Network Technologies and Distributed Systems - ITC5

Fieldbusses I
Controller Area Network (CAN) and introduction to RTaW-Sim

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Networks Technologies and Distributed Systems (ITC5)

Teachers: Jimmy J. Nielsen and Hans-Peter Schwefel

Preliminary course plan (irregular times in calendar due to HPS' availability):

1. **JJN, "Fieldbusses I – CAN"**
2. JJN, "Fieldbusses II – FlexRay"
3. HPS, "Time, order and consistency - part 1"
4. HPS, "Time, order and consistency - part 2"
5. HPS, " Techniques used at Data Link layer: ARQ and MAC concepts"
6. HPS, "Multiple Access Control protocols"
7. JJN, "Technology example: WLAN - IEEE 802.11 standard"
8. JJN, "Technology example: Bluetooth"
9. HPS, "Introduction to fault tolerance"
10. HPS, "Introduction to security - basic security mechanisms"

Evaluation:

- At exam: 2 random questions drawn from post-lecture exercises. A list of questions will be compiled after last lecture.

Learning goals

- Become acquainted to Field busses
  - Know typical applications and requirements
- Be familiar with basic properties of CAN:
  - bus topologies and physical constraints (bit time)
  - frame layout and payload size
  - basic vs. extended frames
- Understand how CAN works with respect to:
  - Addressing method (meaning of frame ID)
  - Bus access mechanism (priority arbitration scheme)
- Become able to simulate CAN networks and understand results

Agenda

- Fieldbusses
- CAN protocol
- Motivation for simulation of CAN networks
- Exercises for RTaW-Sim (group work)

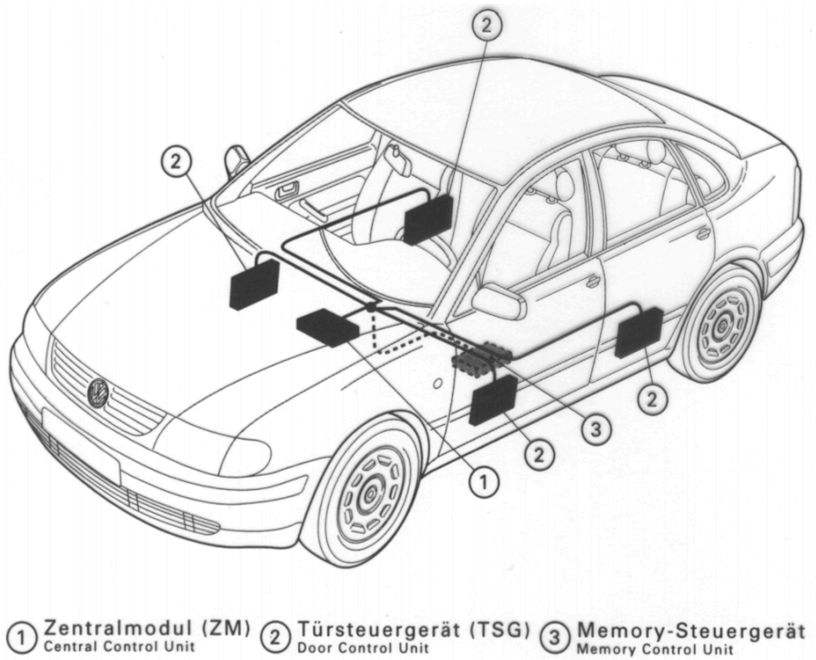
Field bus application areas

- Industrial communication
  - Production engineering
    - Transmission of programs to computerized numerical control machines
    - Control of plants / automation of car manufacturing
  - Process engineering
    - Control loops in a refinery
    - Control and regulation at aluminum smelting
  - Power generation
    - Conventional thermal power station / nuclear power plant
    - Hydroelectric power plant / pumped-storage power station
- Automotive engineering
    - Distributed real time regulation in cars
    - Commercial vehicles – in-car network
    - Control of special functions in work machines
- Building services engineering
    - Light control in residential houses
    - Air-conditioning technology in functional buildings

fast real-time systems with short deadlines and often high frequencies

From: LOMI Universität Ulm, 2004. Lecture. Computer Networks. Fieldbus Systems. Prof. Dr. H. P. Großmann. Dipl.-Ing. Andreas Schmeiser

In-car networks



- Today's cars have up to 50-80 ECUs that exchange messages on dedicated communication busses, e.g.:
  - LIN
  - CAN
  - FlexRay
  - Ethernet (soon)

