June, 2010

Automotive Networking Protocol Overview

FTF-AUT-F0730



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Introduction

- This session (FTF-AUT-F0730) will cover FlexRay, a relatively new, deterministic, fault-tolerant and high-speed automotive network communications protocol under development by the FlexRay Consortium. It is designed to perform better and be faster and more reliable than CAN (Controller Area Network) and LIN (Local Interconnect Network). This session specifically covers:
  - Overview of FlexRay
  - Version 3 of FlexRay
  - CAN & Ethernet – differences and extensions
- Presenter: Peter Spindler, Systems Engineer
- Expertise: FlexRay, FlexRay Conformance Testing, Ethernet, Functional Safety
- This presentation is slated to last 1 hour.

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Session Objectives

- After completion of this session, you will have a better understanding of:
  - The basic concept of FlexRay
  - The new features of FlexRay V3.0
  - The differentiation between FlexRay, CAN, and Ethernet
  - Some extensions of CAN and Ethernet

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Agenda

Outline:

- Part 1: Introduction to FlexRay
- Part 2: New features of FlexRay V3.0
- Part 3: Other network protocols: CAN, Ethernet
- Summary

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Part 1: Outline

- Part 1: Introduction to FlexRay
  - Overview
  - Architecture
  - Freescale Roadmap
  - Access Scheme
  - Time synchronization

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FlexRay: Overview

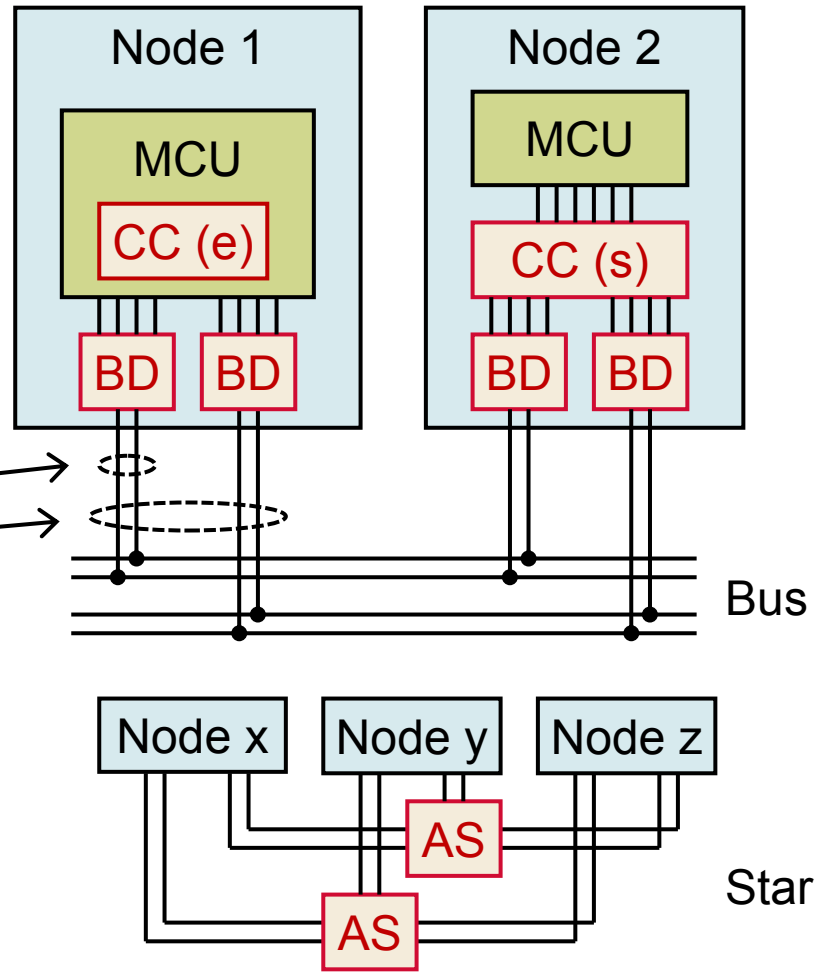
- Communication system: physical layer + data link layer
- Developed by the FlexRay Consortium since 2000:
  - Version 2.1: Publically available since 2005.
  - Version 3.0: Finalized. Publically available soon.
- Time-triggered communication protocol
- Main features:
  - One or two communication channels
  - Up to 10 Mbit/s per communication channel
  - Deterministic behavior (i.e., predetermined message latency)
  - Static and dynamic bandwidth allocation
  - Fully configurable

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FlexRay: Architecture

- MCU: Microcontroller
- CC: FlexRay Communication Controller:
  - embedded (e)
  - standalone (s)
- BD: FlexRay Bus Driver
- AS: FlexRay Active Star
- Cabling: twisted pair unshielded
- Two channels
- Topology: bus or star



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FlexRay: Freescale Roadmap

Application Performance / Integration

FlexRay™

BUILT ON Power™

FlexRay Certificate

MPC5567 — Powertrain, Chassis
Single core: z6, 80 – 132MHz
Flash: 2M, RAM: 80K
130nm

MPC5561 — Advanced Driver Assistance & Safety
Single core: z6, 80 – 132 MHz
Flash: 512K – 1M, RAM: 98K – 192K
130nm

MPC551XG — Body
Dual core: z0+z1, up to 80 MHz
Flash: 512K – 1.5M, RAM: up to 80K
130nm

S12XF — Body, Powertrain, and Chassis
Single Core: S12X, 50Mhz, XGATE
Flash: 128K – 512K, RAM: 8K – 32K
0.18µ

MFR4310 — Body, Powertrain, and Chassis
Standalone FlexRay Controller
0.25µ

MPC567xF — Powertrain, Chassis
Single Core: z7, up to 264MHz
Flash: 3M – 4M, RAM: up to 256K
90nm

MPC5668G — Gateways, Highly integrated body
Dual Core: z0+z6, 116MHz
Flash: 2M, RAM: 592K
90nm

