Real-Time Communications and Internet of Things

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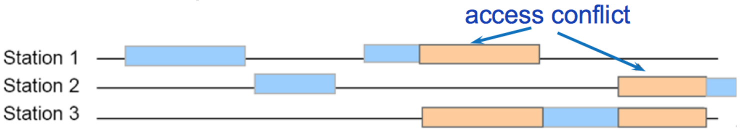
Random Access

- no access control; requires low medium utilization



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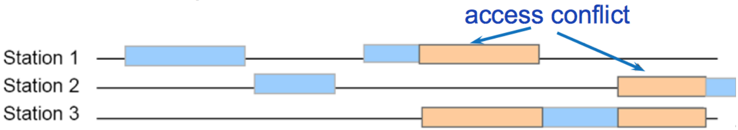
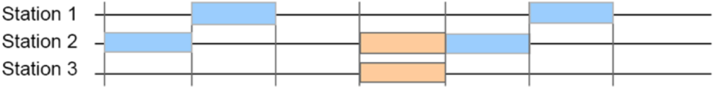


- improved variant: slotted random access



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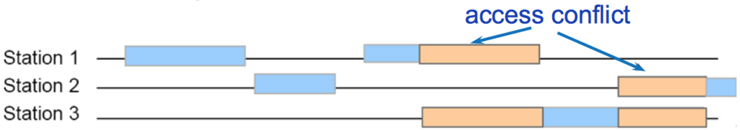

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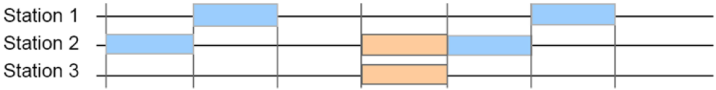
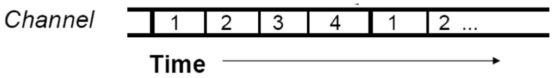


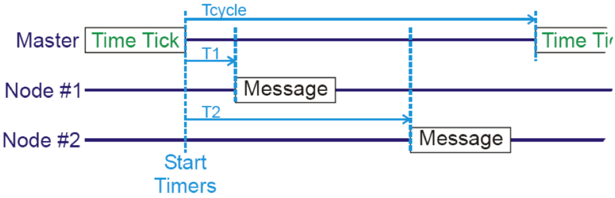
- What is the optimal sending rate p in case of n stations?
  - probability that a slot is not taken by others: $(1-p)^{n-1}$
  - probability to send successfully: $p \cdot (1-p)^{n-1}$
  - the maximum probability with respect to p happens when $d(p \cdot (1-p)^{n-1})/dp = 0$, i.e., $p = 1/n$.

TDMA (Time Division Multiple Access)

- Communication in statically allocated time slots
- Synchronization among all nodes necessary:
  - periodic repetition of communication frame or



  - master node sends out a synchronization frame
- Examples: TTP, static portion of FlexRay, satellite networks

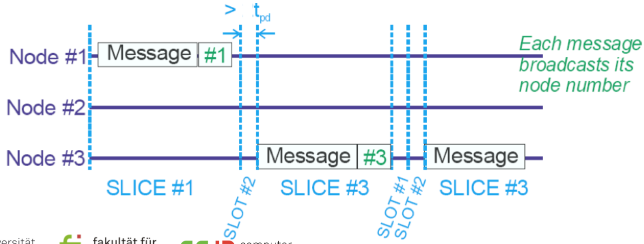


CSMA/CD

- CSMA/CD (Carrier Sense Multiple Access / Collision Detection)
- Try to avoid and detect collisions:
  - before starting to transmit, check whether the channel is idle
  - if a collision is detected (several nodes started almost simultaneously), wait for some time (backoff timer)
  - repeated collisions result in increasing backoff times
- Examples: Ethernet, IEEE 802.3
- Stochastic behavior, and problemic in general for real-time systems without any treatments

CSMA/CA

- Carrier Sense Multiple Access / Collision Avoidance
- Operation:
  - reserve s slots for n nodes; note: slots are normally idle they are (short) time intervals, not signals; if slot is used it becomes a slice.
  - nodes keep track of global communication state by sensing
  - nodes start transmitting a message only during the assigned slot
  - If $s = n$, no collisions; if $s < n$, statistical collision avoidance
- Examples: 802.11, part of FlexRay



