AARHUS
UNIVERSITY
DEPARTMENT OF ENGINEERING

Middleware and Communication Protocols for Dependable Systems TI-MICO

Time Triggered Protocol (TTP) & Time Triggered Architecture (TTA)

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Time-Triggered Architecture (TTA) and Protocol (TTP)

Article:

"The Time-Triggered Architecture"
by
Hermann Kopetz and Günther Bauer,
Proceedings of the IEEE, January 2001.

Introduction article:

"Time Triggered Protocol: TTP/C" by
Ross Bannatyne, Motorola,
Embedded Systems Programming, March 1999

Time-Triggered Protocol - 1 (TTP)

- **TTP:** Family of **TDMA based**, **fault tolerant protocols**
- TTP/C was originally intended to meet the requirements of **SAE class C** for automotive applications
- The development of TTP and TTP/C has been led by Prof. **Hermann Kopetz, Technical University of Vienna**
- TTP is based on more than 20 years development work in research and prototype applications
- TTP integrated circuits have been available since 1998
- Second generation silicon, supporting communication speeds of up to **25 Mbit/s**, is available today
- The commercial development of TTP/C tools and products is led by TTTech (www.tttech.com)
- Existing protocols J1850 and CAN meet the bandwidth specification for an SAE Class C protocol, ***but not the fault tolerant requirements***

Time-Triggered Protocol – 2 (TTP)

- *Time-Triggered Protocol (TTP)* is a **real-time communication protocol** for the interconnection of electronic modules of **distributed fault-tolerant real-time systems**
- The current protocol specification is targeted at distributed real-time systems with strong requirements for **safety**, **availability, and composability** in the **fields of automotive and aerospace electronics as well as industrial control**
- TTP standard (SAE) has been released by SAE as the **SAE AS6003** standard in February 2011.

Two TTP Protocols

- **TTP/A** (SAE **Class A** = Soft Real-Time)
  - A scaled-down version of TTP
  - A cheaper **master/slave** variant
- **TTP/C** (SAE **Class C** = Hard Real-Time)
  - A full version of TTP
  - **A fault-tolerant distributed variant**
- **This presentations focus on TTP/C**

TTP Protocol Objectives

- Message transport with **low latency** and **minimal jitter**
- Support of **composability**
- Provision of a **fault-tolerant membership service**
- **Fault-tolerant clock synchronization**
- Distributed **redundancy management**
- Minimal overhead
- Scalability to high data rates
  - efficient operation both on twisted wires and on optical fibers

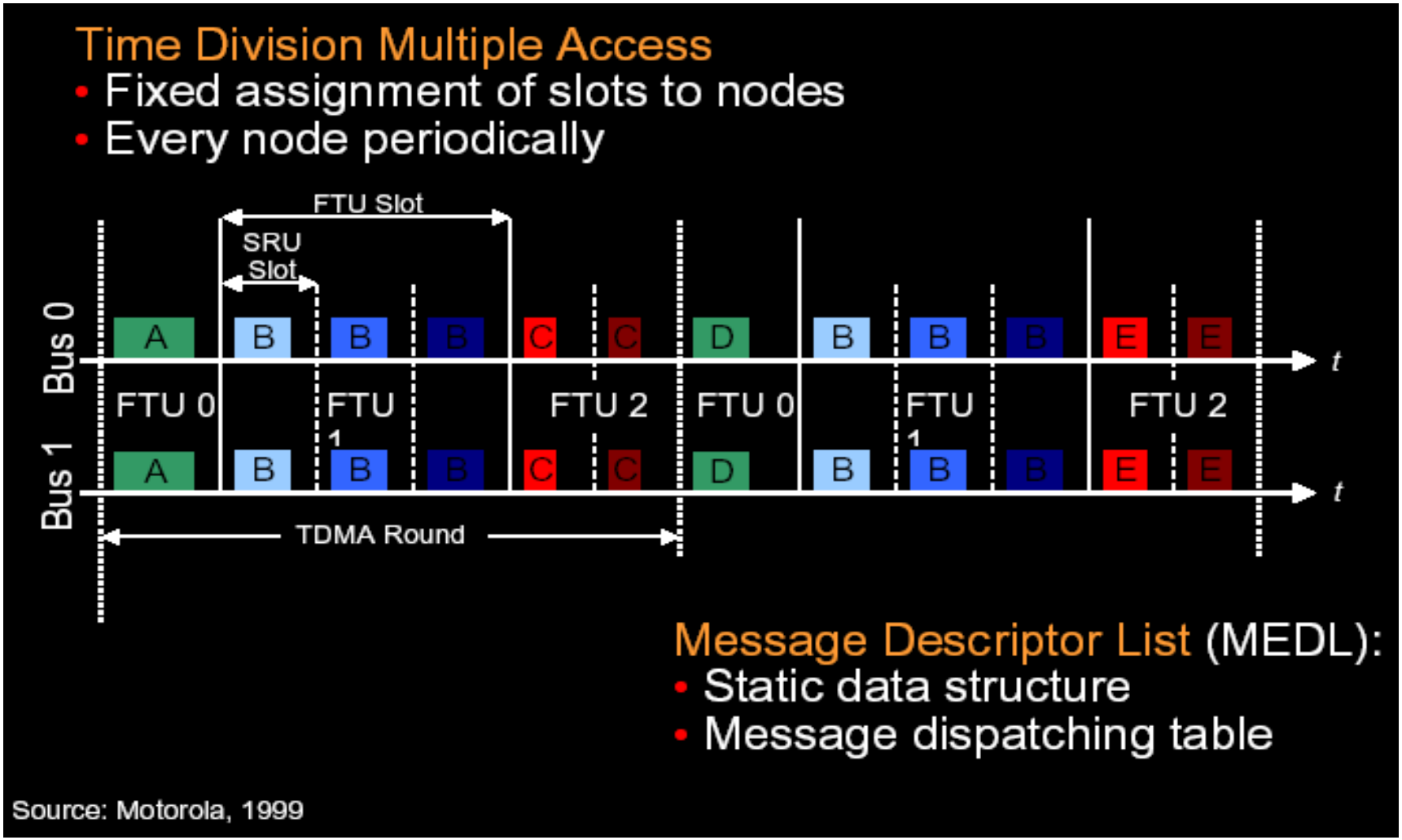
Composability

- A composable architecture has a two level design strategy:
  1. the **architecture level** and
  2. the **node level**
- For an architecture to be **composable** in the temporal domain it must adhere to 4 principles:
  1) **Independent** development of nodes
  2) Stability of prior services
  3) Constructive integration of nodes (a linear process)
  4) Replica determinism
     - all members have same externally visible state

TDMA: Time Division Multiple Access

- A distributed **static** medium access strategy
  - The right to transmit a frame is controlled by the progression of real time
  - Requires that a fault-tolerant global time-base is available to all nodes
- The channel capacity is **statically** divided into a number of slots
- The sequence of sending slots within an ensemble of nodes is called a ***TDMA round***
- ***A unique sending slot is assigned to every node***
  - A node can only send one frame in every TDMA round
  - If there are no data to send, an empty frame is transmitted
- The sequence of all different TDMA rounds is called a ***Cluster Cycle***

