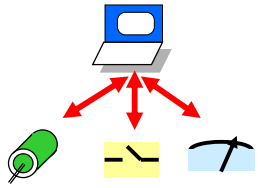
SPRING 2010

即時控制系統設計
Design of Real-Time Control Systems

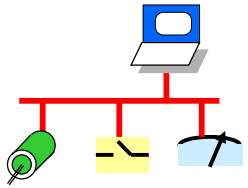
Lecture 31
Real-Time Communications for Control Applications

Feng-Li Lian
NTU-EE
Feb10 – Jun10

- Real-Time Control Systems
  - Controlled by one Computer Processor
    - Centralized control systems
    - Real-time operating systems
  - Controlled by one Communication Medium
    - Distributed control systems
    - Real-time communications

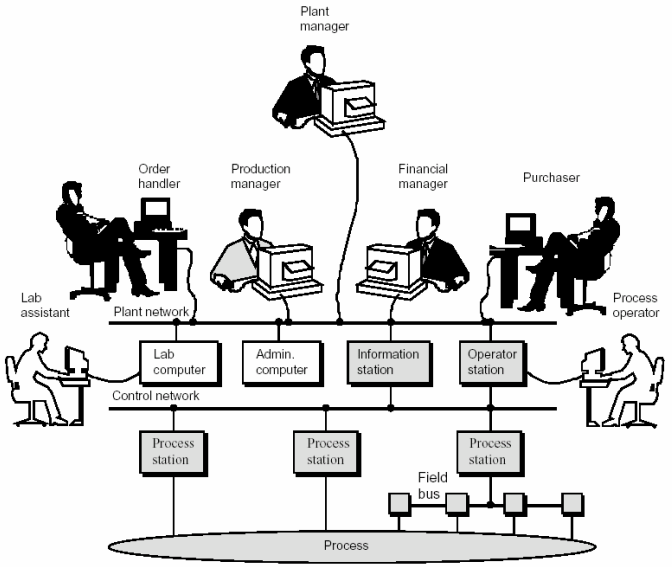


Centralized Control System



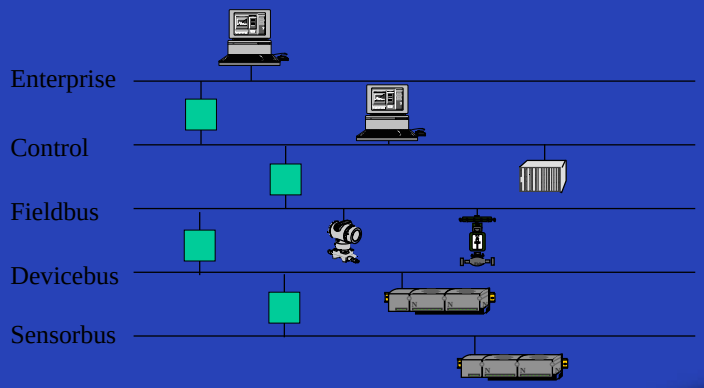
Distributed Control System

- Real-Time Communications
- Networks for Control Applications & Automation
- Comparison
  - Static properties
  - Dynamic properties



