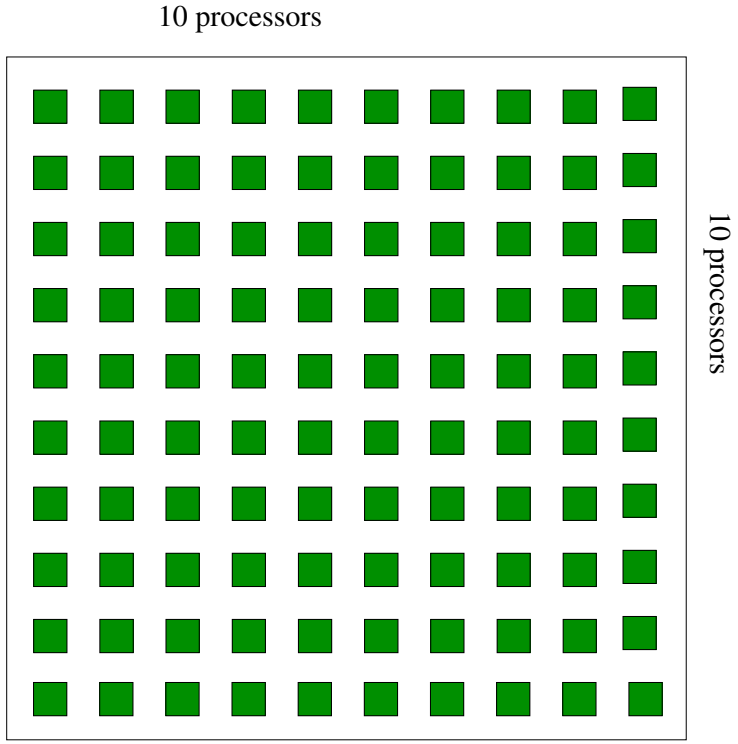
The Nostrum Network on Chip



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December 1, 2004

Overview

Topology and Structure

Protocol Stack

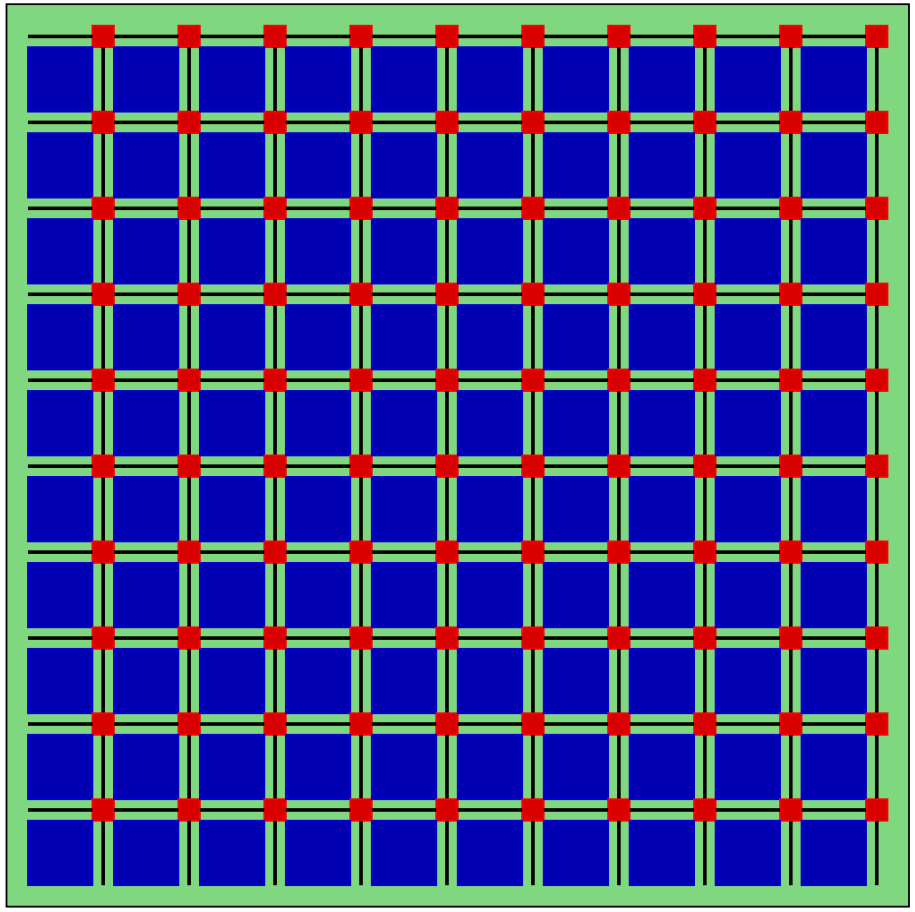
The Network Layer and the Switch

Data Protection

Simulation Environment

Clocking

Nostrum Topology: Mesh



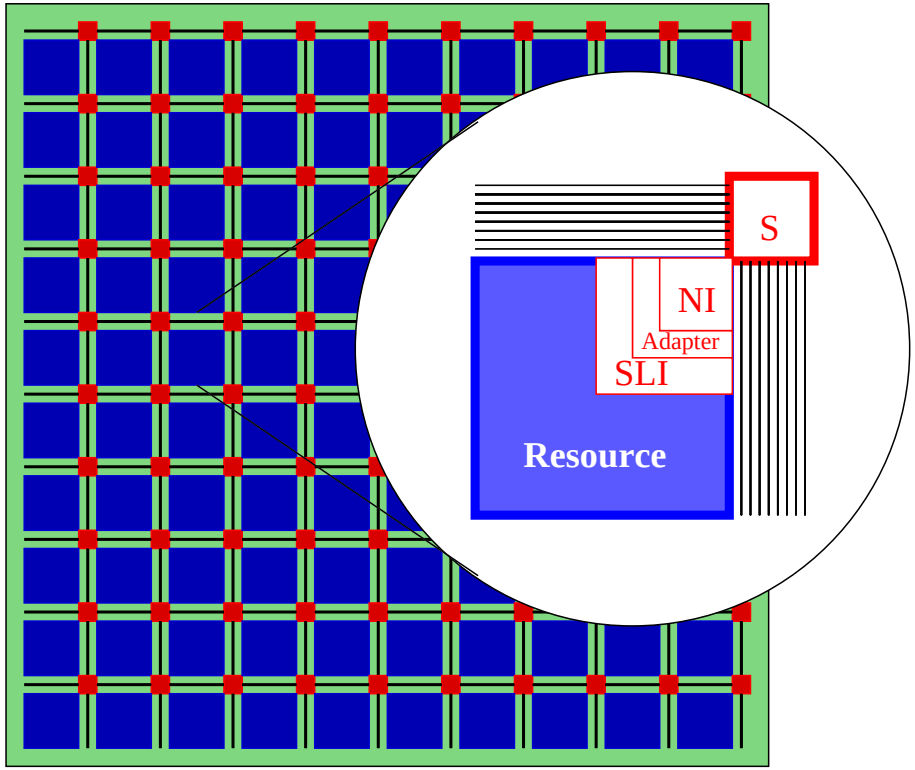
Characteristics:

- Resource-to-switch ratio: 1
- A switch is connected to 4 switches and 1 resource
- A resource is connected to 1 switch
- Max number of hops grows with $2n$

Motivation:

- Regularity of layout; predictable electrical properties
- Expected locality of traffic

The Node in a Mesh



NI: Network Interface:

- Compulsory
- HW
- Implements the network layer protocol

Adapter: Resource specific interface circuit;

SLI: Session Layer Interface:

- Optional
- Hardware and/or software
- Implements the session layer protocol

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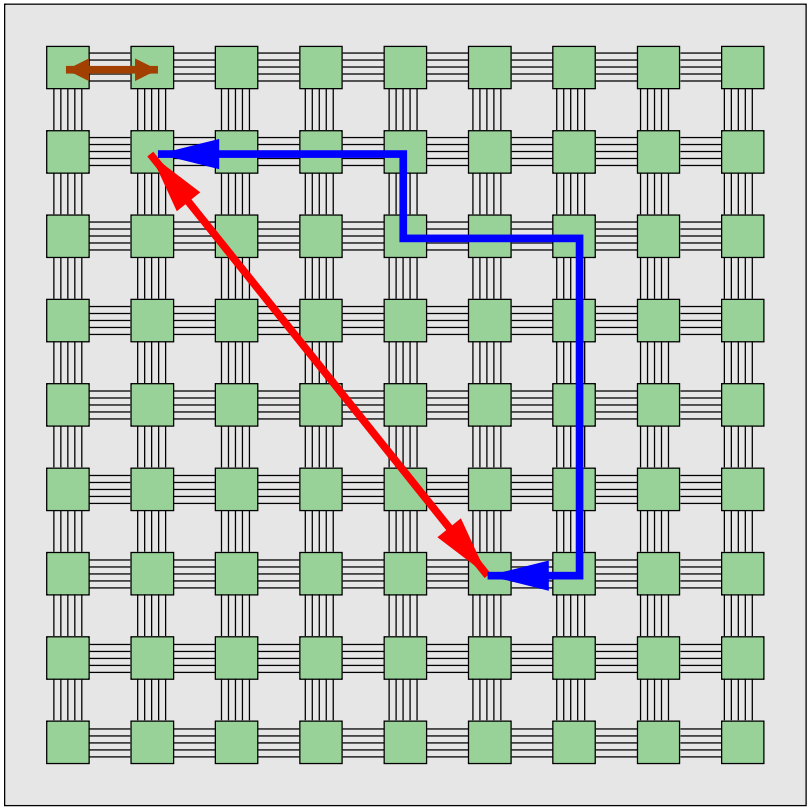
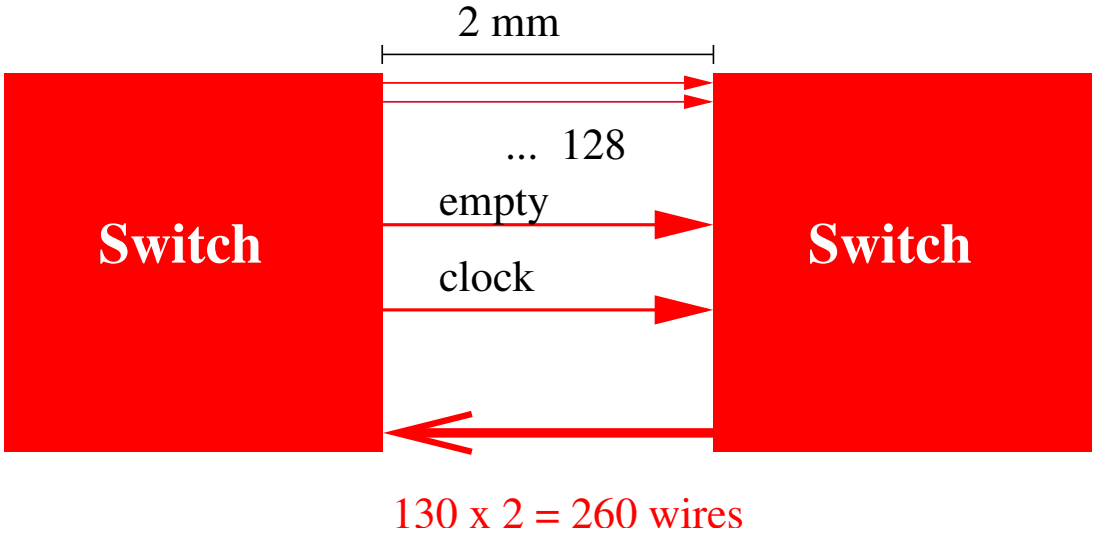
Communication is Key



