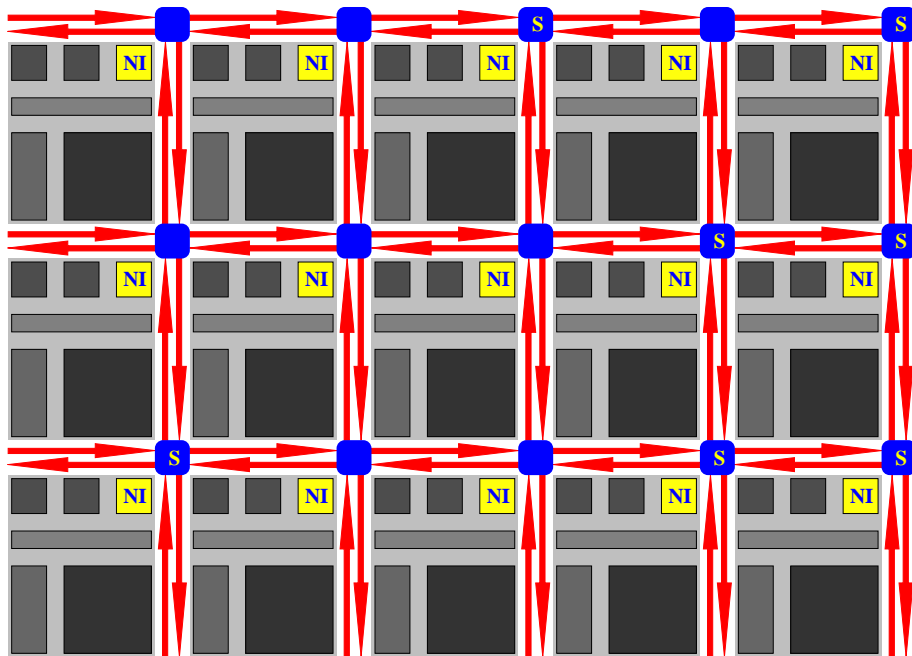


Resource Allocation for Quality of Service On-chip Communication



Axel Jantsch, Zhonghai Lu

Royal Institute of Technology, Stockholm

April 2008

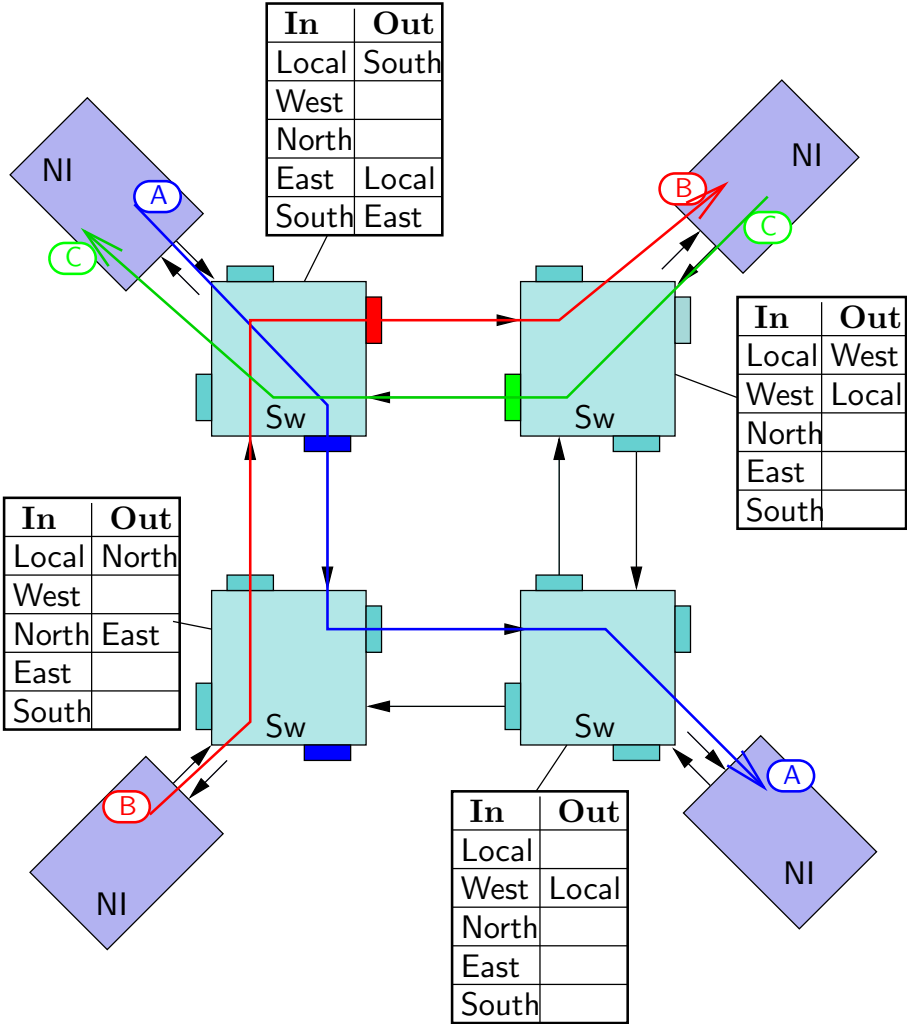
Overview

Circuit Switching

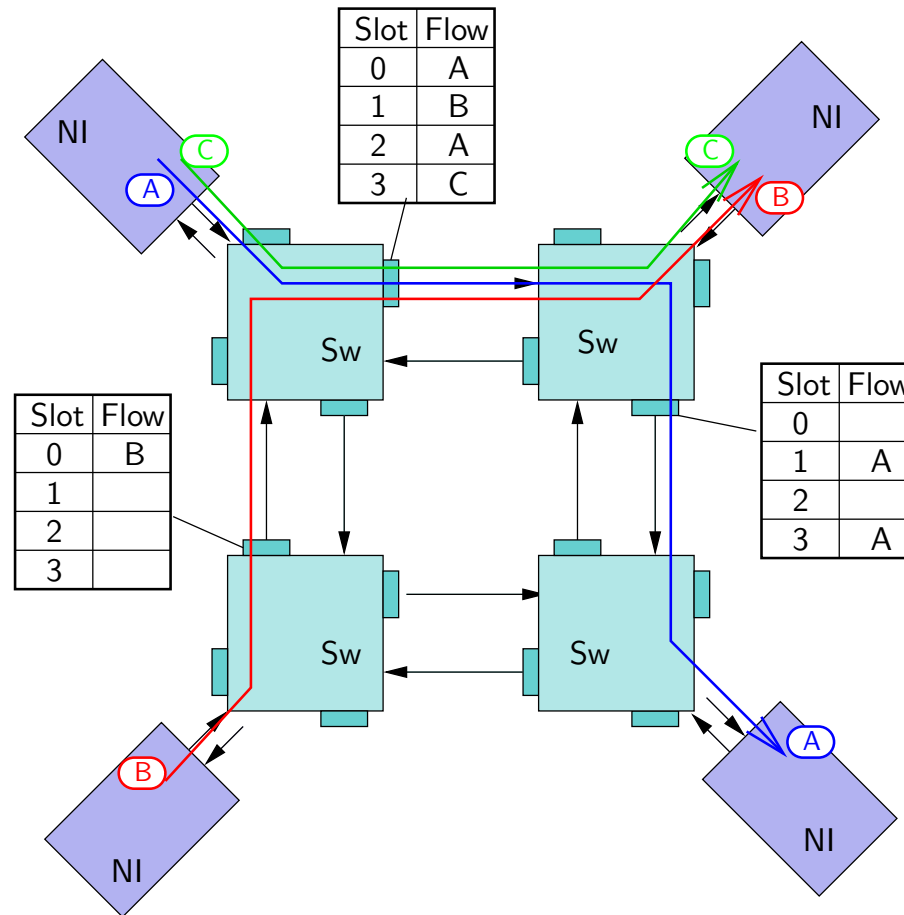
Time Division Multiplexing Virtual Circuits