Amstron & Wittenmark 97

Industrial Bus Hierarchy



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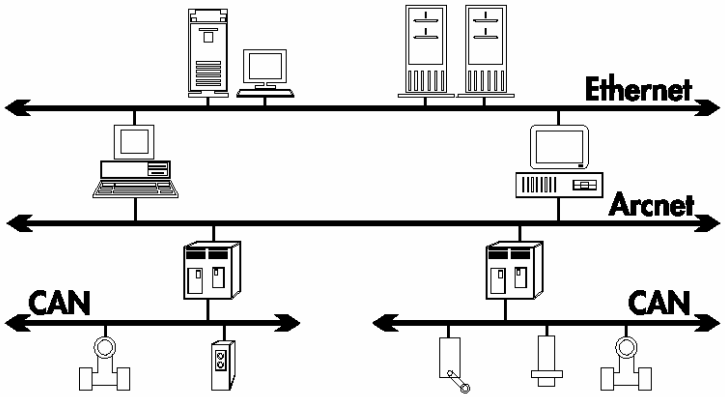
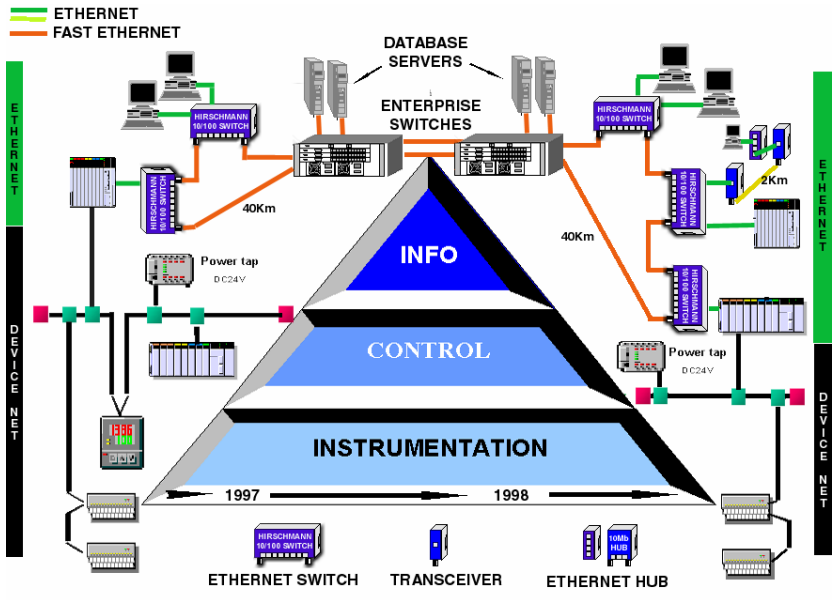
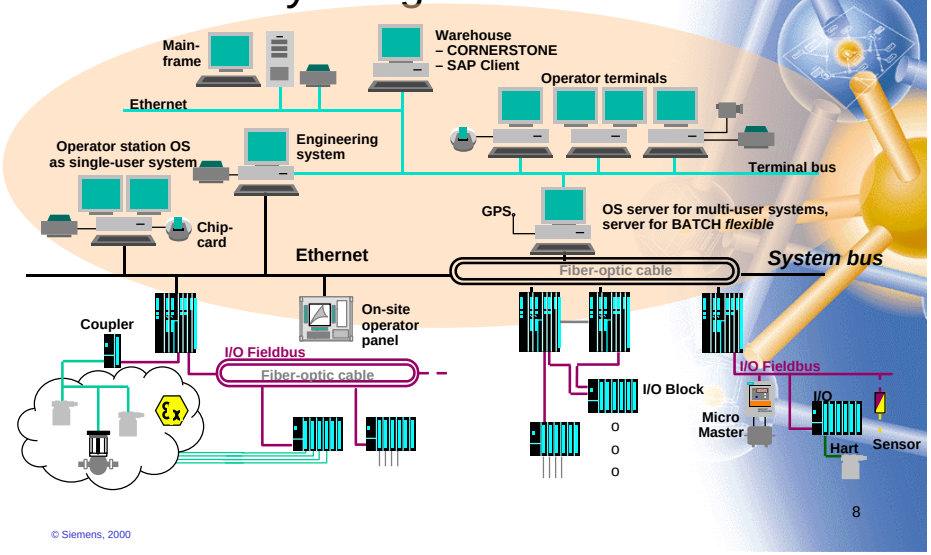


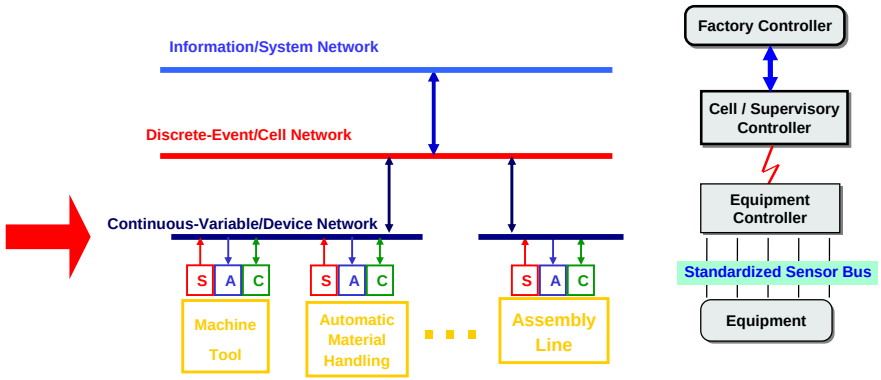


SIEMENS

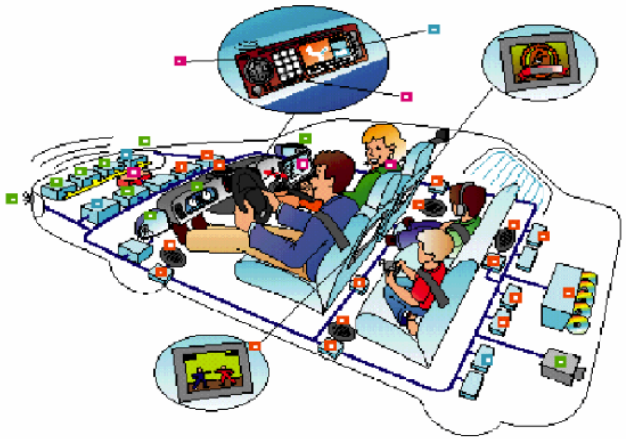
TIA – Totally Integrated Automation



- Definition:
  - Control systems with physically distributed processing power and network communication of control signals



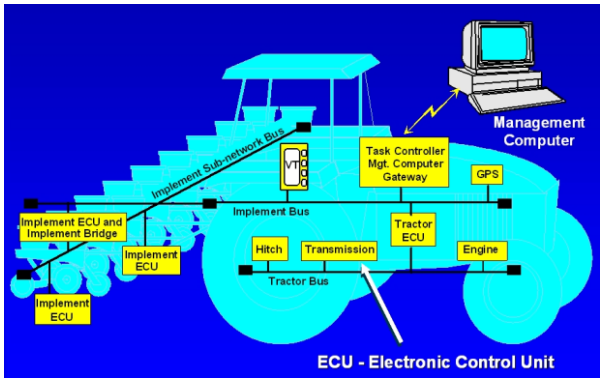
- In-Vehicle Network Systems
  - CAN
  - J1850
  - J1939
  - IDB 1394

