Scheduling in a Time-Triggered Protocol With Dynamic Arbitration

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Introduction

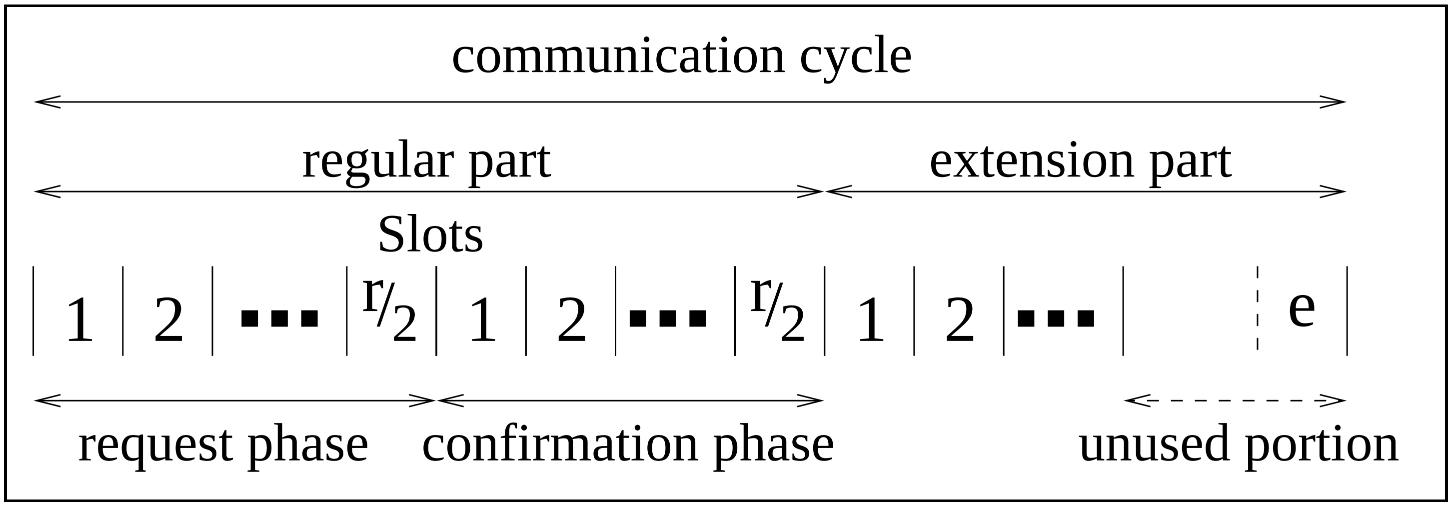
Two methods of arbitration in TDMA-based protocols

- Static arbitration
  - Schedule pre-configured
  - Slots have fixed length
  - Can be implemented in a fault-tolerant way
  - Example: TTP/C, FlexRay (“static segment”)
- Dynamic arbitration
  - Schedule determined at runtime
  - Slots have dynamic length
  - Fault-tolerant implementation difficult
  - Example: Byteflight, FlexRay (“dynamic segment”)

The *Tea* protocol aims to solve the problem of fault-tolerant dynamic arbitration.

Introduction

Tea uses a mixed-mode approach:



