On Resource Overbooking in an Unmanned Aerial Vehicle

ICCPS 2012

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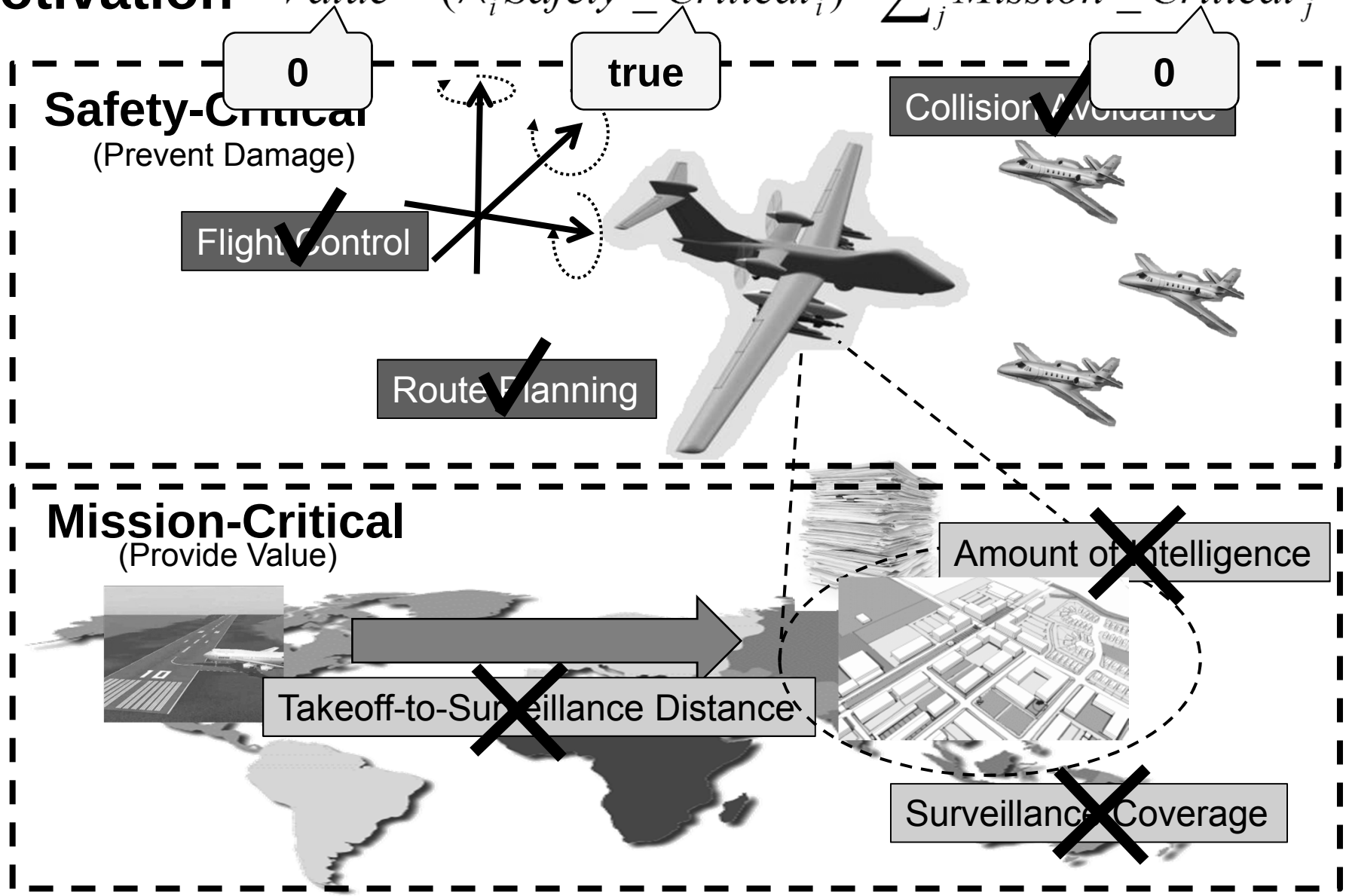
Motivation

$$Value = (\wedge_i Safety\_Critical_i) * \sum_j Mission\_Critical_j$$



Optimization of Mission-Critical Value in Mixed-Criticality Systems

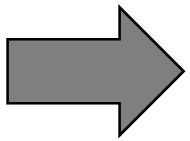
Conservative approach over-allocates resources to safety-critical tasks

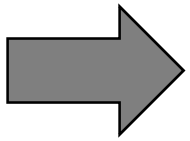
Mission-Critical

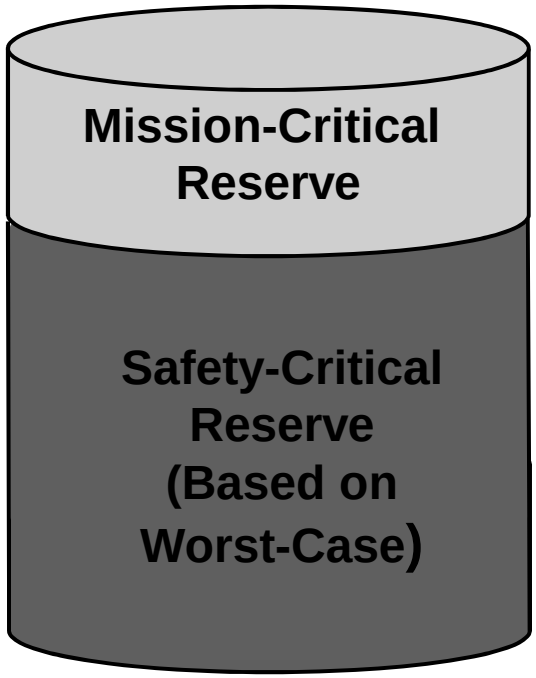
- Surveillance Coverage
- ~~Takeoff-to-Surveillance Distance~~
- ~~Amount of Intelligence Information~~

Safety-Critical

- Flight Control
- Collision Avoidance
- Route Planning







Optimization of Mission-Critical Value in Mixed-Criticality Systems

Conservative approach underutilizes resources

Mission-Critical

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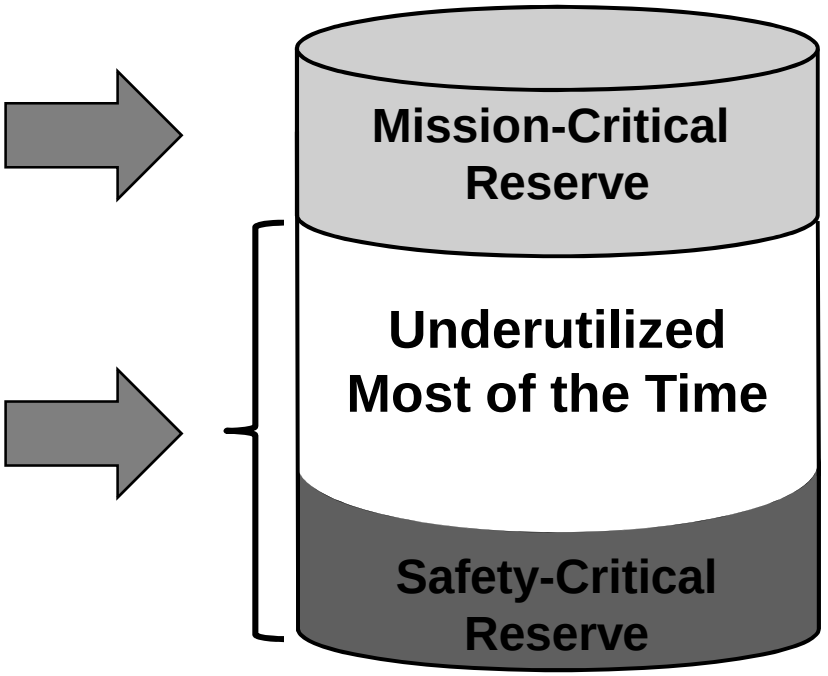
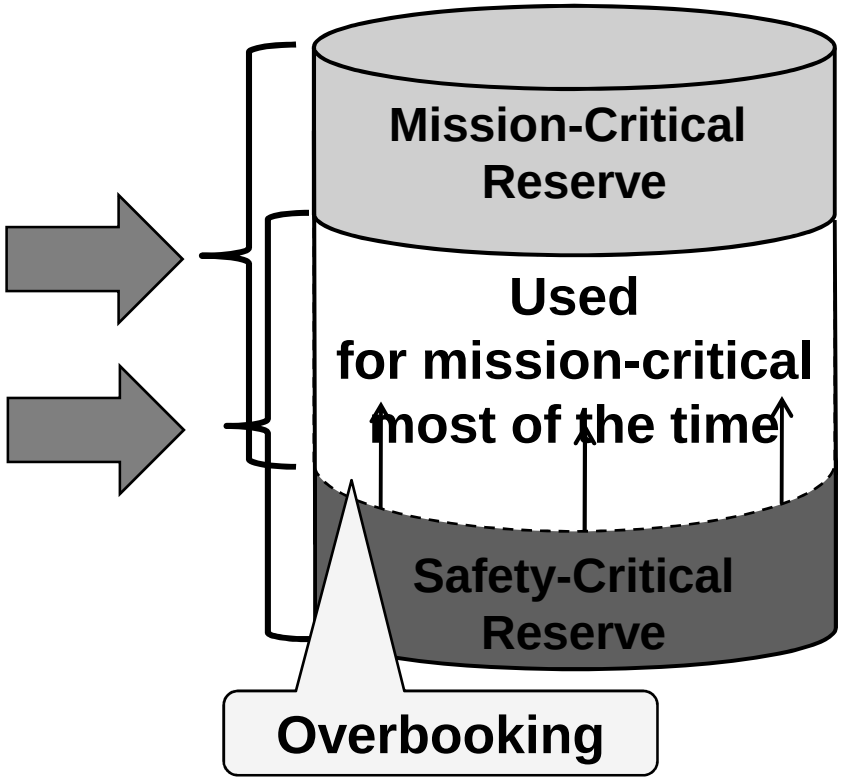