Aggregate Resource Allocation

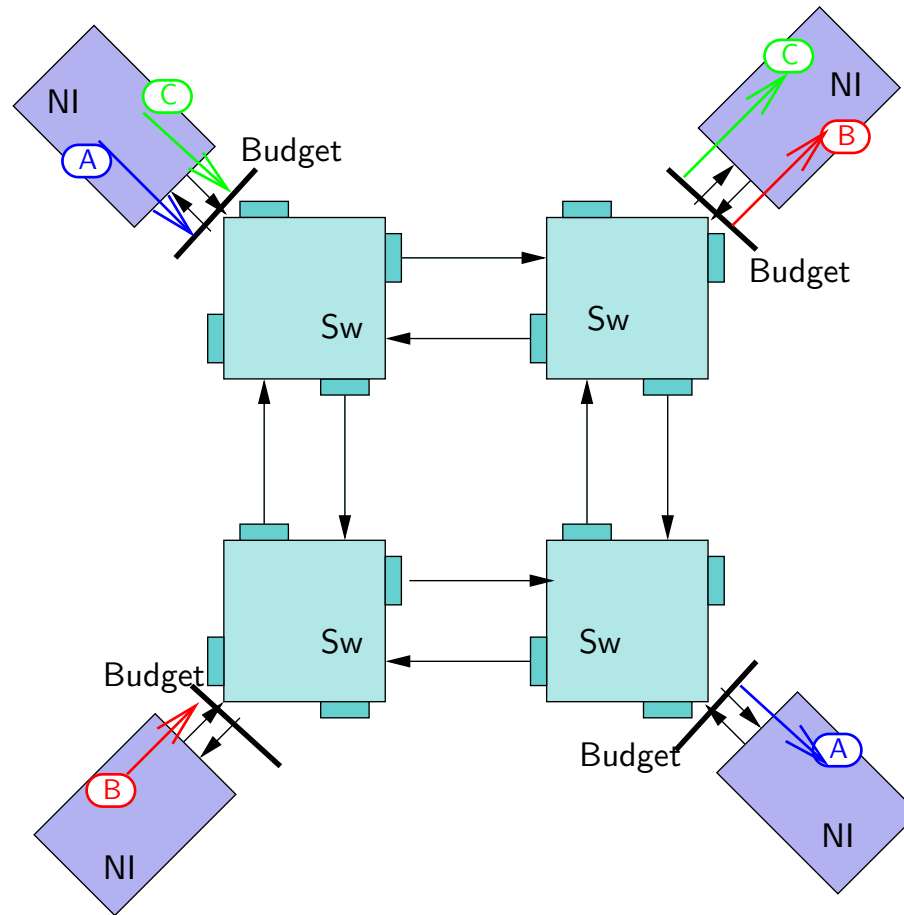
Circuit Switching



Time Division Multiplexing - TDM



Aggregate Traffic Budgets



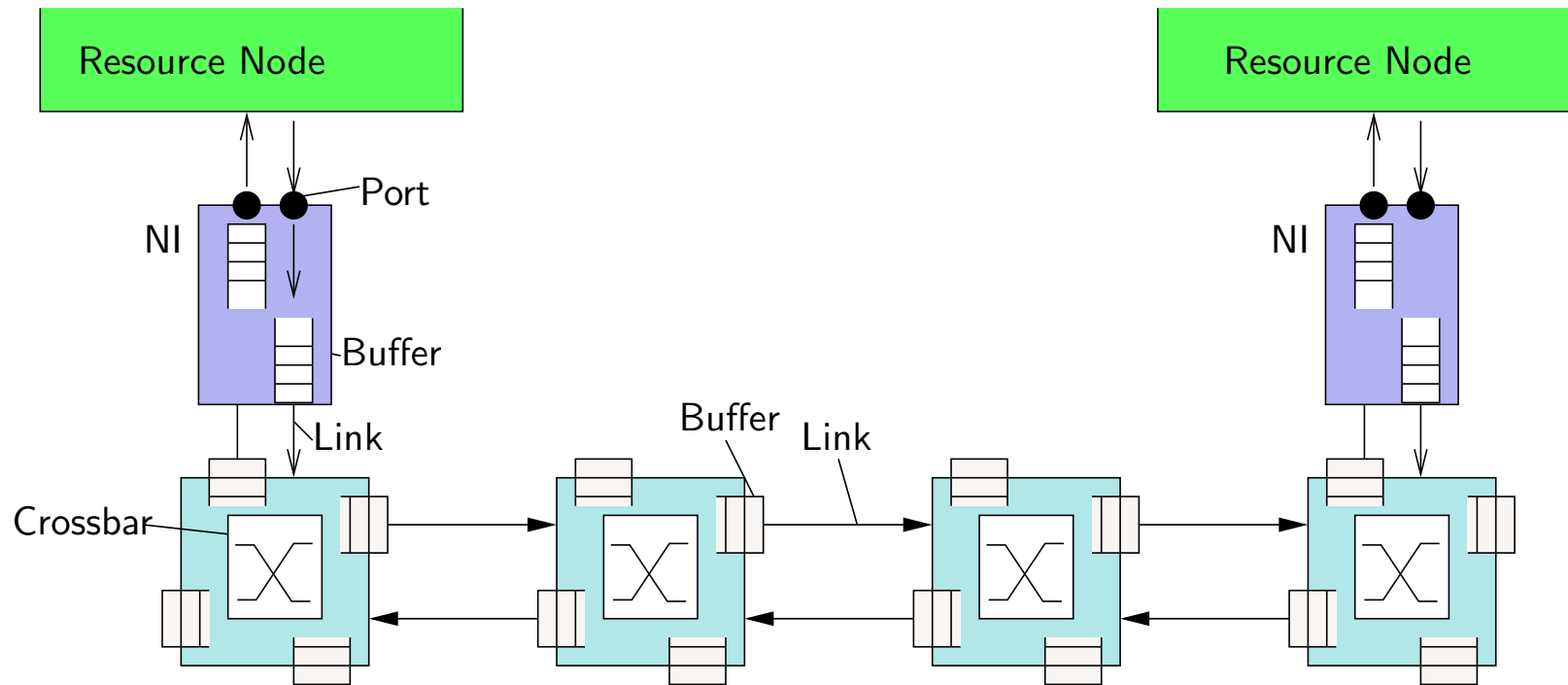
Overview

Circuit Switching

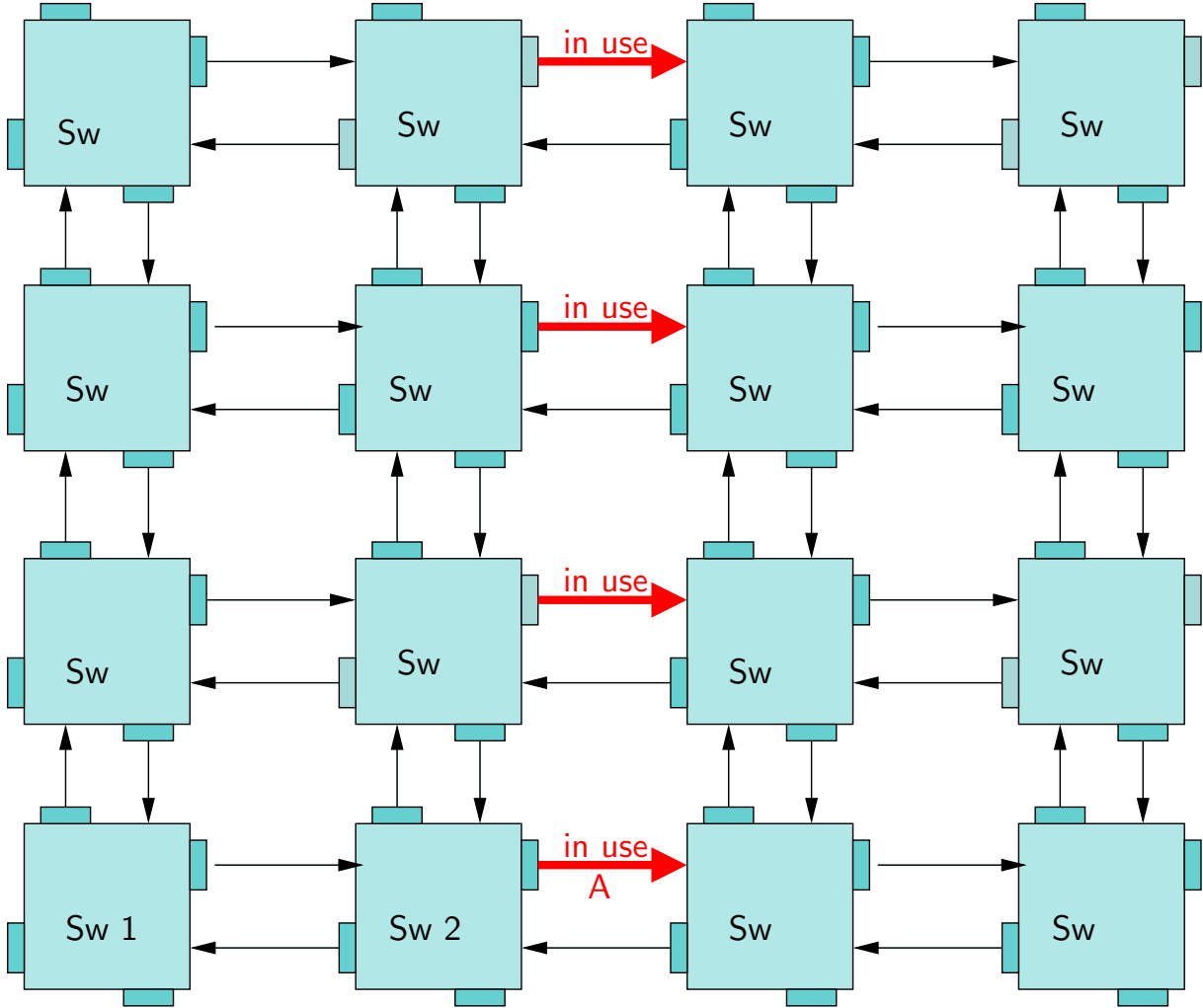
Time Division Multiplexing Virtual Circuits

