Synthesis of Communication Schedules for TTEthernet-based Mixed-Criticality Systems

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1. Introduction

- Safety-critical real-time applications, implemented using distributed architectures.
- Separation is required to implement applications of different criticality levels on the same architecture.

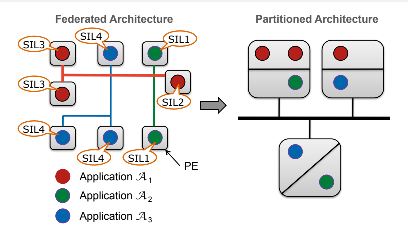


Figure 1. Mixed-criticality applications implemented using a federated architecture (left) and using a partitioned architecture (right).

2. TTEthernet is deterministic, synchronized and congestion-free, Ethernet based and ARINC 664p7 compliant.

- Separation achieved by using virtual links.
- Provides three traffic classes:
  - Time Triggered (TT), sent based on static schedule tables and have the highest priority;
  - Rate Constrained (RC), transmitted if there are no TT messages to be sent;
  - Best Effort (BE), with the lowest priority.

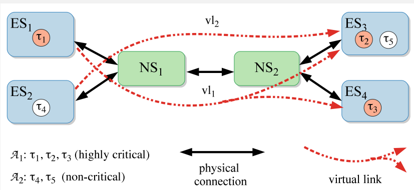


Figure 2. Example of a TTEthernet network, composed of 4 ESes, ES_1 to ES_4, and 2 NSes, NS_1 and NS_2. Each ES consists of a PE containing a CPU, RAM and non-volatile memory, and a network interface card (NIC).

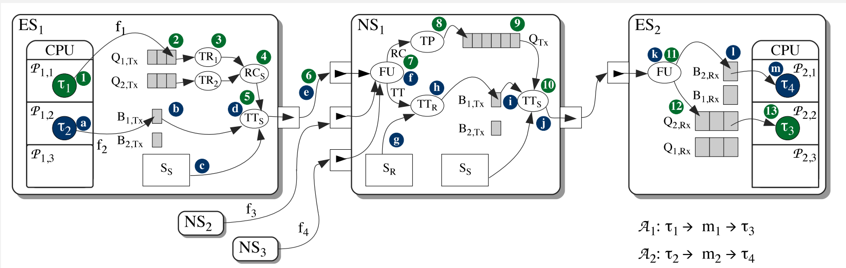
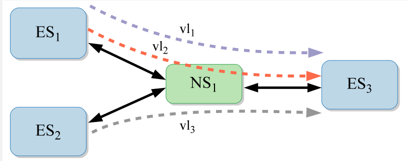


Figure 3. TT and RC message transmission example.



	period (μs)	deadline (μs)	C_i (μs)	$\mathcal{M}$
$f_1 \in \mathcal{F}^{RC}$	300	300	75	vl_1
$f_2 \in \mathcal{F}^{TT}$	200	200	50	vl_2
$f_3 \in \mathcal{F}^{TT}$	300	300	50	vl_3

Figure 4. Example system model. Example architecture model (upper figure) and example application model (lower figure). $\mathcal{F}^{TT}$ is the set of TT frames, while $\mathcal{F}^{RC}$ is the set of RC frames.

3. Problem Formulation

- **Find** the set of TT schedules
- **such that**
  - the deadlines for the given TT and RC frames are satisfied and
  - the end-to-end delay of RC frames is minimized.

4. Schedule Optimization Tabu Search (TS) based optimization strategy.

- The cost function:

$$Cost = w_{TT} \times \delta_{TT} + w_{RC} \times \delta_{RC} \quad (1)$$

$$\delta_{TT/RC} = \begin{cases} c_1 = \sum_i \max(0, R_{f_i} - f_i.deadline) & \text{if } c_1 > 0 \\ c_2 = \sum_i (R_{f_i} - f_i.deadline) & \text{if } c_1 = 0 \end{cases} \quad (2)$$

- Moves applied to TT frames:
  - *advance*
  - *advance predecessors*
  - *postpone*
  - *postpone successors*

- The strategy reserves space for RC traffic using:
  - *add blank*
  - *remove blank*
  - *resize blank*

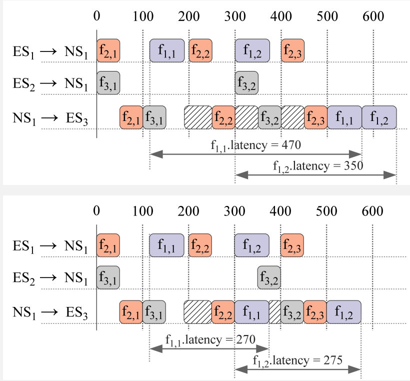


Figure 5. Worst case scenario for RC frame f_1 (see Fig. 2 for system details): initial TT schedule (upper figure) and optimized TT schedule (lower figure). In this example the network implements the *timely* block integration algorithm, thus a RC frame is blocked from transmission on a link if a TT frame is scheduled to be sent before the RC frame would complete its transmission. The white boxes represent these "blocked" time intervals.

5. Experimental Evaluation

Set	Test case	ES	NS	Messages	Frame instances	Load [%]	Δ_{cost} [%]
1	11	13	4	80	12593	50	2.58
	12	25	6	88	1787		24.44
	13	35	8	103	2285		20.06
	14	45	10	165	3299		11.90
2	21	11	4	115	16904	70	9.17
	22	25	6	179	2523		20.61
	23	35	8	154	3698		39.34
3	31	25	6	76	1387	40	37.97
	32			88	1787	50	24.44
	33			115	2503	60	40.47
	34			179	2523	70	20.61
	35			155	2960	80	32.10
4	41	35	8	65	1976	40	38.75
	42			103	2285	50	20.06
	43			89	2801	60	12.73
	44			176	3856	70	12.75
	45			135	3490	80	20.23
5	automotive	15	3	170	38305	80	50.88

Figure 6. Experimental evaluation results. The last column presents the comparison between the proposed strategy and the baseline solution, as a percentage improvement in terms of the cost function (see Eq. 1).

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Acknowledgements This work has been funded by the Advanced Research & Technology for Embedded Intelligence and Systems (ARTEMIS) within the project "RECOMP", support code 01IS1001A, agreement no. 100202.