(Till tentamensvakten: engelsk information behövs)

Exam

Embedded Systems II, DVA404
Västerås, 2018-08-15

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Exam duration:	08:10 – 12:30	
Help allowed:	Calculator, language dictionary, ruler, and APPENDIX attached to this exam.	
Points:	48 p	
Grading:	Swedish grades:	ECTS grades:
	< 26 → failed	< 26 → F
	26 – 34 p → grade 3	26 – 29 → D
	35 – 41 p → grade 4	30 – 36 → C
	42 – 48 p → grade 5	37 – 41 → B
		42 – 48 → A

Instructions:

- Answers MUST be written in English.
- Short and precise answers are preferred. Do not write more than necessary.
- Use a new sheet for each of the six assignments.
- If some assumptions are missing, or if you think the assumptions are unclear, write down what do you assume to solve the problem.
- Write clearly. If I cannot read it, you get zero points.

Good luck!!

Assignment 1: (8 points)

Briefly explain the following concepts related to scheduling and schedulability analysis:

1. Real-time task
2. Feasible schedule
3. Processor utilization factor
4. Schedule hyperperiod
5. Critical instant
6. Server-based scheduling
7. Useful cache blocks (UCBs)
8. Evicting cache blocks (ECBs)

Assignment 2: (8 points)

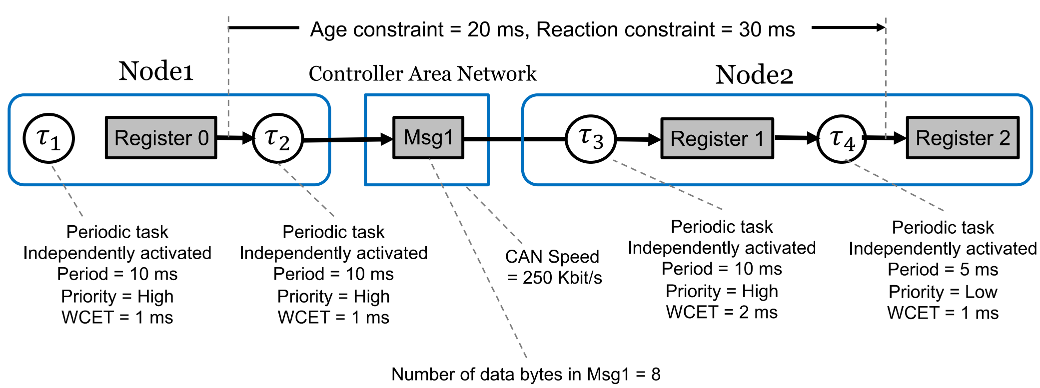
Consider the distributed system shown in the following figure. The system consists of two nodes that are connected by a Controller Area Network (CAN). The speed of the CAN network is 250 Kbit/s. There is only one CAN message that carries the data payload of 8 bytes.

There are two tasks in each node. The parameters of the tasks are shown in the figure. For example, Task τ_2 is independently activated by a 10 ms periodic timer. The priority of τ_2 is high and its Worst Case Execution Time (WCET) is 1 ms.

The system contains one multi-rate chain that reads input data from Register 0 in Node1 and writes output data to Register 2 in Node2. The data from the input to the output of the chain traverses through task τ_2, message Msg1, task τ_3, Register 1, and task τ_4. The Age and Reaction constraints specified on the chain are 20 ms and 30 ms respectively.

Question
Are the specified Age and Reaction constraints satisfied or not? Demonstrate this by calculating the Age and Reaction delays in the multi-rate chain graphically, i.e., by drawing the execution trace of the system and identifying the age and reaction delays.

If you need to make any assumptions, please explicitly specify them.



Assignment 3: (8 points)

Assume we have the following three different schedulability tests:

1. $U \leq 0.69$
2. $U \leq 5(2^{1/5}-1)$.
3. $U \leq 1$.
4. Basic response time analysis with critical instant assumption that all tasks are released simultaneously.

