Real-Time Systems

Hermann Härtig

Real-Time Communication
A short Overview

(following Kopetz, Liu, Schönberg, Löser, Ernst)

TECHNISCHE UNIVERSITÄT DRESDEN

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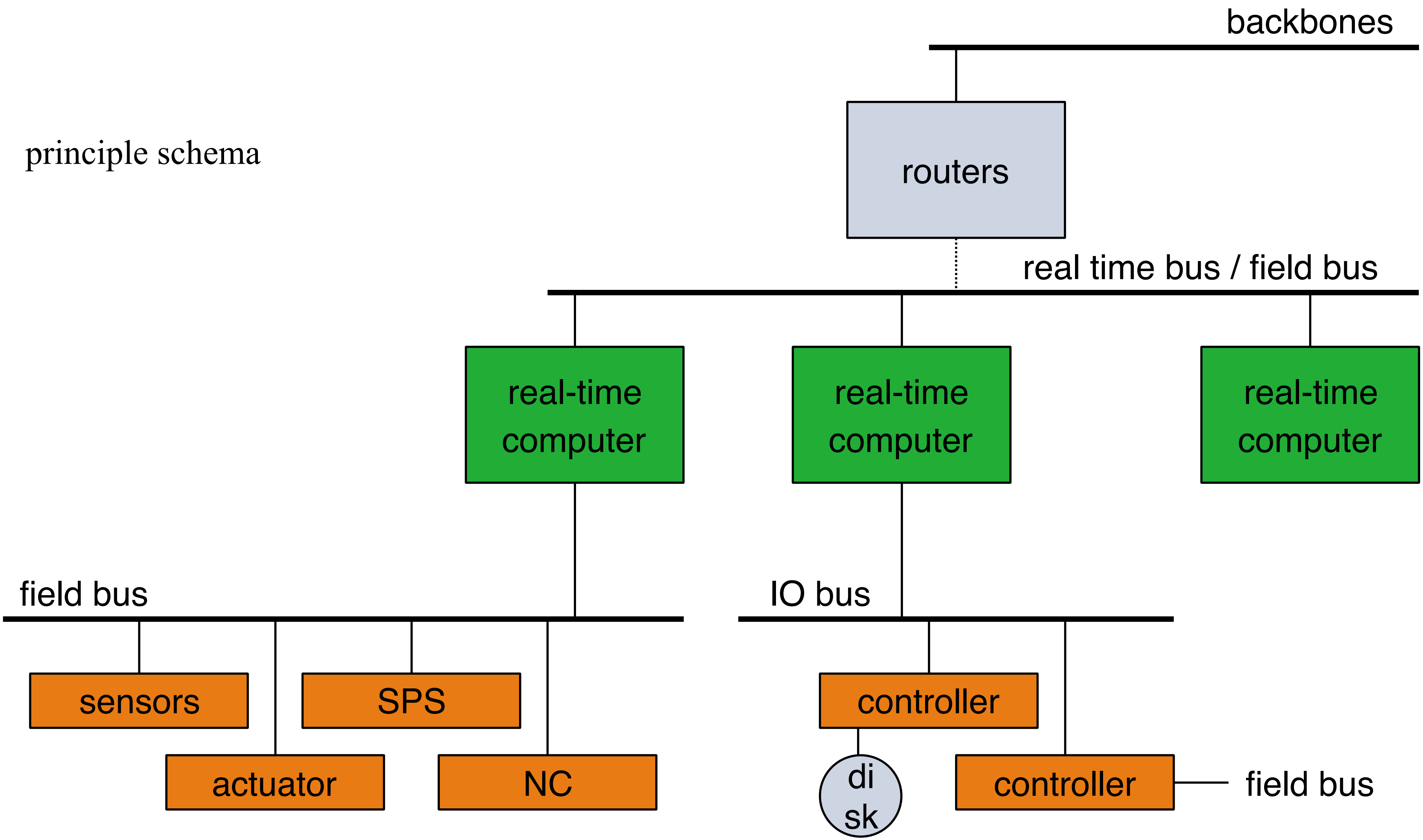
Contents

- Overview
- IO Busses: PCI
- Networks as schedulable resources:
  Priority / Time-Driven / Weighted Round Robin
  - Priority – Based Field: CAN/Token Ring
  - Weighted Round Robin in Wide Area
  - Ethernet in RT:
    - Shaping
    - TT-Ethernet

Where does Real-Time Communication matter ?

principle schema

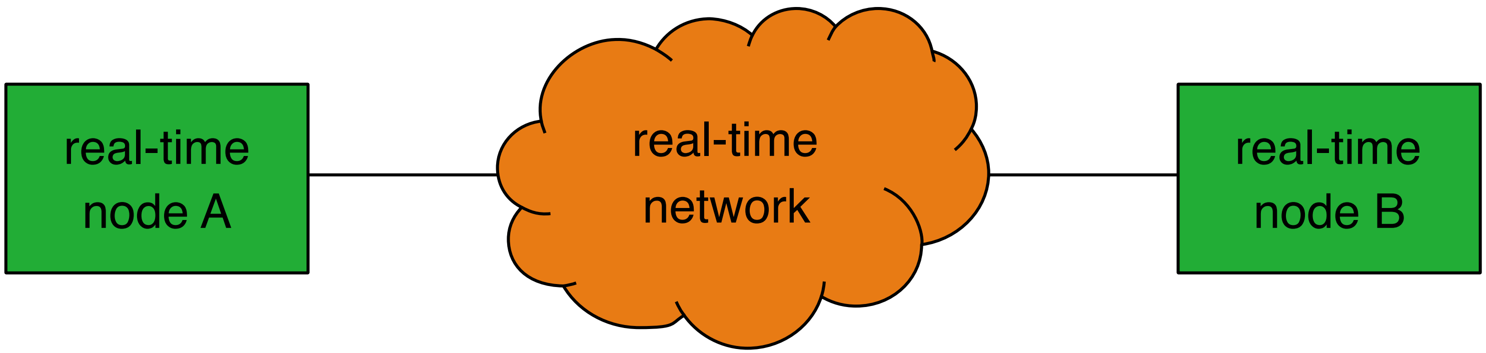


What to expect of a real-time network ?