TTP/C Bus Access Scheme

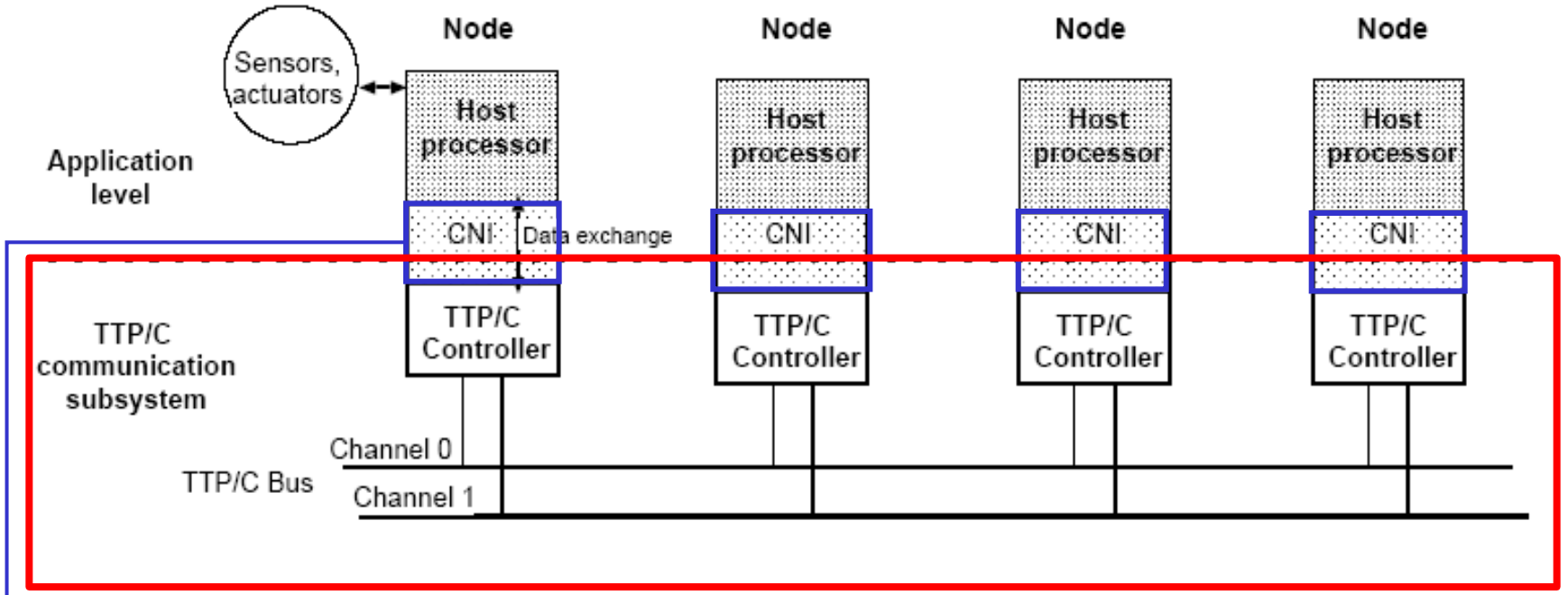


FTU: Fault Tolerant Unit

Time-Triggered Architecture (TTA)

- The *Time-Triggered Architecture (TTA)* **a framework** for the domain of **distributed embedded real-time systems in high-dependability environments**
- A central characteristic of the Time-Triggered Architecture is **the treatment of (physical) real time as a first-order quantity**
- The TTA **decomposes** a large embedded application into **clusters** and **nodes** and provides a **fault-tolerant global time base** of known precision at every node

