Network on Demand Service with Price-based Resource Control

IEEE/IFIP BoD 2010@Osaka

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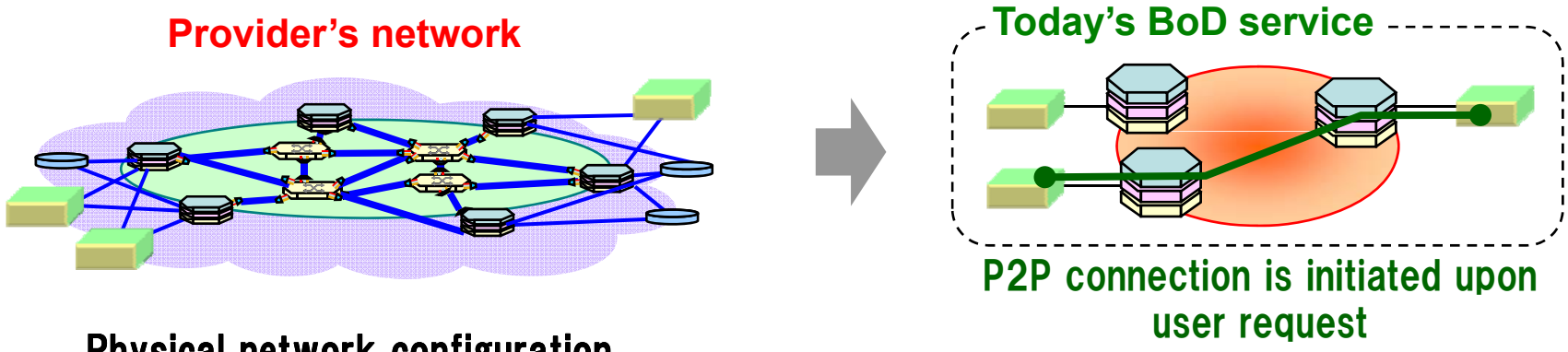
Today's BoD service application scenario

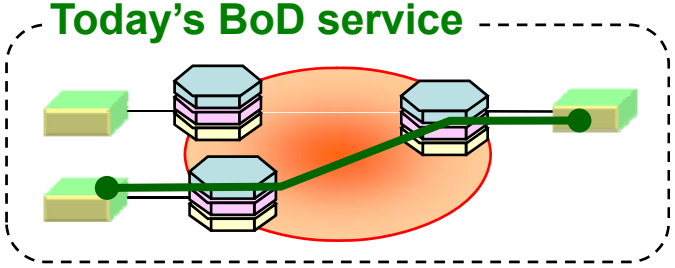
- **Today's BoD service**
  - A network provider offers high-capacity bandwidth to its customers
  - Basically, the connectivity is limited to Point-to-Point.
  - Customers often construct a part of their own network by combining multiple point-to-point connections.



Today's BoD service application scenario *cont'd*

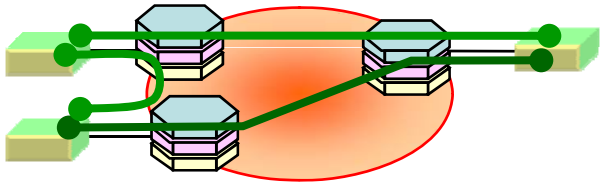
- **Outline of our proposal**
  - The price is basically determined by service parameters (e.g., a holding time, bandwidth, etc.)
  - Customers wish to minimize the total cost while maintaining adequate service quality.
  - We consider a new service that offers a minimum-cost network configuration in combination with multiple point-to-point connections.

Today's BoD service



- Point-to-point connection
- Fixed bandwidth

Our proposal (VNT service)



- Multi-point connection
- Flexible bandwidth & topology

Outline of Talk

1. Concept: VNT service
2. Resource control with Pricing
3. Numerical Examples
4. Concluding Remarks

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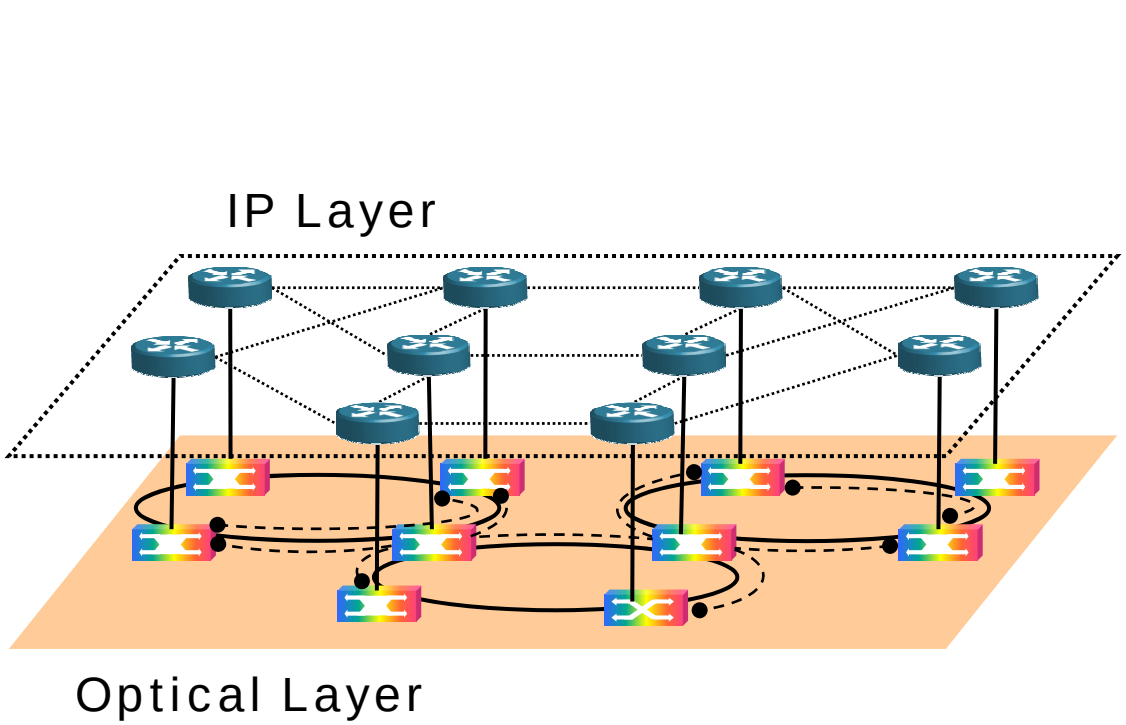
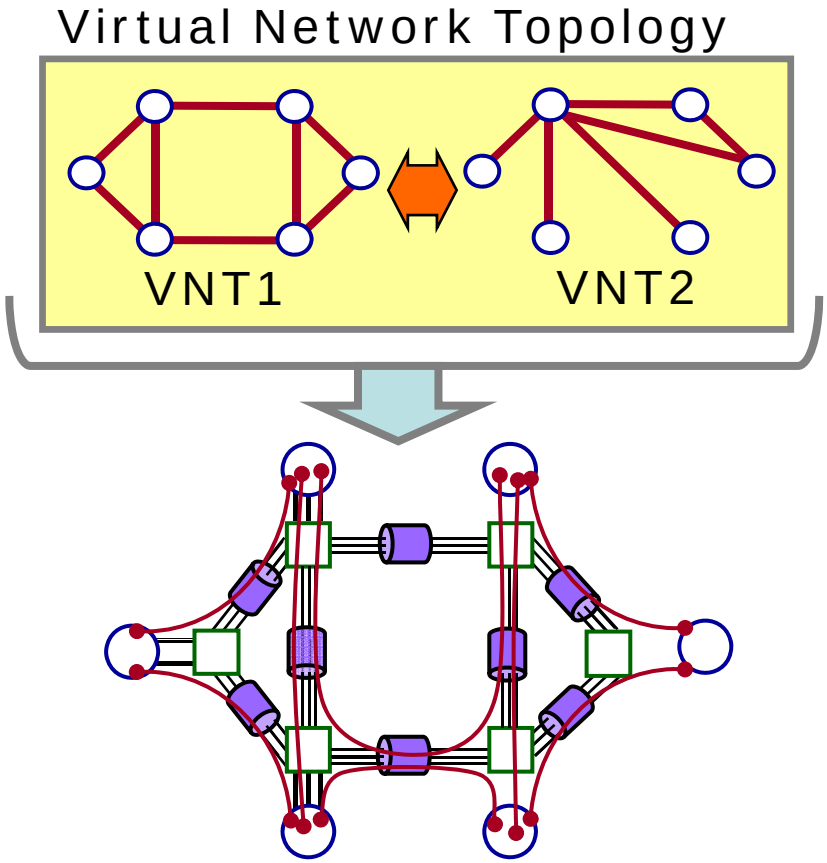
Virtual Network Topology (VNT)

