REAL-TIME NETWORKS Introduction

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Outline

- Definition
- Examples
- Models
- Course content and objective

Definitions

- Response time

> Interval between the instant at which one or more inputs are changed and the instant at which the matching response at outputs can be perceived

- Real-time system

> « A computer system for which correctness of calculations not only depends on the logical behavior but also on the instant at which the result is produced. If the temporal constraints are not fulfilled, it is said that a failure has occurred », real-time systems FAQ

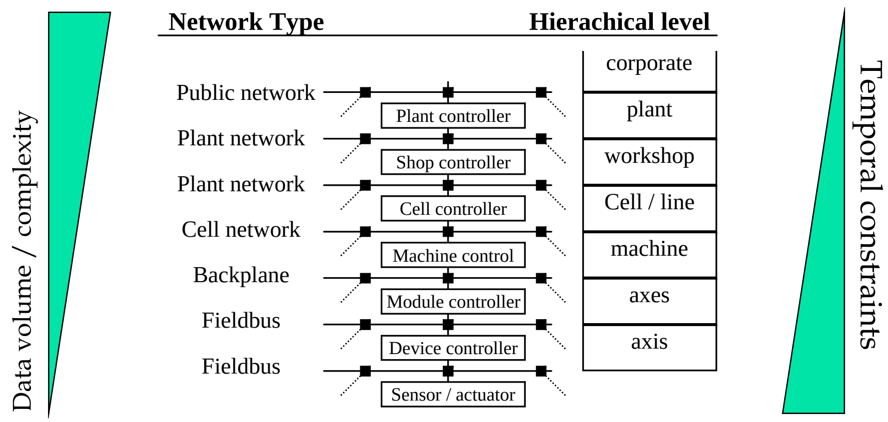
Definitions (2)

> « hence, it is essential that the timing constraints of the system are guaranteed to be met. Guaranteeing timing behavior requires that the system be predictable. It is also desirable that the system attain a high degree of utilization while satisfying the timing constraints of the system », Real-time systems FAQ

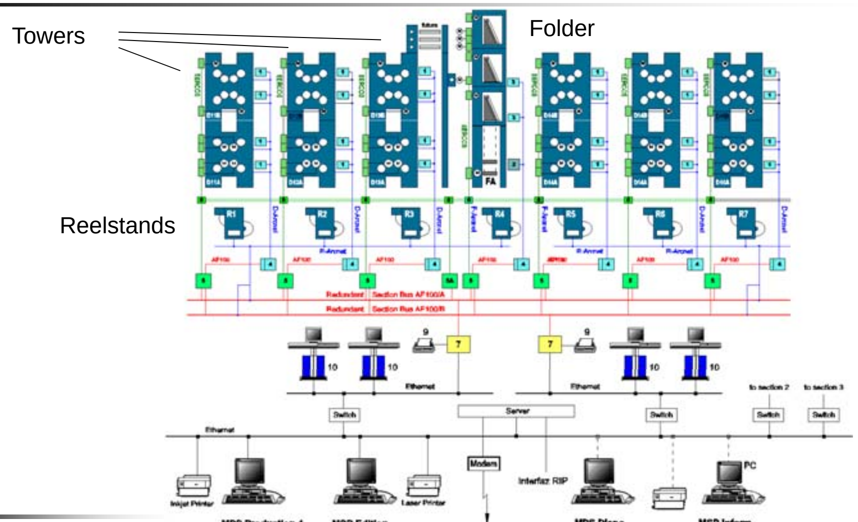
Hard vs soft real-time

- Hard real-time
  - in case of violation of one or more temporal constraints, there is full loss of functionality
- Soft real-time
  - the functionality is not lost but its quality is degraded
  - Still some reward after deadline (value given)
- Firm real-time
  - Same but no value is given if deadline missed