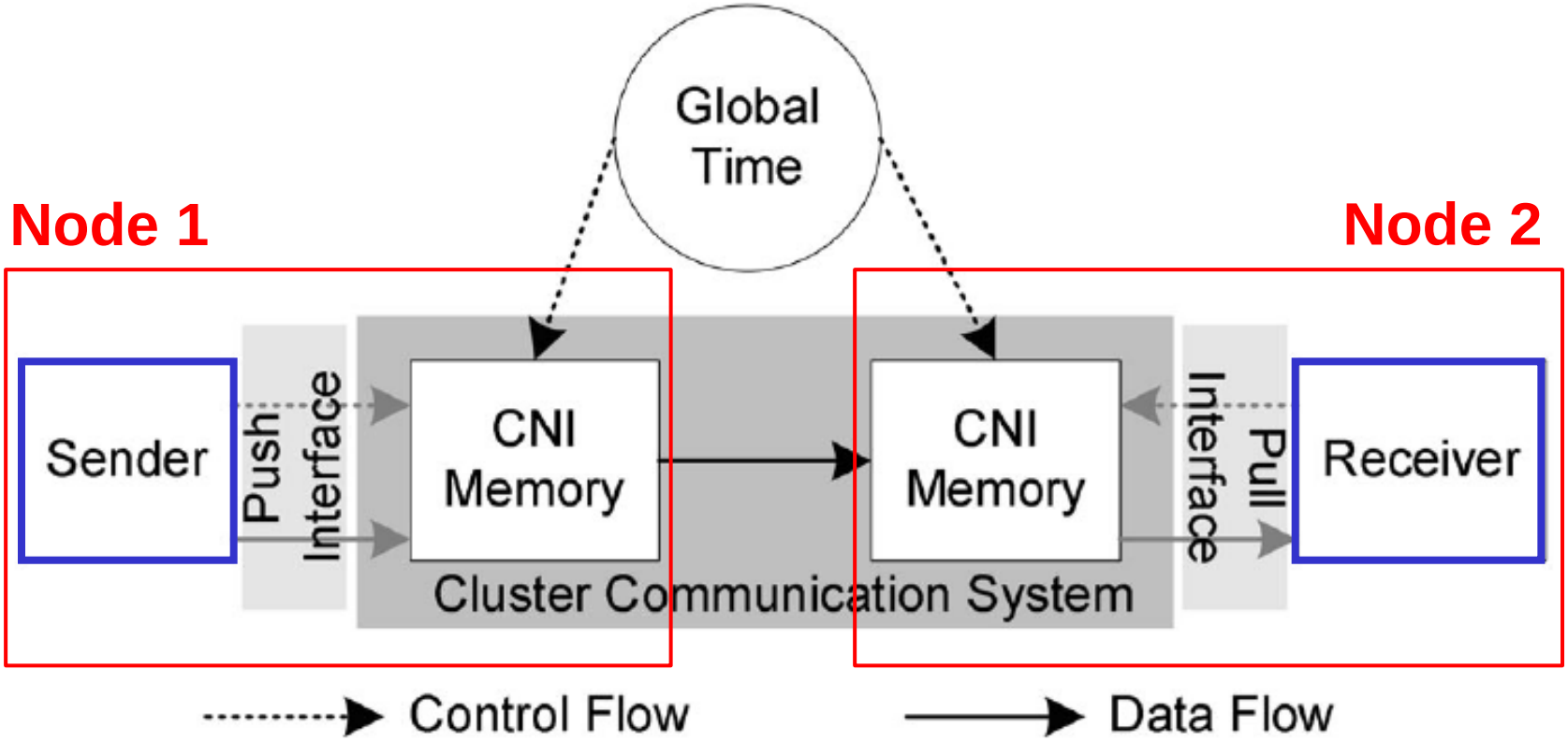
TTA Cluster and Nodes



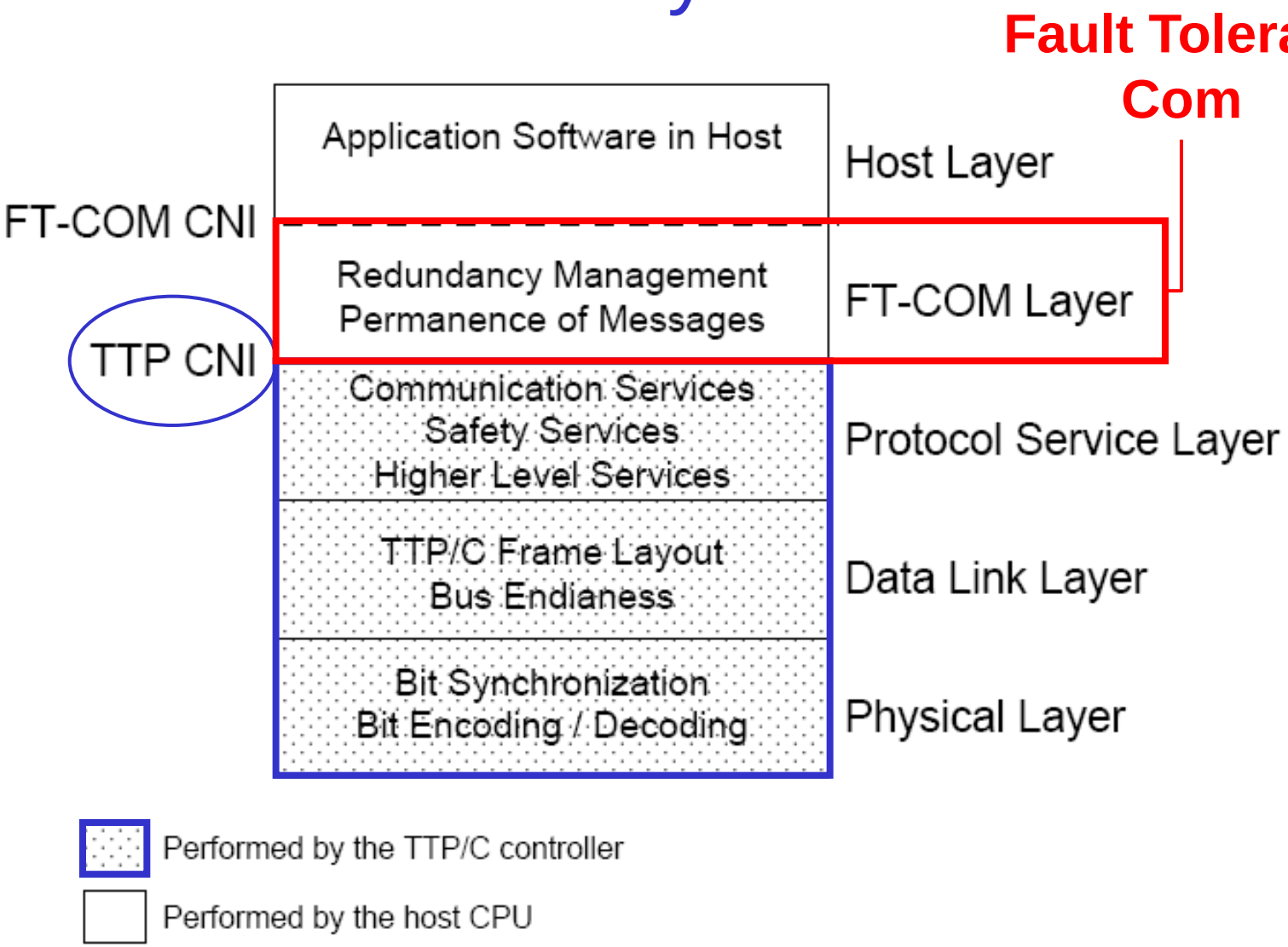
CNI: Communication Network Interface

The Host programming interface to the Time-triggered network

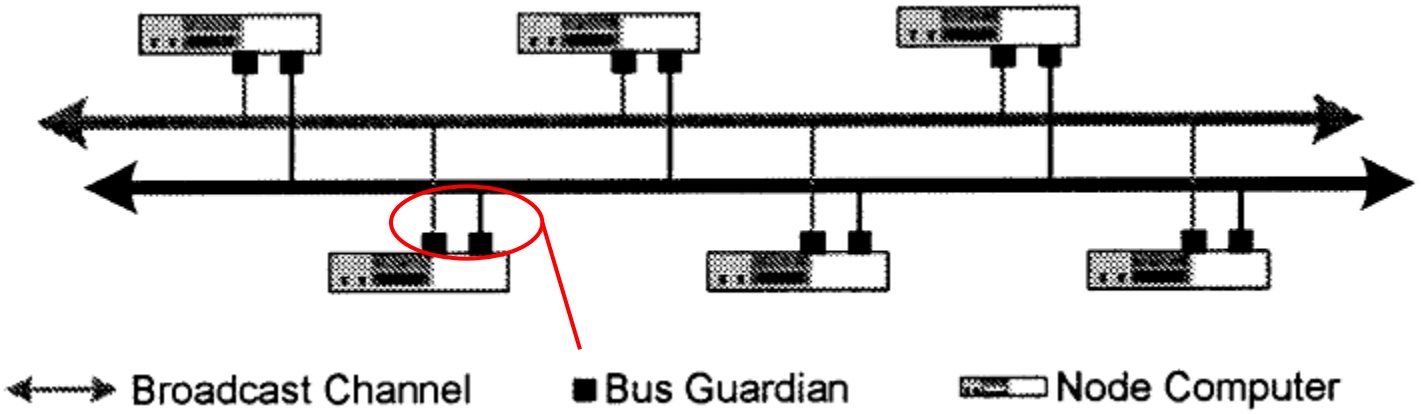
Communication Abstraction

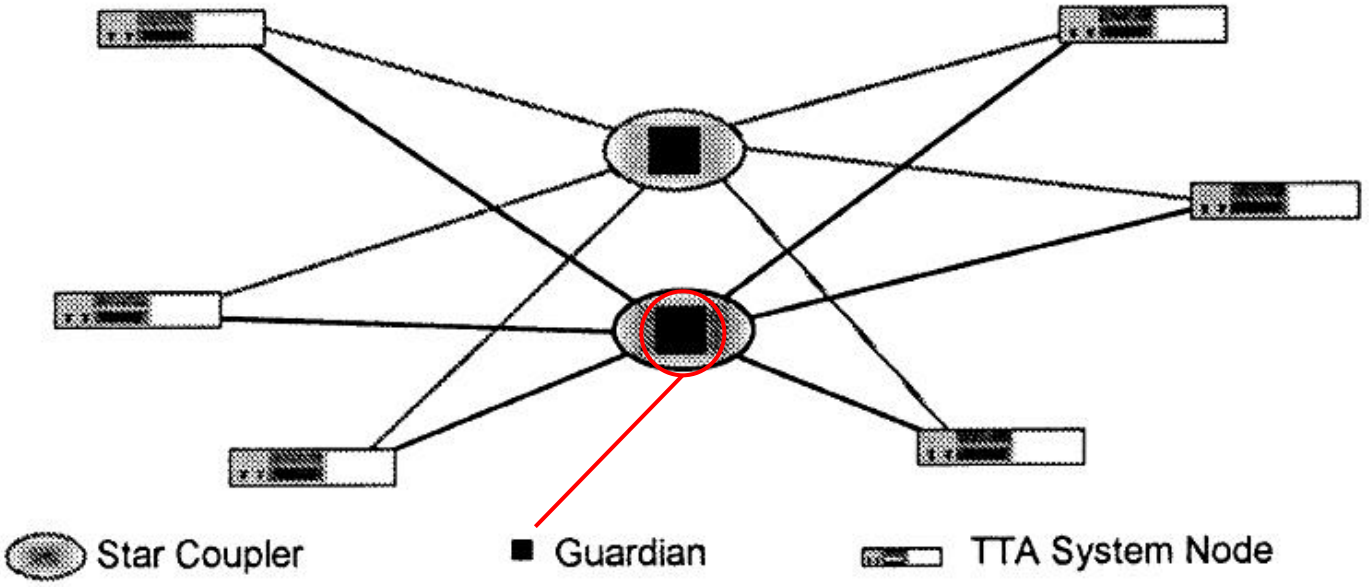


TTA Layers

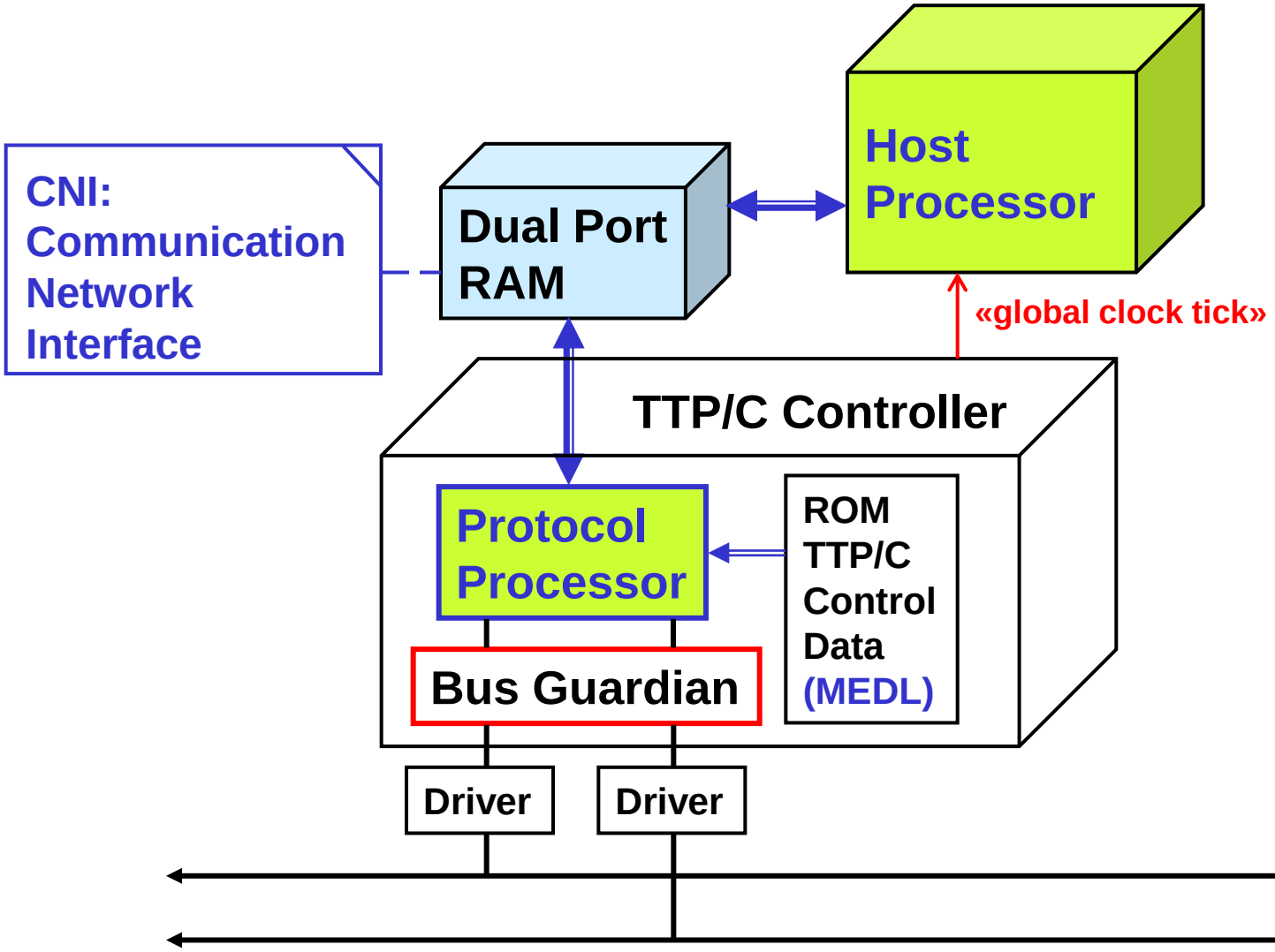

Fault Tolerant Com
Application Software in Host
Host Layer
FT-COM CNI
Redundancy Management
Permanence of Messages
FT-COM Layer
TTP CNI
Communication Services
Safety Services
Higher Level Services
Protocol Service Layer
TTP/C Frame Layout
Bus Endianess
Data Link Layer
Bit Synchronization
Bit Encoding / Decoding
Physical Layer
Performed by the TTP/C controller
Performed by the host CPU

TTA Toplogies (Bus/Star + Bus Guardians)