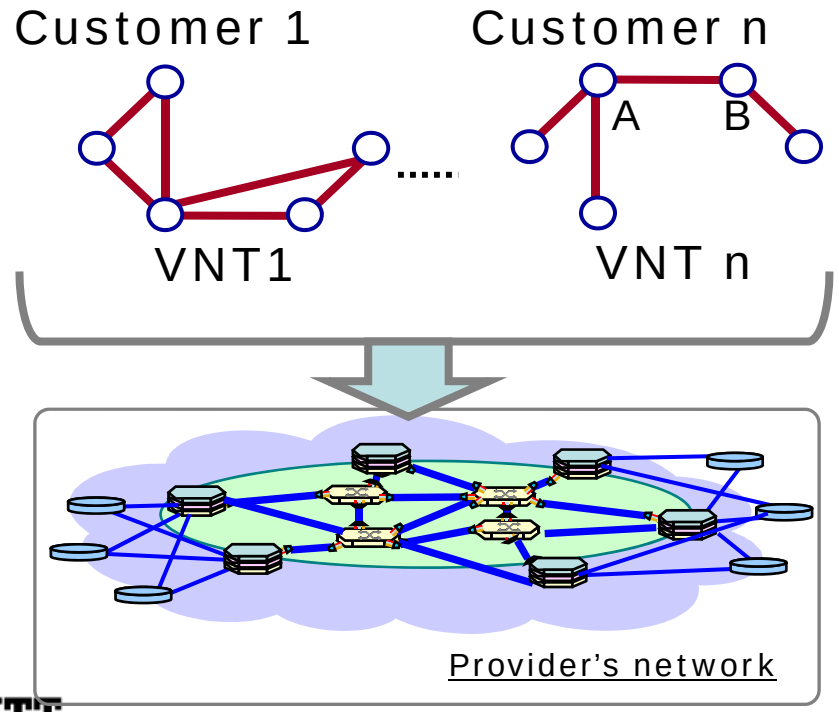
- The network topology formed by optical paths and advertised to the higher layer is called VNT.
- VNT is re-configured by optical paths setup/teardown.

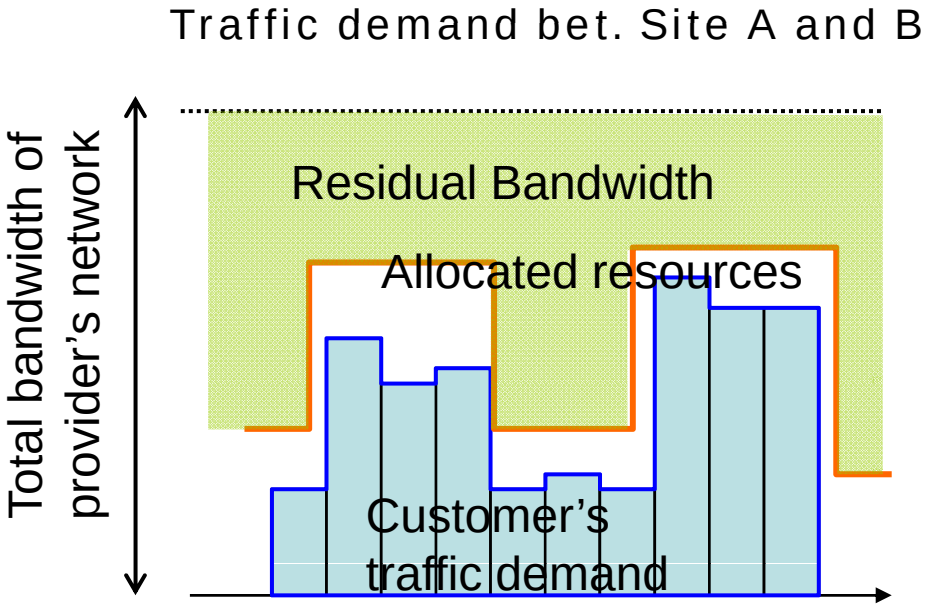




Our proposal: VNT service

- A service provider network provides continuous connections among multiple customer sites.
  - VNT provides a transport among customer's sites
  - Provider accommodates multiple customers (i.e., VNTs)
- Bandwidth of each pipe connecting a pair of customer edges is automatically adjusted in accordance with traffic-demand changes