Reclaiming Unused Resources: Overbooking

Reclaim unused resources & use them to optimize utility of mission-critical tasks while preserving timing guarantees of safety-critical tasks

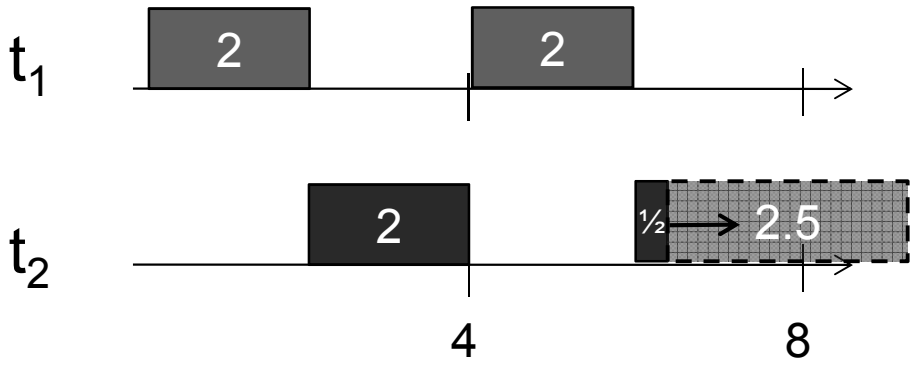
Mission-Critical
- Surveillance Coverage
- Takeoff-to-Surveillance Distance
- Amount of Intelligence Information

Safety-Critical
- Flight Control
- Collision Avoidance
- Route Planning



Overloading in Mixed-Criticality Systems

Task	Period	Criticality	WCET	NCET
t_1 Surveillance Cov.	4	Mission	2	2
t_2 Collision Avoid.	8	Safety	5	2.5



Zero-Slack Rate Monotonic

Task	Period	Criticality	WCET	NCET
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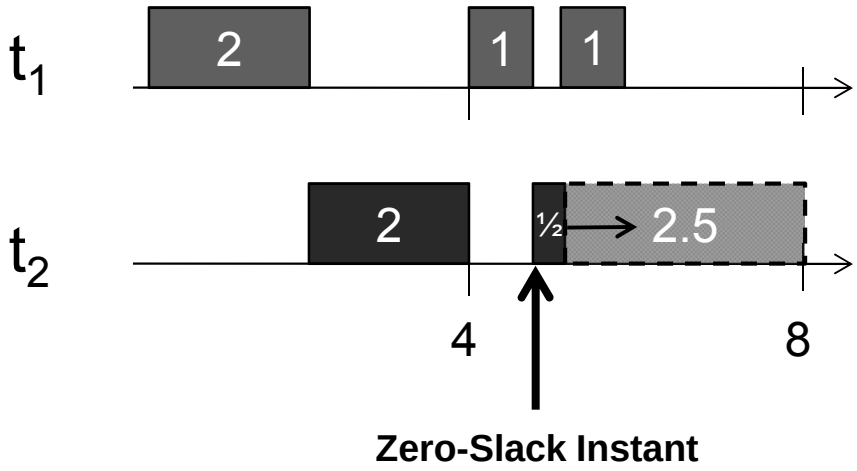

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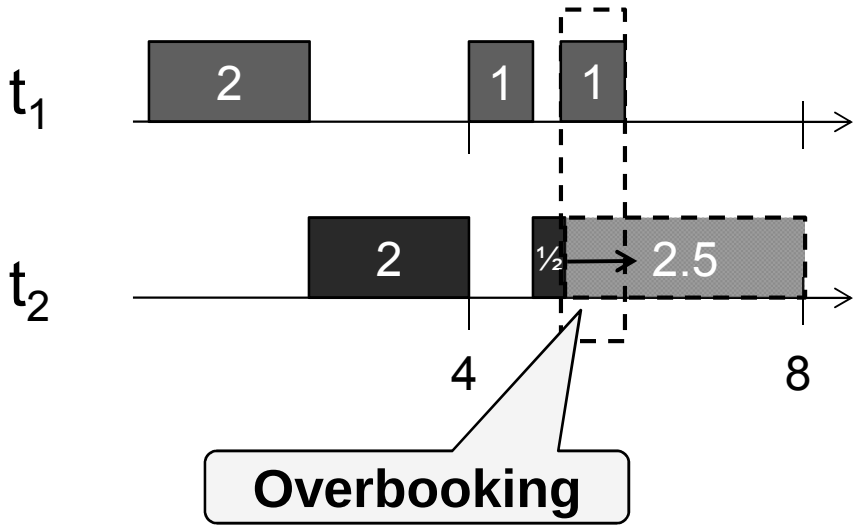
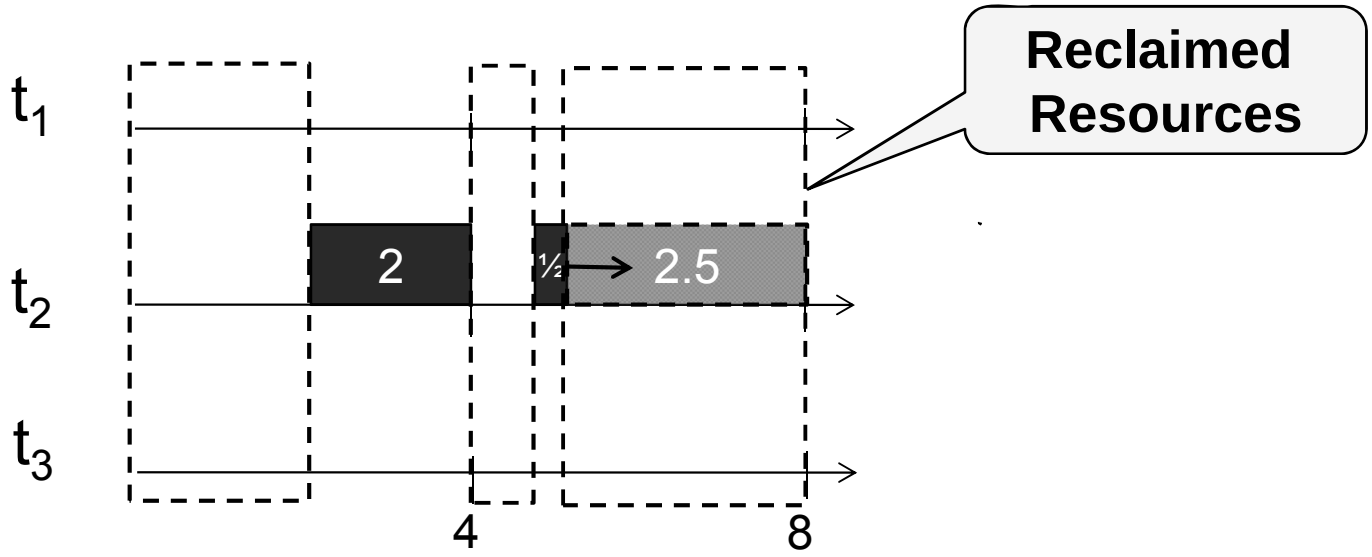