Aggregate Resource Allocation

Circuit Switching - Resource Chain



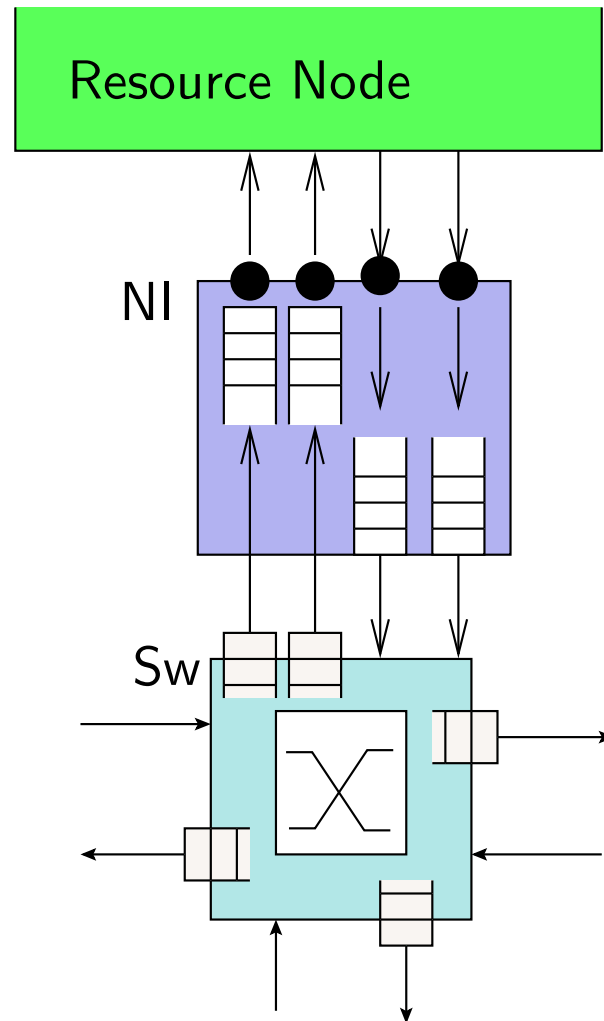
Circuit Switching Inflexibilities



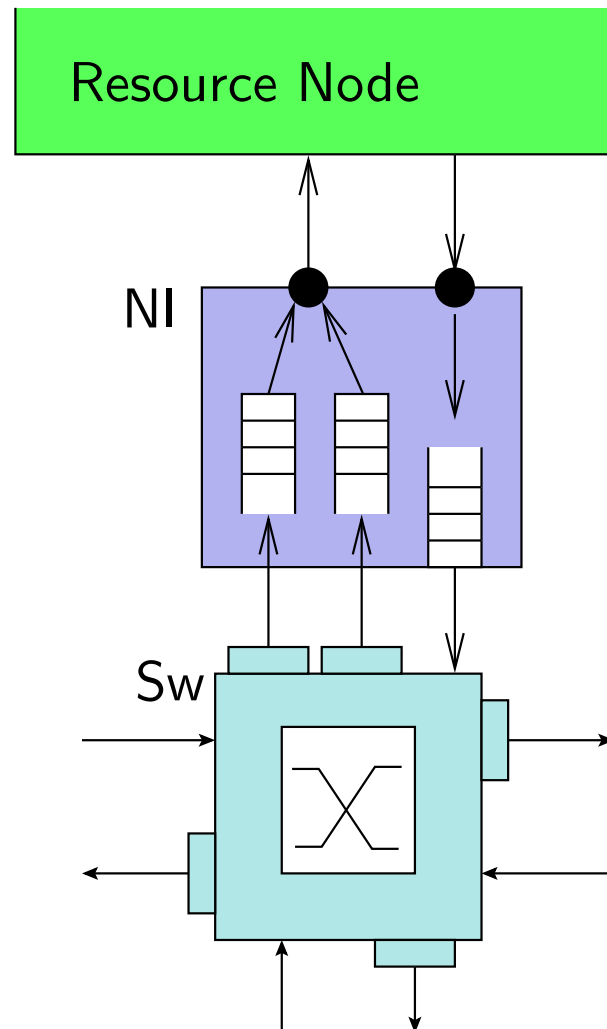
Pure Circuit Switching Can Be Beneficial

- Few static, well understood traffic streams with high throughput demands and long lifetime
- Networks with up to two hops

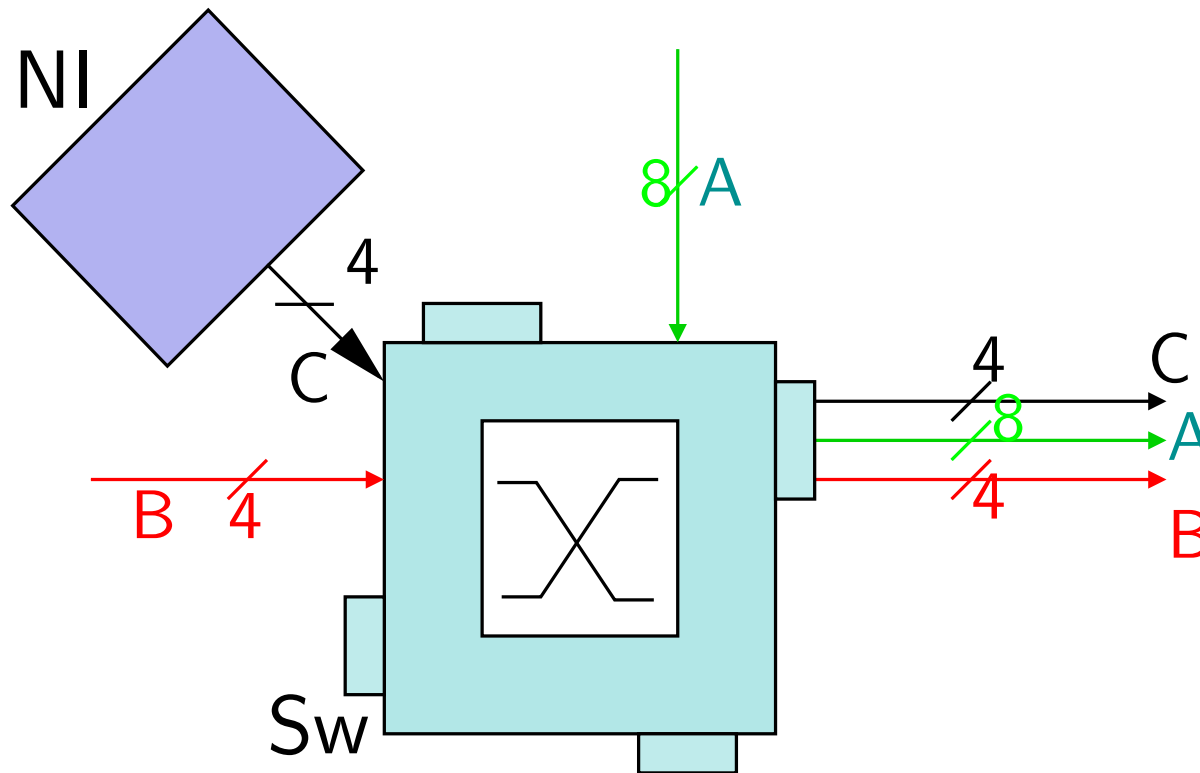
Circuit Switching - Duplication of NI Buffers