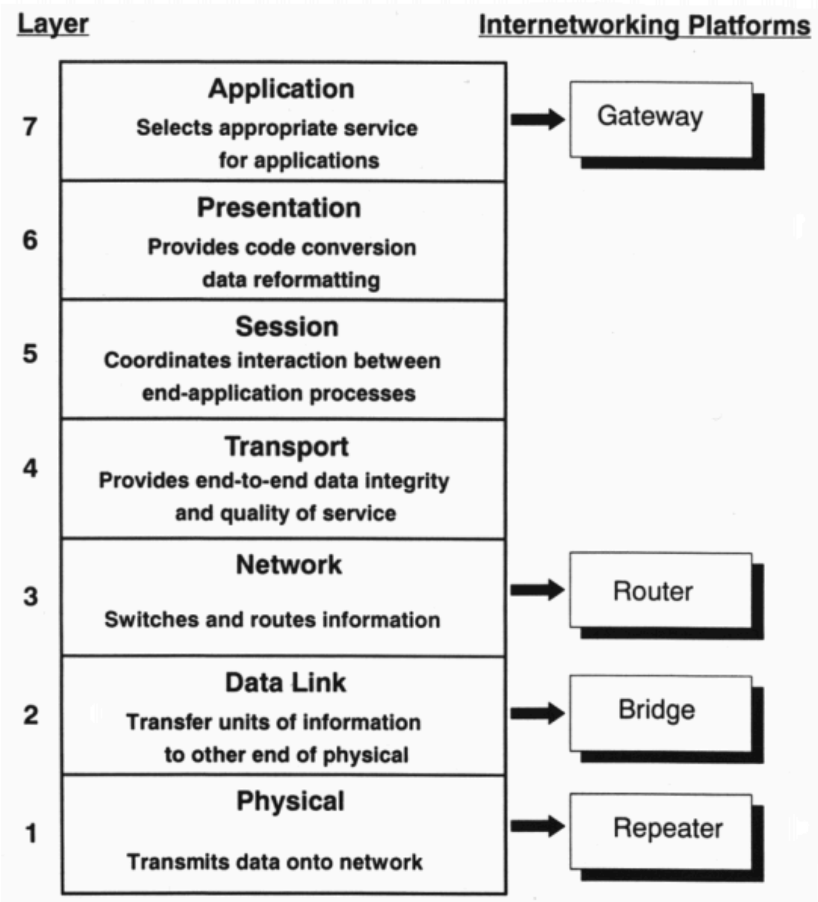
Figure from: LOMI Universität Ulm, 2004. Lecture. Computer Networks. Fieldbus Systems. Prof. Dr. H. P. Großmann. Dipl.-Ing. Andreas Schmeiser

Advantages of fieldbusses over dedicated wires

- Cost savings during assembly of cabling
- Reduction of weight
- Increased reliability
- Decreased amount of maintenance
- Easier and more efficient fault diagnosis
- Increased flexibility of the plant
- Network provides easy access
  - Configurable sensors/actuators
  - Readings and status from sensors/actuators available from everywhere
- Redundancy

From: LOMI Universität Ulm, 2004. Lecture. Computer Networks. Fieldbus Systems. Prof. Dr. H. P. Großmann. Dipl.-Ing. Andreas Schmeiser

Fieldbus vs. OSI model



- Fieldbus systems often define several OSI layers in one standard
- Mostly layers 3 to 6 are nonexistent
  - Efficient, fast data processing
  - No routing
  - No fragmentation
- In the majority only layers 1-2 or layers 1-2-7 are defined

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Controller Area Network (CAN) at a glance

- Number of nodes
  - unlimited
    (dependent on physical layer)
- Topology
  - line
  - star
- Length of bus lines
  (dependent on transfer rate)
  - 40 m at 1 Mbit/s (specified)
  - 620 m at 100 kbit/s
  - 10 km at 5 kbit/s
- Number of message identifiers
  - 2^{11} (standard frame)
  - 2^{29} (extended frame)
- Data bytes per message
  - 0 ... 8
- Bus access
  - CSMA/CA through AMP
    (Carrier Sense Multiple Access/Collision Detection with Arbitration on Message Priority)
  - controlled by message priority
  - non-destructive bit-wise arbitration
- Bus throughput
  - max. 1 Mbit/s (total)
  - max. 577 kbit/s (information/payload)
- Real-time capability
  - guaranteed latency times for high priority messages
    (<134 µs @ 1 Mbit/s)
- Reliability / Safety
  - acknowledgment of message
  - error detection, handling and fault confinement

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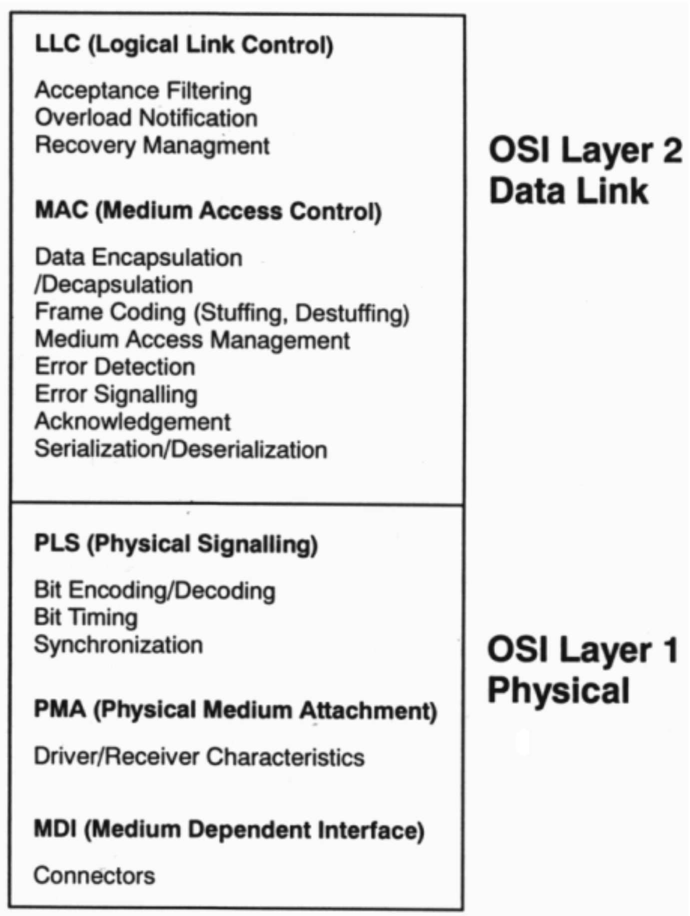
CAN OSI layers 1 and 2