Deliver communication services to the requesting nodes reliably, securely, efficiently and **timely**

- lower bound for bandwidth
- upper bound for latency and jitter

even in case of peak load and faults.

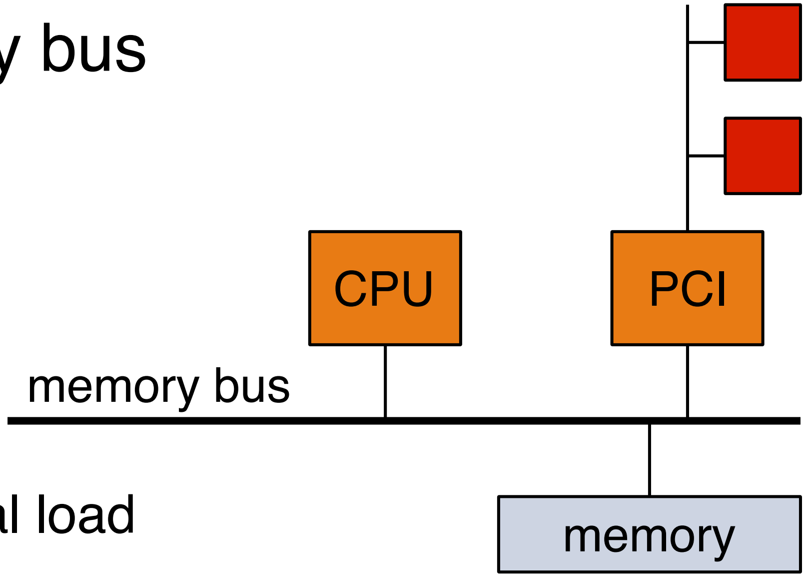


Typical requirements

- Short data in control applications
  Large data in media applications
- Short periods (ms)
  - monitoring, feedback control
- Fast aperiodic (ms)
  - alarms
- Non real-time data
  - configuration, logs
- Multicast
- Predictability in the presence of faults

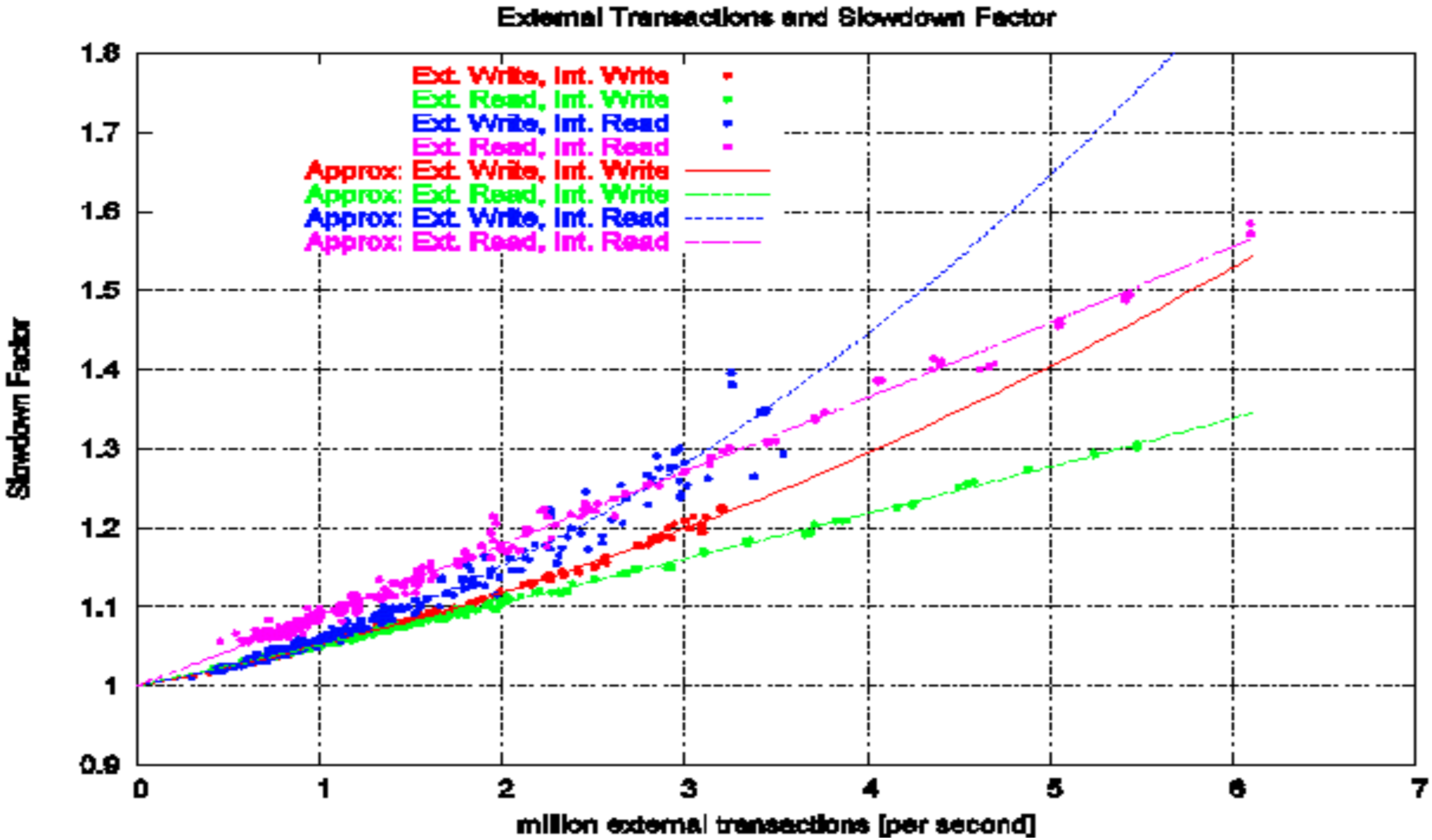
Intra-Node communication: IO bus (PCI)