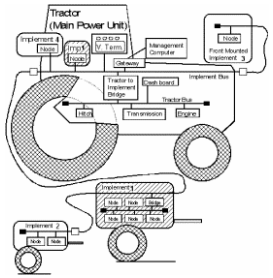


Source: ITS Data Bus Forum

- Network at Tractor and Implement

Protocols:
- J1850
- J1939



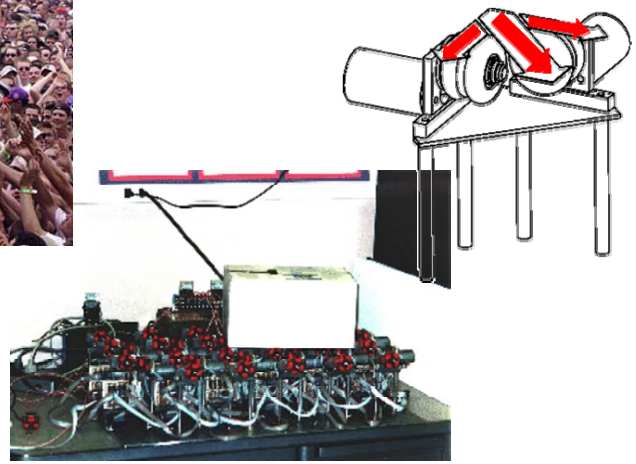


Source: BioSystems Engineering, Oklahoma State Univ.

