Ethernet Everywhere ?!

- From Office to Vehicle/Smart Factory

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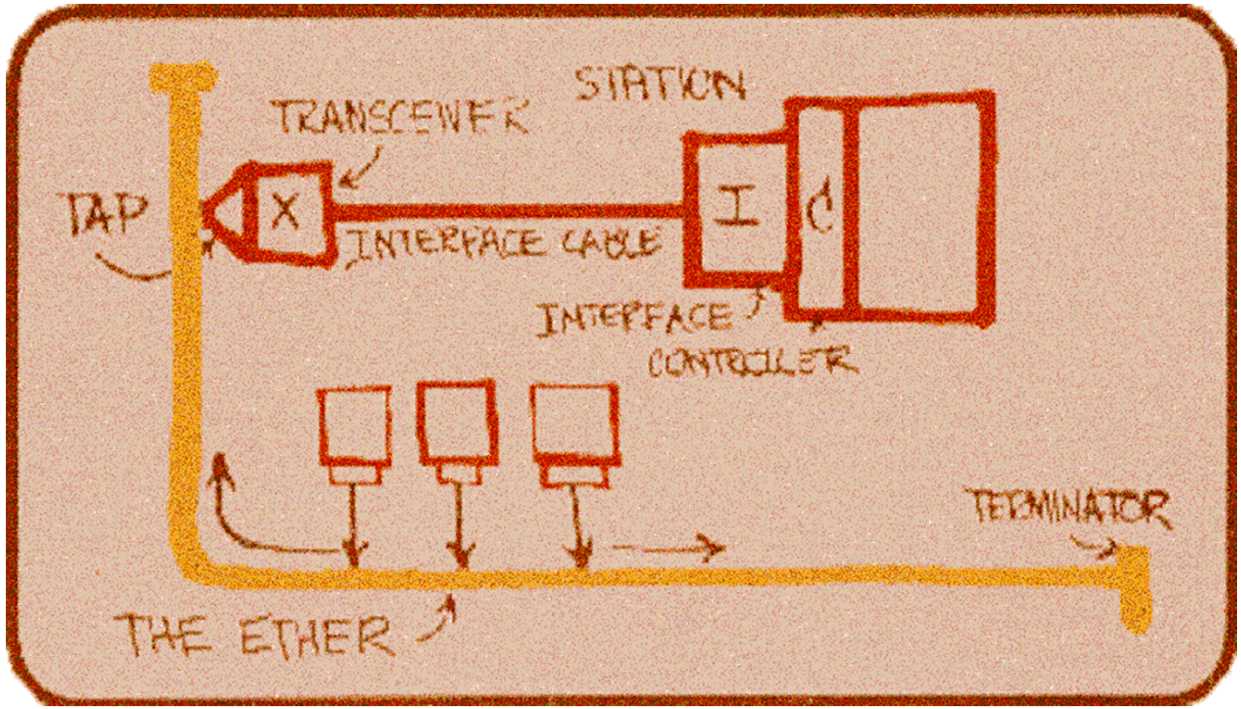
Table of Contents

- Background
- Industrial (Real-time) Ethernet
- Ethernet as In-Vehicle Network
- References
- Q & A

Background

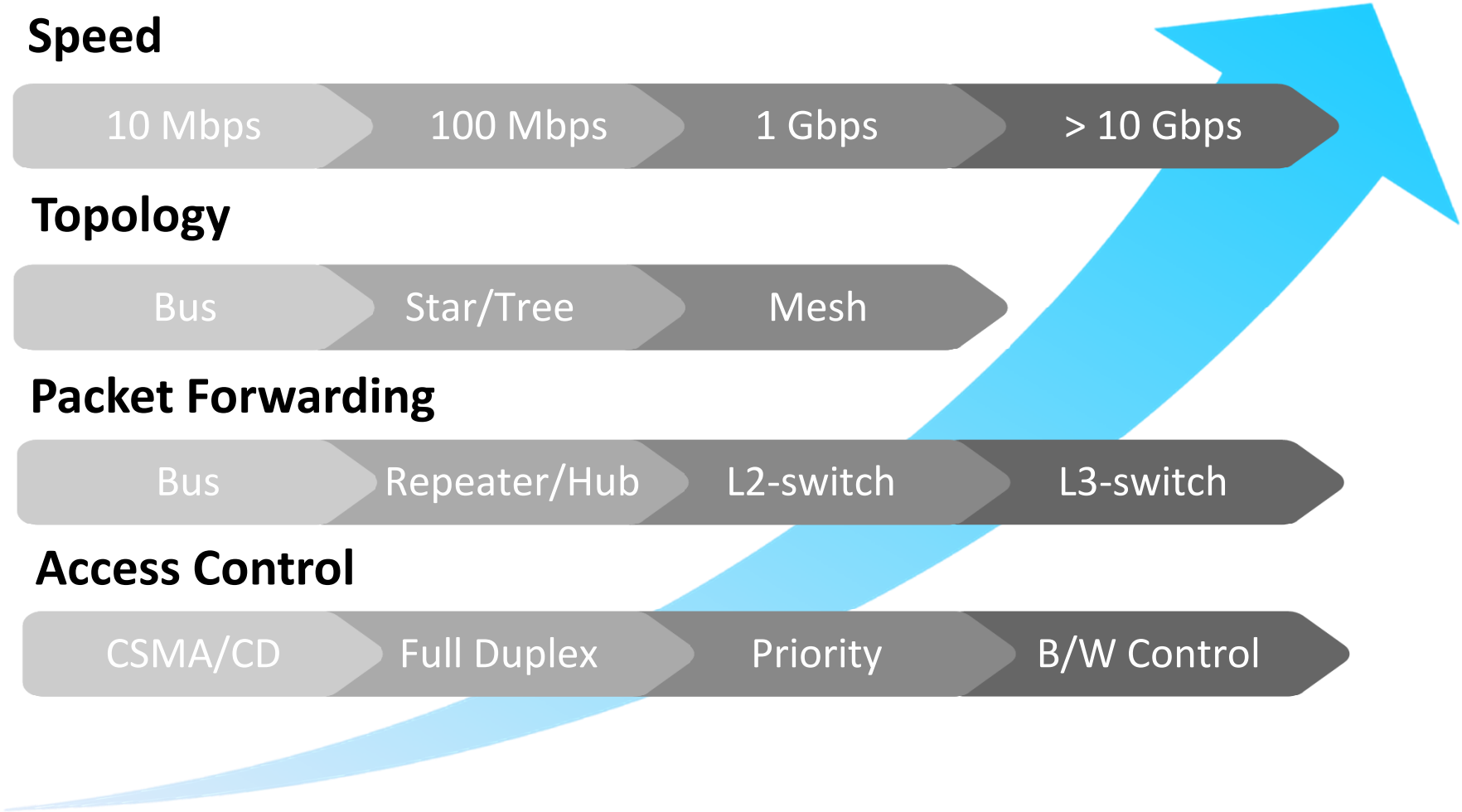
Ethernet – Old, but Evolving Technology

Invented in 1974 by Bob Metcalfe and David Boggs

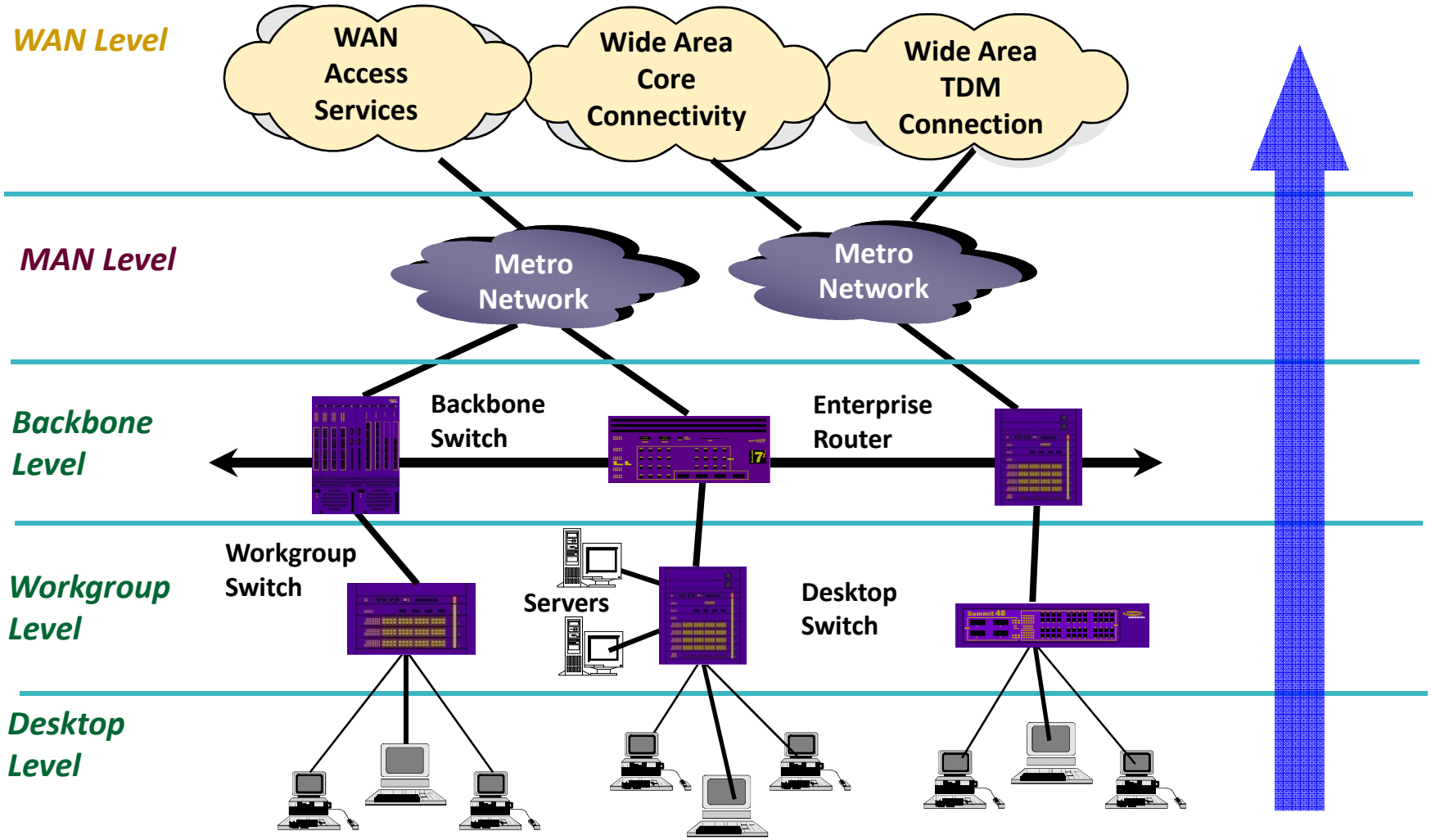


Source: Metcalfe's original conception of the Ethernet

Evolution of Ethernet



Evolution of Ethernet



Why Ethernet ?

- Reasons for Ethernet's success over other LAN technologies
  - It's the first widely deployed high-speed LAN.
  - Other technologies (Token Ring, FDDI, and ATM) were more complex and expensive than Ethernet.
  - Ethernet always evolved, producing versions that operated at equal data rates or higher than its competitors.
  - Because Ethernet has been so popular, Ethernet hardware has become a commodity and is remarkably cheap.

Industrial (Real-time) Ethernet

Evolution of Industrial Automation

- Notable changes in industrial automation
  - Extensive integration of industrial processes
  - Increase in the volume of exchanged data
  - From point-to-point lines (analog data) to serial buses (digital signals) → Era of Fieldbuses

Evolution of Industrial Automation

- Strong needs for unifying several industrial solutions
  - "Variant within a standard" → a collection of established solutions
  - IEC 61158: Digital Data Communications for Measurement and Control – Fieldbus for Use in Industrial Control Systems (2000)
  - IEC 61784-1: Profiles for applications relying on IEC 61158 (Traditional fieldbus technologies)
  - IEC 61784-2: Profiles for Ethernet-based Communication Networks in Real-Time Applications (2007)

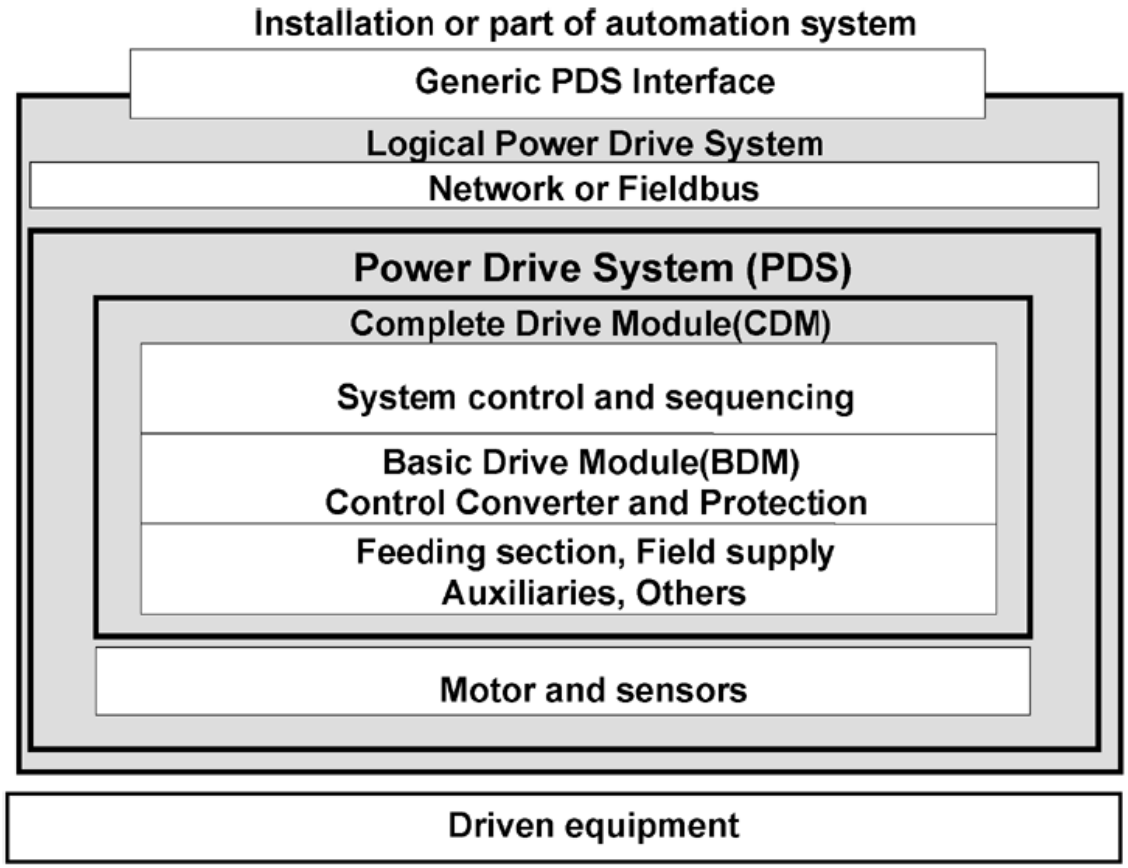
IEC stands for "International Electrotechnical Commission".

