Real-Time Systems

Lecture #8

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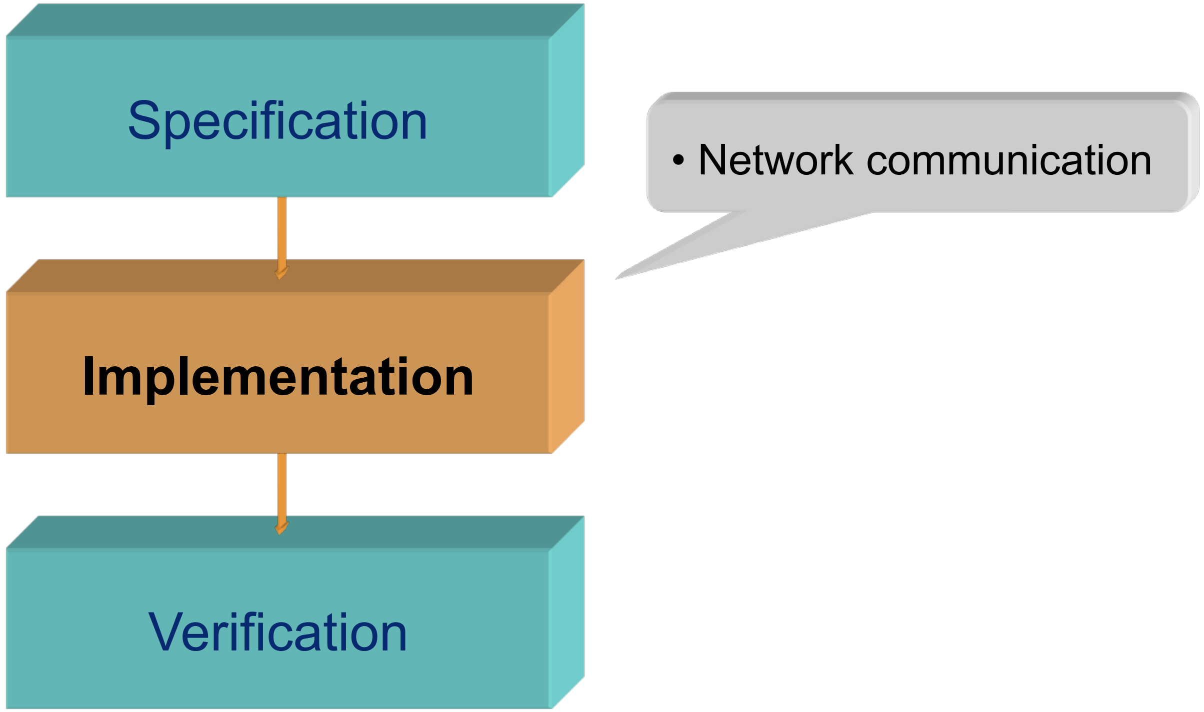
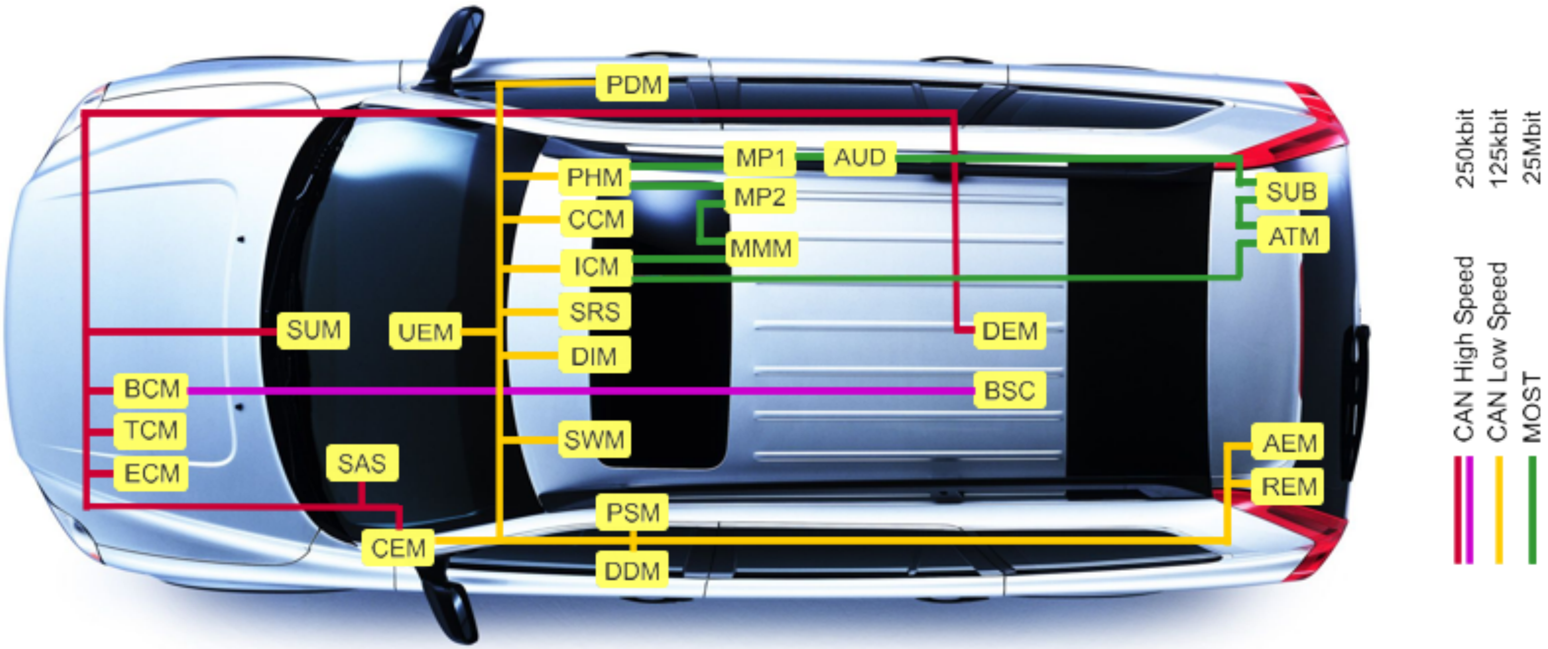
Real-Time Systems