Our proposal: VNT service *cont'd*

- **Merits**
  - Customers: improves flexibility regarding bandwidth and reduces OPEX and CAPEX
  - Providers: Improves efficiency of resource utilization

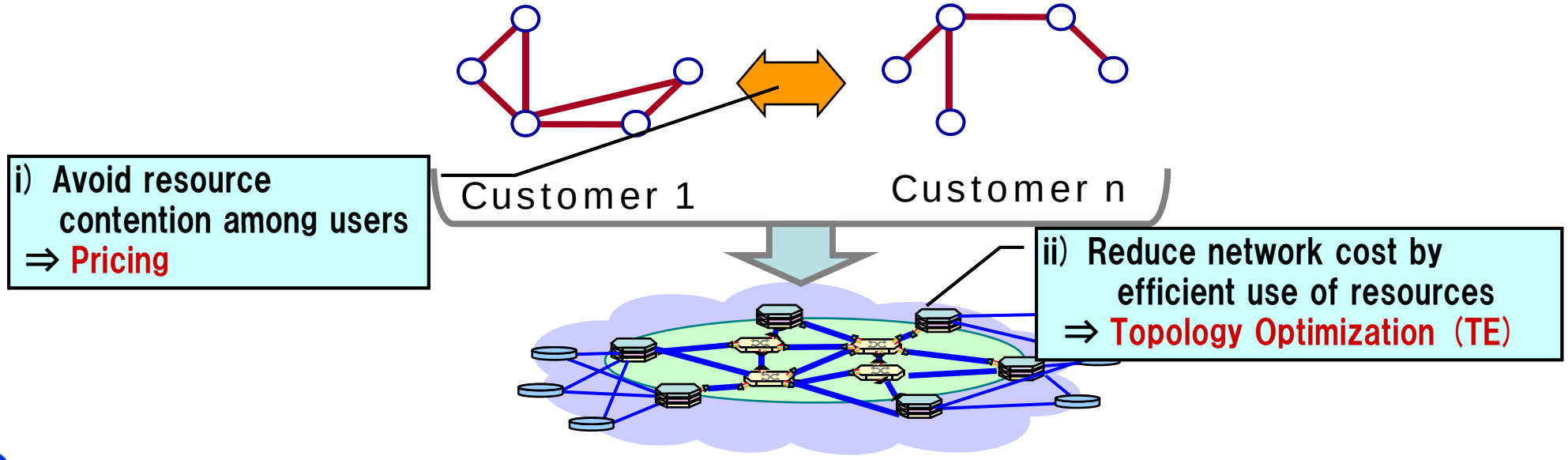
	Conventional BoD Service	VNT Service
Connectivity	Point-to-Point	Muti-point
UNI (Data plane)	Any (L1/L2/L3)	Packet or Frame-based (L2/L3)
Connection initiation /release	Triggered by customer request	Continuously established
Allocated bandwidth	Manually specified upon connection request	Automatically adjusted based on actual demand by service provider
Operation cost for customer network	Estimating traffic demand and/or holding time is very complicated	No additional task is required for traffic demand variation

Challenges for VNT service

- Goal (Economics aspect)
  - We want to maximize the utility of users; at the same time, maximize the profit of the service providers.
- Possible problems

  i) Each user share the same objective. Resource contention will occur.

  ii) Network cost increases if resources are provisioned to cover the peak demand.
- Our approach
  - We introduce pricing mechanism in conjunction with TE technologies.



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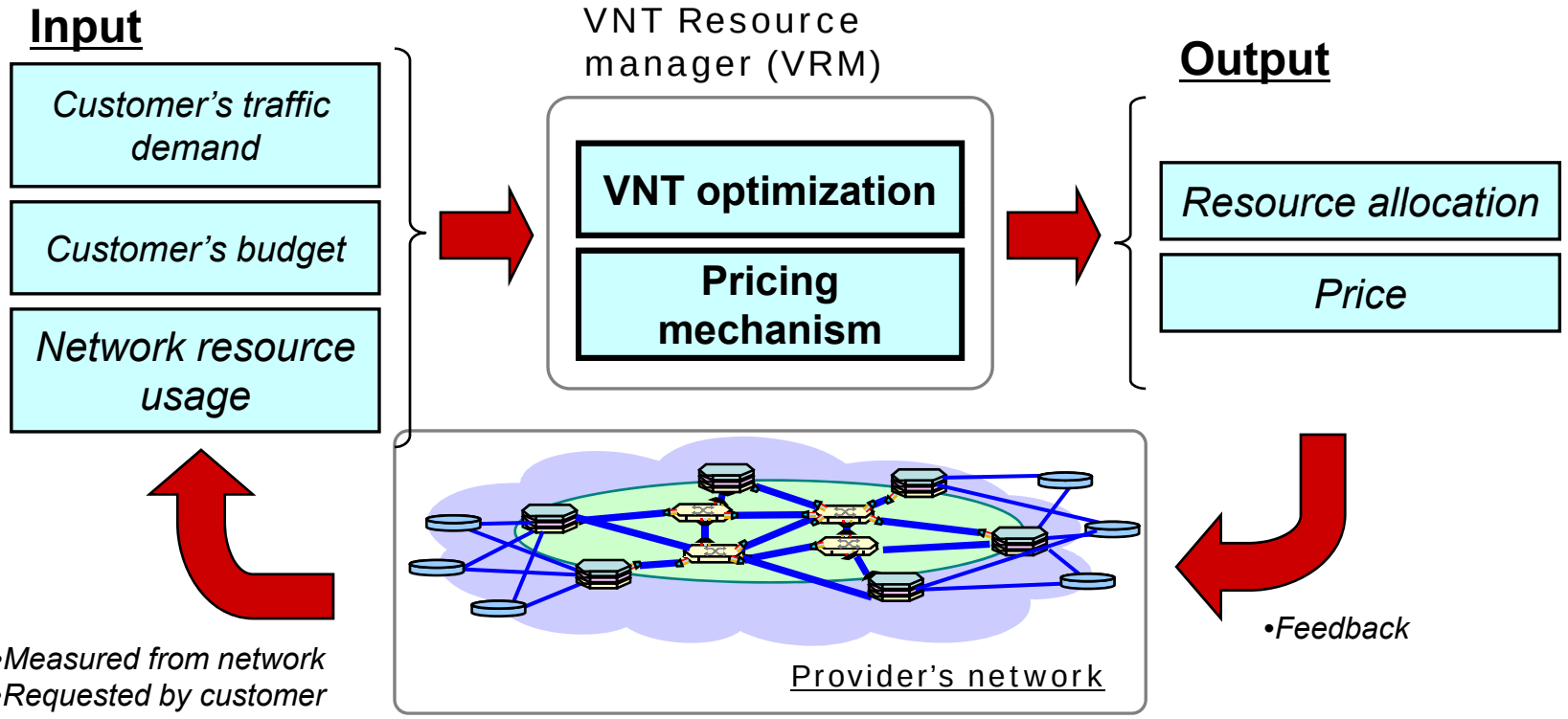
Our final goal: price-based resource control