- All data transfers share the memory bus
  - Memory bus conflicts
  - PCI devices start transfers when data is available
  - CPU-Memory-accesses are influenced by PCI devices
  - applications are slowed down by external load



- Slowdown factor F: (ET: execution time)
  ET under external load/ET without any external load
  - application-specific depends on memory access pattern
  - obtained by measurements attempts to statically predict

Some measurements



Source: Dissertation Sebastian Schönberg (see our Web-Pages)

Intra-Node communication: PCI bus

- PCI bus specification does not prevent real-time implementation
  - Arbitration responsible for granting bus to devices
  - Current implementations use round-robin arbitration

- Telecom Systems
  - PCI bus for control data
  - TDMA bus for real-time data

Intra-Node communication: PCI bus

Alternatives (research proposals)

- real-time capable PCI bus arbiter
  - Assign individual share of the PCI bus to devices
  - Enforce reservation
  - Give unused bandwidth to time-sharing devices
- RT-Bridges
  - Between device and bus
  - Enforces bandwidth restriction

Memory Bus in MultiCore systems:

active area of research

Networks as schedulable resources

- Analogous to CPU scheduling:
  - time driven
  - priority driven
  - (Weighted Round Robin)

- Analogy:
  - WCET: Amount of traffic / message transmission time
  - Periodic tasks: periodic messages
    messages are usually non-preemptive !!
  - Deadline: max delay
  - Admission: connection establishment
  - Schedulers in switches or distributed on nodes

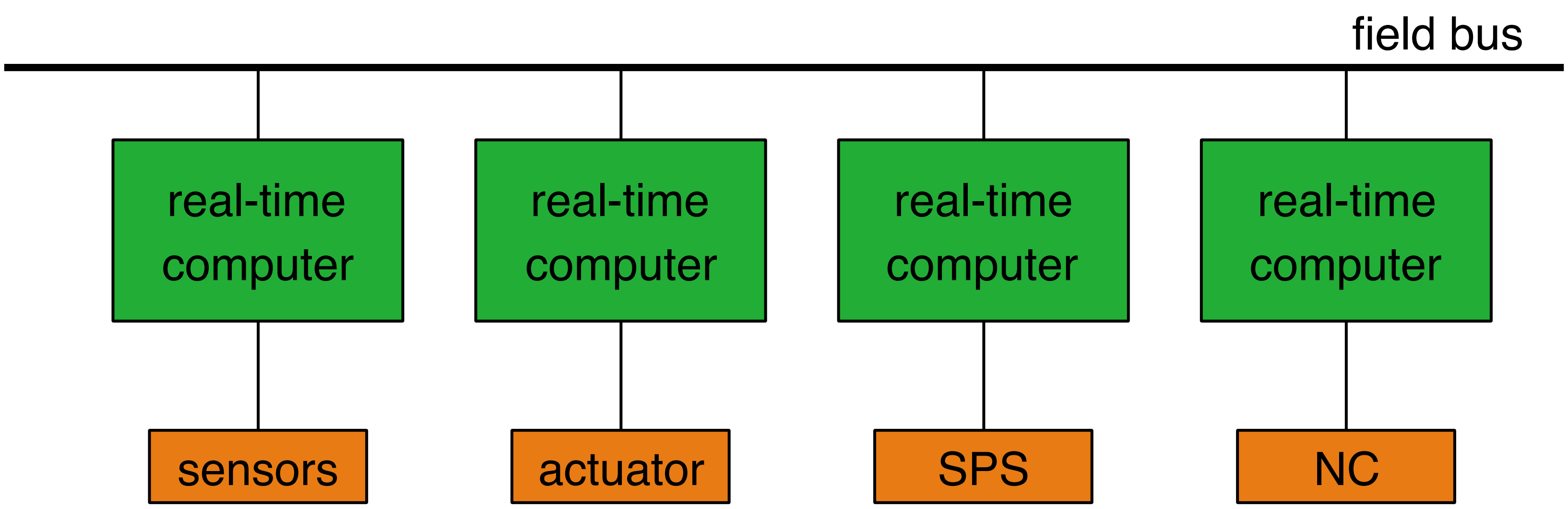
Examples

- Fieldbus:
  - CAN, Token Ring: priority based scheduler
  - TTP/Flexray/TT-Ethernet: time driven scheduling

- Switch:
  - (Delay EDD)
  - Weighted Round Robin
    (neither priority nor time driven !)