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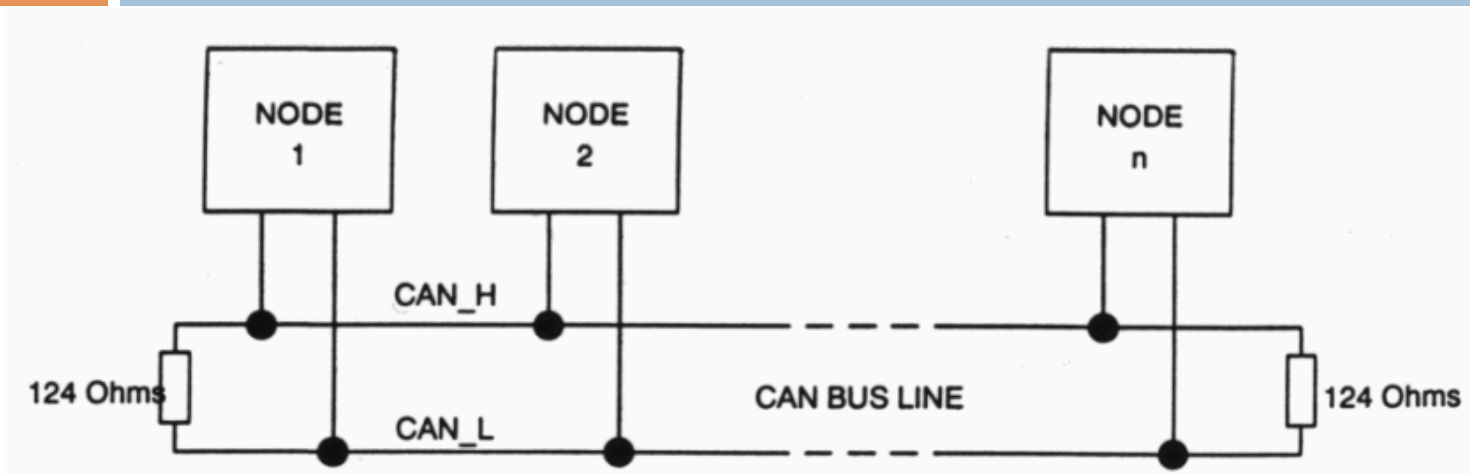
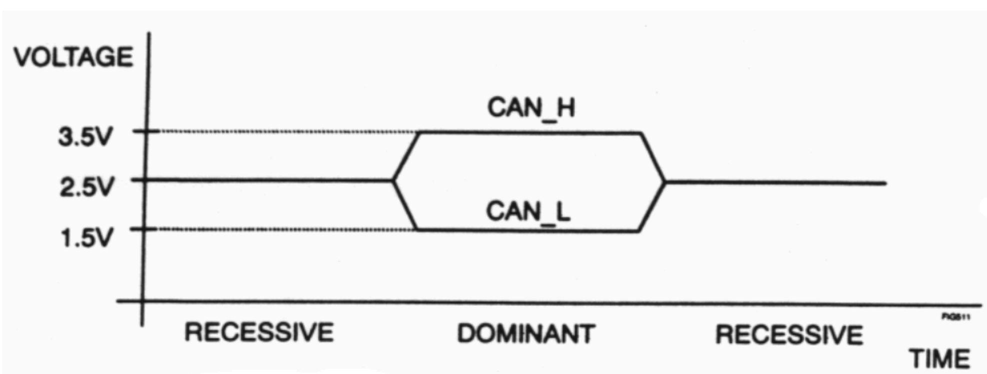
CAN bus





- Bus topology
- Broadcast transmissions
- a bit must "fill" whole bus
  - Limits cable length

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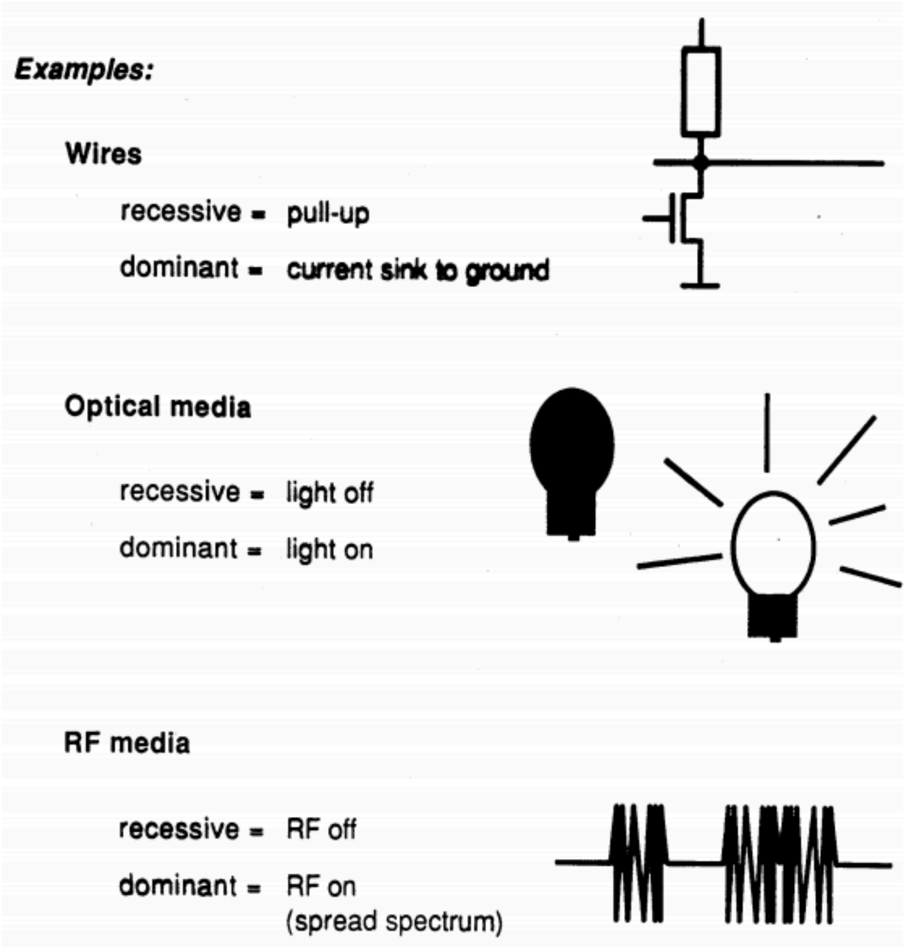
Supported media