Production hierarchy

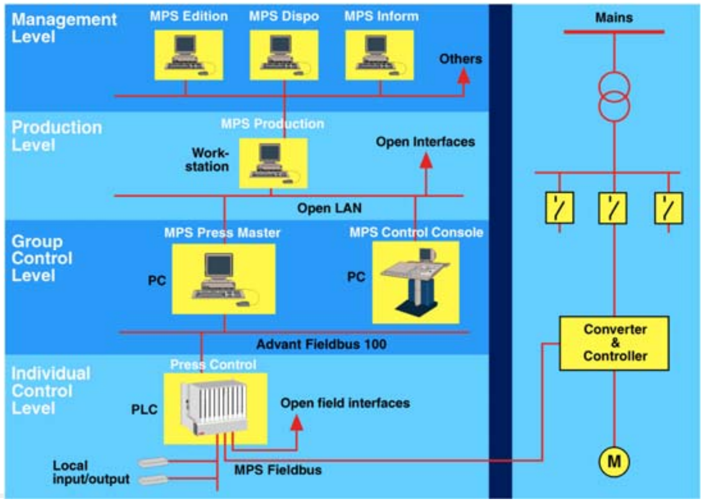


Printing facility



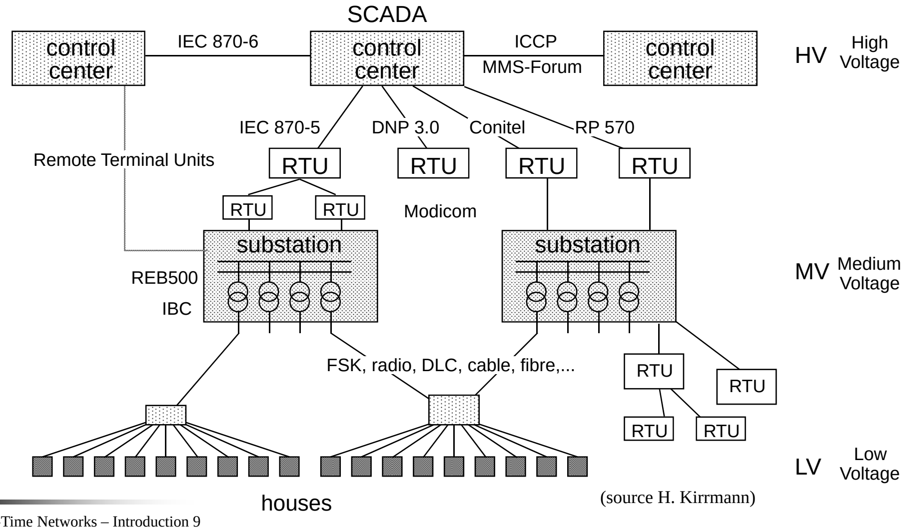
(source H. Kirrmann)

Printing facility architecture



(source H. Kirrmann)

Electricity control network



(source H. Kirrmann)

Data volume in plants

- Power Plant 25 years ago
  - 100 measurement and action variables (called "points")
  - Analog controllers, analog instruments
  - one central "process controller" for data monitoring and protocol.
- Coal-fired power plant today
  - 10'000 points, comprising
    - 8'000 binary and analog measurement points and
    - 2'000 actuation points
    - 1'000 microcontrollers and logic controllers
- Nuclear Power Plant
  - three times more points than in conventional power plants
- Electricity distribution network
  - 100’000 - 10’000’000 points

(source H. Kirrmann)

Distances

- 1-1000 km: Transmission & Distribution.
  - Control/supervision of large distribution nets: water, gas, oil, electricity
- 1-5 km: Power Generation.
  - Out of primary energy sources: waterfalls, coal, gas, oil, nuclear ...
- 50m – 3km: Industrial Plants.
  - Manufacturing and transformation plants: cement works, steel works, food silos, printing , paper, pulp processing, glass plants, harbors, ...
- 500m – 2km: Building Automation.
  - energy, air conditioning, fire, intrusion, repair, ...
- 1m – 1km: Manufacturing.
  - flexible manufacturing cells – robots
- 1m – 800m: Vehicles.
  - Locomotives, trains, streetcars, (trolley) buses, cars, planes, spacecraft, ..

(source H. Kirrmann)

Reaction times

- 10 µs: positionning of offset cylinder in offset printing (0,1 mm at 20 m/s)
- 46 µs: sensor synchro. in bus-bar protection for substations (1º @ 60Hz)
- 100 µs: resolution of clock for a high-speed vehicle (1m at 360 km/h)
- 1.6 ms: sampling rate for protection algorithms in a substation
- 10 ms : resolution of events in the processing industry
- 20 ms: time to close or open a high current breaker
- 200 ms: acceptable reaction to an operator's command (hard-wire feel)
- 1s: acceptable refresh rate for the data on the operator's screen
- 3 s: acceptable set-up time for a new picture on the operator's screen
- 1 min: general query for refreshing the process data base in case of major crash