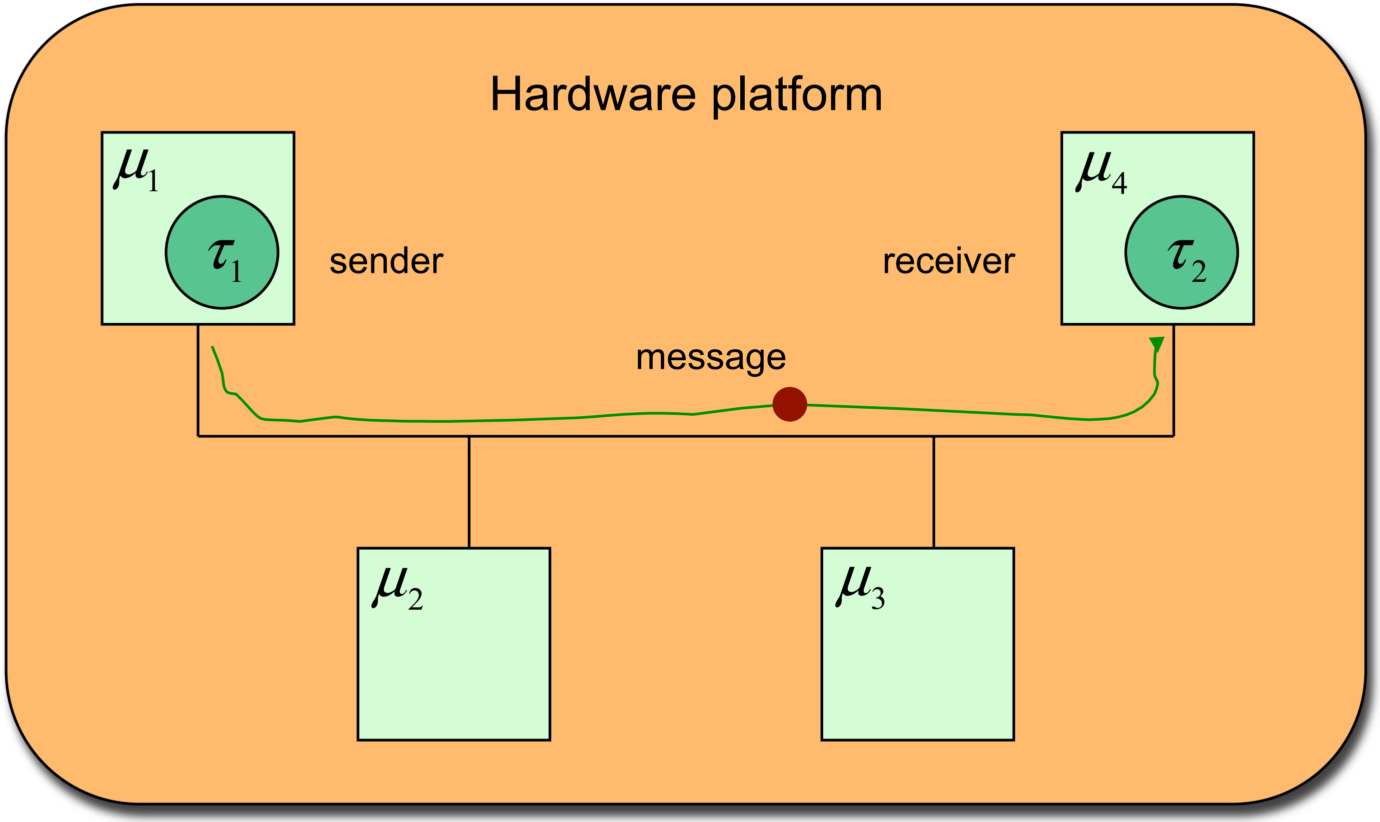


Network communication

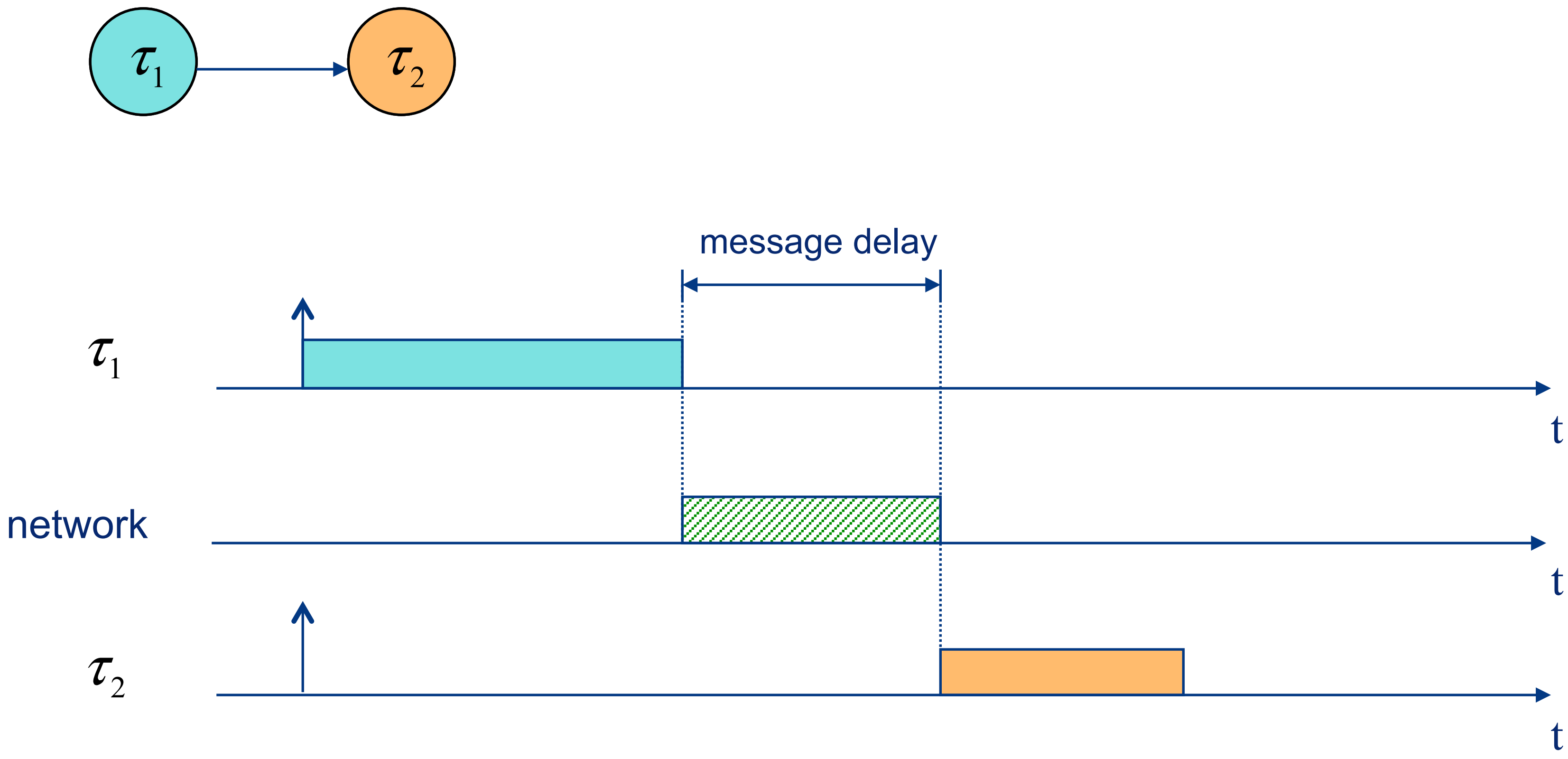
Embedded systems in the aircraft and automotive domain require support for real-time network communication



Network communication



Network communication



Network communication

Message delay:

- Message delays are caused by the following overheads:
  - Formatting (packetizing) the message
  - Queuing the message, while waiting for access to medium
  - Transmitting the message on the medium
  - Notifying the receiver of message arrival
  - Deformatting (depacketizing) the message

Formatting/deformatting overheads are typically included in the execution time of the sending/receiving task.

Network communication

Queuing delay:

- The cause of the queuing delay for a message depends on the actual network used. For example:
  - Waiting for a corresponding time slot (e.g., FlexRay)
  - Waiting for a transmission token (e.g., Token Ring)
  - Waiting for a contention-free transmission (e.g., Ethernet)
  - Waiting for network priority negotiation (e.g., CAN)
  - Waiting for removal from priority queue (e.g., Switched Ethernet)

To be used in a real-time system with hard timing constraints the queuing delay must be bounded.

Network communication

Transmission delay:

- The delay for transmitting the message is the sum of:

a frame delay

– message length (bits)
– data rate (bits/s)

$$t_{\text{frame}} = \frac{N_{\text{frame}}}{R}$$

and a propagation delay

– communication distance (m)
– signal propagation velocity (m/s)

$$t_{\text{prop}} = \frac{L}{v}$$

Network communication

How is the message transfer synchronized between communicating tasks?

- Asynchronous communication:
  - Sending and reception of messages are performed as independent operations at run-time.
- Synchronous communication:
  - Sending and receiving tasks synchronize their network medium access at run-time.