- All types of media that support dominant and recessive states can be used.
- Why not opposite?
  - Dominant always trumps recessive.
- The need for recessive/dominant will be clear soon.



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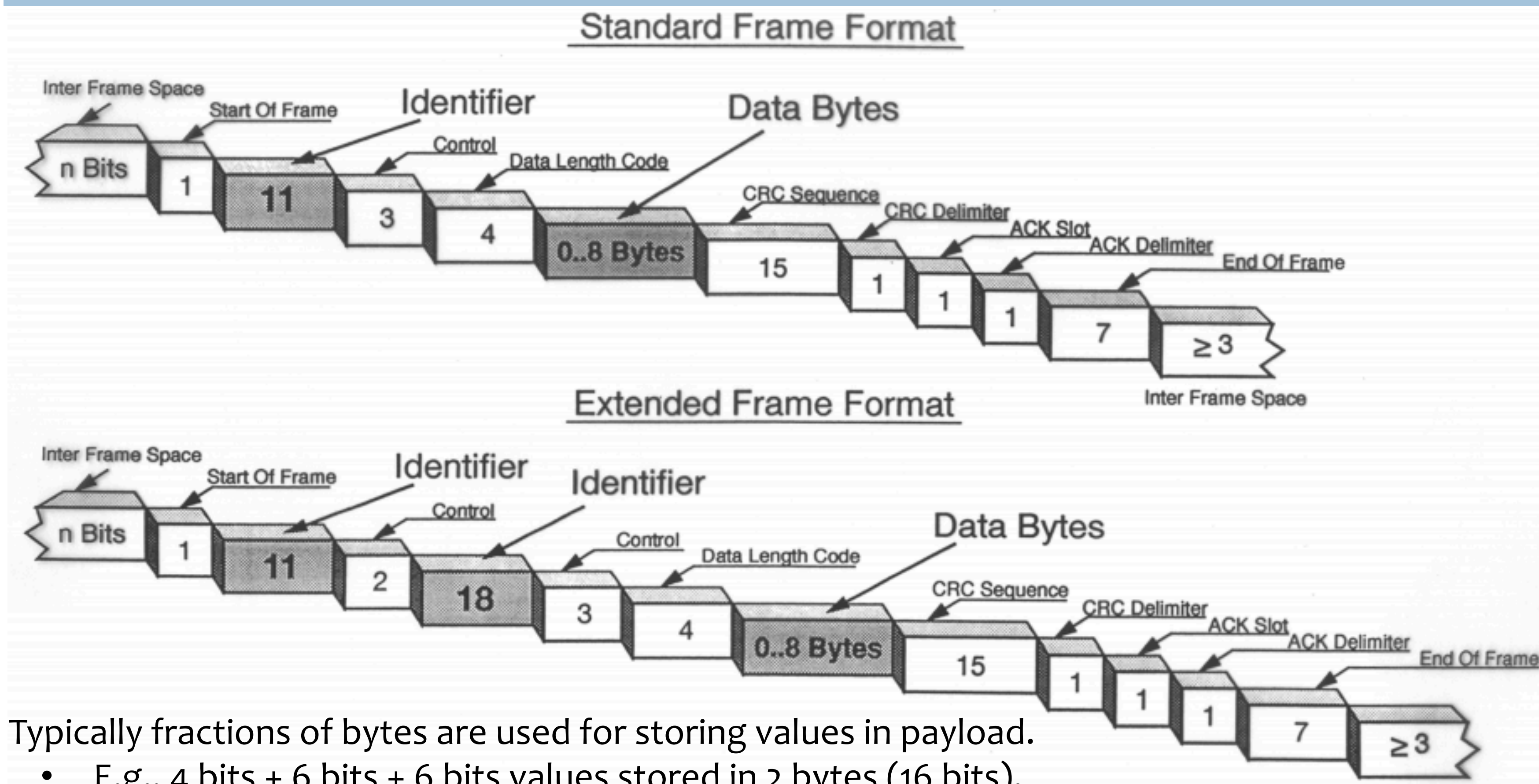
CAN frame format



- Typically fractions of bytes are used for storing values in payload.
  - E.g., 4 bits + 6 bits + 6 bits values stored in 2 bytes (16 bits).
- How to extract and interpret e.g. 6 last bytes in practice?

