Response Time Analysis of Multiframe Mixed-Criticality Systems

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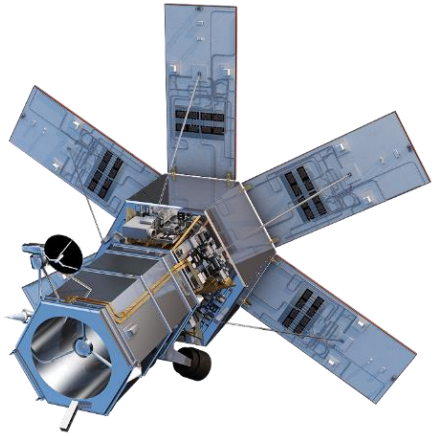
Outline

- Motivation
- Contribution
- Background
- System model
- Proposed analyses
- Evaluation
- Conclusions and future work

Motivation

- Many real-time embedded domains favor mixed-criticality systems.
- Static and adaptive variant of Vestal's improves the processor use efficiency.
- Pessimistic when the WCET of successive instances vary greatly.
- Leverage the known variability in execution time for even more efficiency.



Main contributions

Multiframe Vestal model

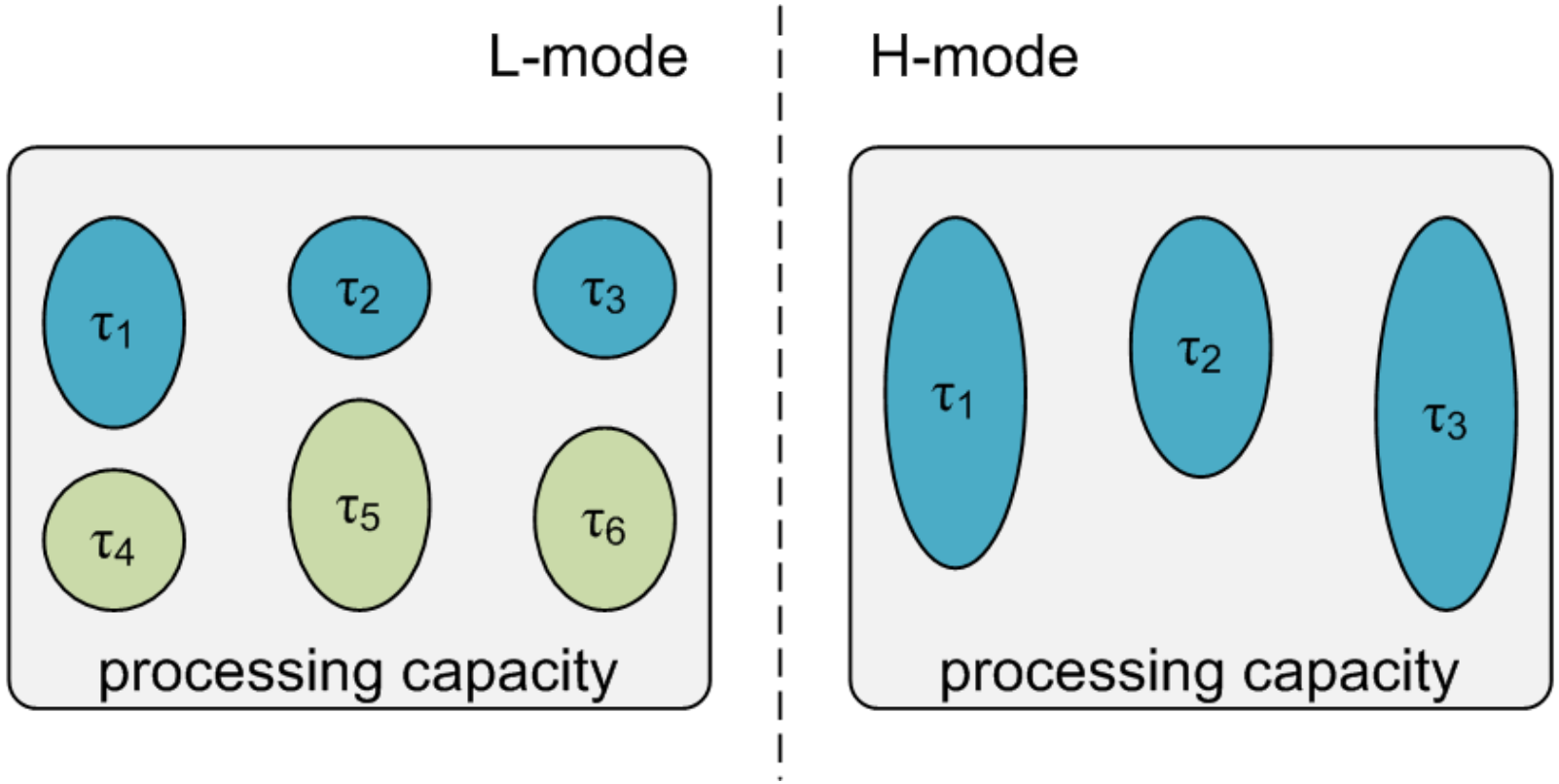
Schedulability analyses for multiframe mixed-criticality systems

Extensive experiments and comparison with frame-agnostic analysis

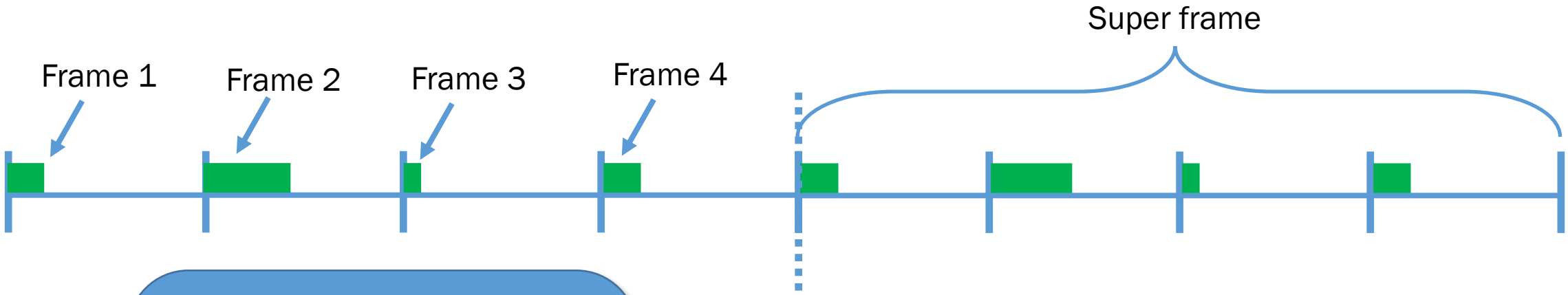
Background: Static mixed-criticality model

- Multiple WCET estimates per task with corresponding degree of confidence.
- The WCET of all the tasks is monitored using Watchdog timers.
- Calculate WCRT of each task using WCETs with confidence level commensurate of analyzed task's criticality.

