The Time-Triggered Architecture

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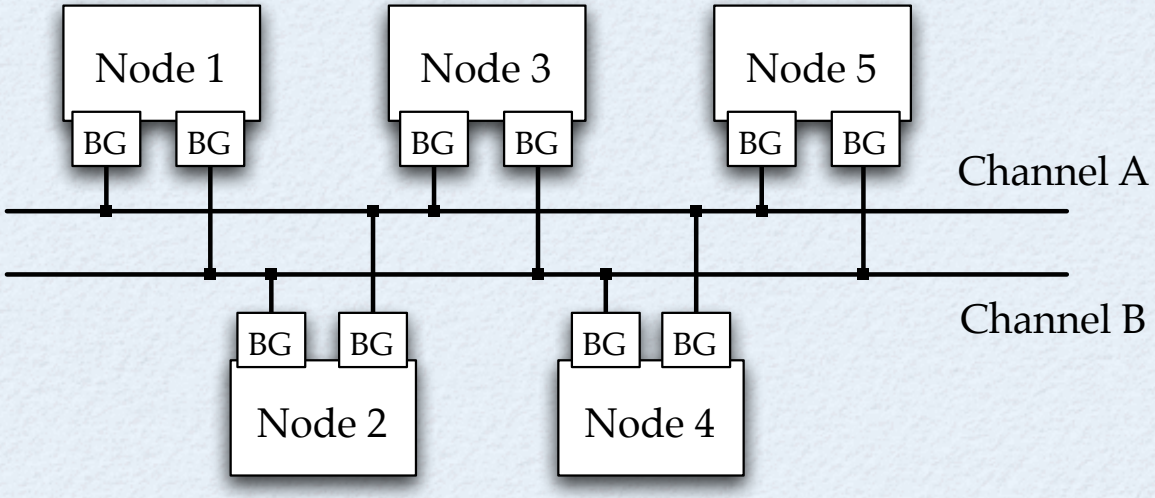
Overview

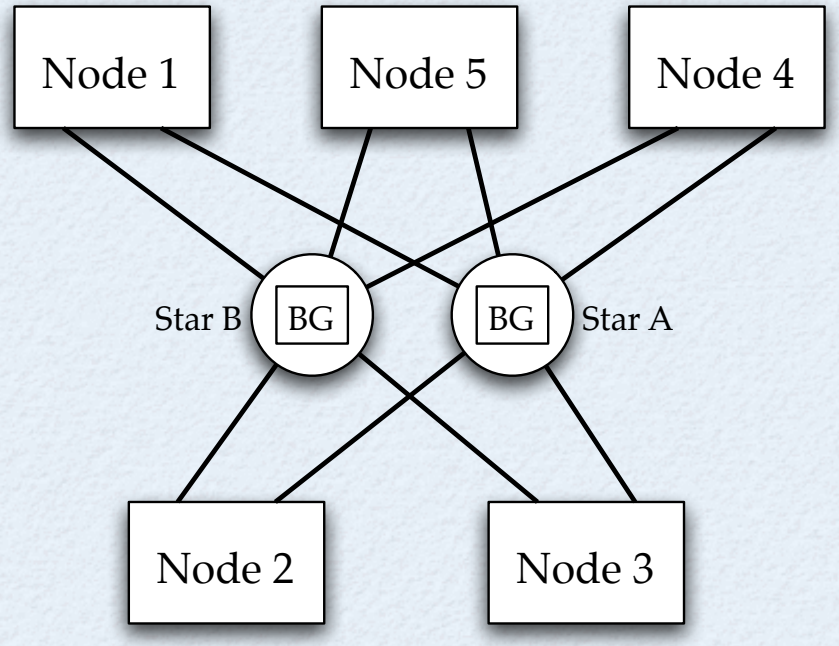
1. Introduction
2. Network Topology
3. Schedule
4. Frame Format
5. Operation Modes
6. Group Membership
7. Clock Synchronization
8. Controller State
9. Summary

1. Introduction

- as FlexRay, TTA provides functionality of a communication bus
- architecture for fault-tolerant, safety-critical real-time systems
- developed by Prof. Kopetz at the Technical University of Vienna (started in 1979)
- first published in 1993, launched in 1998
- deterministic protocol behind TTA: TTP
  - TTP/C:
    full version of TTP; for real-time busses in fault-tolerant distributed systems
  - TTP/A:
    low cost version; to connect sensors and actuators