MPC564xL — Chassis
Dual Core: z4, 120MHz
Flash: 512K – 1M, RAM: 64K – 128K
90nm

MPC560xP — Chassis
Single Core: z0h, 64MHz
Flash: 384K – 512K, RAM: 36K – 40K
90nm

available

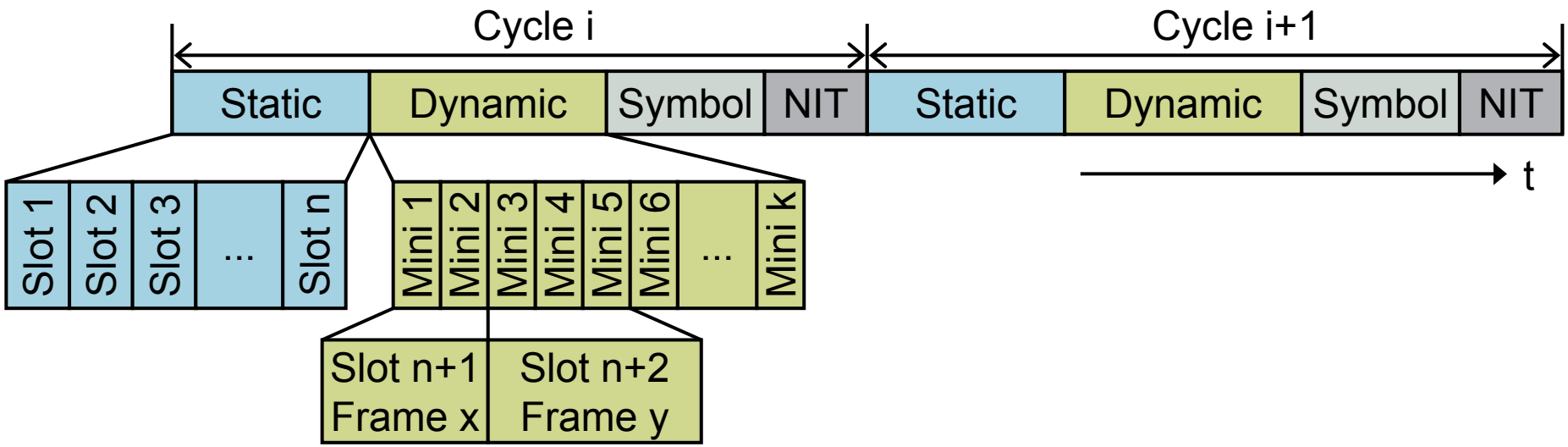
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FlexRay: Access Scheme



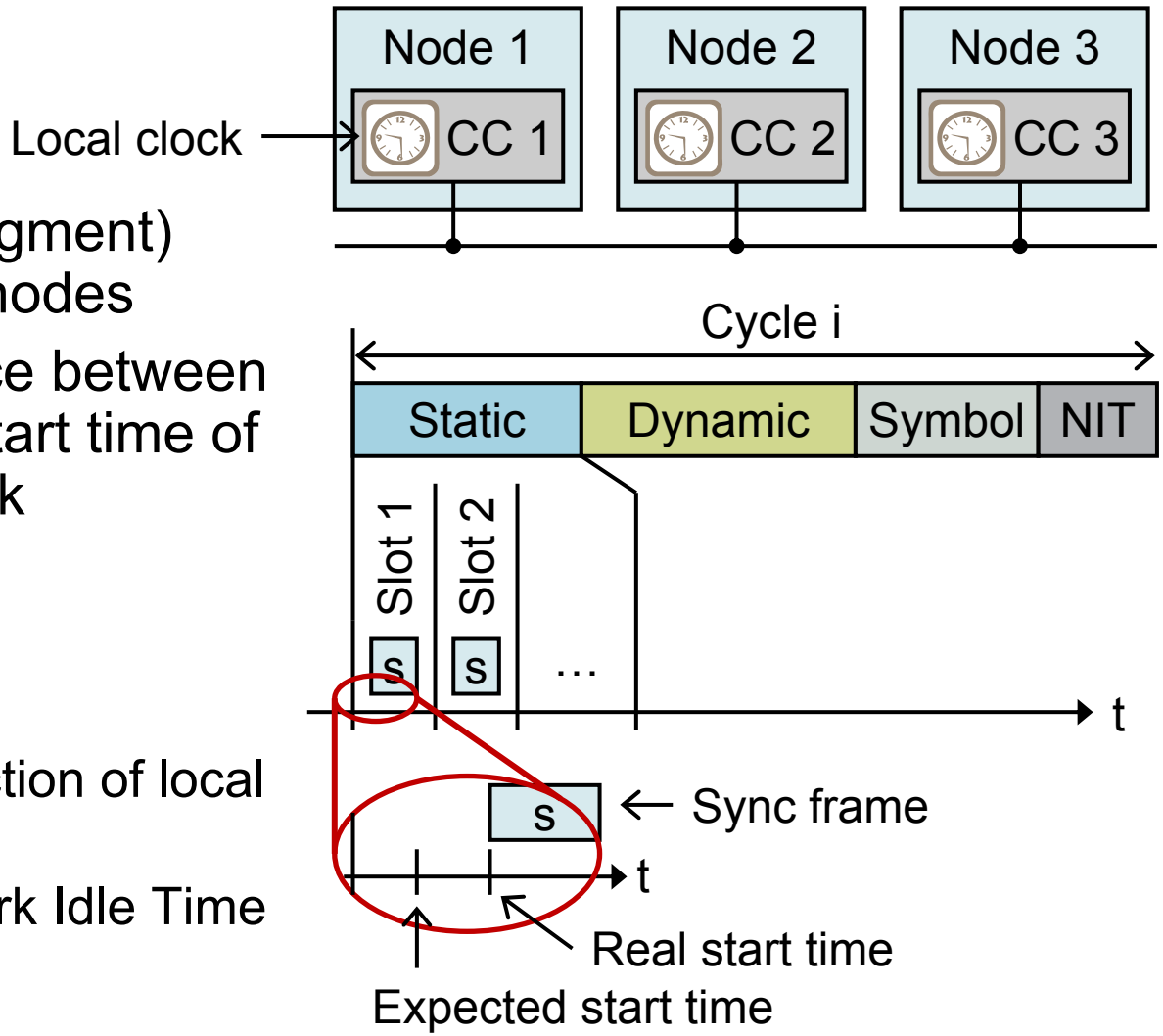
- Static Segment: Slots with fixed length. Fixed assignment between slots and nodes.
  ➔ Time division multiple access: TDMA
- Dynamic Segment: Minislots with fixed length. Minislots can be combined to contain frames with variable length. No fixed assigned between slots and nodes.
- Max. payload per frame (static and dynamic segment): 254 bytes
- Symbol Window: Used for wake-up symbols
- Network Idle Time (NIT): Clock correction

