Guaranteeing Delay and Throughput Properties of a Communication for a Real-Time Application

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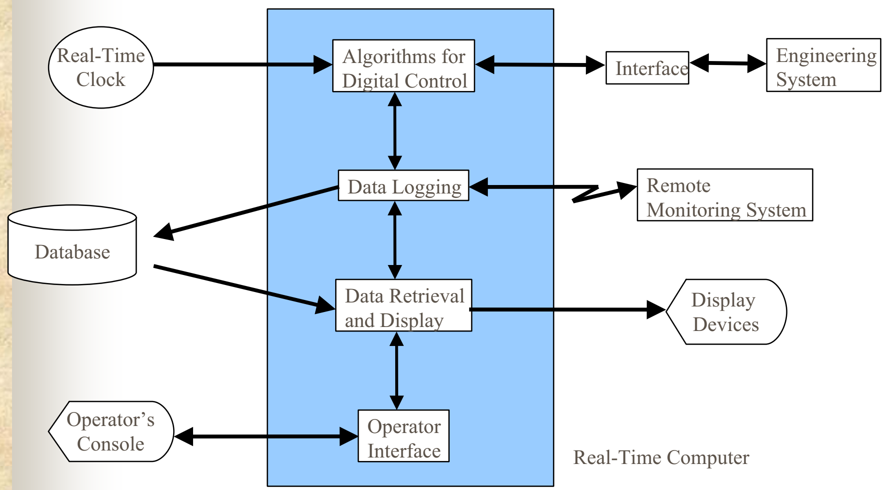
Overview

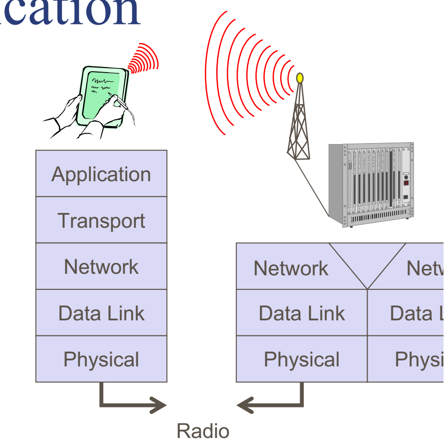
- Real-time application
- Communication environment
- Properties of real-time communication
- Disciplines to guarantee real-time properties in packet-switched networks
- Real-time transfer in sensor networks

Real-time application: generic model



Real-time Application

- Key elements:
  - Node
  - Network
- Node
  - CPU scheduling
- Network
  - Packet scheduling



Scheduling

- Similar mechanisms for CPU and network
- Possible alternatives
  - Static table-based
  - Priority-based
    - Static vs dynamic
  - Deadline-based
- Most studied mechanisms
  - Rate Monotonic
  - Earliest Deadline First

Rate-monotonic (RM)

- Based on static priorities
  - Priorities are directly mapped with the frequency of the periodic task's execution
  - Shorter period – higher priority
- Schedulable utilisation for one processor

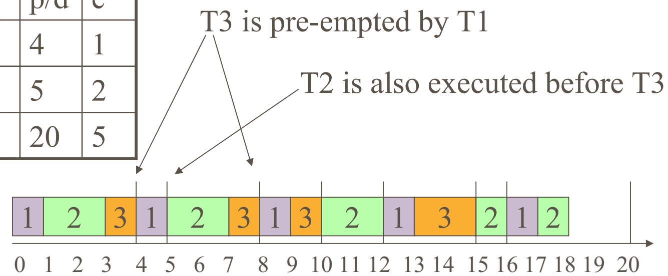
$$U_{RM} = \sum_{i=1}^{n} \frac{e_i}{p_i} \leq n\left(2^{1/n} - 1\right) \underset{n \to \infty}{\approx} 0.693$$

Sufficient, but not necessary condition

Rate monotonic

- The task with highest priority (shortest period) is executed when ever it is ready.

	p/d	e
T1	4	1
T2	5	2
T3	20	5



Earliest-deadline-first (EDF)

- Uses dynamic priorities
  - Current priority depends of the criticality of the task
  - Nearer absolute deadline – higher priority
- Schedulable utilisation for one processor

$$U_{EDF} = \sum_{i=1}^{n} \frac{e_i}{\min(p_i, d_i)} \leq 1$$

sufficient and necessary condition

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Communication connection

- Local network
  - LAN or bus *or wireless*
  - small, fast, reliable
  - hard deadlines
- Wide network
  - WAN, MAN
  - larger, slower
  - soft deadlines

Real-time traffic

- Typical assumptions
  - synchronous traffic,
  - message streams generated continuously
- Traffic models
  - Periodic – duration of the period
  - Sporadic – statistical model (mean, variation)
  - Aperiodic – (must be tranformed to sporadic)

Basic features

- packet, bandwidth, size of the packet, transfer time of one packet, ...
- Simplify: Time is divided by frames, a single fixed-size data packet is sent during one frame
- A periodic message Mi (mi,Ti,Ni)
  - mi – message length in frames
  - Ti – period of the message (frame numbers)
  - Message bandwidth Ui=mi/Ti; deadline Di=Ti

Performance measurements

- Miss ratio, loss ratio
- Delay jitter
- Buffer requirement
- Throughput rate

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Packet-switched networks

- Scheduling packet transmissions
- Priority-Based Service Disciplines
  - WFQ (Weighted Fair-Queueing)
  - Delay Earliest-Due-Date (D-EDD)
  - Jittered-EDD
  - Rate-Controlled Static Priority