Communication Layers:

- Physical layer: switch-to-switch and switch-to-resource
- Data link layer: switch-to-switch and switch-to-resource
- Network layer: resource-to-resource
- Session layer: process-to-process
- Application layer: application-to-application

Physical Layer



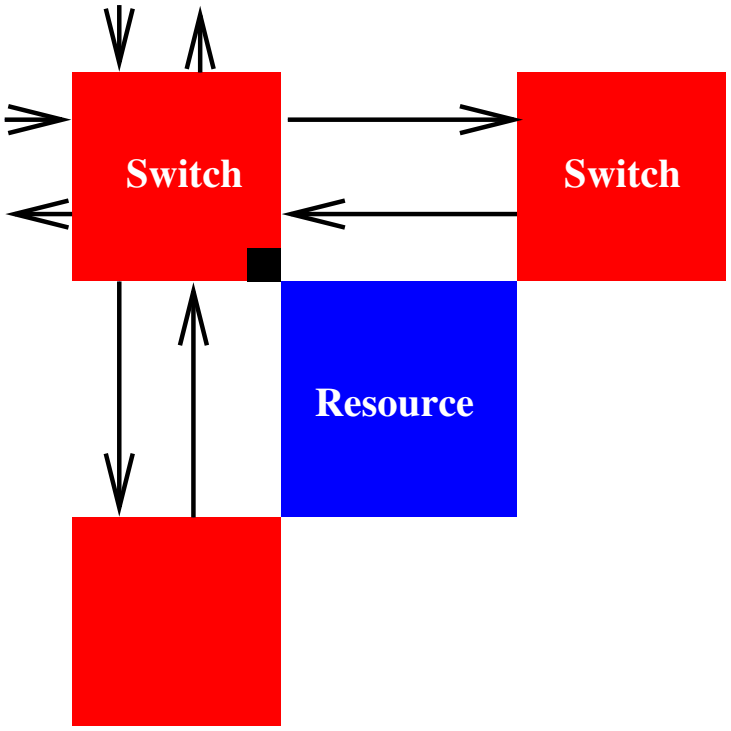
Parameters:

- Physical distance
- Number of lines
- Activity control
- Buffers and pipelining

Nostrum status:

- Channel dimension: $2mm \times 100\mu m$
- 128 data lines in each direction on 4 metal layers
- No pipelining
- On/off control for power saving

Data Link Layer



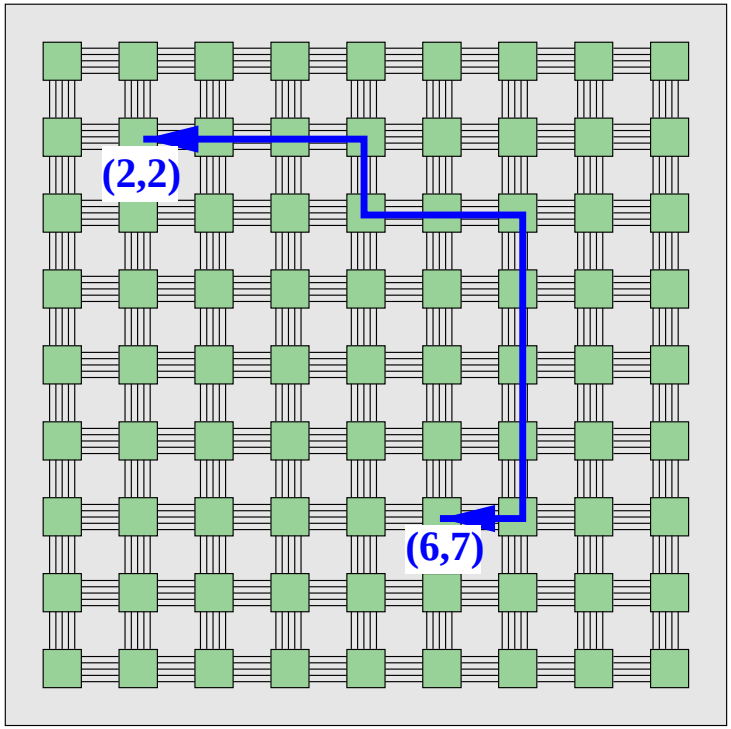
Parameters:

- Line frequency versus switch frequency
- Buffering
- Error correction
- Power optimization encoding

Nostrum status:

- Physical packet = data link packet
- Physical clock = data link clock
- Single packet input buffer
- Error correction
- On/off activity control

Network Layer



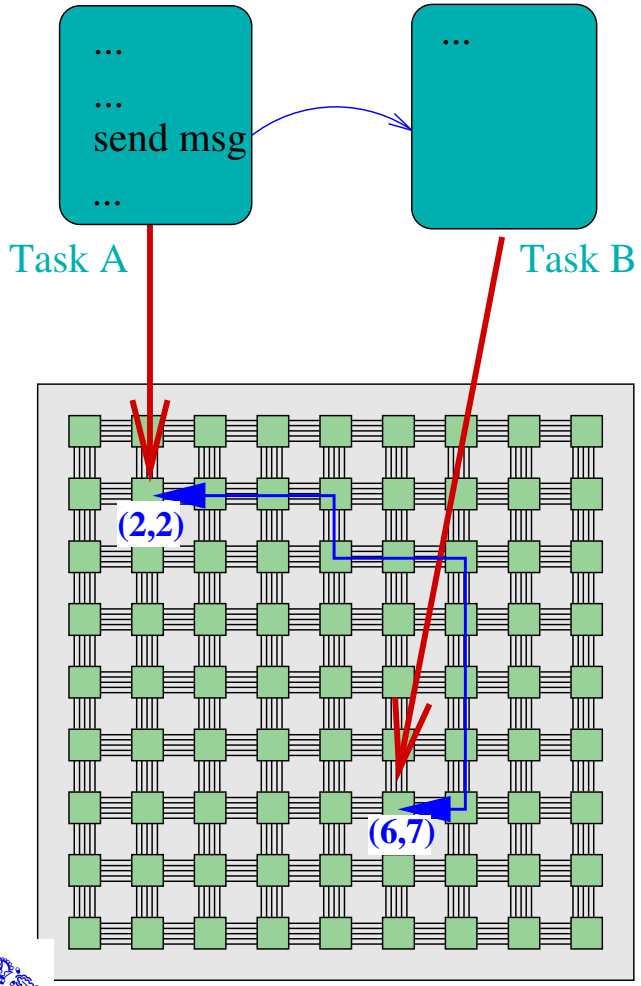
Parameters:

- Link layer cell size vs. network layer packet size
- Network address scheme
- Routing algorithm
- Priority classes
- Error correction

Nostrum status:

- Link layer packet = network layer packet
- Relative x-y addresses
- Deflective routing with no buffers and no routing tables
- Virtual circuits with guaranteed bandwidth and delays
- No error protection

Session Layer



Parameters:

- Task level communication primitives
- Message passing
- Shared memory based communication
- Synchronization
- Error correction

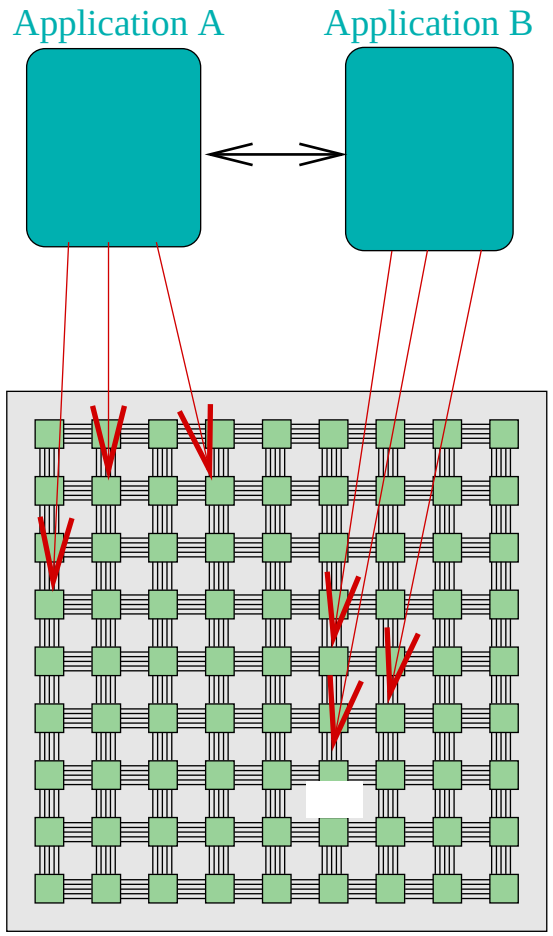
Nostrum status:

- Set of communication primitives defined
- Both message passing and shared memory
- User controlled synchronization
- Optional end-to-end data protection

Session Layer Communication

- Message passing communication:
  - `open/listen/accept/bind` primitives to open a channel
  - `send/receive` to communicate
  - `close` to tear down the channel
  - blocking/non-blocking send/receive
- Shared memory communication:
  - allocation
  - read/write
  - free
  - interruptible/non-interruptible
- VHDL,C and SystemC libraries under development

Application Layers



Application specific communication services;
E.g. the NoC operating system could use:

- Task/resource database access protocol
- Task migration protocol

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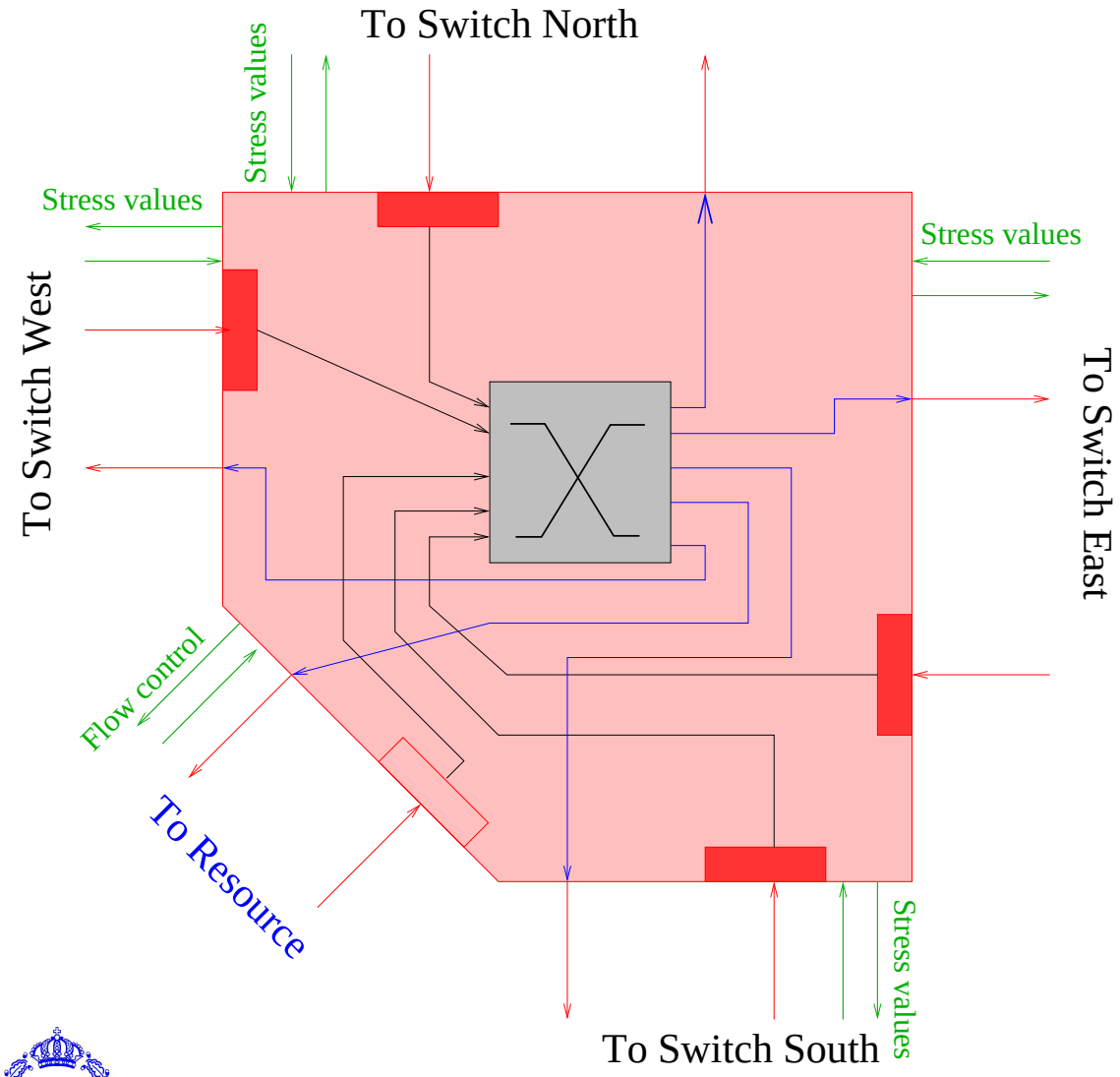
The Network Layer

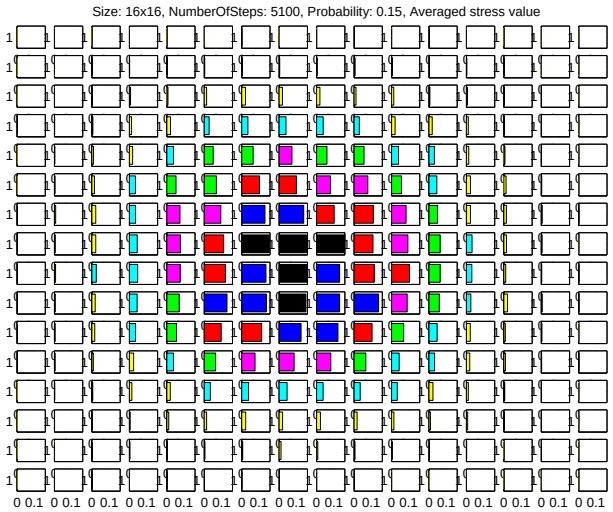
- Packet switched best effort service
  - ⋆ Packets are guaranteed to arrive
  - ⋆ Packet payload may be protected (4 levels of protection)
  - ⋆ Load dependable delay in the network
  - ⋆ Load dependable delay at the network access point
- Virtual circuit service
  - ⋆ Guaranteed bandwidth
  - ⋆ Guaranteed maximum delay
  - ⋆ Multicast circuits
  - ⋆ Based on packet switching service

The Bufferless Switch

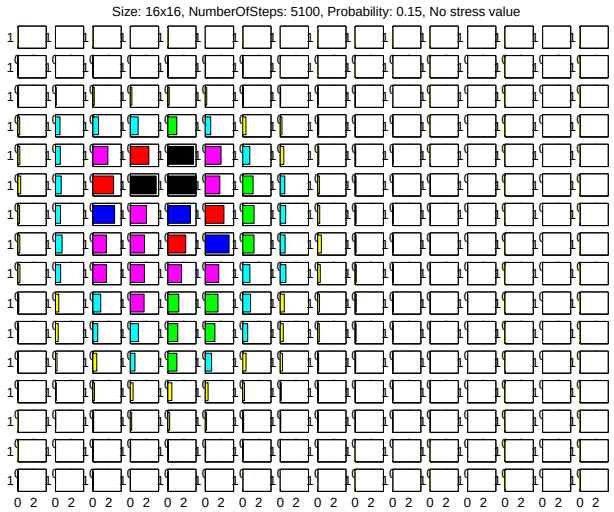


- \+ No buffers
- \+ No routing table
- \+ Small area
- \+ Short delay
- \+ Low power consumption
- – Non-shortest path
- – Header overhead due to destination address

Stress Value Effect on Buffer Sizes and Delays

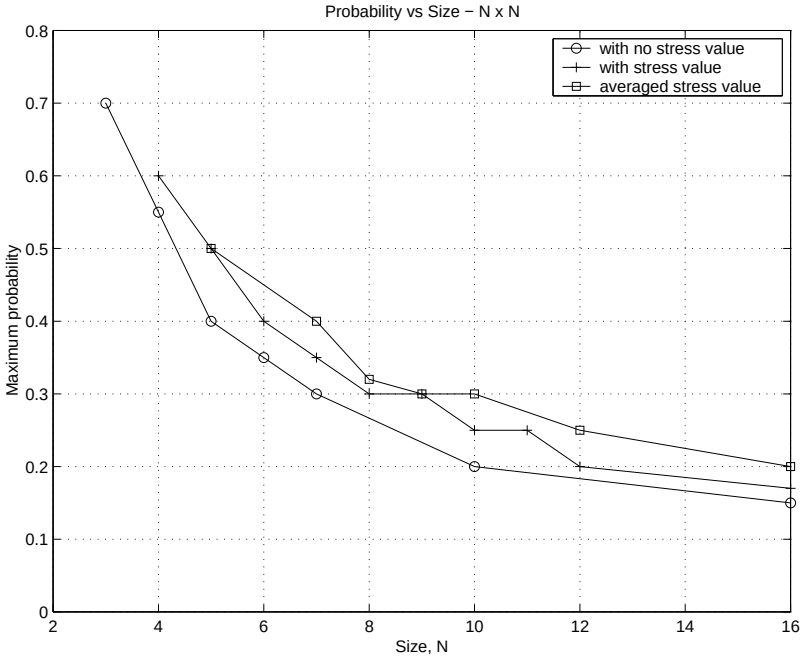


Largest average buffer size: 3.2



Largest average buffer size: 0.1

Stress Value Effect on Maximum Load



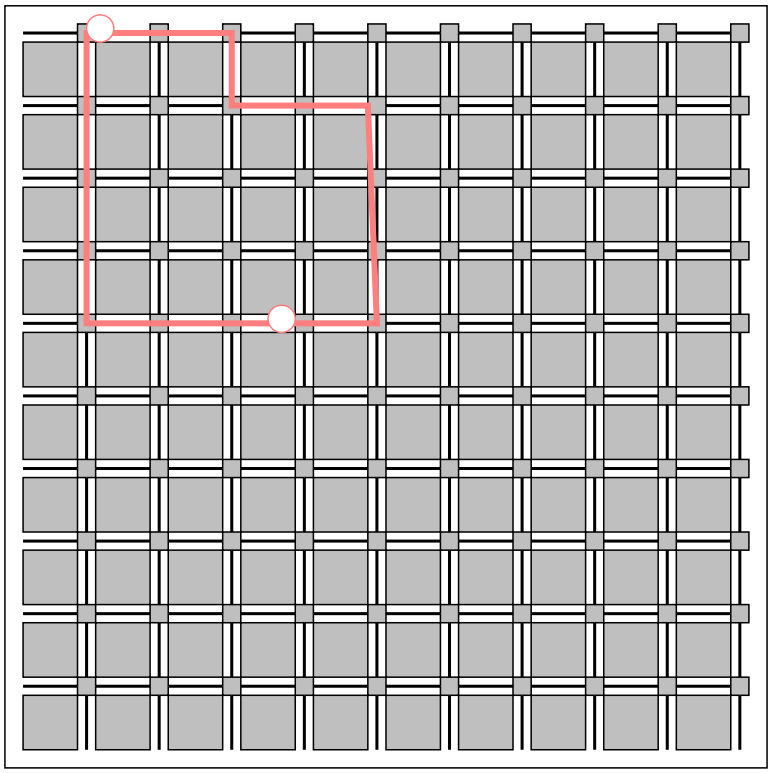
Looped Container based Virtual Circuit

- A container packet loops between two or more end points
- The looping container establish a closed virtual circuit
- The virtual circuit allows multicast and bus protocol emulation
- Possible bandwidth allocation:

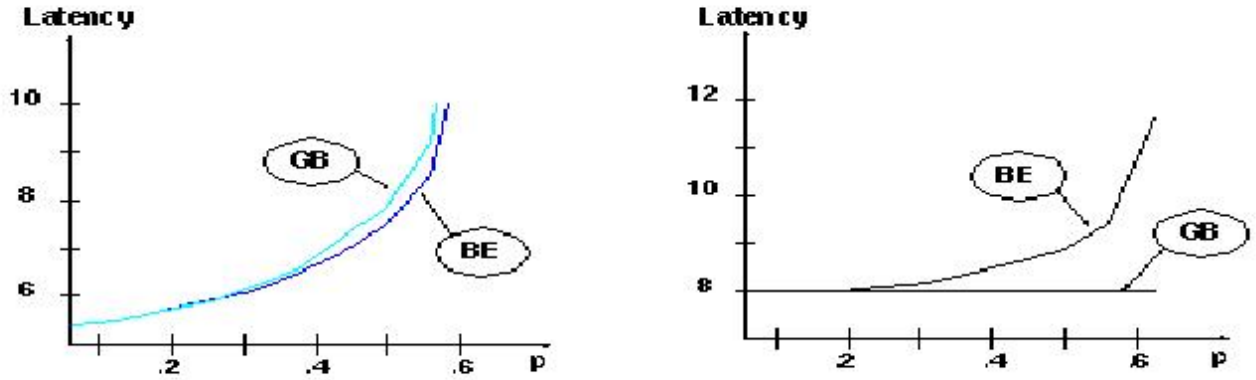
$$2^{j-d}B$$

where B = link bandwidth, d = length of the container loop, $1 \leq j \leq d$

- Examples:
  $d = 2$: possible allocations: 100% and 50%
  $d = 4$: possible allocations: 100%, 50%, 25%, .5%



Best Effort and Guaranteed Bandwidth Traffic



The background traffic and the AB traffic

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Data Protection

- Two level protection: Link layer and session layer
- Data link layer protection:
  - ⋆ SEC-DED header protection (16/26 bits)
  - ⋆ Four levels of payload protection:
    - ∗ Maximum bandwidth - no protection (102/102 bits)
    - ∗ Guaranteed integrity - DED protection (90/102 bits)
    - ∗ Minimum latency - SEC protection (90/102 bits)
    - ∗ High reliability - SEC-DED protection (81/102 bits)
- Session layer:
  - ⋆ Normal mode: Send-and-Forget (SaF) service
  - ⋆ Reliability mode: Acknowledgement-and-Retransmit (AaR) service
    - ∗ window size $N, 1 \leq N \leq 64$
    - ∗ $2N$ packets are buffered in sender and receiver
    - ∗ End-to-end flow control mechanism
- in total 8 modes available

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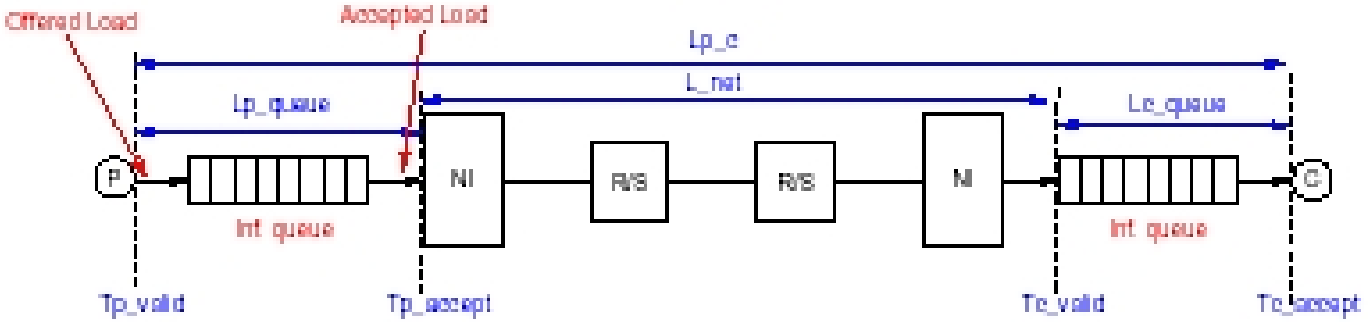
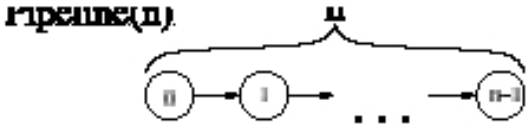
Measurement Framework

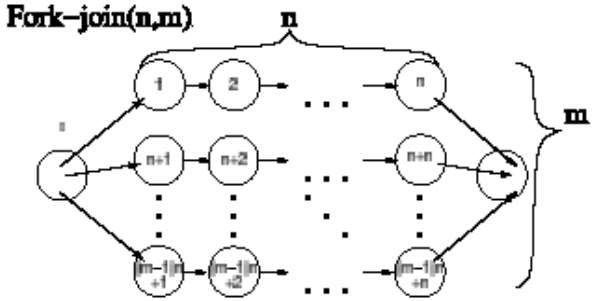
- Ponts of measurement
- Level of abstraction
- Service type

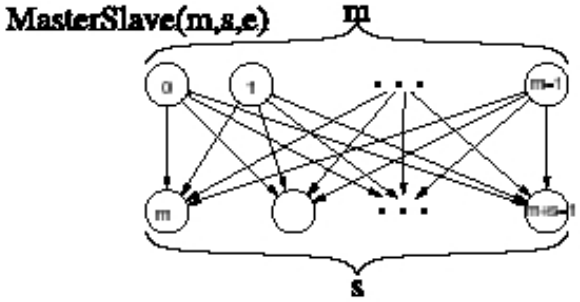


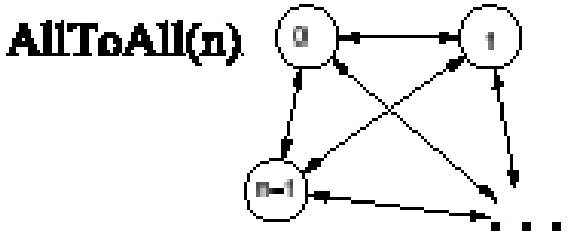
Workload Models

- Spatial patterns
- Spatial probabilit distributions
- Temporal probability distributions