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FlexRay: Clock Synchronization

- Sync frames (static segment) from configured sync nodes
- Based on the difference between expected and actual start time of each sync frame: Clock synchronization
- Clock synchronization:
  - In each node
  - Offset and rate correction of local clock
  - Applied during Network Idle Time (NIT)



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Part 2: Outline

- Part 2: New features of FlexRay V3.0
  - Various Enhancements
  - Dynamic Segment Robustness
  - New synchronization methods: TT-L, TT-E
  - Wake-up during operation

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FlexRay V3.0: Enhancements (1/3)

- Slot Multiplexing:
  - Slot multiplexing: sharing of static communication slots between multiple nodes
- FIFO Buffer:
  - At least one FIFO buffer is mandatory now.
  - Detailed FIFO filter criteria
- Cycle Counter:
  - Configurable cycle counter wraparound: any even number between 8 - 64 is possible
  - Extended cycle counter filtering: repetition values of 5, 10, 20, 40, and 50

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FlexRay V3.0: Enhancements (2/3)

- Timers
  - No relative timers anymore, but two absolute timers
- CHI commands
  - New CHI commands for “save shutdown” at the end of the communication cycle
- Individual buffers
  - Reconfiguration of message buffers
- Network management vector
  - Network management vector is mandatory now
- Status data
  - Number of received startup frames is provided to the host

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FlexRay V3.0: Enhancements (3/3)

- Bit rates
  - Support for 2.5 Mbit/s, 5 Mbit/s, and 10 Mbit/s
- Dynamic Segment
  - Ongoing transmission at the end of the dynamic segment no longer results in a fatal protocol error.
  - Automatic termination of a frame transmission in the dynamic segment if the dynamic segment ends before the frame transmission is complete (no fatal protocol error anymore).
  - Robustness against de-synchronization of slot counter introduced
- Blind Phase
  - Network activity is ignored for a configurable period of time following a transmission to minimize effects caused by echoes/ringing
- New synchronization modes (TT-E, TT-L)
- Wake-up during operation

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FlexRay V3.0: Dynamic Segment Robustness (1/2)

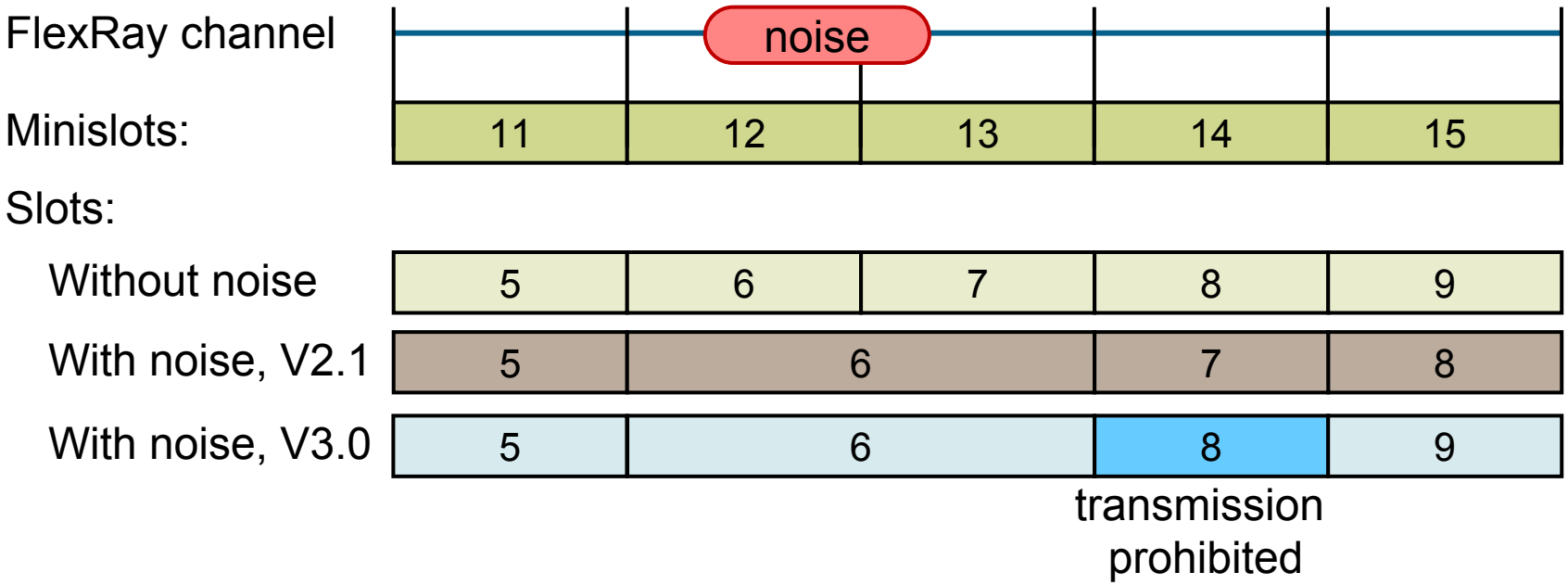
- Key Requirement
  - Improve behavior in case of noise on an undriven link in the dynamic segment (avoid de-synchronization of the slot counter in the cluster)

- Key Characteristics
  - Classification of noise depending on duration of activity
  - Noise does not lead to a slot counter de-synchronization in case of:
    - short symmetric noise
    - short asymmetric noise
    - noise after a frame

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FlexRay V3.0: Dynamic Segment Robustness (2/2)



- Activity shorter than 80 bits is classified as noise.
- Slot counter is increased by two instead of one (i.e., a slot is skipped) to correct the effect of noise on the slot counter.
- Further de-synchronization is avoided by prohibiting transmission in the slot after the detection of noise.
- Efficiency is demonstrated by analytical investigations and statistical experiments.