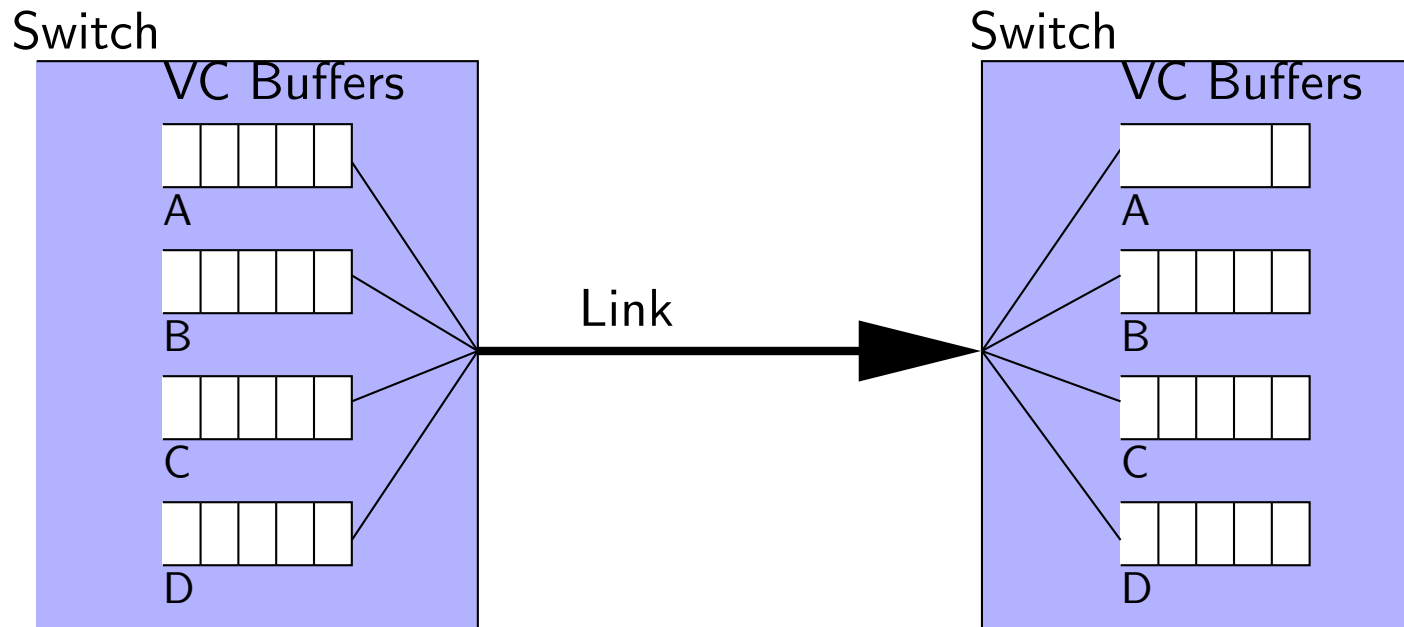
Circuit Switching - Dual Packet Exit



Circuit Switching with Spatial Division Multiplexing



Circuit Switching with Shared Links a lá Mango



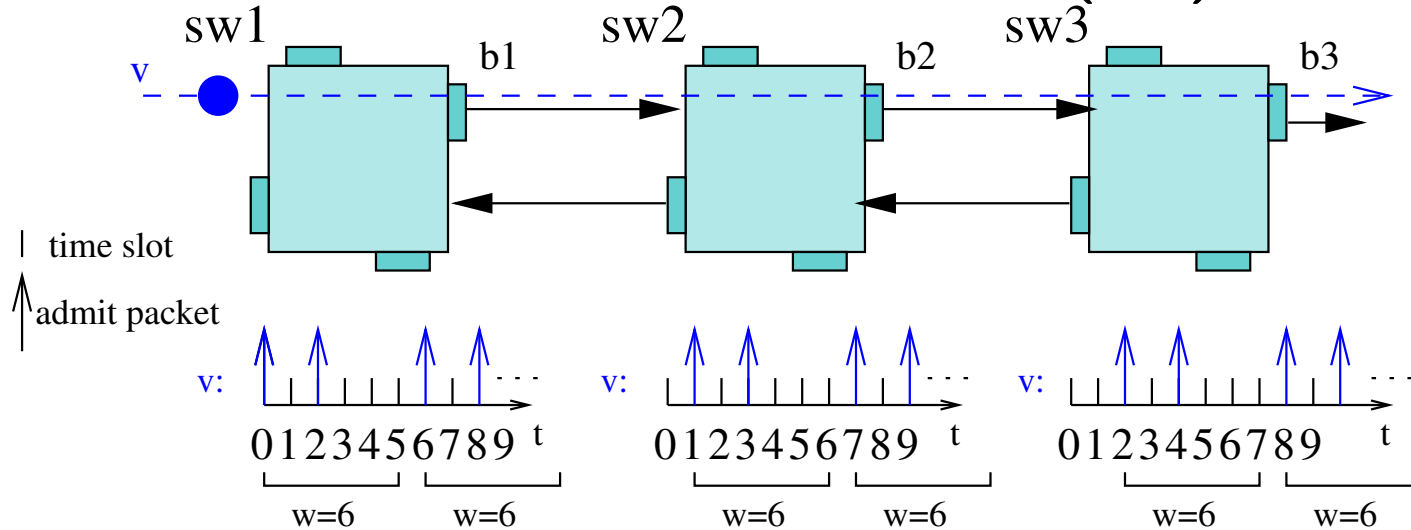
Overview

Circuit Switching

Time Division Multiplexing Virtual Circuits

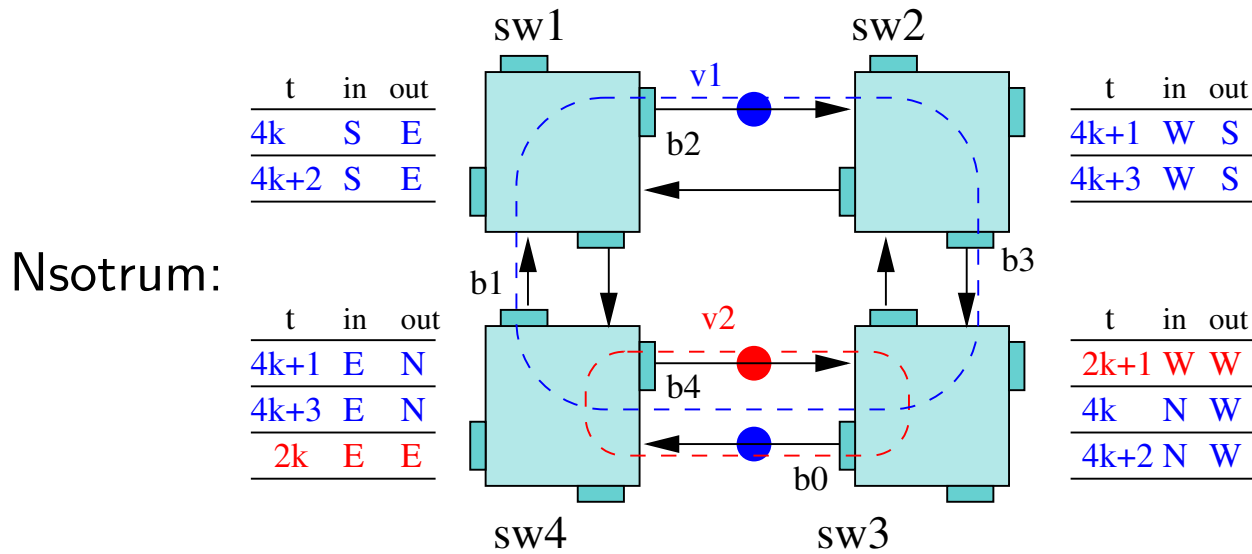
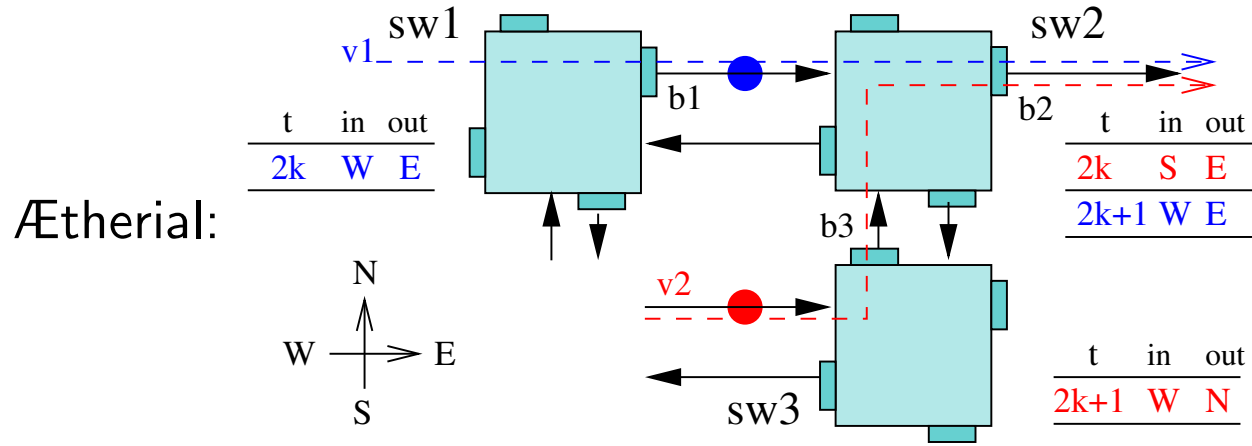
Aggregate Resource Allocation

TDM Based Virtual Circuit (VC)



- Network is synchronized by a global time
- Links and buffers are allocated together
- VCs are defined by routing tables in switches
- Transmission speed is 1 hop/cycle
- Repetitive traffic papper is called an **admission cycle** (e.g. 2 packets per 6 slots)
- Buffer occupation:
 - ★ b_1 : slots 0, 2, 6, 8, 12, 14, ...
 - ★ b_2 : slots 1, 3, 7, 9, 13, 15, ...
 - ★ b_3 : slots 2, 4, 8, 10, 14, 16, ...