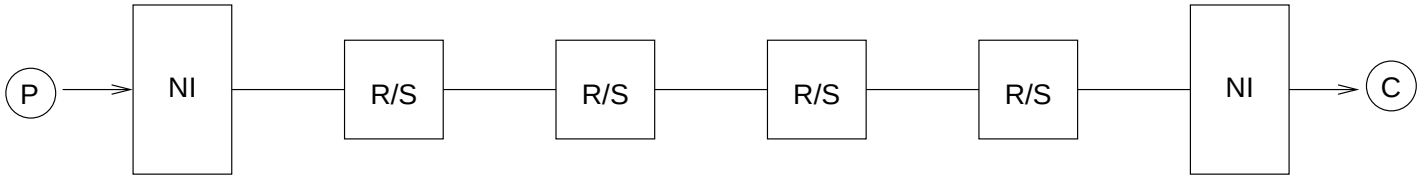




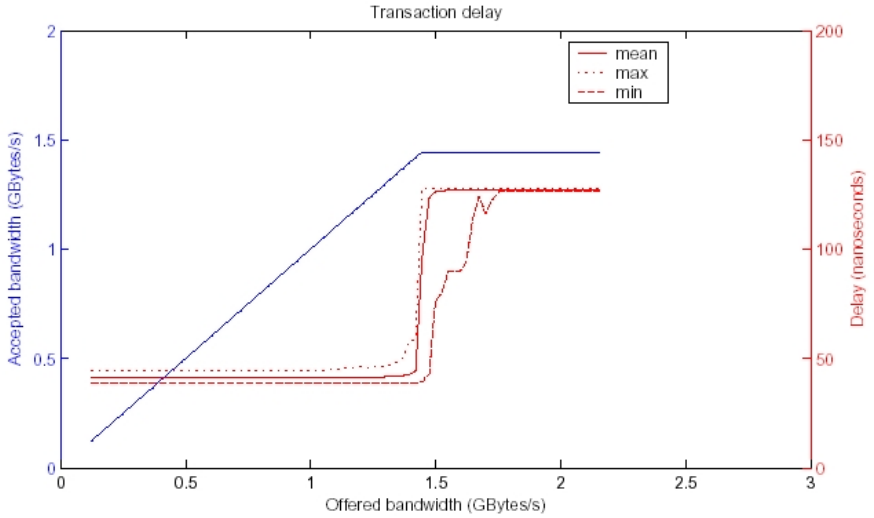


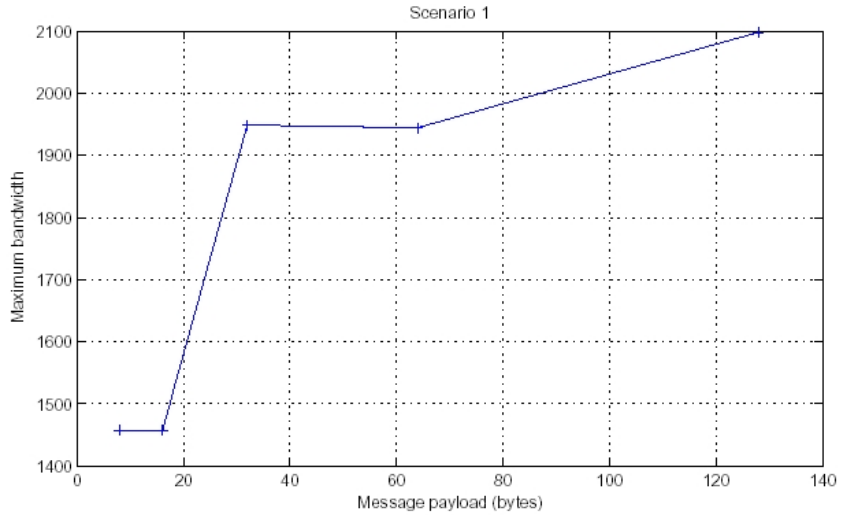


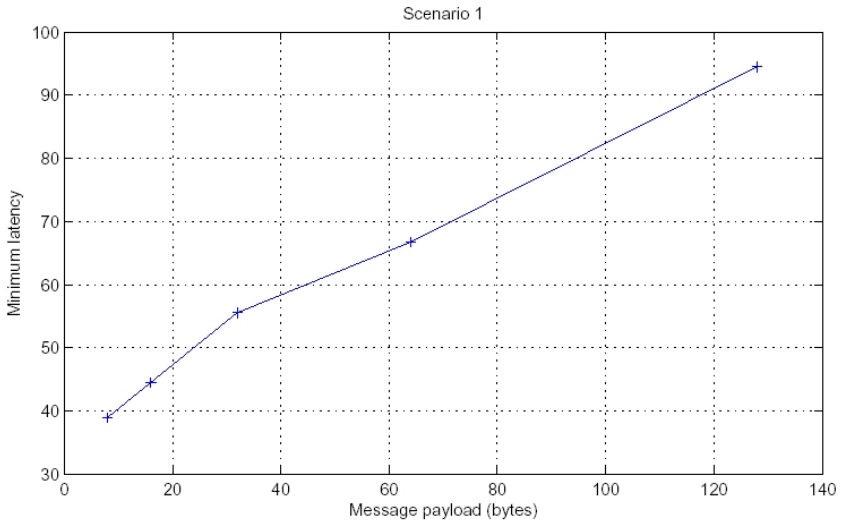
Simulation Scenario 1



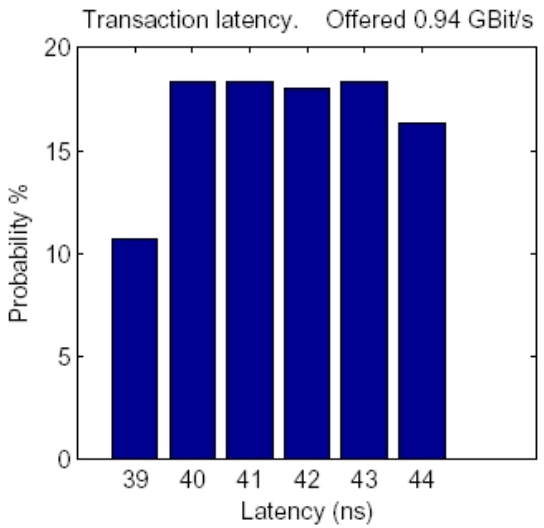
Simulation Scenario 1 - cont'd

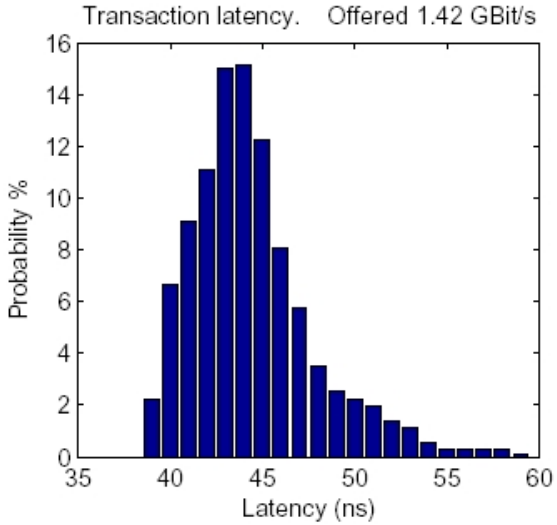


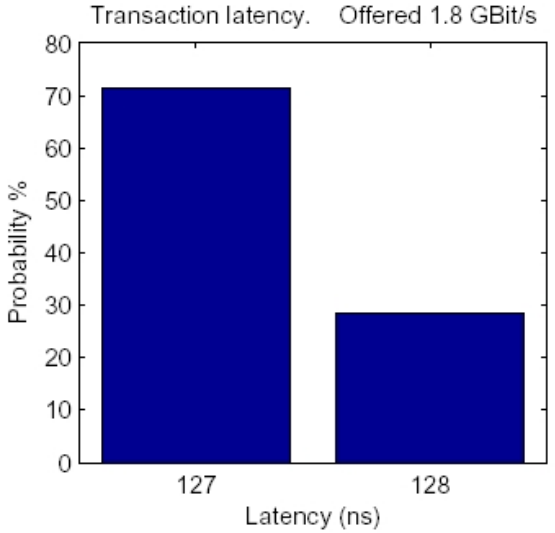




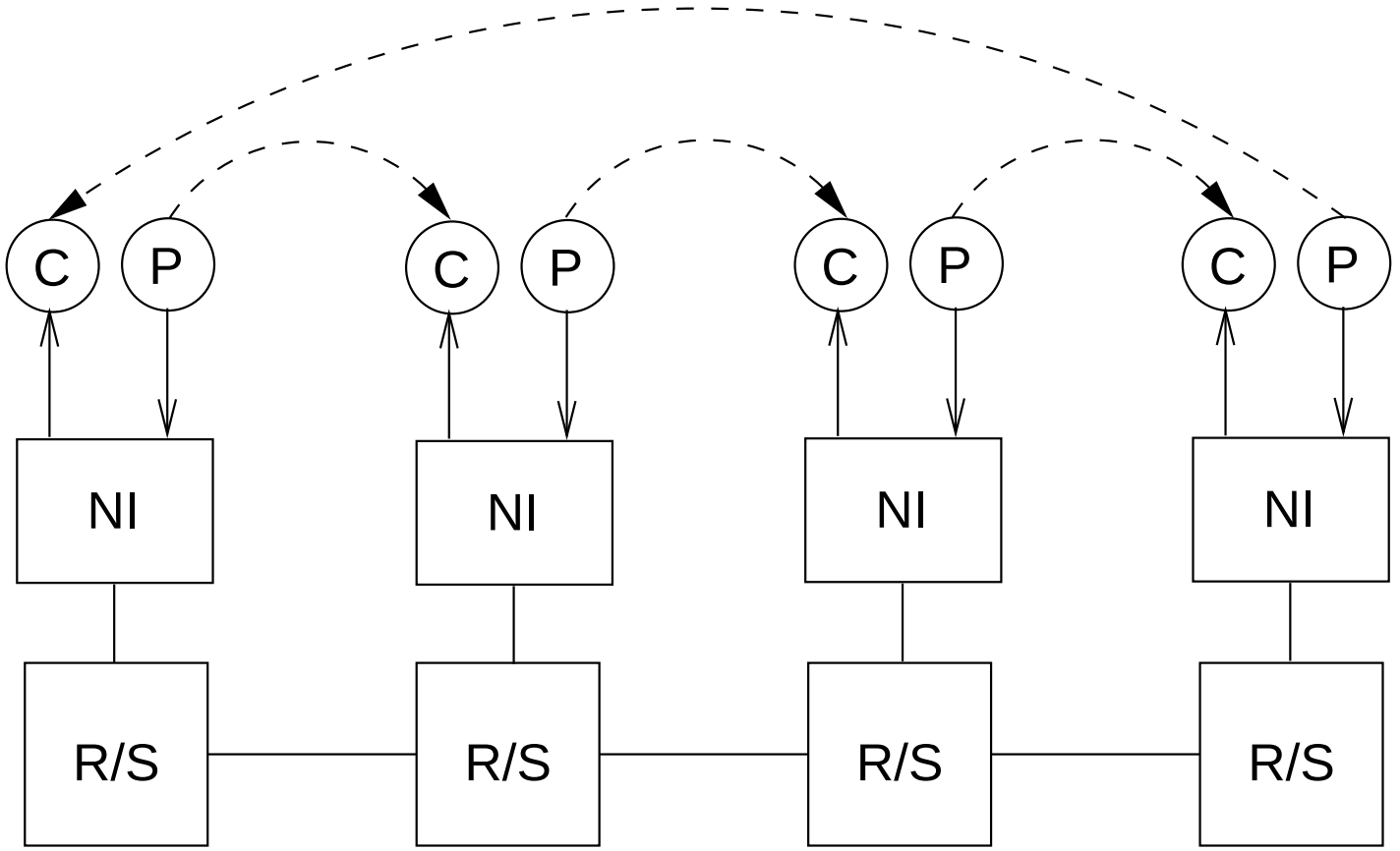
Simulation Scenario 1 - cont'd