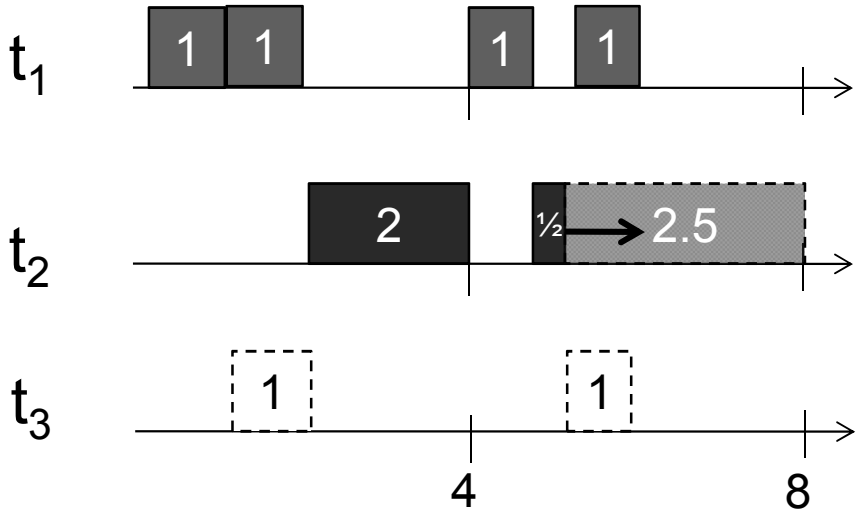
Reclaiming Resources in Mixed-Criticality Systems

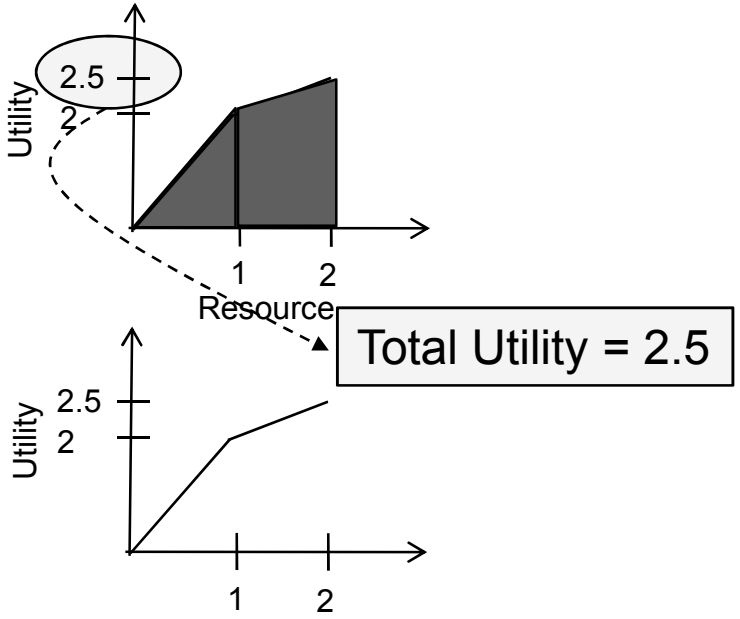
Task	Period	Criticality	WCET	NCET	Utility
t_1 Surveillance Cov.	4	Mission	2	2	{2,2.5}
t_2 Collision Avoid.	8	Safety	5	2.5	
t_3 Amount of Intelligence	4	Mission	2	2	{2,2.5}



Using Reclaimed Resources to Maximized Utility

Task	Period	Criticality	WCET	NCET	Utility Levels
t_1 Surveillance Cov.	4	Mission	2	2	{2,2.5}
t_2 Collision Avoid.	8	Safety	5	2.5	
t_3 Amount of Intelligence	4	Mission	2	2	{2,2.5}





Utility Diminishes: Utility ≠ Criticality

Using Reclaimed Resources to Maximized Utility

Task	Period	Criticality	WCET	NCET	Utility Levels
t_1 Surveillance Cov.	4	Mission	2	2	{2,2.5}
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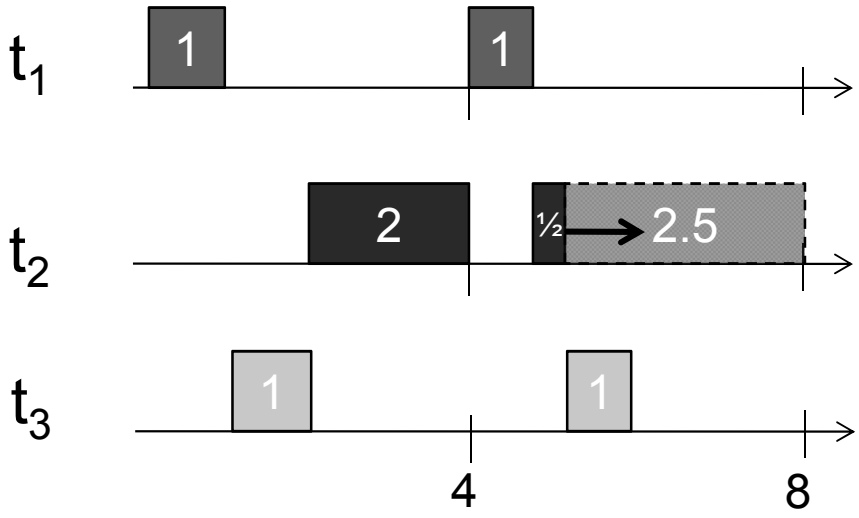
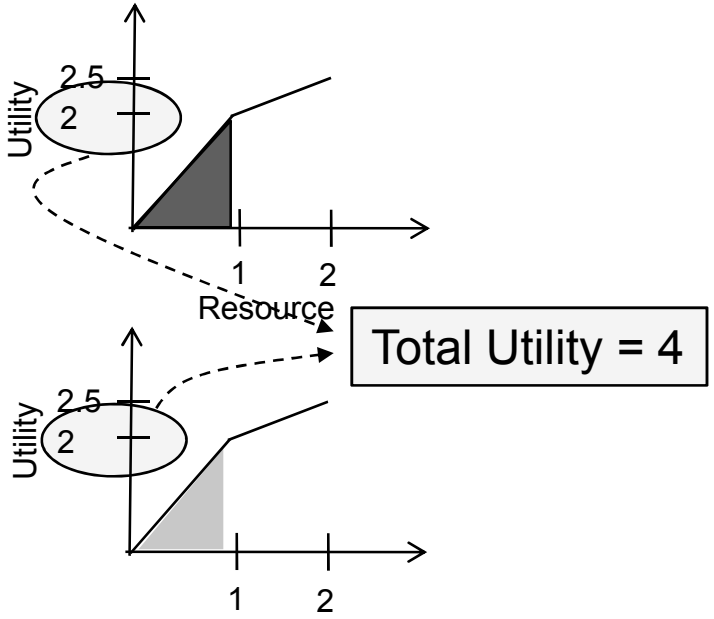
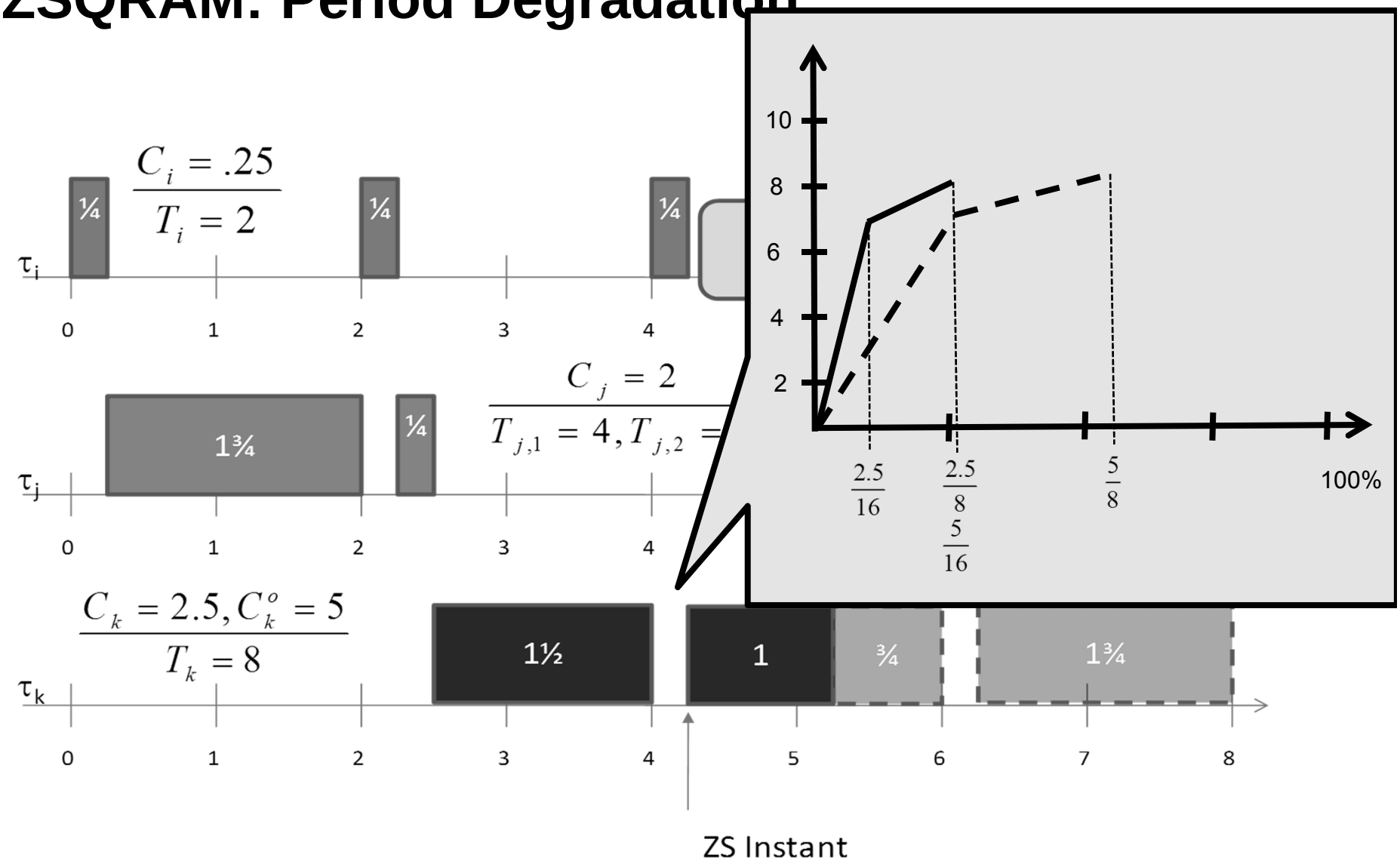