Regular part

Static slot length / static schedule

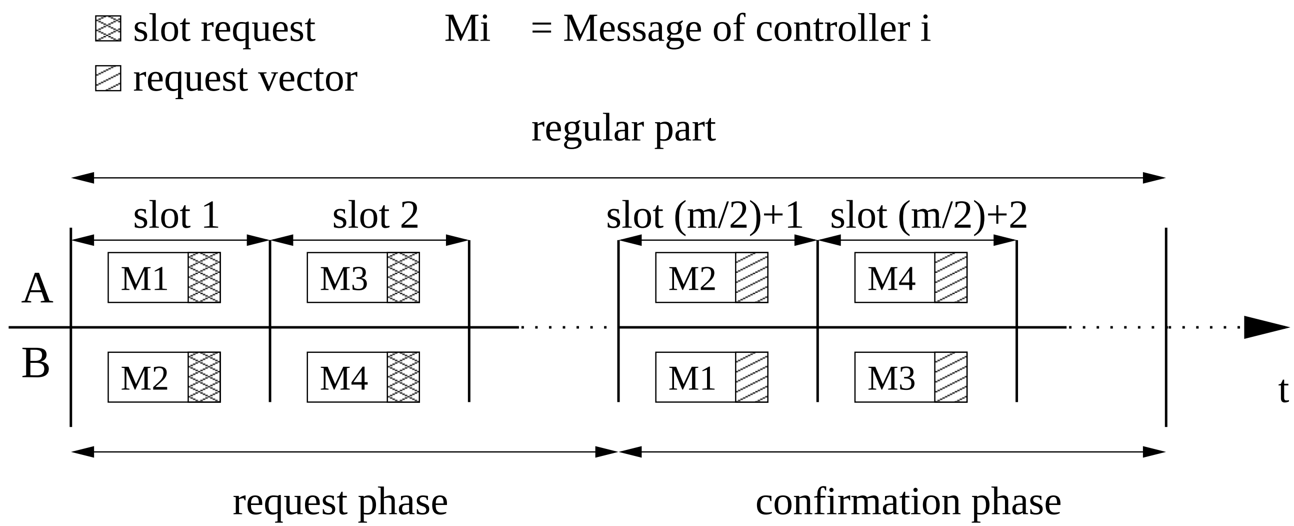
Extension part

Dynamic slot length / dynamic schedule

Every controller can request one additional slot in the extension part

Introduction

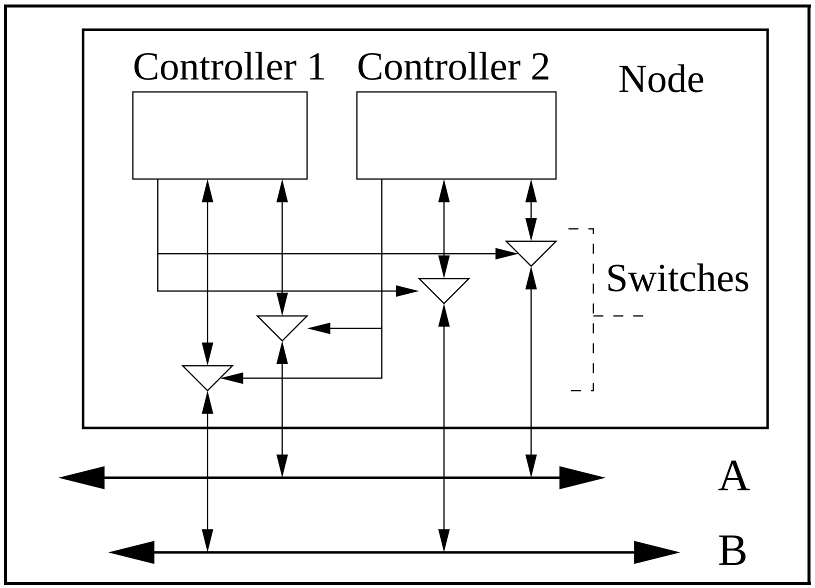
Schedule in extension provided by agreement algorithm



- Slots are shared by two controllers on two channels
- *Request phase:* Contains request bit (`request`, `no_request`)
- *Confirmation phase:* Contains vector of received requests (`request`, `no_request`, `corrupted`)
- Schedule to channels is reversed in confirmation phase

Introduction

Architecture for fault-tolerant operation



- Two completely independent controllers reside on one node
- Double broadcast channel
- Controllers guard each other by controlling the other’s access to the bus
- Guaranteed fail-silent behavior

Fault-tolerant operation

Controller faults

- Controller sends “nonsense” data
  $\longrightarrow$ Valid coding required
- Controller sends unexpectedly
  $\longrightarrow$ Neighbor controller guards channels
- Controller can block neighbor
  $\longrightarrow$ Does not have any impact on the agreement algorithm

Up to 2 controllers affected

Fault-tolerant operation

Channel faults

- Message corruption: Valid checksum (CRC, ...) required
- Message is delivered only to a subset of all controllers, while others receive corrupted messages or no signal:
  - Does not have any impact on the agreement algorithm
  - A request of a controller may be unknown, if it is sending on the faulty channel in the first half of the regular part.

