1. (Distributed real-time systems) Answer the following questions:

a) Moving from a centralized computing system to a distributed computing system, what are the main technical challenges, as you can see?
b) What are the main MAC protocols for shared media accesses in distributed systems?

a) Communication between systems
meet every system's deadline

b) MAC: Medium Access Control

Master - slave

TDMA (Time Division Multiple Access)

Token circulation

CSMA (Carrier-Sense Multiple Access)
→ CSMA-CD (collision detection)
→ CSMA-CR Collision resolution)

2. (CAN bus basics) The CAN protocol is designed to use the priority-based arbitration to resolve collisions in message transmission.

a) Explain how the priority based arbitration is achieved from both physical and frame format designs.
b) Assume that 3 CAN messages M1, M2, M3 are transmitted to the bus at the same time. Their 11-bit identifiers have values of 0x15a, 0x165, 0x192, respectively. Draw a picture to show the arbitration process and which message will be transmitted through the bus.
c) What is bit stuffing? Why need it?
d) Consider a standard CAN frame, what is the possible maximum number of stuffed bits? Illustrate the bit sequence of the message which has maximum stuffed bits.

a) physical design:

Messages have a unique (pre-defined) global identifiers

each node can send many messages

frame format design:

11-bit identifier

Smaller Id value, higher priority

compare bit-by-bit, bigger Id withdraw

b)

M1 = 0x 15A

= 00101011010

M2 = 0x 165

= 00101100101

M3 = 0x 192

= 00110010010

withdraw

M3 0 0 1 1

withdraw

M2 0 0 1 0 1 1

M1 0 0 1 0 1 0

M1 will be transmitted

c) bit stuffing:

if 5 consecutive bits with the same level appear, one bit of inverted data is added

why: 000000 and 111111

are used to signal error

d) maximum number of stuffed bits:

$$\left\lfloor \frac{\overset{34}{g} + 8\overset{8}{s_i} - 1}{4} \right\rfloor = \left\lfloor \frac{98-1}{4} \right\rfloor = 24$$

Before stuffing: 11111 0000 11111 0000 11111 ...

after stuffing: 11111 0 0000 1 11111 0 0000 1 ...

3. (WCRT analysis for preemptive tasks) There are 4 tasks periodically executed in a uni-processor system, which employs priority-based preemptive scheduling. Tasks with a smaller index have a higher priority. The tasks' properties are listed in the table below. The system requires that all tasks meet their deadlines. Determine the tolerable jitter for task T3 and T4.

Task	Period T	Deadline D	Jitter J	Execution time C
T1	5	5	1	2
T2	10	10	2	1
T3	20	20	?	2
T4	30	28	?	3

for task3:

$$W_3^0 = 0$$

$$W_3^1 = 2 + 2\times1 + 1\times1 = 5$$

$$W_3^2 = 2 + 2\times2 + 1\times1 = 7$$

$$W_3^3 = 2 + 2\times2 + 1\times1 = 7$$

$$\therefore \quad W_3 = 7 \qquad J_3 = R_3 - W_3 = 20 - 7 = 13$$

For task4:

$$W_4^0 = 0$$

$$W_4^1 = 3 + 2 + 1 + 2 = 8$$

$$W_4^2 = 3 + 2\times2 + 1\times1 + 2\times2 = 12$$

$$W_4^3 = 3 + 2\times3 + 1\times2 + 2\times2 = 15$$

$$W_4^4 = 3 + 2\times4 + 1\times2 + 2\times2 = 17$$

$$W_4^5 = 3 + 2\times4 + 1\times2 + 2\times2 = 17$$

$$\therefore \quad W_4 = 17 \qquad J_4 = R_4 - W_4 = 28 - 17 = 11$$

4. (Per-node and End-to-End WCRT analysis) Explain the following terms. What are they used for?

a) Critical instant
b) Priority inversion
c) Busy period
d) Attribute inheritance

a) critical instant:

Mi with maximum queuing jitter is queued with all higher priority messages simultaneously, then each of these higher priority messages is subsequently queued again after the ~~shortest~~ possible time interval

the time from release to finishing executing

b) Priority inversion

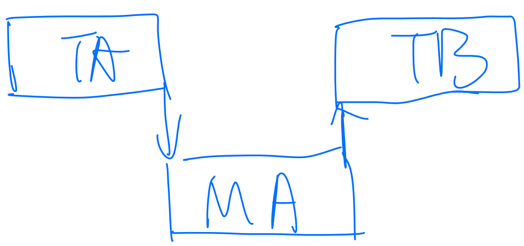
A lower priority message with maximum execution time starts to be transmitted just before the instant

To estimate blocking time

c) Busy period

a time interval during which the resource is occupied continually

d) attribute inheritance



MA inherit the Jitter from TA

TB inherit the Jitter from MA

$J_{MA} = R_{TA}$

$J^{inh}_{TB} = R_{MA}$

to estimate the jitter time

5. (BCRT, WCRT analysis for CAN messages) In a CAN system, the bus length is 50 meters. There are 3 periodic standard messages to be transmitted over the CAN bus. Assume that the messages' deadlines are equal to their periods, determine the following:

a) the BCRT for each message;
b) if the messages can meet their deadlines in any conditions.

Message	Period T (ms)	Jitter J (ms)	Priority	Data length (bytes)
M1	5	1	High	4
M2	10	2	Middle	6
M3	20	3	Low	8

Communication time 34

$C_i = \left(\left\lfloor \frac{g + 8s_i - 1}{4} \right\rfloor + g + 8s_i + 13\right) t_{bit}$ → time to transmit one bit

a) M1 : $34 + 8 \times 4 + 13 = 79$ 0.079 ms

M2 : $34 + 8 \times 6 + 13 = 95$ 0.095 ms

M3 : $34 + 8 \times 8 + 13 = 111$ 0.111 ms

Priority inversion

b) WCRT of M1:

$B_1 = C_3 = 0.111$ ms $W_1 = C_1 + B_1 = 0.079 + 0.111$
$= 0.19$ ms

$R_1 = J_1 + W_1 = 1 + 0.19 = 1.19$ ms ≤ 5ms ✓

WCRT of M2:

$B_2 = C_3 = 0.111$ ms

$w_2^0 = 0$

$w_2^1 = C_2 + B_2 + C_1 = 0.095 + 0.111 + 0.079 = 0.285$

$w_2^2 = C_2 + B_2 + C_1 = 0.285$

$\therefore R_2 = W_2 + J_2 = 0.285 + 2 = 2.285 \leq 10$

✓

WCRT of M3:

$B_3 = 0$ ms

$w_3^0 = 0$

$w_3^1 = C_3 + C_1 + C_2 = 0.111 + 0.079 + 0.095 = 0.285$

$w_3^2 = C_3 + C_1 + C_2 = 0.285$

$R_3 = J_3 + W_3 = 3.285 \leq 20$ ✓

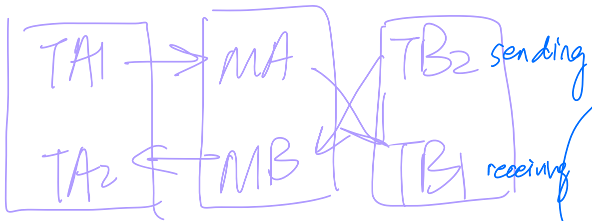
6. (End-to-End WCRT analysis) In a CAN system, ECU A and ECU B are connected via the CAN bus and communicate with each other through the CAN bus.

- Task TA1 in node A periodically sends a message MA to task TB1 in node B.
- Task TB2 in node B periodically sends a message MB to task TA2 in node A.

Assume that tasks executing on an ECU use priority-based preemptive scheduling, the sending tasks have higher priority than the receiving tasks, and message MA has higher priority than MB. The parameters of the tasks and messages are shown in the table below.

Calculate the following:

a) the end-to-end WCRT for TA1->MA->TB1;
b) the end-to-end WCRT for TB2->MB->TA2.