2. Network Topology



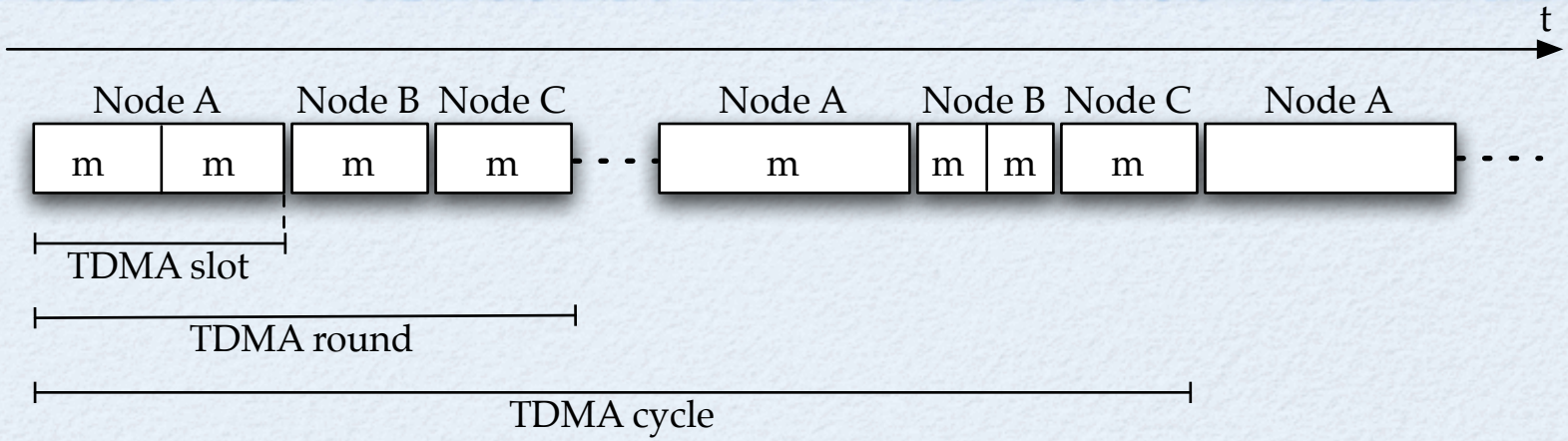


Differences to FlexRay:

- no bus and star combination
- dual-channel only
- bus guardian (BG) obligatory

➡ not as flexible as FlexRay

3. Schedule



- TDMA-schedule
- TDMA cycle: periodically, recurring time unit in TTP
- TDMA slots
  - can have different length
  - more than 1 message per slot
- TDMA round
  - node sequence and slot length same each round
  - message length within slots may differ

3. Schedule

- different approach to start-up, reintegration and clock synchronization
  - ➡ no symbol window and network idle time
- each node: message descriptor list (MEDL)
  - common knowledge of all nodes
  - specifies TDMA cycle (1 per operating mode)
  - assignment node → slot
  - marking of sync nodes (SYF-flag) and synchronization slots (CS-flag)
  - defines when mode changes are allowed

➡ schedule more complex than FlexRay's

4. Frame Format

- 2 different frame formats
- N-frame (normal frame):
  - used during normal operation
  - contains application data
  - acknowledgment bits
    information about message reception of predecessor and pre-predecessor
- I-frame (initialization frame):
  - contain internal controller state
    ➡ integrating nodes can join by taking over the data
  - transmission
    1. during start-up phase
    2. as defined in MEDL during normal operation

5. Operation Modes

- join mode
  - after start-up
  - node transmits I-frames
  - I-frame reception ➡ adoption of controller state and time

  ➡ fast synchronization of all nodes after power-on ➡ change to application mode
- application modes
  - support of more then 1
  - application data transmission
  - mode changes requested with N-frames
  - N- and I-frames as specified in static schedule
- blackout mode
  - error state
  - reintegration

6. Group Membership

- not implemented in FlexRay
- aim: identification of faulty nodes
- each node: private membership list
  records all nonfaulty nodes incl. node itself
- fault hypothesis:
  1. faults 2 or more rounds apart
  2. all or exactly 1 node fail to receive (send or receive fault)

6. Group Membership

- reliability characterized by:

  1. agreement:
     membership lists of all nonfaulty nodes are the same

  2. validity:
     membership lists of all nonfaulty nodes contain all nonfaulty nodes and at most one faulty node

- only satisfiable under the restricted fault hypothesis
  e.g. faults occur too rapidly ➡ validity not guaranteed

- system-wide schedule knowledge
  ➡ easy detection of a not sending node
  ➡ exclusion in membership list

6. Group Membership

- self-diagnostic: send and receive faults
- send fault:
  - Acknowledgment bits of first and second successor
  - if both exclude the node and the second includes the first
    - ➡ send fault
- receive fault:
  - message CRC: generated with help of sender's membership list
    - ➡ receiver: same membership list to pass CRC check
  - counters for CRC fails and passes
  - fail rate larger than pass rate
    - ➡ receive fault

7. Clock Synchronization

- MEDL: nodes with SYF-flag and slots with CS-flag
- clock deviation value of a message: similar to FlexRay
  - MEDL: expected arrival of message i (exp(i))
  - time-stamp on actual arrival of message i (act(i))
    - ➡ deviation(i) = exp(i) - act(i)
- queue with the four latest clock deviation values
  - deviation(i) stored if sender has same group membership and his SYF-flag is set
- clock correction value: fault-tolerant average
  - discard the smallest and biggest values
  - average of the 2 remaining values
- adjustment if current slot's CS-flag is set

8. Controller State (C-State)

- problems in TTA systems: agreement on
  1. operation mode
     data only interpretable if receiver's mode = sender's mode
  2. time view
     communication based on view of time
  3. membership
- aim: only nodes with same C-state can communicate
- solution: CRC of N-frames generated with the sender's current C-state

  ➡ CRC-check can uncover different C-states and message can be dropped

9. Summary

- network topology not as flexible as in FlexRay
- schedule more complex and system-wide common knowledge
- support of different application modes
- different approach to start-up, reintegration and clock synchronization:
  - I-frames
  - rounds marked as sync rounds
- global schedule ➡ group membership

➡ fault-tolerance and functionality more important than flexibility