Background: Adaptive mixed-criticality model



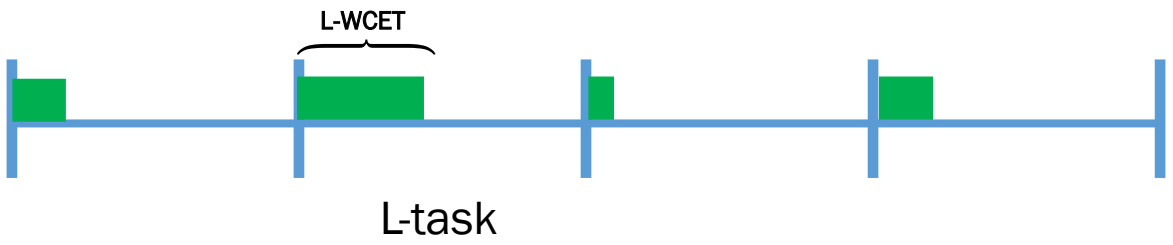
Background: Multiframe task model

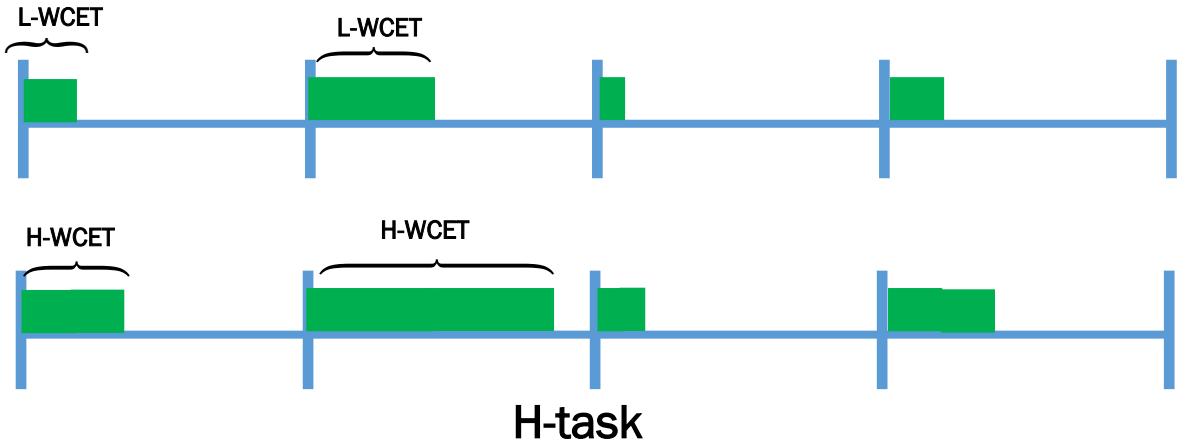


Multiframe task model

Independent multiframe sporadic tasks

Mixed-criticality multiframe task model





Multiframe task model

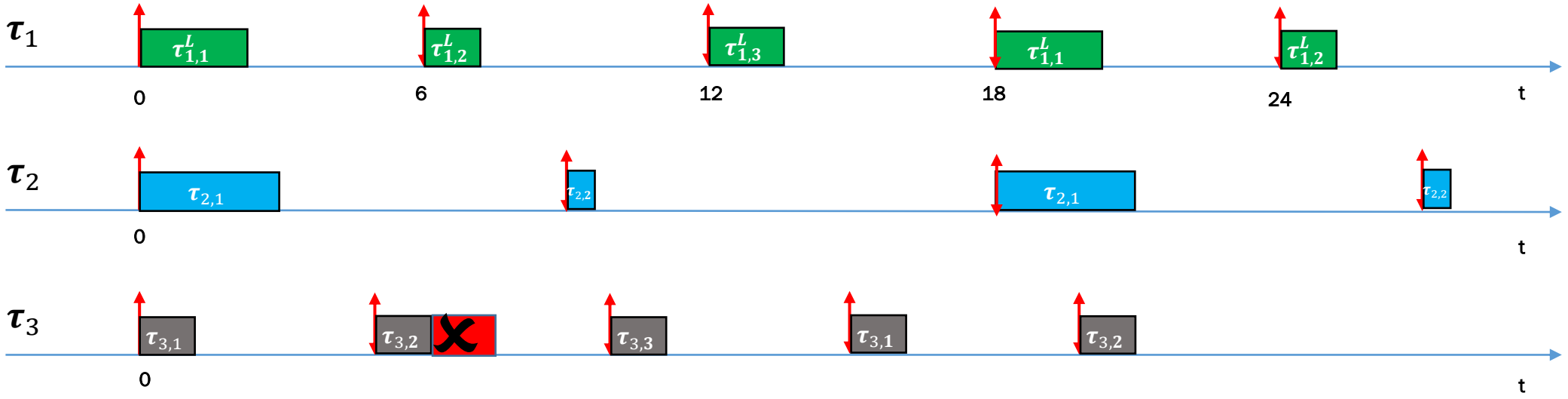
Preemptive fixed-priority scheduling

Independent multiframe sporadic tasks