Fieldbus

- Fieldbus is an industrial network system for real-time distributed control.
  - Proprietary standards: DeviceNet, Profibus, Interbus, SERCOS, and etc.
  - Traditional style communication technology based on non-Open standard (non-Ethernet) physical layer, typically with a bus topology.
- Requirements change
  - It is getting more and more difficult to fulfill the requirements of automation industry with fieldbus solutions
    - Higher bandwidth
    - Openness/Distribution of information
    - Flexibility
    - Scalability
    - Interoperability among different technologies

Industrial automation and PDS

- PDS (Power Drive System)

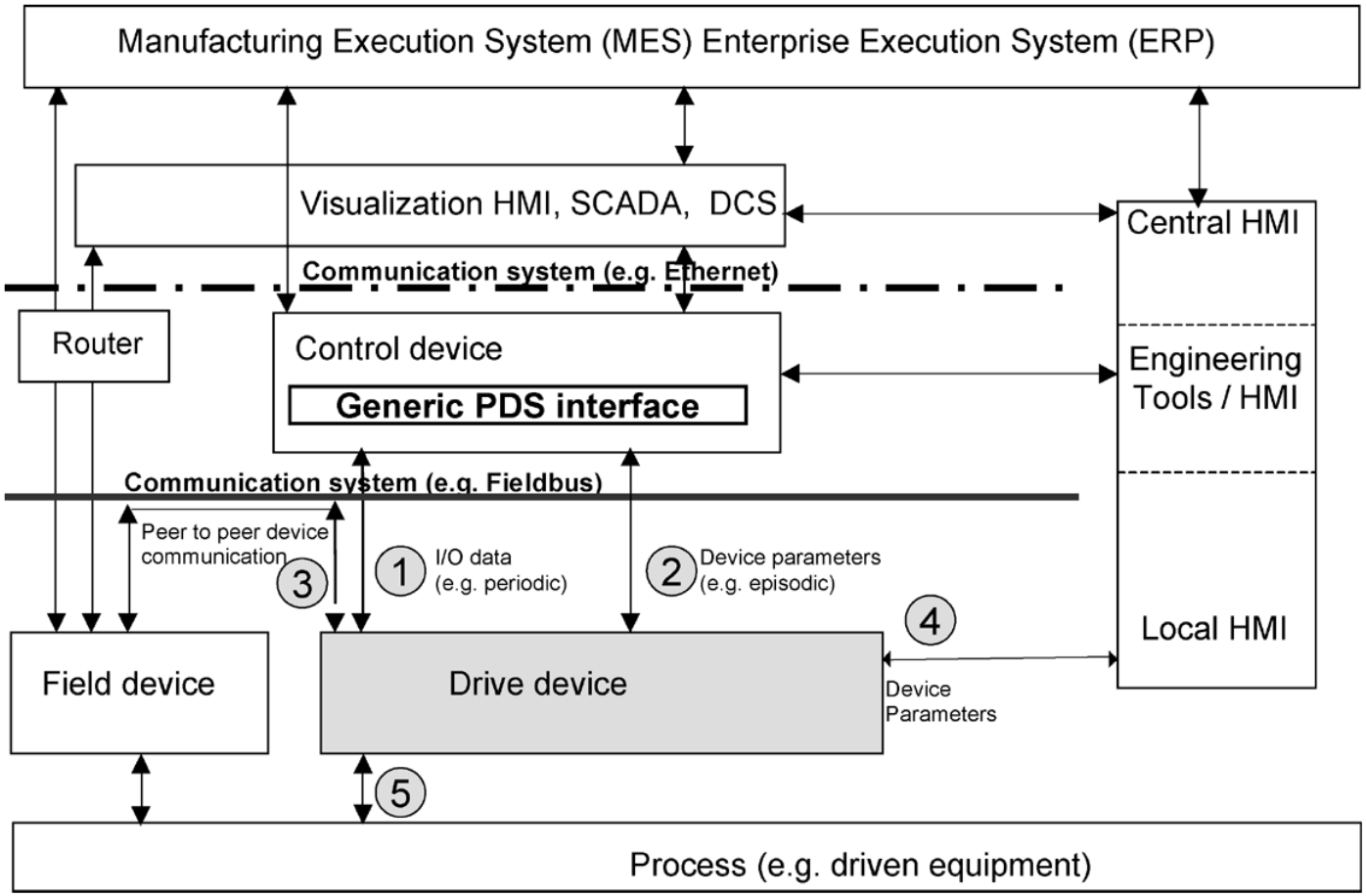


Source: Ref. [Benzi2005]

Generic PDS interface

- A variety of physical interfaces are available for PDS.
  - A number of troubles may arise for system integrators.
  - Defining a generic PDS interface (refer to figure in next slide, according to IEC 61800-7)
    - I/O data: cyclic I/O data exchange
    - Device parameters: acyclic, configuration, monitoring
    - Peer to peer device communication: drive to drive
    - Local interface: drive-local HMI
    - Process interface: drive to device

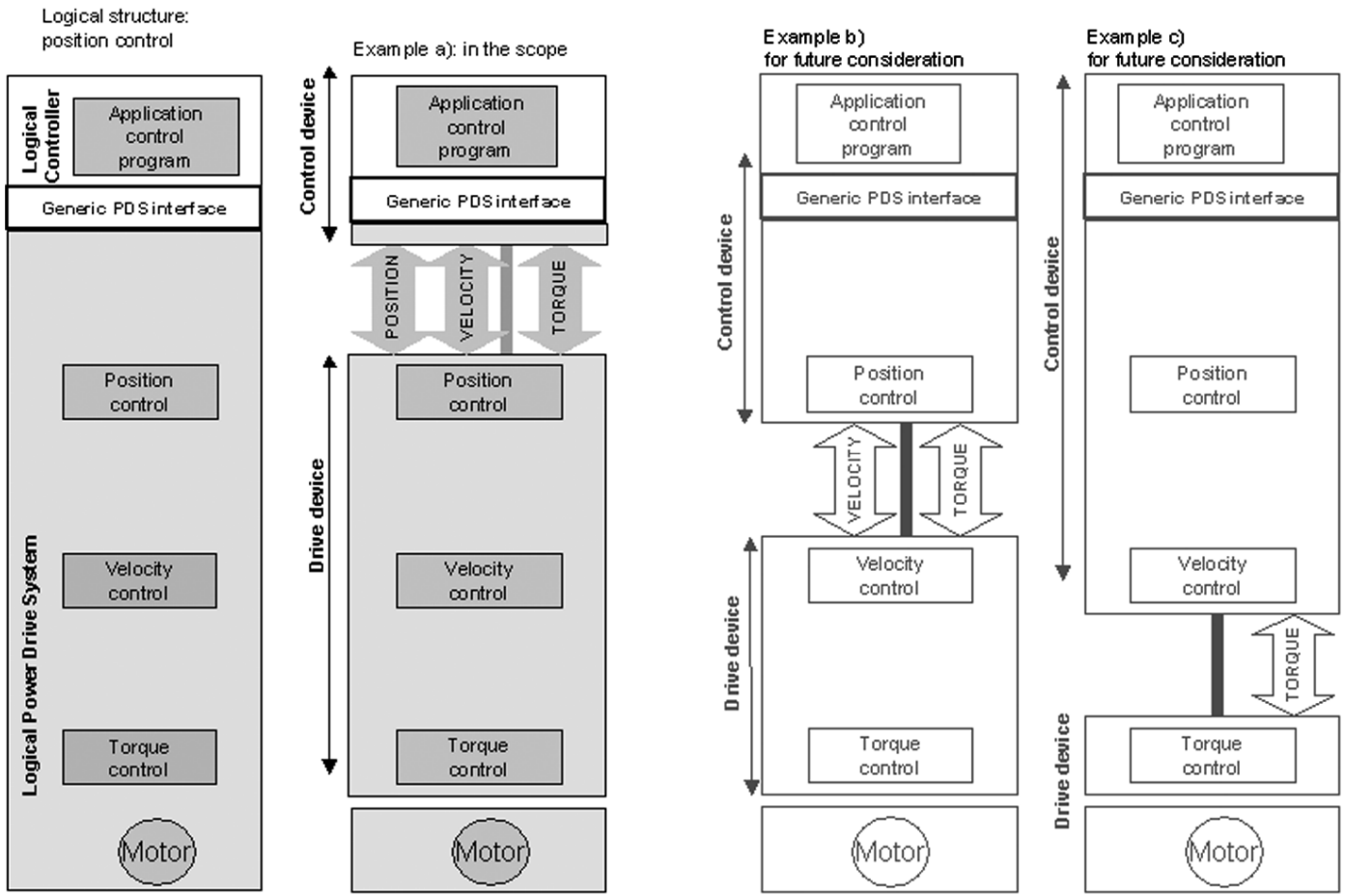
Industrial automation and PDS



Source: Ref. [Benzi2005]

Industrial automation and PDS

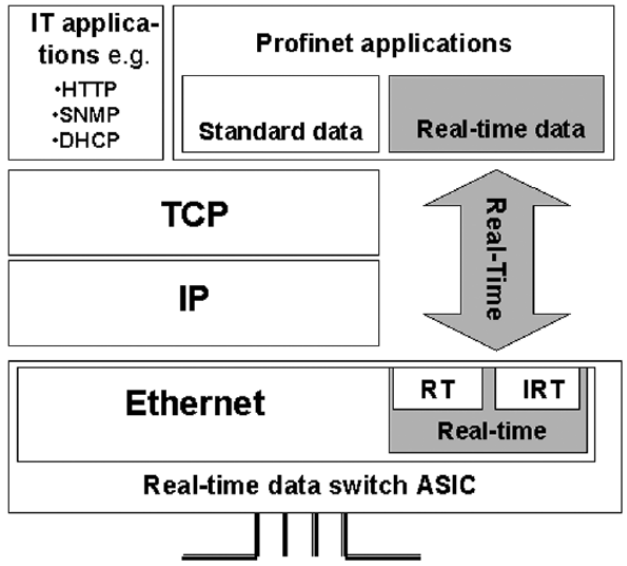
- Examples of control architecture for a single drive



Source: Ref. [Benzi2005]

Real-Time Ethernet for PDS

- Advantages of deploying Ethernet
  - Consistency with the higher level communication systems
  - Short cycle time (high transmission speed)
  - Large availability of compatible chipsets (low cost)
  - Use of many utilities for services and diagnostics (mature technology)



Profinet example

Real-Time Ethernet (RTE)

- Key requirements for fieldbus communication
  - Time-deterministic communication
  - Time-synchronized actions between devices (drives)
  - Efficient and frequent exchange of very small data

- What is RTE ?
  - Fieldbus specification using Ethernet
  - Traditional Ethernet needs to be modified while maintaining the compatibility with Ethernet and the TCP/IP protocols.
    - Support of QoS in data delivery (RT vs. NRT)
    - Packet processing in switches
    - Low-level synchronization between devices

Performance Indicators (PIs)

- Performance indicators defined in IEC 61784-2 represent different requirements for different applications.
  - Delivery time
  - Number of end nodes
  - Basic network topology
  - Number of switches between end nodes
  - Throughput RTE
  - Non-RTE bandwidth
  - Time synchronization accuracy
  - Non-time-based synchronization accuracy
  - Redundancy recovery time

Performance Indicators (PIs)

- Delivery Time
  - Time needed to convey an APDU from one node to another of the network (Application-level end-to-end delay)
- Number of end nodes
  - Maximum number of RTE end devices
- Number of switches between end nodes
  - Possible network layout
- Throughput RTE
  - Total amount of data on a network link per second (Bps)
- Non-RTE bandwidth
  - Percentage of bandwidth, can be used for non-RTE communication

Performance Indicators (PIs)