- Network resources in a provider's network for the VNT service are shared by multiple VNTs
- Some mechanism is required for avoiding the exhaustion or contention of network resources.
  - VNT optimization function computes optimal topology for a given demand
  - Pricing mechanism determines an adequate price and resource allocation considering residual network resources and customer's benefit.

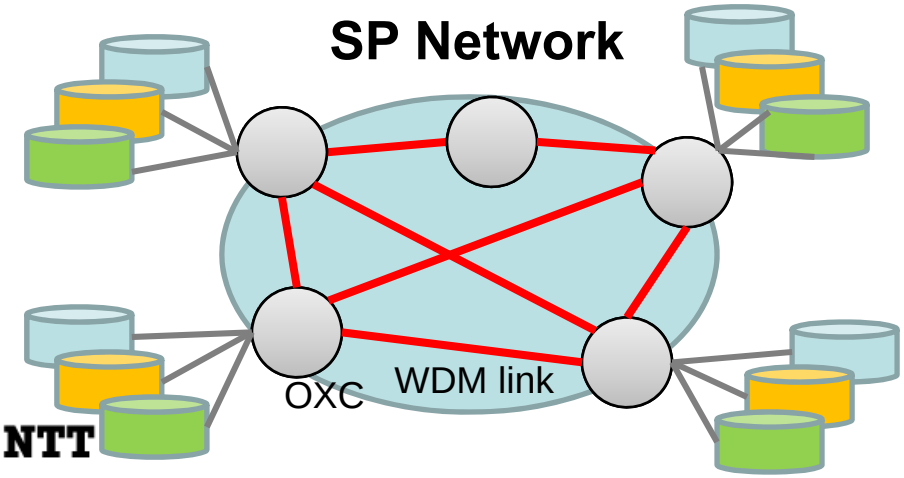


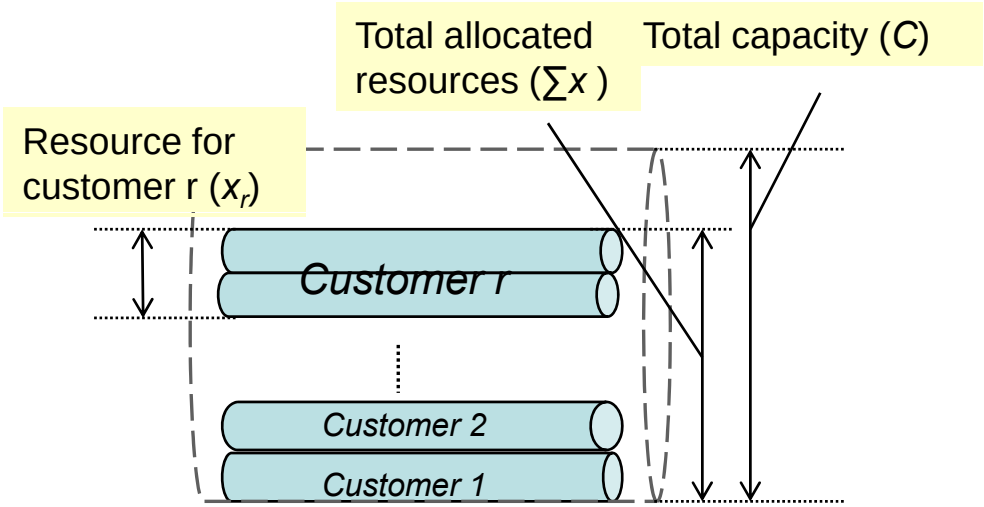
Problem we are solving

- Build mathematical model for proposed services and investigate feasibility of price-based resource control
  1. Clarify the impact of price on resource allocation and users
  2. Evaluate effectiveness of optimized topology
  3. Investigate impact of user behavior (traffic demand distribution)

Model 1: Overview

- Service provider(SP)'s behavior
  - Allocate wavelength resources to users
  - Choose adequate price for a unit of wavelength
- User's behavior
  - Submit information about peak traffic demand and budget
  - Pay cost in proportion to the amount of allocated resources
- Resource allocation policy
  - Maximize the benefit of users under given constraints (for simplicity)





Model 2: Formulation

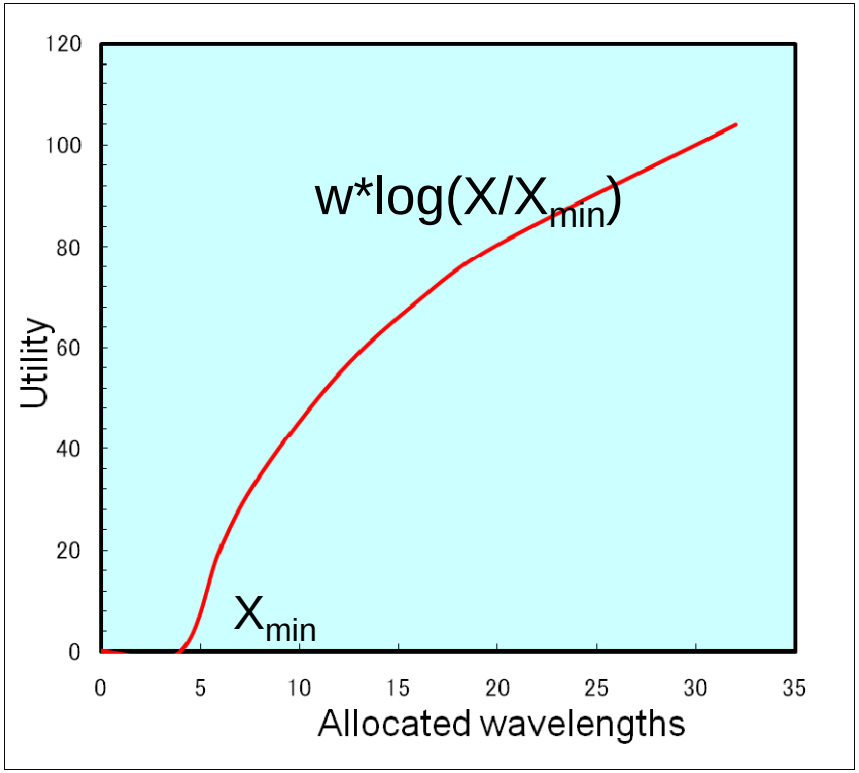
- **Objective**
  - Maximize the sum of user's benefit (utility minus cost)