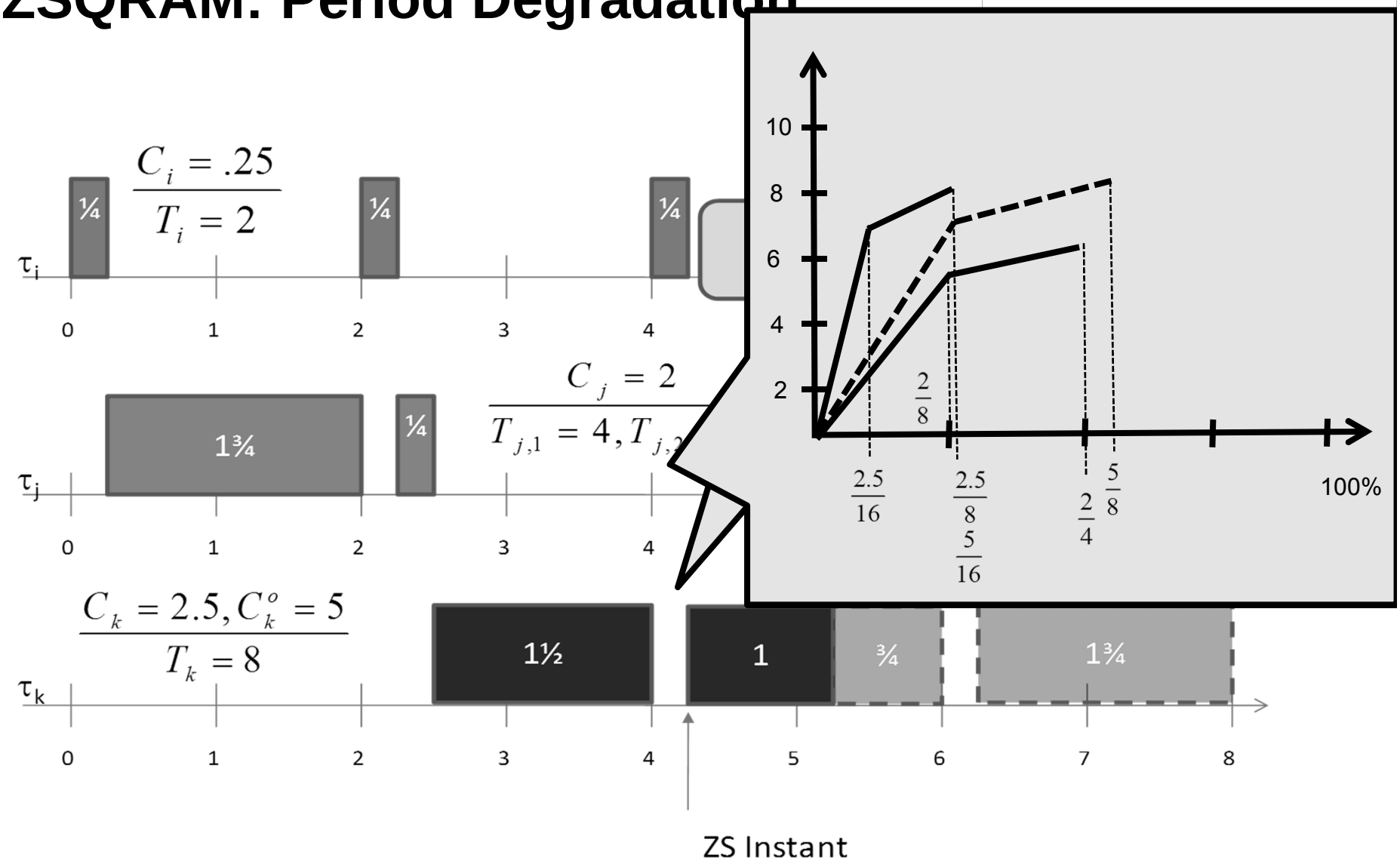


ZS-QRAM: More mission-critical utility from same resources

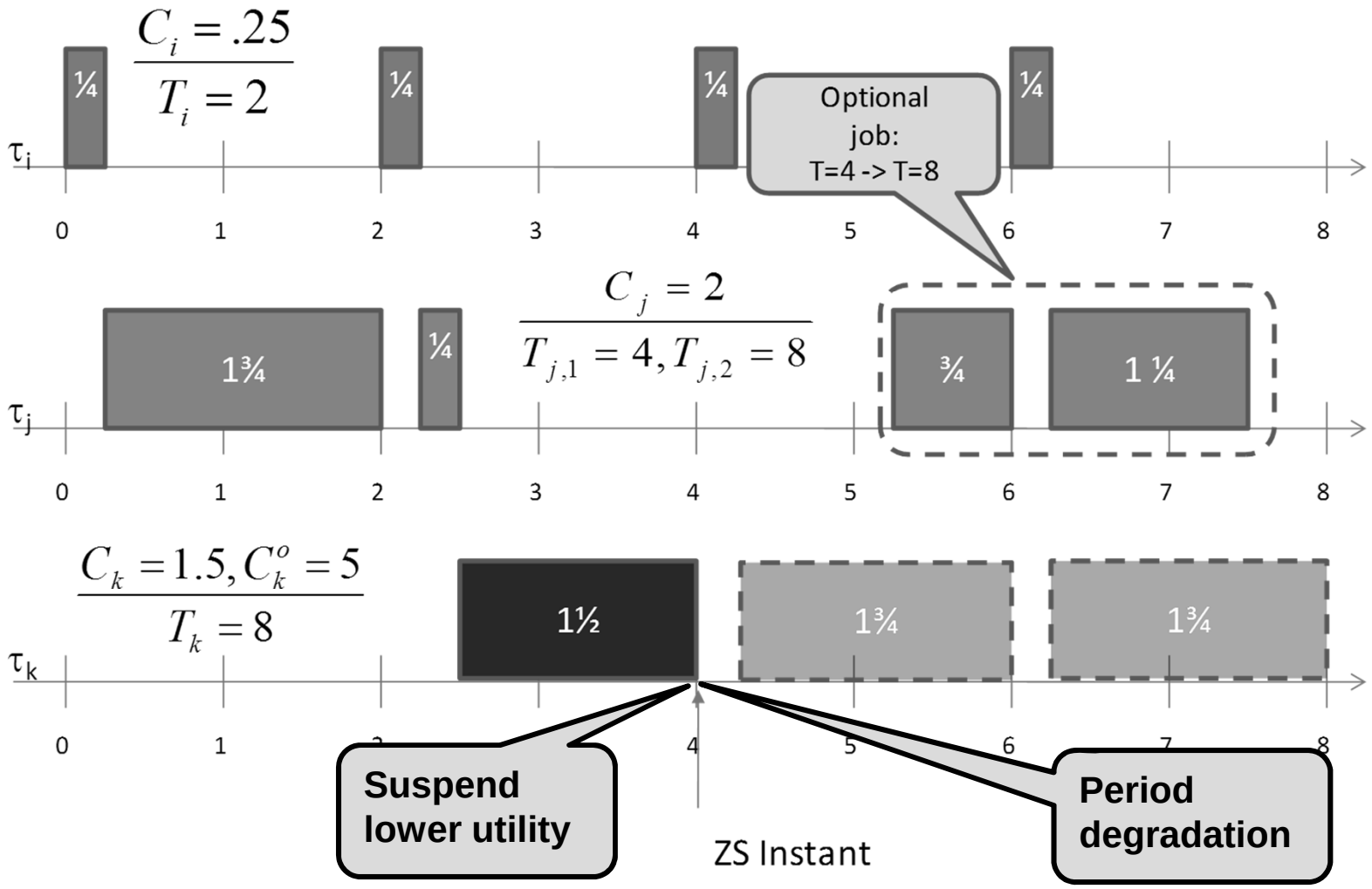
ZSQRAM: Period Degradation



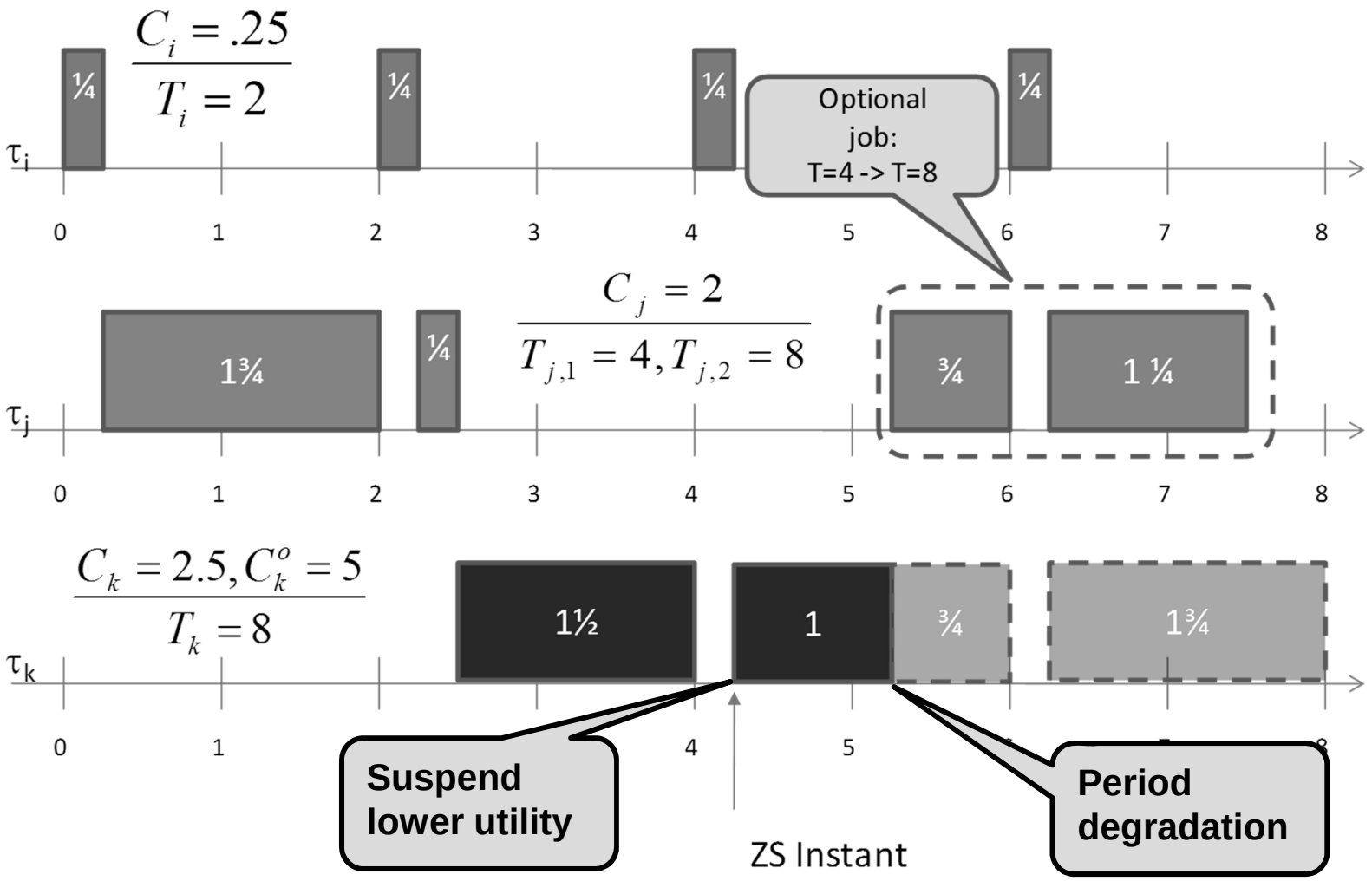
ZSQRAM: Period Degradation



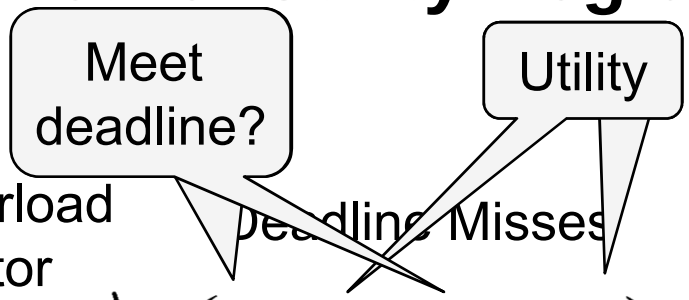
Two Enforcement Points: Before & After Overload



Two Enforcement Points: Before & After Overload



Metric: Utility Degradation Resilience (UDR)



Overload Vector

Deadline Misses