Multiple WCET estimates per frame

Static multiframe MC

High Criticality Task: τ_2 and τ_3
Low Criticality Task: τ_1



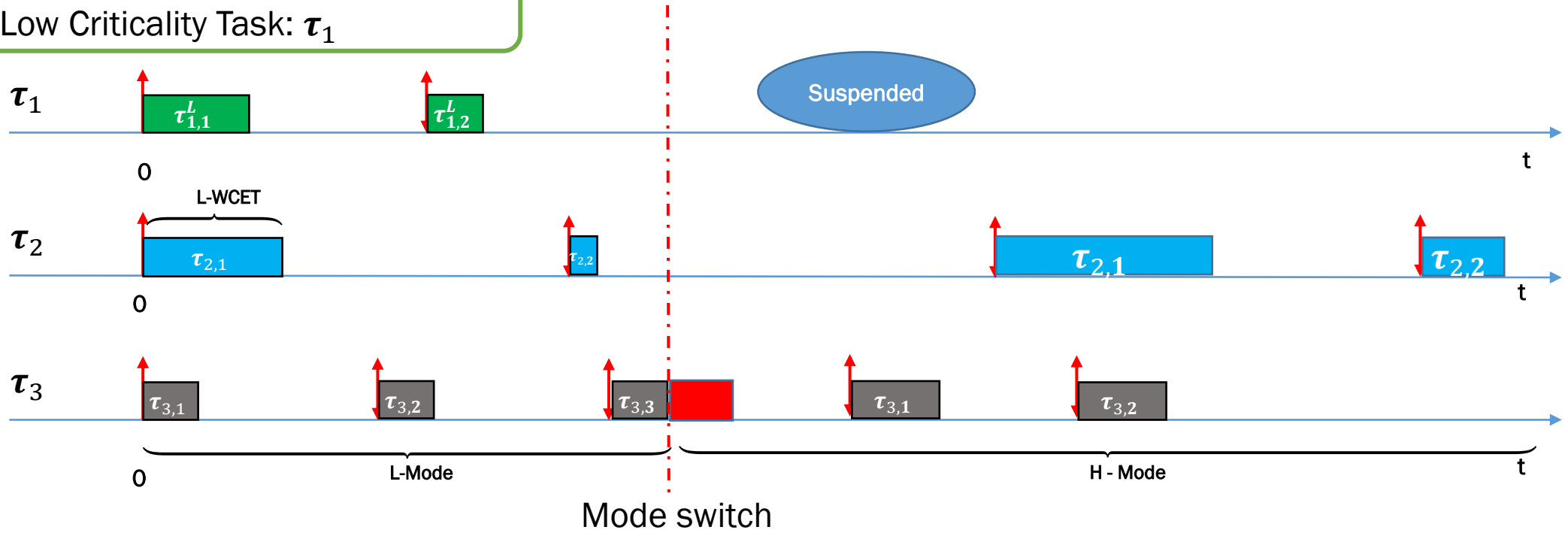
Schedulability Analysis

No L-task misses its deadline as long as all the tasks execute up to $C_{i,j}^L$

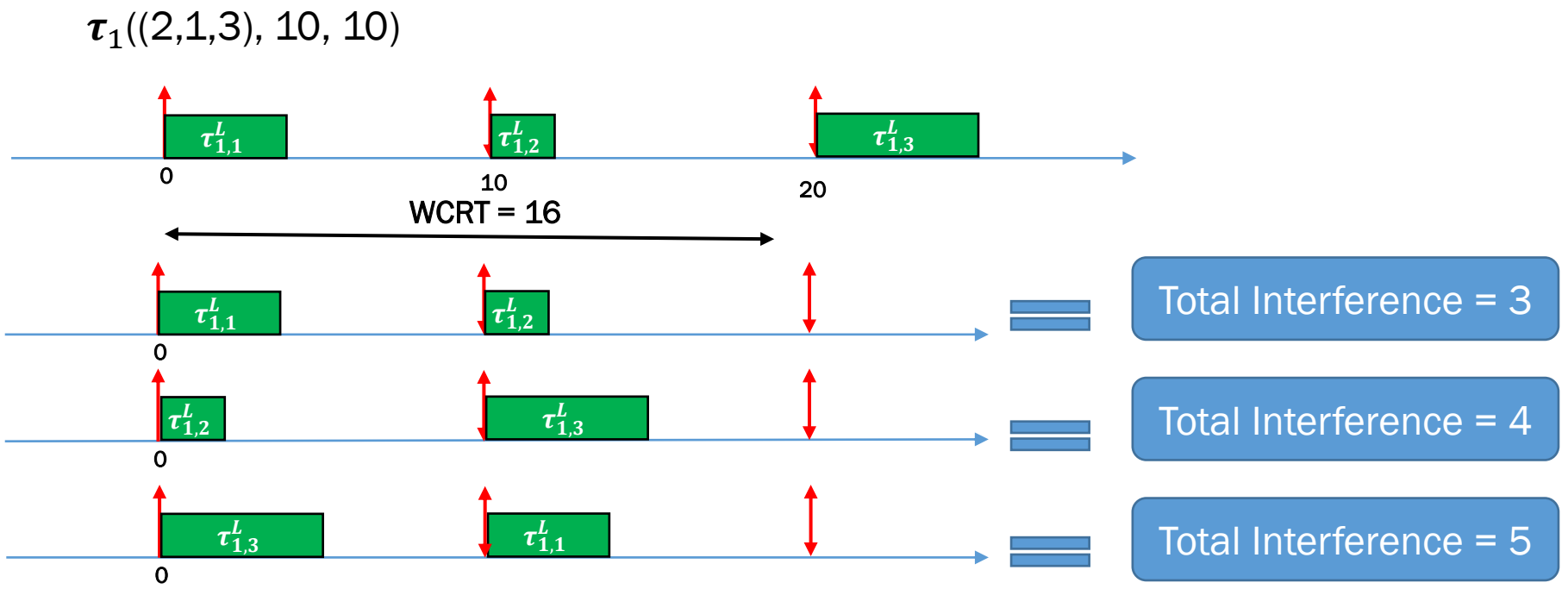
No H-task misses its deadline as long as all the tasks execute up to $C_{i,j}^{k_i}$