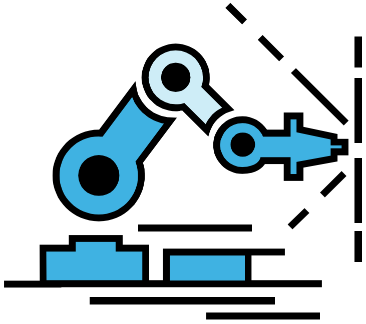
Intra-Node communication: field busses

- Situation is moving
  - Smart sensors, actors
  - Wireless lans



Fieldbus

- Networks for process control, factory automation, cars, avionics, X-by-wire, embedded applications



- Networks are typically called fieldbusses:
  - collapsed network stacks (application services access the data link directly)
  - real-time transport
  - short application messages (no need for fragmentation and reassembling)
  - often a bus, hence a single broadcast domain, no routing

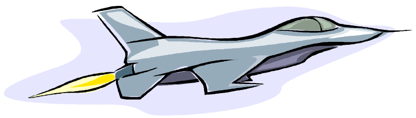


Image source: Microsoft Clip-Art Gallery

Multiple access to shared medium

- CSMA/CD shared ethernet
- CSMA/CR or CSMA/BA with priorities (CAN)
- Token Ring with priorities
- TDMA

CAN – controller area network

- Bosch GmbH, Version 2.0 released in 1991
- ISO Standards 11519 (94) and 11898 (95)
- used in automotive industry, process control, manufacturing automation, embedded application domains
- cost-effective

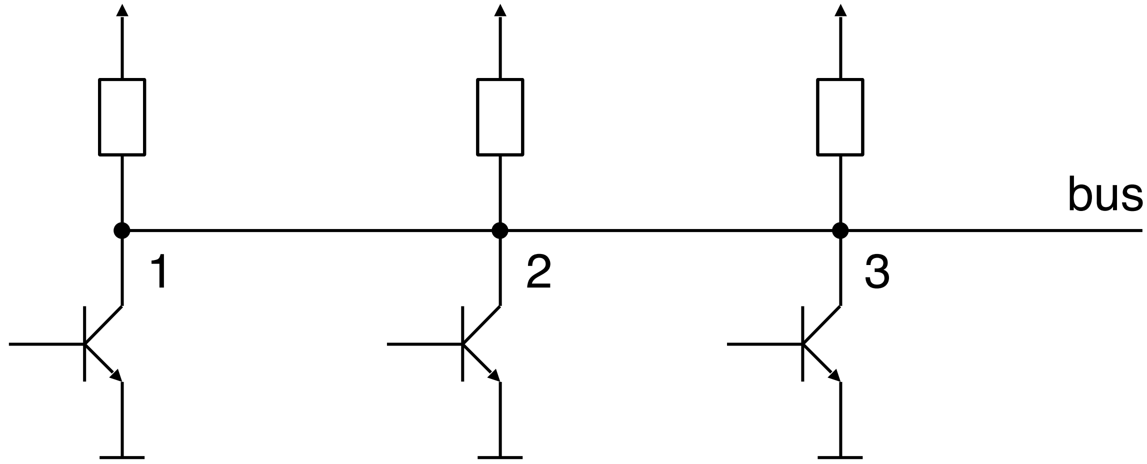
- CSMA/BA:
  carrier sense multiple access/bitwise arbitration

Bus arbitration with CAN (priority based)

- CSMA/BA (carrier sense multiple access/bitwise arbitration)
- Bit-wise collision resolution using message identifiers, sent from HSB to LSB
- Wired "and", implemented with bus drivers

  0 - Dominant level

  1 - Recessive level



- Node stops if a “0” is seen when sending a “1”

CAN message

id: 11	control: 6	data up to: 64	crc: 16	various: 11

- Bit stuffing to allow synchronization at bit level
  - after 4 '0's or 4 '1's: dummy 1 or 0

- Transmission time of a message in bit-times:

=> 13+34+databits+ (34+databits-1)/4

Overhead: 44 Bits + ...