- Distributed Manipulation Systems

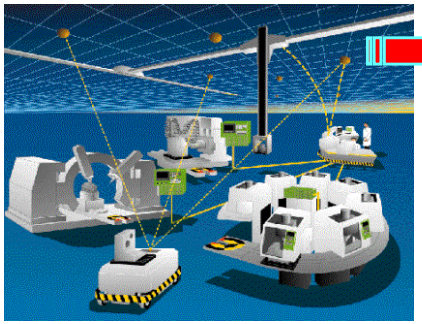
Protocols:
- RS232
- RS485

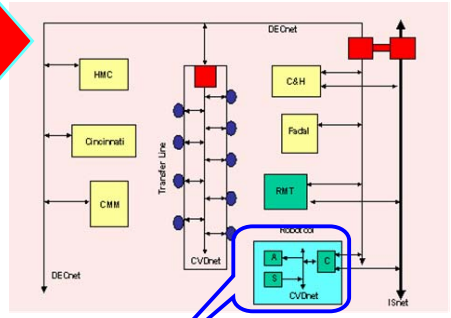
Source: USA Today

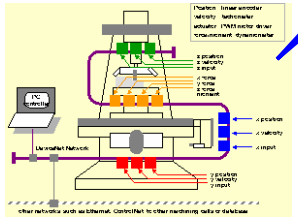


Source: Professor Luntz, ME, Univ. of Michigan, Carnegie Mellon Univ

- Advanced Manufacturing Systems



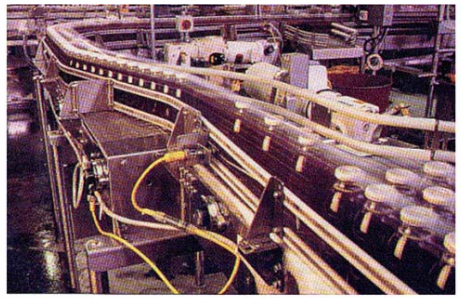




Protocols:
- DeviceNet
- Ethernet
- Remote I/O

- Beverage Packaging & Food Processing

Rhode Island Beverage Packaging Plant



Te Rapa Wholemilk Drier 5

Anchor Products Corporate, New Zealand

Protocols:
- ControlNet
- DeviceNet
- Ethernet
- Profibus

- Automobile Production at OPEL, Germany

Computer Integrated Manufacturing