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FlexRay V3.0: TT-L (1/2)

- TT-L (Time-Triggered Local Master Synchronization)

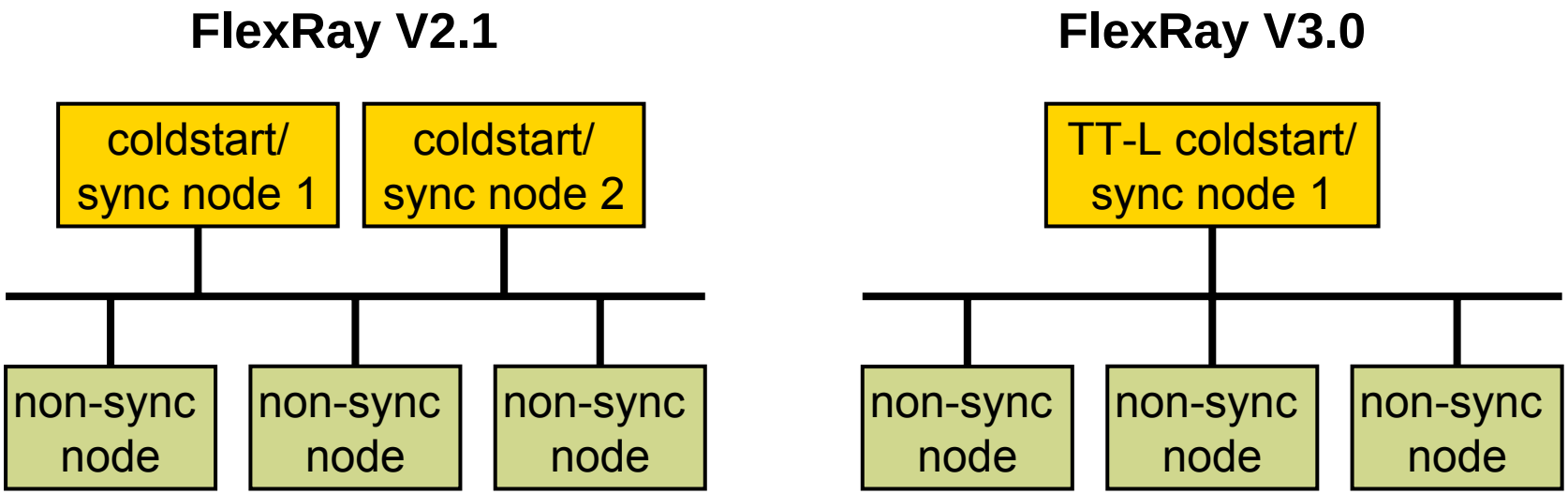
- Key Requirement
  - Provide a simple means for cluster startup and synchronization controlled by a single node.

- Key Characteristics
  - Downward compatible to V2.1
  - Faster cluster startup
  - Better cluster precision
  - Applicable for single or dual channel system

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FlexRay V3.0: TT-L (2/2)



- Coldstart/sync node: Dedicated node for startup of the FlexRay cluster + providing sync frames
- FlexRay V2.1: At least two coldstart nodes are required.
- FlexRay V3.0: Single special coldstart node is allowed (TT-L node).

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FlexRay V3.0: TT-E (1/3)

- TT-E (Time-Triggered External Synchronization)

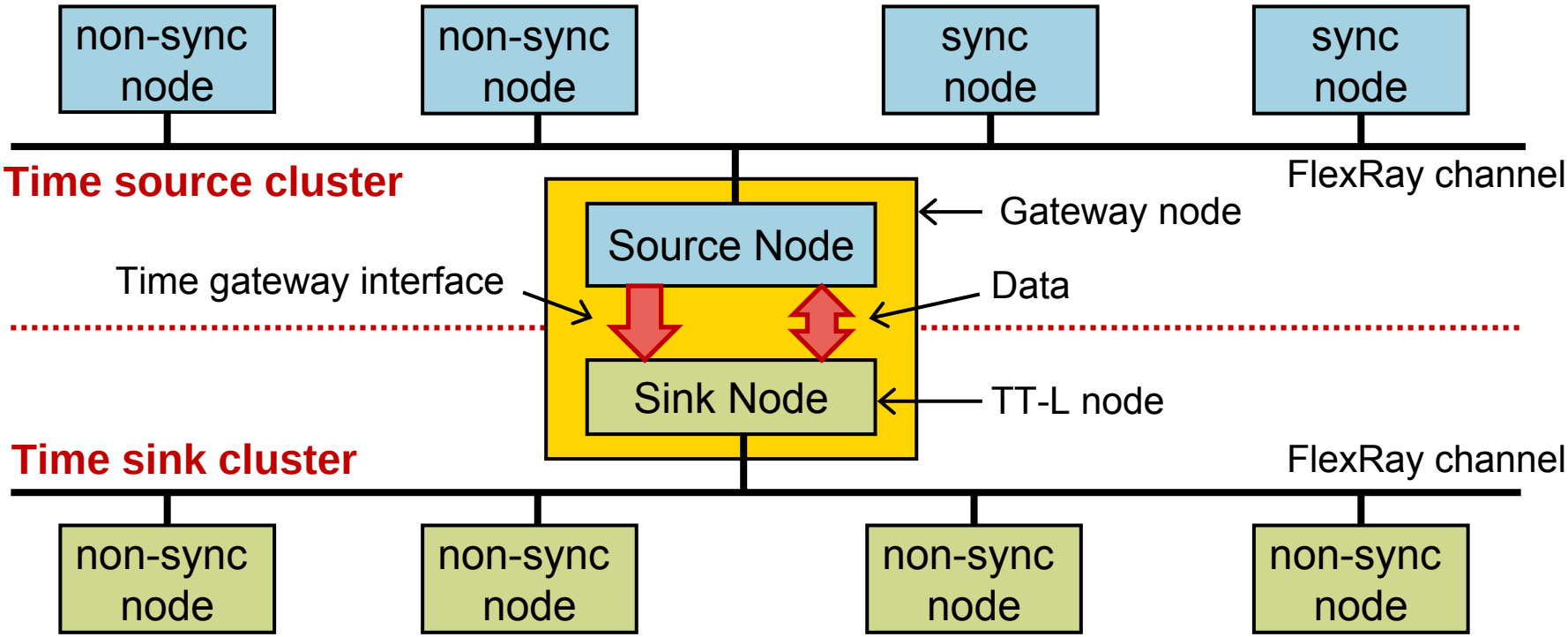
- Key Requirement
  - Provide a simple means for connecting FlexRay clusters such that all clusters are synchronized.