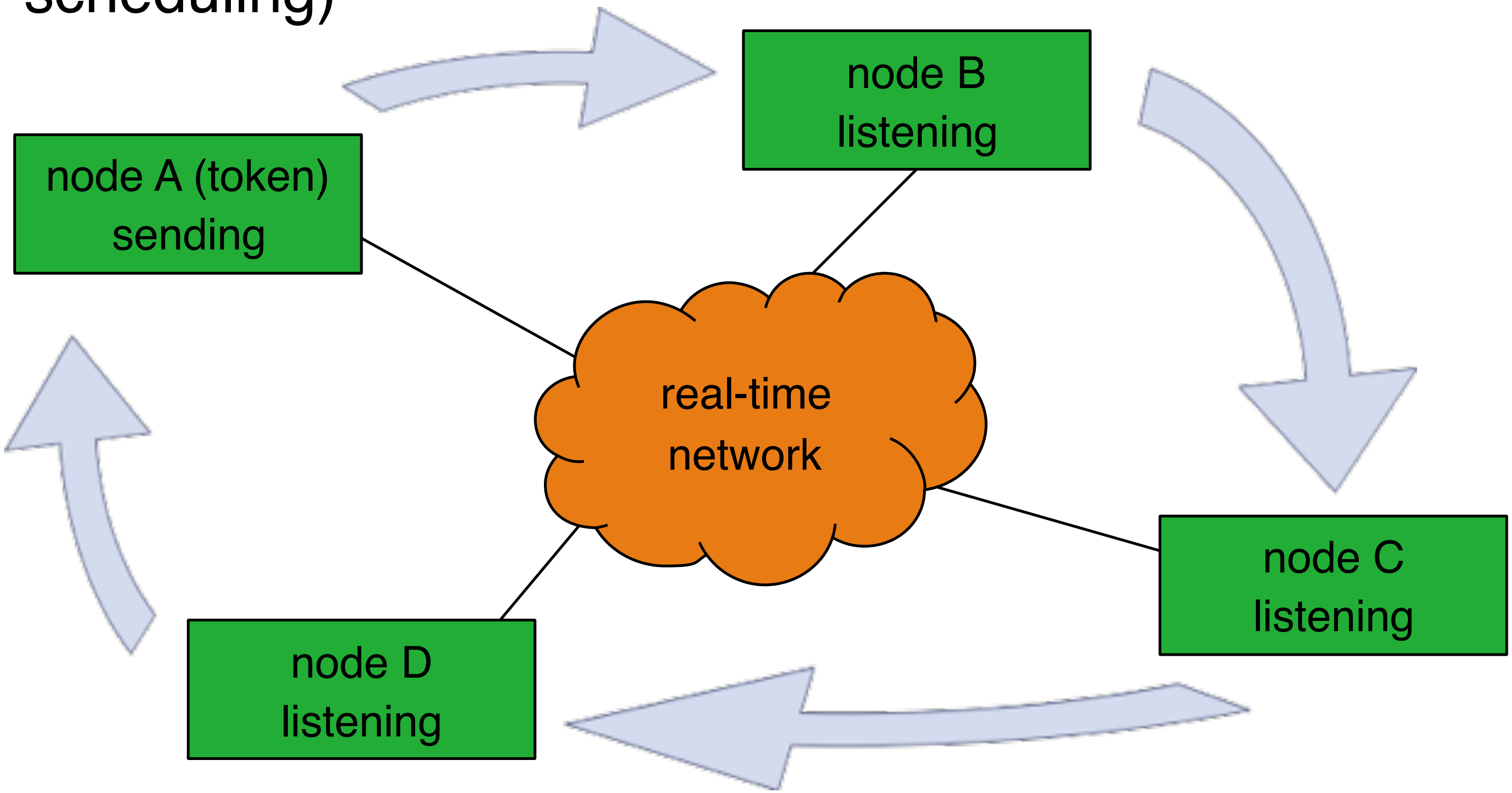
CAN performance

- Transmission rate from 5KBit/s to 1MBit/s
- Bit-synchronized bus access
- Bus length depends on transmission rate
  - 40m with 1MBit/s, 1000 with 50KBit/s
- transmission rate increases with shorter busses
  ... or with increased speed of light

- 2048 priorities (11 Bit) in version A,
  >500 Mio priorities (29 Bit) in version B
- Short messages (0-8 Byte)
- Efficiency depends on msg length: 0%..47%

Medium access control using a token ring

- Messages follow a logical ring
- Token required as permission to send (round robin scheduling)



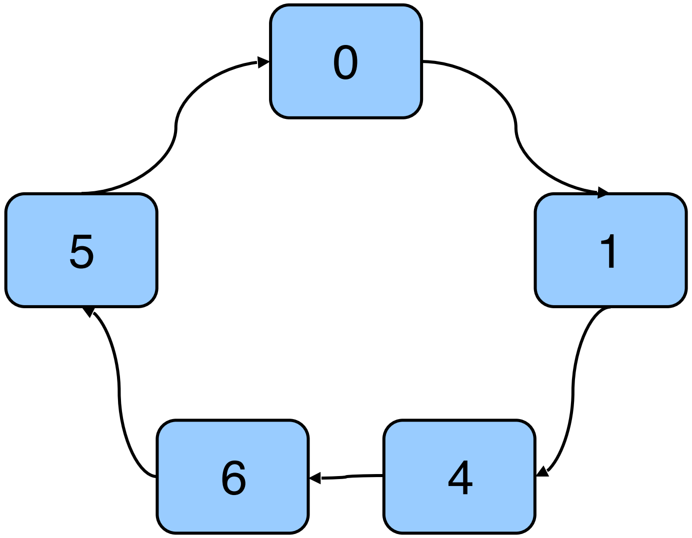
Token Ring with priorities

- Frames: Data, Token
- **Token**: Token Priority field, Reservation Priority field
- **Data**: Data field, Reservation Priority field
- Token can be taken only, if Token Priority is lower than priority field in outgoing data frame
- Reservation Priority is set to highest priority of waiting messages that are passed by packet
- Upon arrival of a data frame at its sender, a token is generated with priority is set to the data frame’s priority reservation field

More on Token Ring

- Not necessarily a strict ring
- Functional Parameters
  - Maximum token holding time at each node
  - Rings: resulting maximum token rotation time
- Problems:
  - lost tokens
  - duplicated tokens

Example (simplified!!)



Notation:
„Data, ResPrio“
„T-Prio, ResPrio“
0,1,4,6 want to send.
Token T-0,0 arrives at 0
NodeNr = Prio
High number → high prio

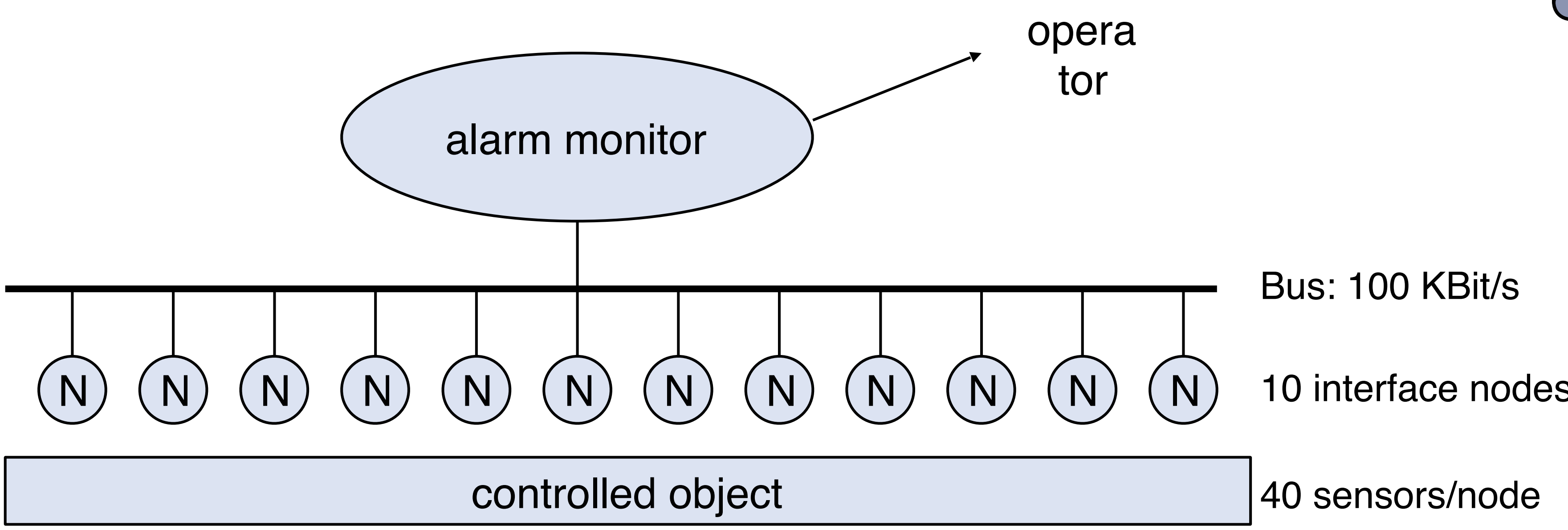
0	sends:	Data,0
1	waits, changes Resprio:	Data,1
4	waits, changes ResPrio:	Data, 4
6	waits, changes ResPrio:	Data, 6
5	does nothing	
0	creates token:	T-6, 0
1	waits, changes ResPrio:	T-6, 1
4	waits, changes ResPrio:	T-6, 4
6	claims token, sends:	Data, 4
6	creates token:	T-4, 0
1	waits, changes ResPrio:	T-4, 1
4	sends, sets ResPrio	Data, 1
4	creates token:	T-1, 0
1	sends,	Data, 0
1	creates token:	T-0, 0

