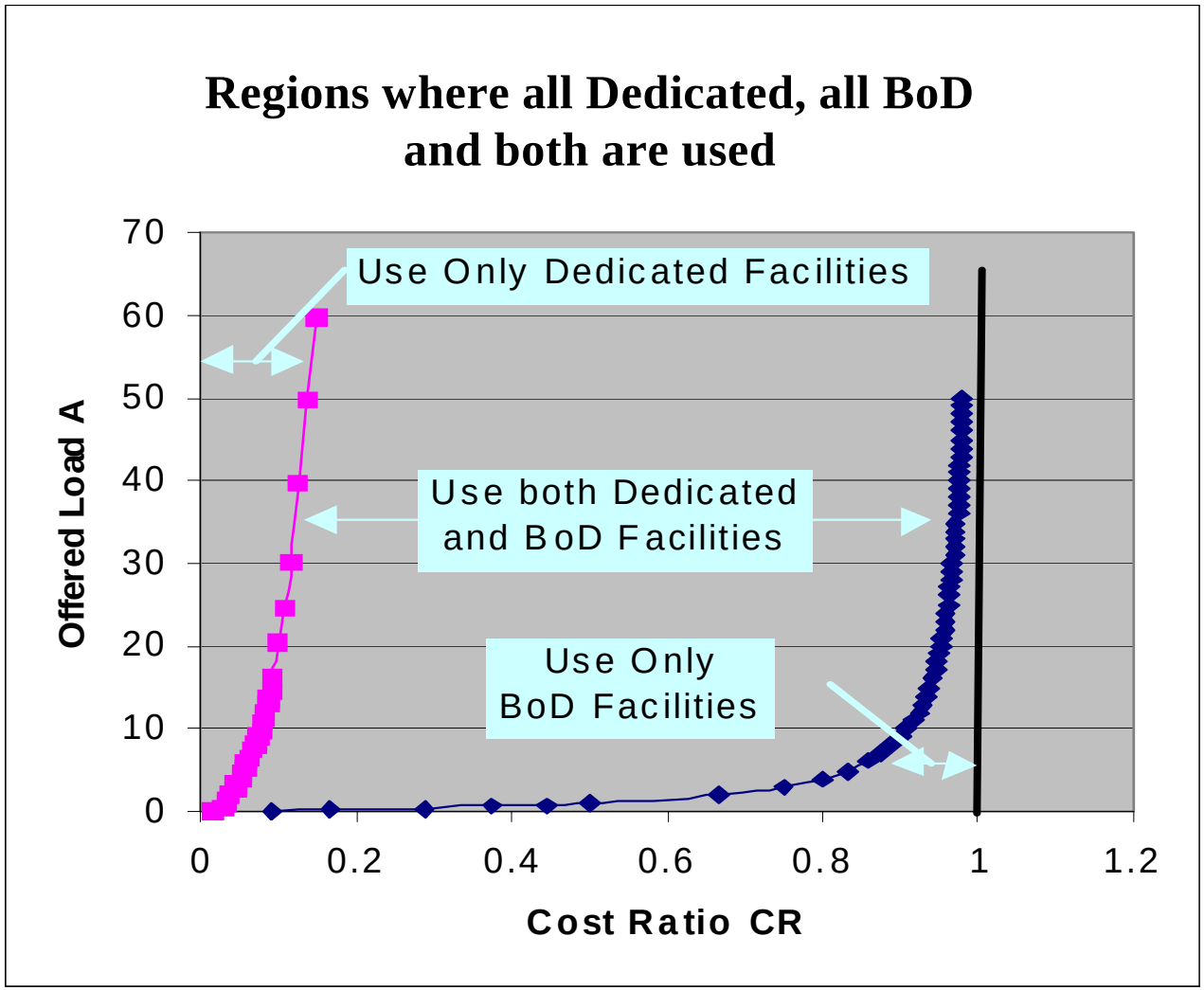
Cost Analysis

- Over a long period of time, the average cost rate per unit time is

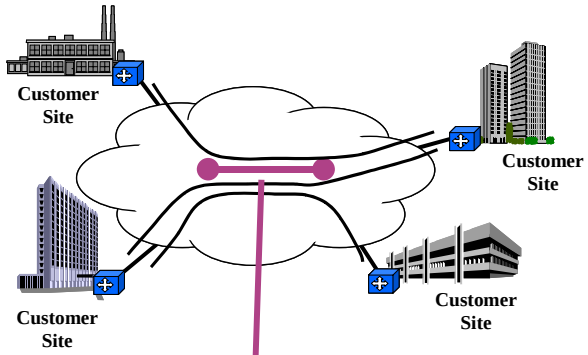
$$C_d N_d + B(N_d, A) AC_{BoD} = C_{BoD}\underbrace{[CR \times N_d + B(N_d, A)A]}_{\text{Normalized Cost}}$$