$$\begin{matrix}\langle 1 & 1\rangle \\ \langle 1 & 0\rangle \\ \langle 0 & 1\rangle \\ \langle 0 & 0\rangle\end{matrix}\begin{pmatrix}1*8 & 0*5\\ 1*8 & 0*5\\ 1*8 & 1*5\\ 1*8 & 1*5\end{pmatrix}$$

32 + 10 = 42

Scheduler favors high utility

Overload Vector

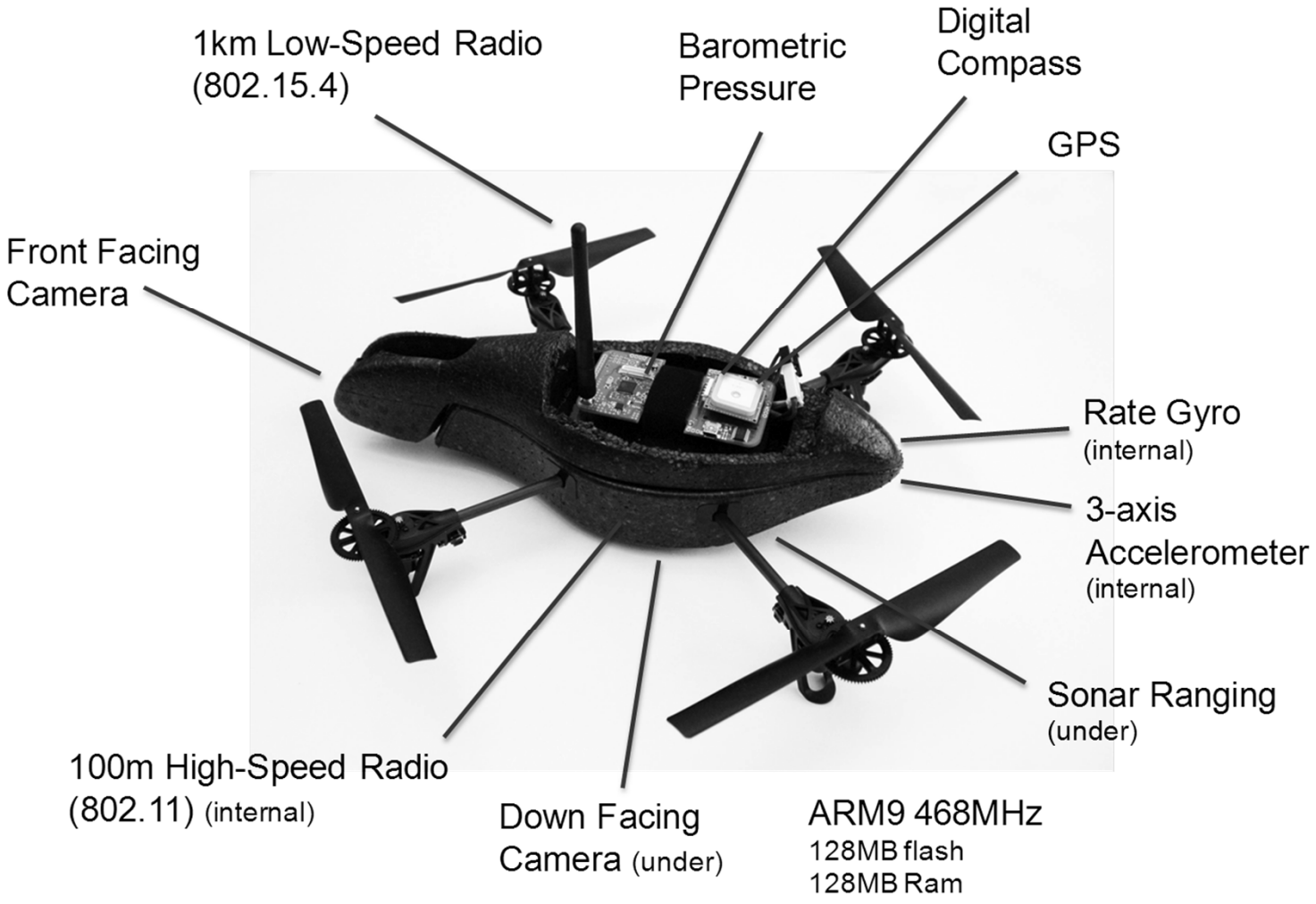
Deadline Misses

$$\begin{matrix}\langle 1 & 1\rangle \\ \langle 1 & 0\rangle \\ \langle 0 & 1\rangle \\ \langle 0 & 0\rangle\end{matrix}\begin{pmatrix}0*8 & 1*5\\ 0*8 & 1*5\\ 1*8 & 1*5\\ 1*8 & 1*5\end{pmatrix}$$