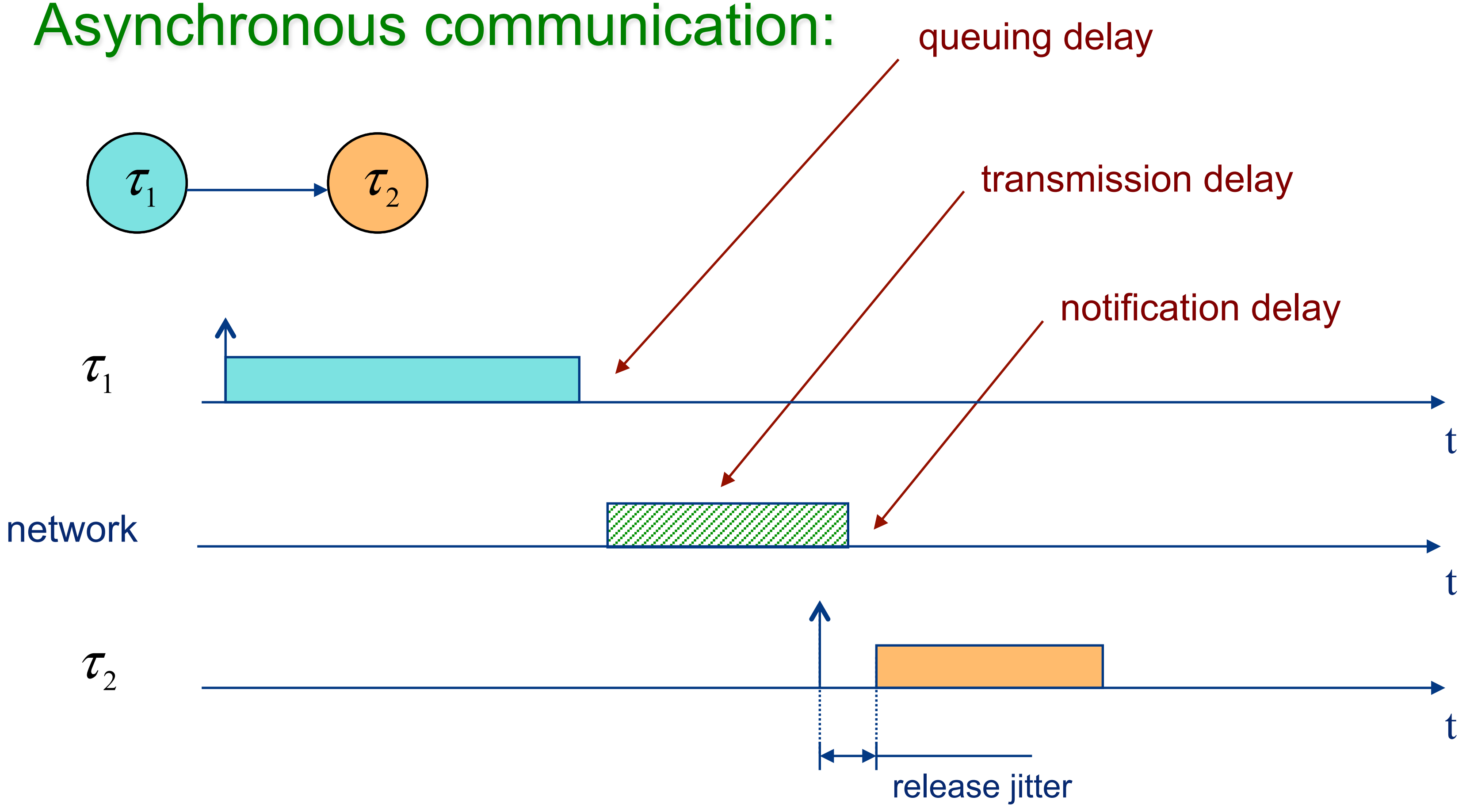
Network communication

Asynchronous communication

- Implementation:
  - Network controller chip administrates message transmission and reception (example: CAN, Ethernet)
  - Interrupt handler notifies the receiver
- Release jitter:
  - Queuing delays at sender and notification delay at receiver cause variations in message arrival time
  - Arrival-time variations gives rise to <u>release jitter</u> at receiving task (which may negatively affect schedulability)
  - Release jitter is minimized by adding offsets to receiving tasks

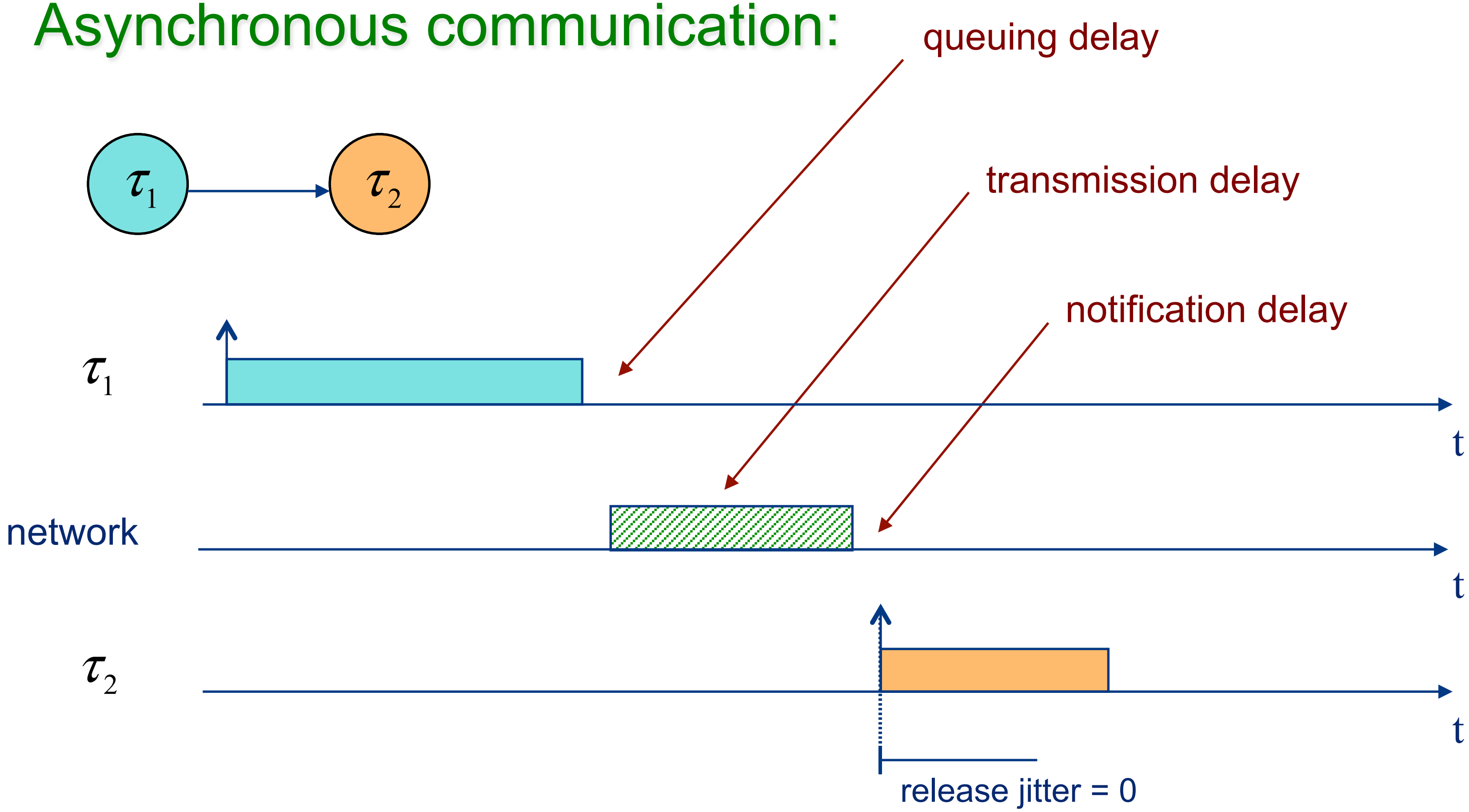
Network communication

Asynchronous communication:



Network communication

Asynchronous communication:



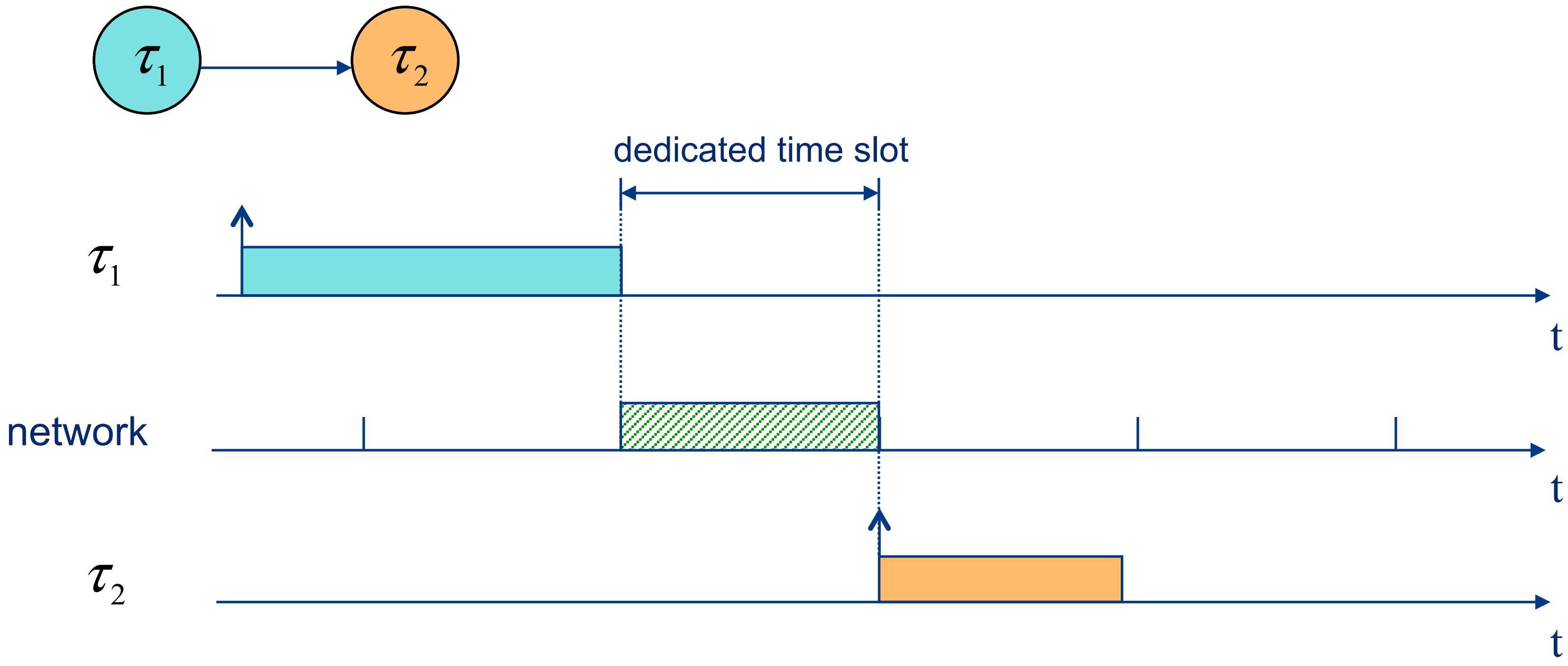
Network communication

Synchronous communication

- Implementation:
  - Network controller chip makes sure message transmission and reception occurs within a dedicated time slot in a TDMA bus network (example: FlexRay)
  - Off-line static (time-table) scheduling is used for matching the time slot with the execution of sending and receiving tasks
  - Queuing and notification delays can be kept to a minimum by instructing the off-line scheduling algorithm to use jitter minimization as the scheduling objective

Network communication

Synchronous communication:



Network communication

How is the message transferred onto the medium?

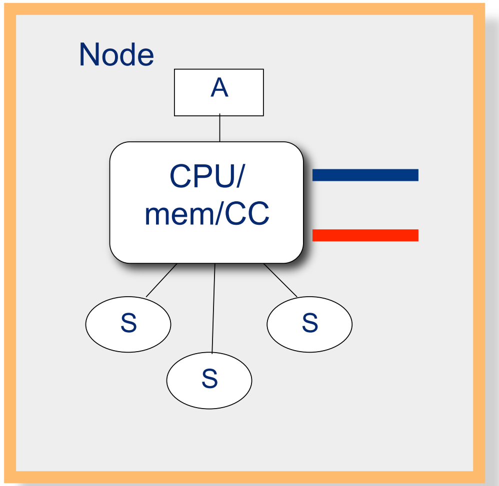
- Contention-free communication:
  - Senders need not contend for medium access at run-time
  - Examples: TTCAN, FlexRay, Switched Ethernet
- Token-based communication:
  - Each sender using the medium gets one chance to send its messages, based on a predetermined order
  - Examples: Token Ring, FDDI
- Collision-based communication:
  - Senders may have to contend for the medium at run-time
  - Examples: Ethernet, CAN

Network communication

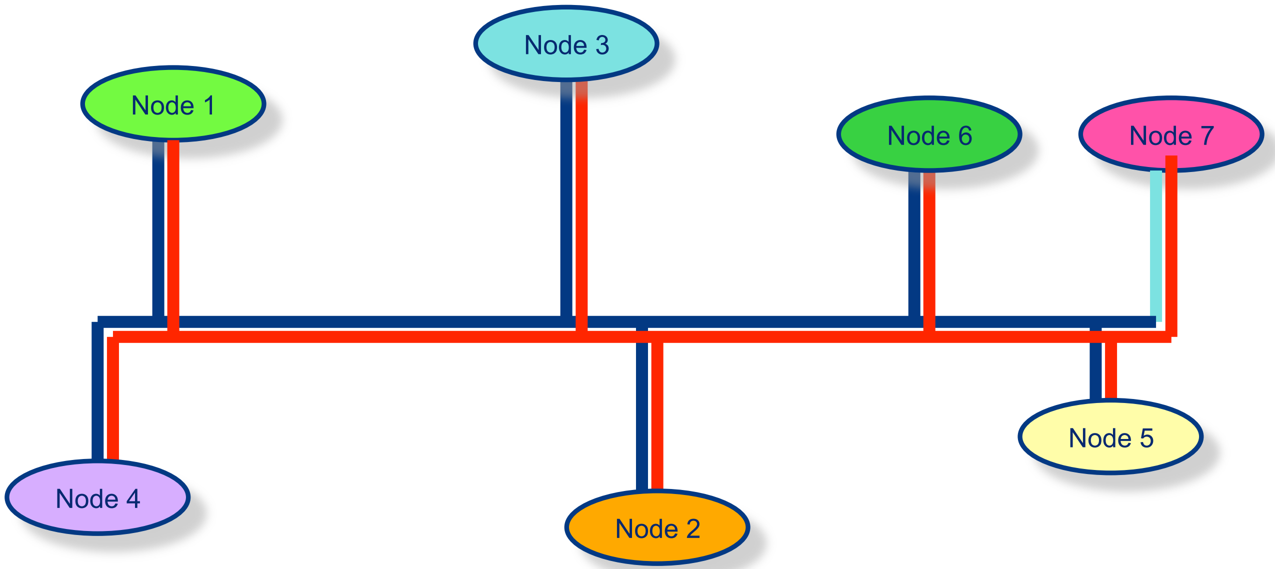
Contention-free communication:

- One or more dedicated time slots for each task/processor
  - Shared communication bus
  - Medium access is divided into communication cycles (normally related to least-common-multiple of task periods)
  - Dedicated time slots provide bounded queuing delays
  - TTCAN ("exclusive mode"), FlexRay ("static segment")
- One sender only for each communication line
  - Point-to-point communication networks with link switches
  - Output and input buffers with deterministic queuing policies in switches provide bounded queuing delays
  - Switched Ethernet