Assume further that we have four different task sets (independent tasks, no blocking) with following properties:

a. 3 tasks with D=T, priorities according to rate monotonic, and scheduling according to static priorities.

b. 5 tasks with D=T, scheduling according to EDF.

c. 5 tasks with D<T, priorities according to deadline monotonic, and scheduling according to static priorities.

d. 5 tasks with D=T, tasks have offsets, priorities according to rate monotonic, and scheduling according to static priorities.

For every task set classify if the three schedulability tests are:

I. Sufficient
II. Necessary
III. Sufficient and necessary
IV. Nor sufficient nor necessary
V. Not applicable: That is, the test cannot be performed on the task set.

That is, construct the following matrix with four rows (the 4 schedulability tests: 1,2,3,4) and four columns (the different task sets:a,b,c,d) and for every location in the matrix, classify I, II, II, IV or V.

	Task set a	Task set b	Task set c	Task set d
Test 1	I-V?	I-V?	I-V?	I-V?
Test 2	I-V?	I-V?	I-V?	I-V?
Test 3	I-V?	I-V?	I-V?	I-V?
Test 4	I-V?	I-V?	I-V?	I-V?

Important note: ½ a point for correct classification, -½ for a wrong classification. So, guessing is a poor strategy. If you do not know, it is better to leave that position blank.

Assignment 4: (4 points)

Consider the following piece of code:

```
A: i = 2;
B: while i < 100 do
C:   if i = x then
D:     x = x*i;
E:   i = i + 1
   end
```

Assume, for elementary statements A - F (assignments, conditions), that their local worst-case execution times are (in clock cycles):

```
A  10
B  7
C  8
D  21
E  9
```

Calculate a WCET estimate for the code using the tree-based method! Try to give an estimate that is as tight as possible while being safe. (4p)

Assignment 5: (12 points)

(a) Consider a task set that consists of three periodic tasks as shown in Table 5-A. The priorities are assigned to the tasks according to the Rate Monotonic algorithm. Define critical instant for the lowest priority task. Using the fixed-priority preemptive scheduling, draw an execution trace up to one hyper period that shows the critical instant for the lowest priority task. Assume the following while defining the critical instant. (3 points)

1) The tasks are independent (no resource sharing; no synchronization).
2) The tasks do not experience any jitter.
3) There are no offset relations among the tasks.

Table 5-A.

Task	Period	Execution Time
τ_1	5	1
τ_2	10	1
τ_3	20	1

(b) Now repeat part (a) by considering that the tasks experience jitter according to Table 5-B. The rest of the assumptions in part (a) remain the same. (3 points)

Table 5-B.

Task	Maximum Jitter	Minimum Jitter
τ_1	5	0
τ_2	9	0
τ_3	0	0

(c) Assume that the tasks in part (a) are scheduled with offsets. The rest of the assumptions in part (a) remain the same. Further assume that the three tasks in part (a) belong to a transaction, denoted by Transaction 1. The tasks have the following offsets:

Offset of τ_1 = 0, Offset of τ_2 = 4, Offset of τ_3 = 1.

Also assume another transaction, denoted by Transaction 2, which contains only one task. The priority of this task is lower than the priority of each task in Transaction 1. The offset of this task is 0.

Describe critical instant for the only task belonging to Transaction 2. Draw an execution trace up to one hyper period of Transaction 1 that shows the critical instant for the only task in Transaction 2. (6 points)

Assignment 6: (8 points)

Assume a real-time system with seven periodic tasks:

Task	Period (T)	Deadline (D)	Exec.time(C)
A	1000	20	3
B	100	100	10
C	50	50	20
D	57	10	5
E	33	33	1
F	7	7	1
G	30	5	2

There are also four semaphores used to protect shared resources, accessed by the tasks as follows:

Task	Semaphore	Length of critical section
A	S_1	2
	S_3	2
B	S_2	7
	S_3	5
	S_4	2
D	S_1	2
C	S_2	1
G	S_1	1

For example, we can see above that task B uses three semaphores S_2, S_3 , S_4, and the length of the critical sections of task B is 7 when using S_2, 5 for S_3 and 2 for S_4.