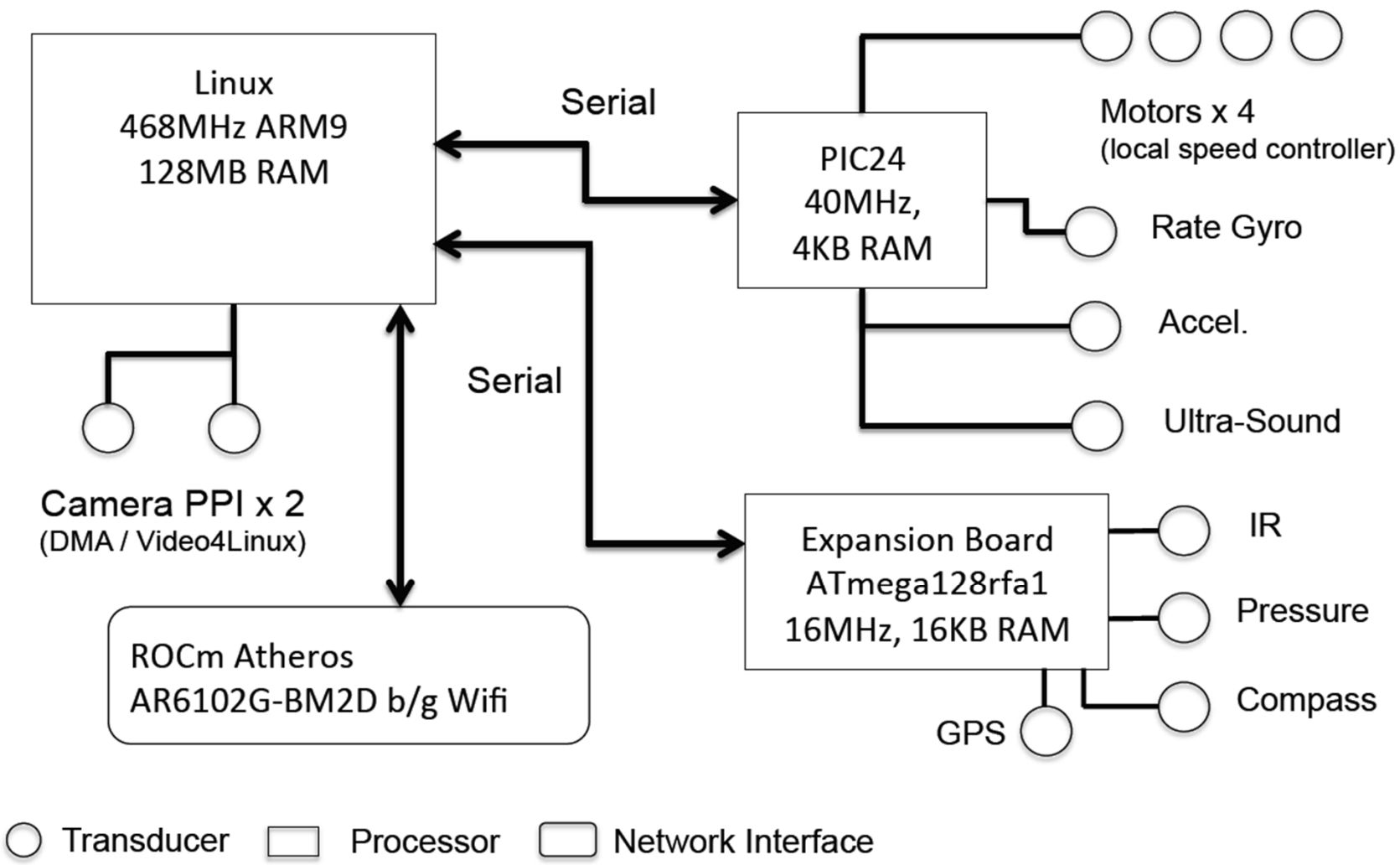
16 + 20 = 36

Scheduler does not favor high utility

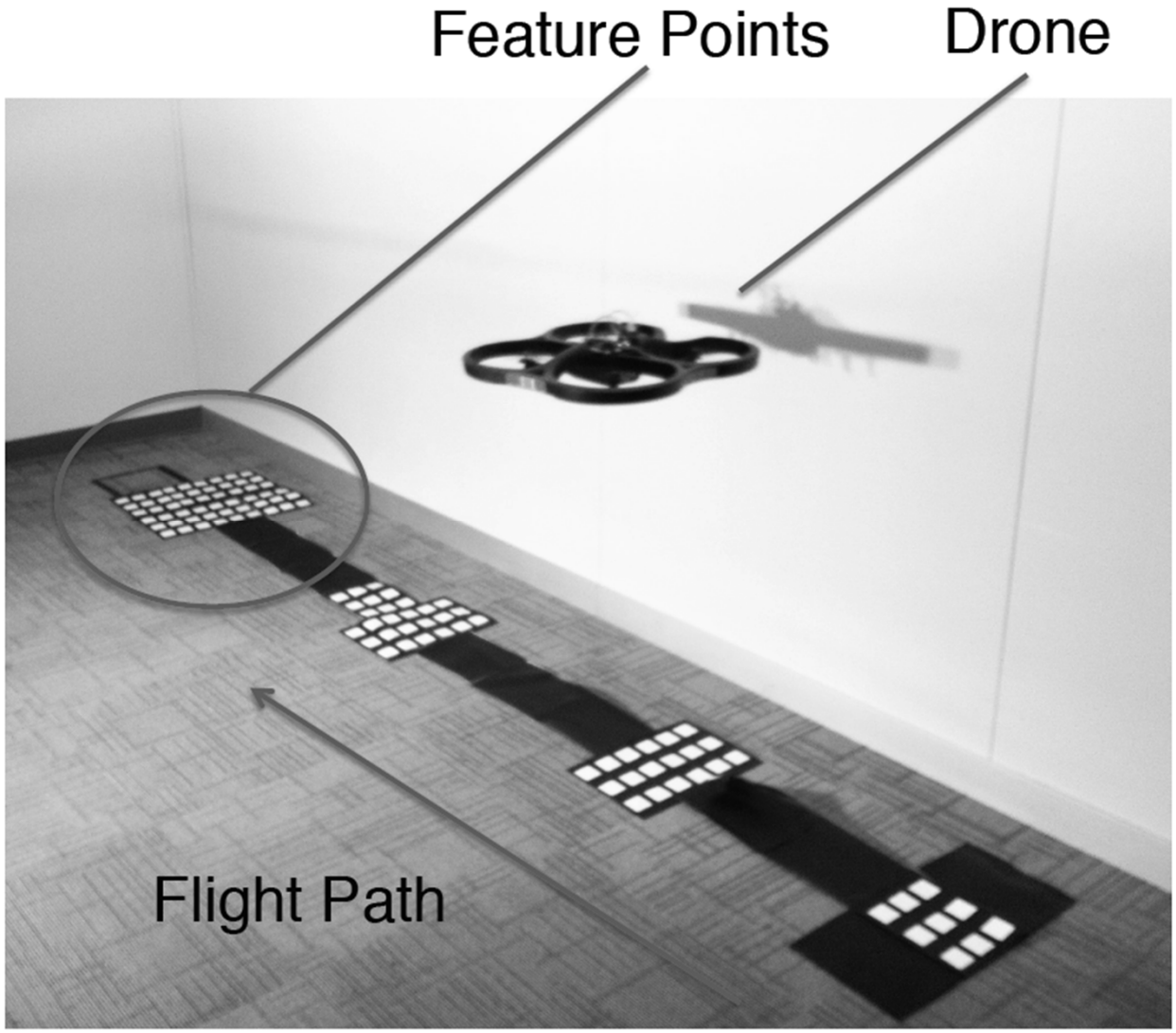
Drone RK (www.drone-rk.org)