Open Ended and Closed Loop VCs



TDM VC Configuration Problem

Given a set of VC specifications (source, destination, minimum bandwidth), determine and implement the necessary VCs.

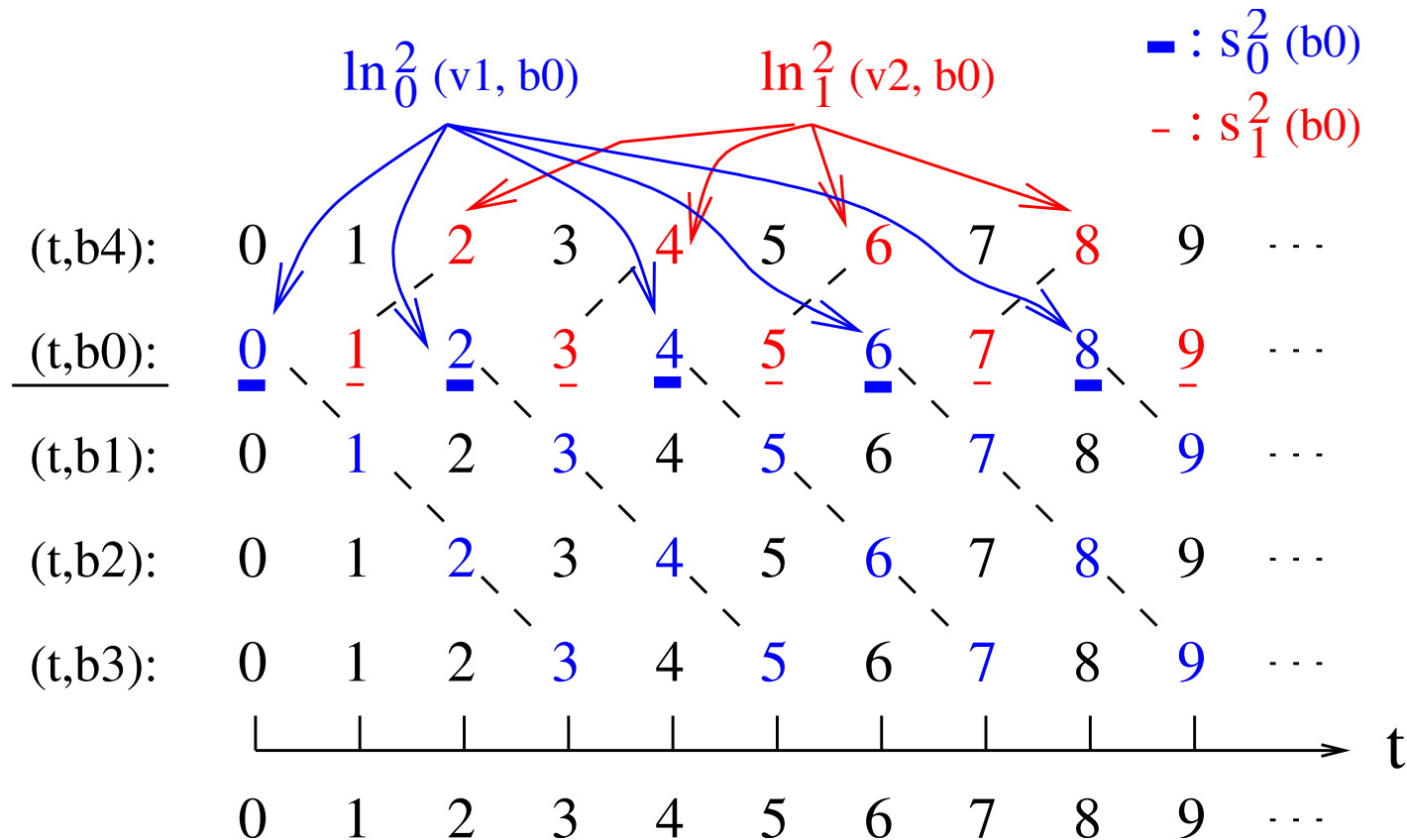
- **Path selection:** For each VC determine the sequence of nodes between source and destination.
- **Slot allocation:** For each VC determine the allocated time slots for each buffer in the VC.

Conditions to be satisfied:

- All VCs are contention free;
- All VCs allocated sufficient number of slots to provide the require bandwidth;
- The network must be deadlock free and livelock free;
- Sufficient bandwidth must remain for best effort traffic;

Logic Networks

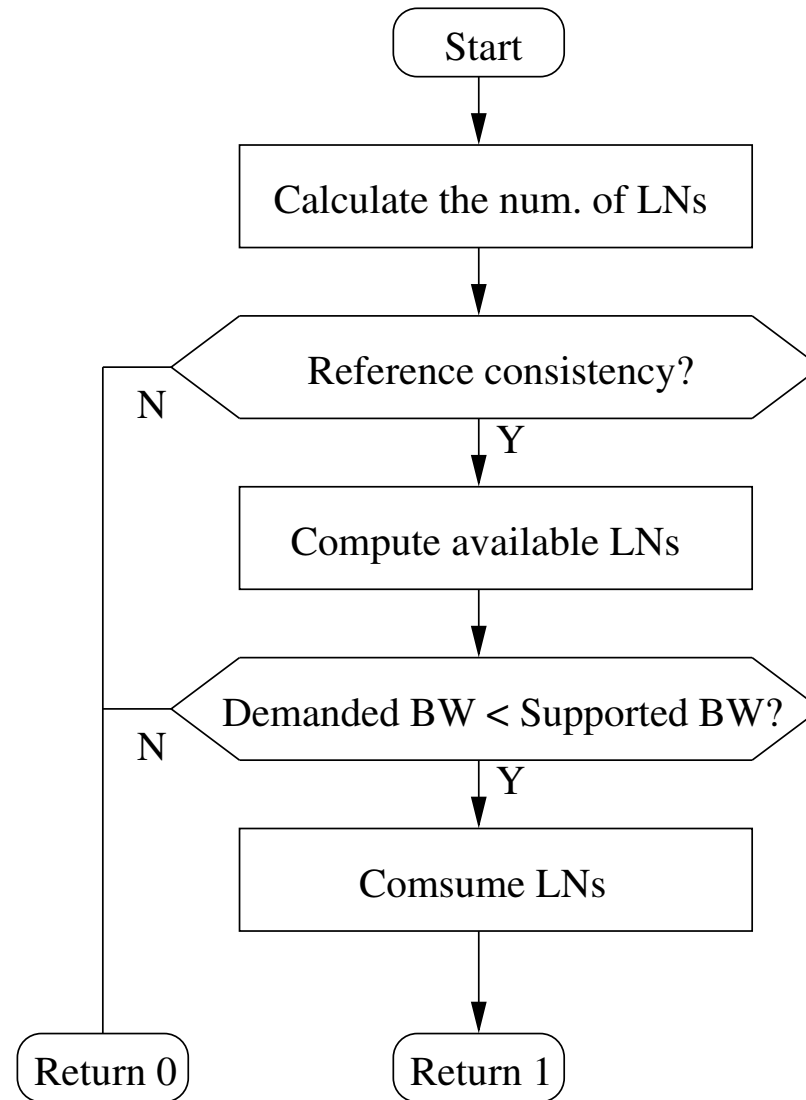
A logic network (LN) is an infinite set of associated *(time slot, buffer)* pairs with respect to a buffer on a path.