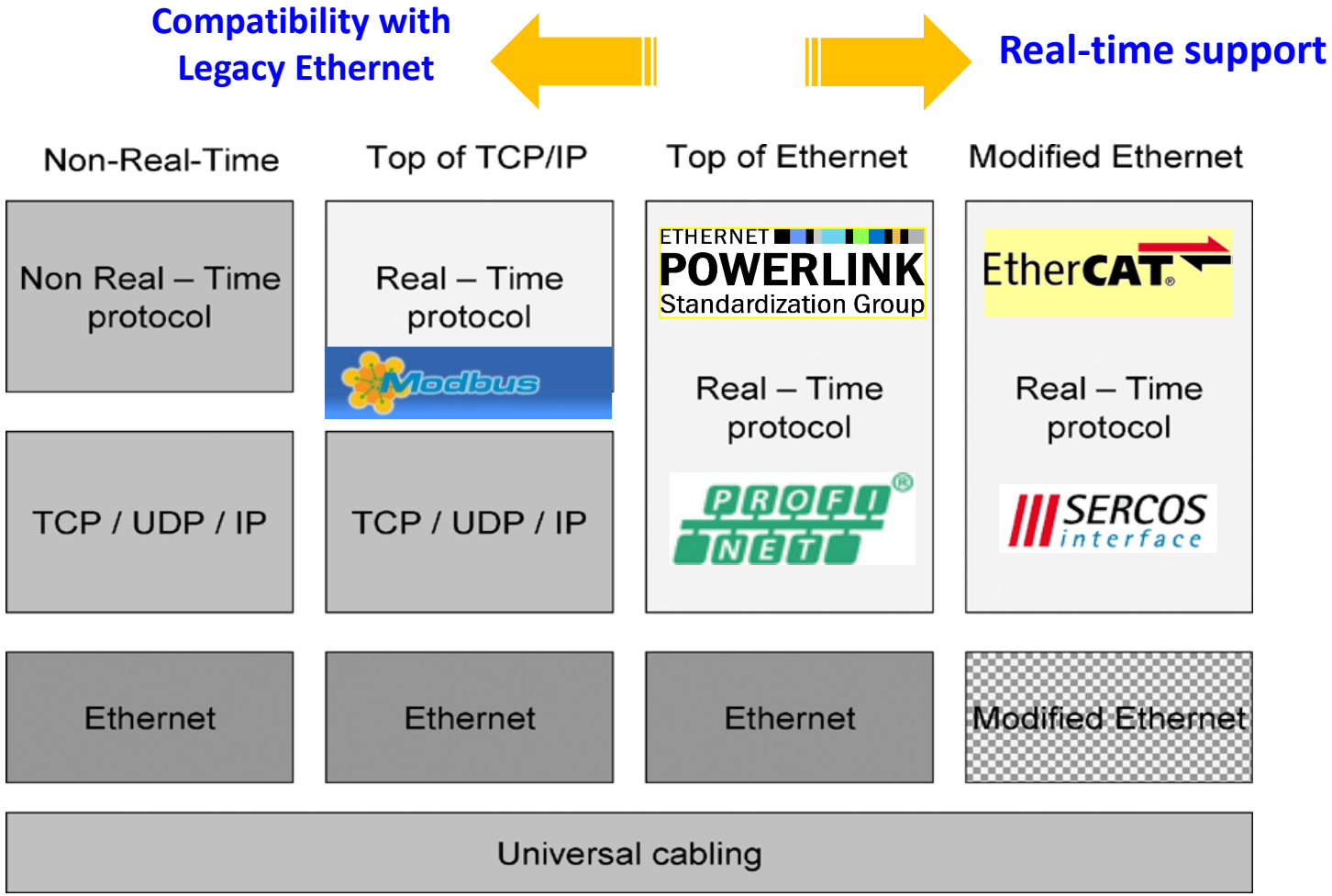
- Time synchronization accuracy
  - Maximum deviation between any two node clocks
- Non-time-based synchronization accuracy
  - Maximum jitter of the cyclic behavior of any two nodes
- Redundancy recovery time
  - Maximum recovery time from a single permanent error

PI Examples for CPFs

CPF	Trade name	Delivery time	Troughput RTE	Non-RTE bandwith
CP 2/2	EtherNet/IP	0,13 to 20,4 ms	3,44 Mbyte/s	0-100 %
CP 2/2.1	EtherNet/IP with Time Synchronization	0,13 to 0,19 ms	3,44 Mbyte/s	0-100 %
CP 3/4	PROFINET IO Class A cycle of 120 ms	128 ms	3,32 Mbyte/s	23,5 %
CP 3/6	PROFINET IO Class C IRT with cycle of 1 ms	1 ms	3,32 Mbyte/s	23,5 %
CP 4/3	P-NET on IP	0,564 to 6,3 ms	5 – 64 Kbyte/s	75 %
CP 10/1	VNET/IP different domain	50 to 200 ms	10 Mbyte/s	< 50 %
CP 10/1	VNET/IP same domain	20 to 60 ms	10 Mbyte/s	< 50 %
CP 11/1	TCnet-star only RT	2ms / 20ms / 200ms	7,3 Mbyte/s	0 %
CP 11/2	TCnet-loop mixed RT and NRT	2ms / 20ms	4,8 Mbyte/s	< 20 %
CP 12/1	EtherCAT Simple I/O small system cycle of 60 µs	0,15 ms	10,75 Mbyte/s	50,6 %
CP 12/2	EtherCAT Mailbox / Synchronization cycle 200 µs	< 0,519 ms	10,5 Mbyte/s	55,9 %
CP 13/1	Ethernet Powerlink small system cycle of 150 µs	0,4 ms	1,9 Mbyte/s	19,6 %
CP 13/1	Ethernet Powerlink medium system cycle of 500 µs	1,1 ms	2,5 Mbyte/s	11,5 %
CP 13/1	Ethernet Powerlink large system with cycle of 2700 µs	5,5 ms	4 Mbyte/s	4,4 %
CP 14/1	EPA master to bridges	5 ms	1,5 Mbyte/s	85 %
CP 14/2	EPA field devices to bridges	0,1 ms	1,538 Mbyte/s	85 %
CP 14/3	EPA master to field devices	0,1 ms / 0,2 ms	3,84 Mbyte/s	0 %
CP 16/3	SERCOS III small cycle of 31,25 µs	0,0398 ms	11,52 Mbyte/s	0 %
CP 16/3	SERCOS III medium cycle of 500 µs with NRT	0,513 ms	9,248 Mbyte/s	25 %

Source: Ref. [Felser2010]

Realization of RTE



Source: Ref. [Felser2005]

Realization of RTE

- On top of TCP/IP (Ethertype: 0x0800 IP)
  - Modbus/TCP (Schneider Electric)
    - Designed for soft real-time applications (client-serer architecture)
    - Use well-known TCP port 502 to transmit data and can be controlled remotely
  - Ethernet/IP (Rockwell)
    - “IP” stands for “Industrial Protocol”.
    - Based on the Common Industrial Protocol (CIP)
    - Prioritization of Ethernet frame and IEEE 1588 synchronization
  - Vnet/IP (Yokogawa)
    - Uses special application-level real-time extension, called Real-Time and Reliable Datagram Protocol (RTP)
    - Strictly, it is not an RTE solution. Just uses the UPD/IP to transport RTP packet.

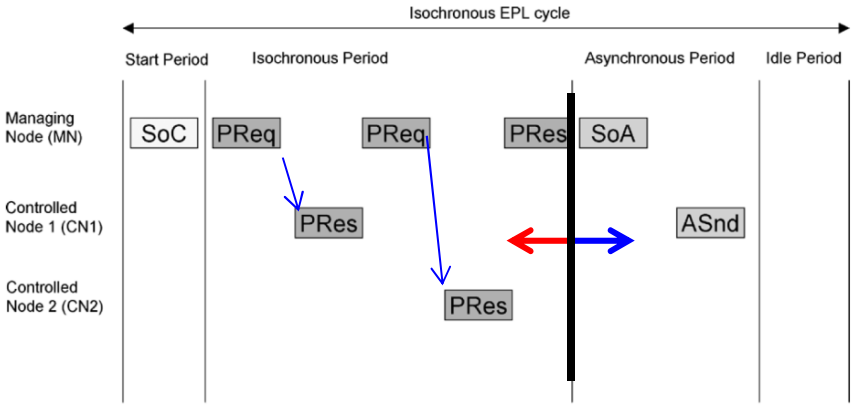
Realization of RTE

- On top of Ethernet
  - Do not alter Ethernet hardware, but use a special protocol type (Ethertype)
  - EPL, TCnet, EPA

IEC 61784 Profile	Brand names	Ethertypes
CPF-2	ControlNet (Ethernet/IP)	(0x0800 IP)
CPF-3	PROFIBUS / PROFINET	0x8892
CPF-4	P-Net	(0x0800 IP)
CPF-10	Vnet/IP	(0x0800 IP)
CPF-11	TCnet	0x888B
CPF-12	EtherCAT	0x88A4
CPF-13	Ethernet POWERLINK (EPL)	0x88AB
CPF-14	EPA	0x88BC
CPF-15	MODBUS – RTPS	(0x0800 IP)
CPF-16	SERCOS	0x88CD

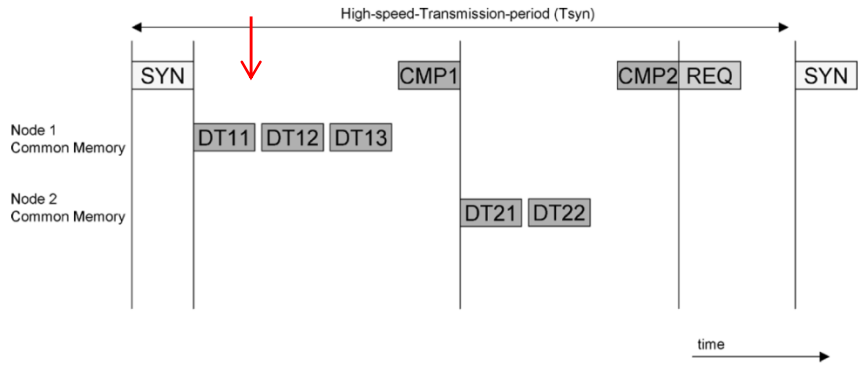
Realization of RTE

- On top of Ethernet

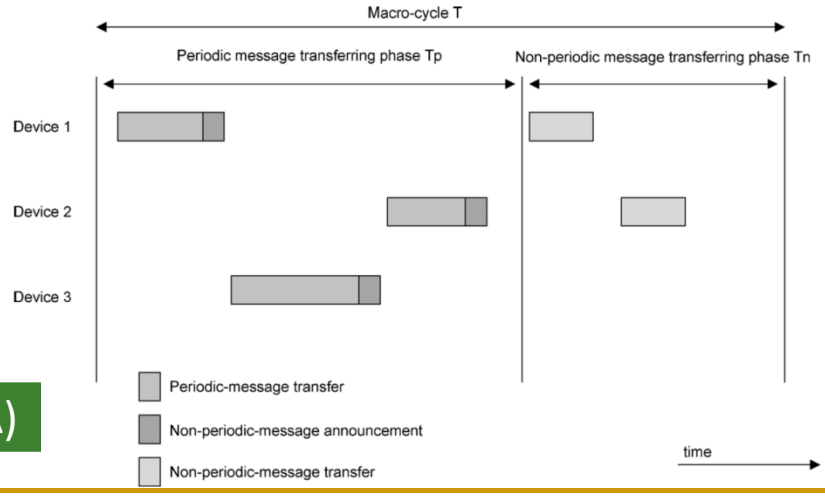


Ethernet PowerLink (EPL), B&R

Schedule is planned during configuration



Time-Critical Control Network (TCnet), Toshiba



Ethernet for Plant Automation (EPA)

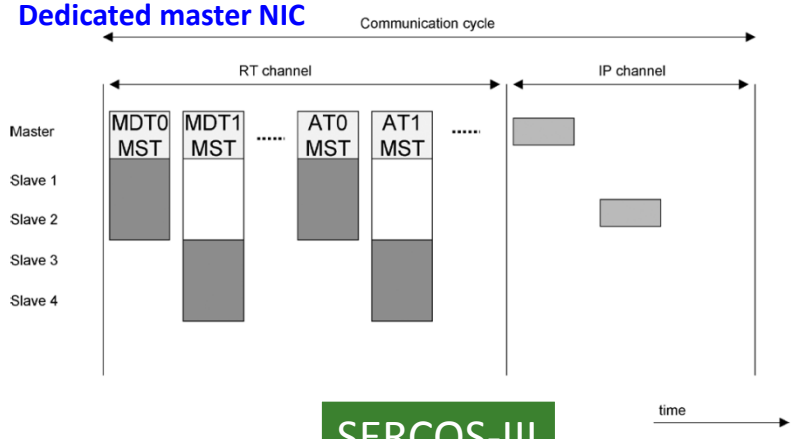
Realization of RTE

- Modified Ethernet
  - Support for hard real-time services
  - Switching functionality is integrated into the device
  - SERCOS-III, EtherCAT, PROFINET (Siemens)