Adaptive multiframe MC

High Criticality Task: τ_2 and τ_3
Low Criticality Task: τ_1



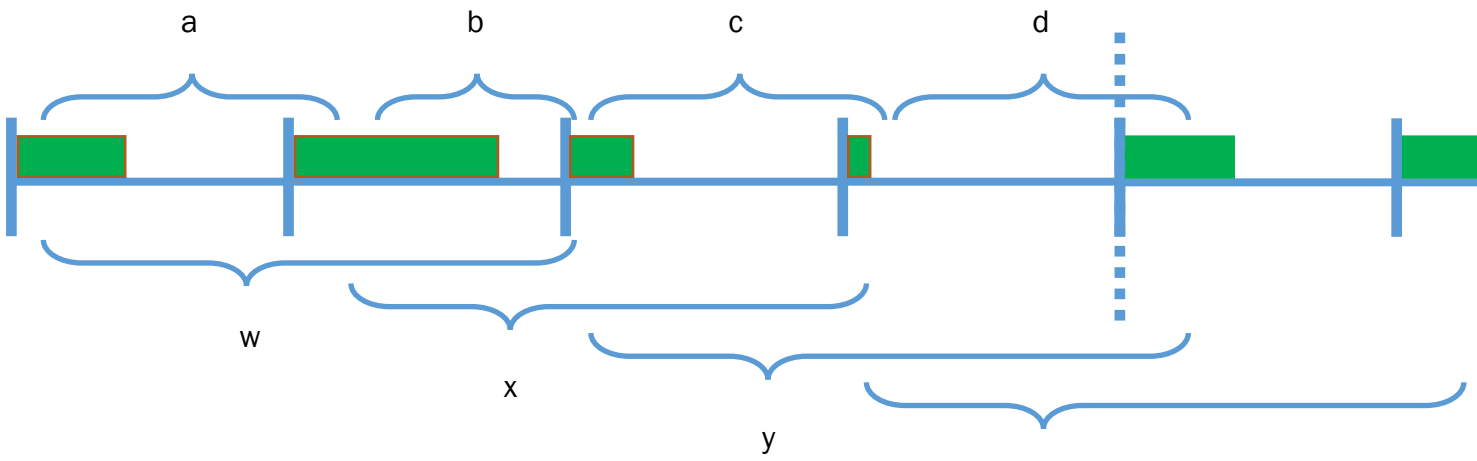
Interference by a multiframe task



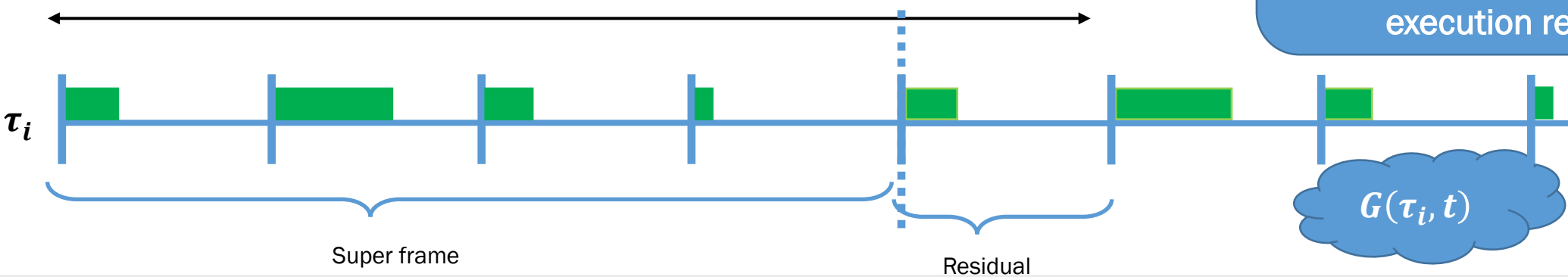
Maximum cumulative execution requirement (Baruah's approach)

Interference by a multiframe task

For two frames = Max (a, b, c, d)



For three frames = Max (w, x, y, z)

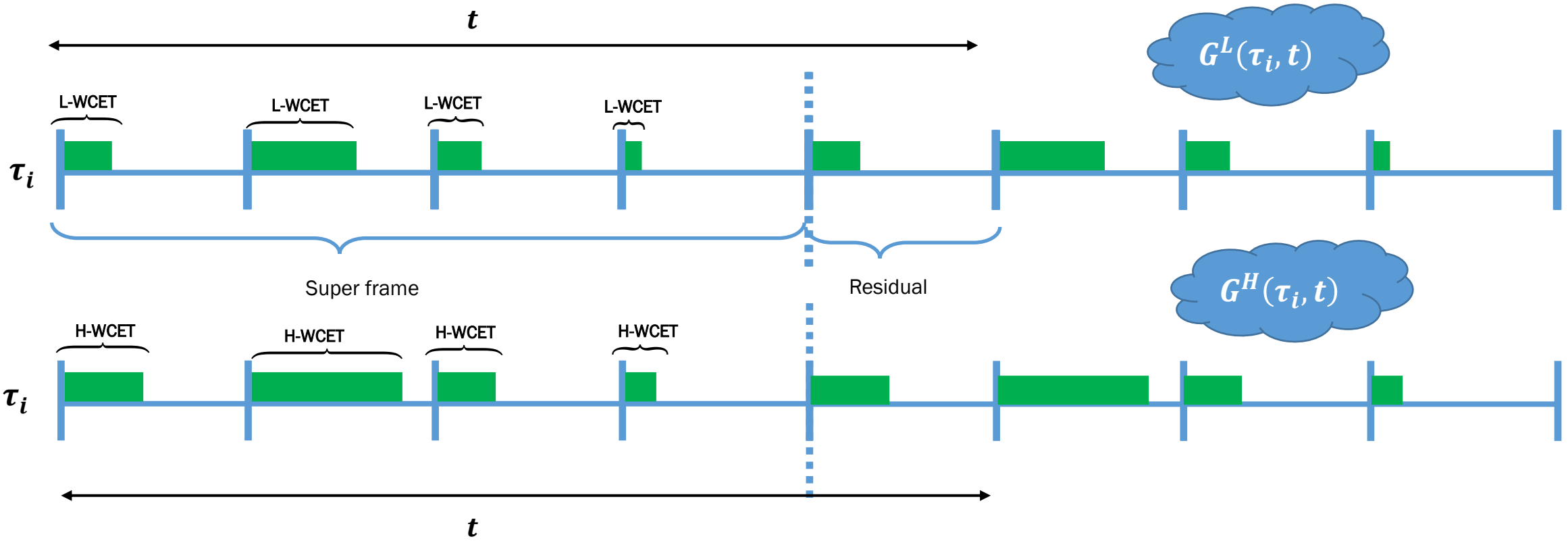


Compute number of interfering jobs of each higher priority task

Sum their maximum cumulative execution requirement

$G(\tau_i, t)$

Interference by a multiframe task



Response time analysis (SMMC)

$$\boldsymbol{R_i} = \boldsymbol{C_i^H} + \sum_{\boldsymbol{\tau_j \in hpL(i)}} \boldsymbol{IL_j(R_i)} + \sum_{\boldsymbol{\tau_k \in hpH(i)}} \boldsymbol{IH_k(R_i)}$$