Parameters Determining When Dedicated and BoD Resources are Used



BoD Network Traffic Analysis Model



Span Providing Shared BoD Capacity
C_{BoD} Bandwidth Units

C_{BoD} Chosen to meet Blocking Objective

Overflow load to BoD Network

Dedicated Capacity
S_i BW Units

S_1 S_2 • • • S_N

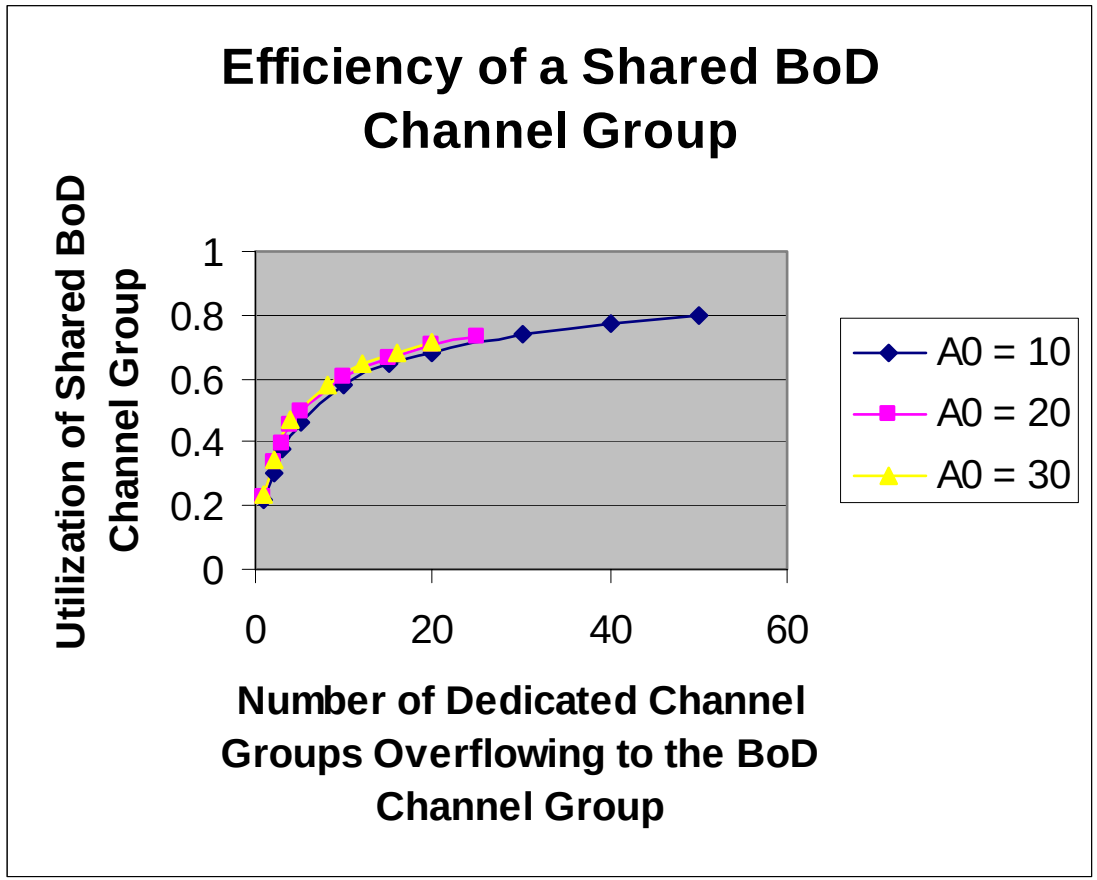
A_1 A_2 A_N

Site Offered Load to Dedicated Capacity

Overflow Load is Bursty Traffic!

Effect of Bursty Traffic on BoD Network

- BoD facility utilization is low if there are few pt-pt pairs requesting BoD capacity, regardless of how high the load A_0 is.