Logic Network Properties

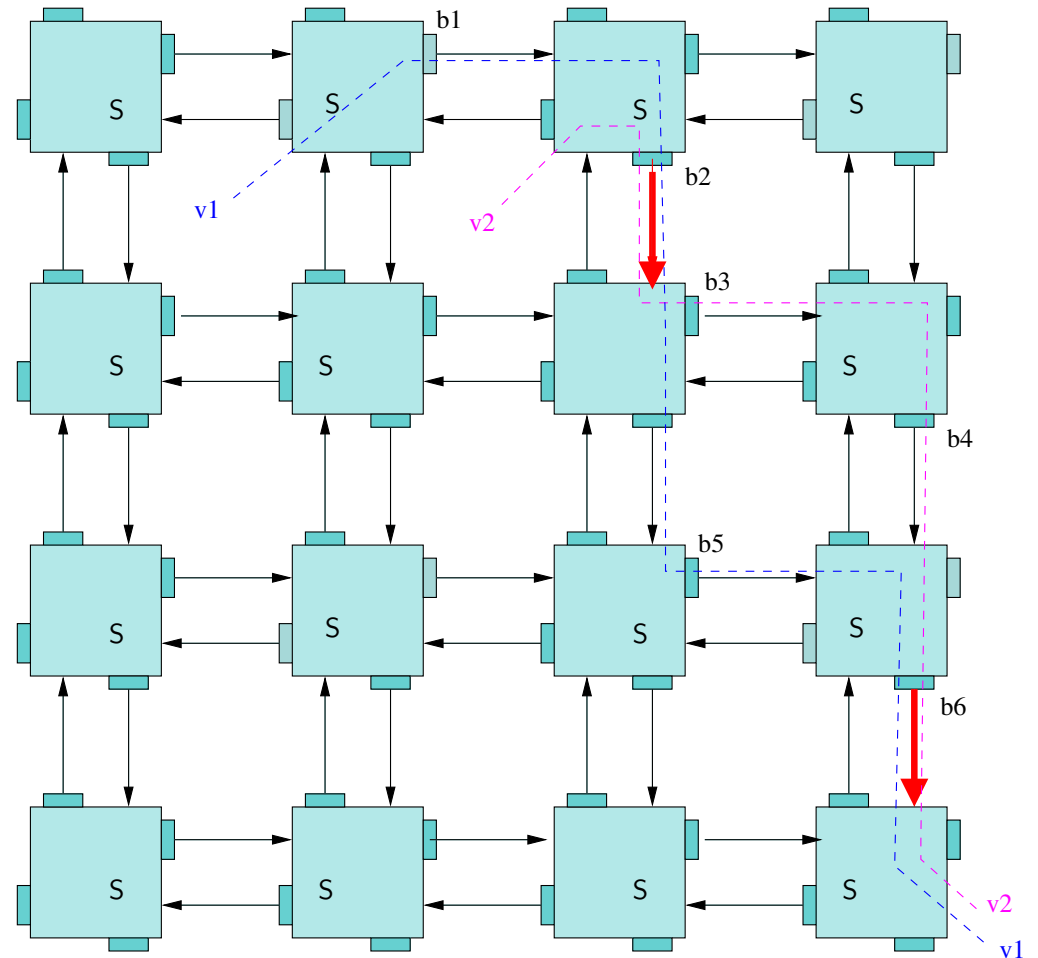
- The maximum number N of LNs that can be constructed such, that two VCs v_1 and v_2 subscribe to different LNs without conflict, is $\gcd(D_1, D_2) \geq N$ (D_1 and D_2 are admission cycles of v_1 and v_2); The bandwidth of an LN is $1/N$ packet/cycle.
- Assigning v_1 and v_2 to different LNs is sufficient and necessary to avoid conflict;
- If v_1 and v_2 have multiple shared buffers, they need to be *reference consistent*; reference consistency can be checked linearly;

Logic Network based Slot Allocation



Slot Allocation Example

- $v_1 = b_1, b_2, b_5, b_6, BW(v_1) = 3/8,$
 $v_2 = b_2, b_3, b_4, b_6, BW(v_2) = 7/16,$
- $N = GCD(8, 16) = 8$
- Shared buffers are b_2 and b_6
- Distance between b_2 and b_6 is 2 along both v_1 and $v_2 \Rightarrow$ Buffers are reference consistent
- With b_2 as reference buffer we have as slot set: 0, 1, 2, 3, 4, 5, 6, 7, each represents an LN
- We allocate slots 0, 2, 4 $\rightarrow v_1;$
 1, 3, 5, 7 $\rightarrow v_2;$



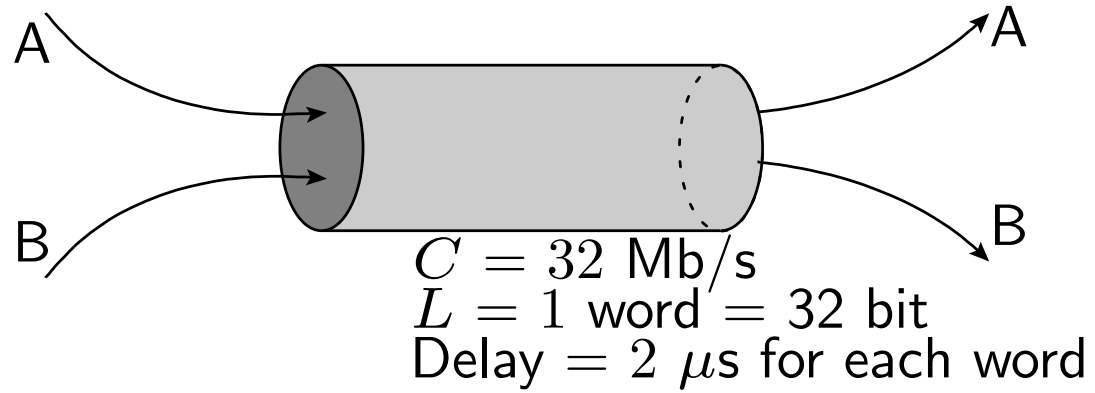
Overview

Circuit Switching

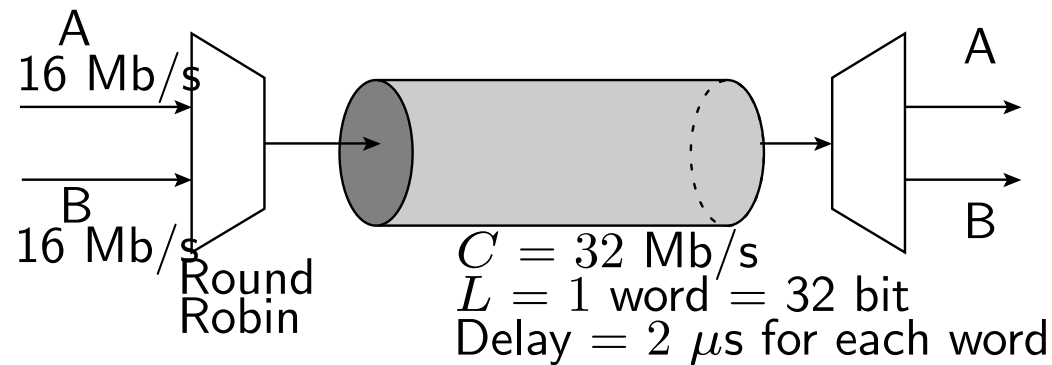
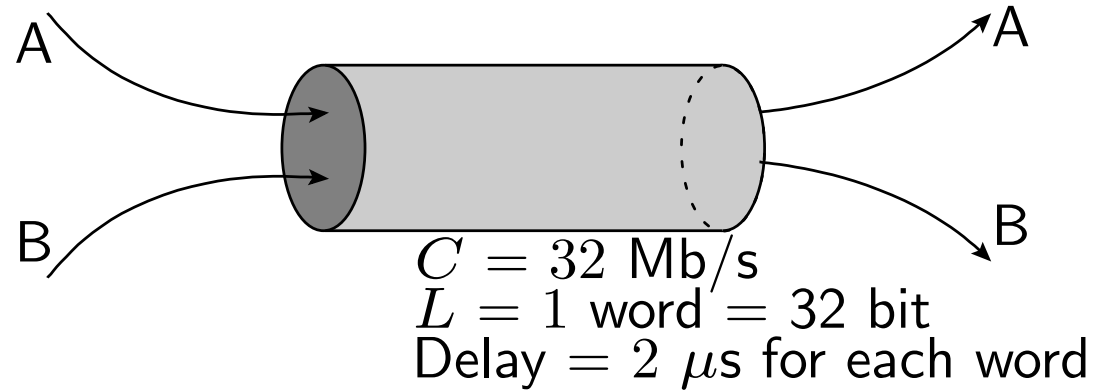
Time Division Multiplexing Virtual Circuits

Aggregate Resource Allocation

Aggregate Allocation of a Channel



Aggregate Allocation of a Channel



- Characteristics of the flows
- Arbitration policy for channel access

(σ, ρ) Regulated Flows

A Flow F is (σ, ρ) regulated if

$$F(b) - F(a) \leq \sigma + \rho(b - a)$$

for all time intervals $[a, b]$, $0 \leq a \leq b$ and where

$F(t) \cdots$ the cumulative amount of traffic between 0 and $t \geq 0$.