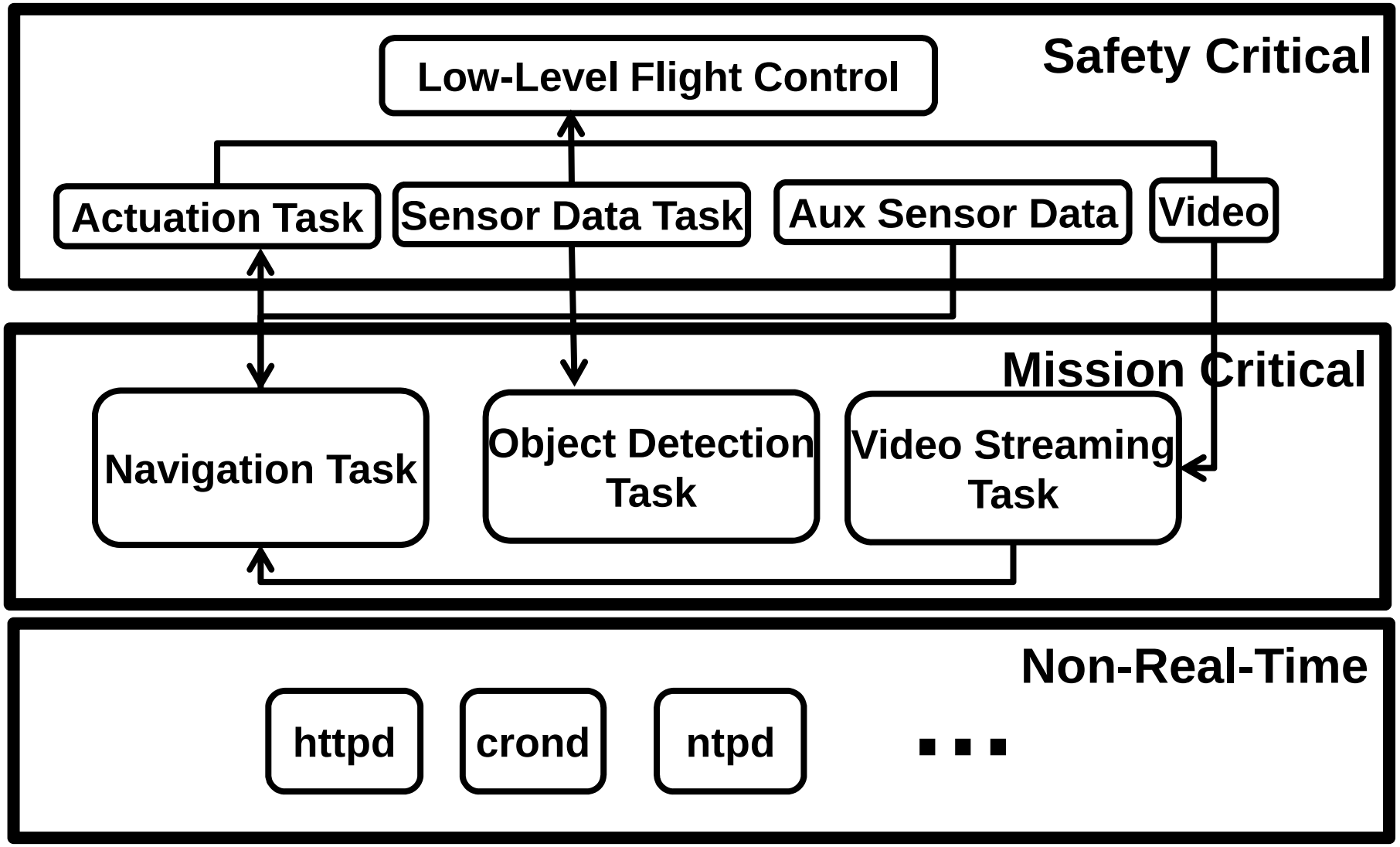
AR Drone Hardware



Experiment Setup



Software Structure

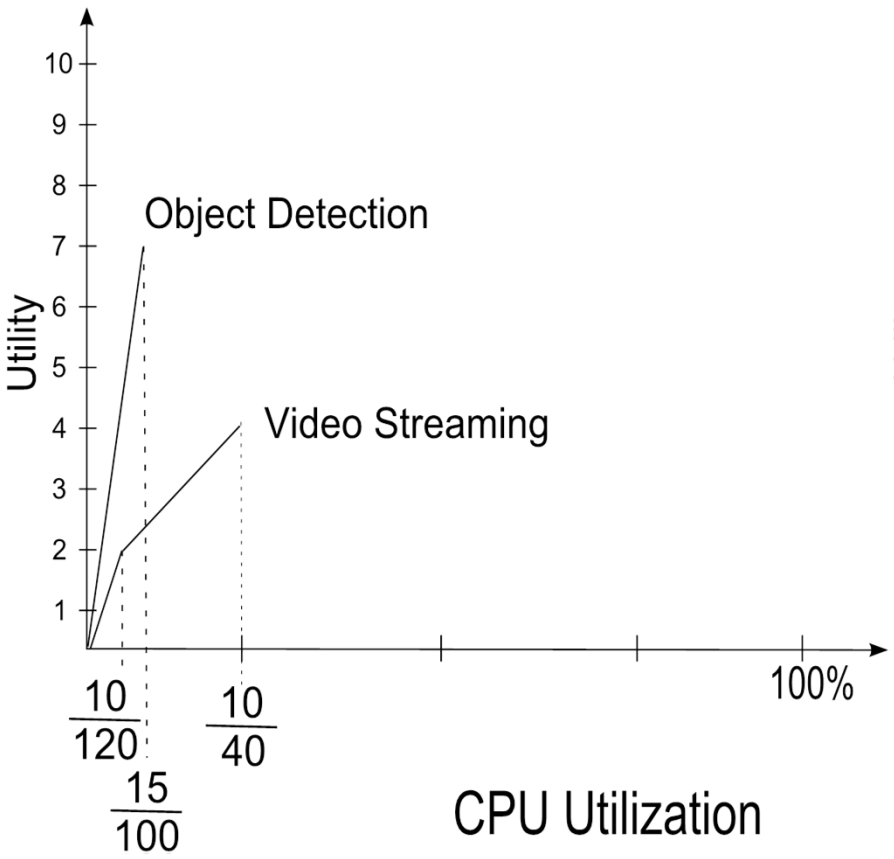


UAV Taskset Parameters

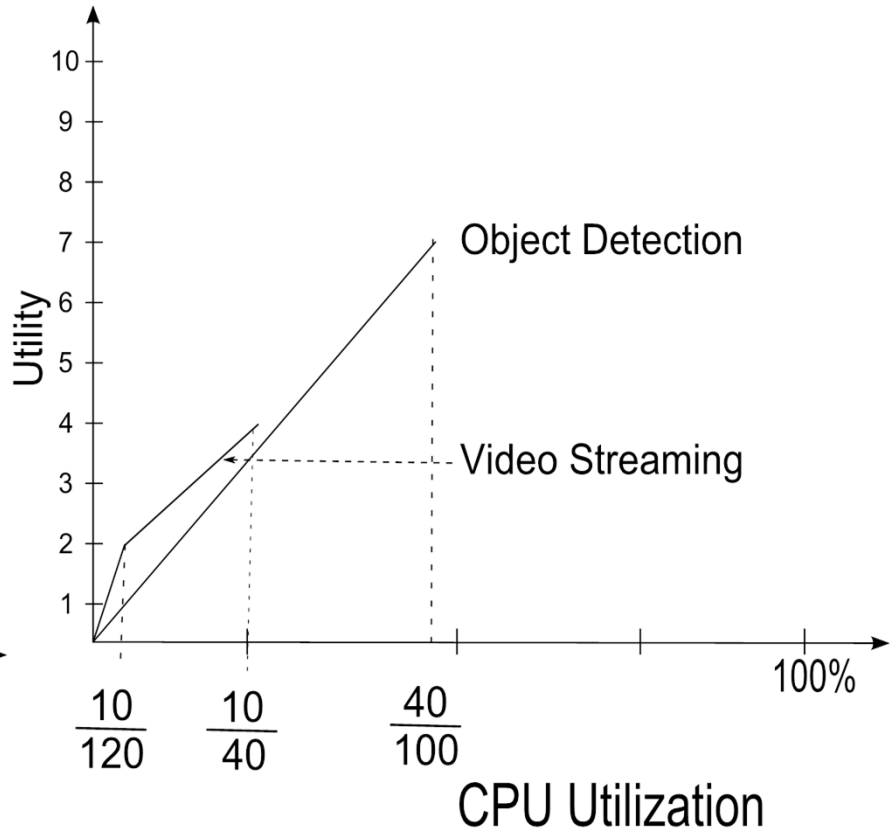
Task	$Util_1$	$Util_2$	C	C^o	T_1	T_2	ZS
Actuation			1	1		30	30
Sensor Data			0.1	0.1		65	65
Aux Sensor Data			0.5	0.5		50	50
Navigation			11	11		50	49
Object Detection		7	15	40		100	87
Video Streaming	2	4	10	10	120	40	40