	Period T	Jitter J	Execution Time C
TA1	100	3	7
TA2	—	3	5
TB1	—	2	5
TB2	100	2	6
MA	—	—	5
MB	—	—	8

a) WCRT of TA1

$w^0_{TA_1} = 0$

$w^1_{TA_1} = C_{TA_1} = 7$

$w^2_{TA_1} = C_{TA_1} = 7$

$\therefore\ w_{TA_1} = 7,\ R_{TA_1} = 3 + 7 = 10$

WCRT of MA:

$J_{MA} = R_{TA} = 10$ priority inversion. $\underset{MA}{5} + \underset{MB}{8}$

$R_{MA} = J_{MA} + C_{MA} = 10 + 13 = 23$

WCRT of TB1:

$J_{TB} = J^{inh}_{TB} + J^{processing}_{TB}$

$= 23 + 2 = 25$

$R_{TB} = J_{TB} + C_{TB} = 25 + \underbrace{11}_{\underset{TB1}{5} + \underset{TB2}{6}} = 36$

b) WCRT for TB2

$W^0_{TB_2} = 0$

$W^1_{TB_2} = 6$

$R_{TB_2} = W_{TB_2} + J_{TB_2} = 6 + 2 = 8$

WCRT for MB:

$J_{MB} = R_{TB_2} = 8$

$R_{MB} = J_{MB} + C_{MB} = 8 + (8+5) = 21$

WCRT for TA_2:

$J_{TA_2} = J^{inh}_{TA_2} + J^{processing}_{TA_2} = 21 + 3 = 24$

$R_{TA_2} = J_{TA_2} + W_{TA_2} = J_{TA_2} + (C_{TA_2} + R_{TA_2})$

$= 24 + (5+7) = 36$

7. (End-to-End WCRT analysis) In the same system above, we make another assumption that the <u>receiving tasks</u> have higher priority than the <u>sending tasks</u>, and still message MA has higher priority than MB. Use the same parameters, re-calculate the following:

    a) the end-to-end WCRT for TA1->MA->TB1;
    b) the end-to-end WCRT for TB2->MB->TA2.

ⓐ WCRT of TA_1:

$R_{TA_1} = J_{TA_1} + W_{TA_1} = 3 + 7 + 5 = 15$

WCRT of MA:

$R_{MA} = J_{MA} + C_{MA} = 15 + 5 + 8 = 28$

WCRT of TB_1:

$R_{TB_1} = J_{TB_1} + W_{TB_1} = (28+5) + 2 = 35$

b) WCRT of TB_2:

$R_{TB_2} = J_{TB_2} + W_{TB_2} = 2 + 6 + 5 = 13$

WCRT of MB:

$R_{MB} = J_{MB} + W_{MB}$

$= 13 + 8 + 5 = 26$

WCRT of TA_2

$R_{TA_2} = J_{TA_2} + W_{TA_2}$

$= (26+3) + 5$

$= 34$

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8. (MAC protocols) There exist a number of MAC protocols, which have pros and cons for real-time networking. Discuss if the following protocols suit for real-time communication performance.

   a) Token circulation
   b) CSMA CD (Collision Detection)
   c) CSMA CR (Collision Resolution) or CA (Collision Avoidance)
   d) TDMA

a) not suitable.
priority are fixed, can't give higher priority to urgent tasks

b) CSMA-CD

non-deterministic. not suitable
urgent task can be interrupted by other (collision)

c) CSMA-CR : suitable
avoid collision

d) TDMA : suitable despite latency, can still arrange urgent task

9. (CAN, TTP and FlexRay) A student makes the following statements after learning CAN, TTP and FexRay. Determine if they are correct or incorrect? Why?

a) The CAN bus requires that all nodes must use a global clock to synchronize the message transmission.
b) In TTP architecture, message communication time depends on if there are other messages waiting to be transmitted.
c) Like CAN, TTP prioritizes messages in order to speed up the transmission of urgent ones.
d) The TTP protocol requires that all nodes share the same notion of time. This has to be achieved using a shared global clock. ?
e) FlexRay is also event-triggered. Just like CAN, it uses ~~CSMA~~ CR as its MAC protocol.