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CAN data rates

Payload length	Throughput data rate	
	Std. Frame	Ext. Frame
0	–	–
1	72,1 kBit/s	61,1 kBit/s
2	144,1 kBit/s	122,1 kBit/s
3	216,2 kBit/s	183,2 kBit/s
4	288,3 kBit/s	244,3 kBit/s
5	360,4 kBit/s	305,3 kBit/s
6	432,4 kBit/s	366,4 kBit/s
7	504,5 kBit/s	427,5 kBit/s
8	576,6 kBit/s	488,5 kBit/s

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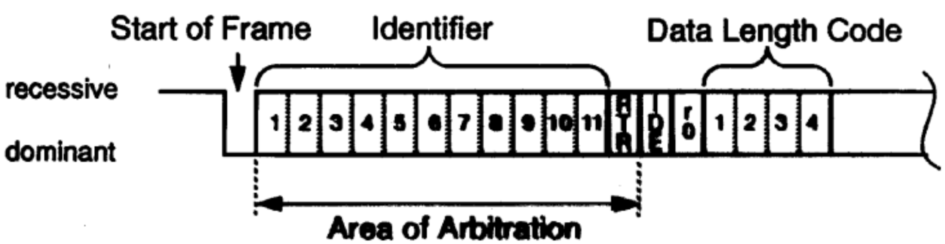
10 min break

up next: CAN medium access using CSMA/CD+AMP:

(Carrier Sense Multiple Access/Collision Detection with Arbitration on Message Priority)

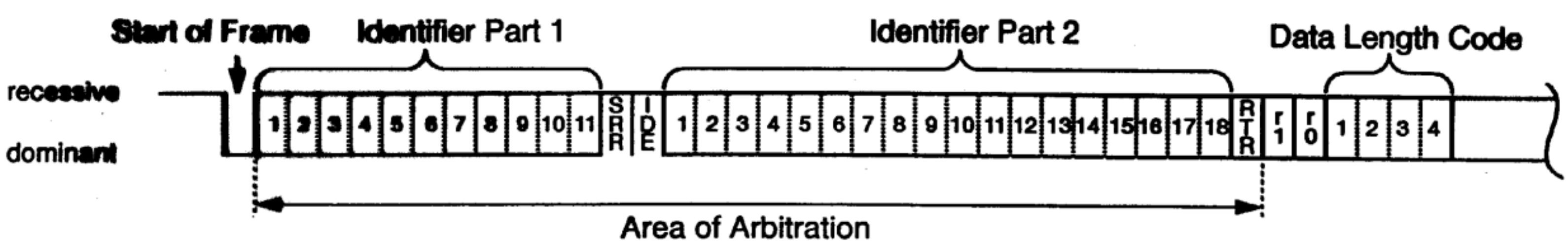
CAN arbitration

- All nodes transmit on shared medium (bus)
- Collision detection + avoidance using CSMA/CD+AMP:
  (Carrier Sense Multiple Access/Collision Detection with Arbitration on Message Priority)



TX	Bus (RX)	Action
rec.	rec.	proceed with arbitration
dom.	dom.	proceed with arbitration
rec.	dom.	arbitration lost
dom.	rec.	bit error

Extended Frame Format



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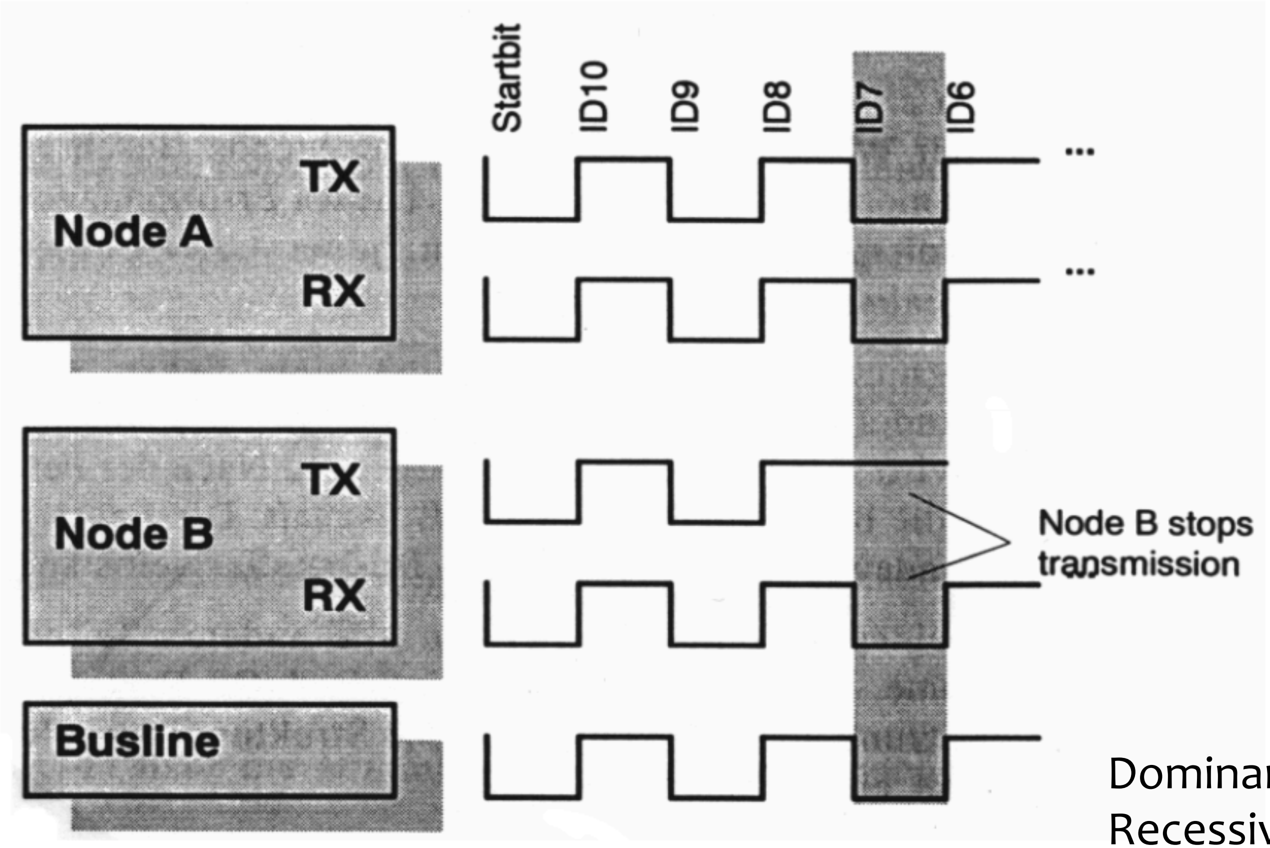
CAN arbitration