Time division multiple access (TDMA)

- Divide Time periodically into Slots
- Allocate Slots
- Slots:
  - Cooperative (BUT: failures)
  - enforced

Kopetz: event vs. time triggered @ Peak Load

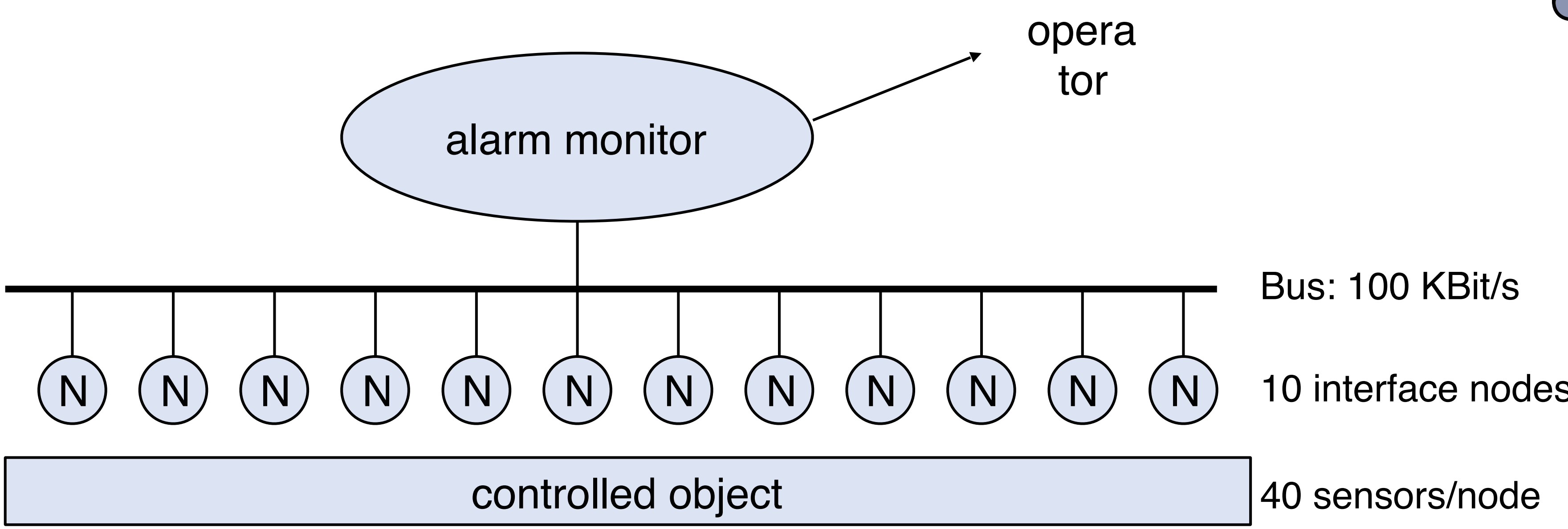
Kopetz



- Each node supervises 40 alarm conditions and sends messages
- Deadline: 100 ms to notify operator
- Communication bandwidth: 100 kbits/second

Kopetz: event triggered (ex. CAN)