Up to $\frac{c}{2}$ controllers affected

Combinations of controller and channel faults possible

Scheduling Policies

Number of slots in the extension part is limited

$\longrightarrow$ scheduling policy required

Common criteria:

- Arrival time (cycle)
- Priority

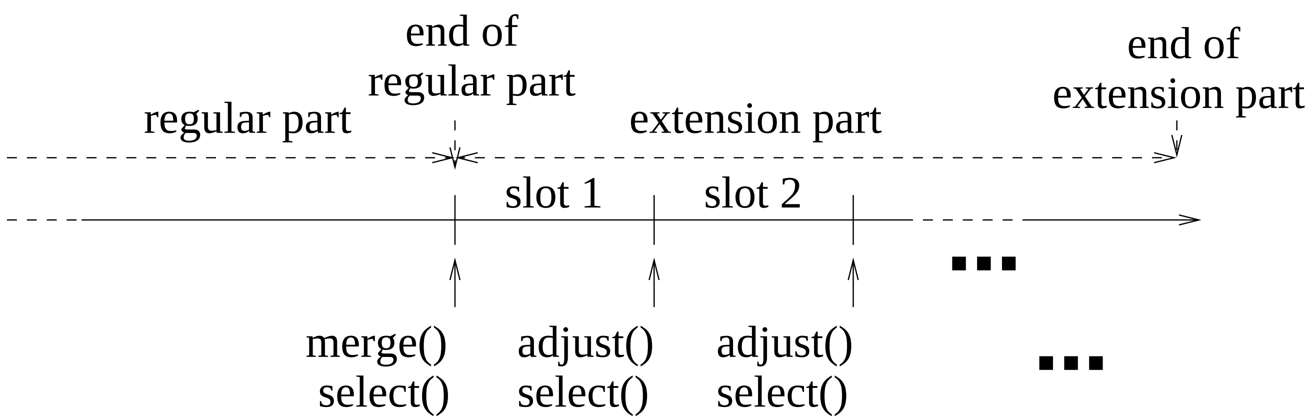
Common strategies:

- First-in-first-out
- Static priorities
- Priority-first
- FIFO-first

HW requirements should be minimized.

Basic Algorithm

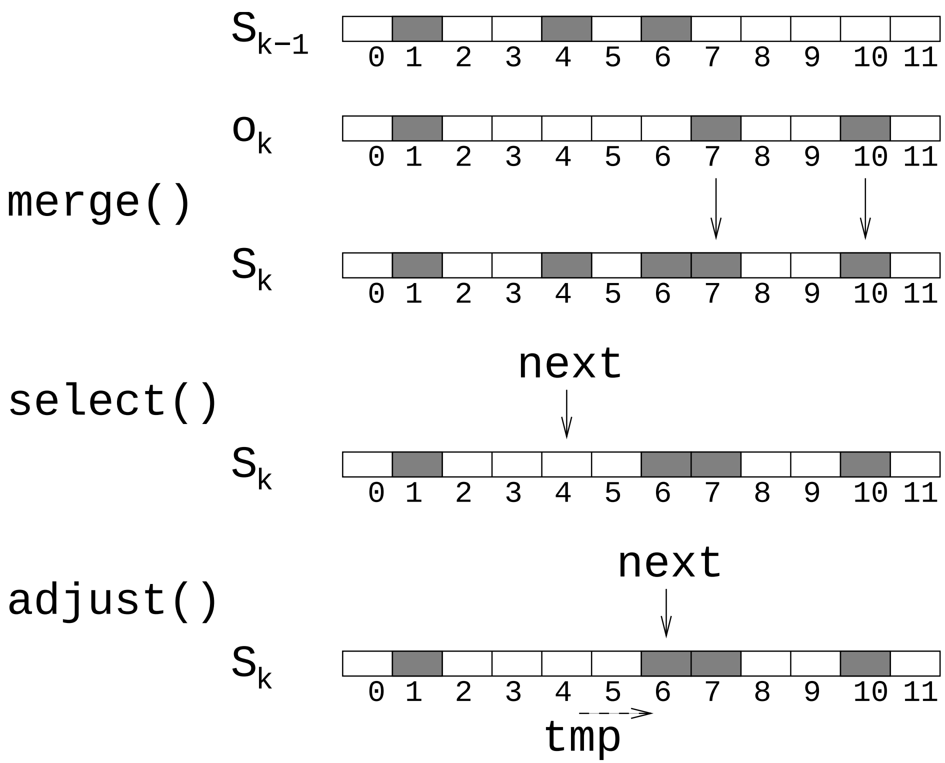
The basic scheduling algorithm consists of three subroutines.