CSMA/CR

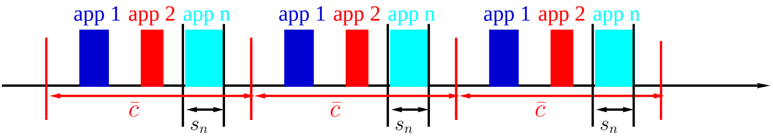
- Carrier Sense Multiple Access / Collision Resolution
- Operation:
  - Before any message transmission, there is a global arbitration

  - Each node (or each message type) is assigned a unique identification number
  - All nodes wishing to transmit compete by transmitting a binary signal based on their identification value
  - A node drops out the competition if it detects a dominant state while transmitting a passive state
  - Thus, the node with the lowest identification value wins
- Example: CAN Bus

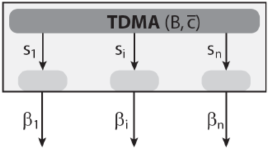
Outline

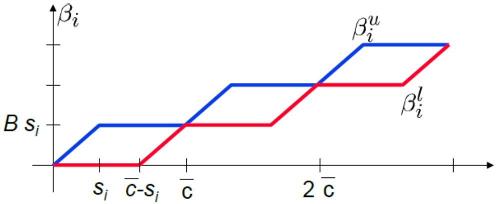
Recall: TDMA Resource in Real-Time Calculus

- Consider a real-time system consisting of n applications that are executed on a resource with bandwidth B that controls resource access using a TDMA (Time Division Multiple Access) policy.
- Analogously, we could consider a distributed system with n communicating nodes, that communicate via a shared bus with bandwidth B, with a bus arbitrator that implements a TDMA policy.
- TDMA policy: In every TDMA cycle of length $\bar{c}$, one single resource slot of length s_i is assigned to application i.



TDMA Resource

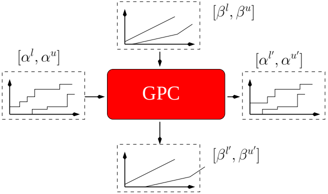


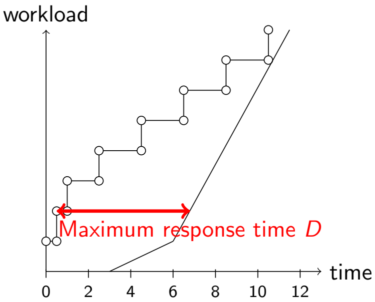


$$\beta^{u}_{TDMA}(\Delta) = B \min \left\{ \left\lceil \frac{\Delta}{\bar{c}} \right\rceil s_i, \Delta - \left\lfloor \frac{\Delta}{\bar{c}} \right\rfloor (\bar{c} - s_i) \right\}$$

$$\beta^{l}_{TDMA}(\Delta) = B \max \left\{ \left\lfloor \frac{\Delta}{\bar{c}} \right\rfloor s_i, \Delta - \left\lceil \frac{\Delta}{\bar{c}} \right\rceil (\bar{c} - s_i) \right\}$$

Arrival Curve Served by TDMA





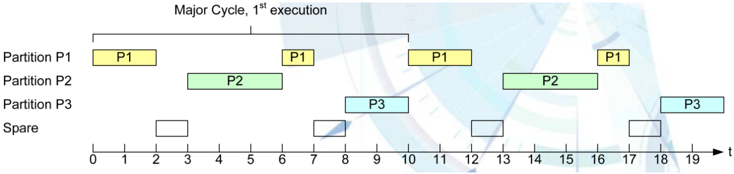
$$D = \sup_{t \geq 0} \{\inf\{\tau \geq 0 : R(t) \leq R'(t+\tau)\}\}$$

$$= \sup_{\Delta \geq 0} \{\inf\{\tau \geq 0 : \alpha^u(\Delta) \leq \beta^l(\Delta + \tau)\}\}$$

Additional Remarks

Why is TDMA interesting?