a) no
event-triggered, doesn't rely on clock

b) X doesn't depend on other messages

c) V actually, TTP can prioritize messages
but it doesn't work like CAN

d) X doesn't necessarily need a shared global clock

e) X event-triggered + time-triggered
TDMA

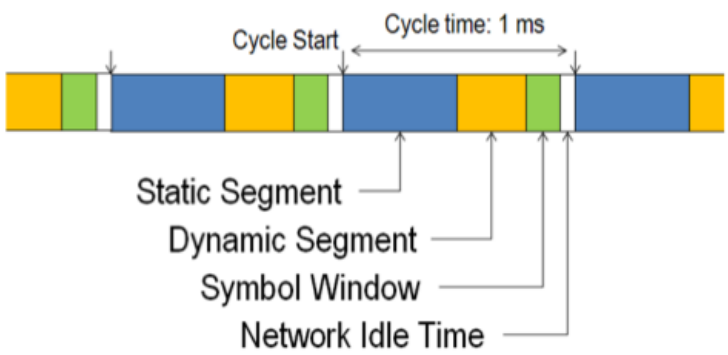
10. (FlexRay and CAN) FlexRay has both event-triggering (similar to CAN) and time-triggering (similar to TTP) features. Answer the following questions.

a) What is the communication cycle? How is it defined?
b) What is the static segment, and how is it used to send messages?
c) What is the dynamic segment, and how is it used to send messages?
d) Discuss the bus utilization for CAN, TTP/C, and FlexRay.

a) communication cycle:

The fundamental element of the media-access scheme within FlexRay

Data is sent and received in predictable time-frames, and dynamic event-driven communication



b) static segment

all static slots have the same duration

each static slot is assigned to one node.

if a node owns the current slot,

if a frame is ready, the node transmits the frame in the slot.

if no frame is ready, or a frame is not scheduled to transmit in the given slot, node sends a special null frame.

c) dynamic segment

used for dynamic event-driven communication

use minislots.

Dynamic slots with one ECU broadcasting data.

ECUs 2 and 3 broadcasting in their minislots and leaving no time for the lower-priority minislots.

d)

CAN: event-triggered system

⇒ system that transmits event messages

TTP: Time Triggered system

⇒ system that transmits state messagel

11. Briefly explain how credit-based shaping works and discuss its pros and cons.

when no frame in the queue, credit is set to 0

A queue is available to transmit when credit is nonnegative

Credit increased by idleslope when there is at least a frame in the queue

Credit decreased by SendSlope when a frame is transmitted

pros: fairer scheduling to low-priority packets
Smooths out the traffic flow

cons: increase average delay

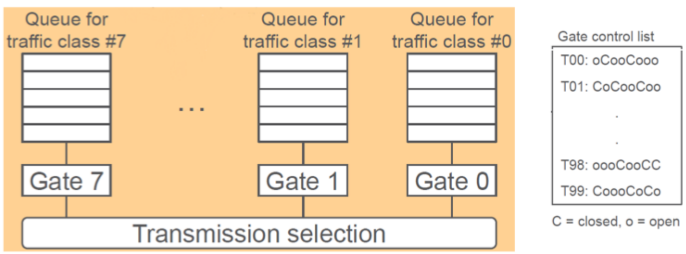
adopt non-preemptive scheduling

delay ~~too~~ high for control applications

12. Briefly explain how time-gated communication works and discuss its pros and cons.

different gate for different kinds of traffic

- Gated communication



- IEEE 802.1Qbv time-aware scheduler is designed to separate communication on the Ethernet network into fixed length, repeating time cycles.
- Within these cycles, different time slices can be configured or assigned to one or several of the eight Ethernet priorities.
- The basic concept is TDMA.

Here, each cycle comprises two time slices. Time slice 1 only allows the transmission of traffic tagged with VLAN priority 3, and time slice 2 allows for the rest of the priorities to be sent.
Within time slice 2, the priorities are handled according to standard IEEE 802.1Q *strict priority scheduling*.

Pros: bandwidth reservation
can prioritize urgent missions
deterministic delays

Cons: additional guard, network size not scalable