- *merge*: Merges the vector of current requests into the vector with outstanding requests
- *select*: Selects the next controller before the start of a new slot
- *adjust*: Adjusts the index registers

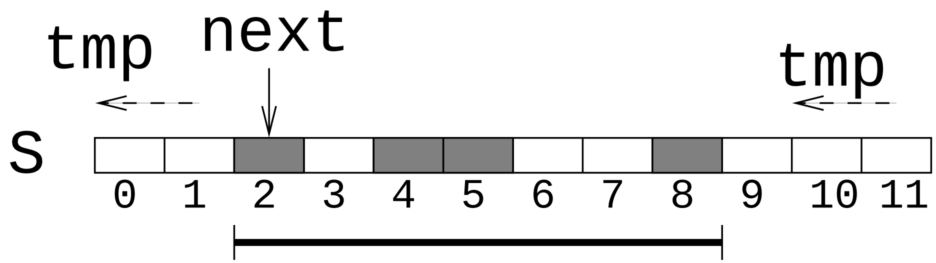
Basic Algorithm

The following algorithm implements a basic round-robin-strategy



First-in-first-out

Implemented by modifying *merge*



- Region of requests not yet processed remains untouched
- Requests are processed in order of arrival

Static Priorities

Implemented by modifying *select*

- Every controller has a priority
- Controllers with higher priority are selected first

Danger: Lower prioritized controllers may never get a slot!

Solution: Use FIFO-first strategy

FIFO-first

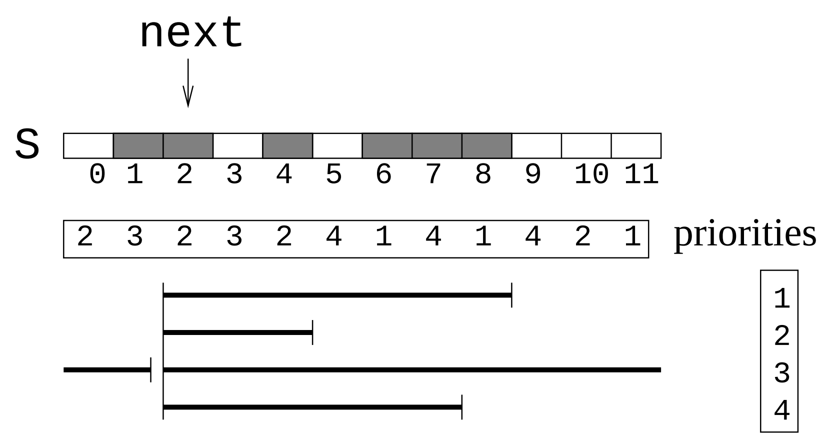
Implemented by modifying *merge* and *select*

- *merge*:
  Merge only if all outstanding requests have been processed.
- *select*:
  (same as in static priorities)

Requests are always the same age and processed in the order of their priority.