$\sigma \geq 0$ is the burstiness constraint;

$\rho \geq 0$ is the maximum average rate;

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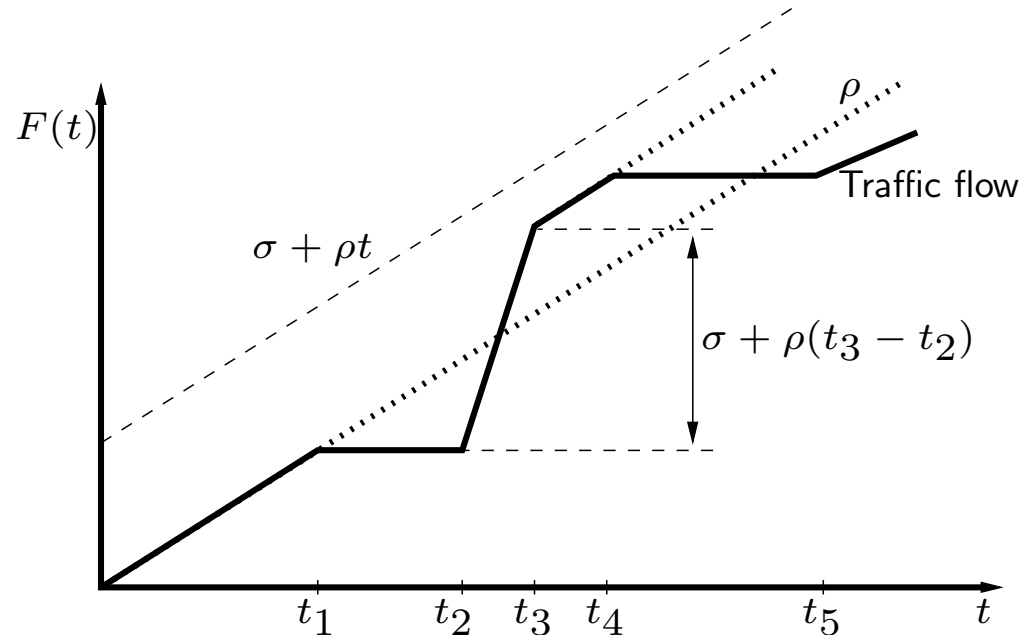
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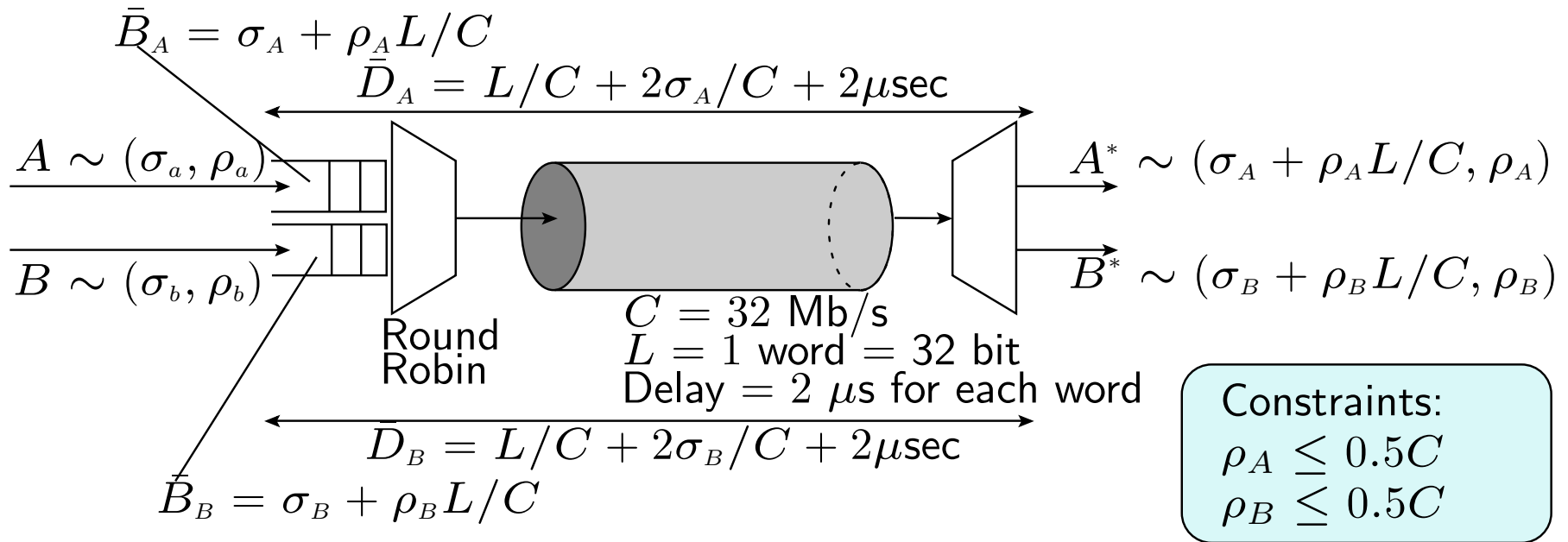
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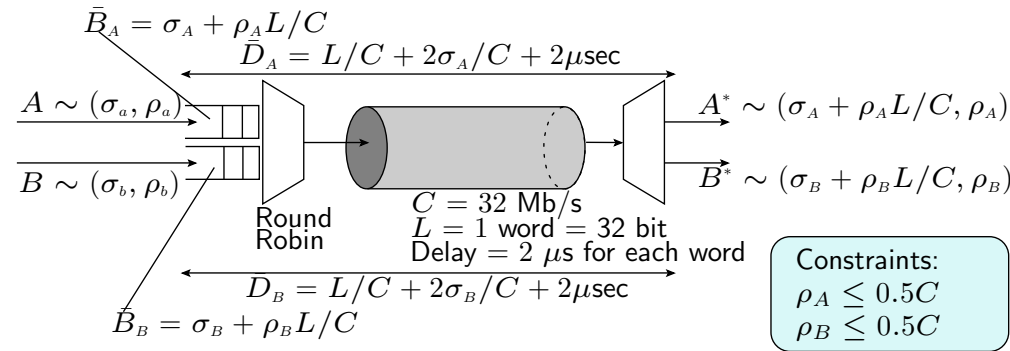
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Channel Shared by Two Regulated Flows - Round Robin