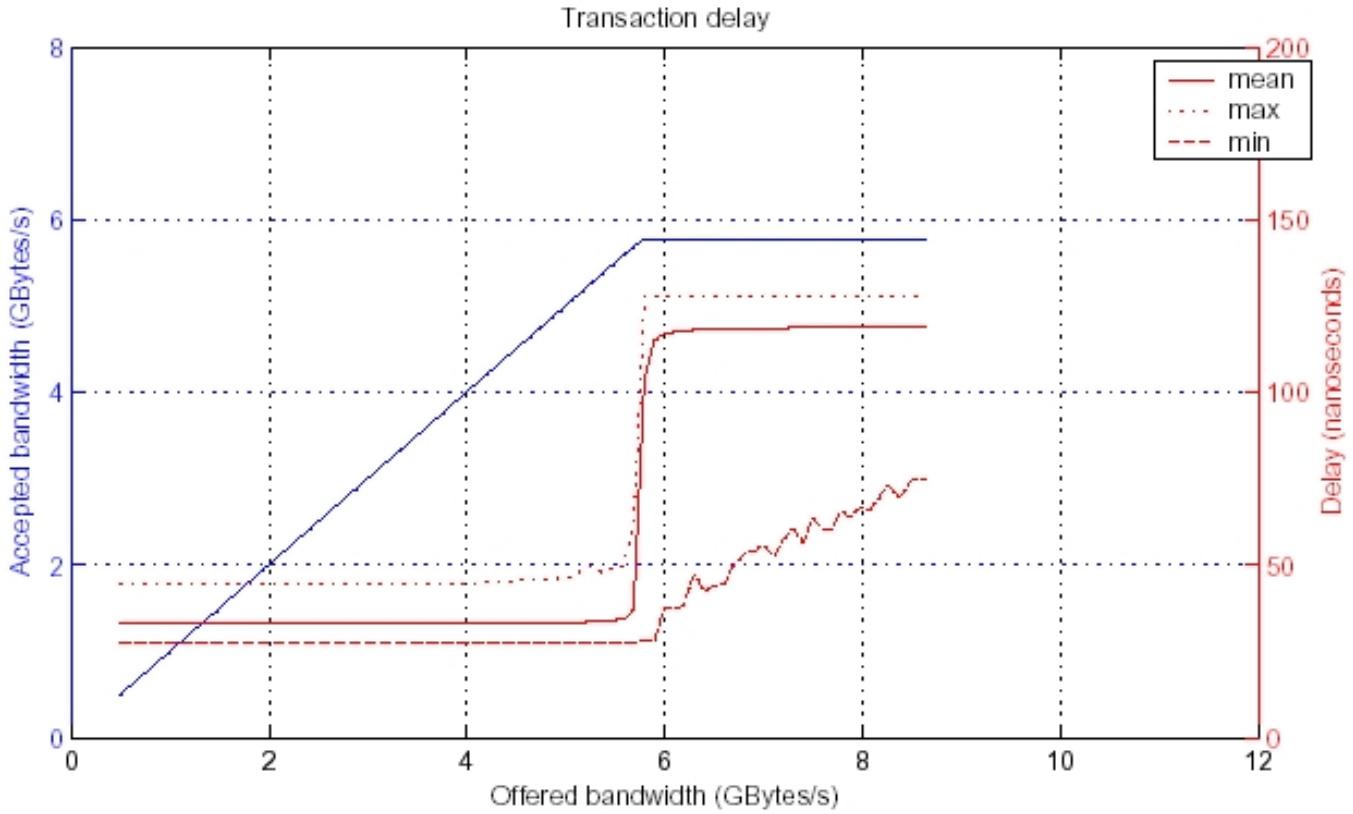




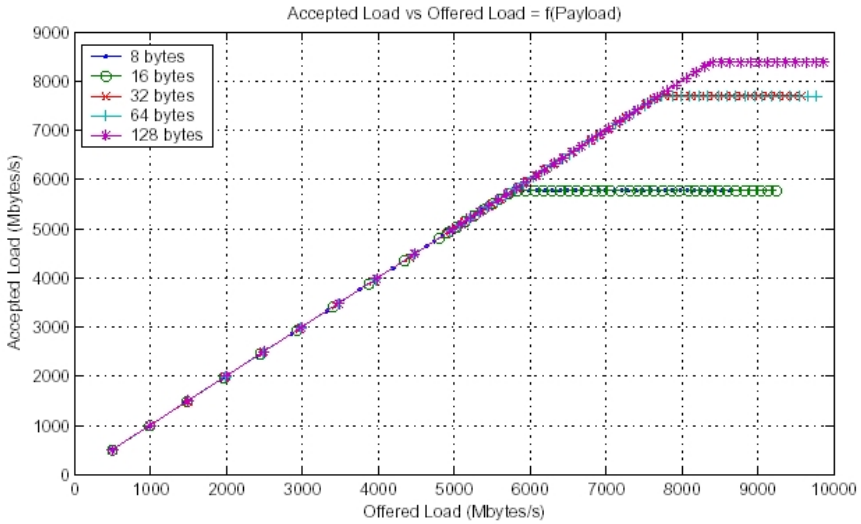
Simulation Scenario 2

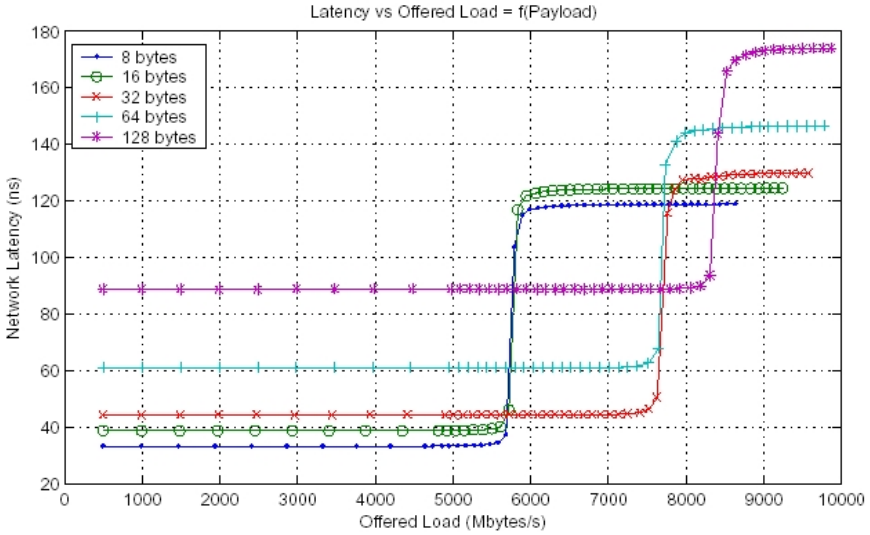


Simulation Scenario 2 - cont'd

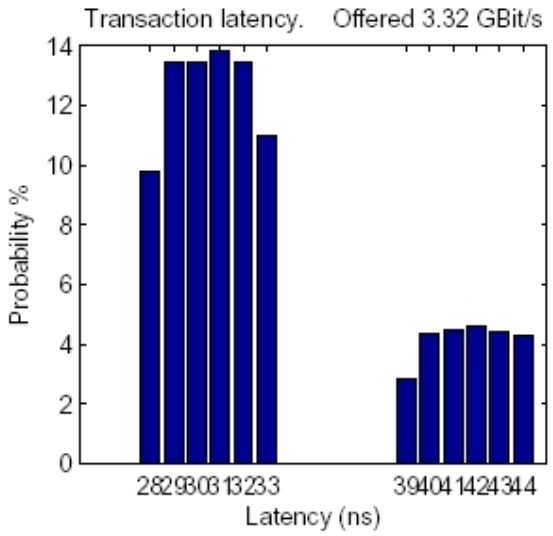


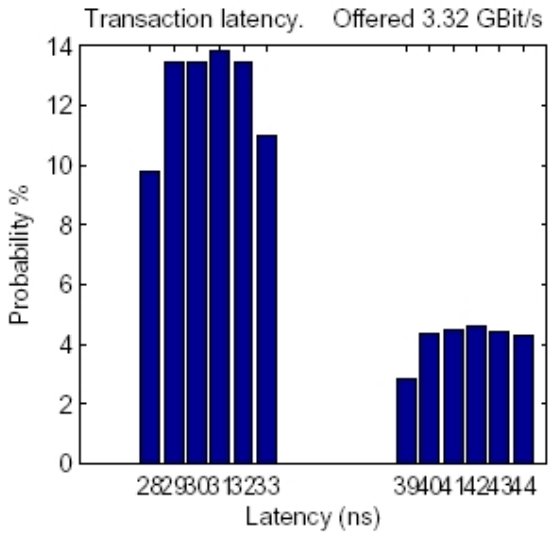
Simulation Scenario 2 - cont'd

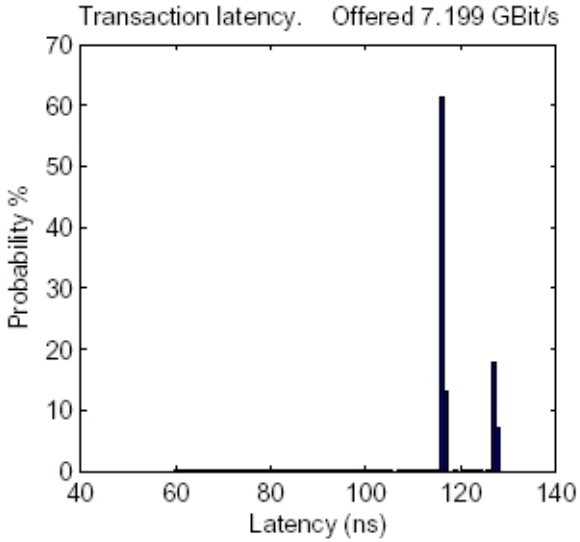




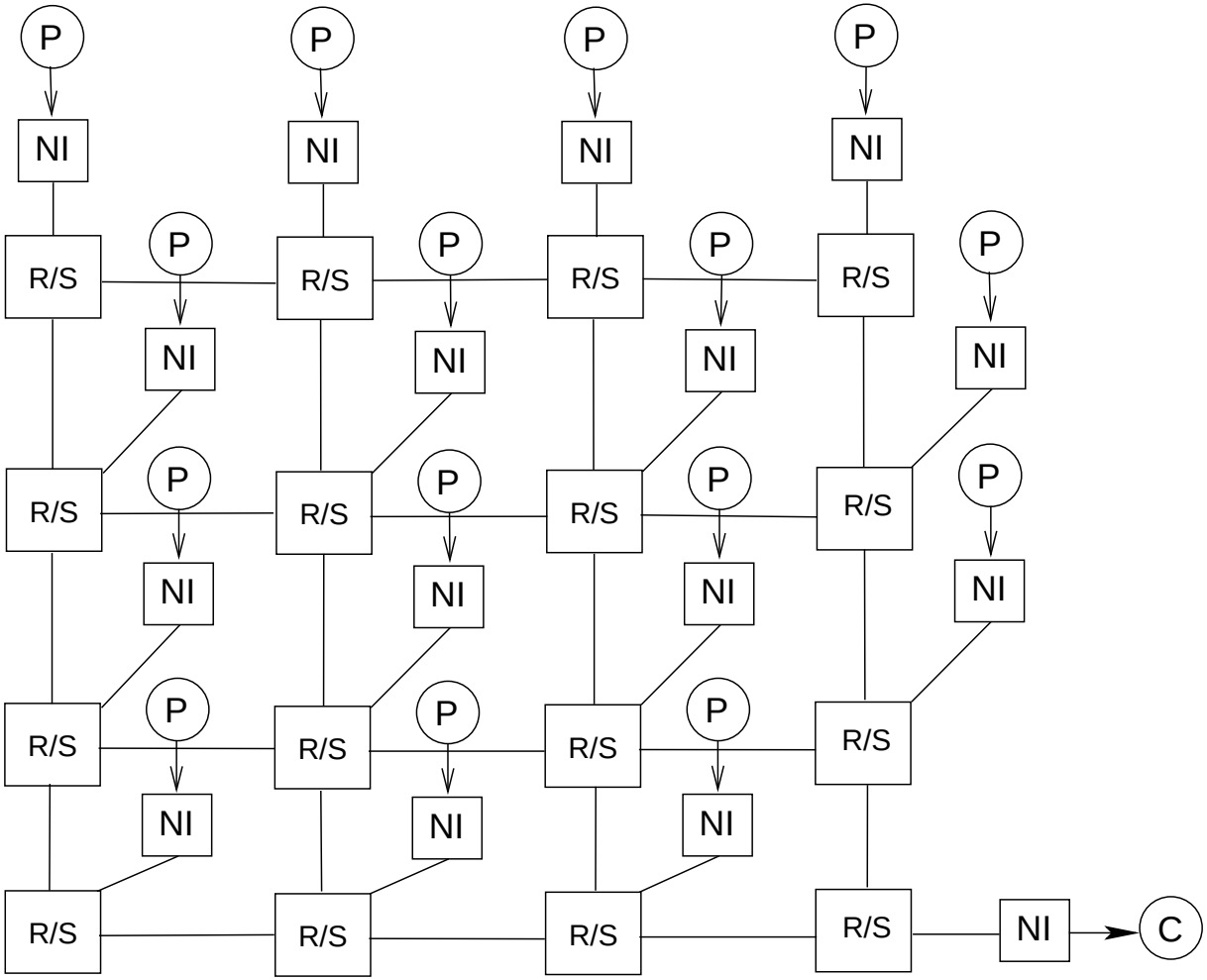
Simulation Scenario 2 - cont'd



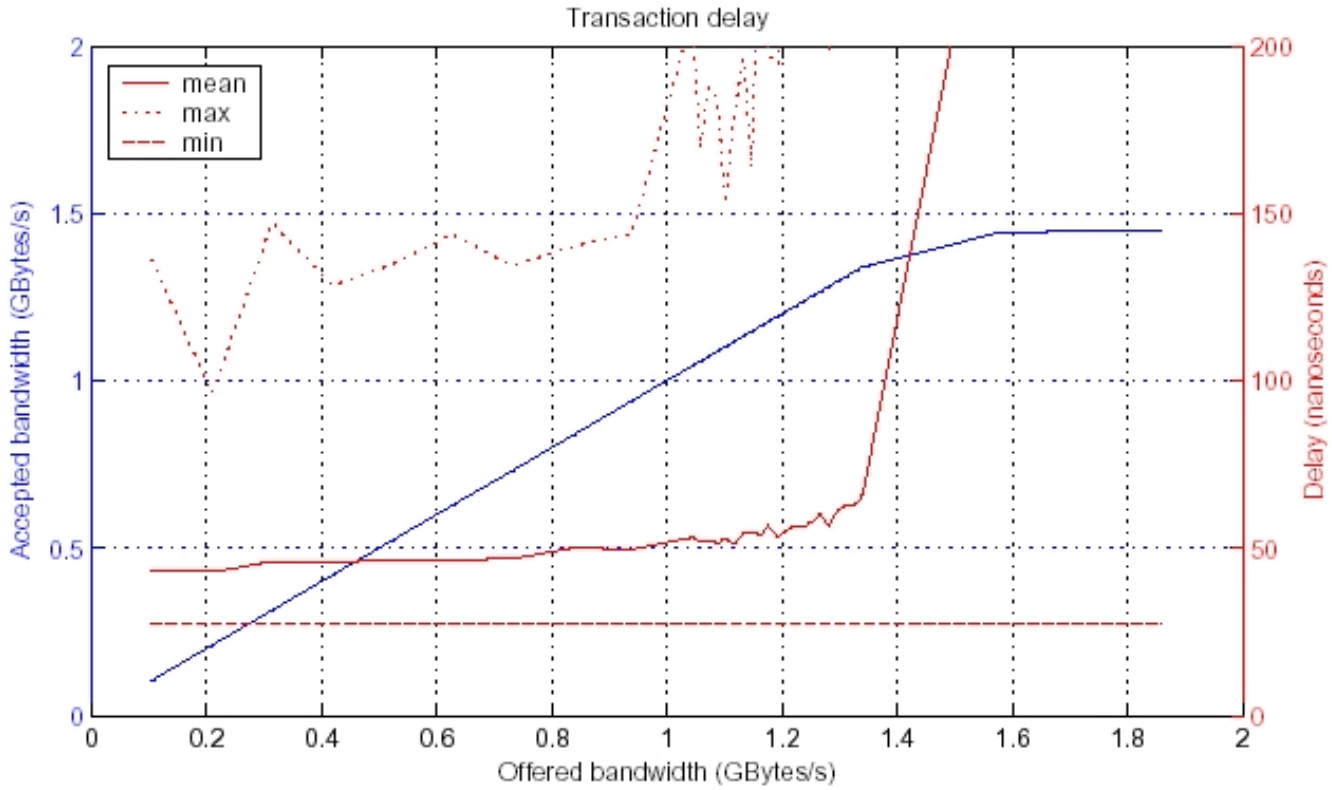