Dominant bit: voltage on bus
Recessive bit: listen only

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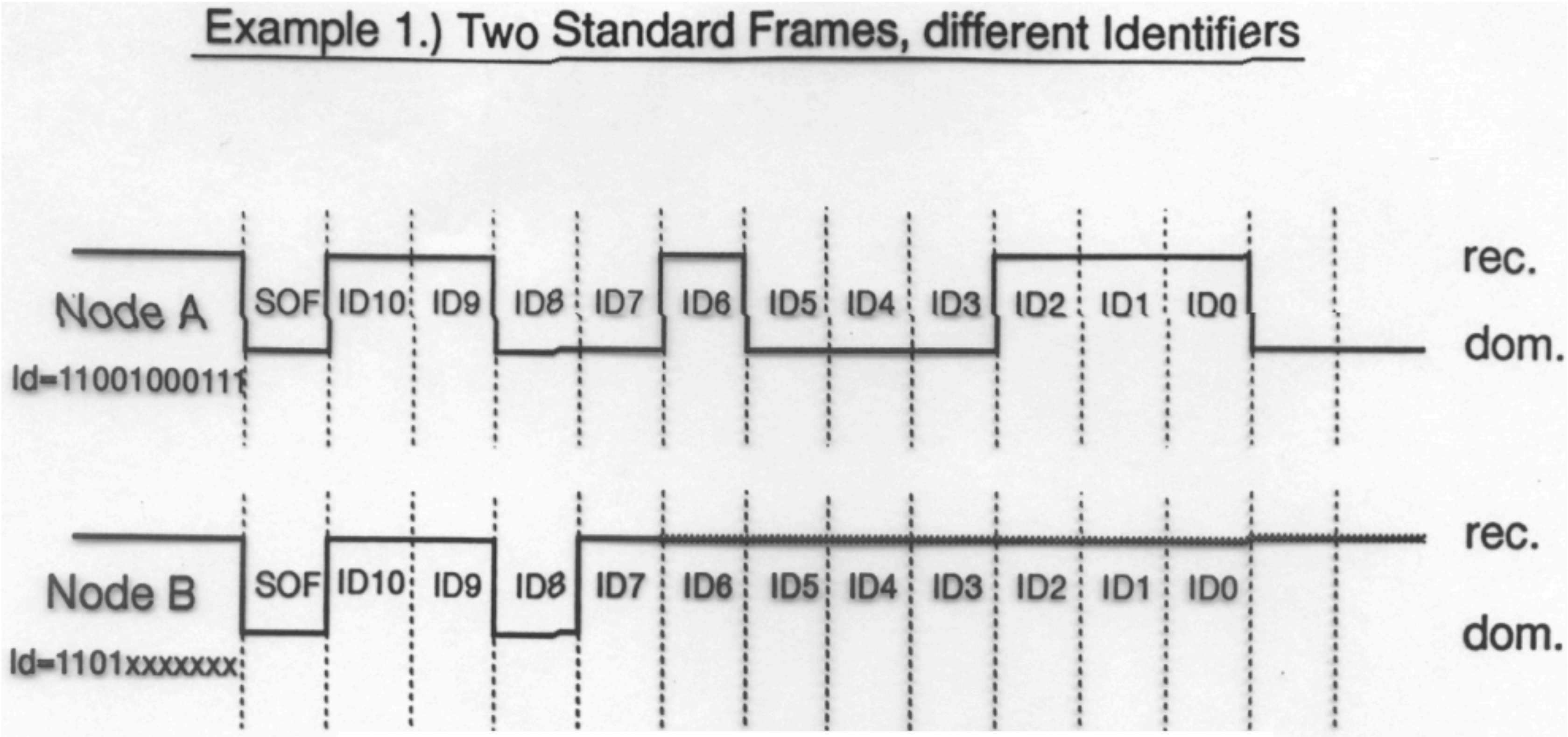
CAN arbitration: blackboard