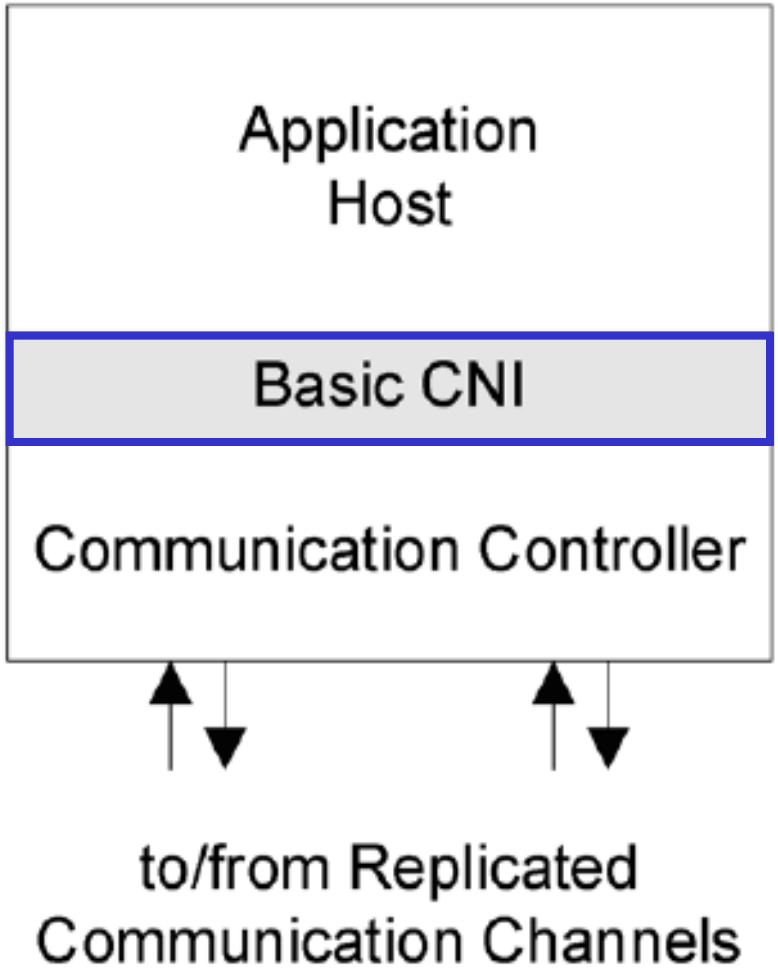




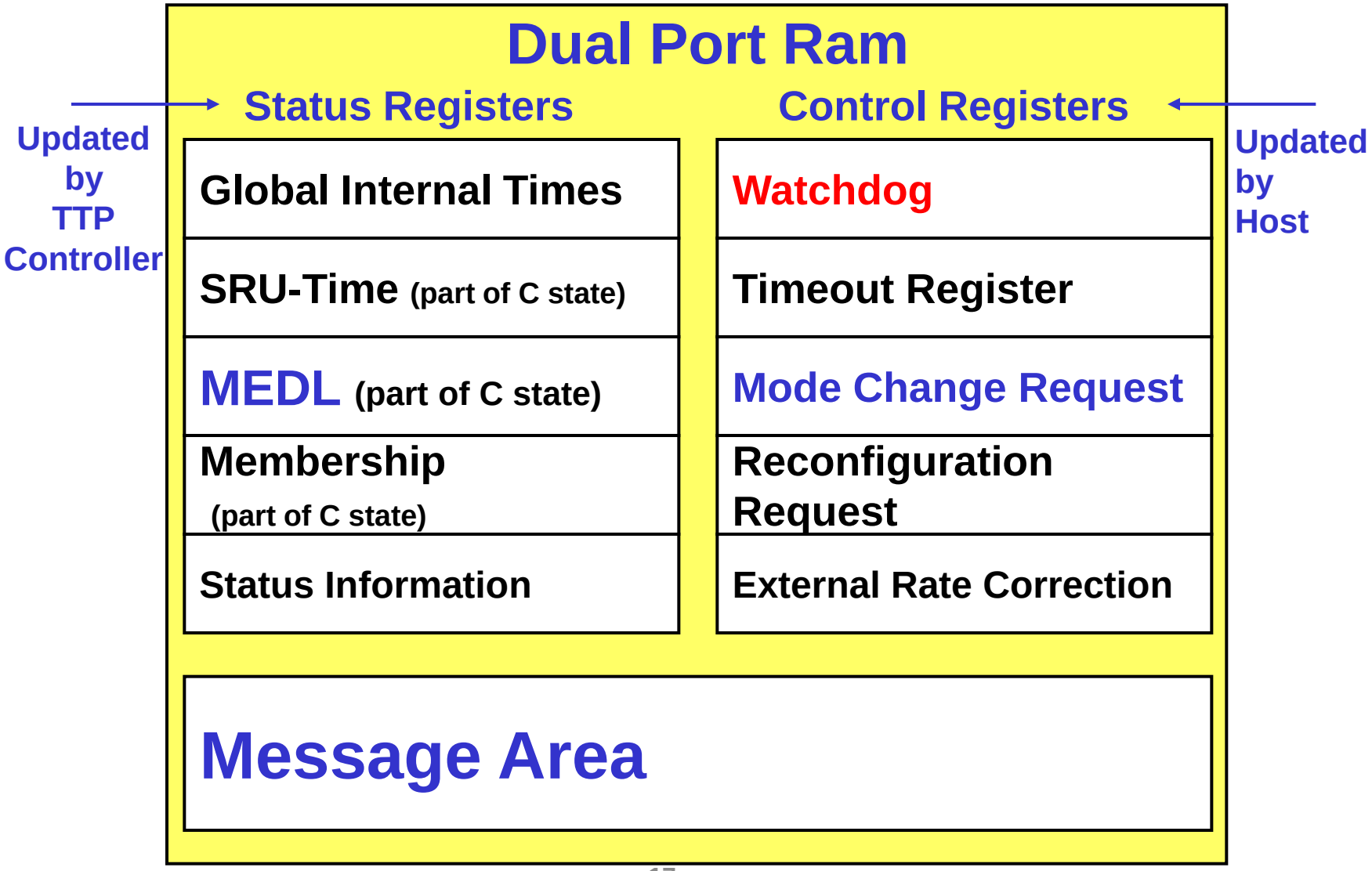
TTA/TTP Node Configuration



Communication Network Interface - CNI



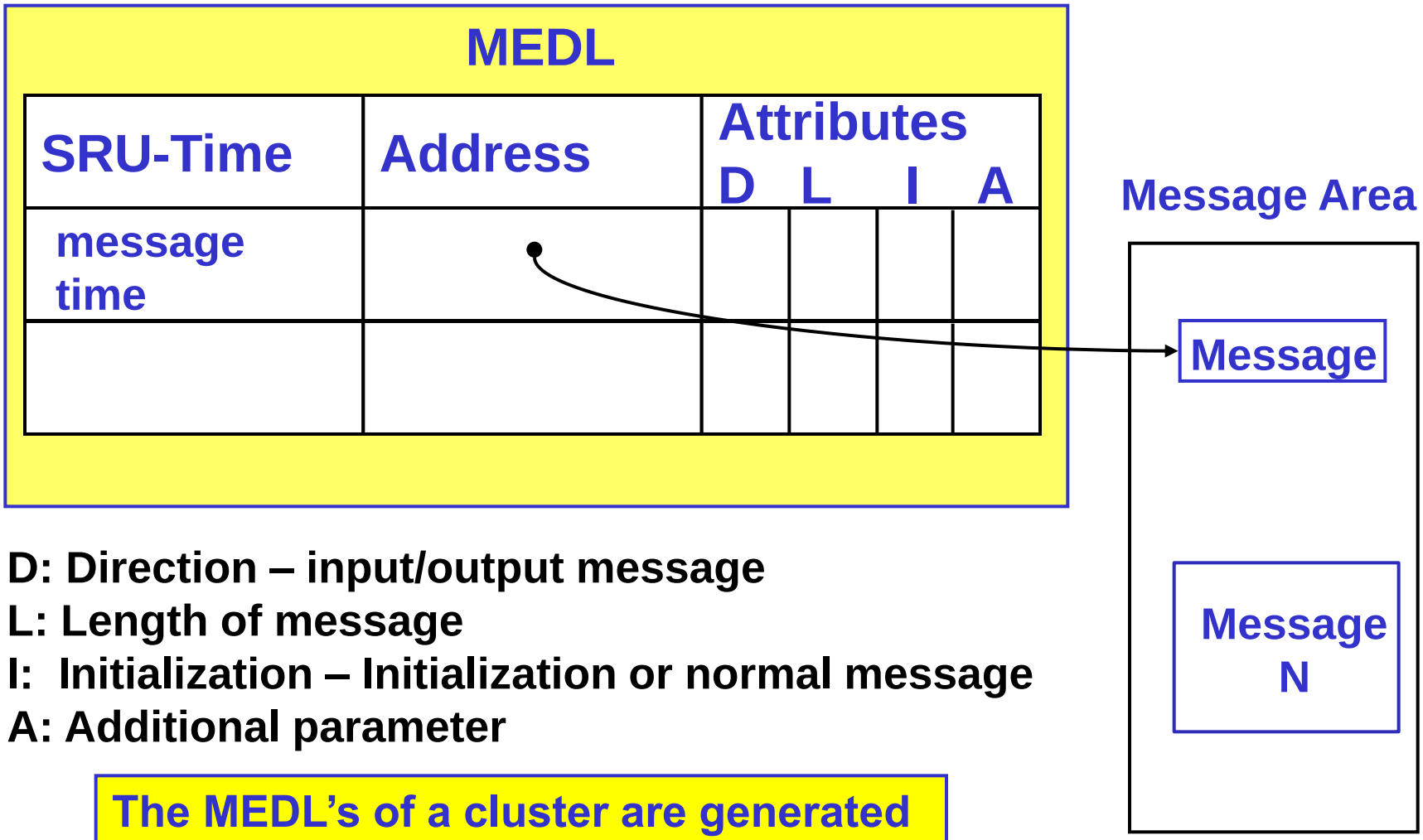
The Basic CNI Structure



Node Membership

- The node membership vector
  - contains as many bits as there are nodes in a cluster
  - each node is assigned to a specific bit position
    - a “TRUE” indicates that the node was operating during the last sending slot
    - a “False” indicates that the node was not operating

The Message Descriptor List (MEDL)

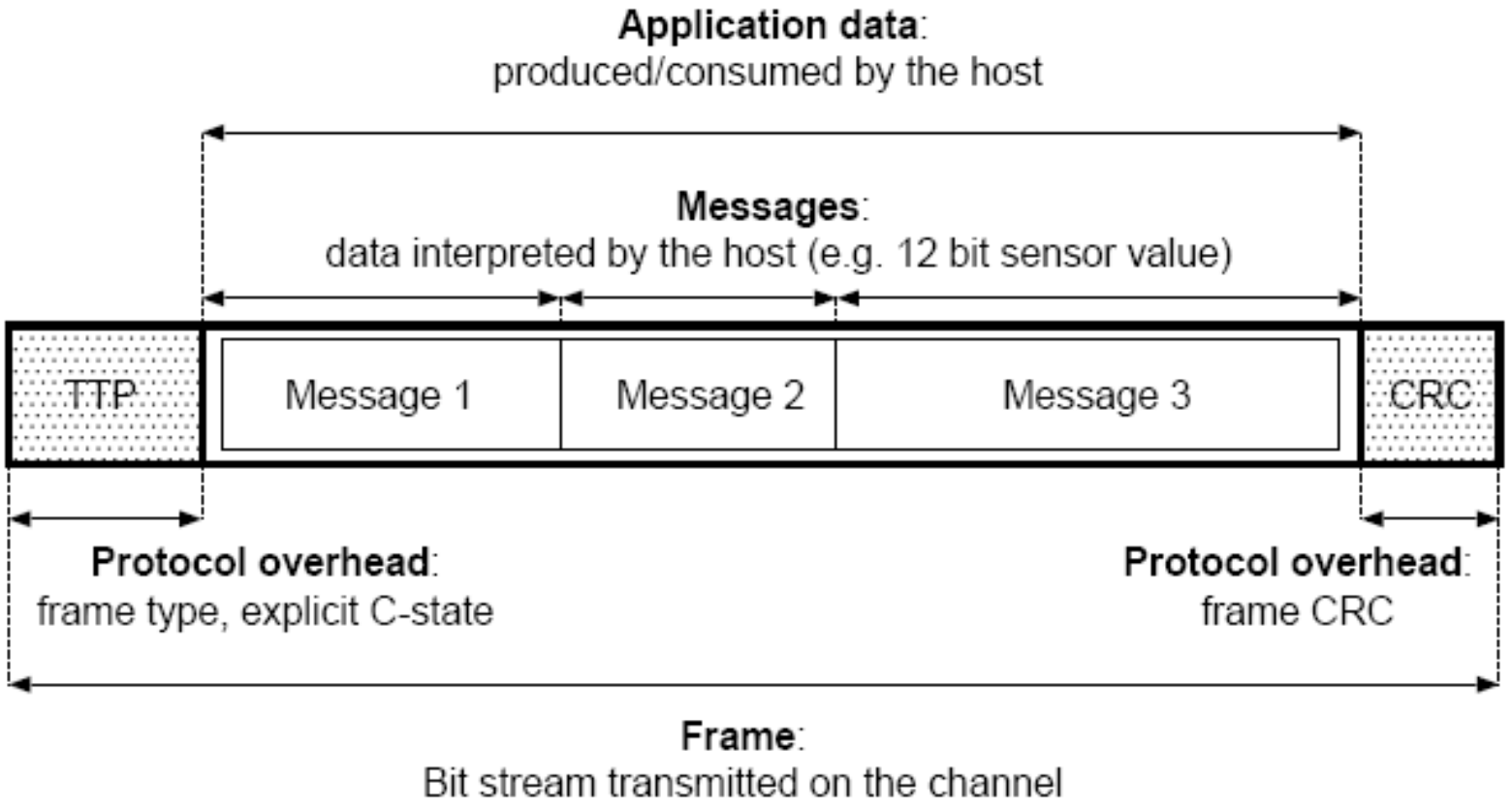


D: Direction – input/output message
L: Length of message
I: Initialization – Initialization or normal message
A: Additional parameter