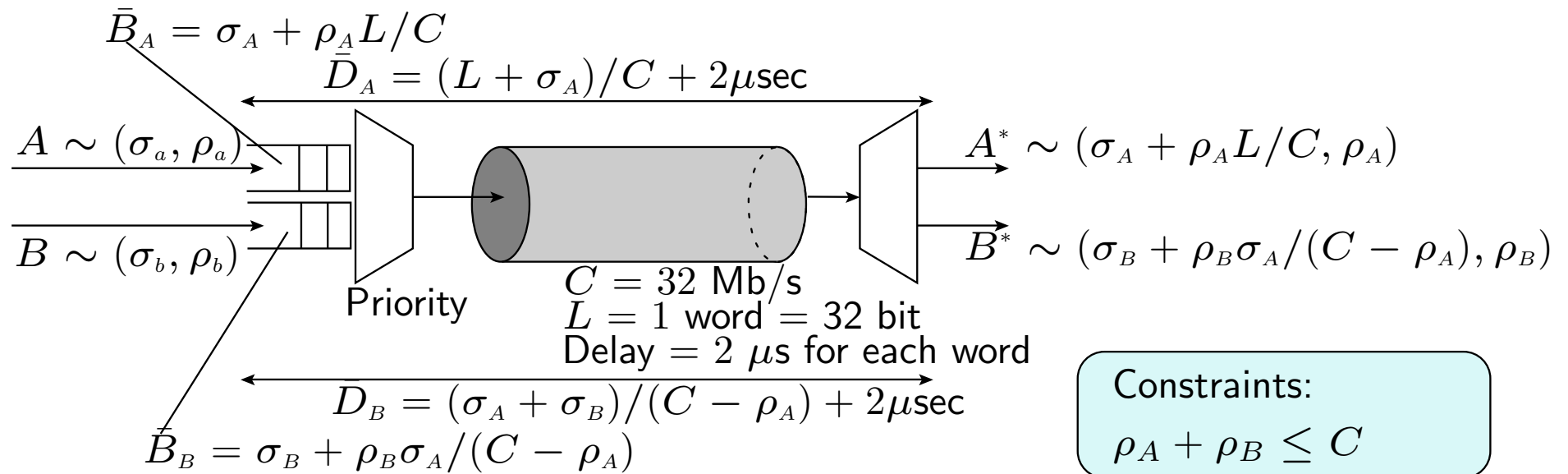


Channel Shared by Two Regulated Flows - Round Robin

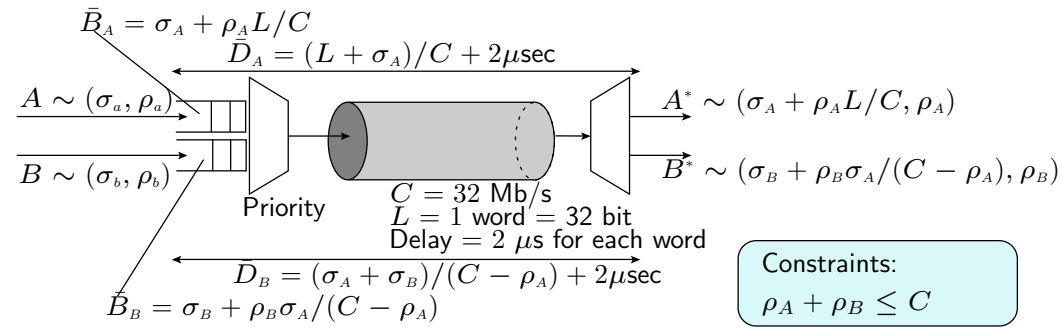


A	B	\bar{B}_A	\bar{D}_A	A	\bar{B}_B	\bar{D}_B	B
(σ_A, ρ_A)	(σ_B, ρ_B)			$(\sigma_{A^*}, \rho_{A^*})$			$(\sigma_{B^*}, \rho_{B^*})$
(0, 16.00)	(0, 16.00)	32	3	(32, 16.00)	32	3	(32, 16.00)
(0, 12.80)	(0, 12.80)	32	3	(32, 12.80)	32	3	(32, 12.80)
(0, 9.60)	(0, 16.00)	32	3	(32, 9.60)	32	3	(32, 16.00)
(0, 6.40)	(0, 16.00)	32	3	(32, 6.40)	32	3	(32, 16.00)
(0, 3.20)	(0, 16.00)	32	3	(32, 3.20)	32	3	(32, 16.00)
(0, 16.00)	(0, 16.00)	32	3	(32, 16.00)	32	3	(32, 16.00)
(32, 16.00)	(0, 16.00)	64	5	(64, 16.00)	32	3	(32, 16.00)
(64, 16.00)	(0, 16.00)	96	7	(96, 16.00)	32	3	(32, 16.00)
(128, 16.00)	(0, 16.00)	160	11	(160, 16.00)	32	3	(32, 16.00)
(256, 16.00)	(0, 16.00)	288	19	(288, 16.00)	32	3	(32, 16.00)

Channel Shared by Two Regulated Flows - Priority

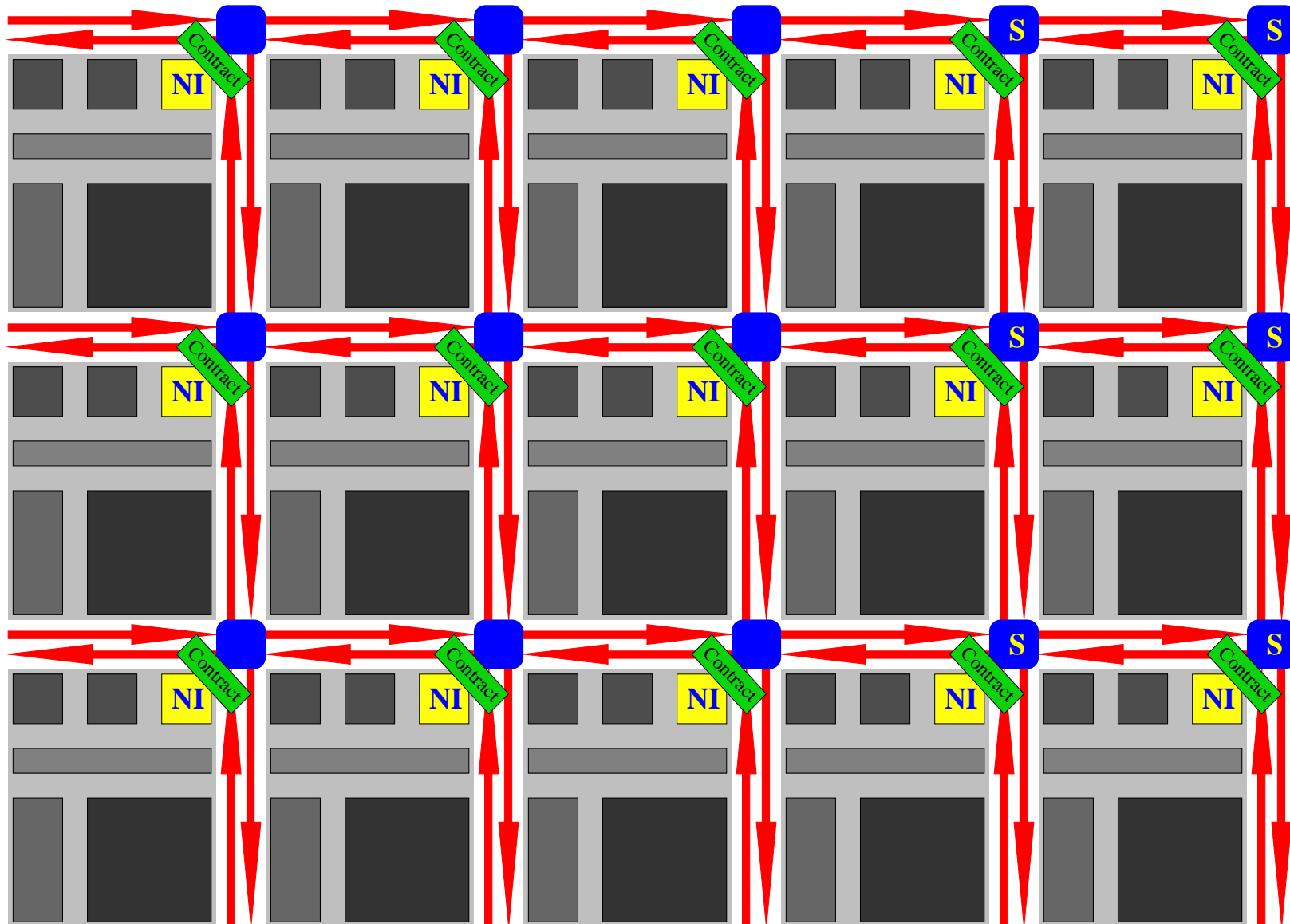


Aggregate Allocation of a Channel



A	B	A			B		
(σ_A, ρ_A)	(σ_B, ρ_B)	\bar{B}_A	\bar{D}_A	$(\sigma_{A^*}, \rho_{A^*})$	\bar{B}_B	\bar{D}_B	$(\sigma_{B^*}, \rho_{B^*})$
(0, 16.00)	(0, 16.00)	32	3	(32, 16.00)	32	4	(32, 16.00)
(0, 12.80)	(0, 12.80)	32	3	(32, 12.80)	32	4	(32, 12.80)
(0, 9.60)	(0, 16.00)	32	3	(32, 9.60)	32	3	(32, 16.00)
(0, 6.40)	(0, 16.00)	32	3	(32, 6.40)	32	3	(32, 16.00)
(0, 3.20)	(0, 16.00)	32	3	(32, 3.20)	32	3	(32, 16.00)
(0, 16.00)	(0, 16.00)	32	3	(32, 16.00)	32	4	(32, 16.00)
(32, 16.00)	(0, 16.00)	64	4	(64, 16.00)	32	4	(32, 16.00)
(64, 16.00)	(0, 16.00)	96	5	(96, 16.00)	64	6	(64, 16.00)
(128, 16.00)	(0, 16.00)	160	7	(160, 16.00)	128	10	(128, 16.00)
(256, 16.00)	(0, 16.00)	288	11	(288, 16.00)	256	18	(256, 16.00)

Aggregate Resource Allocation for the Entire Network



Aggregate Resource Allocation In Nostrum

$$\sum_{h \in H_r^o} E_h \leq B_r^o$$

$$\sum_{h \in H_r^i} E_h \leq B_r^i$$

$$\sum_r B_r^o = \sum_r B_r^i \leq \kappa C_{\text{Net}}$$

$$\text{BW}_h = \frac{n_h}{W}$$

$$\text{maxLat}_h = 5DN$$

$$\text{avgLat}_h = d_h \delta$$

Summary

- QoS Provision is about resource allocation
- Circuit switching
- Time Division Multiplexing
- Aggregate resource allocation
- Exclusive allocation - shared resources
- Average case - worst case
- Allocation flexibility - cost efficiency