Node B loses arbitration; node A proceeds

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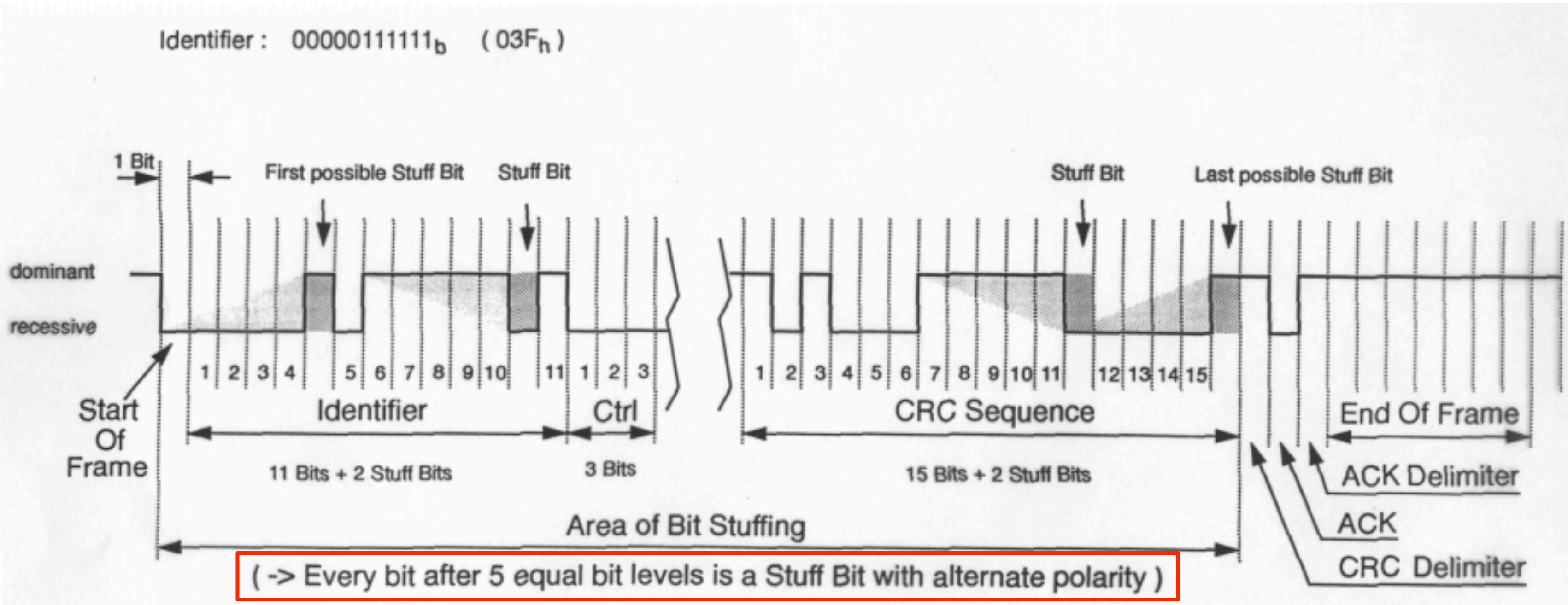
Discussion

- What is the difference between:
  - CAN frame ID
  - Ethernet frame address

- Solution:
  - The CAN frame ID is the identifier of a message, any node can listen and receive any frame if it "subscribes" to the frame ID.
    - A node will typically use different message IDs for different connected sensors/actuators:
      - Example: window up/down, motor RPMs, speedometer, cabin light status, radio channel, …
  - The Ethernet frame address specifies the destination interface address (MAC address).
    - Only a single recipient or all, in case of broadcast.

CAN bit-stuffing



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- High bit-variability gives slightly better efficiency.
- Stuff-bits allow re-synchronization to align bits