The MEDL's of a cluster are generated automatically by a cluster compiler

TTP Frame

Application data length is variable for each node

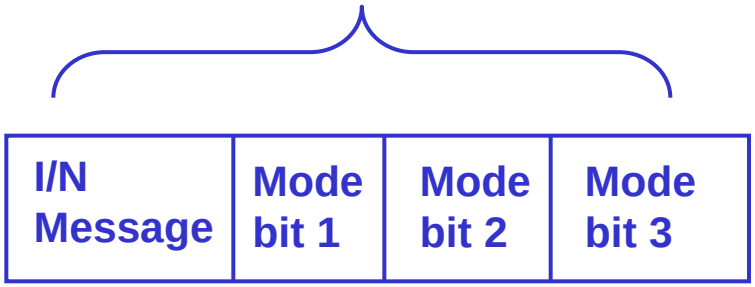


TTP/C Frame Types: N-Frames

An efficient protocol

N-Frames (Normal Frames):
- Periodic transmission of state messages
- Majority of frames during normal operation

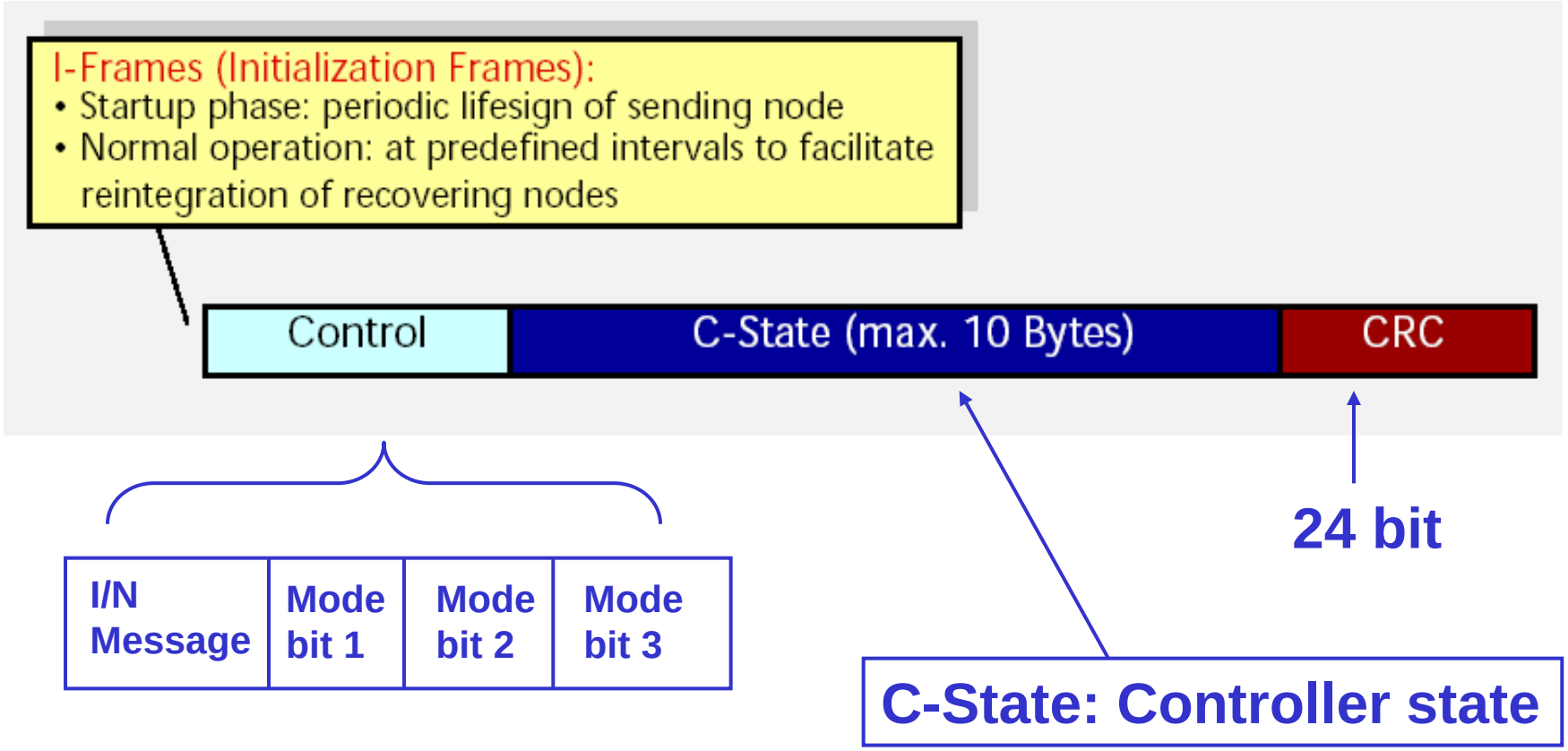
No identifier!
Message contents are derived from time of sending.