$$\text{Maximize} \quad \{\sum_{r \in R} (U_r(x_r) - C_r(x_r))\}$$

- **Determine**
  - Allocated wavelength resources to each users
  - Note that unit price is a given parameter in our model

- **Subject to**
  - Capacity constraint
  - Budget constraint
  - Service quality constraint

Fig. Utility function



* Logarithmic utility function is approximated by piece-wise linear function.

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Aims of numerical study

Aims:

- Understand basic characteristics of the proposed architecture and investigate feasibility

Numerical experiments:

1. Investigate impact of price
2. Even traffic vs uneven traffic
3. Effectiveness of optimized topology

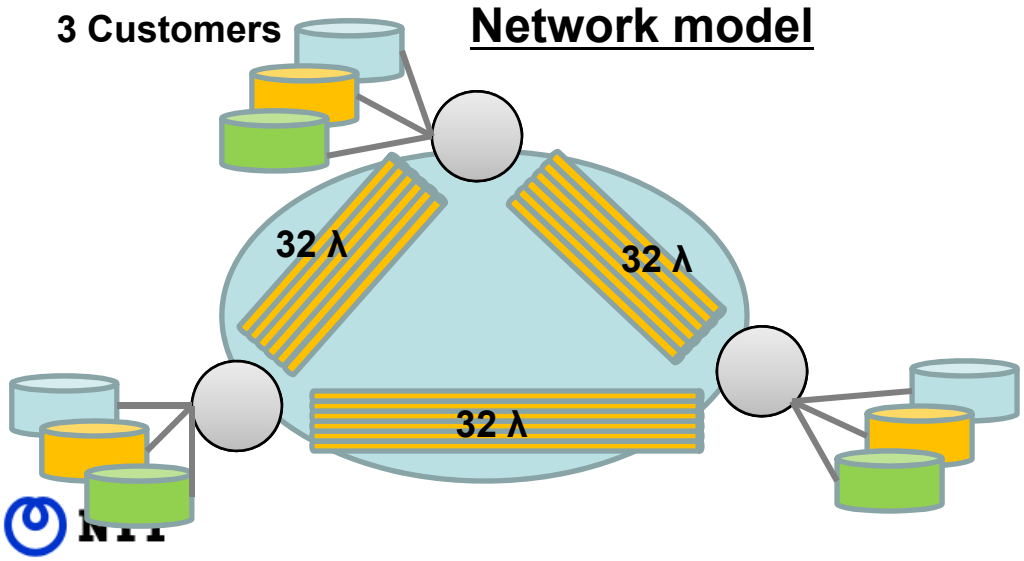
Conditions: Network and Traffic model

Network model

- Simple 3 nodes topology with 32 wavelength per link
  - 3 customers are accommodated in SP network
- Each wavelength is dedicatedly allocated

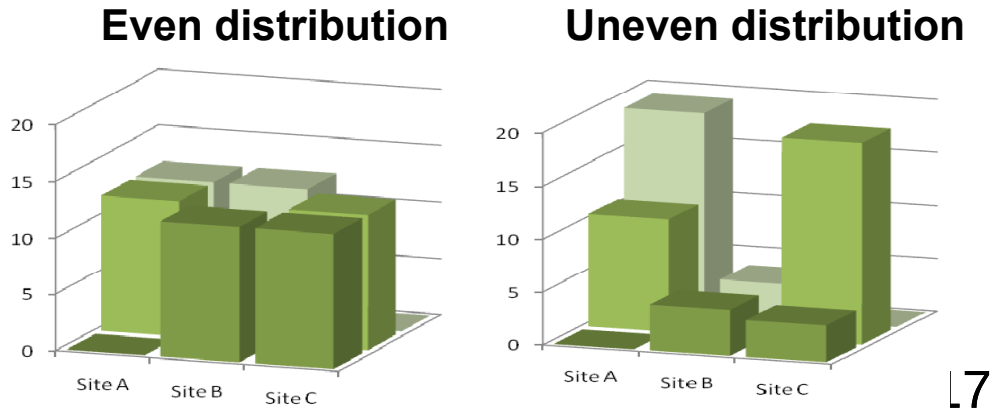
Traffic demand model

- Consider stable traffic matrix of even and uneven distribution
  - 5 uneven traffic patterns were randomly generated
  - Result for uneven traffic is average of 5 patterns



Network model

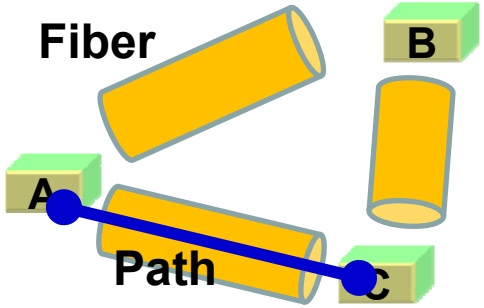
Traffic demand model



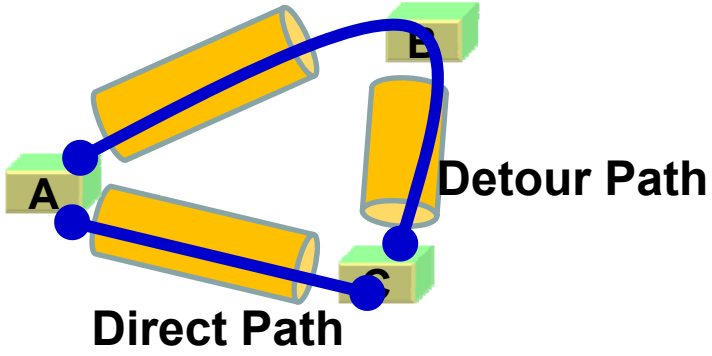
Conditions2: Topology optimization

- Simple single-layer optimization is considered.
  - Optimal route for wavelength path is calculated by our formulation.
- Optimized topology can utilize entire resources more efficiently.
  - Fixed topology: Always use a single hop path
  - Optimized topology: use a detour router in conjunction with sigle hop route