- Key Characteristics
  - Alignment of schedules
  - Synchronization transparent to higher level/host MCU
  - Applicable to single and dual channel systems
  - Backward compatible, i.e., can be used to synchronize two FlexRay V2.1 clusters

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FlexRay V3.0: TT-E (2/3)

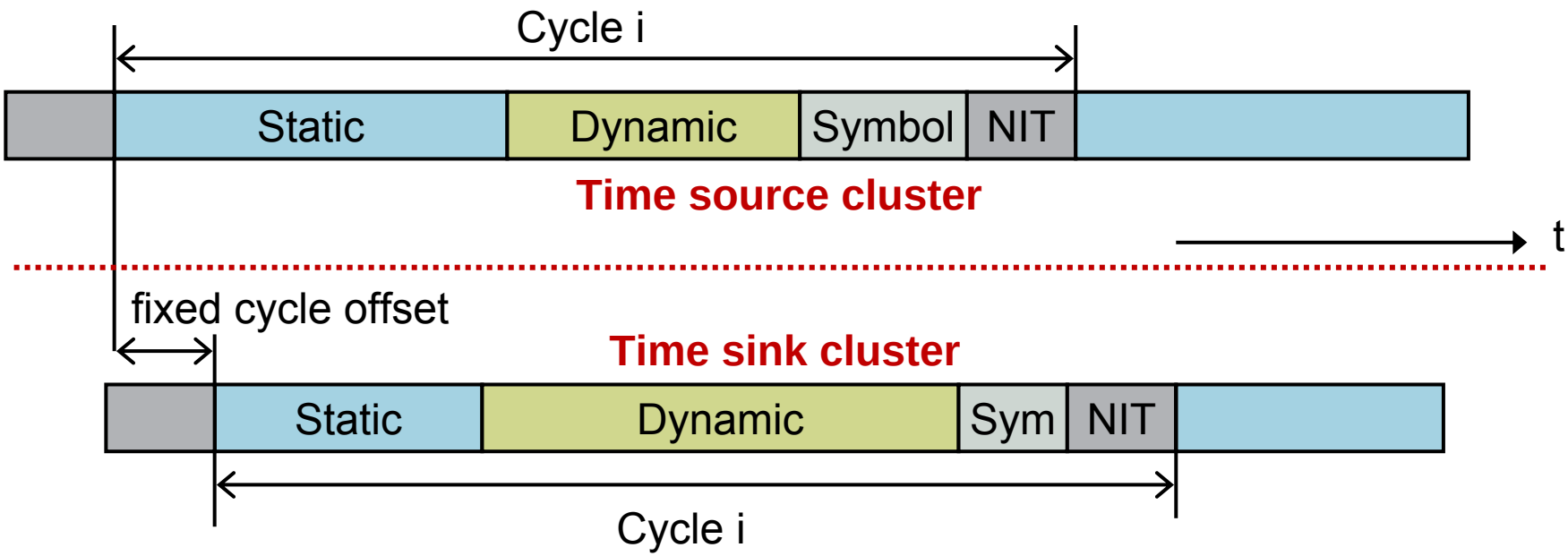


- Single gateway node connects both FlexRay clusters
- Gateway node: time gateway source node + time gateway sink node
- Time gateway interface: Clock synchronization
- Time gateway sink node: TT-L node, i.e., single node which drives synchronization in sink cluster

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FlexRay V3.0: TT-E (3/3)



- Same cycle length in both clusters
- Fixed cycle offset between clusters
- Clusters can have different schedules (i.e., different numbers of static slots, sizes of static slots, lengths of dynamic segment, lengths of minislots, or lengths of NIT.)

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FlexRay V3.0: Wake-up (1/2)

- Wake-up during communication

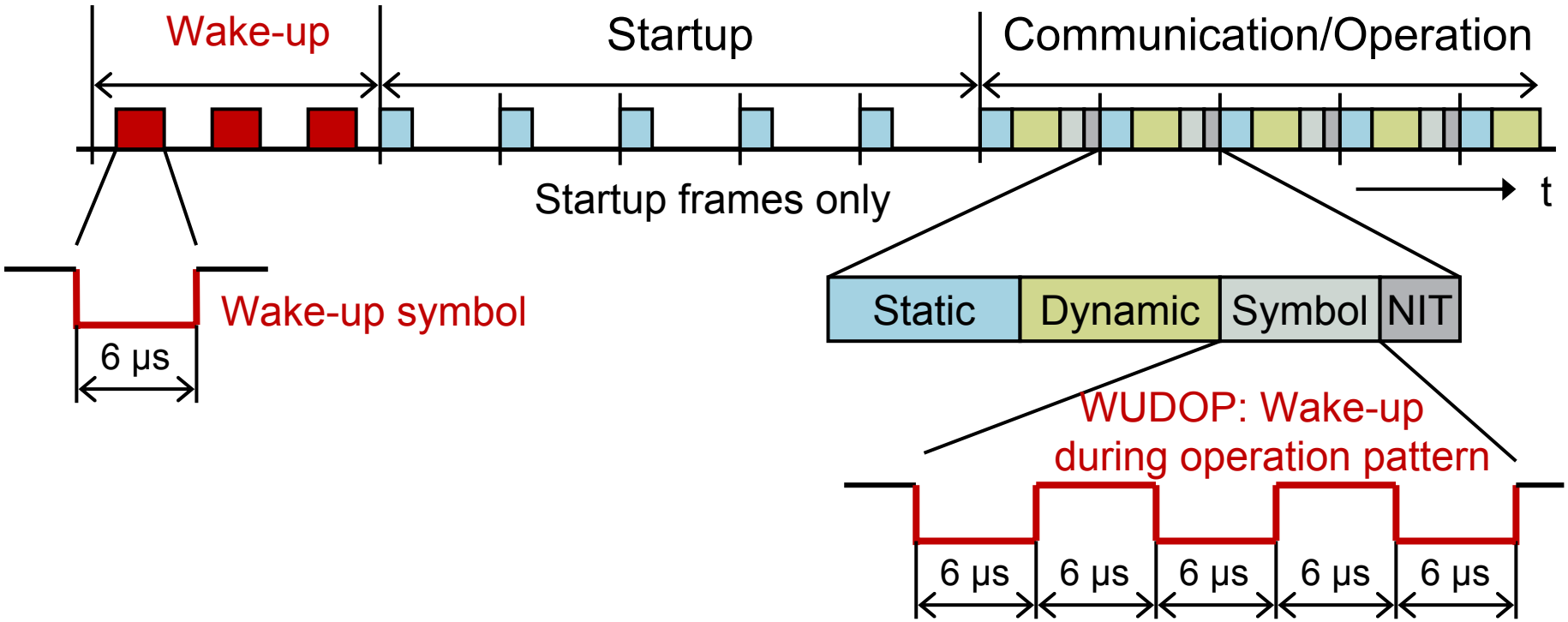
- Key Requirement
  - Wake-up of node(s) during operation/communication