- $\boldsymbol{C_i}$ = WCET of task under analysis
- $\boldsymbol{IL_j}$ = Interference from L-tasks
- $\boldsymbol{IH_k}$= Interference from H-tasks

$$R_i = g^H(\tau_i, 1) + \sum_{\tau_j \in hpL(i)} G^L(\tau_j, R_i) + \sum_{\tau_k \in hpH(i)} G^H(\tau_k, R_i)$$

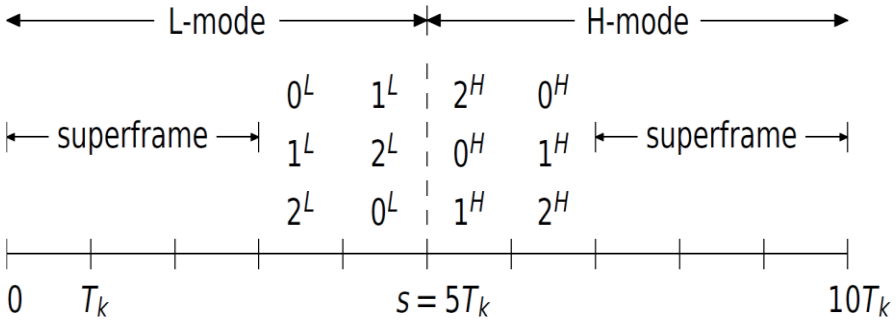
- WCET of task under analysis
- Interference from L-tasks
- Interference from H-tasks

Response time analysis(AMMC-rtb)

- All higher-priority L-tasks interfere over [0, R_i^L) only; L-WCETs used.
- For higher-priority H-tasks, their H-WCETs are used.

$$\boldsymbol{R_i^* = C_i + \sum_{\tau_j \in hpL(i)} IL_j(R_i^L) + \sum_{\tau_k \in hpH(i)} IH_k(R_i^*)}$$

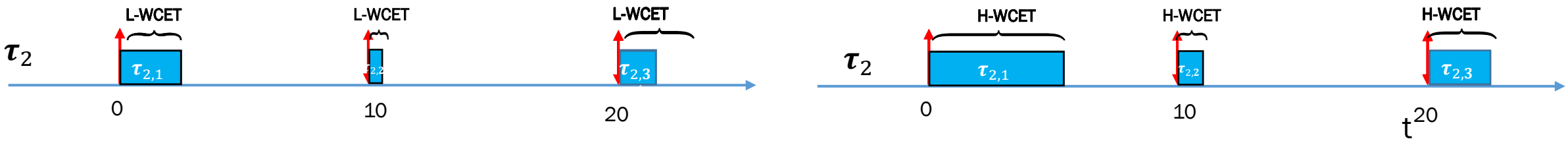
$$R_{i,j}^* = g^H(\tau_i, 1) + \sum_{\tau_j \in hpL(i)} G^L(\tau_j, R_{i,j}^L) + \sum_{\tau_k \in hpH(i)} G^H(\tau_k, R_{i,j}^*)$$



Response time analysis (AMMC-max)

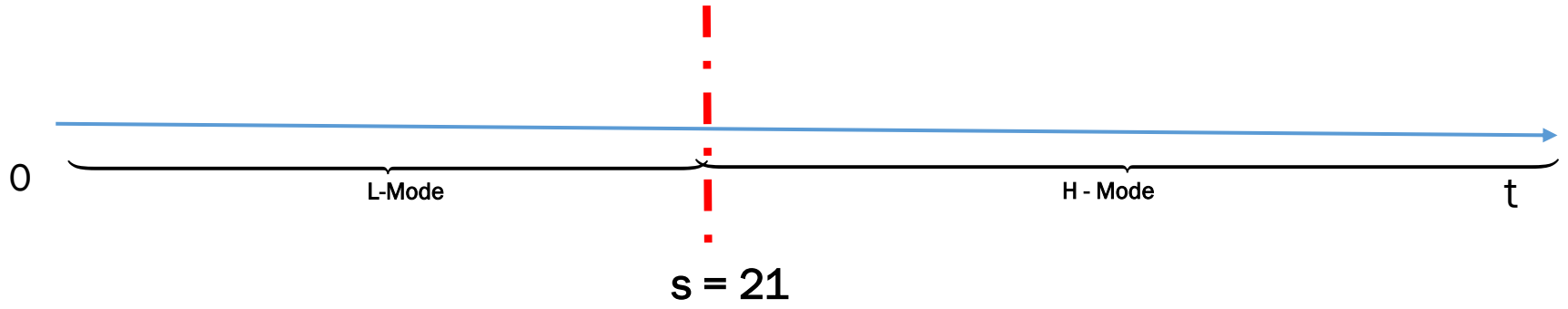
- Pessimism in A(M)MC-rtb is reduced by explicitly considering the mode change instant s.
  - L-WCETs can then be used for jobs completed in [0, s).
  - Conservatively overestimating number of jobs in H-mode.
- Eliminating another source of pessimism.
  - The frame sequences before/after the mode change should “match”.
  - After frame k comes frame (k+1) mod F.