Realization of RTE

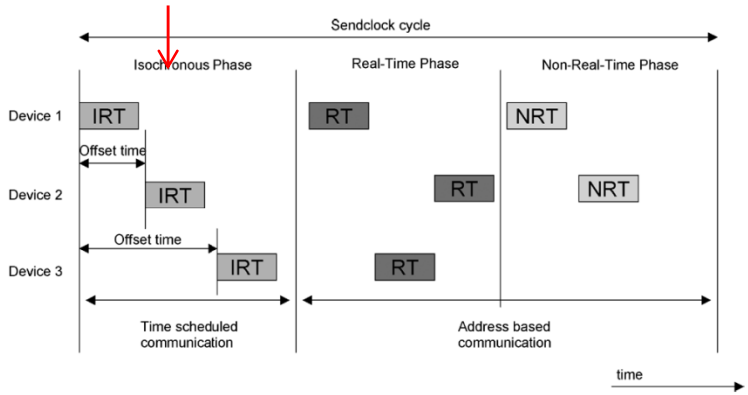
- Modified Ethernet

Dedicated master NIC



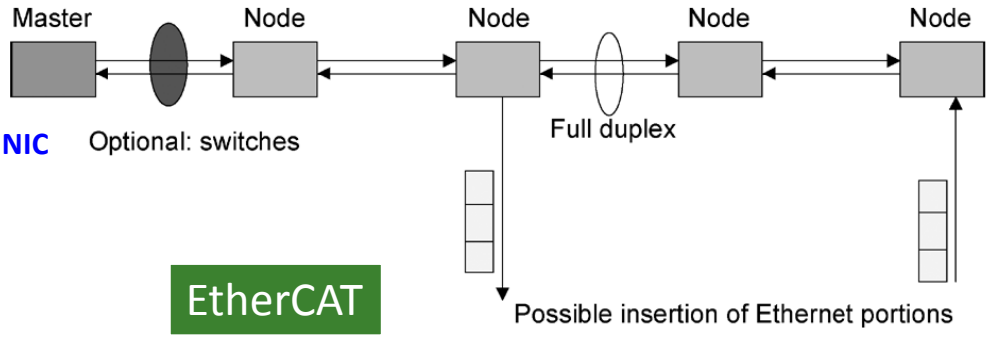
SERCOS-III

Fixed timetable, fixed route



PROFINET I/O

On-the-fly frame switching at slave

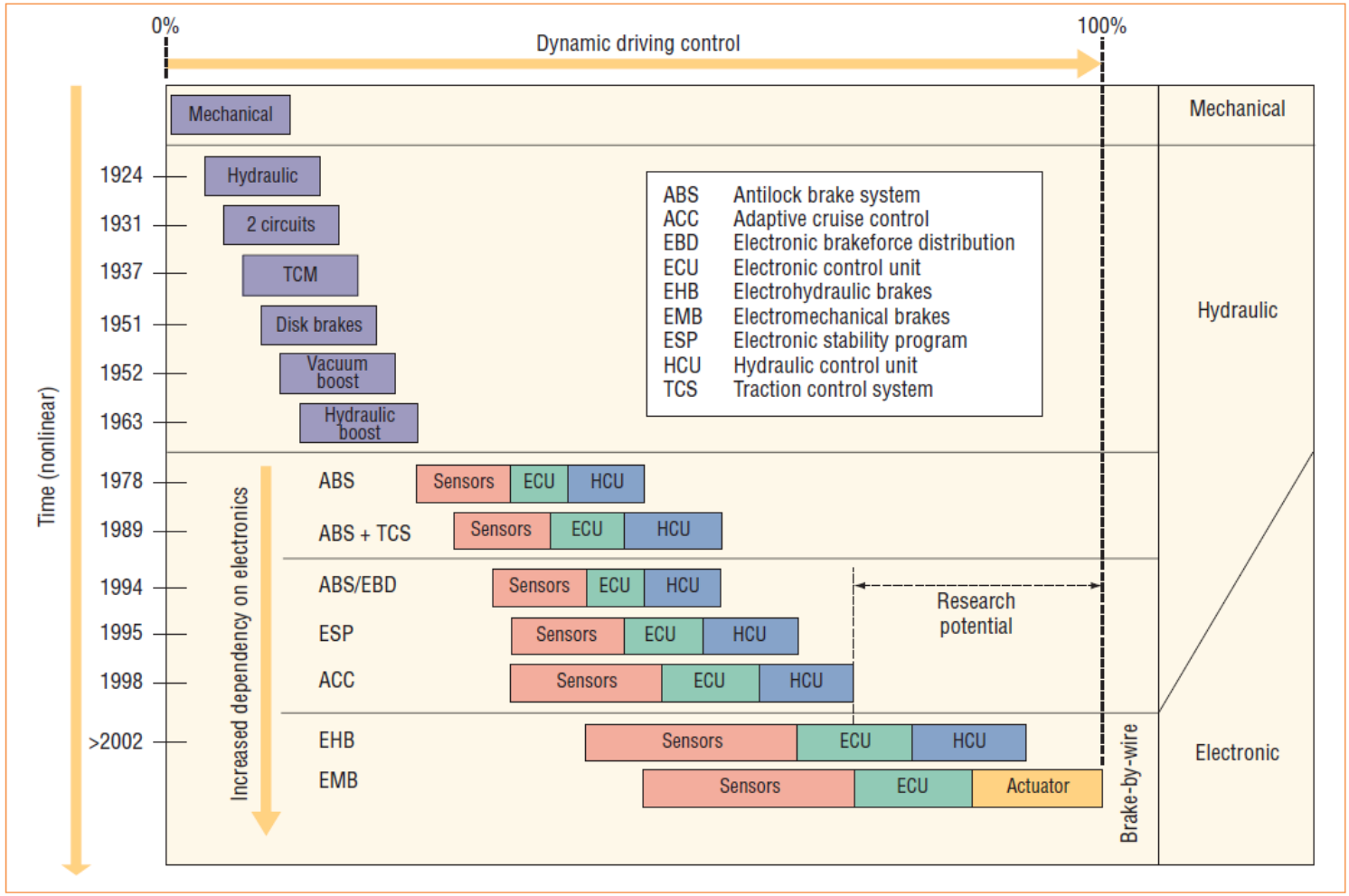


Generic Ethernet NIC

EtherCAT

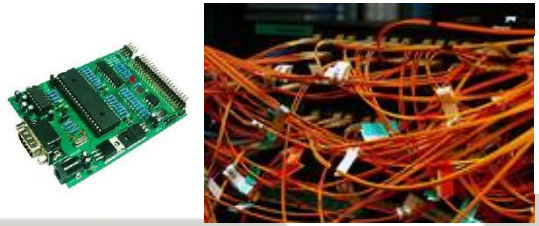
Ethernet as In-Vehicle Network

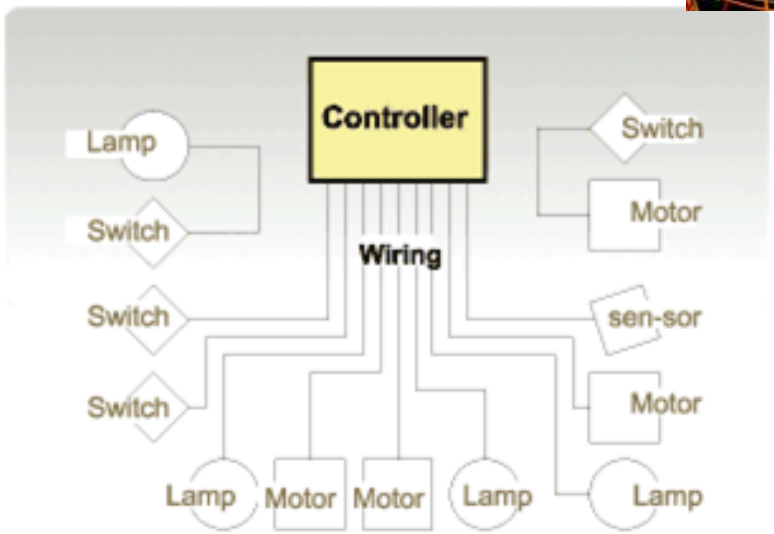
Fundamental Changes in Automotive Systems

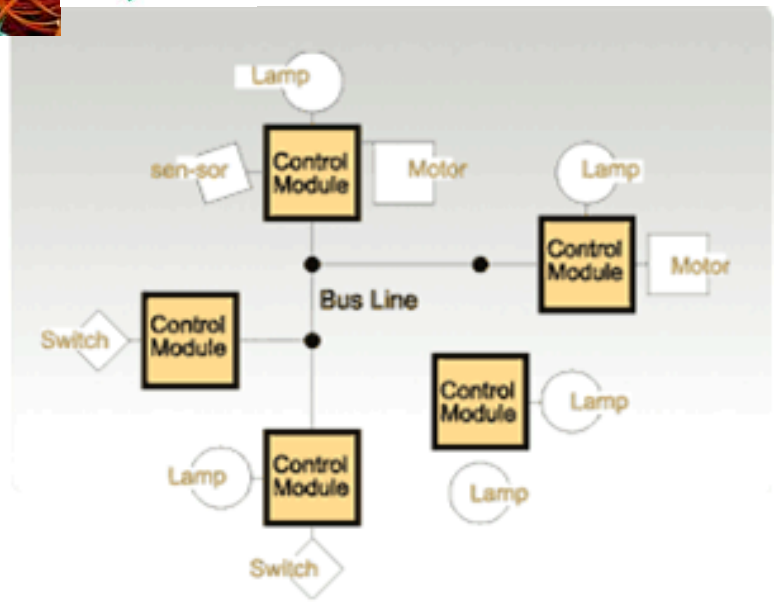


Source: Ref. [Leen2002]