Simulation Scenario 3



Simulation Scenario 3 - cont'd



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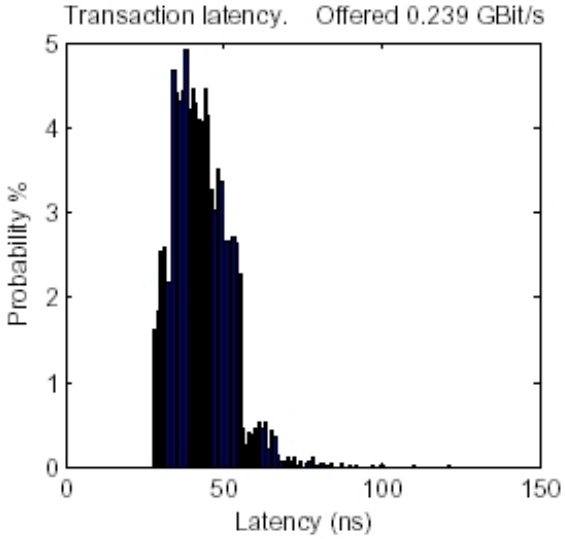
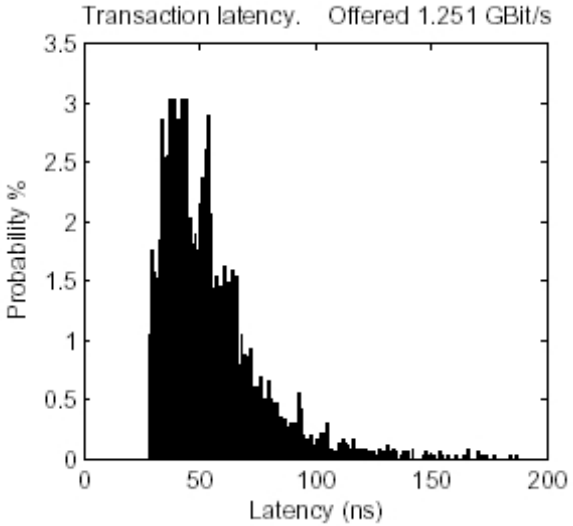
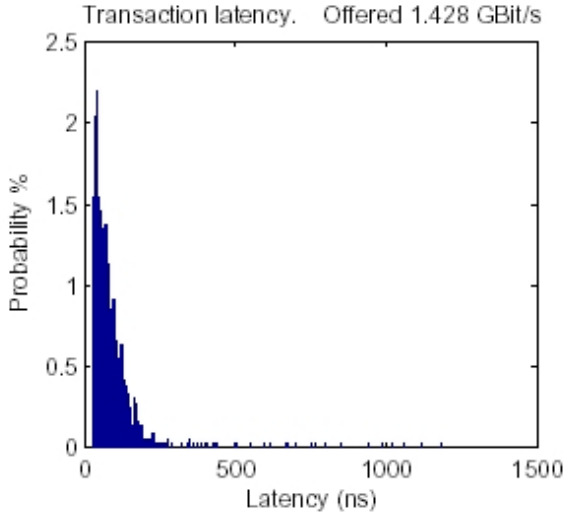
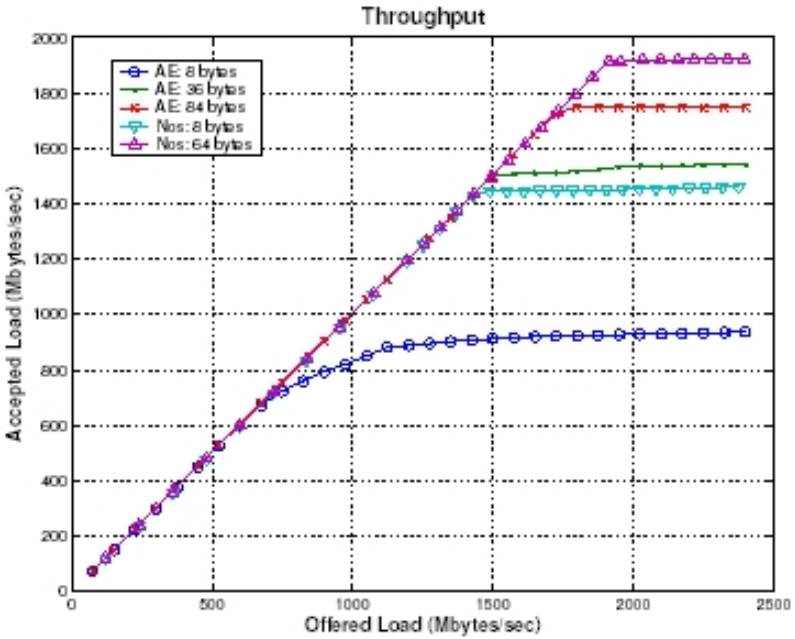
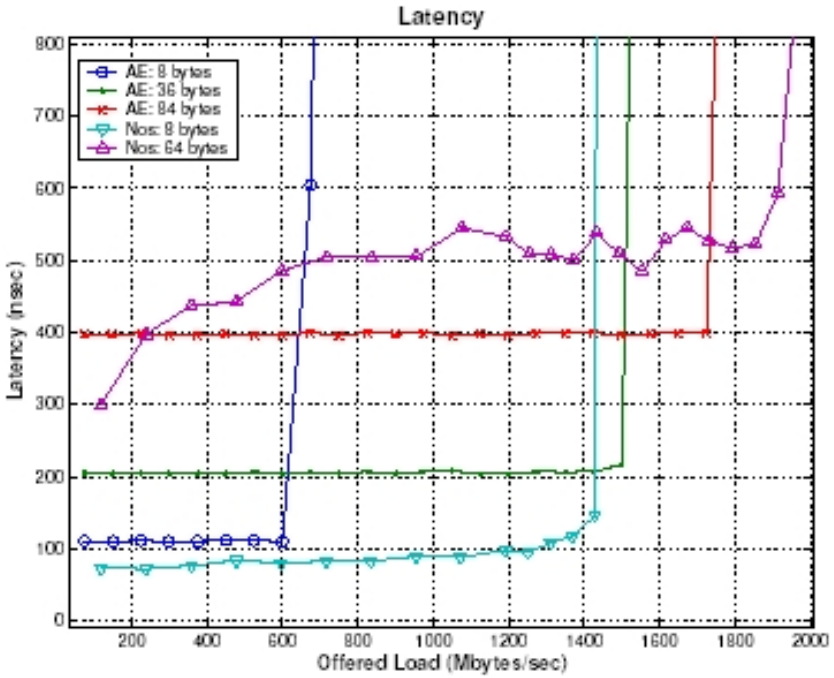






Aethereal and Nostrum





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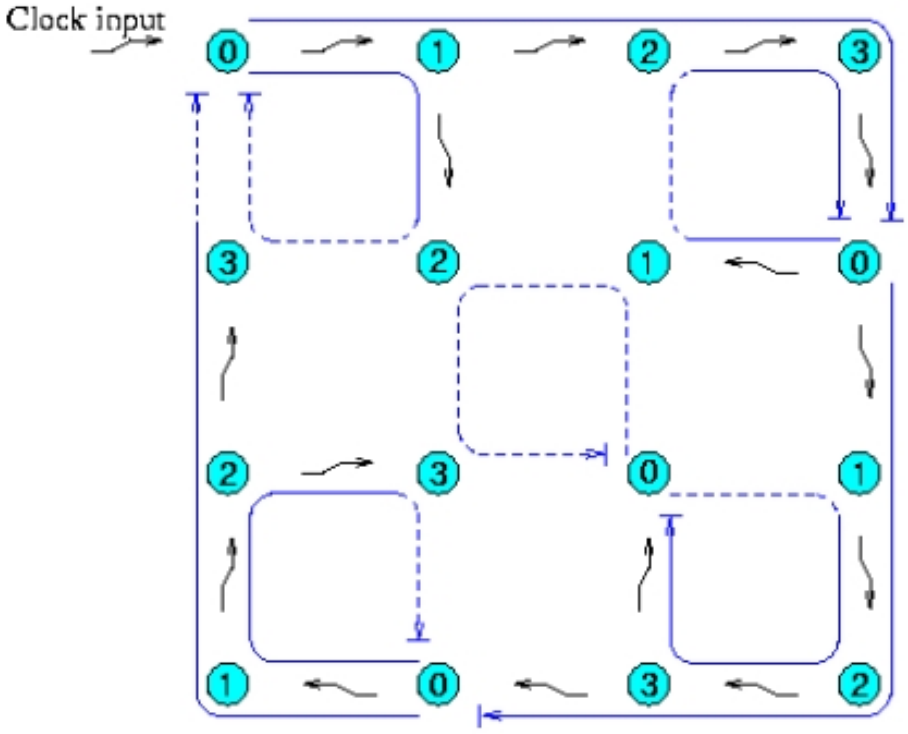
Clocking