Final Assembly: Marriage of chassis and body

Protocols: ControlNet, DeviceNet, Ethernet, Profibus

- Beer Brewing at Germany

Protocols: ControlNet, DeviceNet, Ethernet, Profibus

- Orange Picking Robot

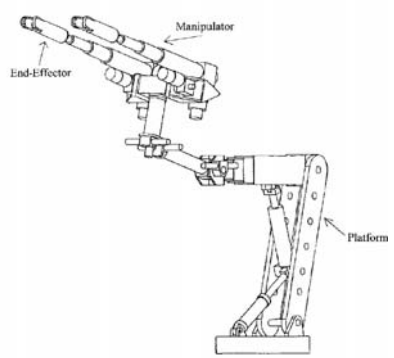
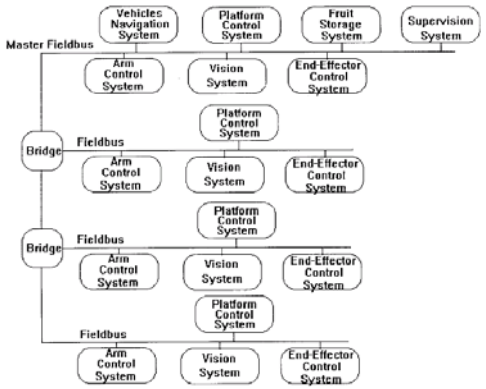
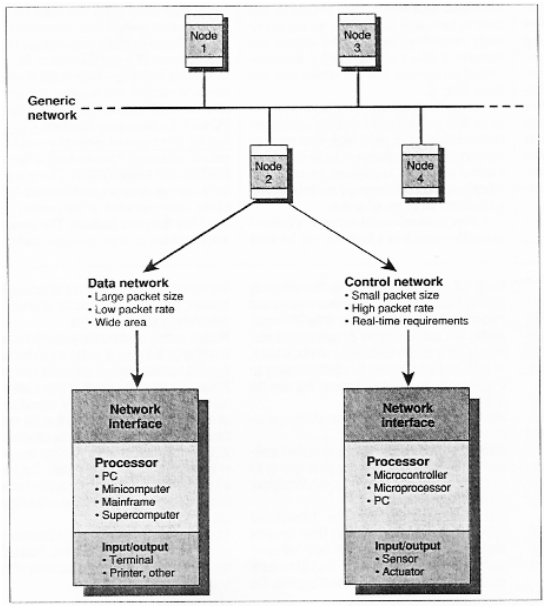


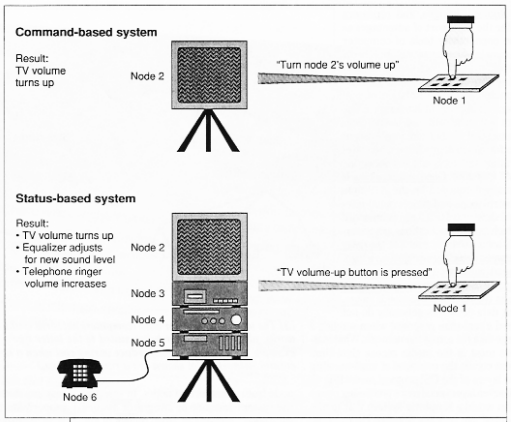
Fig. 4. One of the four platforms of the orange picking robot.



Cavalieri, Stefano, Mirabella 97



Raji 94



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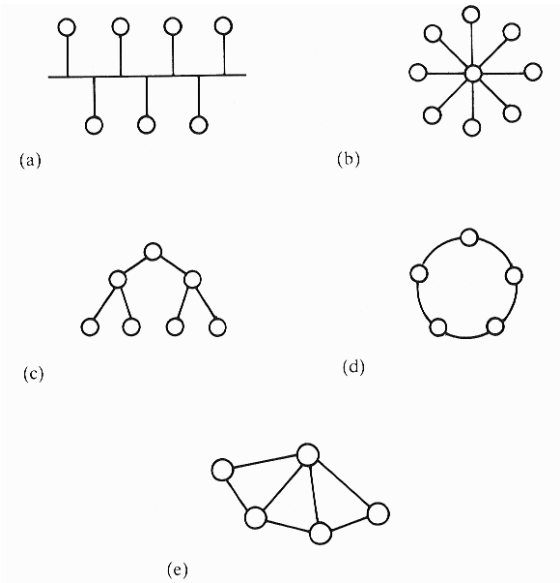
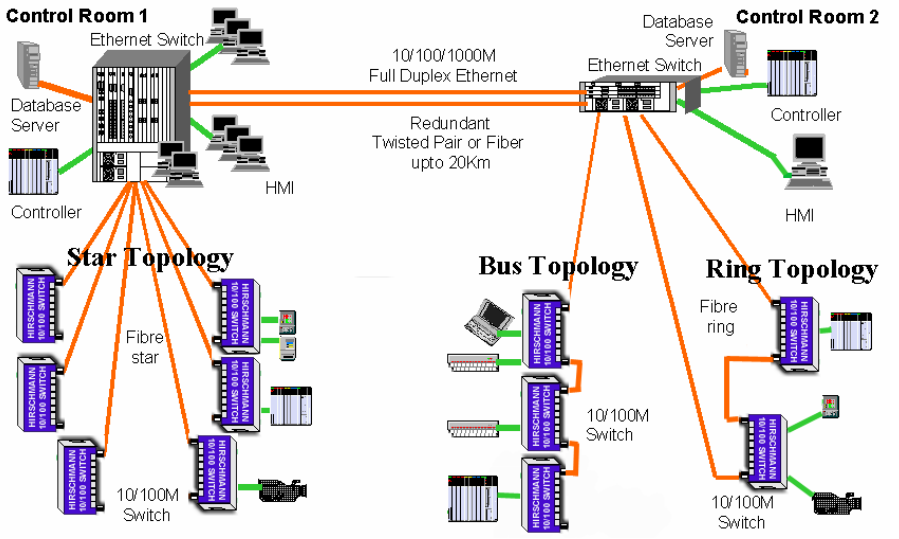
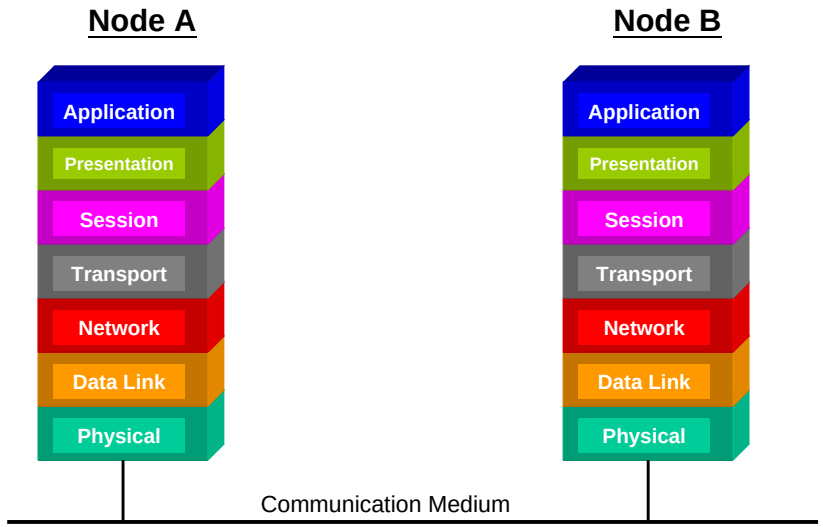
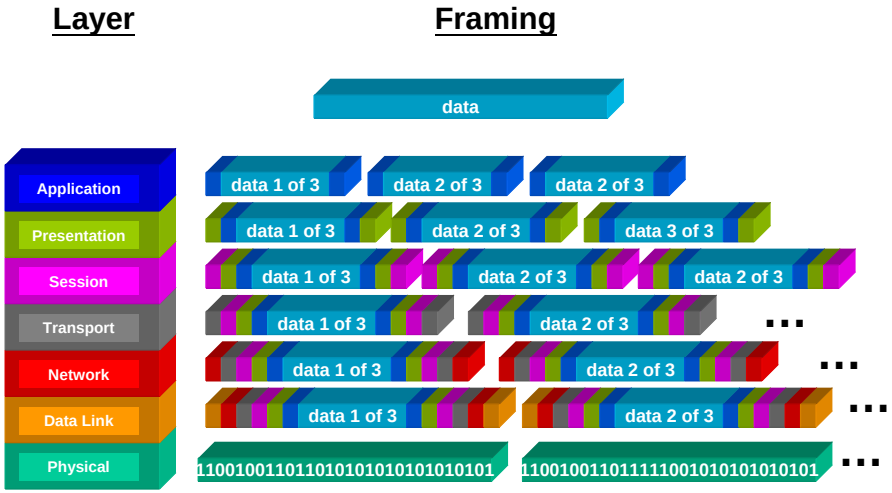


