

Thermal Management of Cyber Physical Systems

CNS-1329702



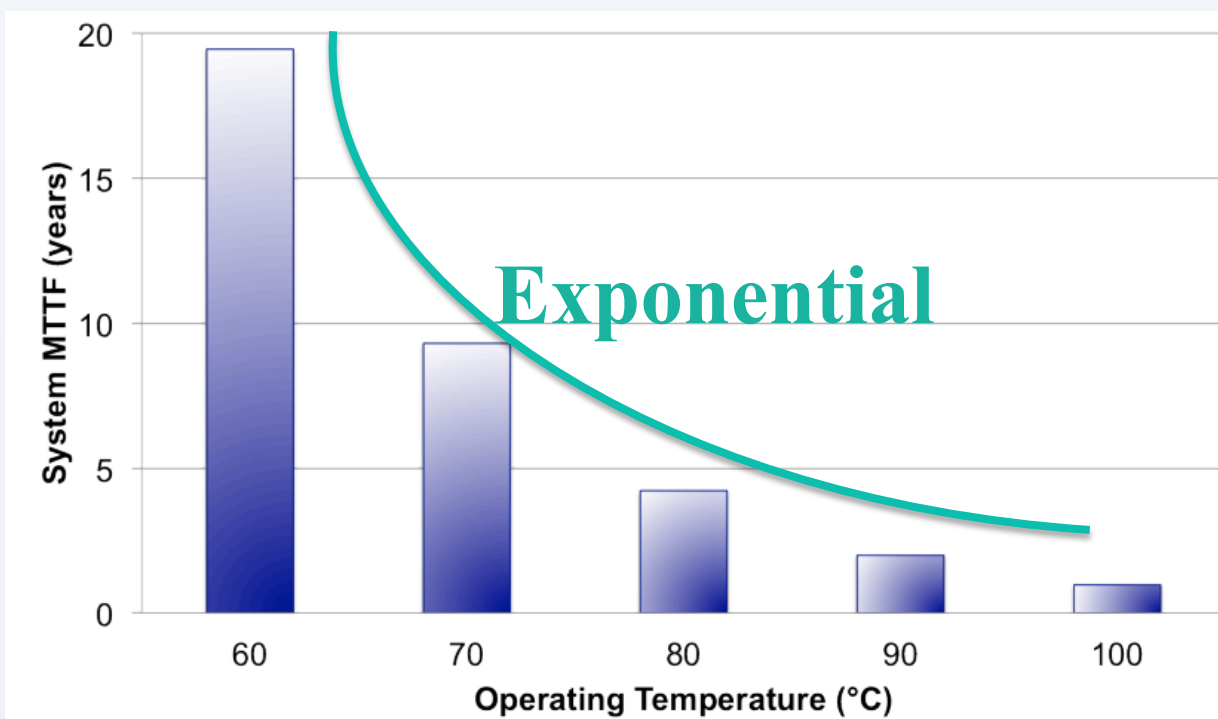
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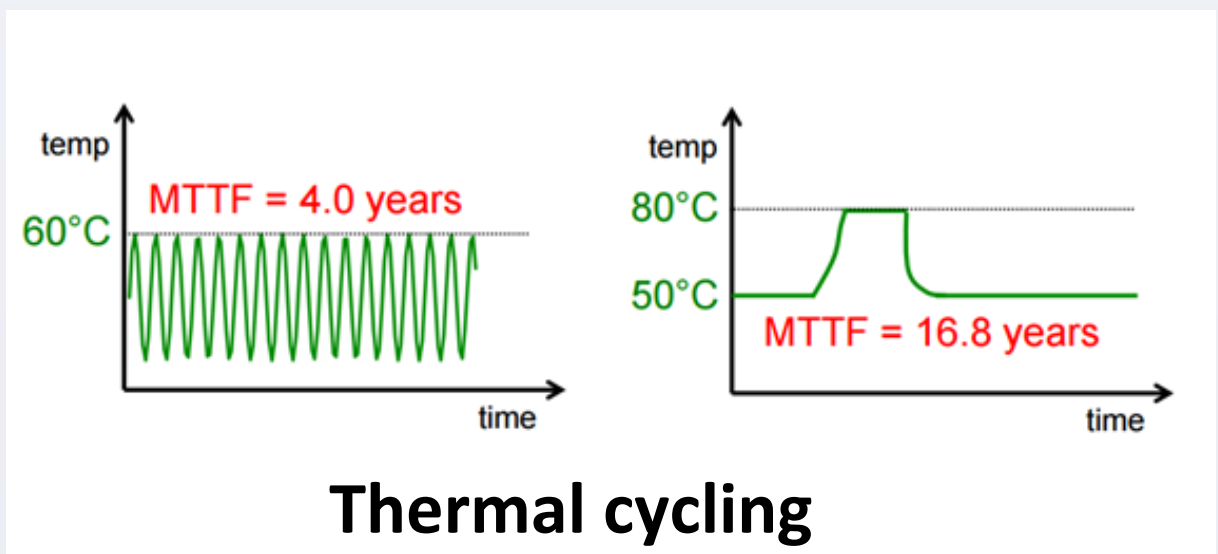