The TTCAN protocol



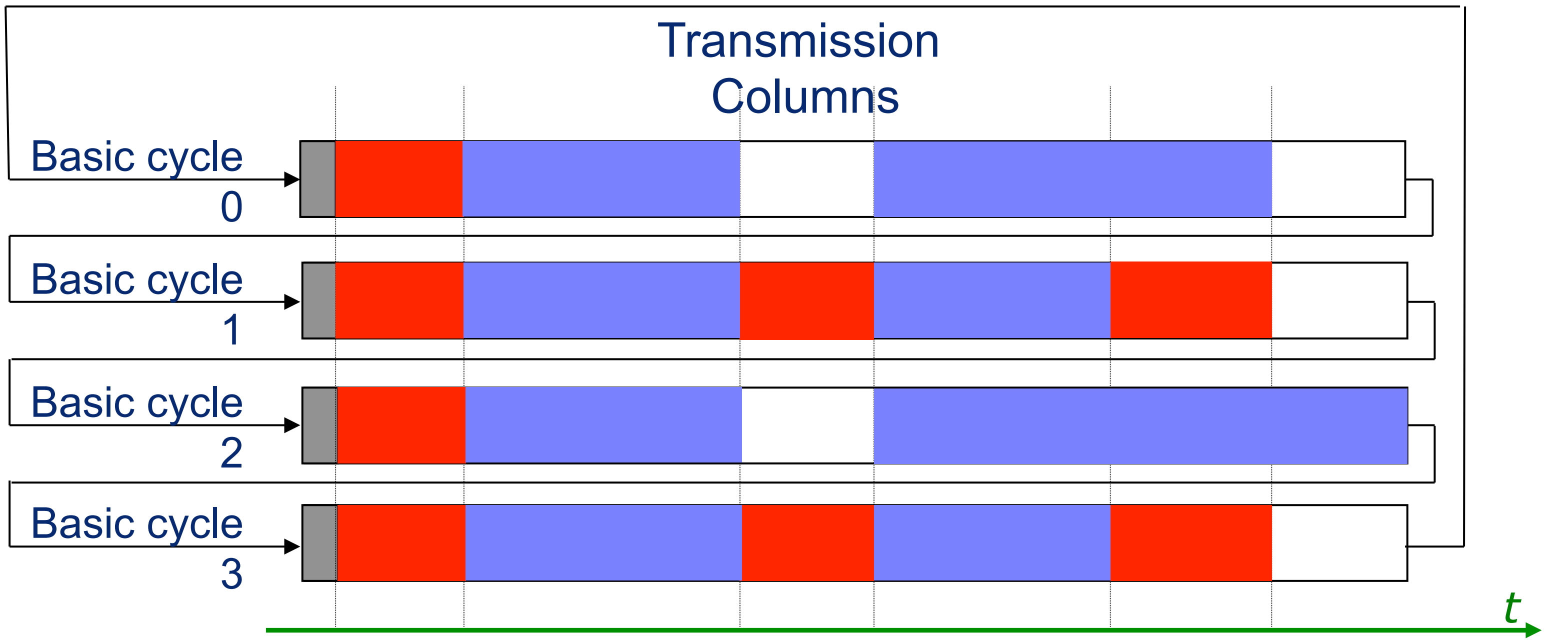
- Widely used in today's automotive systems
- Based on the CAN protocol
- Bus topology
- Media: twisted pair
- 1Mbit/s



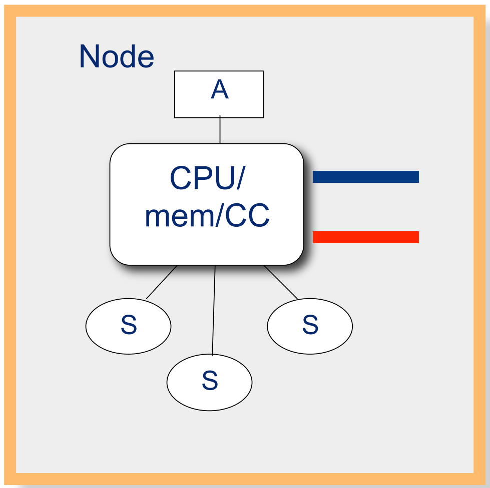
A second controller is required to implement the redundant bus

The TTCAN protocol

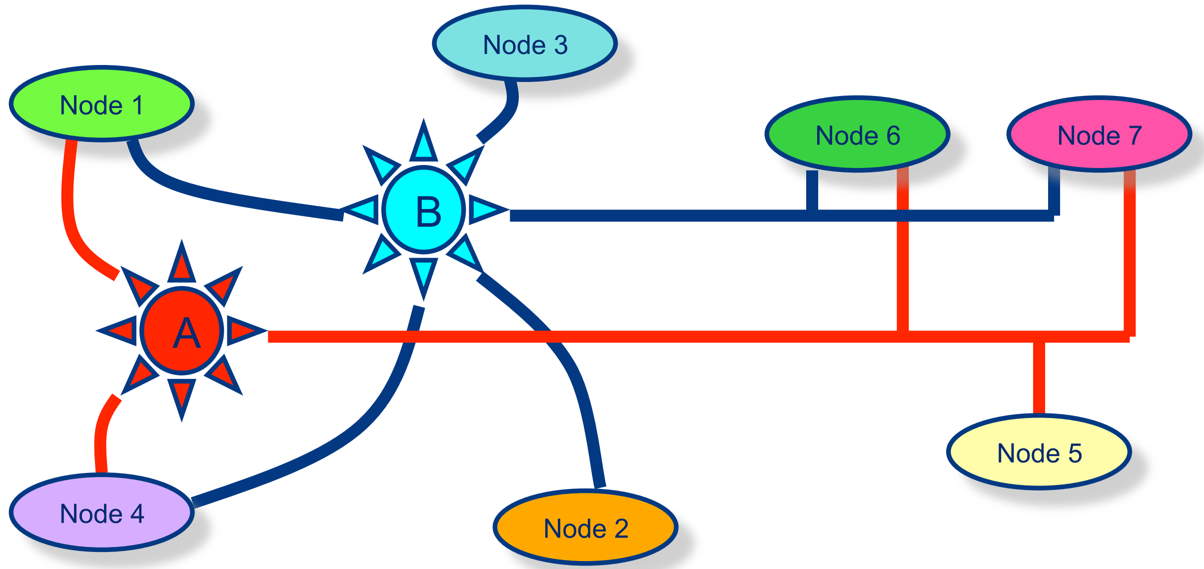
- ”Exclusive” – guaranteed service
- ”Arbitration” – guaranteed service (high ID), best effort (low ID)
- ”Reserved” – for future expansion...