(a) bus
(b) star
(c) tree
(d) ring
(e) mesh

Bennett 94







Layer	Functions
Application	Real data to send to another network device (IE, FTP, telnet, email)
Presentation	Encoding data (different computers have different coding systems)
Session	Token management (task exchange), synchronization (checkpoint)
Transport	Split data into packets, and manage to the connect (TCP)
Network	Add addressing for switching and routing (IP, ROUTER/GATEWAY)
Data Link	Add error detection, flow control, and physical addressing (Medium Access Control, BRIDGE/SWITCH)
Physical	Transmits data over the medium (i.e., cable: fiber, twisted pair, etc. HUB/REPEATER)

Layer	Control Networking Requirements	
Application	– Data objects	
Presentation	– Standardized networking structures	– Networking structures – Data interpretation
Session	– Authentication – Network Management	
Transport		– End-to-end ACK – Duplicate detection – Automatic retries
Network	– Addressing, unicast, multicast, broadcast – Routers	
Data Link		– MAC, collision avoidance/detection – Framing, data encoding
Physical		– Priority – Media transceivers

Typical Industrial Networks

7	Application	Application layers
6	Presentation	
5	Session	
4	Transport	Data transport layers
3	Network	
2	Data link	
1	Physical	

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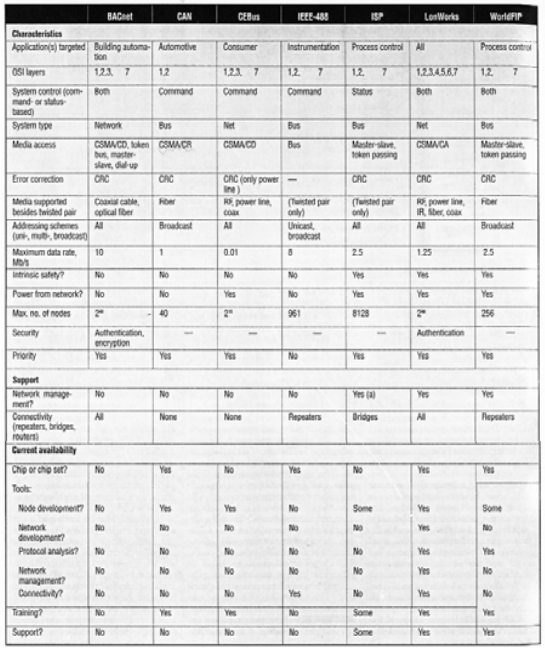
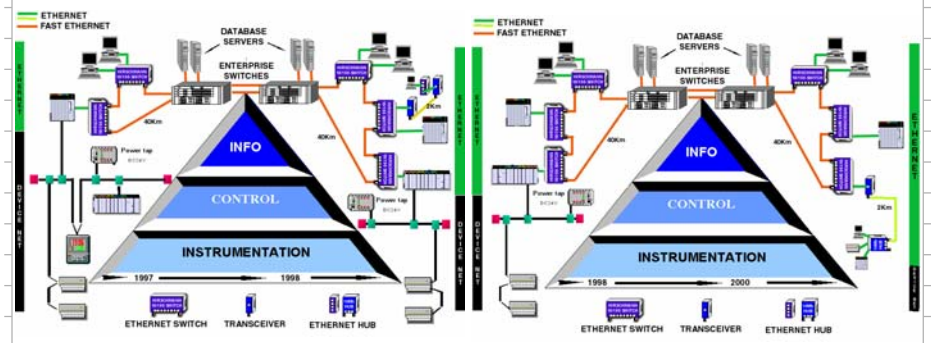
Characteristics	Twisted Pair	Radio	Power Line	Coaxial	Infrared	Fiber Optics
Range (m)	1-1000	50-10,000	10-5,000	10-10,000	0.5-30	10-10,000
Data rate (kb/s)	0.3-2000	1.2-9.6	0.06-10,000	300-10,000	0.05-20	1-100,000
Node cost	$10-30	$50-100	$50-150	$30-50	$20-75	$75-200
Installation cost	Low	-	None-Low	Medium	-	Medium-high



	BACnet	CAN	CEBus	IEEE-488	ISP	LonWorks	WorldFIP
Characteristics							
Application(s) targeted	Building automation	Automotive	Consumer	Instrumentation	Process control	All	Process control
OSI layers	1,2,3, 7	1,2	1,2,3, 7	1,2, 7	1,2, 7	1,2,3,4,5,6,7	1,2, 7
System control (command- or status-based)	Both	Command	Command	Command	Status	Both	Both
System type	Network	Bus	Net	Bus	Bus	Net	Bus
Media access	CSMA/CD, token bus, master-slave, dial-up	CSMA/CR	CSMA/CD	Bus	Master-slave, token passing	CSMA/CA	Master-slave, token passing
Error correction	CRC	CRC	CRC (only power line)	—	CRC	CRC	CRC
Media supported besides twisted pair	Coaxial cable, optical fiber	Fiber	RF, power line, coax	(Twisted pair only)	(Twisted pair only)	RF, power line, IR, fiber, coax	Fiber
Addressing schemes (uni-, multi-, broadcast)	All	Broadcast	All	Unicast, broadcast	All	All	Broadcast
Maximum data rate, Mb/s	10	1	0.01	8	2.5	1.25	2.5
Intrinsic safety?	No	No	No	No	Yes	Yes	Yes
Power from network?	No	No	Yes	No	Yes	Yes	Yes
Max. no. of nodes	2^{64}	40	2^{15}	961	8128	2^{64}	256
Security	Authentication, encryption	—	—	—	—	Authentication	—
Priority	Yes	Yes	Yes	No	Yes	Yes	Yes
Support							
Network management?	No	No	No	No	Yes (a)	Yes	Yes
Connectivity (repeaters, bridges, routers)	All	None	None	Repeaters	Bridges	All	Repeaters
Current availability							
Chip or chip set?	No	Yes	No	Yes	No	Yes	Yes
Tools:							
Node development?	No	Yes	Yes	No	Some	Yes	Some
Network development?	No	No	No	No	No	Yes	No
Protocol analysis?	No	No	No	No	No	Yes	Yes
Network management?	No	No	No	No	No	Yes	No
Connectivity?	No	No	No	Yes	No	Yes	No
Training?	No	Yes	Yes	No	Some	Yes	Yes
Support?	No	No	No	No	Some	Yes	Yes



Capability Hierarchy

- Level of functionality
  - Enterprise bus (**Ethernet**)
  - Control bus (**HSE**, ControlNet)
  - Fieldbus (**Foundation Fieldbus**, Profibus PA)
  - Device bus (**DeviceNet,** Profibus DP, Interbus-S)
  - Sensor bus (**CAN,** ASI, Seriplex, LonWorks)

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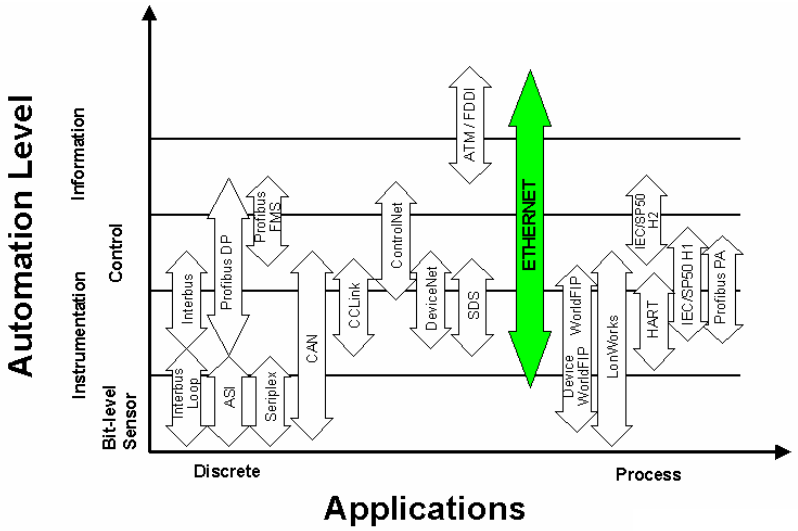