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Choice of Bandwidth Granularity

- Bandwidth granularity matches subscriber needs
  - allows assigned resources to closely match actual load
  - yields high traffic efficiency (lower blocking; higher resource utilization)
- Too fine a granularity results in:
  - Frequent bandwidth provisioning activity as loads change
  - Most users ask for batches of bandwidth units (caps traffic efficiency)
- Too large a granularity results in inefficiencies:
  - More assigned capacity than needed (stranded capacity)
  - Low traffic efficiency (higher blocking; lower resource utilization)

The Key questions are:

- **What is the right level of granularity?**
- **What determines the network's load carrying capacity?**

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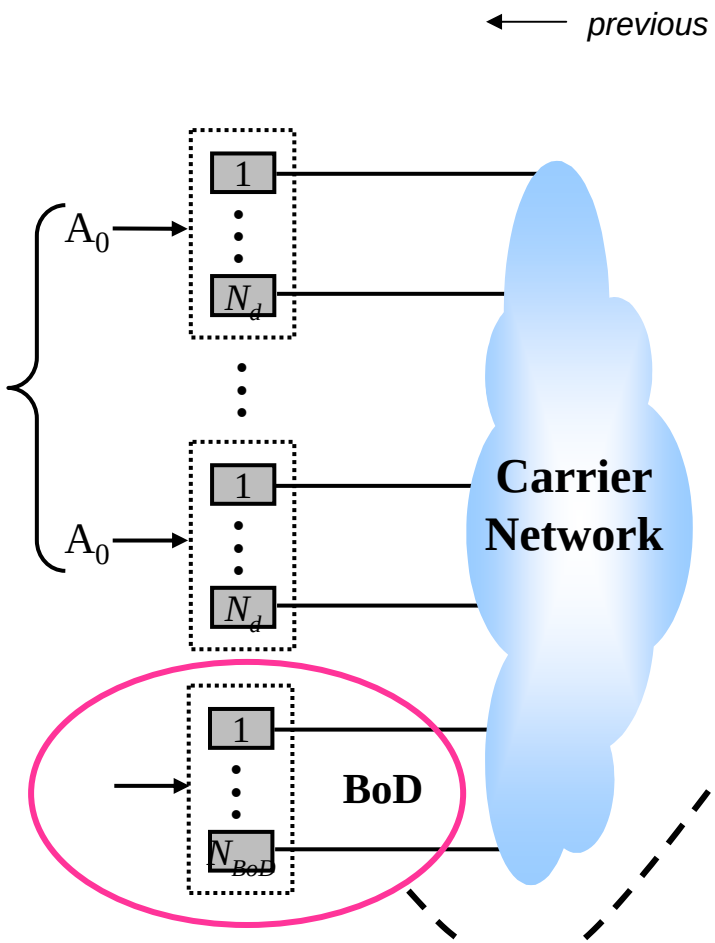
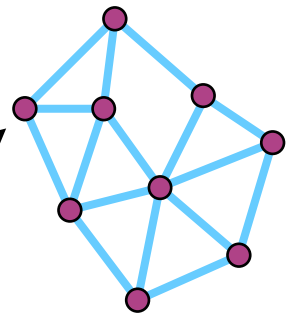
Bandwidth Granularity



Realistic Network Topology



Design = efficient use of network capacity

- Design of Flexible Optical Switching Network for BoD requests
- Number of channels vs. blocking probability

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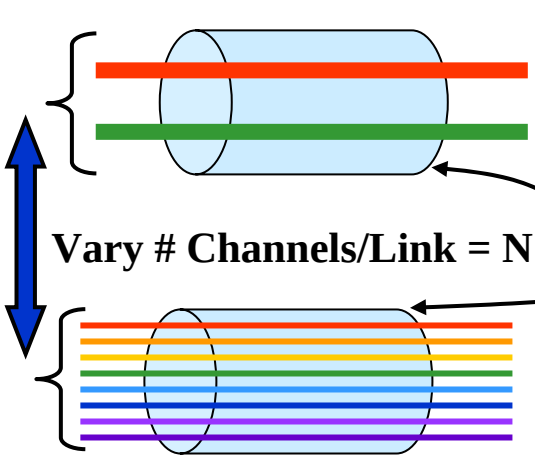
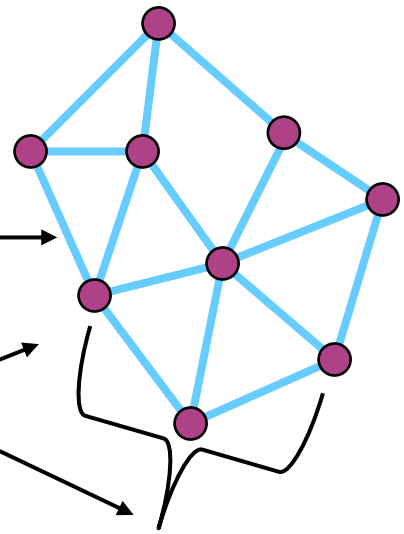
Network Model to Study Granularity