Fundamental Changes in Automotive Systems



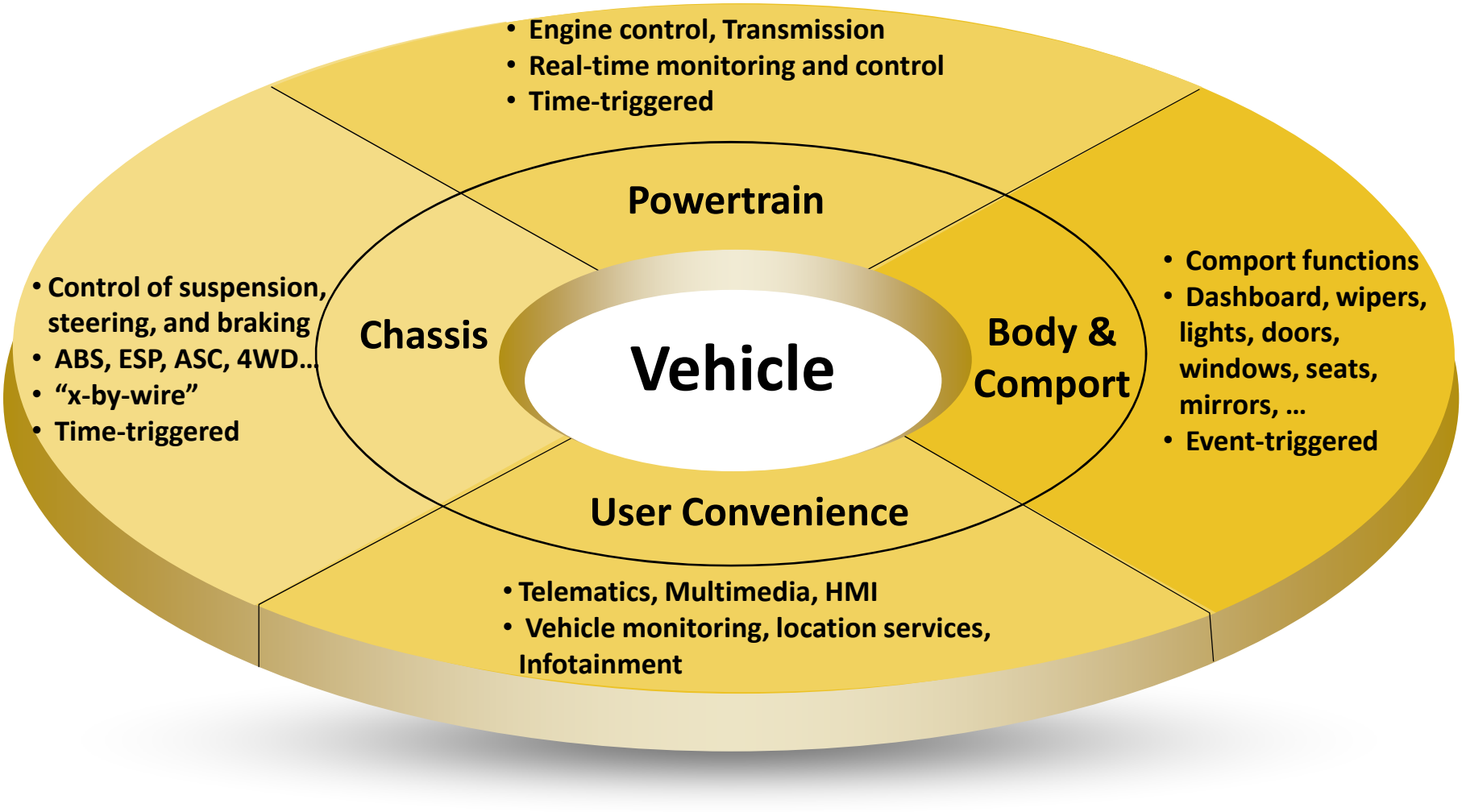




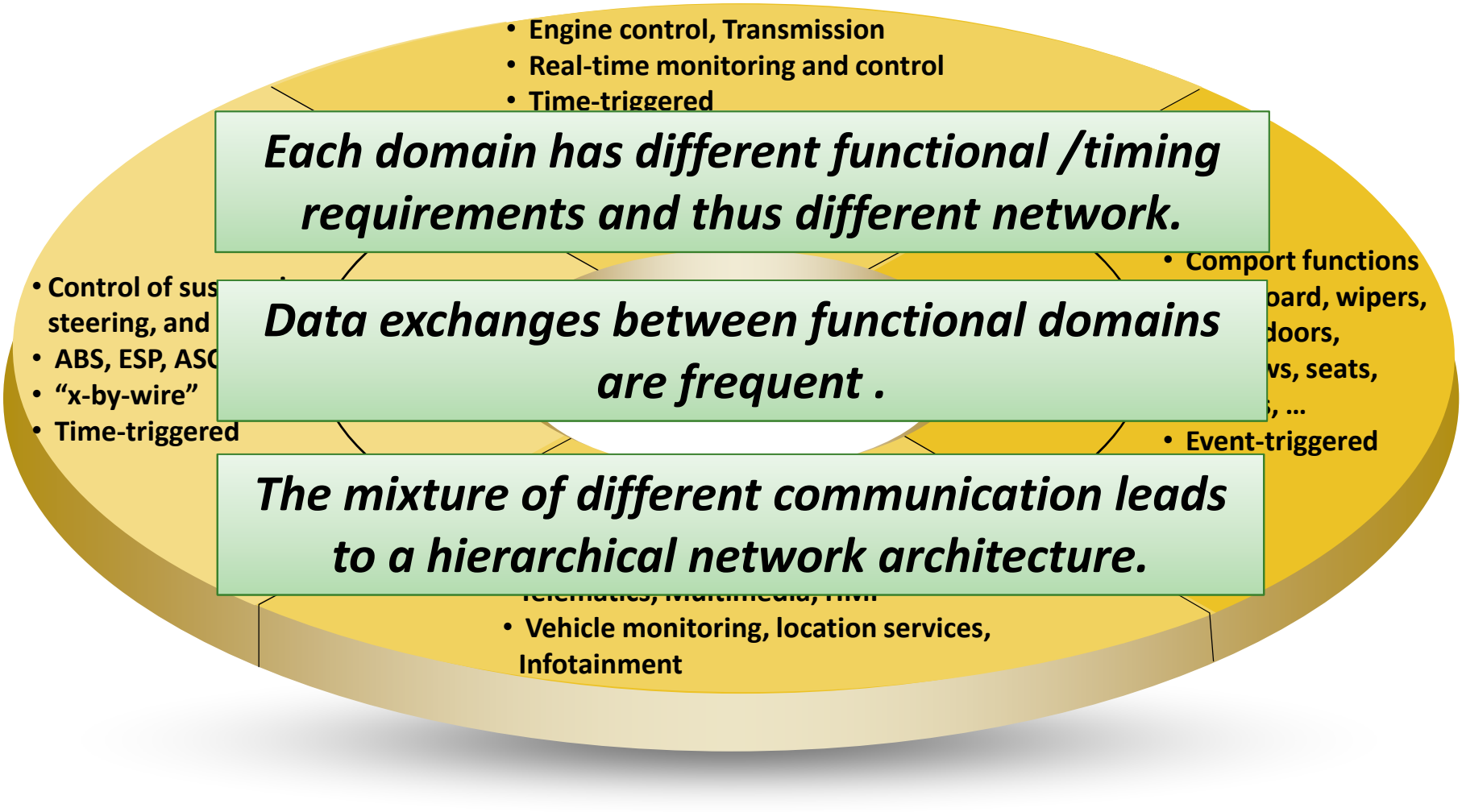
Point-to-Point

Multiplexed, Hierarchical

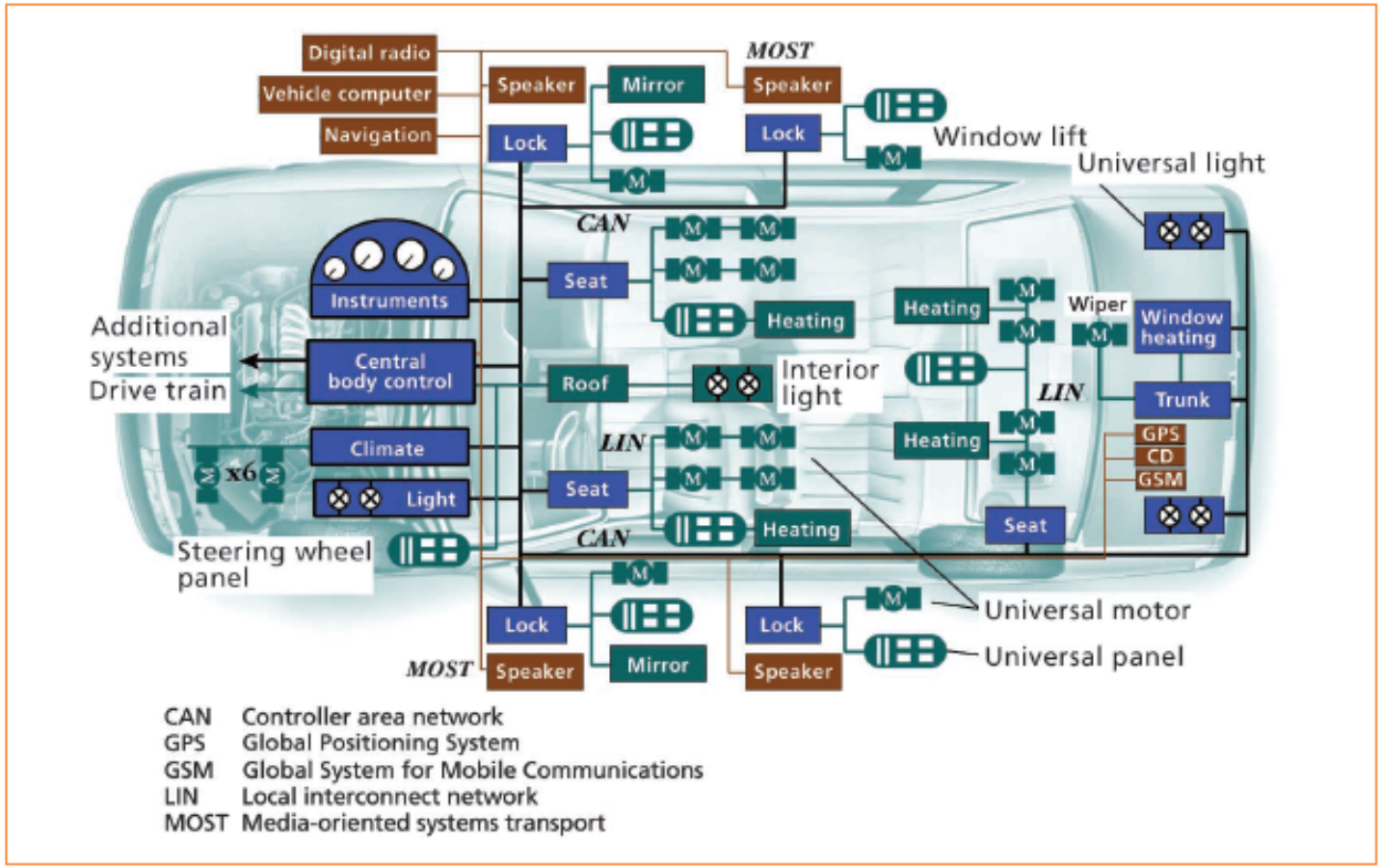
Functional Domains of In-car Embedded Systems



Functional Domains of In-car Embedded Systems



Network Architecture of Modern Vehicle



Source: Ref. [Leen2002]

Communication Requirements for Automotive

Fault Tolerance

- Tolerant to defective circuits, line failures etc.
- Constructed using redundant H/W or S/W architectures
- Should provide error containment

Determinism

- Provide guarantees in terms of timeliness
- For example, message have to be sent at predefined time instants (or within precise time intervals)

Bandwidth

- In general, high bandwidth is required.
- However, there is a trade-off between required bandwidth and the cost of providing such a bandwidth.

Flexibility

- The ability to handle event- and time-triggered messages
- The possibility to cope with varying load, scalability and extensibility of the network

Security

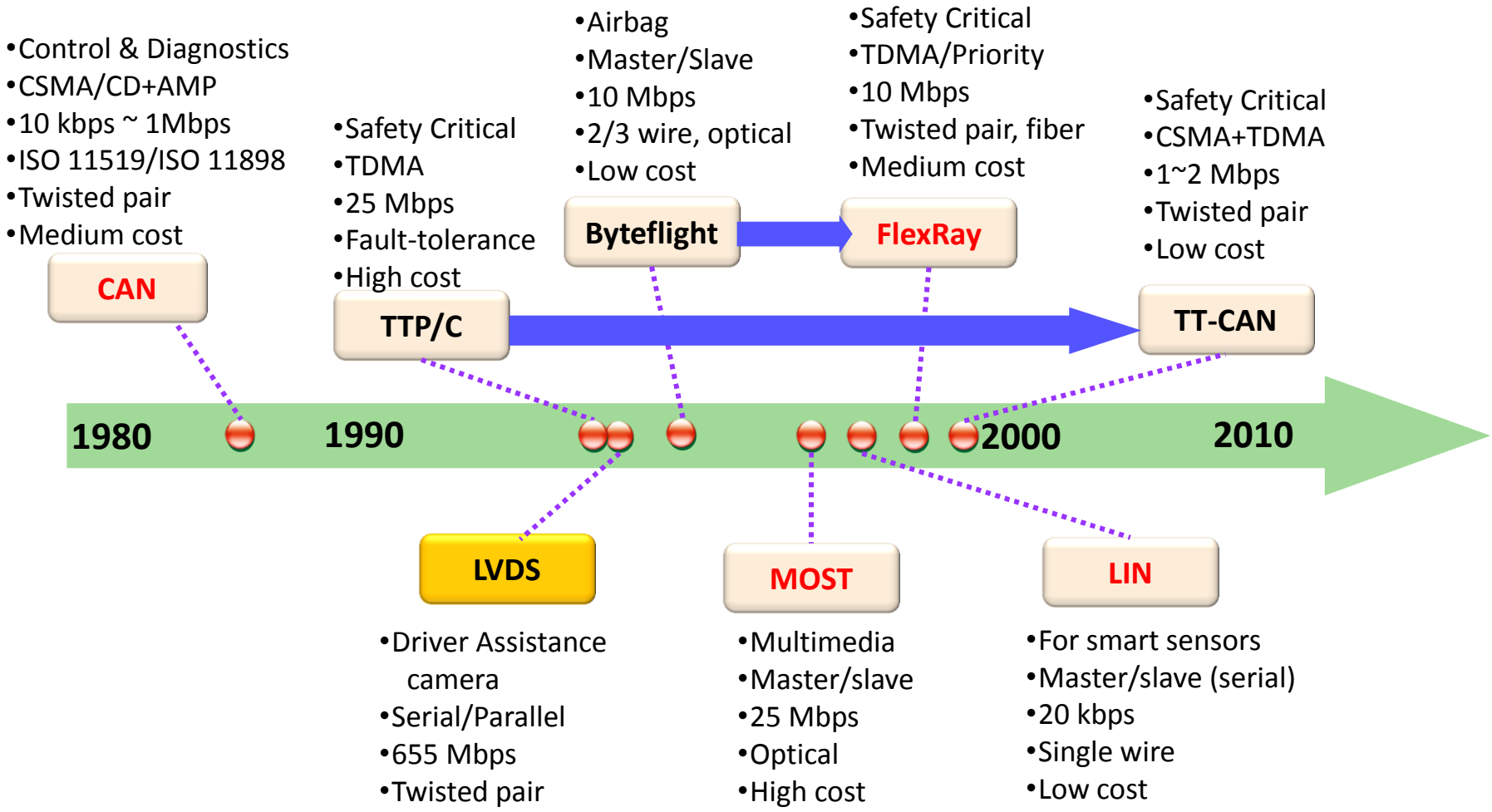
- When the communication is reachable from outside the vehicle, it is important to ensure the security of the system.

Subsystems and Their Requirements

Subsystem	Fault-tolerance	Determinism	Bandwidth	Flexibility	Security
Chassis	O	O	Δ	X	X
Air-bag	O	O	Δ	X	X
Powertrain	Δ	O	O	Δ	X
Body and comport	X	Δ	Δ	O	X
X-by-wire	O	O	Δ	X	X
Multimedia/ Infotainment	X	Δ	O	O	X
Wireless/ Telematics	X	Δ	Δ	O	O
Diagnostics	X	Δ	X	O	O

Source: Ref. [Nolte2005]

Automotive Communication Technologies



For details, refer to [Lupini2010] & [Tuohy2014]

Use Case and Requirements of Technologies

Usage	LIN	CAN	Byteflight	TTP	TT-CAN	FlexRay	MOST
Chassis	X	O	X	Δ	O	X	X
Air-bag	X	O	O	X	X	X	X
Powertrain	X	O	O	Δ	O	Δ	X
Body and comport	O	O	X	X	X	X	X
X-by-wire	X	Δ	O	O	O	O	X
Multimedia/ Infotainment	X	X	X	X	X	X	O
Wireless/ Telematics	X	X	X	X	X	X	X
Diagnostics	Δ	O	Δ	Δ	Δ	Δ	Δ
Reqs.	**LIN**	**CAN**	**Byteflight**	**TTP**	**TT-CAN**	**FlexRay**	**MOST**
Fault-tolerance	X	Δ	O	O	Δ	O	X
Determinism	O	O	O	O	O	O	Δ
Bandwidth	X	Δ	O	O	Δ	O	O
Flexibility	O	O	O	Δ	O	O	O
Security	X	X	X	X	X	X	Δ

Source: Ref. [Nolte2005]

Driving Forces for Next-generation Vehicle Network



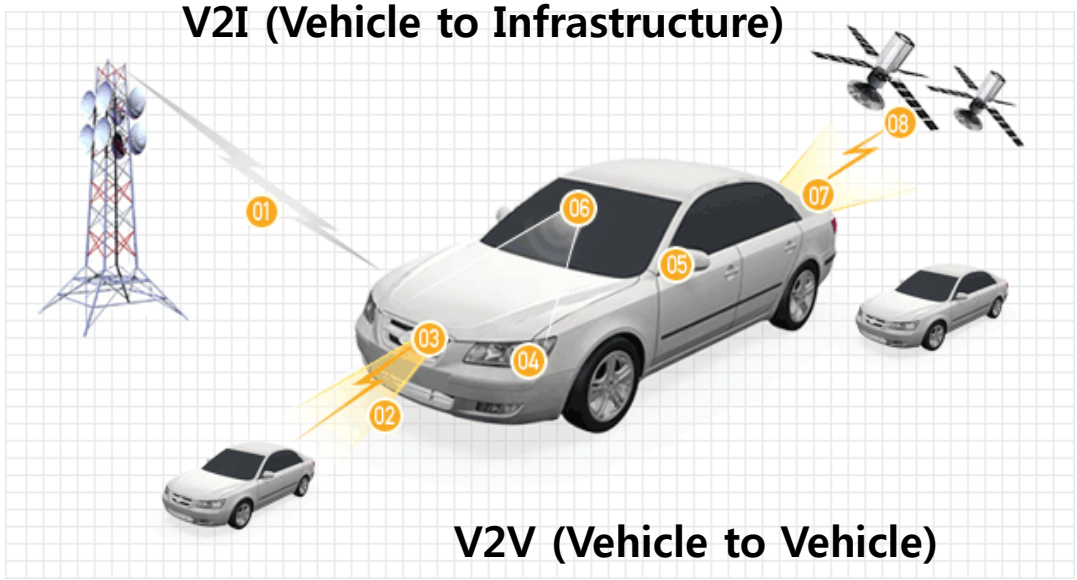
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Source: CNN