The FlexRay protocol



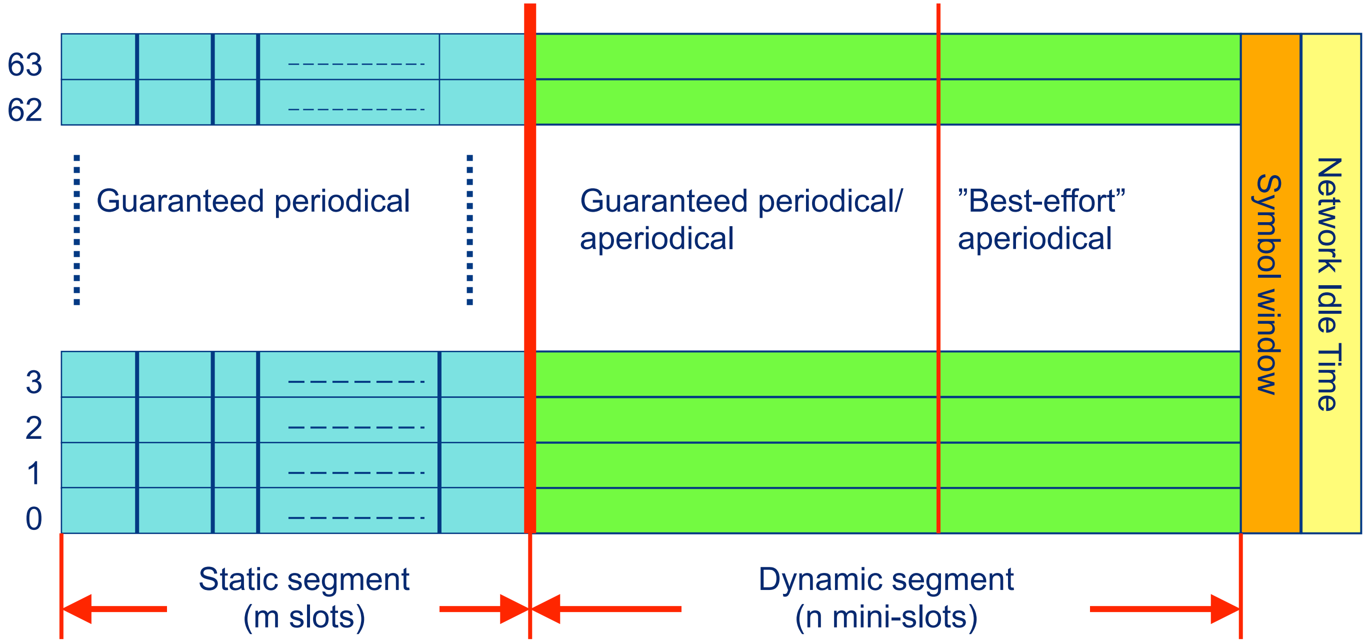
- For next-generation automotive systems
- Double channels, bus or star (even mixed).
- Media: twisted pair, fibre
- 10 Mbit/s for each channel



Redundant channel can be used for an alternative schedule

The FlexRay protocol

- ”Static segment” (compare w/ TTCAN ”Exclusive”) – guaranteed service
- ”Dynamic segment” (compare w/ TTCAN ”Arbitration”) – guaranteed service (high ID), ”best effort” (low ID)



Max 64 nodes on a Flexray network.

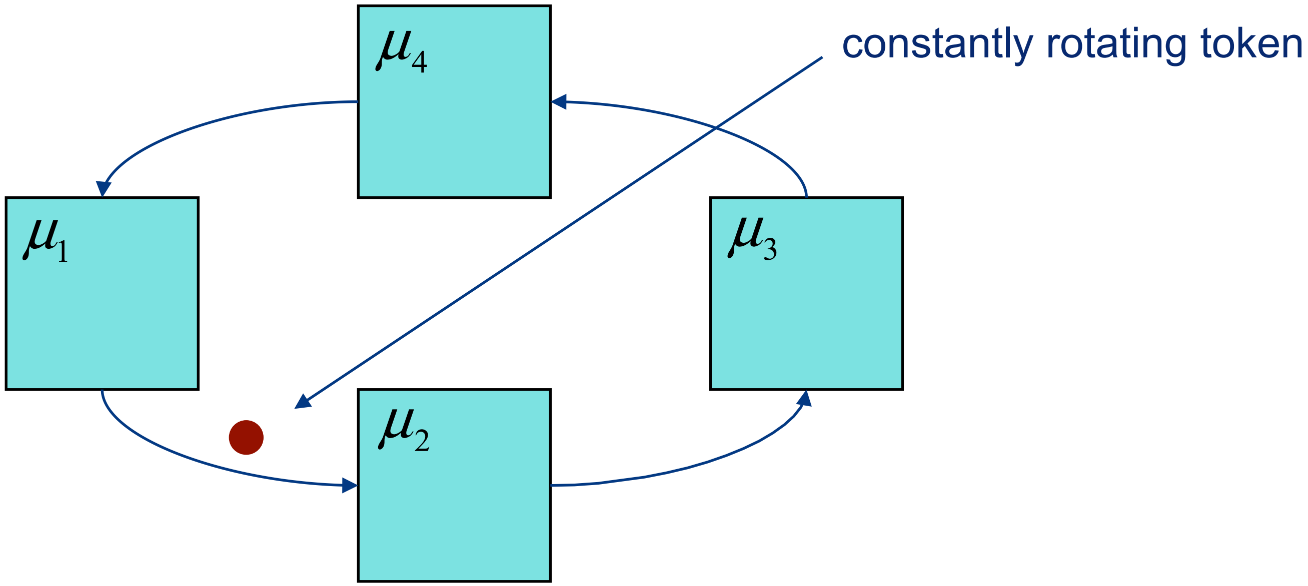
Network communication

Token-based communication:

- Utilize a token for the arbitration of message transmissions on a shared medium
  - The sender is only allowed to transmit its messages when it possesses the token
  - Message priorities can provide bounded queuing delays
- Examples:
  - Token Ring (IEEE 802.5)
  - FDDI (ANSI X3T9.5)

Token-based communication

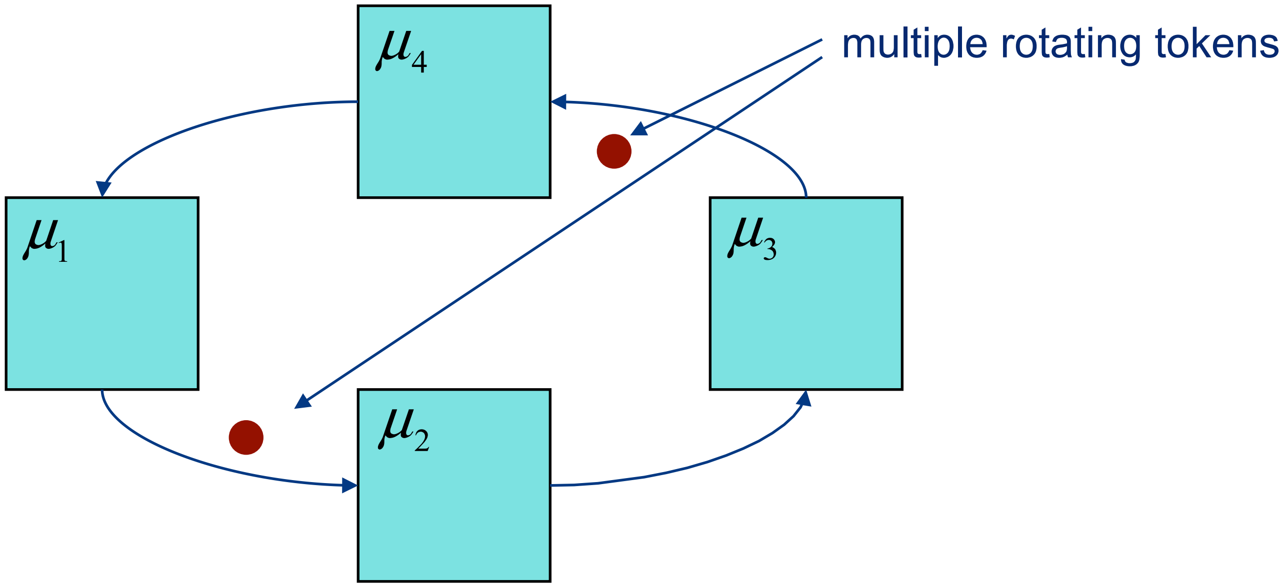
Token Ring: (IEEE 802.5)



Single rotating ring, twisted pair, 4 Mbit/s

Token-based communication

Fiber Distributed Data Interface: (ANSI X3T9.5)



Dual counter-rotating rings, optical fibre, 100 Mbit/s

Network communication

Collision-based communication:

- Utilize collision-detect mechanism to determine validity of message transmissions on a shared medium
  - The sender tries to send messages independently of other senders' intention to do so
  - Attempts may be done at any time or when some specific network state occurs
- Examples:
  - Ethernet w/ multiple senders (IEEE 802.3)
  - CAN (ISO 11898)