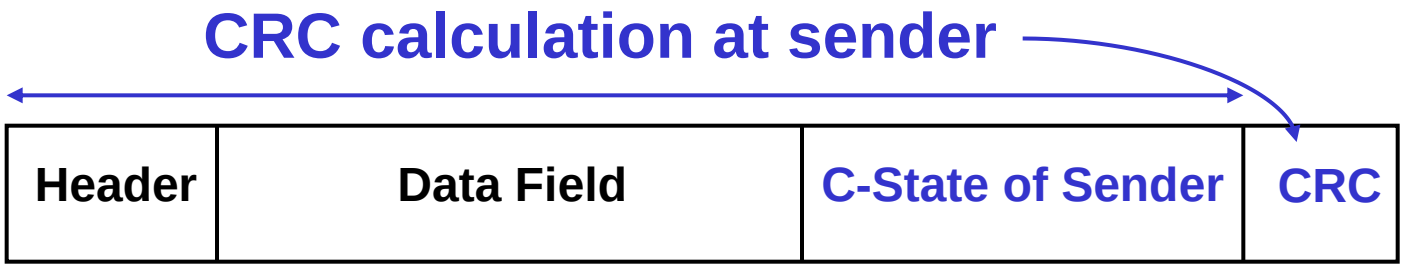
4 bit Header

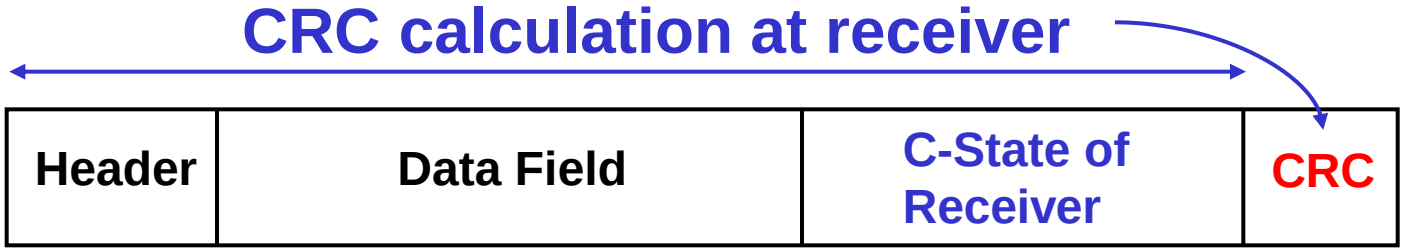
24 bit

TTP/C Frame types: I-Frames

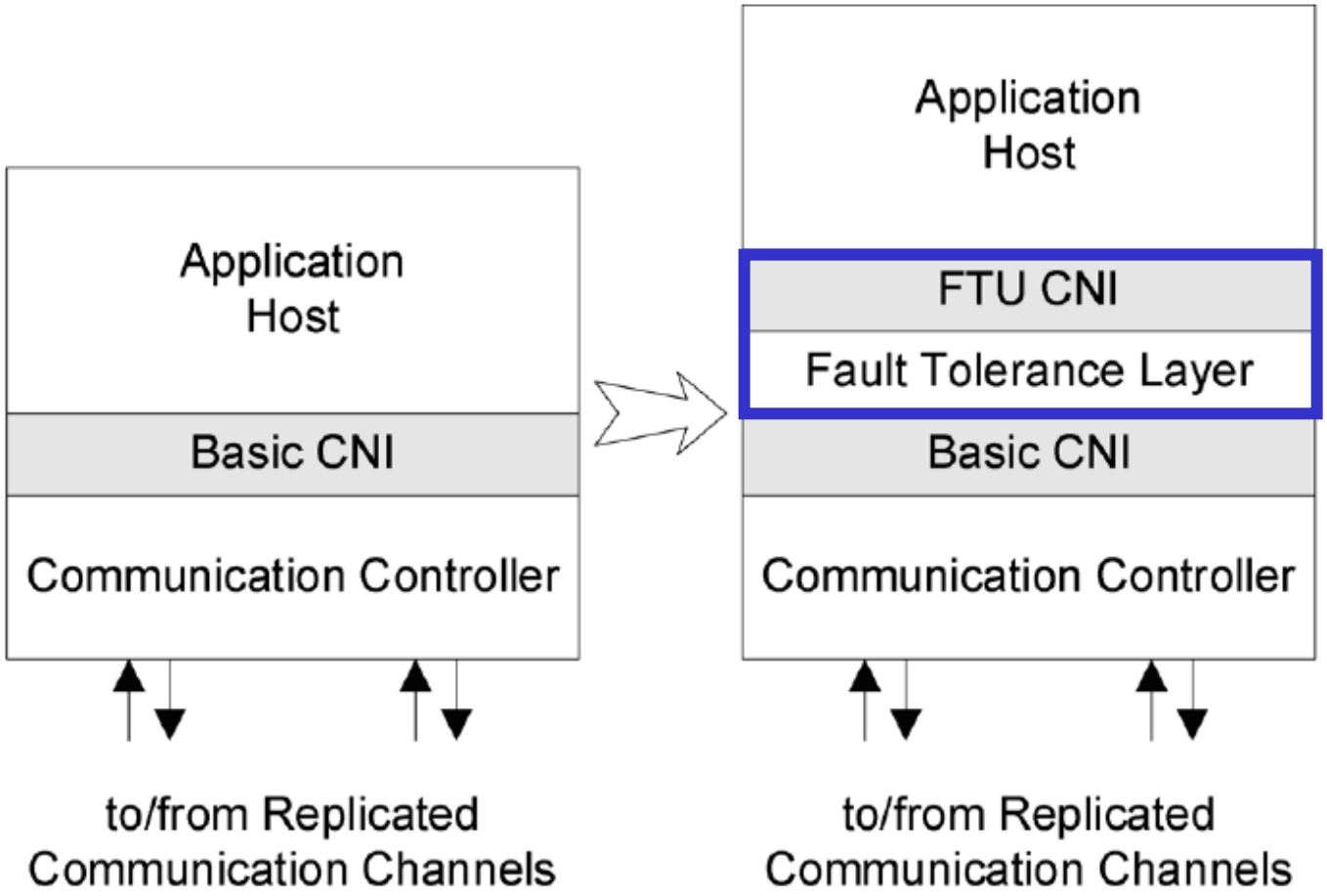


CRC Calculation

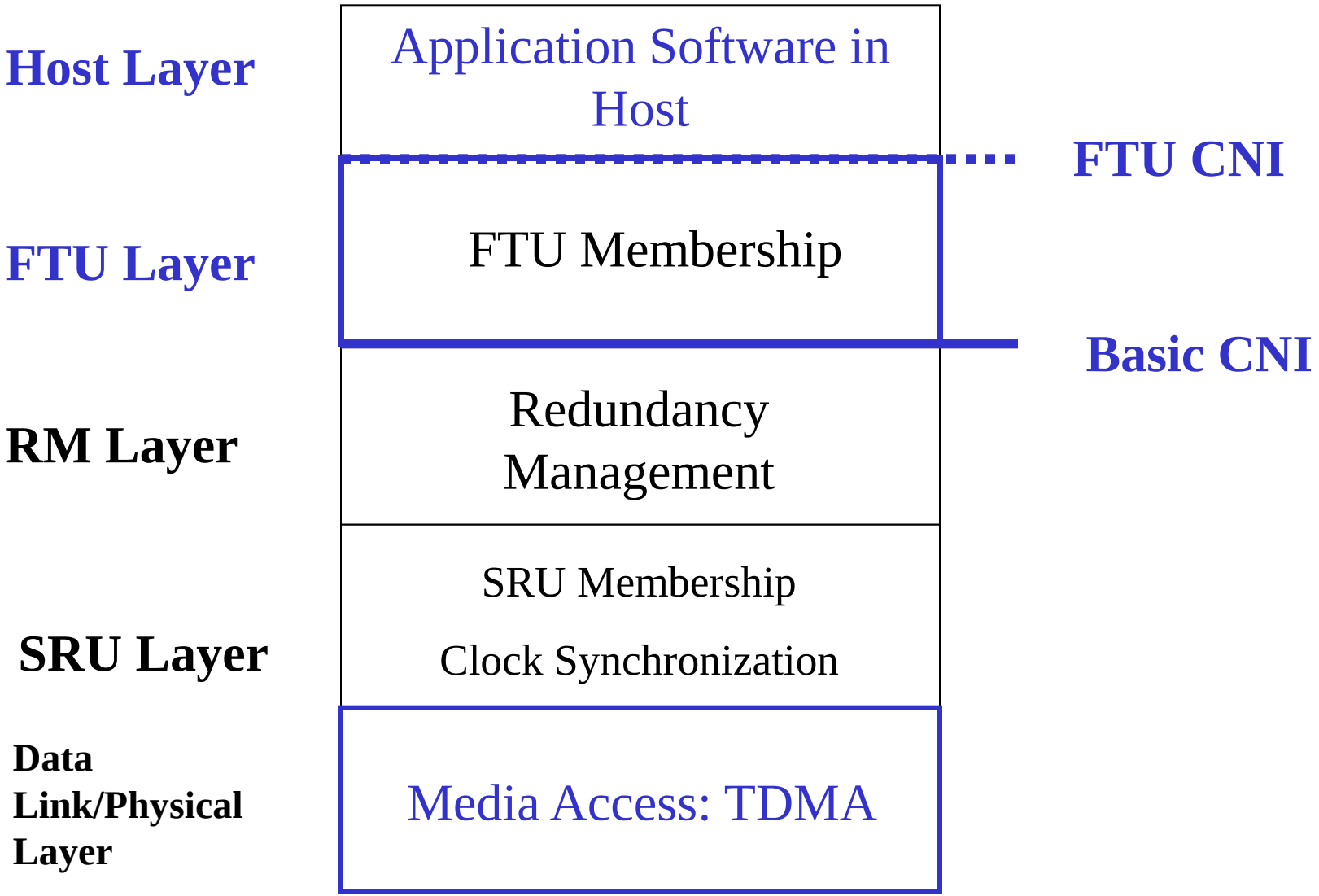




Fault-tolerant Node



Conceptual Layers of TTA



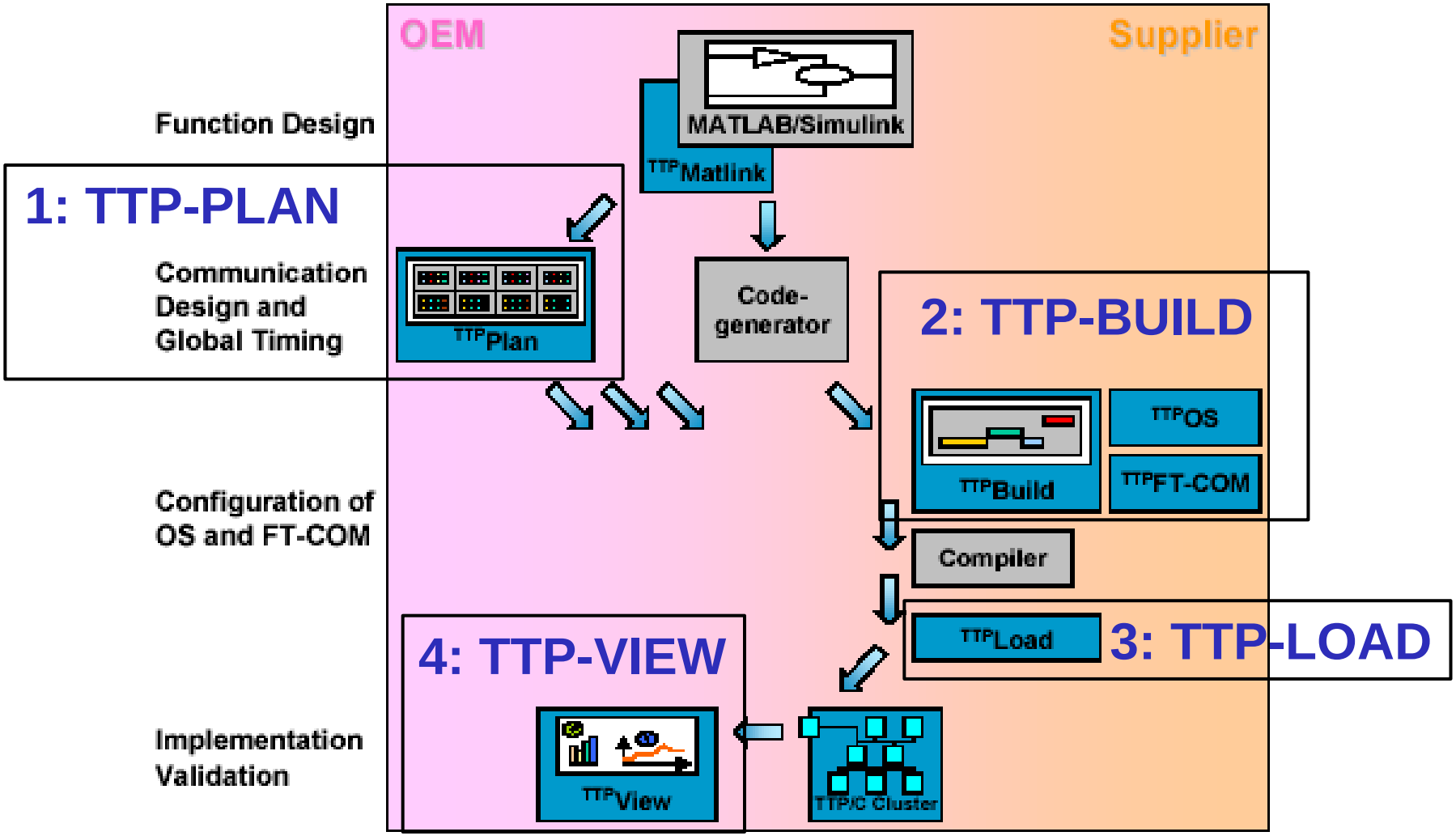
TTP/C Communication Properties

- Static Scheduling
  - Guaranteed delivery times with known variance (jitter)
- Clock Synchronization
  - All nodes synchronized to within one microsecond each TDMA round
- Composability
  - TTP/C nodes are temporally composable as well as functionally composable
- Fail Silent
  - The bus guardians ensure transmission only during the correct timeslot, in all cases
- Membership
  - Every node's membership is available during each TDMA round

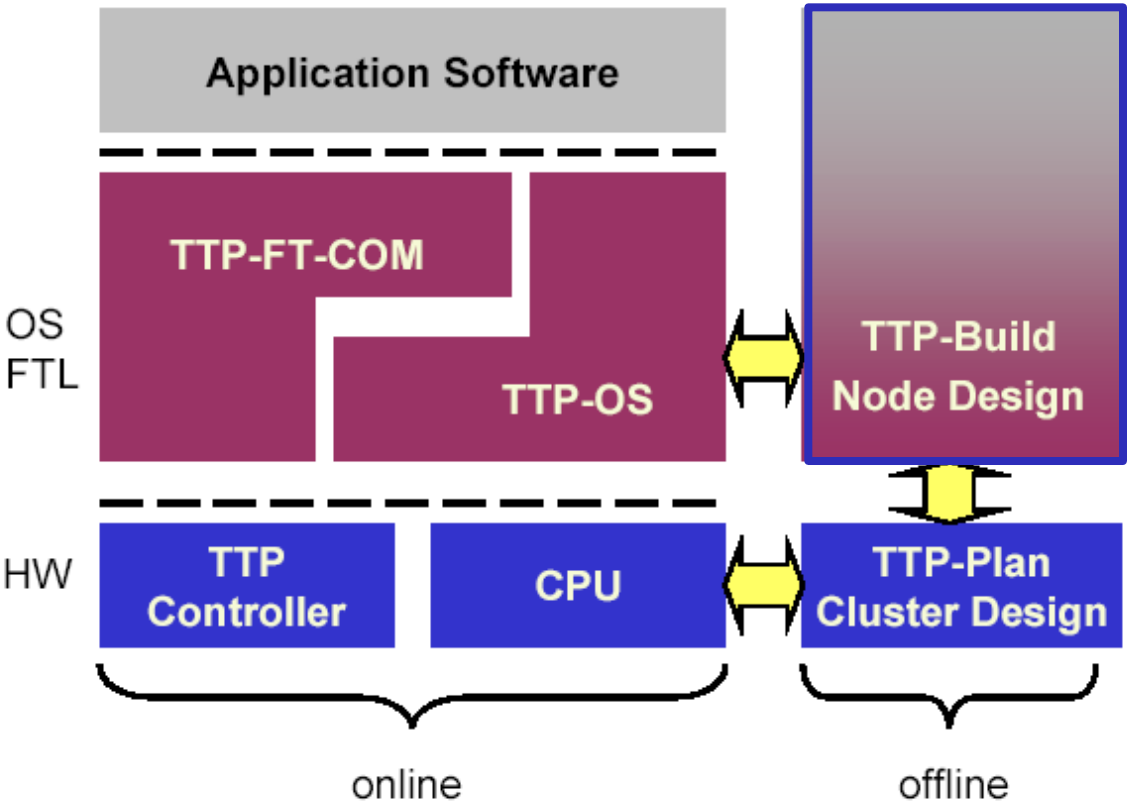
Advantages/Disadvantages of TTP

- Advantages
  - Simple protocol to implement
  - Deterministic response time
  - No wasted time for Master polling message
- Disadvantages
  - Wasted bandwidth when some nodes are idle
  - Static solution
  - Fixed network size after installation
  - Event communication is not directly supported (must be simulated on top of TTP)

TTA/TTP Software Tool Suite



TTP-OS: Time-Triggered OS



TTP OS – Time-Triggered Operating System with TTP Support

TTP-IP Module – The IndustryPack-Compatible TTP Node