Example



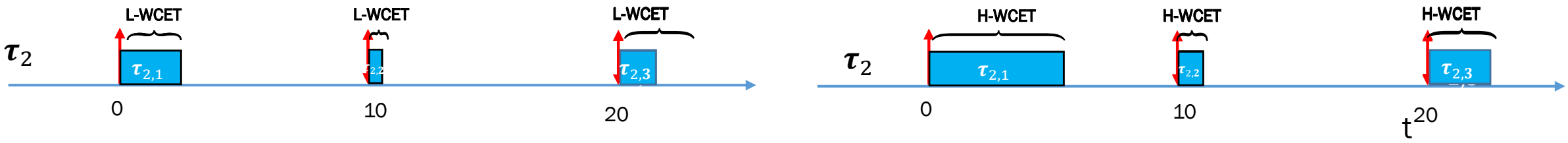
2 L-jobs

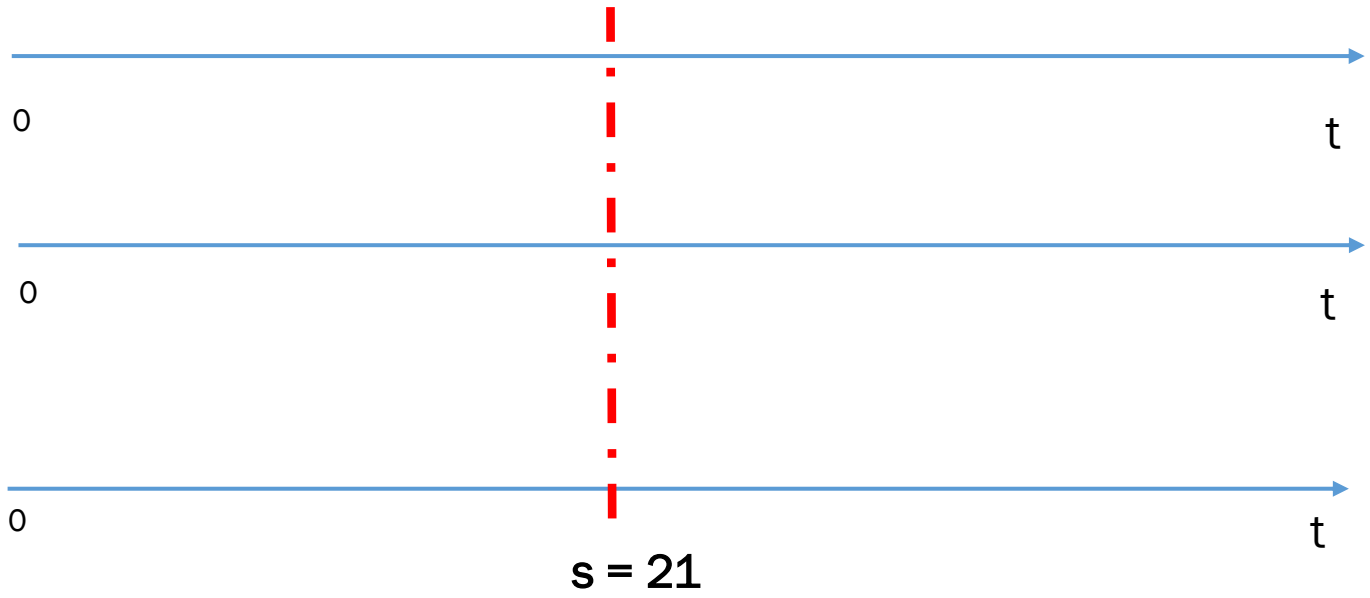
2 H-jobs



= 8.4

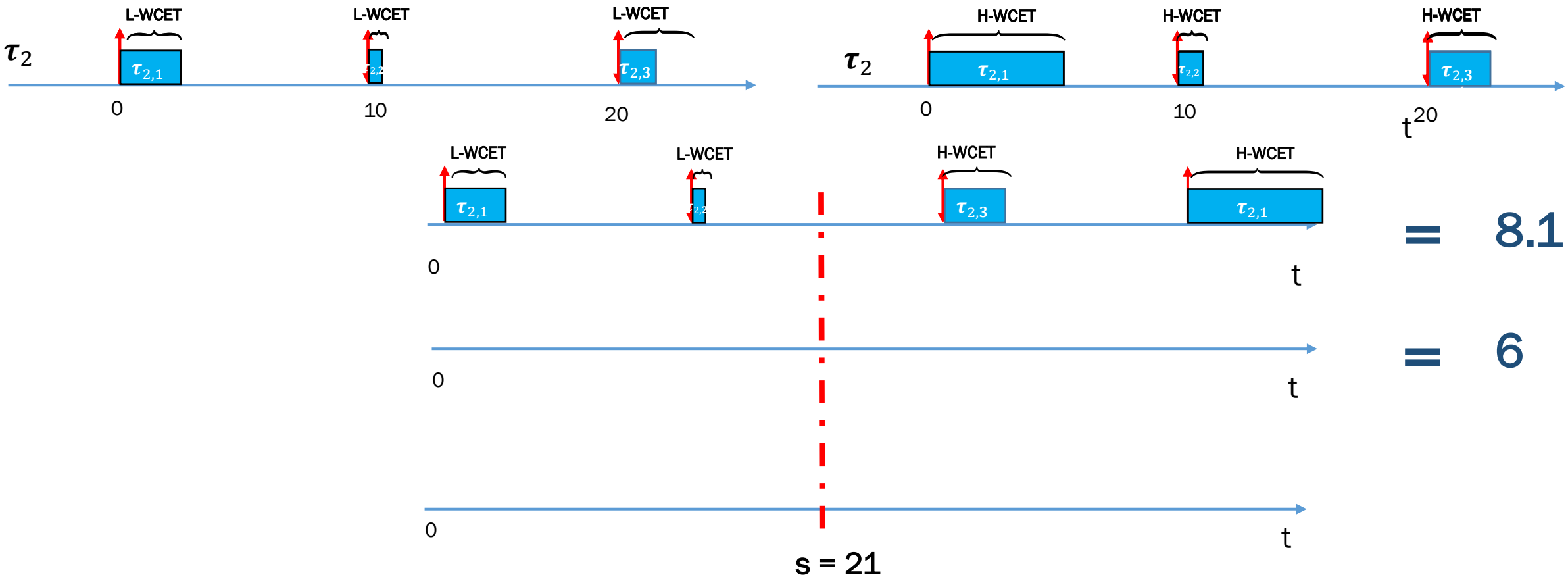
Example


L-WCET
L-WCET
L-WCET
τ_2
$\tau_{2,1}$
$\tau_{2,2}$
$\tau_{2,3}$
0
10
20
H-WCET
H-WCET
H-WCET
τ_2
$\tau_{2,1}$
$\tau_{2,2}$
$\tau_{2,3}$
0
10
20
t