Source: ElectronicsWeekly.com



High Bandwidth

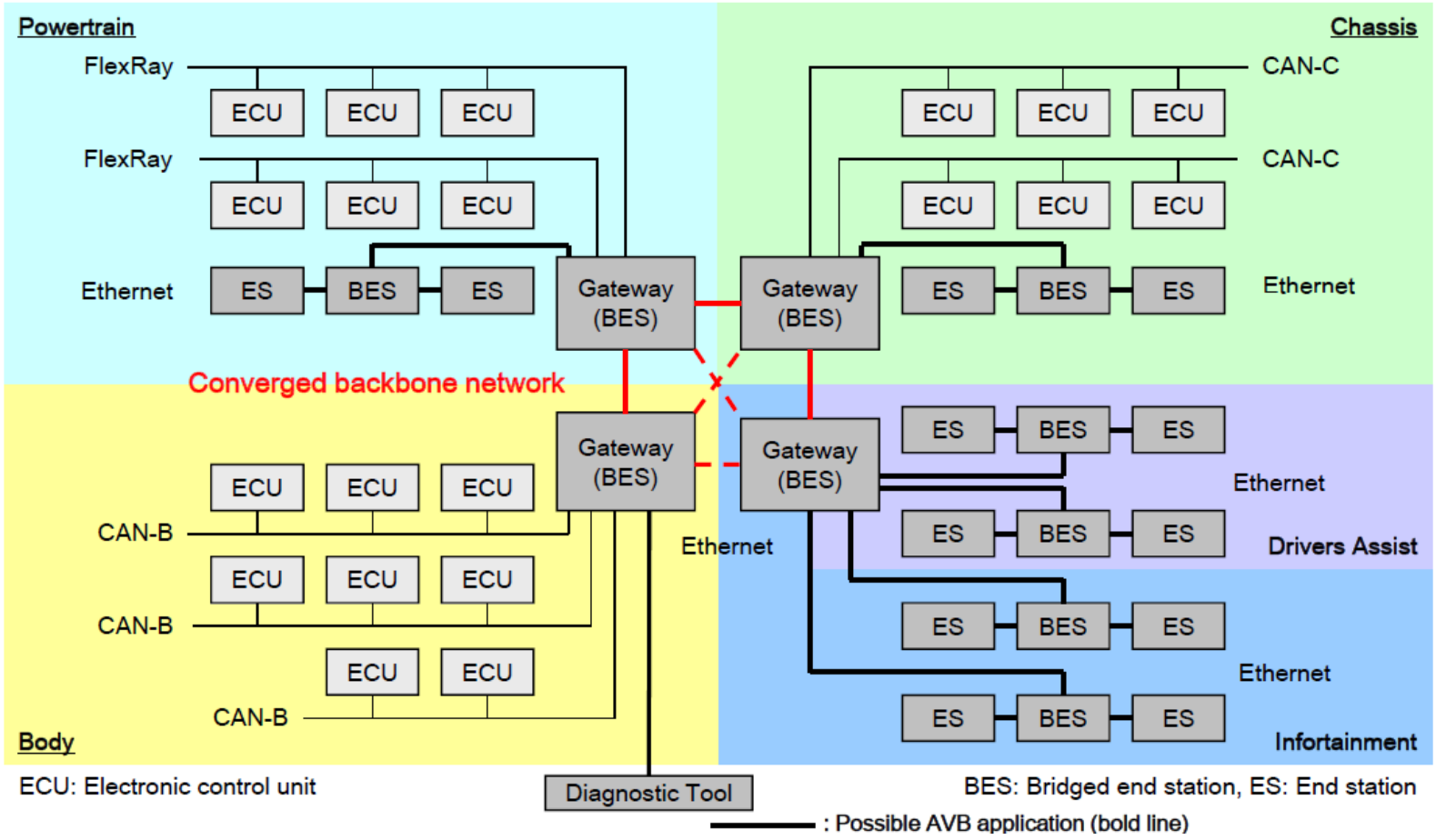
Interoperable with external world

Reasonable cost (Maturity)

Scalability

Determinism

Ethernet as a Backbone of in-Car Network



Source: Ref. [Kim2011]

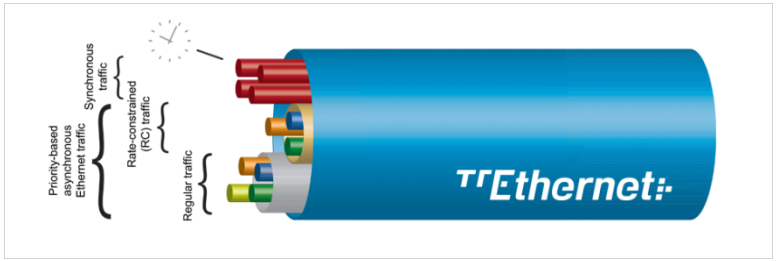
Ethernet for Automotive Industry

- Is Ethernet ideal solution for automotive network ?
  - In general, network communication can be split into two types: event-triggered (Ethernet and CAN) and time-triggered (FlexRay).
    - Event-triggered
      - Aperiodic
      - Probabilistic guarantee of communication latency
    - Time-triggered
      - Periodic
      - Deterministic guarantee of communication latency
  - Ethernet cannot be used for safety critical applications as it cannot guarantee deterministic behavior without proper modification.

Ethernet for Automotive Industry

- How to overcome the limitation of legacy Ethernet in order to deploy Ethernet as an automotive network ?
  - Industrial Ethernet protocols in IEC 61784 ?
    - IEC 61784 technologies are not as widely used as standard Ethernet → Too costly for automotive domain
    - No intention to use any Industrial Ethernet for the automotive case in place
  - Real-time and compatible with legacy Ethernet
    - **Ethernet AVB** and **TT-Ethernet**

IEEE 802.1 AVB
(Audio Video Bridging)



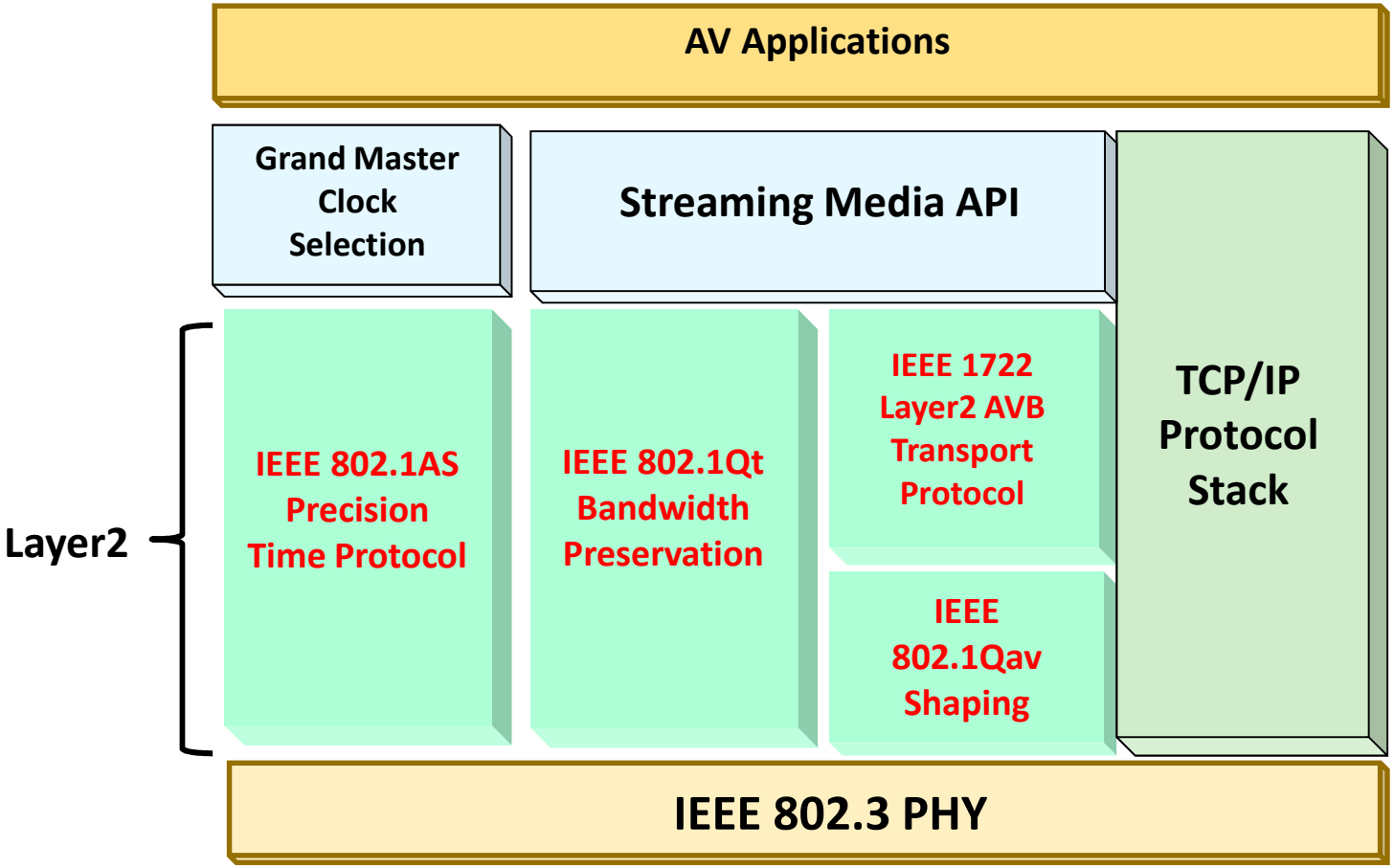
TT-Ethernet
(Time Triggered Ethernet)

IEEE 802.1 AVB (Ethernet AVB)

- An enhancement to the IEEE 802.3 Ethernet standard for the support of low-latency, time-sensitive streaming applications over Ethernet.
  - Standardized and maintained by IEEE 802.1 AVB working group
  - The AVnu Alliance develops device certification for the application market.
  - Supported features (implemented using the extension of MAC and bridges)
    - Precise synchronization with an accuracy of less than 1 us over up to 7 hops
    - Traffic shaping for media streams (Class A: 2 ms, Class B: 50 ms)
    - Admission control of new media stream
    - Identification of non-participating devices

IEEE 802.1 AVB (Ethernet AVB)

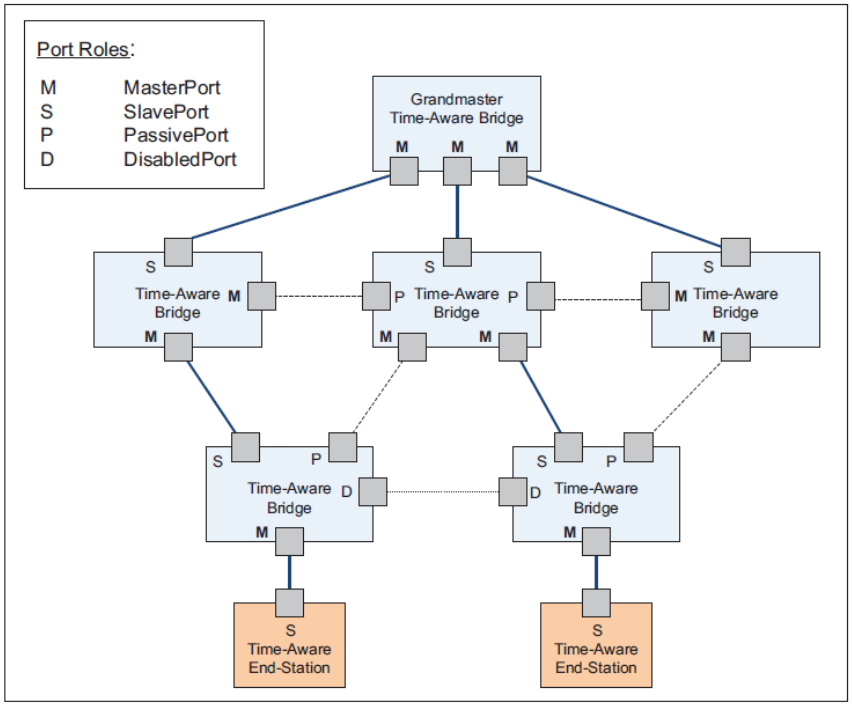
- IEEE 802.1 AVB Protocol Hierarchy



IEEE 802.1 AVB (Ethernet AVB)