All figures in milliseconds

Utility Functions



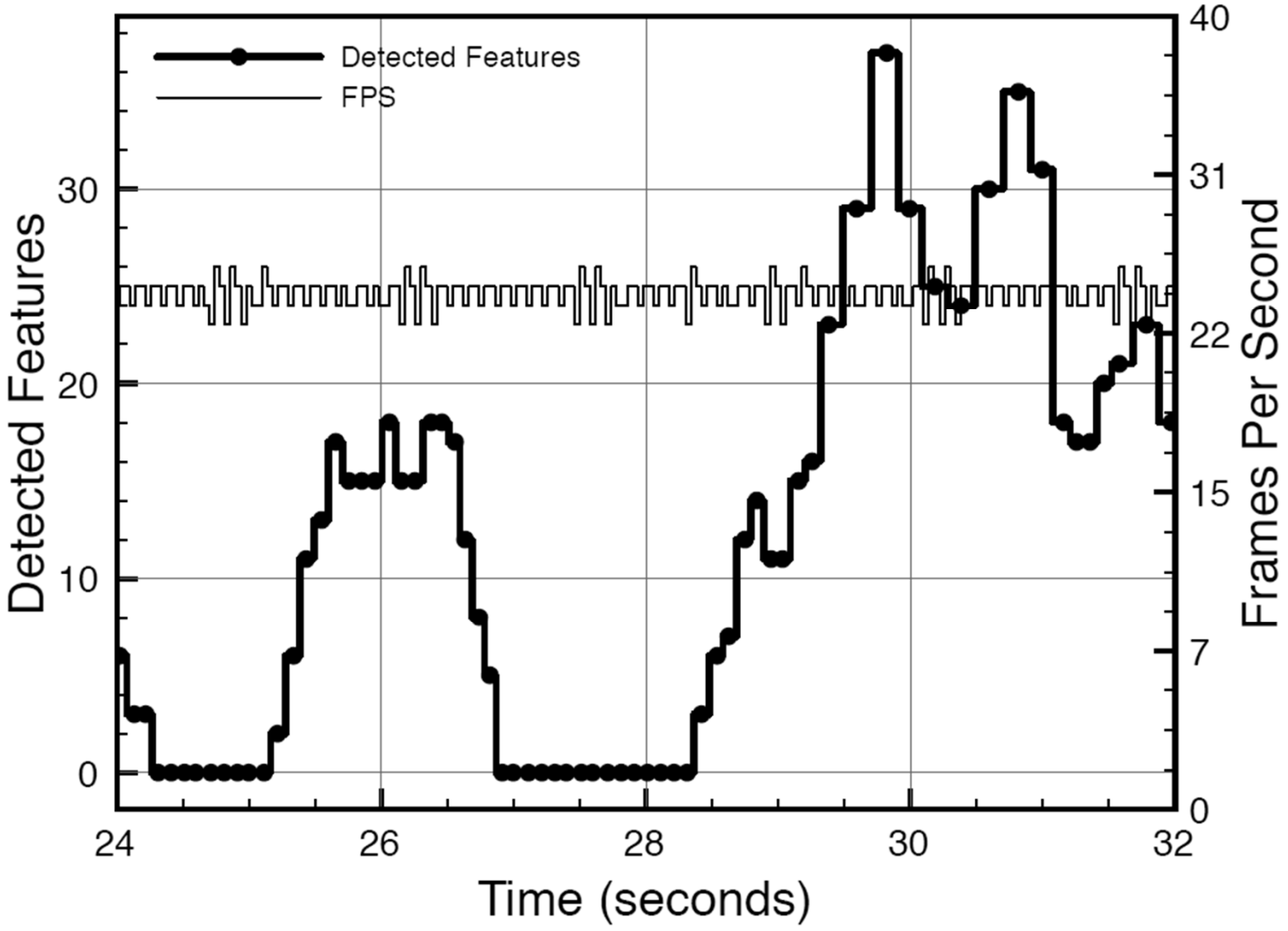
Nominal



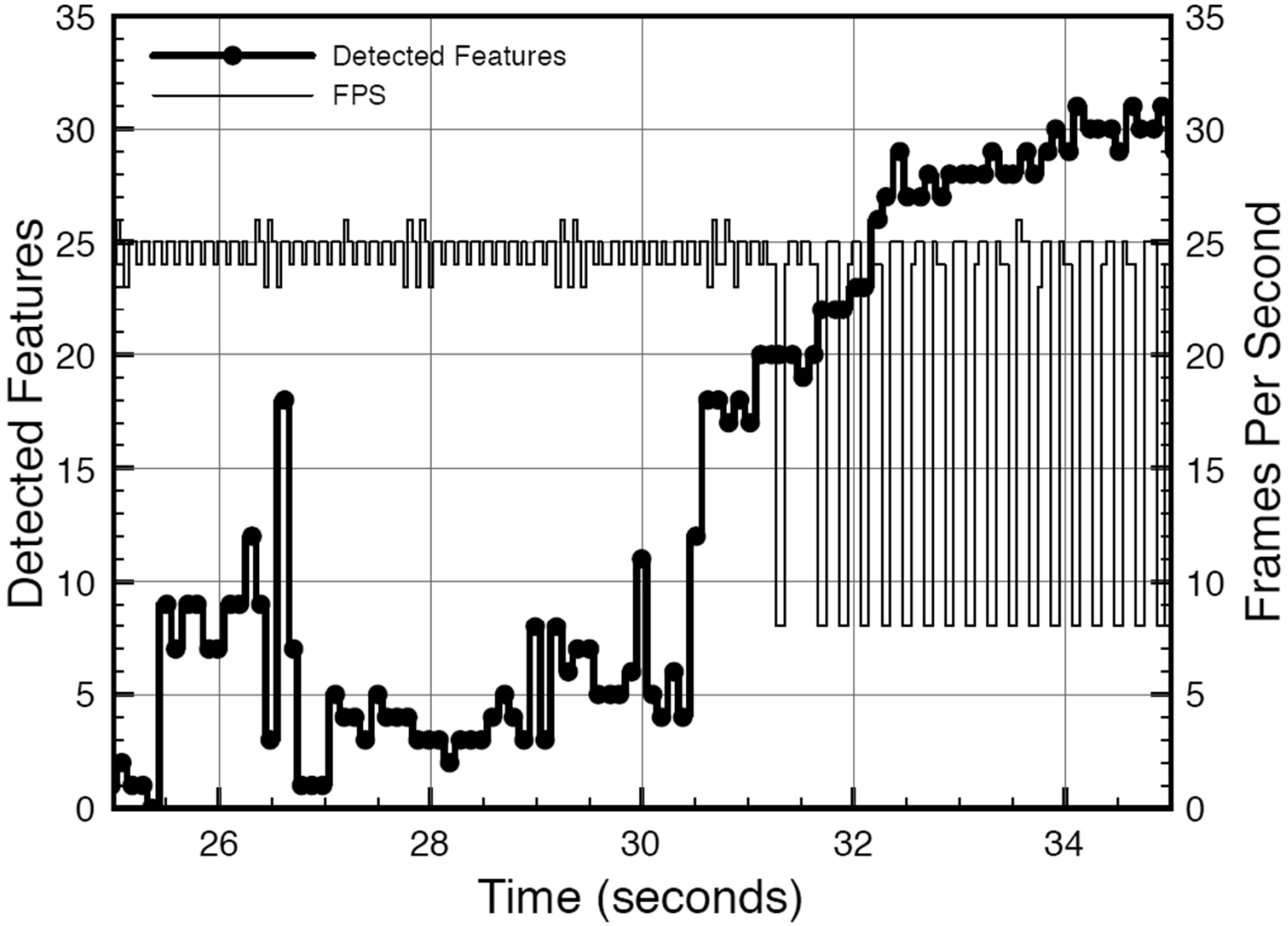
Overloaded

Demo

Object Detection vs. FPS with RMS



Object Detections vs. FPS with ZS-QRAM



Concluding Remarks

CPS requires new scheduling mechanisms that can cope with uncertainty in the environment (variable execution time)

Criticality-based overbooking protects safety-critical tasks allowing them to steal cycles from mission-critical ones

- But fails to encode diminishing returns within mission-critical tasks

ZS-QRAM optimizes mission-critical value

- Encoded as concave utility functions
- Overbooking within mission-critical tasks

Developed a metric that captures the capacity of the scheduler to retain utility in overloads

Demonstrated in a surveillance mission on our drone-rk platform