- Key Characteristics
  - Low bandwidth consumption by new wake-up method
  - Applicable for all bit rates
  - Every node can initiate wake-up
  - Downward compatibility: FlexRay V2.1 nodes are not disturbed by the new wake-up method

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FlexRay V3.0: Wake-up (2/2)



- FlexRay V2.1: Wake-up before startup/communication only
- FlexRay V3.0: Wake-up also during operation possible: WUDOP

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Part 3: Outline

- Part 3: Other network protocols
  - Comparison between FlexRay, CAN, and Ethernet
  - Extensions of CAN: TTCAN (Time-Triggered Controller Area Network)
  - Extensions of Ethernet:
    - TTEthernet
    - PTP (Precision Time Protocol)
    - AVB (Audio Video Bridging)

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Comparison: Overview

	CAN	FlexRay	(Fast) Ethernet
Access Scheme	CSMA/CR Carrier sense multiple access/collision resolution	TDMA Time division multiple access	CSMA/CD Carrier sense multiple access/collision detection
Focus	Event triggered, best for small payload	Time triggered, deterministic behavior, best for medium payload	Event triggered, best for high payload
Automotive Application	ECU-ECU, ECU-Sensors	Distributed control systems, Backbone	Backbone, Programming ECUs, Multimedia
Cabling, Topology	Twisted pair unshielded, bus	Twisted pair unshielded, bus/star	With special automotive bus driver: Twisted pair unshielded, star
Redundancy	No	Built in: two separate channels (using 2 x Twisted pair)	No (single channel)
Deterministic behavior	By extension: TTCAN	Built in	By extensions: TTEthernet, PTP, AVB

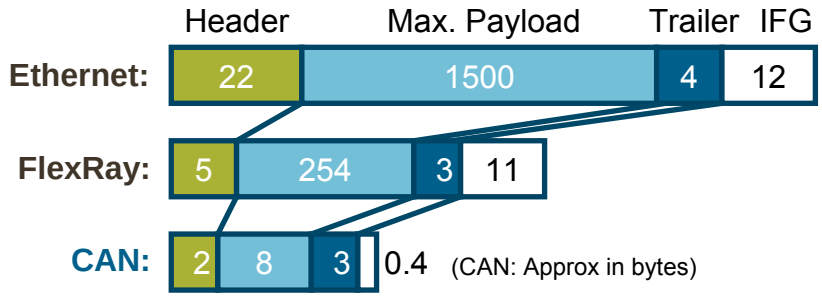
ECU: Electronic Control Unit, PTP: Precision Time Protocol, TT: Time Triggered

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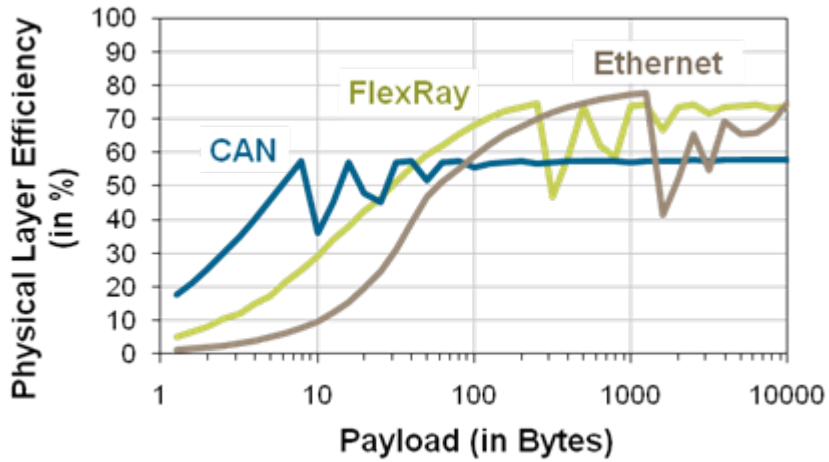
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Comparison: Frame Format

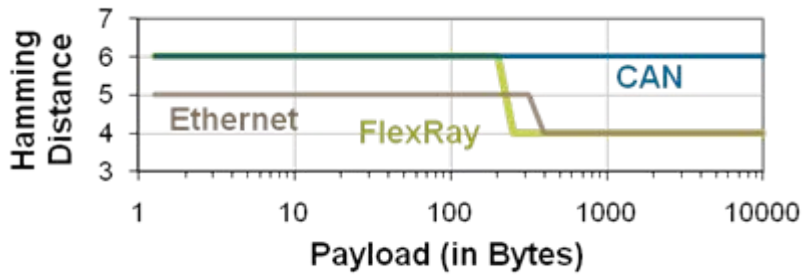
- Frame format:
  - Header: Source, destination, payload length
  - Trailer: CRC (Cyclic Redundancy Check)
  - IFG: Intra frame gap



- Physical layer efficiency:
  - Payload length / (Frame length + IFG)
  - Considers coding scheme. FlexRay: NRZ, (Fast) Ethernet: 4B5B



- Hamming distance:
  - Ability to detect corrupted data
  - Ethernet: Some ability to detect corrupted data, but FlexRay and CAN are better.