CAN bit timing

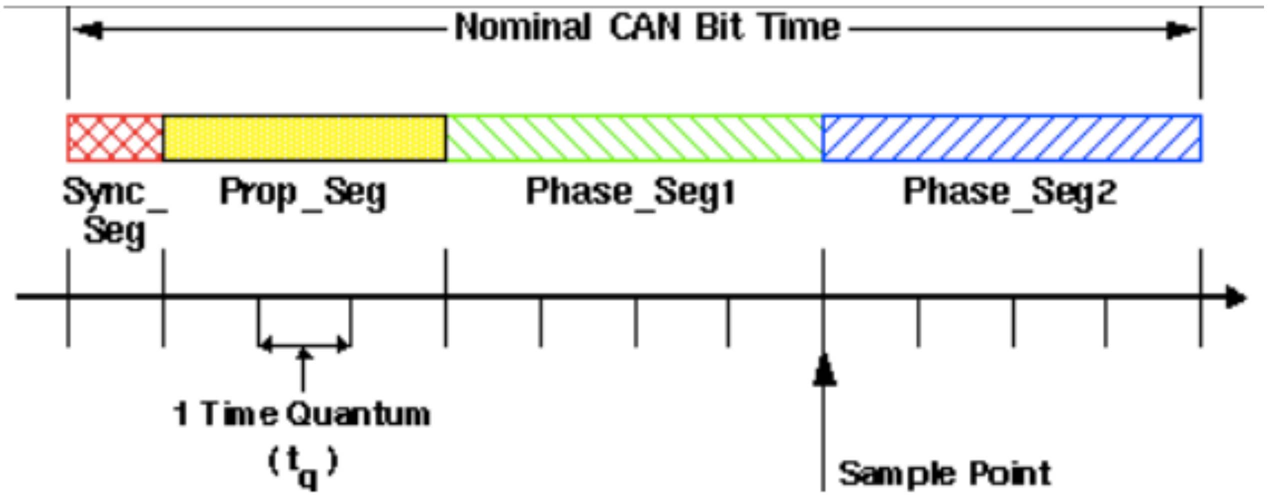


Figure 1 : Bit Timing

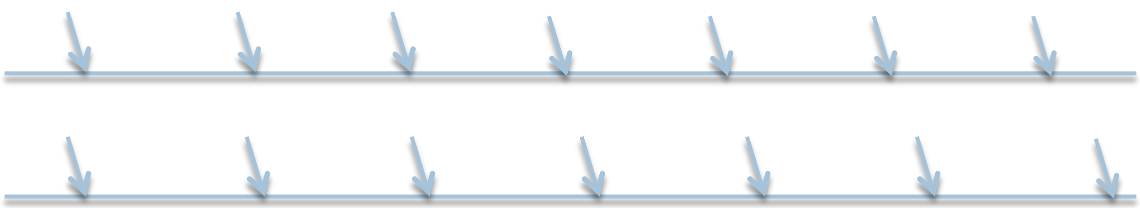
Parameter	Range	Remark
BRP	[1 .. 32]	defines the length of the time quantum t_q
Sync_Seg	1 t_q	fixed length, synchronization of bus input to system clock
Prop_Seg	[1 .. 8] t_q	compensates for the physical delay times
Phase_Seg1	[1 .. 8] t_q	may be lengthened temporarily by synchronization
Phase_Seg2	[1 .. 8] t_q	may be shortened temporarily by synchronization
SJW	[1 .. 4] t_q	may not be longer than either Phase Buffer Segment
This table describes the minimum programmable ranges required by the CAN protocol		

Table 1 : Parameters of the CAN Bit Time

From: http://www.can.bosch.de

CAN clock drift

- Applications on different ECUs are not necessarily clock-synchronized
  - (Even though CAN controllers are bit-synchronized)
  - For example two tasks with “same” cycle time:



  - Time-varying offset → non-deterministic scheduling
  - We need to be aware of actual worst case
  - Easy to analyze for 2 ECUs, but whole system with gateways?

Field bus complexity

Today's CAN networks:

- Hundreds of messages
  - a message is an application input/output, usually 1 CAN ID.
- Multiple and mixed busses (CAN+FlexRay)
  - Connected using gateways (queuing in GWs)
- Latency requirements of down to 5 ms or less (end-to-end!)
- Both periodic and aperiodic traffic (event based)
- Target bus loads of 50% – 60% and even more

- How to ensure requirements?

http://www.slideshare.net/fullscreen/REALTIMEATWORK/can-in-automotive-applications-a-look-forward/4

Verification of field bus configuration

- Ensure application real-time requirements are satisfied
  - Requirement example:
    - message arrival interval of 5ms ± 10% in 90% of cases.
    - at most 3 consecutive deadline misses.
- Methods:
  - Exhaustive worst-case search
    - Not feasible in complex networks
  - Network calculus (intro on 7th semester)
    - Analytic modeling of traffic flows
    - Takes link capacities and queuing bottlenecks into account
  - Simulation of realistic scenarios
    - Represents typical behavior
    - No guarantees for seeing worst case

Simulation of CAN networks

- Vector CANoe
  - Commercial product
  - Vector's tool chain is used by many car manufacturers for in-car network design.
  - Windows only, ~800MB
- **RTaW-Sim**
  - Free (starter edition)
  - Less polished than CANoe, but powerful analysis options.
  - Should work on both Windows and Linux, ~20MB
    - However, windows version seems to not work currently.

RTaW-Sim

- Download software and manual/tutorial from http://www.realtimeatwork.com/downloads/

- Group exercises – learning by doing:
  - Follow the steps in the tutorial and answer the questions on the following slides.
  - Remember, these questions will be used for the exam, so answer them properly…
  - Send your answers in an email to me, 1 set of answers per group.
    - email: jjn@es.aau.dk
    - please use the subject:
      "**ITC5 NTDS CAN lecture questions group 13grXXX**",
      replacing XXX by your group id.

Questions (1) monobus

- Section 2.2:
  - Use the figure on page 14 to argue: “How long time is it necessary to simulate this scenario to get a representative view of performance?”
    Note: be aware that the x-axis shows frame ids, not time!
- Section 2.3:
  - Lower figure on page 21:
    - Explain why frame 37 is delayed.
    - If frame 37 has a max delay requirement of 4 ms (which is not fulfilled currently), which change could a network designer make to fulfill this?
- Section 2.4:
  - *Note: on page 25, bottom, the text says “left-click on the BusSimulation field”, however, I had to right-click and choose Set.*
  - Figure on page 28:
    - Why is the red curve above the green?
    - Why do frames with high IDs have higher response times than low ID frames?
- Section 2.5:
  - Explain how the delay caused by a frame transmission error can be longer than the time it takes to retransmit the frame.

Questions (2) gateway

- Section 2.6:
  - Which delays can occur in a gatewayed system like this?
  - Figure on page 44: What does the difference between the curves represent?
  - Optional: Figure on page 45: Explain how the “Bus_1 local delays” (green) can be higher than “Bus_2 cluster delays” (purple)?