Vary # Channels/Link = N

Same Fixed Capacity Installed on Each Link

Realistic LATA Network



Arrivals of Connection Requests to Network

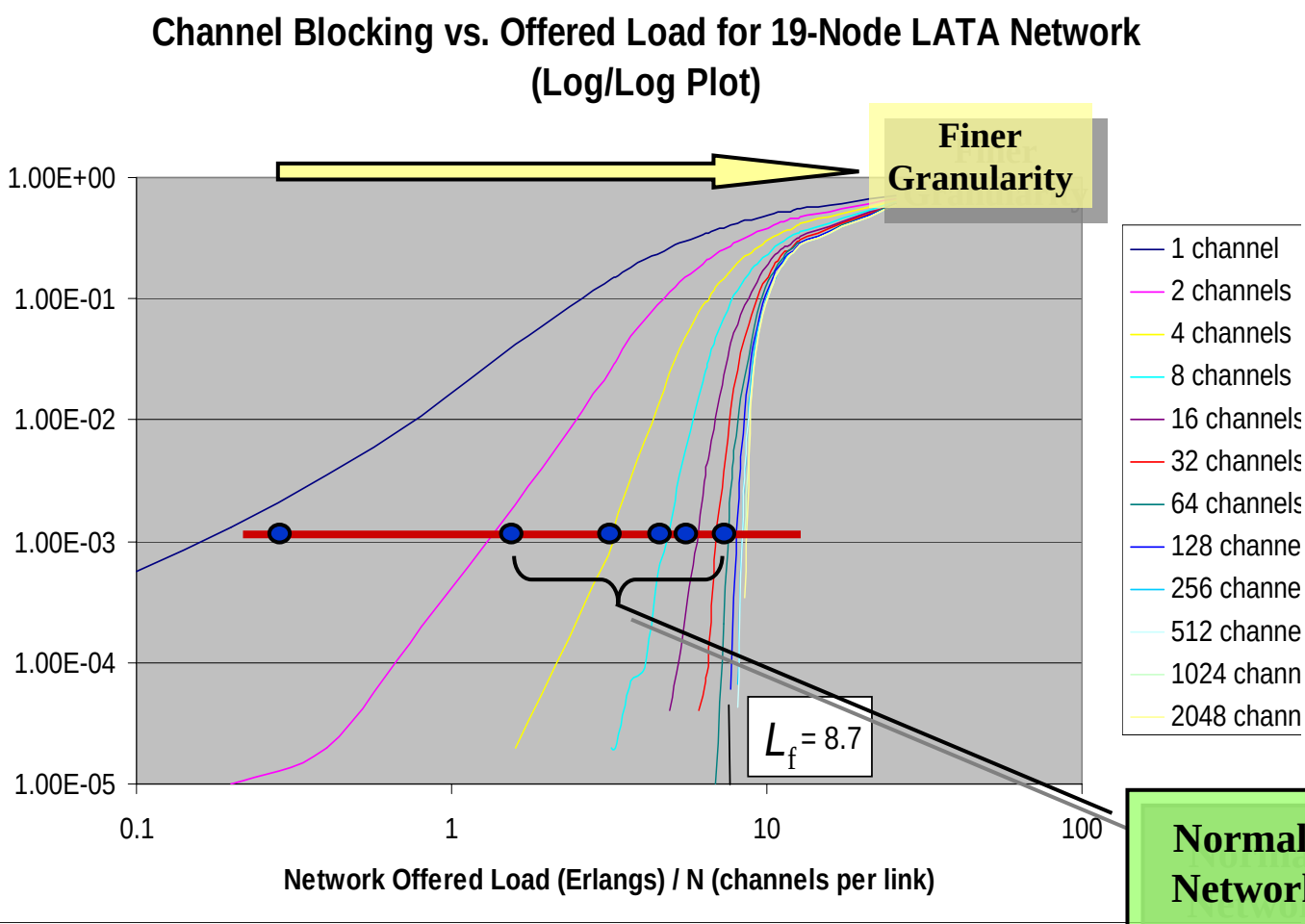
Connection Arrivals Randomly Assigned to Node-Pairs (based on node degree)