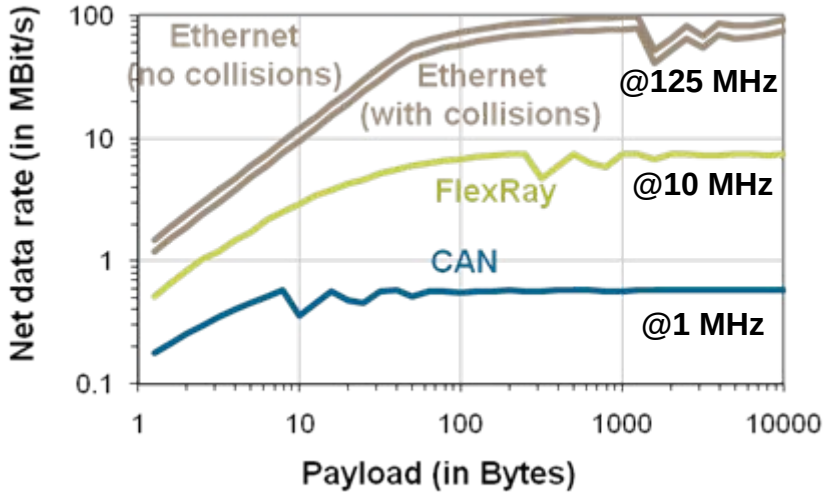


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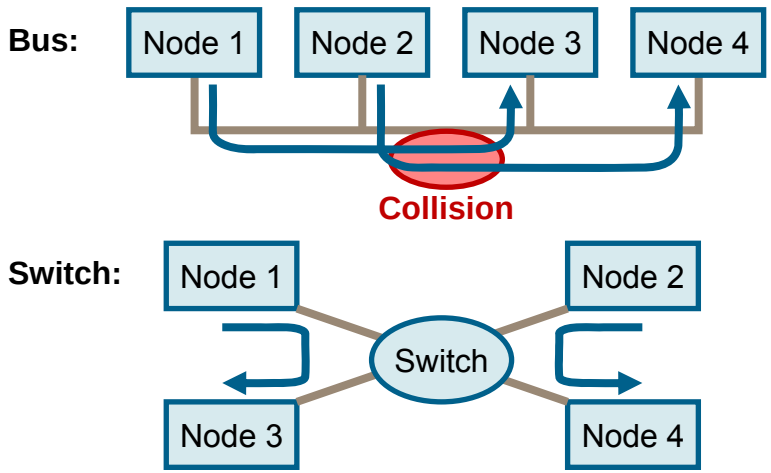
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Comparison: Net Data Rate

- Net data rate:
  - Based on physical bit rate:
    - CAN: 1 MHz
    - FlexRay: 10 MHz
    - Fast Ethernet: 125 MHz
  - Considers:
    - Header/trailer
    - Intra frame gap
    - Collisions (in Ethernet)



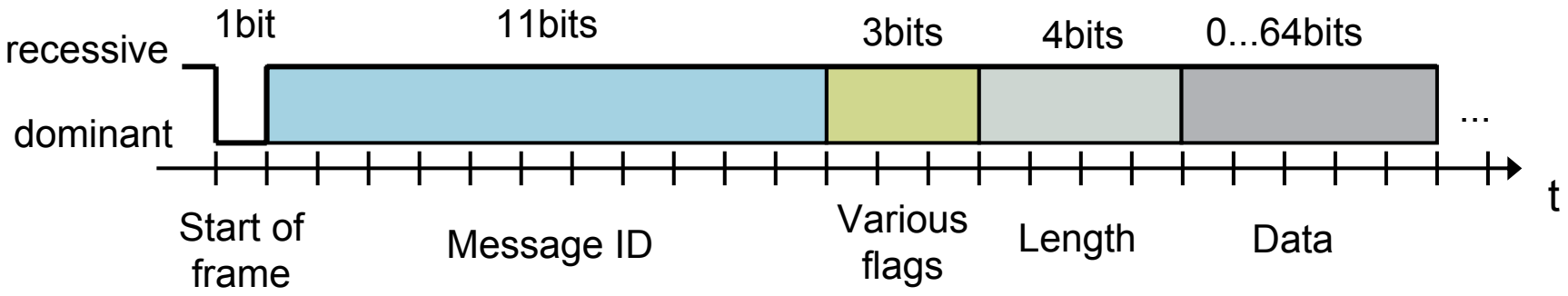
- Collisions in Ethernet:
  - Due to access scheme (CSMA/CD)
  - Experiments: ~20% losses in net data rate due to collisions [Boggs et. al., 1988]
  - Collisions can be reduced/avoided in switched Ethernets.



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CAN Extension: TTCAN

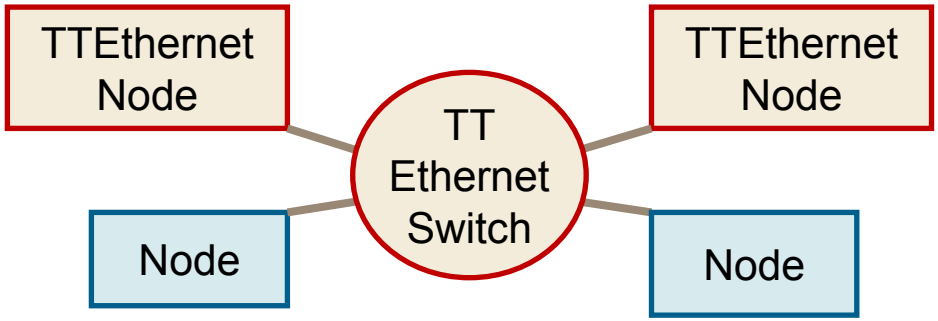


- CAN:
  - Standardized as ISO 11898
  - CSMA/CR: Carrier Sense Multiple Access/Collision Resolution
  - Collision resolution: Bit-wise arbitration in Message ID: “0” dominates over “1” → higher IDs dominate over lower IDs
  - Latency of messages not deterministic if low ID and more than one sender
- TTCAN:
  - Standardized in Part 4 of ISO 11898
  - Time triggered extension for CAN: Determinism for CAN
  - Special TTCAN nodes transmit sync frames → Schedule
  - Can be implemented in software

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Ethernet Extension: TTEthernet