TTP-IP Module is an IndustryPack® -compatible high-performance node for the Time-Triggered Protocol (TTP®). It is equipped with a **Freescale MPC555 PowerPC®** and the **TTP controller AS8202NF** and suitable for **distributed hard real-time systems**.

It supports the fault-tolerant real-time operating system TTP-OS which is based on OSEKtime and specifically designed for applications based on time-triggered technology.

TTA/TTP Summary

- TTP – a Communication Standard for Advanced Control Systems (Standardized by SAE in 2011).
- TTP is the mature network solution that is low cost and can handle safety-critical applications.
  - It is used in commercial applications
  - TTP is based on more than 20 years development work in research and prototype applications
- Based on stable specifications
  - TTP integrated circuits have been available since 1998
  - Second generation silicon, supporting communication speeds of up to 25 Mbit/s, is available today
  - Coupling this high speed with efficiencies of up to 80% allows data transfer 25 to 50 times faster than currently implemented automotive networks

References (TTA/TTP)

[TTP2003]
"*Time-Triggered Protocol TTP/C High-Level Specification Document*", Protocol Version 1.1, 19-nov-2003, TTTech & TTA Group

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"Real-Time Systems – Design Principles for Distributed Embedded Applications", second edition Hermann Kopetz, Technische Universität Wien, Kluwer Academic Publishers, 2011.