Priority-first

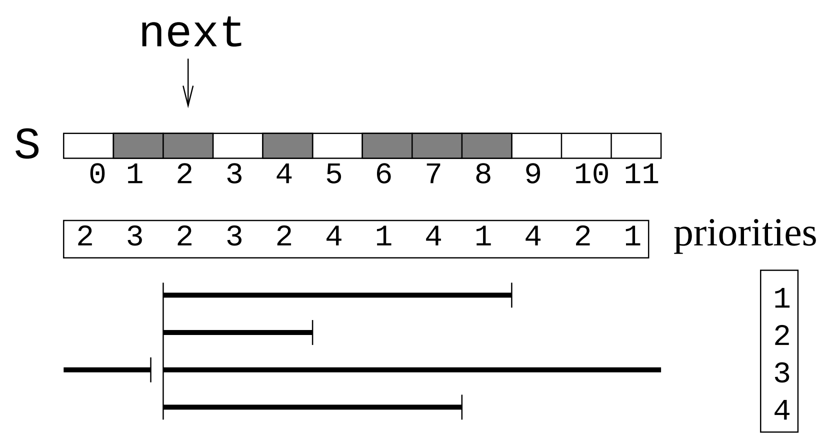
Implemented by modifying *merge* and *select*



- *merge*:
  - Follow the FIFO-strategy
  - Stop the `tmp` register if a request with same priority is found
  - Unique region for each priority level where requests cannot be merged

Priority-first

Implemented by modifying *merge* and *select*



- *select*:
  - Select next request with highest priority
  - Move `next` index only, if current request have been selected
  - Ignore priority when moving to the next request

Controller Faults

- Neighbor prevents bus access of faulty controller
- Empty slots are possible, but can be ignored
- Input to scheduling algorithm is the value `unknown`

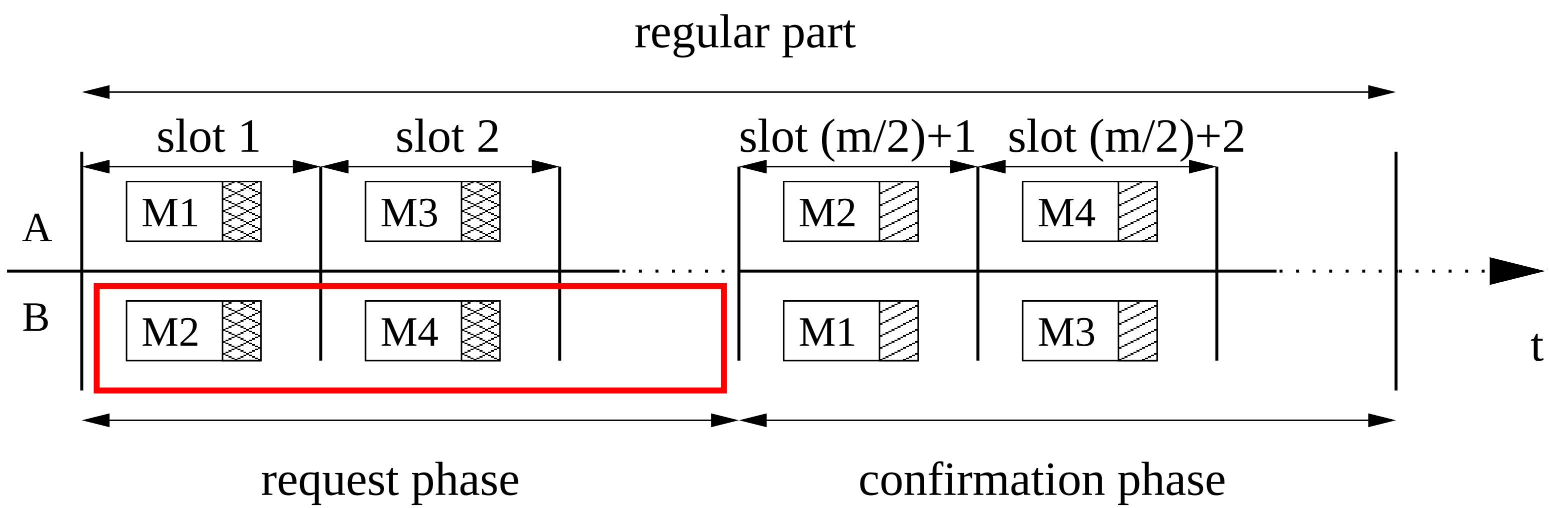
  Possible solutions:
  - Count as `no_request`: Clear the respective bit if set
  - Count as `request`: Set the respective bit if allowed
  - Leave bit unaffected