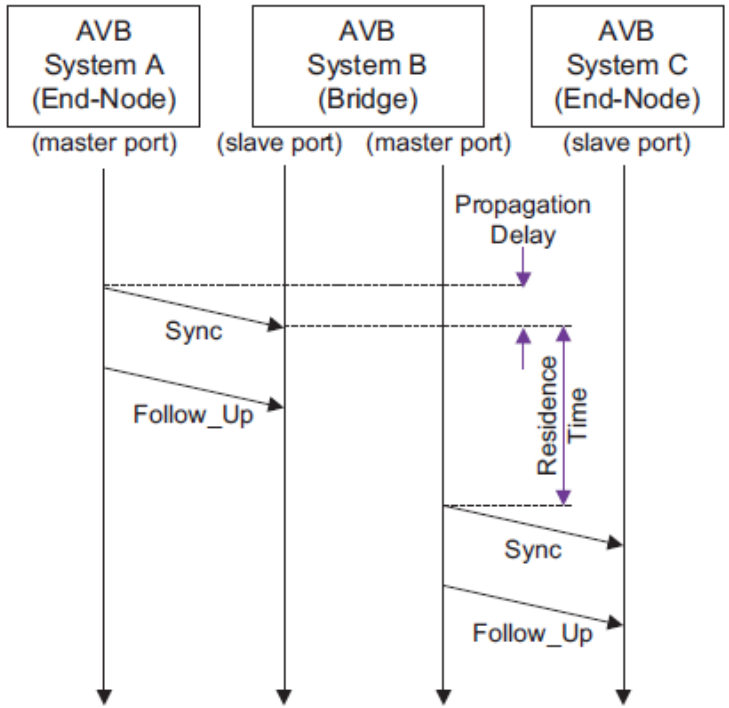
- IEEE 802.1AS: Layer-2 synchronization services

1. Selection of a Grandmaster node using Best Master Clock (BMC) algorithm in IEEE1588



Source: Ref. [Lim2011b]

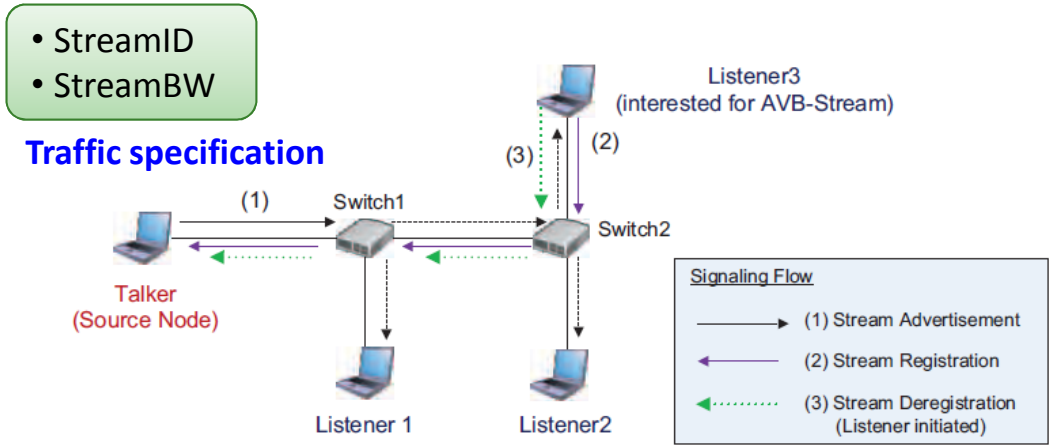
2. Synchronization of distributed nodes



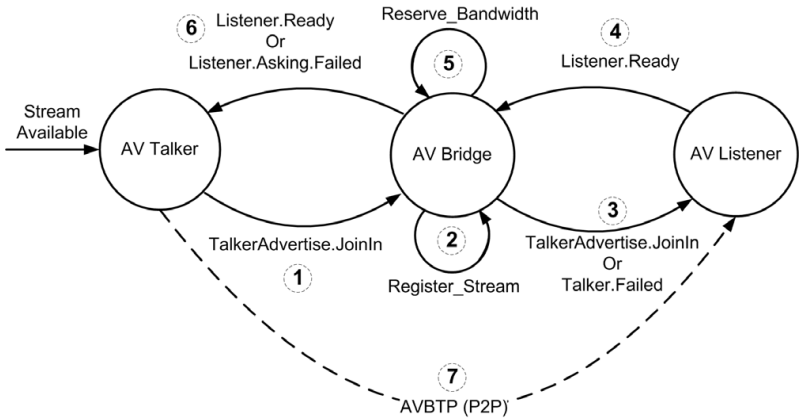
Source: Ref. [Lim2012]

IEEE 802.1 AVB (Ethernet AVB)

- IEEE 802.1Qat : Stream Reservation Protocol (SRP)
  - Define a signaling protocol to allow an end-to-end management of resource reservation
  - SR-Class A (interval time: 125 us, 802.1Q Priority 3) and SR-Class B (interval time: 250 us, 802.1Q Priority 2)
  - The bandwidth allocated for both SR classes is limited to 75% of the total bandwidth.



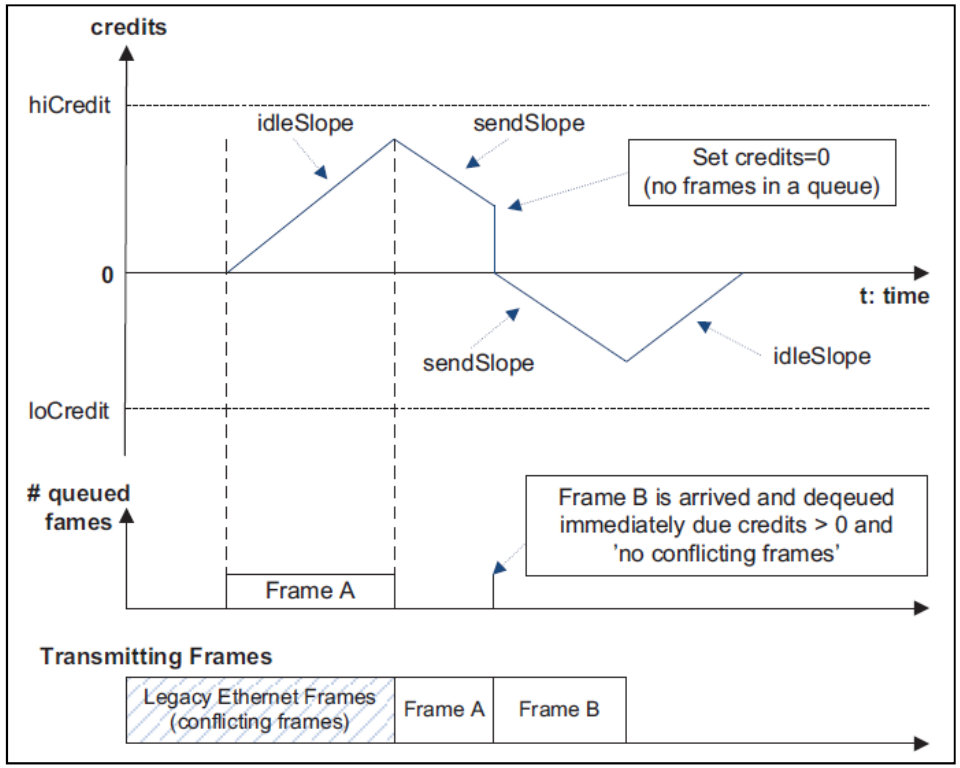
Source: Ref. [Lim2012]



Source: Ref. [Imtiaz2011]

IEEE 802.1 AVB (Ethernet AVB)

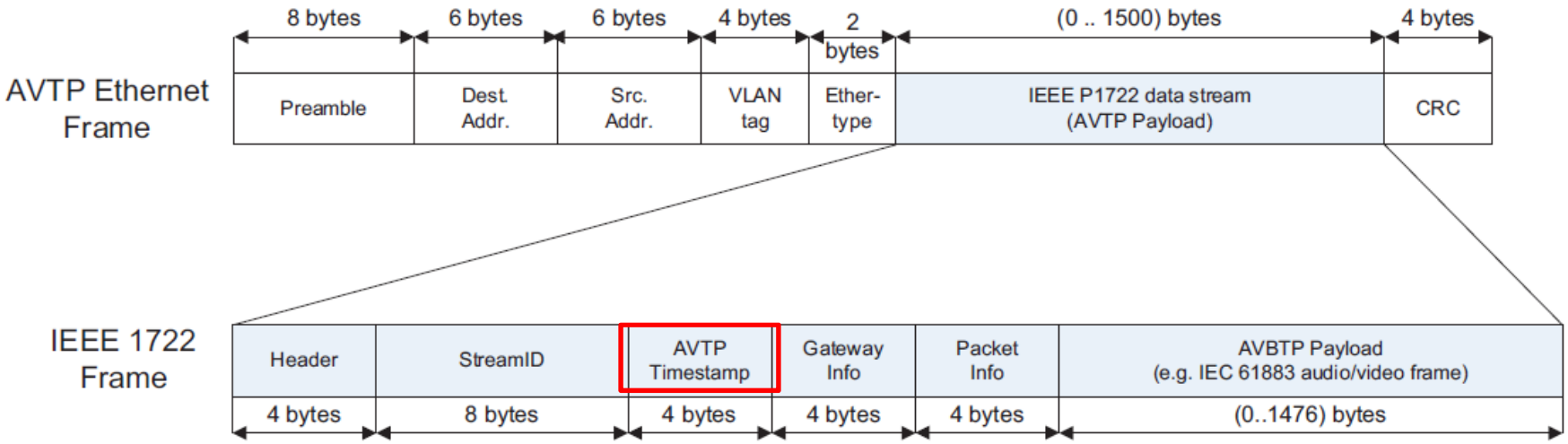
- IEEE 802.1Qav: Forwarding and Queuing for Time-Sensitive Streams (Traffic Shaping)
  - Re-mapping of priority values to AVB classes
  - Transmission selection algorithm
    - Strict Priority (SP) transmission for legacy Ethernet frames
    - Credit Based Shaper (CBS) transmission for AVB frames



Source: Ref. [Lim2012]

IEEE 802.1 AVB (Ethernet AVB)

- IEEE 1722: Layer-2 transport protocol
  - A particular encapsulation of audio and video frames
  - Time stamping of the frames indicating the receiver node to play the information at the exact play time
  - Ensure the synchronization between different listeners connected to a given streaming data in combination with IEEE 802.1AS



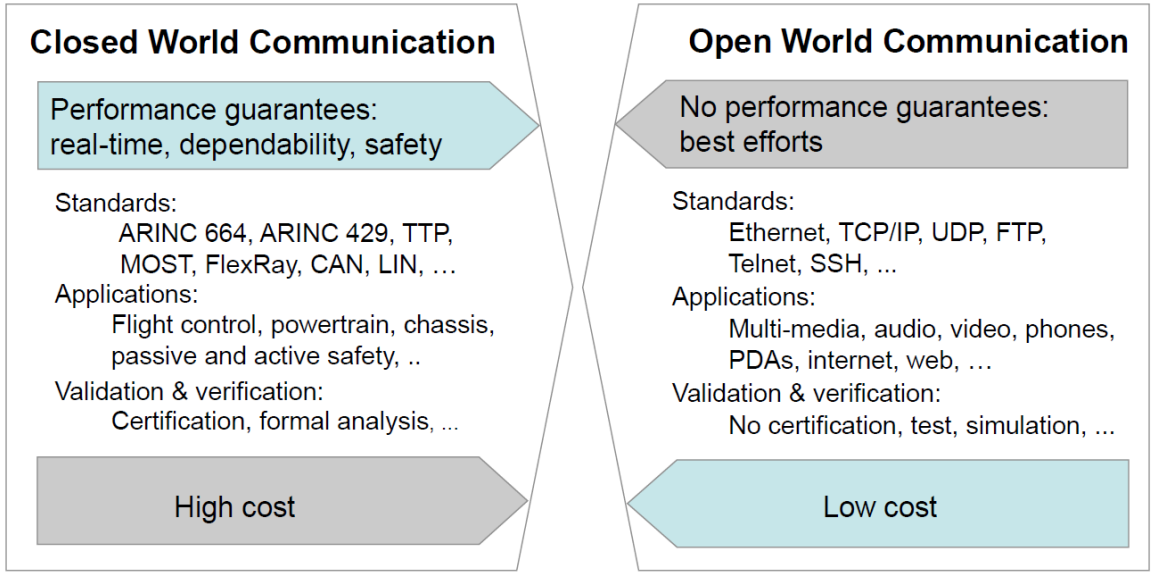
Source: Ref. [Lim2012]

IEEE 802.1 AVB (Ethernet AVB)

- On-going standardization activities (IEEE AVB Generation 2)
  - IEEE 802.1ASbt: Enhancements to IEEE 802.1AS
    - Support for new media types and additional parameter sets for non AV traffic
  - IEEE 802.1Qca: Extension of IEEE 802.1Qat
    - Redundancy for data flows and distribution of control parameters for time synchronization and scheduling
  - IEEE 802.1Cb
    - Protocols for providing redundant transmission efficiently
  - IEEE 802.1Qbv
    - Enhancements to support scheduled traffic in both bridges and end stations based on timing derived from the IEEE 802.1AS
  - IEEE 802.1Qbu
    - procedures to suspend the transmission of a non-time critical frame and allow for one or multiple time-critical framed to be transmitted
  - IEEE 802.1Qcc
    - Support for Configurable Stream Reservation classes and streams