Total Network Offered Load

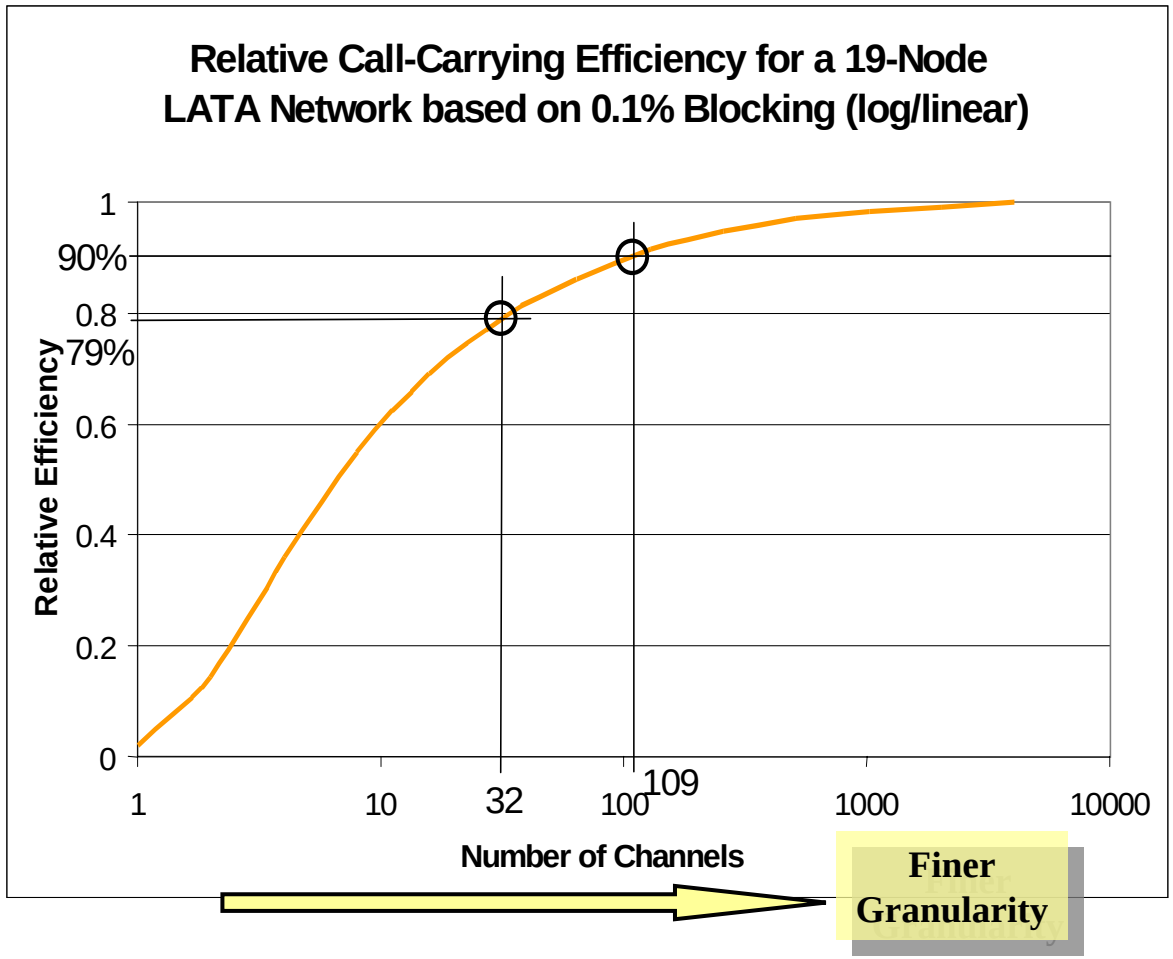
$L = \lambda \times h$ Erlangs

Network Offered Load Parameter is L/N

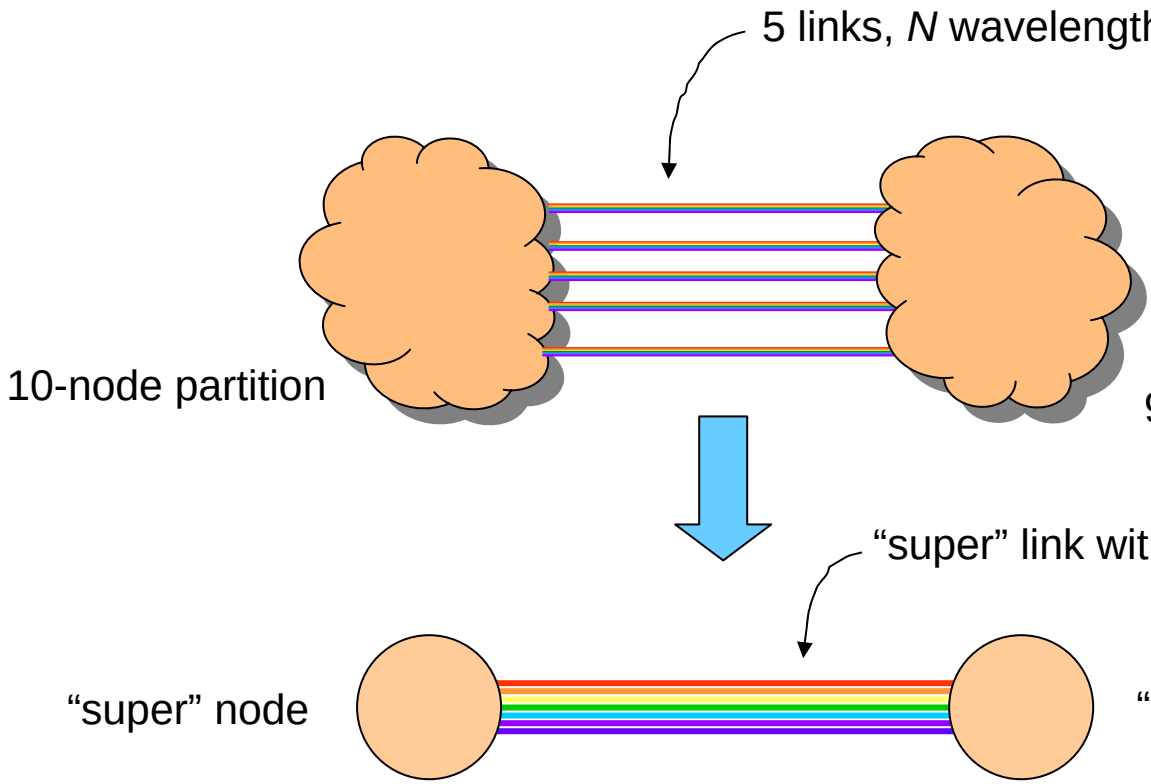
Blocking Probability vs. Offered Load Parameter L/N



Efficiency vs Granularity



Impact of Network Topology
Minimal Balanced Cutset



Likely half or more the average traffic appears across such a minimal cutset

Equivalent Single-Link Network For Efficiency Ratio

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Effect of Network Topology on Network Capacity

# Nodes / # Links	Average Nodal Degree	# Links in Minimal Balanced Cutset	L_f @ 0.1% Blocking (Erlangs/ch)	# of chs @ 90% Efficiency Ratio	Efficiency Ratio @ 32 Channels
2 / 1	1	1	1.001	559	0.57
19 / 31	3.3	5	8.7	109	0.79
71 / 138	3.9	6	7.5	121	0.79
200 / 361	3.6	13	14.6	164	0.71

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Coarse Granularity Bandwidth Management

- Coarse granularity (Gb/s) is required for applications requiring large data transfers in a relatively short time interval
  - e.g., collaborative activities needing near real-time exchanges
- If these activities are infrequent, then a BoD model based on random arrivals and blocking is very inefficient
  - Either very low facility utilization or very high blocking.
- Alternative models are to use scheduling or random arrivals with queueing
  - Coordinated scheduling between, processing, storage and network resources would be required
  - Work along these lines is being done in the Global Grid Forum
- This is an area that needs significantly more work

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Conclusions

Fine Granularity Bandwidth Management

- The **grid site pt-pt load** and **cost ratio** are the main parameters that determine how much BoD is used.
- **In most situations** the optimal strategy is to **use both** dedicated capacity and BoD.
- The **bandwidth granularity** used for BoD has a **significant impact** on the **cost efficiency**:
  - Up to a point, finer granularity provides greater cost efficiency and more BoD use.
- The network providing BoD must be designed so the facilities efficiently handle **bursty overflow traffic**,
  - e.g., the design needs to aggregate loads (many traffic streams) to get efficient resource utilization.
- The network topology (e.g., size of cut sets) has a significant impact on the network's maximum throughput capacity (L_f)

Coarse Granularity Bandwidth Management

- Coarse granularity bandwidth management appears best to be handled by scheduling rather than random arrival/blocking disciplines

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Thank You!

Questions?

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