(source H. Kirrmann)

Application model

- Time-triggered
  - Application work cyclically
    - Wait beginning of period
    - Sample inputs
    - Compute some algorithm (using inputs and parameters)
    - Make the results available at outputs
  - Special cases: acquisition, distribution
  - Periodicity is not always mandated
    - If yes, limited jitter may be required
- Event-triggered

Application model (2)

- Time-triggered
- Event-triggered
  - Activated upon event occurrence
    - Computes some algorithm using system state and parameters
    - Sends the results (local or remote)
  - Need to know the order of occurrence of events
  - Maximum end-to-end delay between event occurrence and answer (result of algorithm)
  - Actions (computations) may need to be synchronized
    - Axis movements for instance (see printing facility)

Data Model

- process data,
- configurations and parameters,
- programs

- Properties
  - Temporal consistency
    - Absolute
    - relative
  - Spatial consistency

Temporal consistency

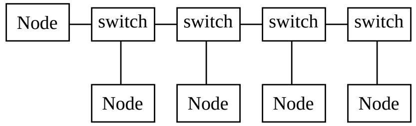
- Let $[a, t_a, v_a]$ and $[b, t_b, v_b]$ be the internal representations of variables a and b where t_a and t_b indicate the instants at which the values v_a and v_b of a and b have been acquired.
- At instant t, v_a is said absolutely consistent if and only if: $t - t_a < A$ (A: absolute consistency threshold for a)
  - freshness
- v_a and v_b are said relatively consistent if and only if: $|t_a - t_b| < R$ (R: relative consistency threshold)

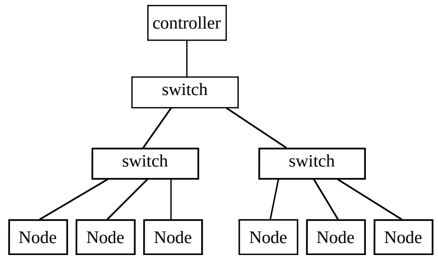
Spatial Consistency

- Applies when copies of the same information is made available on different locii of control (nodes)
- Spatial consistency = copies are identical

Network model

- Single sub-network
- Traffic may come from or go to external world but has no RT constraints
- Free topology





Definitions

- Data circuit (ISO 7498) “a common path in the physical media for OSI among two or more physical-entities together with the facilities necessary in the physical layer for the transmission of bits on it”;
- Real subnetwork (ISO 7498) “a collection of equipments & physical media which form an autonomous whole & can be used to interconnect real systems for the purpose of data transfers”
- subnetwork (ISO 7498) – “an abstraction of a real subnetwork”;
- data link (IEC 8802.2) – “an assembly of two or more terminal installations and the interconnecting communication channel operating according to a particular method that permit information to be exchanged. In this context, the term terminal installation does not include the data source and the data sink”.

Definitions (2)

- LAN – a data link using the same physical layer and medium access control protocols.
- segment – synonymous to data circuit when the nodes are connected through wires.
- Cell – synonymous to data circuit but in the case of wireless medium.

Traffic model

- Real-time periodic
  - $M_{p,i}=\{T_i, D_i. C_i\}$
    - C_i length of message, T_i period of transfer, D_i relative deadline from beginning of period (absolute deadlines are $d_{n,i} = n\ T_i + D_i$)
- Real-time sporadic
  - $M_{s,i}=\{T_i, D_i. C_i\}$
    - T_i min. interarrival time, D_i relative deadline from arrival time (absolute deadlines are $d_{n,i} = arr_{n,i} + D_i$)
- Best effort
  - Configuration data
  - File transfer
- Multimedia

Traffic model (2)

- File transfer
  - $M_{ft,i}=\{T_{i,inner}, T_{i,outer}, n_i, D_i. C_i\}$
    - File transfer flow I happens at most every $T_{i,outer}$. When it occurs, n_i packets (messages) are transferred at a rate given by $T_{i,inner}$
- Multimedia
  - Characterized by uneven arrivals and varying packet lengths
  - Not real-time but we would like to provide more than best effort
  - Solution is often to provide some share of bandwidth
  - $M_{m,i}=\{T_i, C_i\}$
    - C_i bits each T_i
- Best effort traffic may not play the game (tries to send the maximum)