Fixed topology



Optimized topology



Results 1: Impact of Pricing

- Evaluate social welfare and cost while varying price
  - Fixed topology & Even traffic pattern
  - Adequate pricing is beneficial for SP and users
    - Avoids congestion and maximize revenue (=cost for users)

Fig. Impact of price on welfare and cost

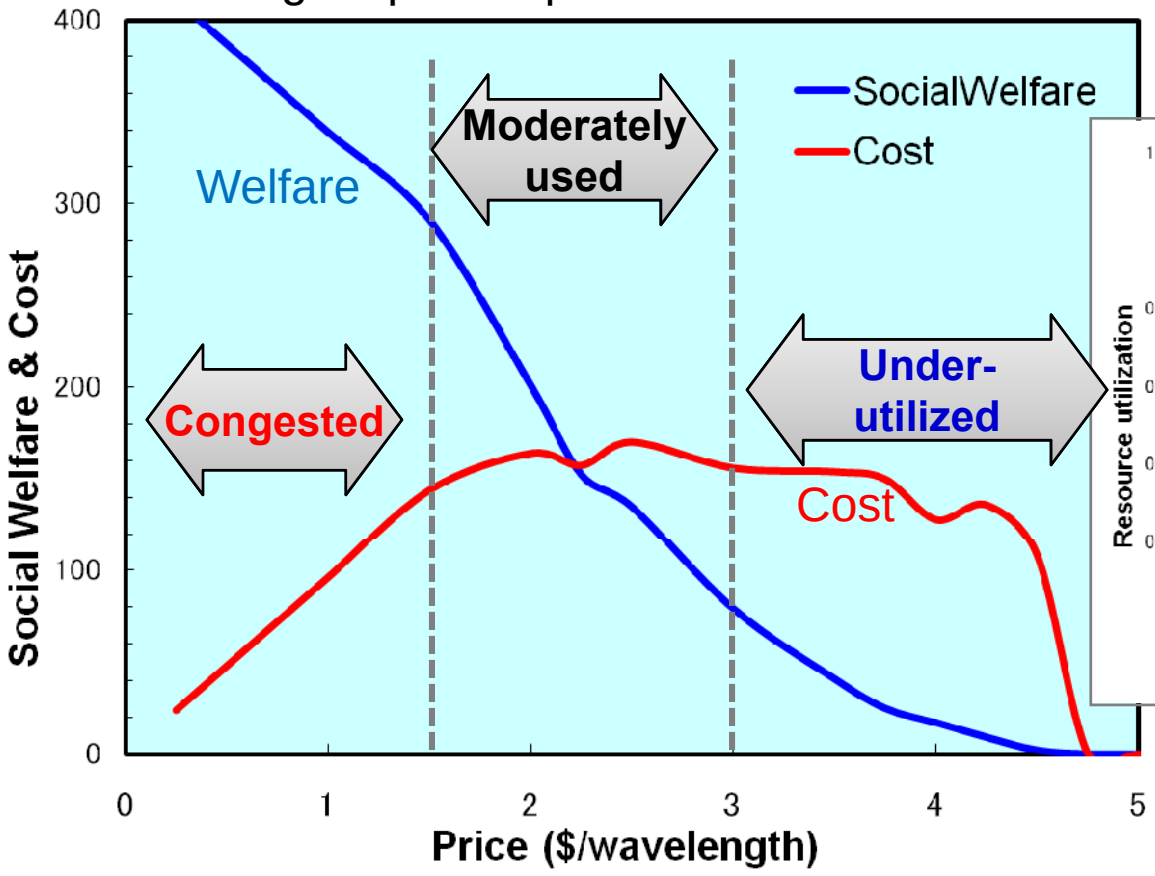
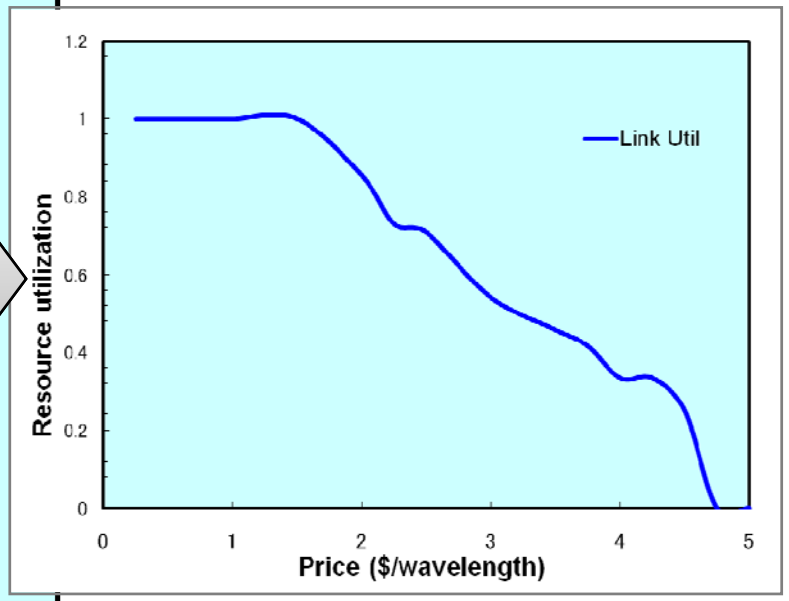


Fig. Resource utilization



Results 2: Impact of uneven traffic

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- Investigate the traffic patter on social welfare and resource utilization
  - Uneven traffic leads to inefficient resource utilization and lower welfare
  - Even traffic outperforms uneven traffic by 20+% for lower price.
  - High prices suppresses customer's demand and no significant difference between even and uneven traffic pattern