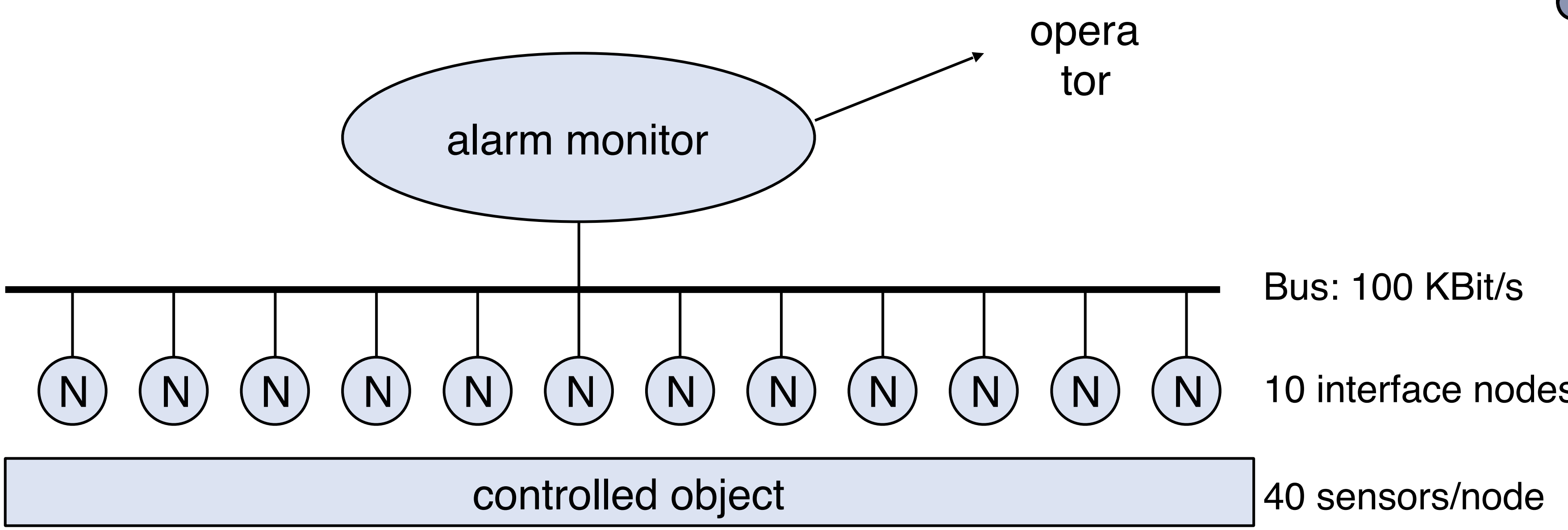
Kopetz



- Send message as soon as alarm condition is seen
  size = alarm name (8 Bit) + CAN overhead (44+4 Bit) = 56 Bit
- allows 180 messages within deadline of 100ms
- worst case requirement: 400 messages ...

Kopetz: event triggered (TDMA bus)

Kopetz



- Each node sends state message every 100ms
  size: Data field (40 Bit) + overhead (44) + gap (4) = 88 Bit
- allows 110 messages within 100ms period
- but, just 10 required!
  - i.e. 10 % of bandwidth

TT Ethernet as an example for TDMA

- Participants request slots
- Switch enforces slots
- Based on sparse time (determinism)

- See propaganda slides by TT-Tech

Real-Time communication in WANs

Jane Liu

Principles

- “find” connection (reservations)
- determine local properties at each node of connection depending on node-local scheduler
- add up delays
- take care for jitter (provide buffer, traffic shapers)

Example in this lecture: Weighted Round Robin

Other:

- Dynamic, EDF: e.g., Delay-EDD “Service Discipline”

See text books

Weighted Round Robin

Jane Liu

Principle:

- Message passes multiple nodes from source to dest.

During set up (admission) a *weight(wt)* is assigned to each input buffer of all involved switches

- Scheduler at each node
  - Visits input buffers in round robin
  - processes *wt* number of units of messages at each buffer per round

Scheduling example: Weighted Round Robin

Jane Liu

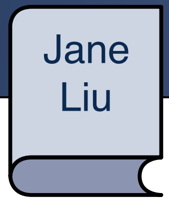
Messages:

- e_i max „length“ of message in “units”
- p_i Period: minimum inter-arrival time
- ρ number of hops
  nodes passed by message from source to destination