Assume Deadline Monotonic (DM) priority assignment for the tasks, and Priority Ceiling Protocol (PCP) for semaphore access.

a) Calculate the system load (1p)
b) Calculate the blocking factor for each task (2p)
c) Calculate the response-time for task G (2p)
d) Calculate the response-time for task A (2p)
e) Are tasks A and G schedulable? (1p)

NOTE! There is an appendix with equations on the next page!!

APPENDIX 1: Formulas and equations

$$U = \frac{C_1}{T_1} + \frac{C_2}{T_2} + \ldots + \frac{C_n}{T_n} = \sum_{i=1}^{n} \frac{C_i}{T_i}$$

$$\forall L \in D : L \geq \sum_{i=1}^{n} \left(\left\lfloor \frac{L - D_i}{T_i} \right\rfloor + 1 \right) C_i$$

$$U \leq n(2^{1/n} - 1)$$

$$D = \{ d_{i,k} \mid d_{i,k} = kT_i + D_i, d_{i,k} < LCM, 1 \leq i \leq n, k \geq 0 \}$$

$$U_P + U_s \leq (n+1)(2^{1/(n+1)} - 1)$$

$$d_k = \max(a_k, d_{k-1}) + \frac{C_k}{U_s}$$

$$d_k = a_k + \frac{C_k}{U_s}$$

$$T_s + \left\lceil \frac{C_a}{C_s} \right\rceil T_s \leq D_a$$

$$W_{ic}(\tau_{ua}, t) = \sum_{\forall j \in hp_i(\tau_{ua})} \left\lceil \frac{t - \Phi_{ijc}}{T_i} \right\rceil C_{ij},$$

$$\Phi_{ijc} = O_{ij} - O_{ic} \bmod T_i$$

$$U_p \leq n \left[\left(\frac{U_s + 2}{2U_s + 1} \right)^{1/n} - 1 \right]$$

$$w_i^{n+1} = C_i + B_i + \sum_{\forall j \in hp(i)} \left\lceil \frac{w_i^n + J_j}{T_j} \right\rceil C_j$$

$$R_i^{n+1} = C_i + \sum_{\forall j \in hp(i)} \left\lceil \frac{R_i^n}{T_j} \right\rceil C_j$$

$$R_i = w_i + J_i^{\max}$$

$$W_i^*(\tau_{ua}, t) = \max_{\forall c} \left(W_{ic}(\tau_{ua}, t) \right)$$

$$R_i^{n+1} = C_i + B_i + \sum_{\forall j \in hp(i)} \left\lceil \frac{R_i^n}{T_j} \right\rceil C_j$$

$$R_{ua} = C_{ua} + \sum_{\forall i} W_i^*(\tau_{ua}, R_{ua})$$

$$w_i^{n+1} = C_i + B_i + \sum_{\forall j \in hp(i)} \left\lceil \frac{w_i^n + J_j}{T_j} \right\rceil C_j$$

$$R_i^{n+1} = C_i + \sum_{\forall j \in hp(i)} \left\lceil \frac{R_i^n}{T_j} \right\rceil C_j$$

$$R_i = w_i + J_i^{\max}$$

$$W_i^*(\tau_{ua}, t) = \max_{\forall c} \left(W_{ic}(\tau_{ua}, t) \right)$$

$$U_P + U_S \leq 1$$

$$R_i^{n+1} = C_i + B_i + \sum_{\forall j \in hp(i)} \left\lceil \frac{R_i^n}{T_j} \right\rceil C_j$$