- Integrated Modular Avionics (IMA) exactly partitions the functions by using a *flexible* TDMA, and uses fixed-priority preemptive scheduling within each partition
- Partitions are scheduled according Time Division Multiple Access(TDMA)
- Execution times, number of partitions windows and offsets are defined in the Major Cycle



https://www.symtavision.com/downloads/success-stories/06_IMA_SchedulingIssues_EADS_Breunig.pdf

Outline

CAN (Controller Area Network)

- Initiated in the late 70's to connect a number of processors over a cheaper shared serial bus
- From Bosch (mid 80's) for automotive applications
- De facto standard for in-vehicle communications.
- Fair cost
- Shared broadcast bus (one sender/many receivers) (CSMA/CR)
- CAN bus is a twisted wire
- Medium speed:
  - Max: 1Mbit/sec; typically used from 35 Kbit/sec up to 500Kbit/sec
- Highly robust (error mechanisms to overcome disturbance on the bus) and
- Real-time guarantees can be made about CAN performance

Bit Transmssion on CAN

- Fundamental requirement: Everyone on the bus sees the current bit before the next bit is sent
  - This permits a very clever arbitration scheme (later)
- Global time is assumed and maintained
- Bits per second (depending on the length of CAN bus):
  - 1 Mbps CAN bus → 1 micro sec per bit: a bit can travel 100 m per 1000ns (thus max bus length 40˜50 m)
  - 40 Kbps CAN bus → 25000 ns per bit: A bit can travel 2500 m per 25000 ns (thus max bus length 1000˜1250 m)
- Bandwidth
  - 1 Mbps up to 40˜50 m (normal)
  - 0.5 Mbps upto 80˜100 m
  - 40 Kbps up to ˜1000 m
  - 5 Kbps up to ˜10,000 m (maximum)

CAN Frame

- Small sized frames (messages): 0 to 8 bytes:
  - perfect for many embedded control applications
- Relatively high overhead: a frame size of more than 100 bits to send 64 data bits
  - do not use this for bulk data transfer
- Interrupt only after an entire message is received

CAN Addressing

- CAN bus can have an arbitrary number of nodes
  - Nodes do not have proper addresses
  - Each message has an 11-bit "field identifier"
  - Everyone interested in a message type listens to it
  - Works like this: "I'm passing a ball"
  - Not like this: "I'm passing a ball to Reus"
- Designer should allocate the message identifiers to the stations (different nodes send different messages!)
- Each node has a queue for messages ordered by priorities/identifiers

The CAN Arbitration Mechanism

- Shared broadcast bus
- Bus behaves like a large AND-gate - if all nodes sends 1 the bus becomes 1, otherwise 0.
  - 0: dominant bit (in fact, sending 0 by high voltage)
  - 1: recessieve bit
- A frame is tagged by an identifier
  - indicates contents of frame
  - most importantly, it is used for arbitration as priority
- Bit-wise arbitration
  - Each message has unique priority $\Rightarrow$ node with message with lowest id wins arbitration
- Lowest id $=$ highest priority!
- The CAN bus is a fixed-priority-based scheduled resource
- What happens if a CAN node goes crazy/haywire and transmits too many high priority frames?
  - This can make the bus useless
  - Assumed not to happen

CAN Message Scheduling and Analysis

- Each frame should be non-preemptive
- This is a non-preemptive fixed-priority scheduling
- The maximum bits per frame is 135 bits (by considering all the overheads and bitstuffing)
- This results in a maximum blocking time due to a frame of 135 bits in CAN
- For a CAN with 1Mbit/s, the blocking time is up to 135 μs

Theorem

A system $\mathcal{T}$ of periodic, independent, preemptable, and constrained-deadline message-passing tasks is schedulable on a CAN bus if

$$\forall \tau_i \in \mathcal{T} \; \exists t \text{ with } 0 < t \leq D_i \;\; and \;\; B_i + C_i + \sum_{j=1}^{i-1} \left\lceil \frac{t}{T_j} \right\rceil C_j \leq t,$$

where the higher-priority message types have lower indexes and B_i is the blocking time of message type i.

Outline

Analysis of TDMA

CAN (Controller Area Network)

Flexray

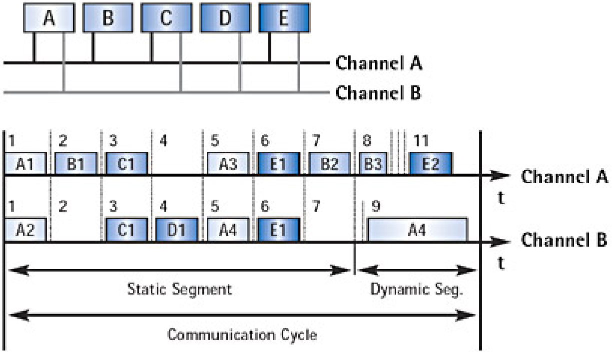
Summary of Other Busses

Flexray

- Developed by the FlexRay consortium (BMW, Ford, Bosch, DaimlerChrysler, . . .)
- Meets requirements with transfer rates $\gg$ CAN standard
  - High data rate can be achieved:
  - initially targeted for ˜ 10Mbit/sec;
- Design allows much higher data rates
- Improved error tolerance and time-determinism
- Flexible TDMA protocol
- Cycle subdivided into a static and a dynamic segment.
  - Static segment is based on a fixed allocation of time slots to nodes.
  - Dynamic segment for transmission of ad-hoc communication with variable bandwidth requirements.