    (best solution in connection with channel faults)

Channel Faults

Problem:

Channel faults may lead to the value `unknown` for requests of *fault-free* controllers



Channel Faults

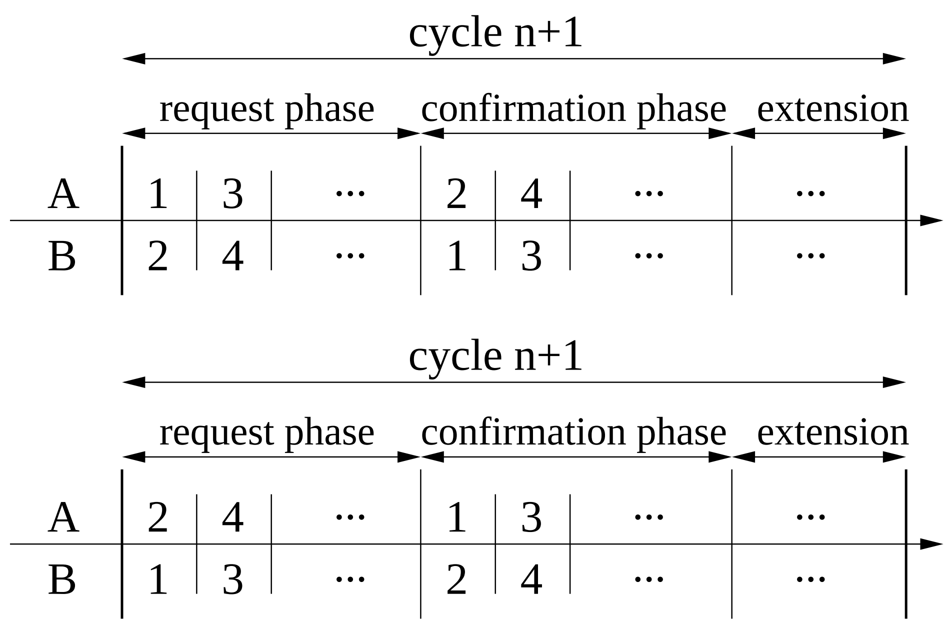
Solution 1: **Leave bit unaffected**

- Slot is reserved if controller could successfully request slot at least once
- Good compromise if permanent faults are assumed to be unlikely
- Hardware changes not required
- No change of schedule in regular part required
- No extra cycle time required
- At least $\frac{c}{2} - 2$ fault-free controllers may never successfully request a slot!

Channel Faults

Solution 2: **Double cycle**

Reverse schedule of controllers in the regular part every two cycles

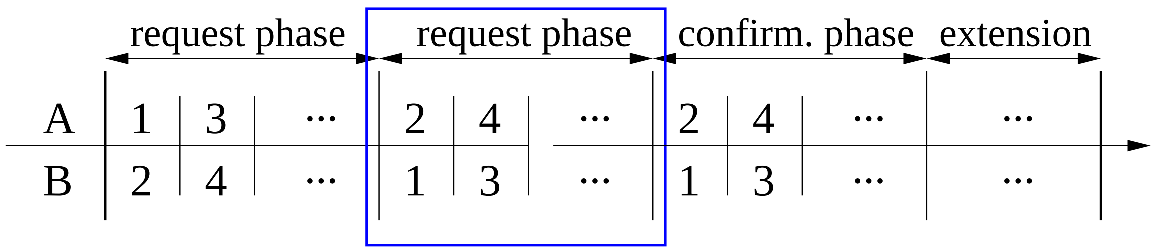


- Fault-free controllers can successfully request a slot within a double-cycle
- Can cause further delays