Bus	User*	Application	Sponsor
CANs	25%	Automotive, Process control	CiA, OVDA, Honeywell
Profibus (3 kinds)	26%	Process control	Siemens, ABB
LON	6%	Building systems	Echelon, ABB
Ethernet	50%	Plant bus	alle
Interbus-S	7%	Manufacturing	Phoenix Contact
Fieldbus Foundation, HART	7%	Chemical Industry	Fisher-Rosemount, ABB
ASI	9%	Building Systems	Siemens
Modbus	22%	obsolete point-to-point	many
ControlNet	14%	plant bus	Rockwell

*Source: ISA, Jim Pinto (1999)

Sum > 100%, since firms support more than one bus

**European market in 2002: 199 Mio USD, 16.6 % increase (Profibus: 1/3 market share)
**Source: Elektronik, Heft 7 2002

Worldwide most popular field busses

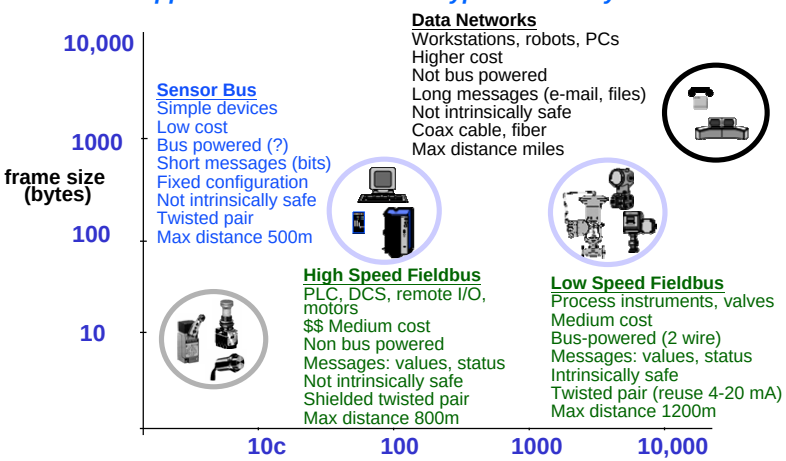
Criterion	WorldFIP	CAN +	LONTalk	Seriplex	ISP	BITBUS
Perf. / Speed / Determinism	Good	Good	Poor	Medium	Good	Medium
Interoperability	Good	Medium	Good	Poor	Good	Medium
Cost and Tech. Leverage	Medium	Good	Medium	Poor	Medium	Medium
Product Availability	Medium	Good	Good	Medium	Poor	Good
Development and Impl. Cost	Poor	Good	Medium	Good	Poor	Good
Outlook	Medium	Good	Good	Good	Medium	Medium
Reliability	Good	Good	Good	Medium	Good	Good
Peer-to-Peer Capability	Medium	Good	Good	Poor	Medium	Poor
Memory Requirements	Poor	Good	Medium	Good	Poor	Medium
User Friend. / Tools	Medium	Medium	Good	Medium	Medium	Medium
Ownership	Good	Good	Poor	Poor	Good	Good
Instal. Base Sem. Mfg. / Proven	Poor	Medium	Good	Good	Poor	Good
Board Size	Poor	Good	Medium	Good	Poor	Good
Msg. Passing Capability	Good	Medium	Good	Poor	Good	Medium
Remaining Work	Good	Poor	Good	Poor	Medium	Medium

Table: Qualitative Candidate Analysis W.R.T. Selection Criteria (Selection criteria listed in order of importance)

Source: ANALYSIS OF SENSOR / ACTUATOR BUS INTEROPERABILITY STANDARD ALTERNATIVES FOR SEMICONDUCTOR MANUFACTURING James R. Moyne, Nader Najafi 1 , Daniel Judd 2 , and Allen Stock 3 *University of Michigan*, Center for Display Technology Manufacturing, Ann Arbor, MI 48109-2108, 1 *IBM*, 2 *Arlington Laboratories*, 3 *SEMATECH / Advanced Micro Devices*

Worldwide most popular field busses

One bus type cannot serve all applications and all device types efficiently...