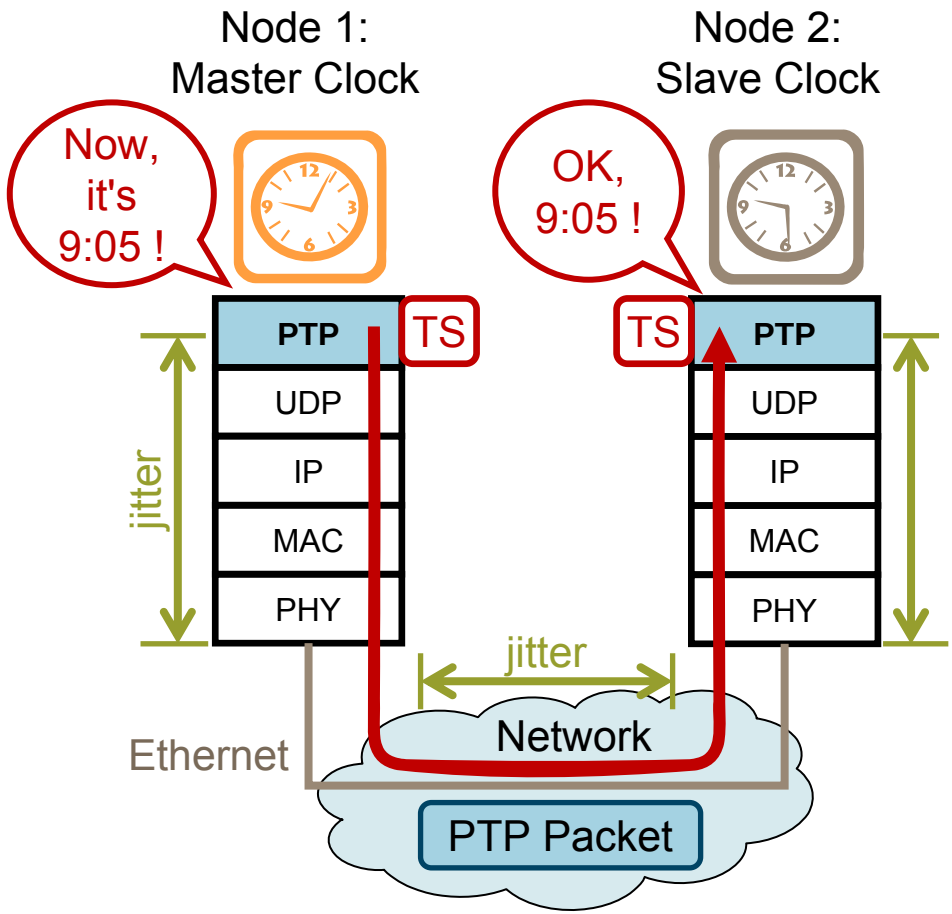
- Ethernet:
  - Standardized in IEEE 802.3
  - CSMA/CD: Carrier Senses Multiple Access/Collision Detection
  - Collision detection: Before sending: check for activity. If Activity: Retry after certain amount of time
  - Latency of messages not deterministic if more than one sender
- TTEthernet:
  - Time triggered extension for Ethernet: Determinism for Ethernet
  - Special TTEthernet nodes transmit sync frames → Schedule
  - TTEthernet switch required to guarantee transmission of sync frames
  - TTEthernet in nodes can be implemented in software

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Ethernet Extension: PTP

- PTP: Precision Time Protocol (IEEE 1588)
- Time synchronization in a network
- Time stamping (TS) in nodes required
- Alternatives for time stamping:
  - In software by microcontroller
    → lowest precision (~20µs)
  - In hardware by extended Ethernet module (MAC)
  - In hardware by extended physical bus driver (PHY)
    → best precision (~40ns)

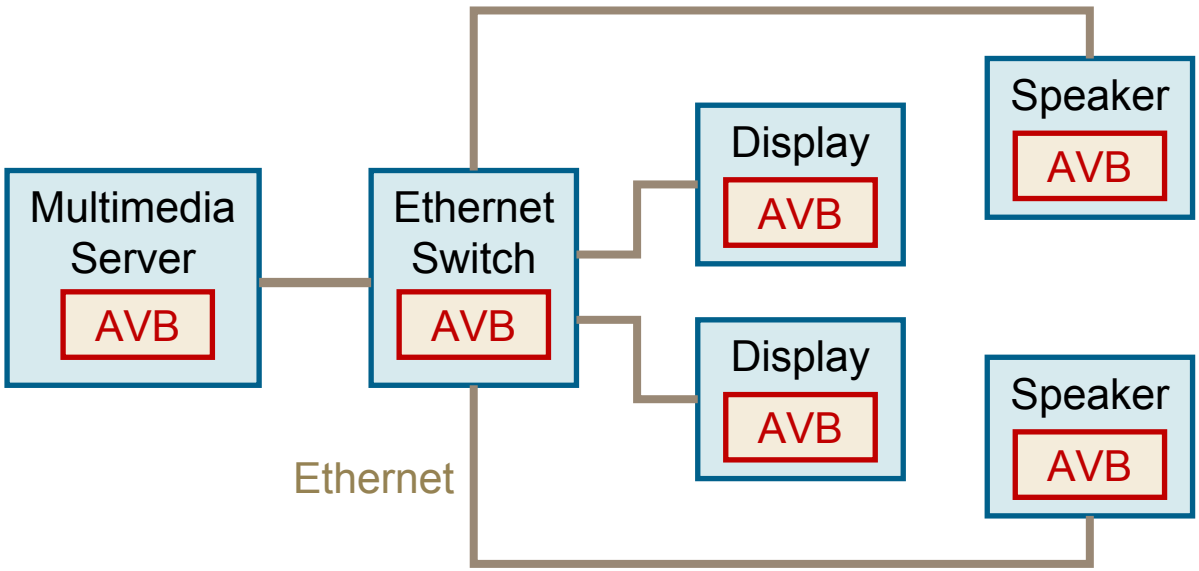


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Ethernet Extension: AVB

- AVB: Audio Video Bridging
  - Extension to IEEE 802.1 (Network bridging)
  - Target: 2 ms guaranteed latency through 7 Ethernet bridges/switches
  - Time synchronization by PTP: IEEE 802.1AS
  - Quality of service, stream reservation: IEEE 802.1Qat
  - Forwarding and queuing: IEEE 802.1Qav



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Session Summary

- FlexRay:
  - Built-in time triggered: deterministic communication
  - V3.0: downward compatible + interesting new features
  - Best for medium data rates (~10 Mbit/s)
- CAN:
  - Event triggered, not deterministic
  - Best for low data rates (~1 Mbit/s)
  - Extensions available
- Ethernet:
  - Event triggered, not deterministic
  - Best for high data rates (>10 Mbit/s)
  - Extensions available

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For Further Information

- FlexRay:
  - www.Freescale.com/**Flexray**
  - www.flexray.com

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