Globally Pseudosynchronous - Locally Synchronous Clocking

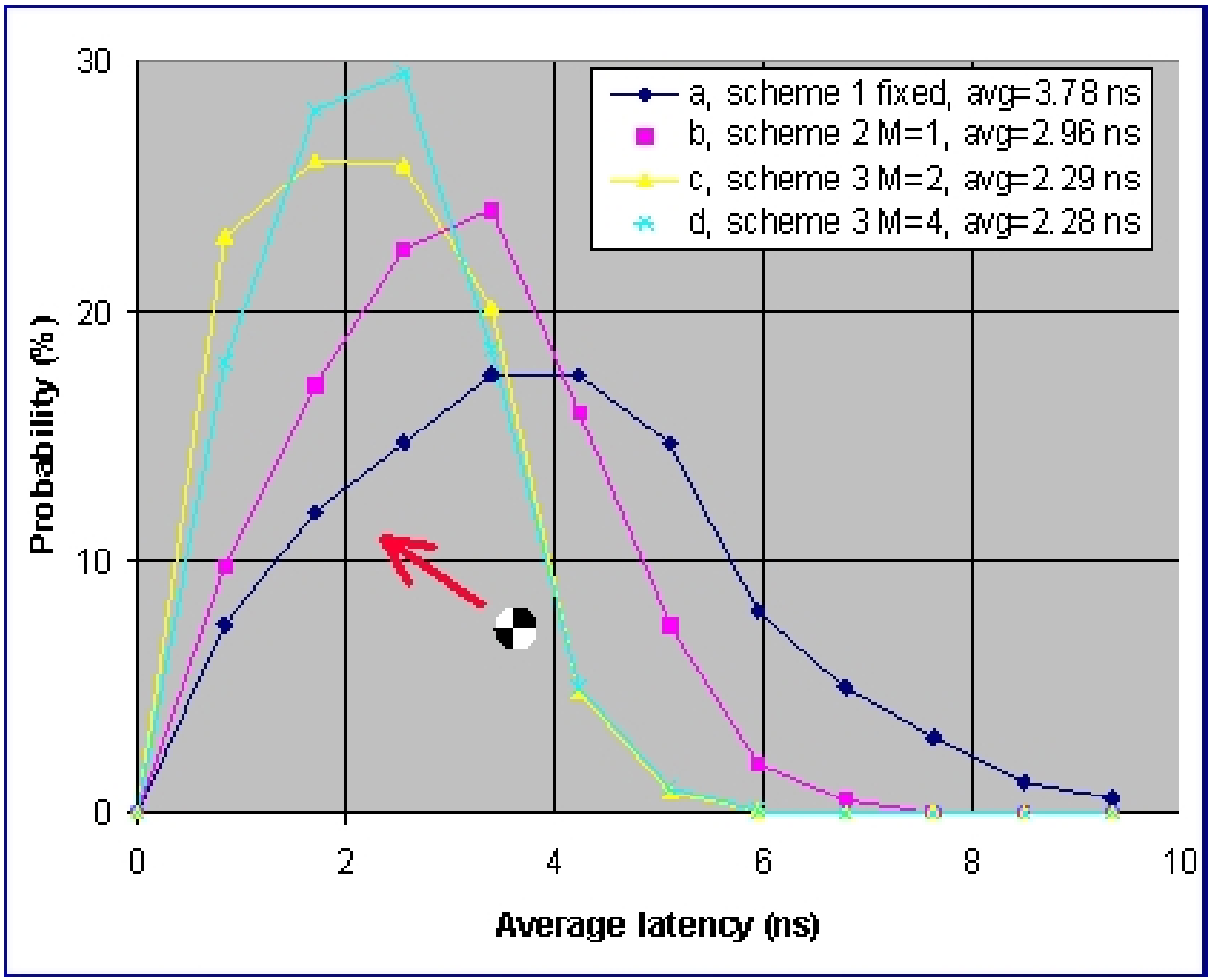
- Latency reduce with 29% at low load; 40% at high load
- Can handle 10% higher load
- More skew tolerant
- Clock skew and jitter is depending only on local constraints
- No global clock distribution with associated power gains
- Reduced peak power with 50% at best
- Jitter reduced significantly

Globally Pseudosynchronous Clocking - cont'd

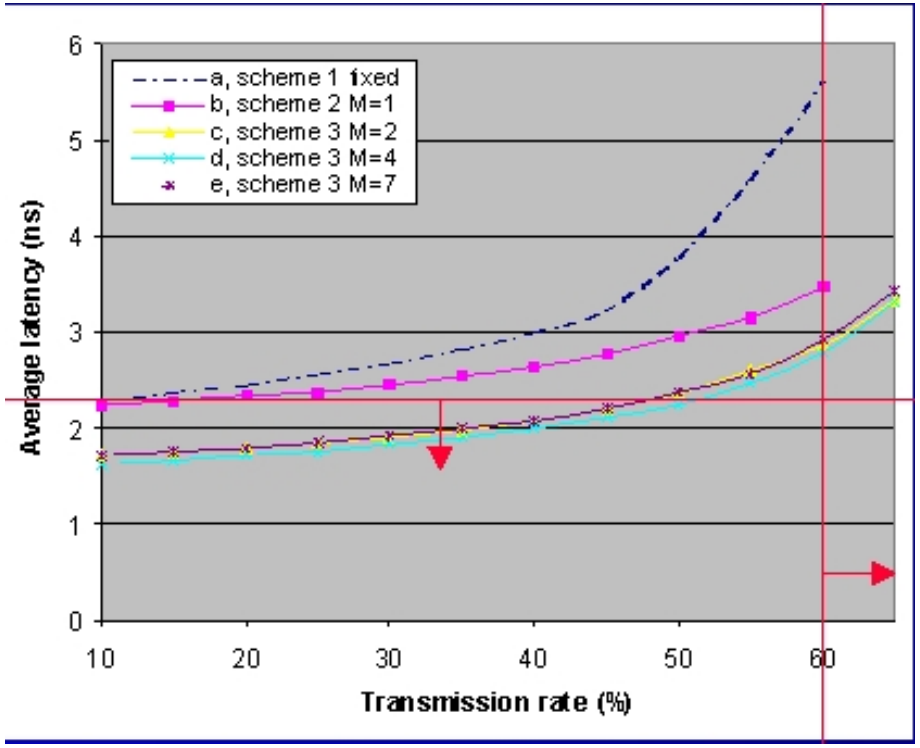


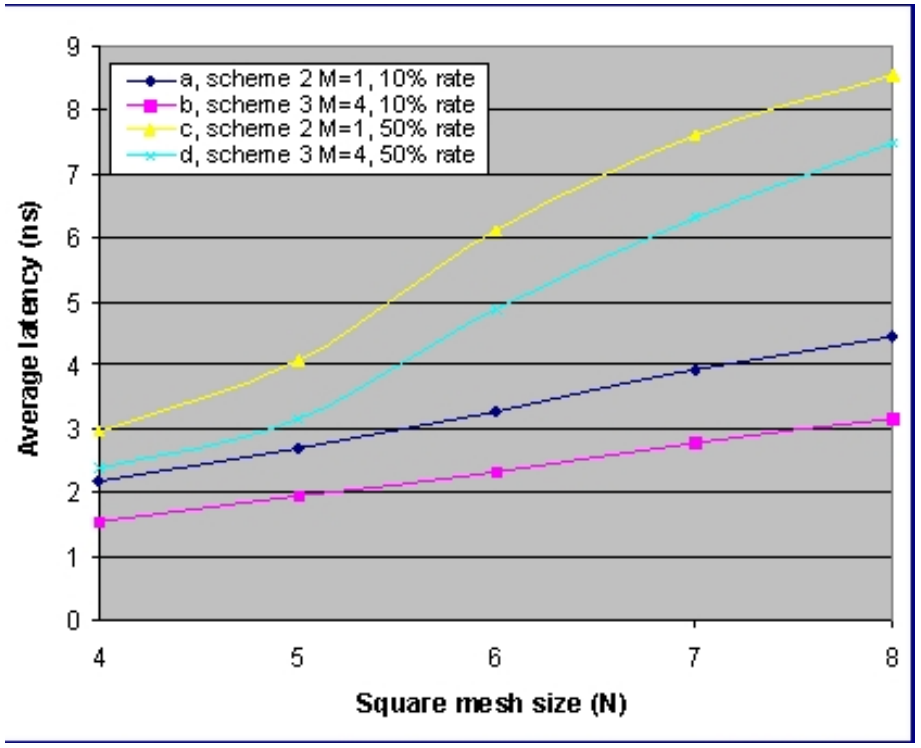
- Downstream data create low latency paths (Data Motorways)
  - ⋆ Guaranteed data motorways
  - ⋆ Phase related data motorways
- Periphery roundtrip:
  - ⋆ 14 cycles downstream
  - ⋆ 21 cycles upstream
  - ⋆ 24 cycles synchronous

Globally Pseudosynchronous Clocking - cont'd



Globally Pseudosynchronous Clocking - cont'd





Summary of Nostrum Status

- Nostrum defines a 2 D mesh topology;
- Protocol stack for link layer, network layer and session layer;
- Packet switched and virtual circuit communication services;
- Buffer-less, loss-less switch with no routing tables;
- 2 level data protection scheme;
- Session layer communication primitives;
- Flexible NoC Simulator;

Further information: www.imit.kth.se/info/FOFU/Nostrum/

Research Challanges

- Power management
  - ⋆ Error correction and fault tolerance
  - ⋆ Dynamic frequency and voltage scaling
  - ⋆ Integrated network-resource power management
- Reconciliation of dynamic power management with real-time constraints
- Admission protocol
- Communication refinement
- Application mapping and traffic planning
- Application designers interface and programmers model

Master Thesis Projects

- Comparison of wormwhole routing and virtual circuits
- Laypout planning with constraint logic programming
- Components in the Nostrum configuration tool
  - ⋆ Resources - VHDL and SystemC
  - ⋆ Switches - VHDL and SystemC
  - ⋆ Network interfaces - VHD and SystemC