Fig. Social Welfare

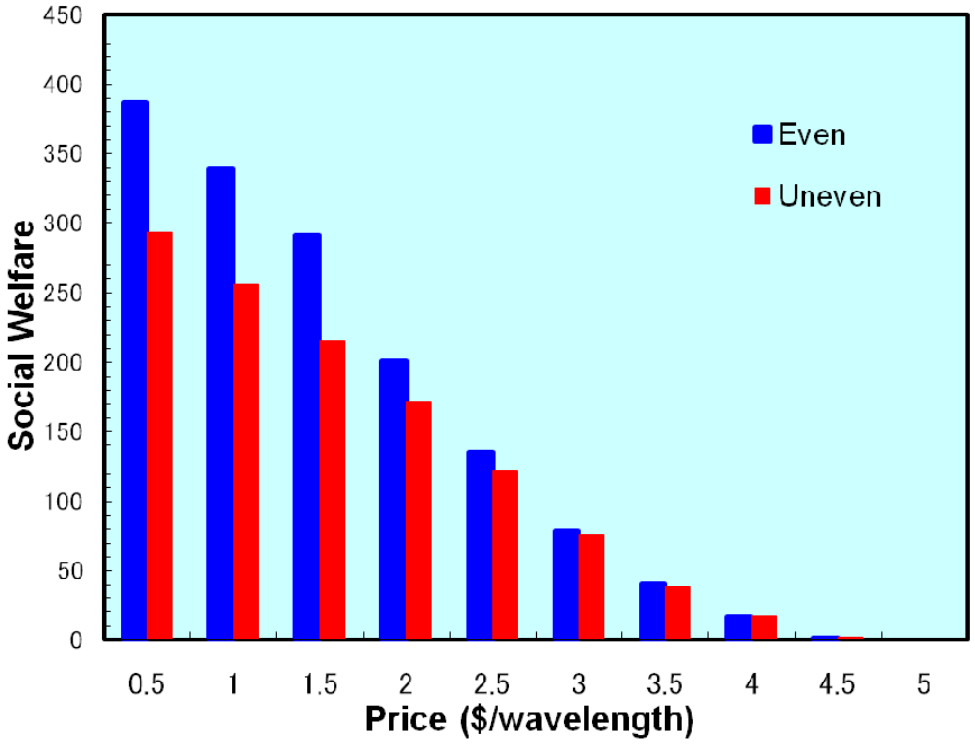
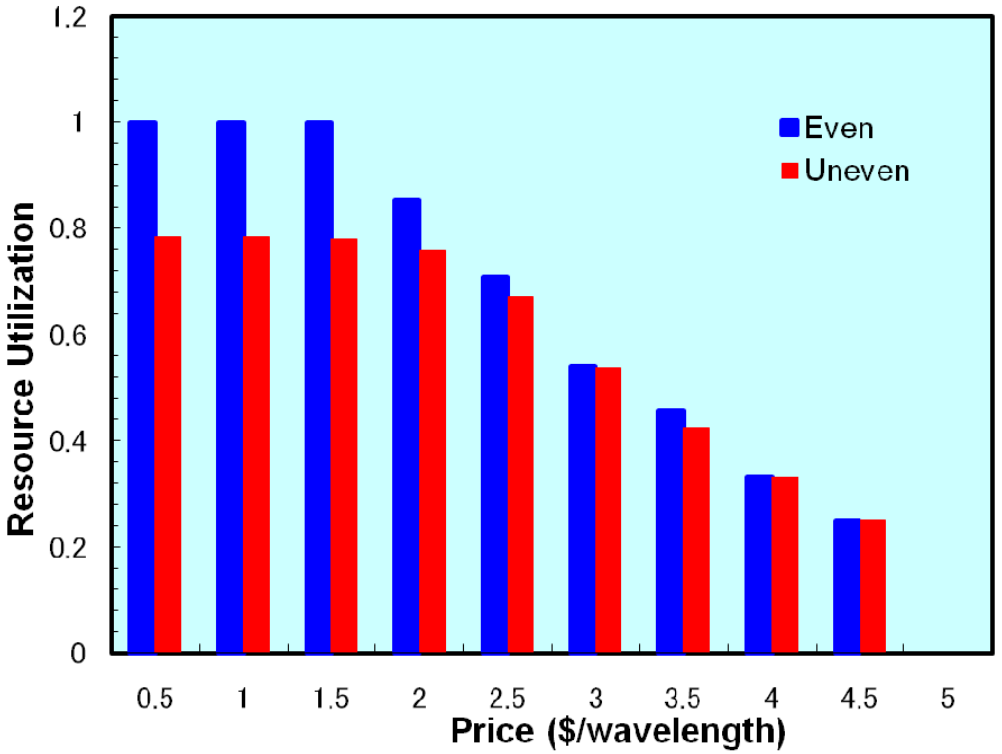


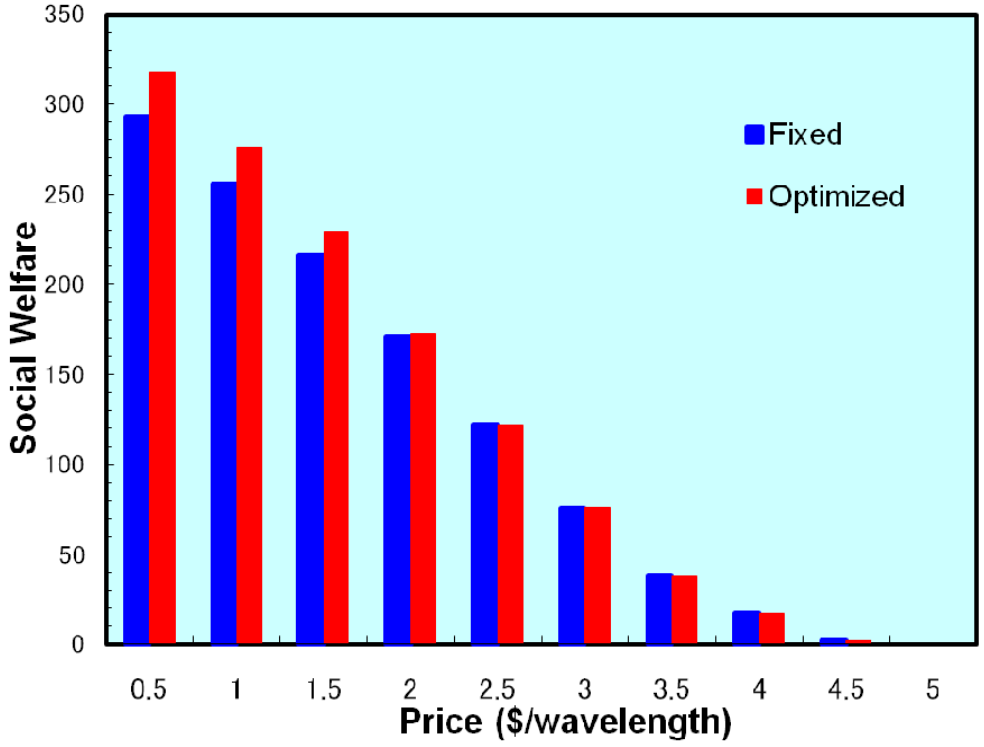
Fig. Resource Utilization



Results 3: Fixed vs optimized topology

- Investigate effectiveness of optimized topology under uneven traffic
  - Compensate uneven resource utilization and improve resource utilization
  - More effective for lower price (about 10% gain for welfare)
  - No gain for optimized topology for even traffic distribution (not shown)