Channel Faults

Solution 3: **Double request phase**

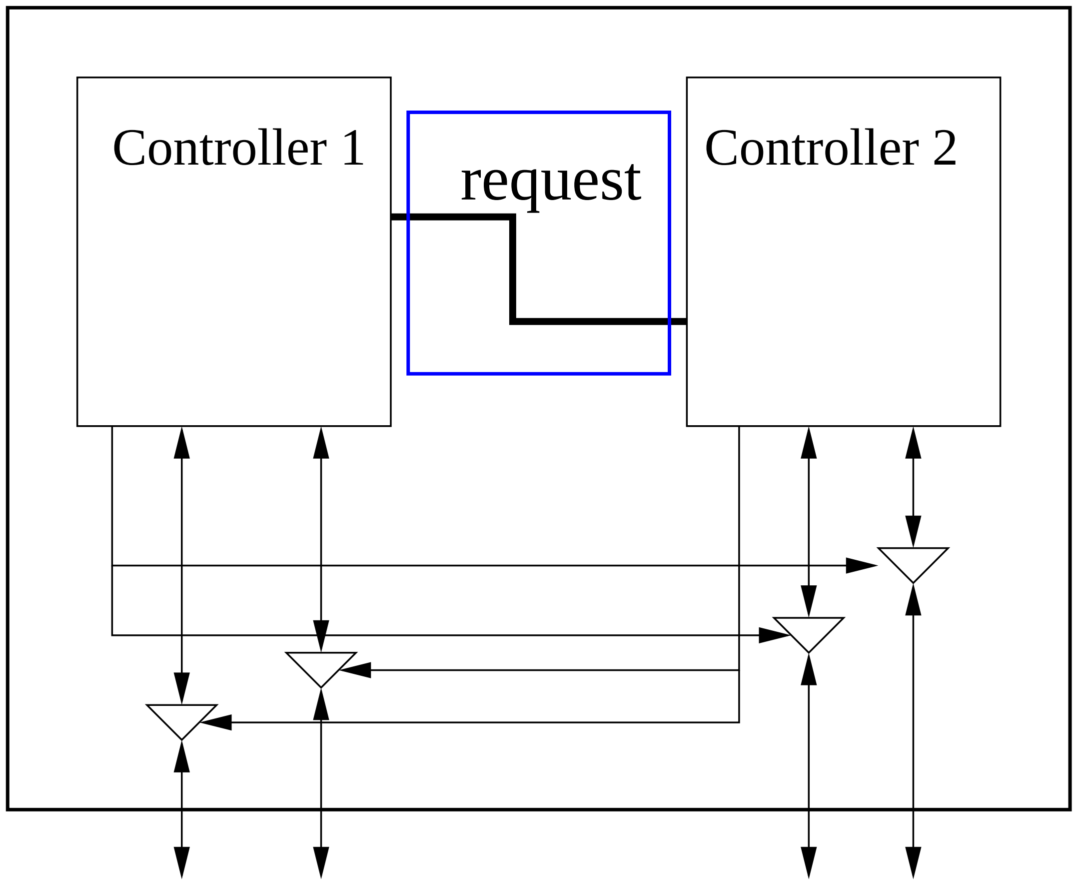
Reverse schedule of controllers in two consecutive request phases



- Request of fault-free controllers are guaranteed within a cycle
- Cycle length grows by $\frac{c}{2}$ static slots permanently

Channel Faults

Solution 4: **Additional link between both controllers in a node**



Channel Faults

Solution 4: **Additional link between both controllers in a node**

- Controller must also provide request for neighbor (extra bit necessary in request phase)
- Both controllers must be scheduled for different channels
- Request of fault-free controllers are guaranteed within a cycle
- No need to extend cycle

Conclusion

- A fault-tolerant solution for dynamic allocation in time-triggered protocols is provided by the *Tea* protocol
- Controllers can be statically scheduled
- Extra slots can be requested dynamically
- Fault-tolerance can be assured
- Dynamic allocation requires dynamic scheduling
- Well known policies are available with low effort in hardware registers
- Requests can be guaranteed in case of channel faults
- Requests cannot be guaranteed for a fault-free neighbor of a faulty controller