Collision-based communication

Ethernet protocols w/ multiple senders:

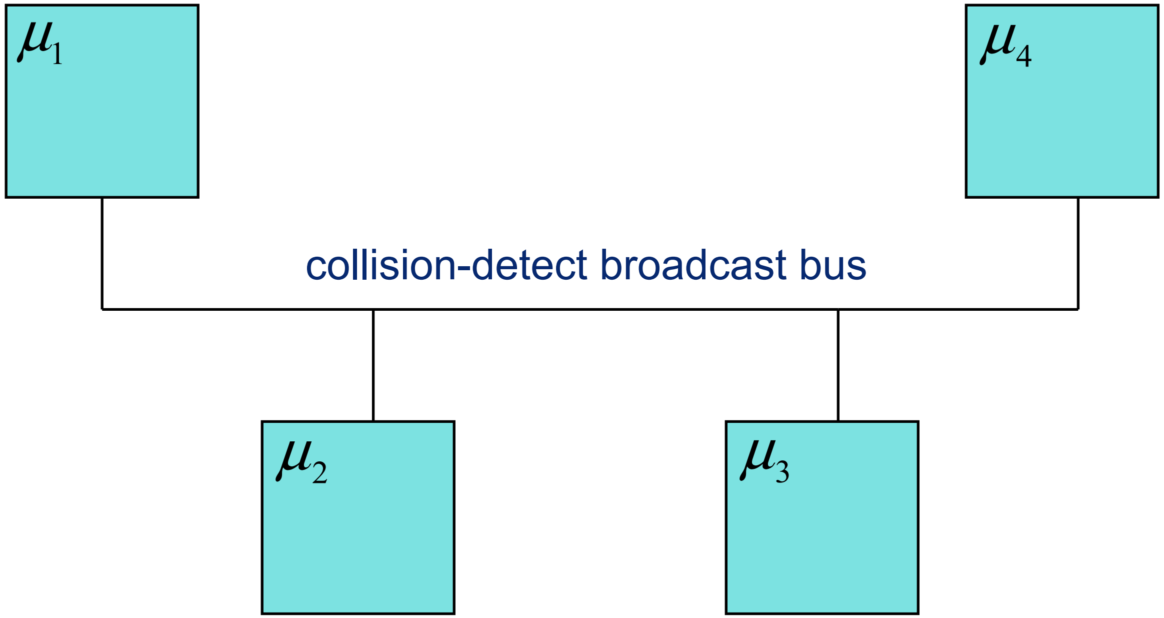
- Senders attempt to send a complete message
- If messages collide, all transmissions are aborted
- After collision, re-transmission is made after a random delay

Message queuing delay can in general not be bounded!

Therefore, these protocols do not give any guarantees for meeting imposed message deadlines!

Collision-based communication

Controller Area Network (CAN): (ISO 11898)



Broadcast serial bus, dual wire (resistor terminated), 1 Mbit/s

Collision-based communication

Controller Area Network (CAN):

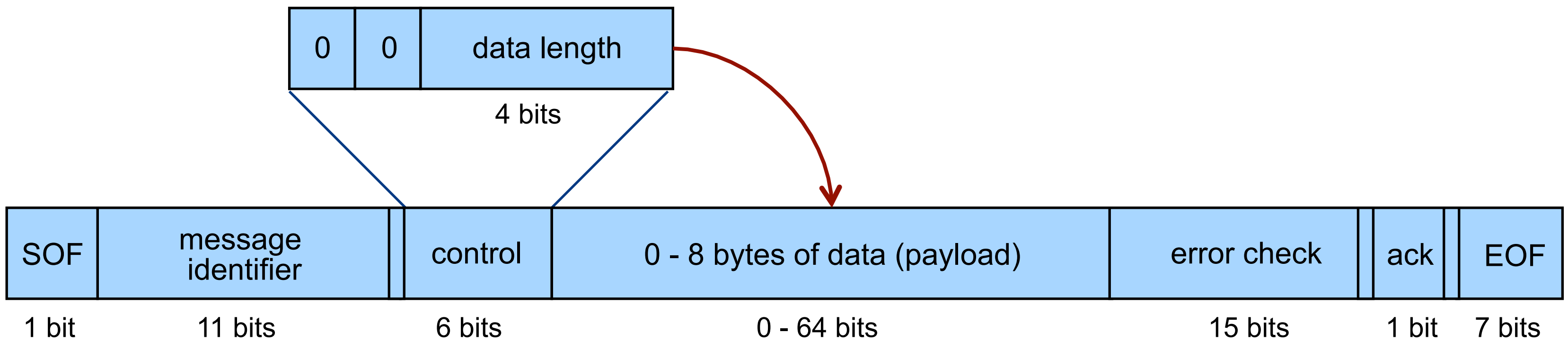
- Senders transmit a message header (with an identifier)
- If messages collide, a hardware-supported protocol is used to determine what sender will be allowed to send the rest of the message; transmissions by other senders are aborted

Message queuing delay can be bounded with appropriate identifier assignment!

Therefore, this protocol makes it possible to meet imposed message deadlines!

The CAN protocol

CAN message frame format: (short format)

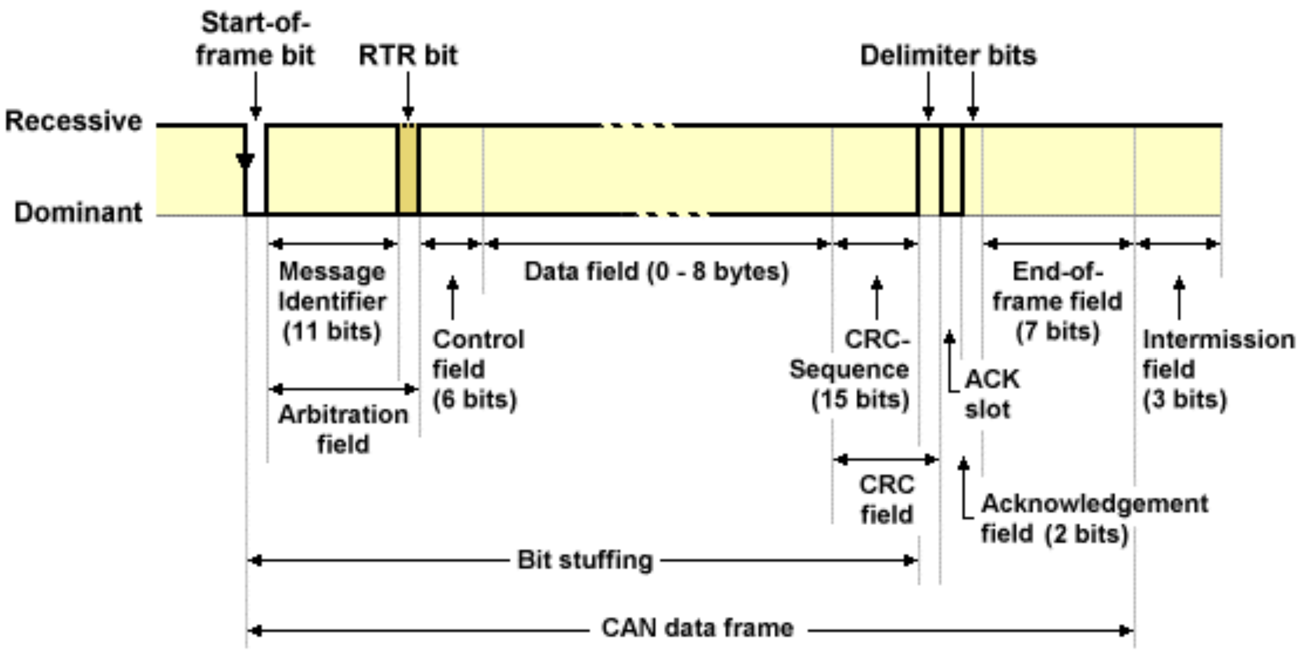


Message identifier can be used for several purposes:

- enable receiver to filter messages (original purpose)
- assign a priority to the message (low number ⇒ high priority)

The CAN protocol

CAN message frame format: (short format)



The CAN protocol

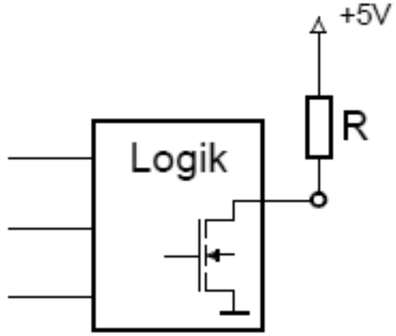
CAN protocol: (binary countdown)

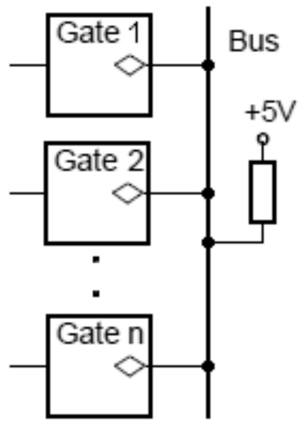
Wired-AND:

Each node monitors the bus while transmitting.

If multiple nodes are transmitting simultaneously and one node transmits a '0', then all nodes will see a '0'.

If all nodes transmit a '1', then all nodes will see a '1'.





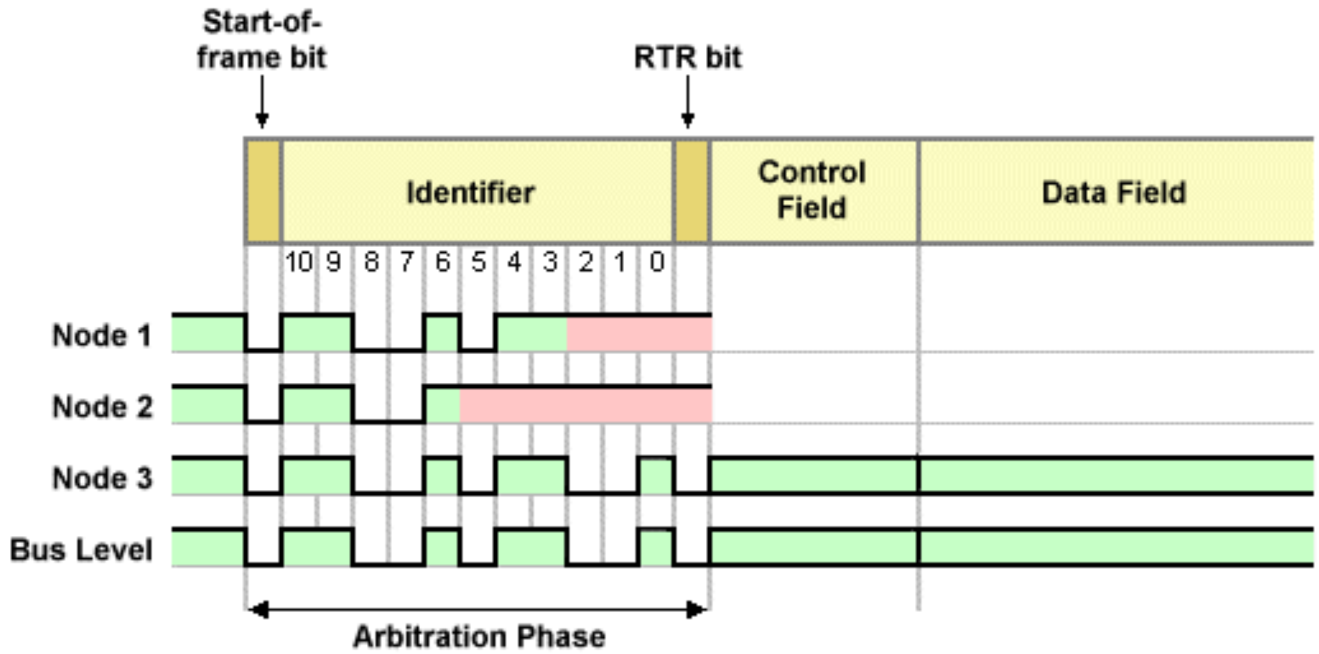
The CAN protocol

CAN protocol: (binary countdown)

1. Each node with a pending message waits until bus is idle.
2. The node begins transmitting the highest-priority message pending on the node. Identifier is transmitted first, in the order of most-significant bit to least-significant bit.
3. If a node transmits a recessive bit ('1') but sees a dominant bit ('0') on the bus, then it stops transmitting since it is not transmitting the highest-priority message in the system.
4. The node that transmits the last bit of its identifier without detecting a bus inconsistency has the highest priority and can start transmitting the rest of the message frame.

The CAN protocol

CAN protocol: (binary countdown)



Interrupt handlers in TinyTimber

Example: implementing a CAN interrupt handler:

1. Define class `Can`, and add state variables for:
   - the hardware base address of the device
   - call-back information for a method if data received by the handler needs to be taken care of by the user-level code (the call back should be done using an `ASYNC()` call)
   - necessary local storage (buffers, queues, etc)

2. Define a symbol `CAN_PORT0` representing the hardware base address of the device.

```
#define CAN_PORT0 device_hardware_address
```

3. Create an object `can0` of class `Can`, and initialize it with:
   - the hardware base address `CAN_PORT0`
   - any possible call-back information

Interrupt handlers in TinyTimber

Example: implementing a CAN interrupt handler (cont'd):

In file 'application.c':

```
App app = { initObject(), 0, 'X' };

void receiver(App*, int);

Can can0 = initCan(CAN_PORT0, &app, receiver);

void receiver(App *self, int unused) {   // call-back function
    CANMsg msg;
    CAN_RECEIVE(&can0, &msg);
    SCI_WRITE(&sci0, "Can msg received: ");
    SCI_WRITE(&sci0, msg.buff);
}
```

Interrupt handlers in TinyTimber

Example: implementing a CAN interrupt handler (cont'd):

4. Write an interrupt handler as a method `can_interrupt` and associate it with the object.
5. Declare a symbol `CAN_IRQ0` and assign to it the TinyTimber kernel's logical number of the hardware interrupt:

```
#define CAN_IRQ0 interrupt_logical_number
```

6. Inform the TinyTimber kernel that the method is a handler for interrupt `CAN_IRQ0`, by making a call to

```
INSTALL(&can0, can_interrupt, CAN_IRQ0);
```

This should be done <u>before</u> the call to `TINYTIMBER()`

Interrupt handlers in TinyTimber

Example: implementing a CAN interrupt handler (cont'd):

7. Provide an operation `CAN_INIT()` that takes care of performing any remaining initialization of the device.
8. Call `CAN_INIT()` in the "kick-off" method that was supplied as argument to the `TINYTIMBER()` call.

Interrupt handlers in TinyTimber

Example: implementing a CAN interrupt handler (cont'd):

In file 'application.c':

```
void startApp(App *self, int arg) {
     CANMsg msg;
     CAN_INIT(&can0);
     …
     CAN_SEND(&can0, &msg);
}

int main() {
     INSTALL(&can0, can_interrupt, CAN_IRQ0);
     TINYTIMBER(&app, startApp, 0);
}
```

Interrupt handlers in TinyTimber

Example: implementing a CAN interrupt handler (cont'd):

In file 'canTinyTimber.h':

```
typedef unsigned char uchar;

typedef struct {
    uchar msgId;  // Valid values: 0-127
    uchar nodeId; // Valid values: 0-15
    uchar length;
    uchar buff[8];
} CANMsg;
```

`CANMsg` holds the user-relevant parts of the CAN message frame.

- `nodeID` holds the four least-significant bits of the identifier field
- `msgID` holds the seven most-significant bits of the identifier field