Fig. Social Welfare



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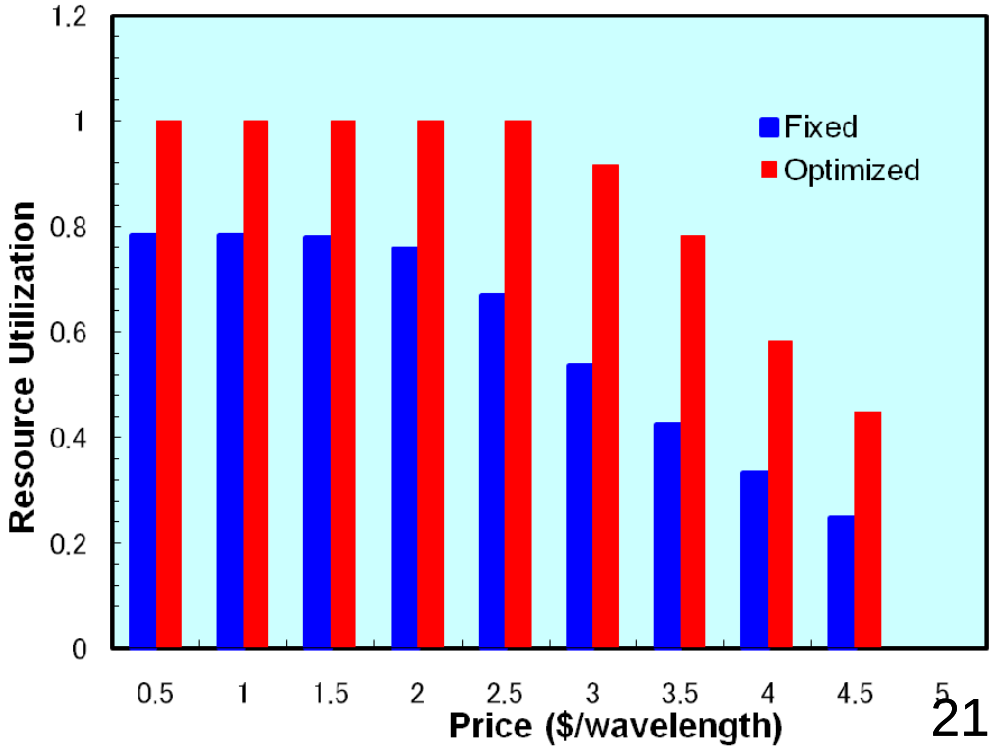

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Concluding Remarks

- **Conclusion:**
  - The VNT service can improve flexibility regarding bandwidth while reducing operation overhead and maintaining advantages of existing BoD services.
  - Considering today's customer's traffic usage (highly variable and uneven distribution), topology optimization and resource control with pricing is beneficial.
  - It is important to choose adequate price considering traffic demand and residual network resources.

- **Further study:**
  - Introduce more sophisticated optimization strategies (e.g., Multilayer TE)
  - Investigate the merit of service provider (how to utilize effectively residual bandwidth)
  - Consider time-varying traffic demand
  - Establish the pricing strategies

Backup Slides 2: Topology seen by user network

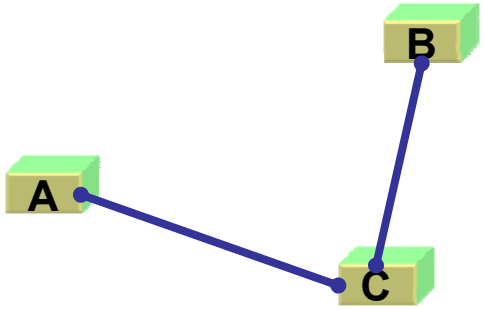
- Case 1: User site terminates optical paths routed on the providers network
  - Some UNI signaling for controlling optical paths is required
- Case 2: User-Provider is packet-based interface. Provider offers IP routing functionality.
  - User site regard Provider network as one large router.

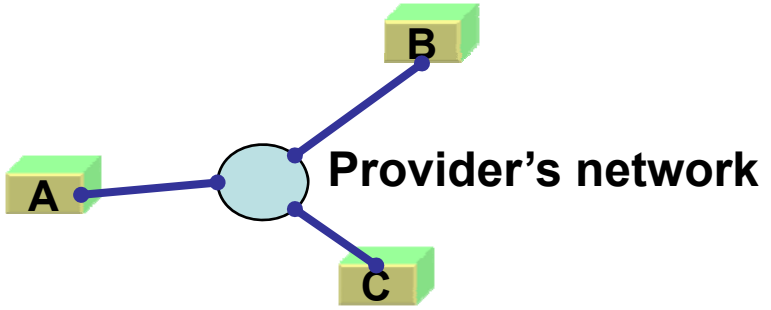
Case 1:

Case 2:

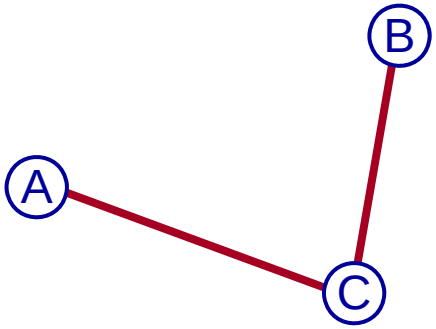
Topology

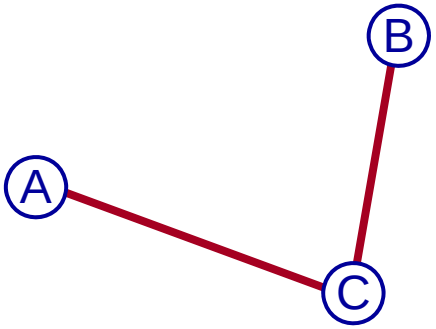
Seen by user





VNT





Backup Slides 1: Optimizing VNT

- Optical VNT is determined by traffic demand and physical network topology.