TT-Ethernet

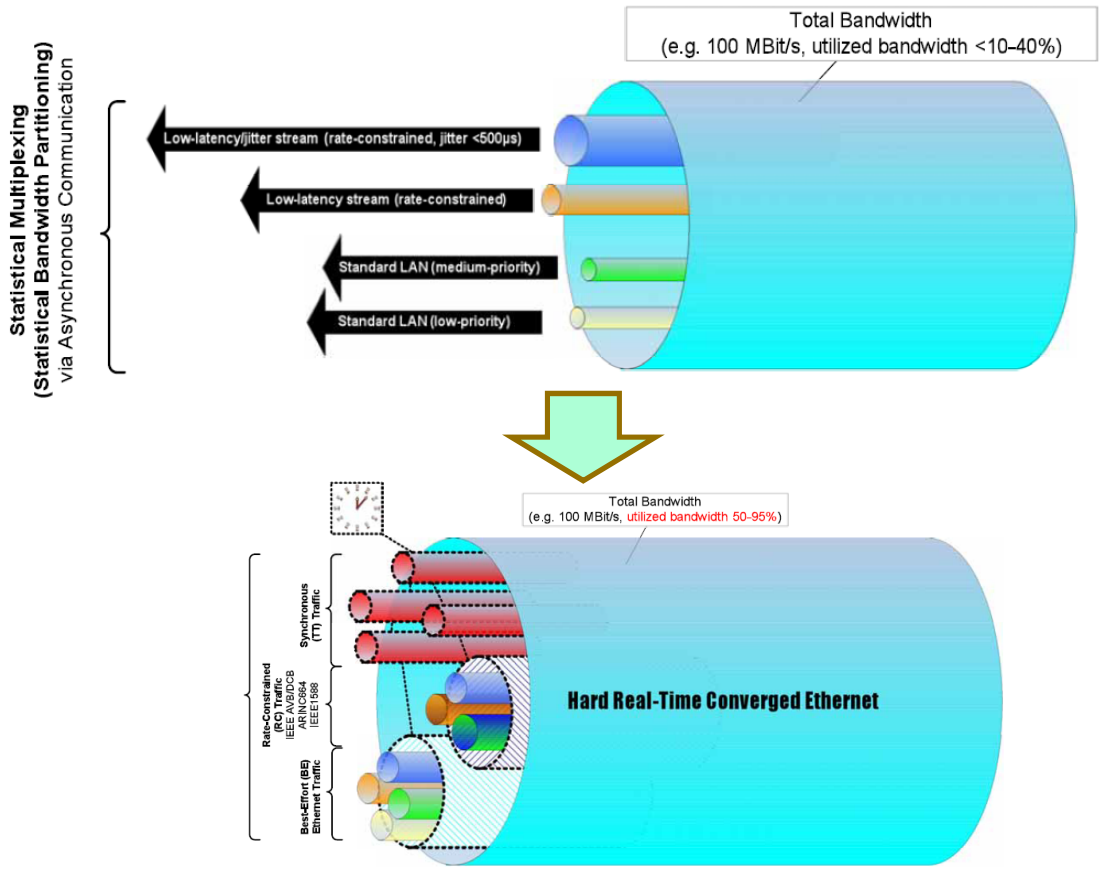
- Another Ethernet-based candidate for real-time communication in automotive or industrial networks
  - First presented by the research group in Vienna University of Technology (Prof. Hermann Kopetz)



  - Standardized in Society of Automotive Engineers (SAE) AS6802 and developed by TTTEch.

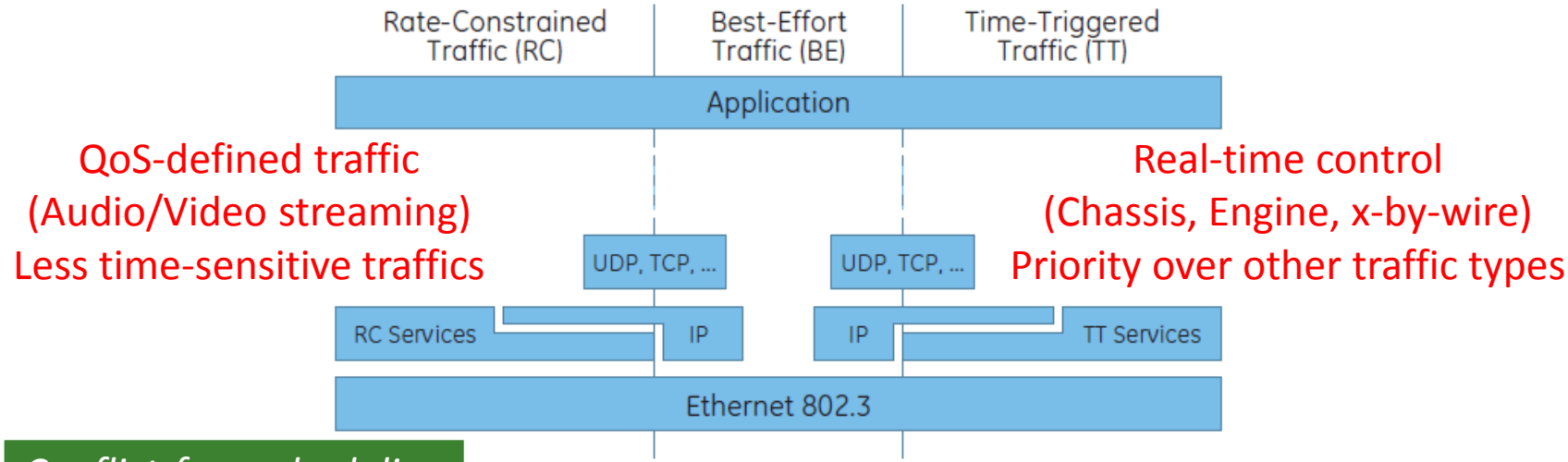
TT-Ethernet

Ethernet + Clock Synch. + Time-Triggered Communication + Rate Constrained Communication + Safety

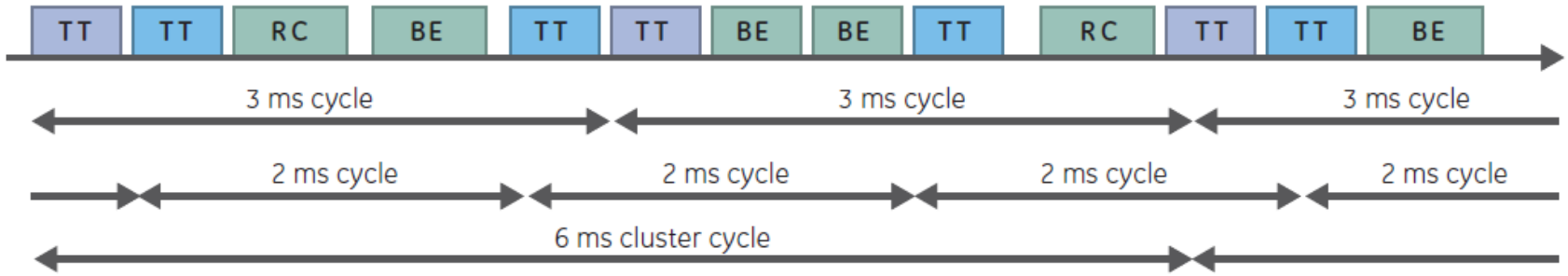


TT-Ethernet

- Three different traffic types are provided:
  - Time-triggered (TT), Rate-constrained (RC), Best-effort (BE)

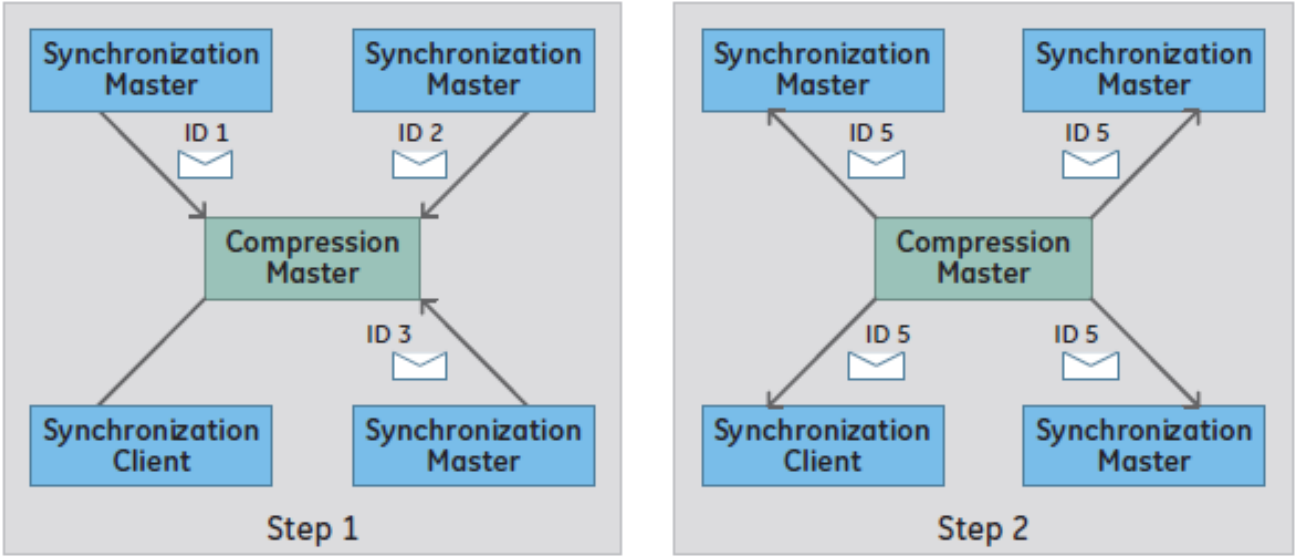


Conflict-free scheduling



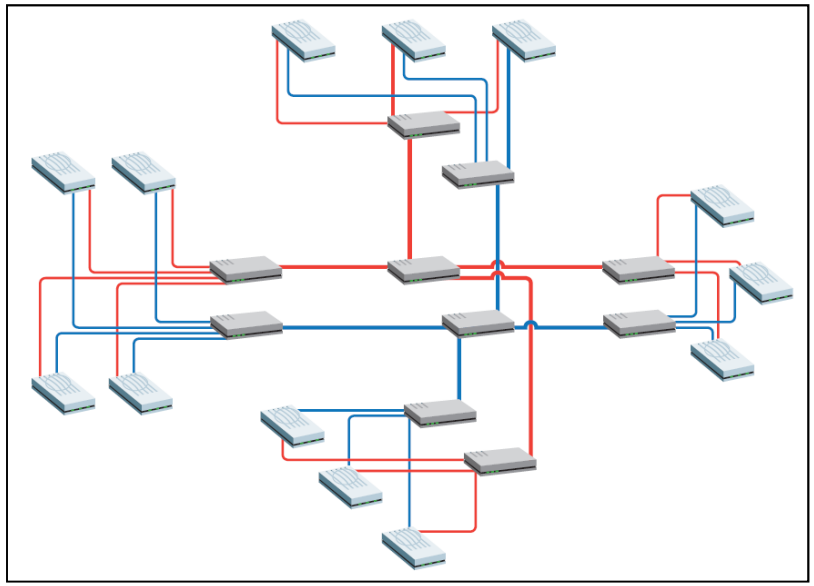
TT-Ethernet

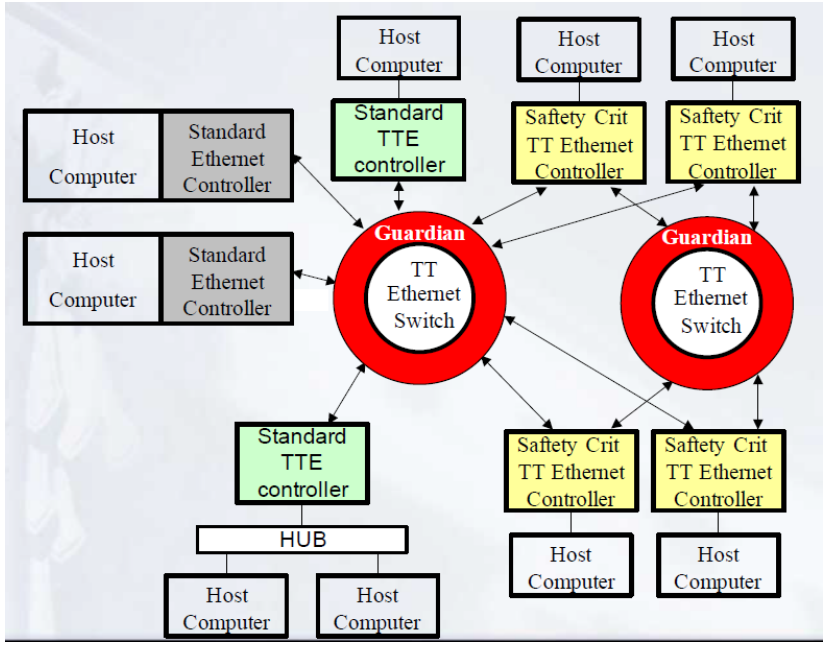
- Synchronization control
  - Events in TT-Ethernet occur at predefined times with a precision at the single microsecond level.
  - TT-Ethernet relies on a redundant hierarchical master-slave method that has a distributed fault-tolerant majority nodes and master switches to provide the time in the system.



TT-Ethernet

- Safety and Fault Tolerance
  - TT-Ethernet networks can be set up with multiple redundant end systems, switches and segments. → Tolerance for multiple fault
  - TT-Ethernet allows the integration of guardians in switches and end systems.
    - Guardians check the fault and isolate the fault network segment or port.





Prospective Usage of Ethernet in Automotive

- Ethernet usage in cars is expected to spread in several domains.
  - Diagnostics and firmware update (already in use as a replacement for CAN)
  - Multimedia and infotainment domains (Rear Seat Entertainment)
  - Advanced Driver Assistance Systems
- However, it is expected that Ethernet will not replace existing automotive networks completely in the next few years.
  - Car makers are usually conservative. (CAN → FlexRay)
  - Potential EMC (Electromagnetic Compatibility) issues
  - Switched Ethernet topology may cause the violation of critical data constraints.
- Next generation electrical vehicles can be a good opportunity for the adoption of Ethernet in automotive domain.

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Q&A