Performance of Priority-Based Service Disciplines

Liu: Table 11-1

Performance Measures	WFQ	Delay-EDD	Jitter-EDD	RCSP
Acceptance test	O(1)	O(1)	O(1)	O(1)
Scheduling Complexity	O(n)	O(log n)	O(log n)	O(log n)
End-to-End Delay Bound	$E/u + \rho(e+1)$	$\leq D$	$\leq D$	$\leq D$
End-to-End Jitter	const* ρ	const* ρ	const	const
Buffer Space Requirement	const* ρ	const* ρ	const	const

Delay Earliest-Due-Date (D-EDD)

- EDF to schedule the transmissions of packets on each output link.
- Rate-control during acceptance for timing protection.
  - During request-for-connection message, each switch when accepting the connection reserves the requested bandwidth and buffer space for the connection and attached a local reletive deadline for the messages of this connection.
  - Destination client can then allocates the remaining free time to the switches on the route and return the answer.

Jitter-EDD

- Jitter-EDD is simply an enhancement of Delay-EDD.
- Main difference: Jitter-EDD is designed to keep the end-to-end delay jitter smaller.
- Jitter-EDD is nongreedy; the scheduler holds incoming packets in a holding queue and releases them for transmissions at more regularly spaced time instances.
- The end-to-end jitter is always less than the local relative deadline of the connection at the last switch.

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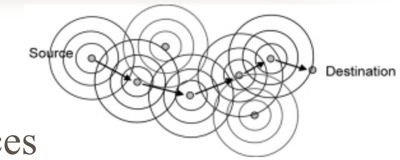
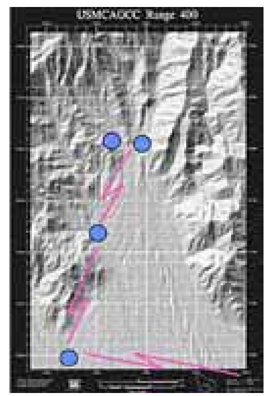
Sensor network



- large number of devices
- unattended deployment
- energy constraints
- common device failures
- frequent configuration changes
- wireless, broadcast



Features of a sensor network

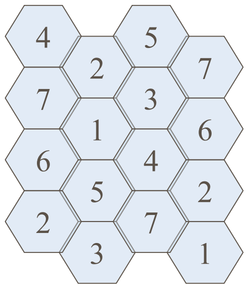
- No base station with wired backbone
- Messages in the network are periodic
- Messages need guaranteed bounded delay
- Sensors can create a lot of redundant data.
- Nodes are typically fixed in the network; the tracket target moves inside the network

Medium Access Control (MAC)

- Aloha
- CSMA/CD (carrier sense multiple access / collision detection) - no guarantee
- TDMA (time division multiple access)
  - Usually table-driven (static)
  - Novel idea: use EDF-like scheduling of messages at MAC layer

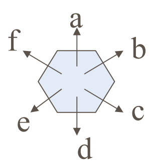
Network architecture

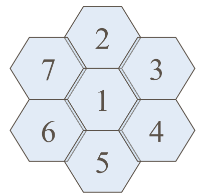
- Router nodes
  - two transmitters
  - simultaneous sending and receiving
- Cell structure
  - intra-cell – dynamic scheduling
  - inter-cell – static TDMA

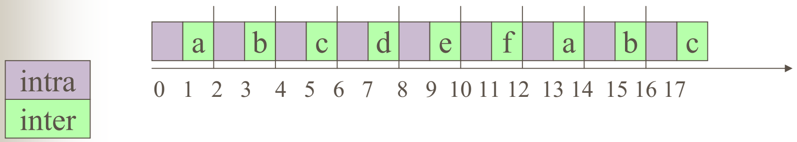


Inter-cell communication

- Periodic comm.
- Each cell has a router
- Router transmits and receives simultaneously during the inter-cell frame
- Frames reserved for inter-cell comm.







Intra-cell communication

- Conflict-free transmission scheduling
- Every node inside one cell schedules the same set of messages using the same algorithm
- No control messages, no negotiation during transmission
- Initialisation: transmit the message table to all nodes in one cell
- Implicit-EDF

Implicit-EDF Advantages – Disadvantages

- Energy-efficient
  - no extra listening
- Bound transfer time
  - within the deadline
- Scalability
  - number of cells not restricted
- Less inter-cell traffic
  - only the common information, not all measurements

- More computation
  - all nodes makes synchronously the same decision
- Scalability
  - The message table large, if large cell
- Traffic model
  - only periodic
  - can allow aperiodic with no deadlines

Conclusion

- EDF is widely used in all real-time scheduling issues
- EDF is useless in overload situation. It needs some kind of admission control to avoid this
- Traditional traffic model used in this presentation – *periodic tasks with deadlines* – is not suitable to all situation, but it is well studied

References

- Jane Liu: Real-Time Systems. Prentice Hall, 2000
- Jochen Schiller: Mobile Communications, second edition. Addison Wesley, 2003
- Marco Caccamo & Lynn Y. Zhang: The capacity of Implicit EDF in Wireless Sensor Networks. In Proceedings of Euromicro Conference on Real-Time Systems (ECRTS´03), 2003.