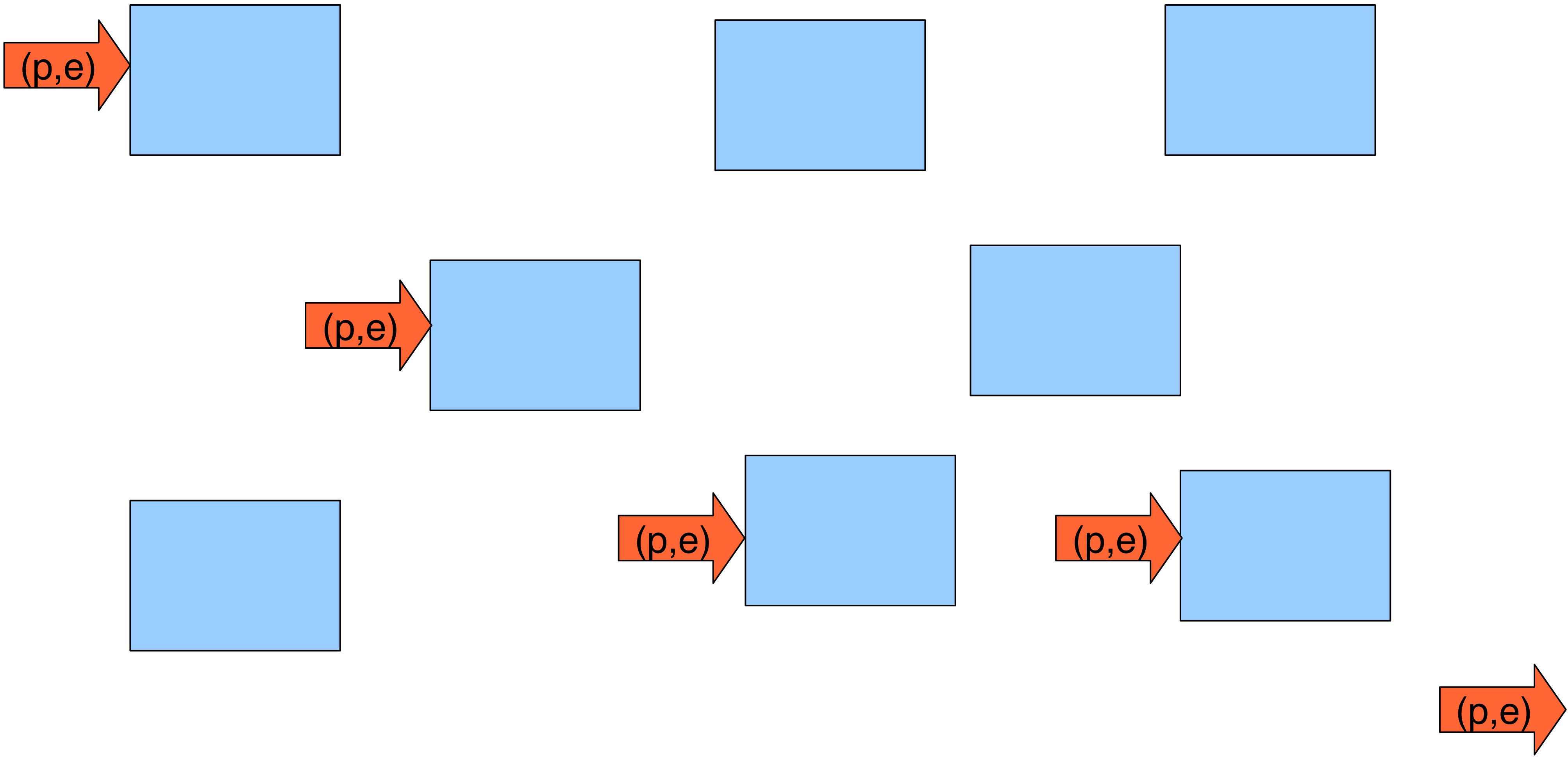
how to guarantee

- Bandwidth (p_i, e_i) and
- end-to-end delay

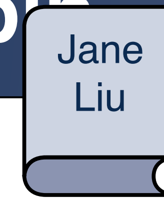
Scheduling example: reservation



(p,e)



Scheduling example: Weighted Round Robin



Nodes:

wt_i	each connection is given wt_i slots per round.
RL	round length (switch design parameter)
e_i	max „length“ of message in units
	if wt_i=1 → e_i rounds at the switch are needed

$\Sigma\ wt_i <= RL$

Round lengths ?

Weights?

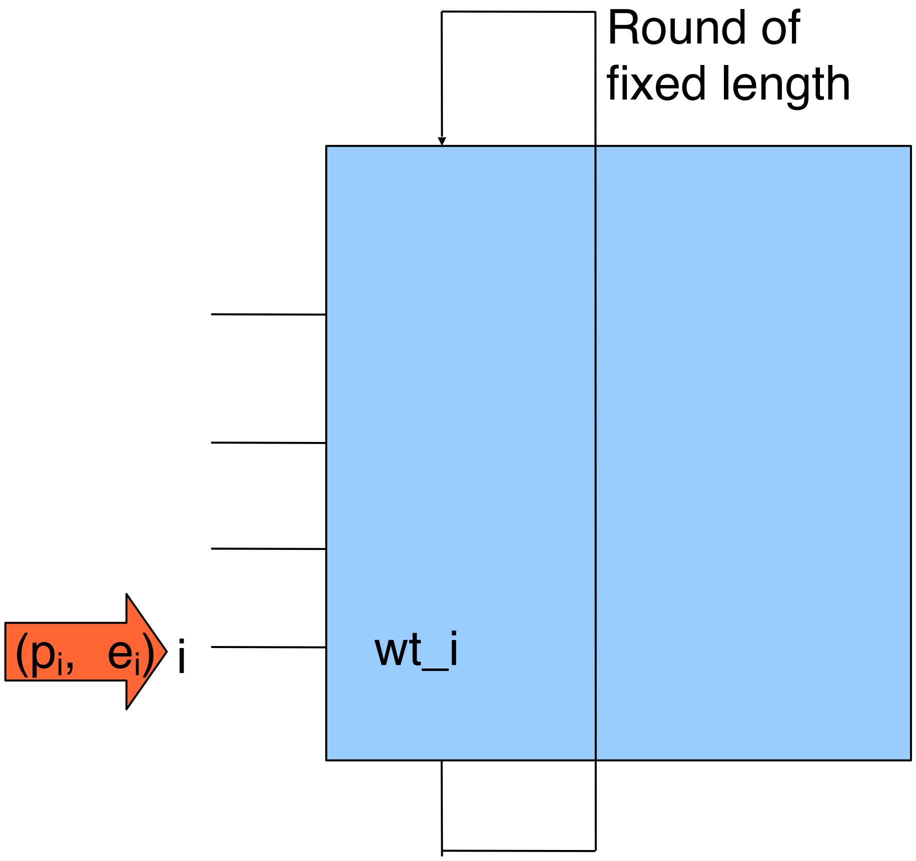
Delay? Per Node, end to end?

Scheduling example: Weighted Round Robin

Jane Liu

In each round, wt_i message units are taken from input i

Assign wt sufficient for (p,e)



Examples RL==16 :
- (8, 1)   not possible
- (16, 4) → NoR: 1   → wt = 4
- (32, 4) → NoR: 2   → wt = 2
- (32, 5) → NoR: 2   → wt = 3
- (31, 5) → NoR: 1   → wt = 5

General:
- RL <= min p_i
- Σ wt_i <= RL
- $wt_i >= \lceil e_i / \lfloor p_i / RL \rfloor \rceil$

Scheduling example: weighted round robin

Jane Liu

Some Calculations:

Delay per Node:

$RL * (\lceil e_i / wt_i \rceil)$

RL is bound by delay guarantees of Node for example, to guarantee that messages are transmitted within a period:

$RL <= \min p_i$

$wt_i >= \lceil e_i / \lfloor p_i / RL \rfloor \rceil$

end to end delay (pipelined “execution”):

$(\lceil e_i / wt_i \rceil + \rho - 1) * RL$

Summary

- Field busses
  - Scheduling analysis analog to processors
    - Use time driven / static priority / table based scheduling
- Switched LANs
- WANs
  - Dynamic
  - Use local scheduling disciplines in switches/routes to enforce system wide behaviour
  - Admission for connections required