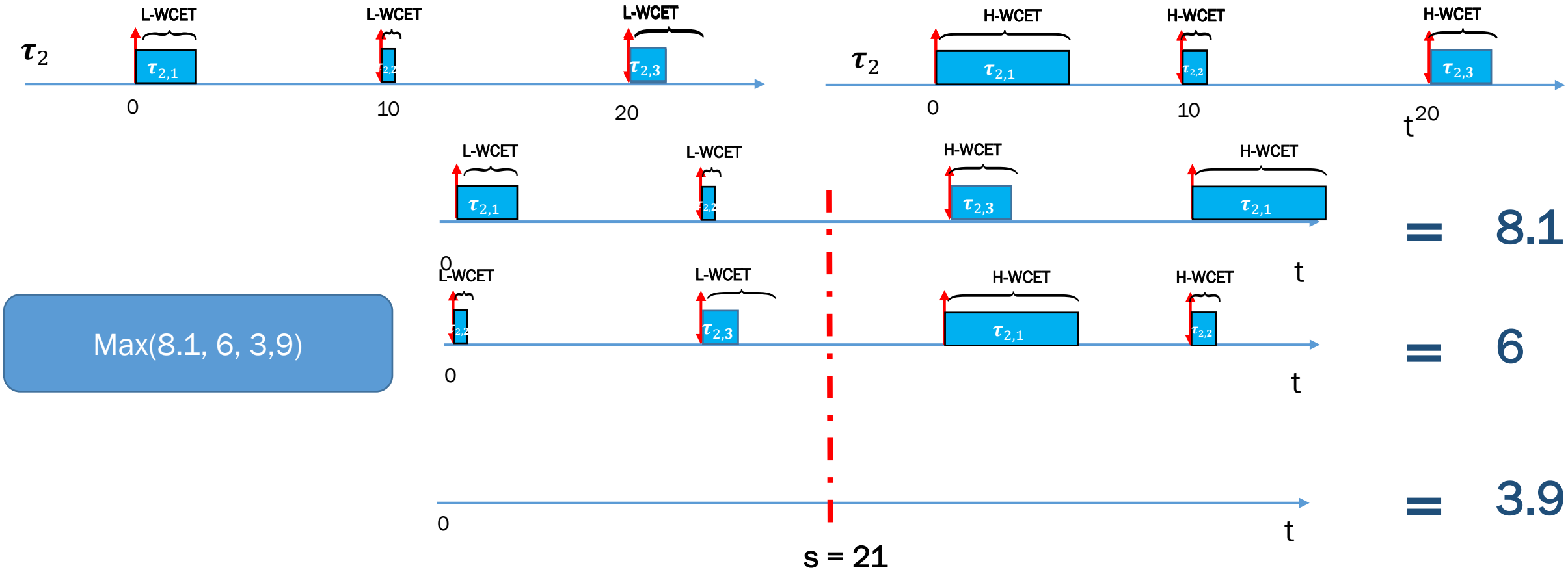

0
t
0
t
0
t
s = 21

= 8.1

Example


L-WCET
L-WCET
L-WCET
τ_2
$\tau_{2,1}$
$\tau_{2,2}$
$\tau_{2,3}$
0
10
20
H-WCET
H-WCET
H-WCET
τ_2
$\tau_{2,1}$
$\tau_{2,2}$
$\tau_{2,3}$
0
10
20
t
L-WCET
L-WCET
H-WCET
H-WCET
$\tau_{2,1}$
$\tau_{2,2}$
$\tau_{2,3}$
$\tau_{2,1}$
0
t
= 8.1
0
t
= 6
0
t
s = 21

Example

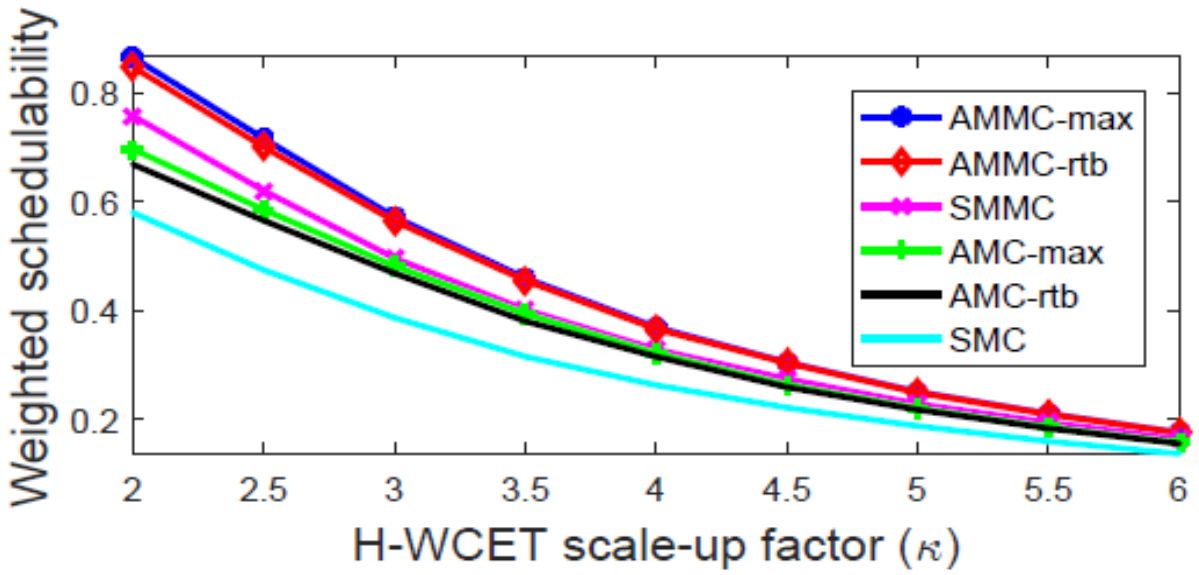


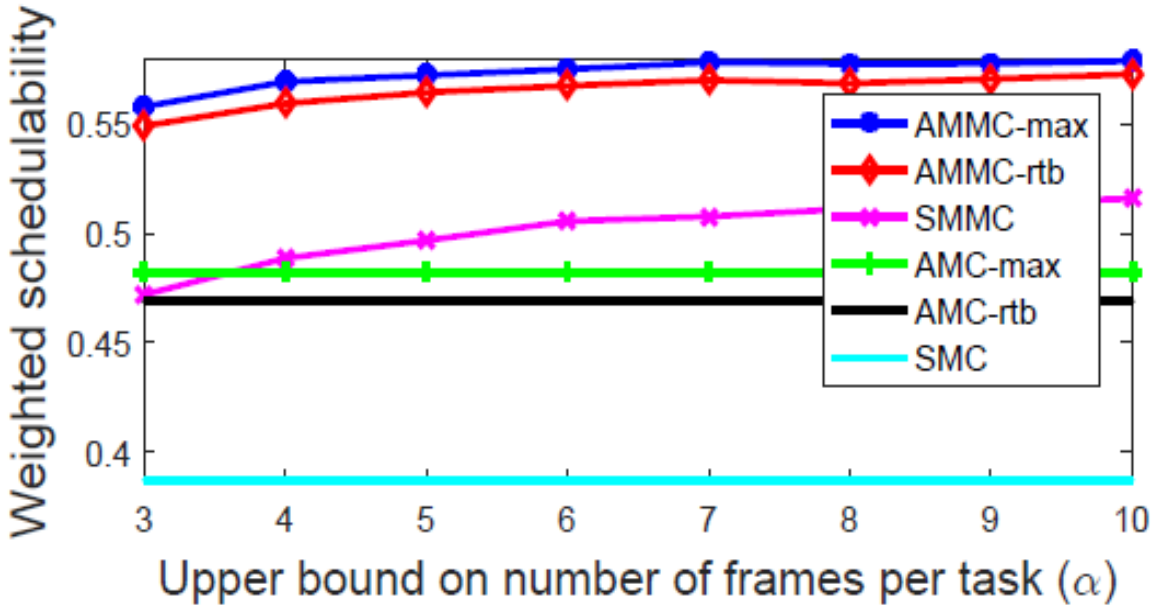
Max(8.1, 6, 3,9)