Error model

- Most studies assume “errorless” networking
  - Close to reality for networks on cables
  - Not representative for wireless networks
- Error model depends on type of media
  - Wireless -> interferences (bursts) and fading (long)
  - Wireline -> well modeled by packet error rate with no correlation
- Model
  - Omissions: fail to receive a packet
  - Duplications: receive same packet twice or more
  - Collisions: emissions from two or more nodes at same time
  - Babbling idiot: node starts to send without limits
  - Node failure

Quality of Service (QoS)

- Observable properties of the network
  - Transfer delay bounds
  - Transfer delay variations (jitter)
  - Throughput

Course Objective

- Master the main problems and solutions related to communications under real-time QoS constraints
  - in transportation systems
  - in the control of industrial processes
  - In multimedia
- Deep insight into how
  - to guarantee QoS at the protocol level
  - to assess the QoS properties
- Introduction to research in the domain

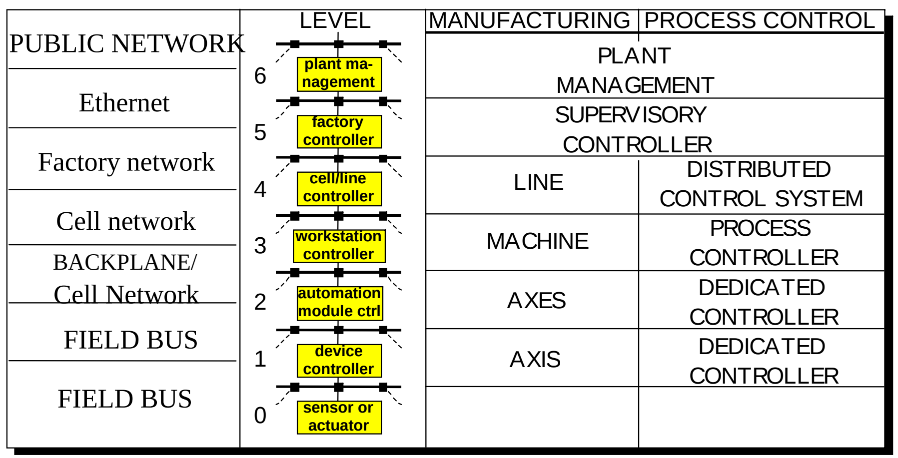
Course Content

- Introduction
  - Requirements (delay, jitter, predictability, topology, cost, etc.)
- Layers and impact on the temporal behaviour
  - Physical layer impact
  - Medium Access Control and Logical Link Control
  - Other layers (network, transport, application, clock synchronization, network management)
- Real-Time performance assessment (scheduling, without error, in presence of errors)
- Fieldbusses and analysis of the main solutions (Profibus, FIP, MVB, CAN, ASi, etc.) and how they fulfill the requirements
- Ethernet and the many ways to offer real-time performances
- Wireless solutions (802.11, Zigbee, Bluetooth, sensor networks)