$$R_{ua} = C_{ua} + \sum_{\forall i} W_i^*(\tau_{ua}, R_{ua})$$

$$w_i^{n+1} = B_i + \sum_{\forall j \in hp(i)} \left\lceil \frac{w_i^n + J_j + \tau_{bit}}{T_j} \right\rceil C_j$$

$$C_i = \left(m + 8n + \left\lfloor \frac{34 + 8n - 1}{4} \right\rfloor \right) \tau_{bit}$$

$$R_i = J_i + w_i + C_i$$

m = number of control bits in a CAN frame (47 for 11-bit identifiers)
n = number of data bytes in a CAN frame
τ_{bit}= time needed to transfer one bit on the bus
(depends on the bus speed)

APPENDIX 2 – Formulas in LaTeX:

```
U = \frac{C_1}{T_1} + \frac{C_2}{T_2} + \dots + \frac{C_n}{T_n} = \sum_{i=1}^n \frac{C_i}{T_i}

U \leq n(2^{1/n}-1)

U_p + U_s \leq (n+1)(2^{1/(n+1)}-1)

\begin{align}
\forall L \in & D : L \geq \sum_{i=1}^n\left(\left\lfloor\frac{L-D_i}{T_i}\right\rfloor + 1 \right) C_i
\\ \notag
D = & \{ d_{i,k} | d_{i,k} = kT_i+D_i, d_{i,k} < LCM, 1 \leq i \leq n, k \geq 0 \}
\end{align}

d_k = a_k + \frac{C_k}{U_s}

d_k = \max(a_k, d_{k-1}) + \frac{C_k}{U_s}

T_s = \left\lceil\frac{C_a}{C_s}\right\rceil T_s \leq D_a

U_p \leq n \left(\left(\frac{U_s + 2}{2U_s+1}\right)^{1/n} - 1 \right)

\begin{align}
  W_{ic}(\tau_{ua}, t) = &
    \sum_{\forall j \in hp_i(\tau_{ua})} \left\lceil\frac{t-\Phi_{ijc}}{T_i}\right\rceil C_{ij}
  \\ \notag
  \Phi_{ijc} = & ( O_{ij}- O_{ic} ) \mod T_i
\end{align}

R_i^{n+1} = C_i + \sum_{\forall j \in hp(i)} \left\lceil\frac{R_i^n}{T_j}\right\rceil C_j

\begin{align}
  w_i^{n+1} = & C_i + B_i + \sum_{\forall j \in hp(i)}\left\lceil\frac{w_i^n + J_j}{T_j}\right\rceil C_j
  \\ \notag
  R_i = & w_i + J_i^{\max}
\end{align}

U_p + U_s \leq 1

R_i^{n+1} = C_i + B_i \sum_{\forall j \in hp(i)} \left\lceil\frac{R_i^n}{T_j}\right\rceil C_j

\begin{align}
  W_i^*(\tau_{ua},t) = & \max_{\forall c} \left(W_{ic}(\tau_{ua}, t)\right)
  \\ \notag
  R_{ua} = & C_{ua} + \sum_{\forall i} W_i^*(\tau_{ua}. R_{ua})
\end{align}

\begin{align}
  w_i^{n+1} = & B_i + \sum_{\forall j \in hp(i)}
  \left\lceil\frac{w_i^n + J_j + \tau_{bit}}{T_j}\right\rceil C_j
  \\ \notag
  R_i = & w_i + J_i + C_i
\end{align}

\begin{align}
C_i = & \left( m + 8n +
\left\lfloor\frac{34+8n-1}{4}\right\rfloor\right)\tau_{bit}
\\ \notag
m = & \text{number of control bits in a CAN frame (47 for 11-bit identifiers)}
\\ \notag
n = & \text{number of data bytes in a CAN frame}
\\ \notag
\tau_{bit} = & \text{time needed to transfer one bit on the bus (depdends on the bus speed)}
\end{align}
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