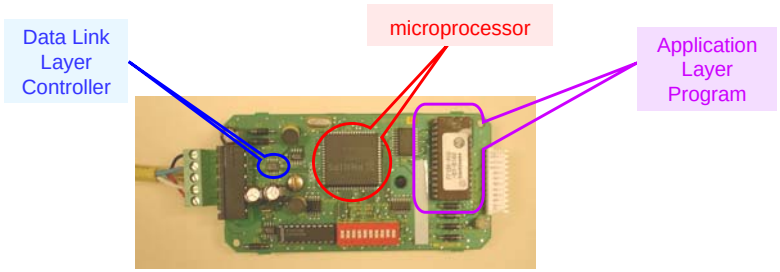


Research Issues in Network Systems

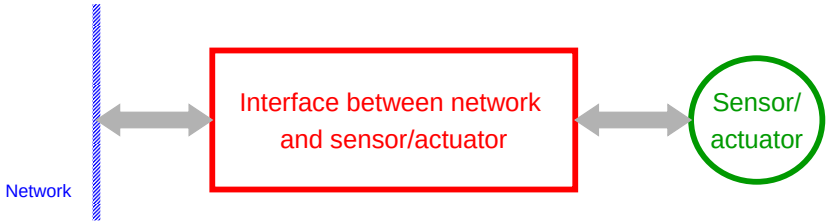
- Architecture:
  - Information/System Network (Information)
    - > Throughput Analysis, Flow Control, Database Management
  - Discrete-Event/Cell Network (Control)
    - > Correct & Safe Operation, Logic Control
  - Continuous-Variable/Device Network (Instrumentation)
    - > Real-Time Control & Processing
- Static Parameters:
  - Medium Length
  - Node Number
  - Data Rate
- Dynamic Parameters:
- Performance:

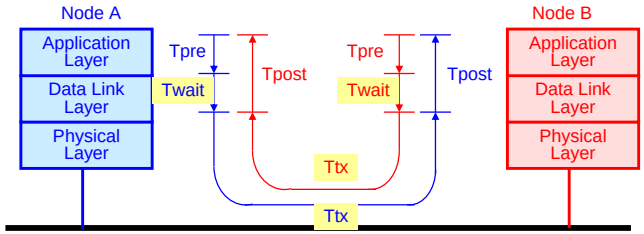
Research Issues in Network Systems

- Architecture:
- Static Parameters:
- Dynamic Parameters:
  - Message Connection
  - Medium Access Control
- Performance:
  - Network QoS
    - > Throughput
    - > Network Utilization
    - > Network Efficiency
    - > Network Stability
  - Network Delay
    - > Message Period
    - > Delay Statistics



DeviceNet network interface card



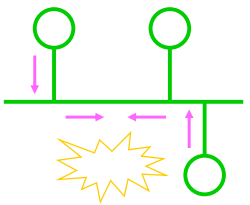


- Total end-to-end delay is the sum of
  - Pre-processing time: microprocessor
  - Waiting time: network protocol - MAC
  - Transmission time: data rate & length
  - Post-processing time: microprocessor

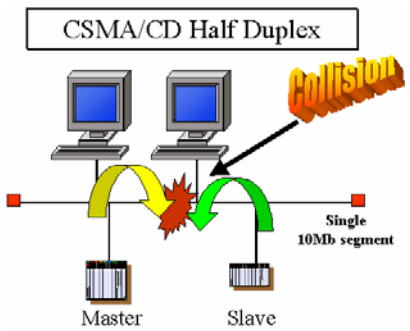
Depend on network protocol and loading

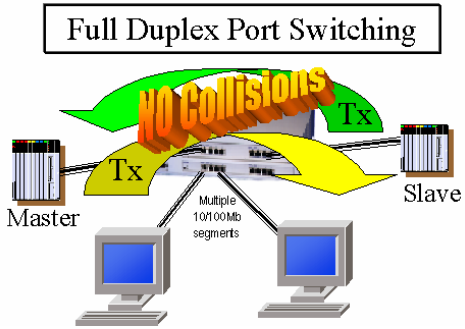
- 3 main types of Medium Access Control (MAC)
  - Ethernet:
    - EIB, EtherNet/IP, LonWorks, Modbus/TCP
  - Token Passing:
    - BACnet, ControlNet, FDDI, MAP, P-Net, Profibus, SP50, WorldFIP
  - Priority Based:
    - CAN, DeviceNet, SDS, CANOpen, CAN-Kingdom

- Carrier Sense Multiple Access / Collision Detection (CSMA/CD)
  - listen ⇒ busy ⇒ wait
  - listen ⇒ idle ⇒ send
  - collision ⇒ backoff
- Backoff algorithm
  - standard binary exponential backoff
  - max collision = 16
  - ⇒ potential for lost data

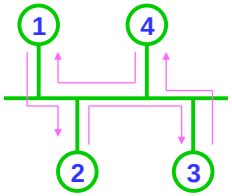


- Random time delays



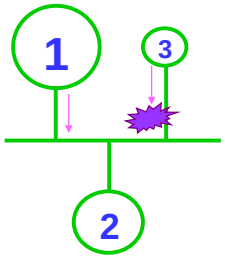


- Concurrent Time Domain Multiple Access (CTDMA) / Implicit Token Passing Bus
  - a token rotating around the logical ring
  - every device can listen to the network
  - without token ⇒ wait
  - with token ⇒ send messages



- Bounded time delays

- Carrier Sense Multiple Access / Arbitration on Message Priority (CSMA/AMP)
  - a bit-synchronized bus
  - devices and messages have different priorities
  - listen ⇒ busy ⇒ wait
  - listen ⇒ idle ⇒ send
  - collision ⇒ low-priority node backoff,
    high-priority node keep on sending



- Constant time delays