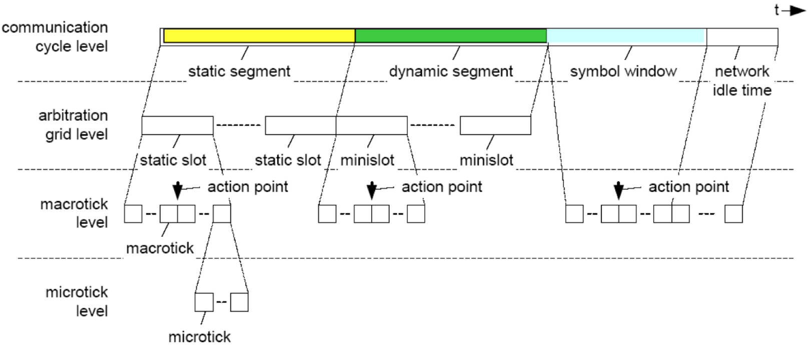
Flexray

- Use of two independent channels to eliminate single-point failures and to allow flexibility of different channel configurations
- Bandwidth in the dynamic segment is used only when it is actually needed.



http://www.ixxat.de/introduction_flexray_de.html?markierung=flexray

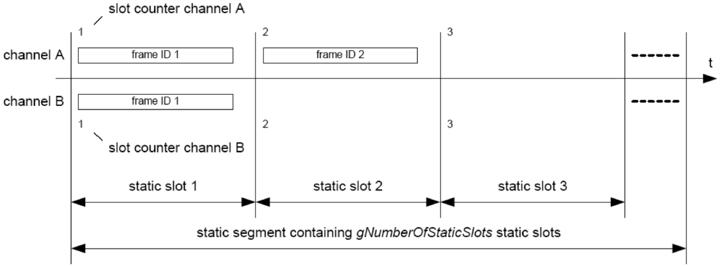
FlexRay Message Cycle



Static Segment

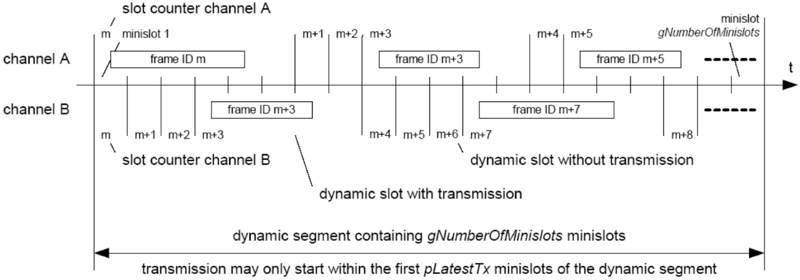
TDMA messages, most likely used for critical messages

- All static slots are the same length
- All static slots are repeated in order every communication cycle
- All static slot times are expended in cycle whether used or not



Dynamic Segment

- Each minislot is an opportunity to send a message
- If message isnt sent, minislot elapses unused (short idle period)
- All nodes watch whether a message is sent so they can count minislots



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Summary of Other Busses

Other Busses

- IEEE 488: Designed for laboratory equipment.
- LIN: low cost bus for interfacing sensors/actuators in the automotive domain
- MOST: Multimedia bus for the automotive domain (not a field bus)
- MAP: bus designed for car factories.
- Process Field Bus (Profibus): used in smart buildings
- The European Installation Bus (EIB): bus designed for smart buildings; CSMA/CA; low data rate. Upgrade: KNX-Bus
- Attempts to use Ethernet. Timing predictability an issue.

Wireless Communication: Examples

- IEEE 802.11 a/b/g/n
- UMTS; HSPA; LTE
- Bluetooth
- WirelessHART
- ZigBee

Summary

- Communication in embedded systems
- Timing analysis
  - TDMA
  - CAN bus
- Flexray architecture