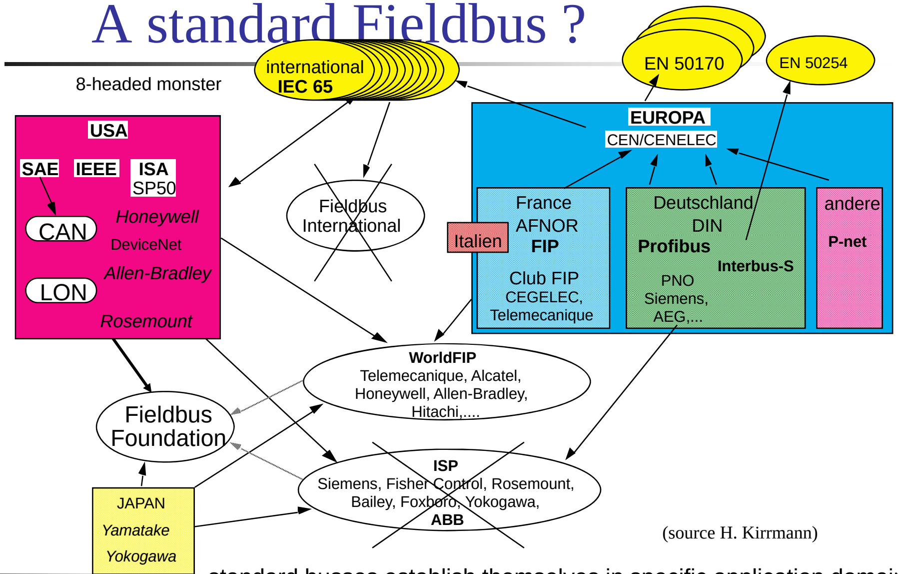
Real-Time Networks

- A-bus
- Arcnet
- Arinc 625
- * ASI
- Batibus
- Bitbus
- * CAN
- ControlNet
- DeviceNet
- DIN V 43322
- DIN 66348 (Meßbus)
- FAIS
- EIB
- Ethernet
- Factor
- * Fieldbus Foundation
- FIP
- Hart
- IEC 61158
- IEEE 1118 (Bitbus)
- Instabus
- * Interbus-S
- ISA SP50
- IsiBus
- IHS
- ISP
- J-1708
- J-1850
- LAC
- * LON
- MAP
- Master FB
- MB90
- MIL 1553
- MODBUS
- MVB
- P13/42
- P14
- Partnerbus
- P-net
- * Profibus-FMS
- Profibus-PA
- Profibus-DP
- PDV
- * SERCOS
- SDS
- Sigma-i
- Sinec H1
- Sinec L1
- Spabus
- Suconet
- VAN
- * WorldFIP
- ZB10
- ...

Communication hierarchy



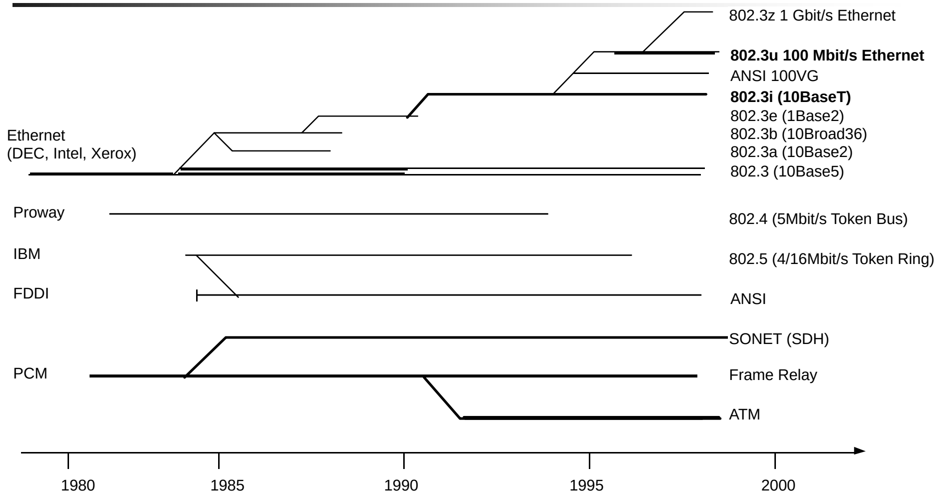
A standard Fieldbus ?



(source H. Kirrmann)

standard busses establish themselves in specific application domains

LAN evolution



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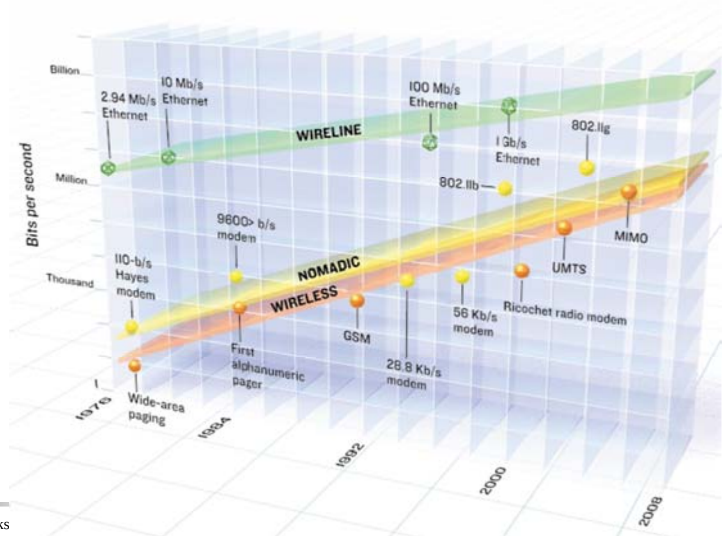
Edholm's law [Cherry 04]



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