Experimental setup

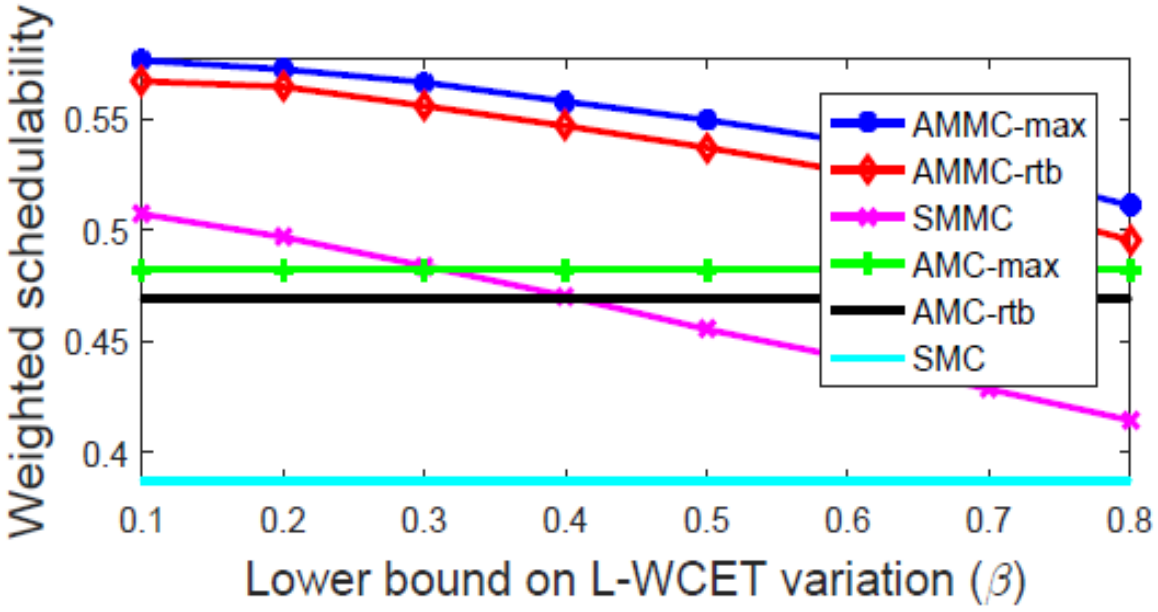
- Inter-arrival time: Log-uniform distribution (10ms - 1s)
- Implicit deadlines (though algorithm works for constrained deadlines)
- L-Utilization: UUnifast-discard algorithm
- L-WCET of first frame = inter-arrival time × L-Utilization
- Number of frames: Selected randomly
- L-WCET of other frames
  - Randomly selected with log-uniform distribution
  - Between user defined value and L-WCET of first frame
- H-WCET estimates are derived by linearly scaling up L-WCET
- 1000 random task-sets per set point
- Audsley for priority assignment

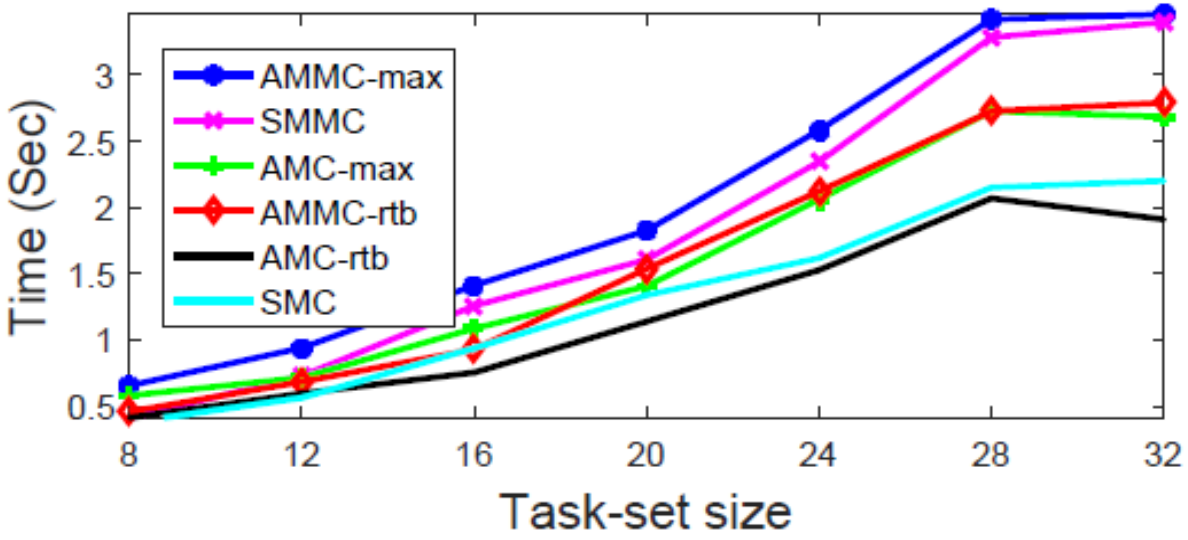
Experimental evaluation





Experimental evaluation





Conclusion and Future Work

- Conclusion
  - We have presented multiframe mixed criticality model.
  - Schedulability analyses for Multiframe mixed criticality systems dominates the single frame counter part.
  - Multiframe analysis are less pessimistic but are always slower compared to single frame analysis.
- Future Work
  - Incorporate the effect of memory stalls under memory access regulation into schedulability Analysis.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Thank you!