Motivation

- High temperature and/or temporal/spatial gradient
- System faults ↑ Lifetime ↓



Exponentially decreasing lifetime

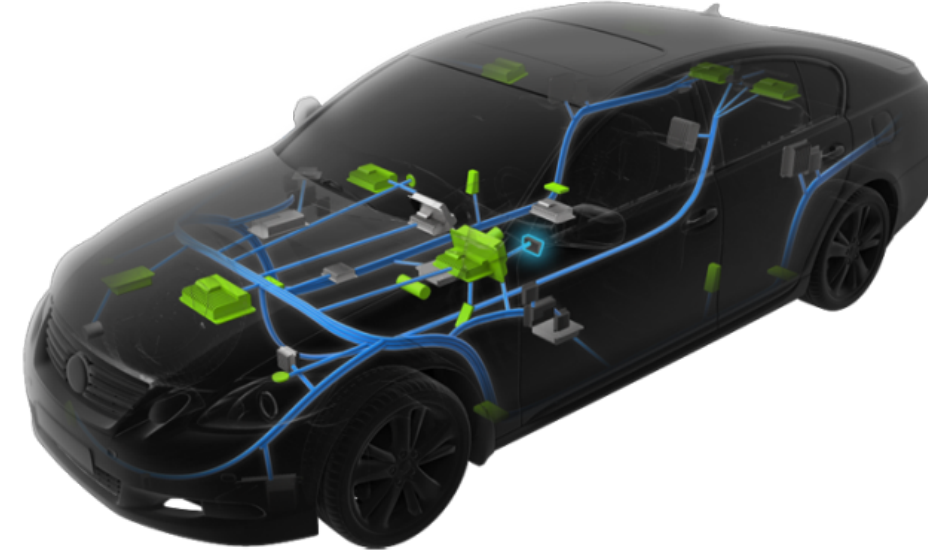


CPS approach

Cyber space

- Thermal behavior prediction
- Reliability-cost function
- Mathematical optimization
- Adaptive fault-tolerance

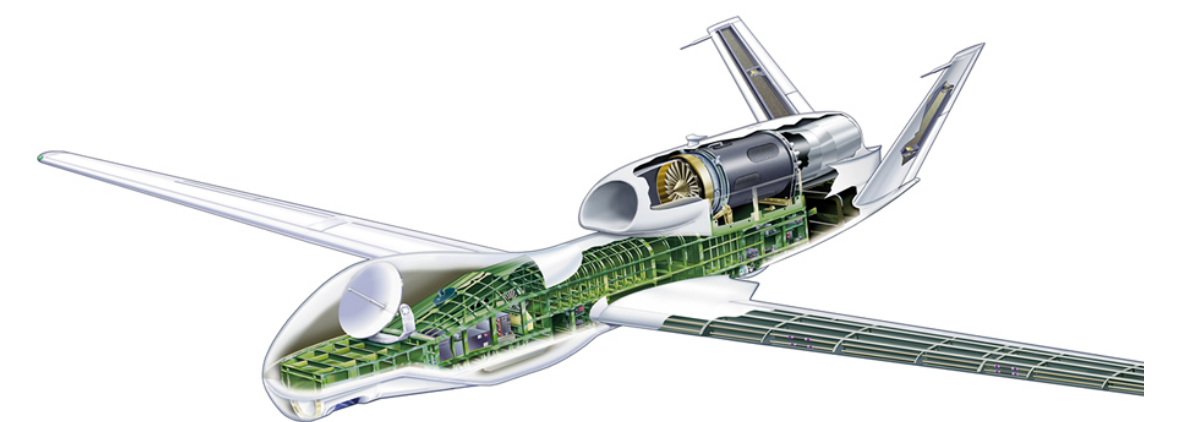
Physical system



Vehicle ECUs



Mobile system



UAV system

Control Knobs

Task(τ_{in})
Utilization(u_{in})
DVFS(V_{dm}, f_{dm})
....

Thermal model

$T(t, V, f, u, ...)$

Reliability model

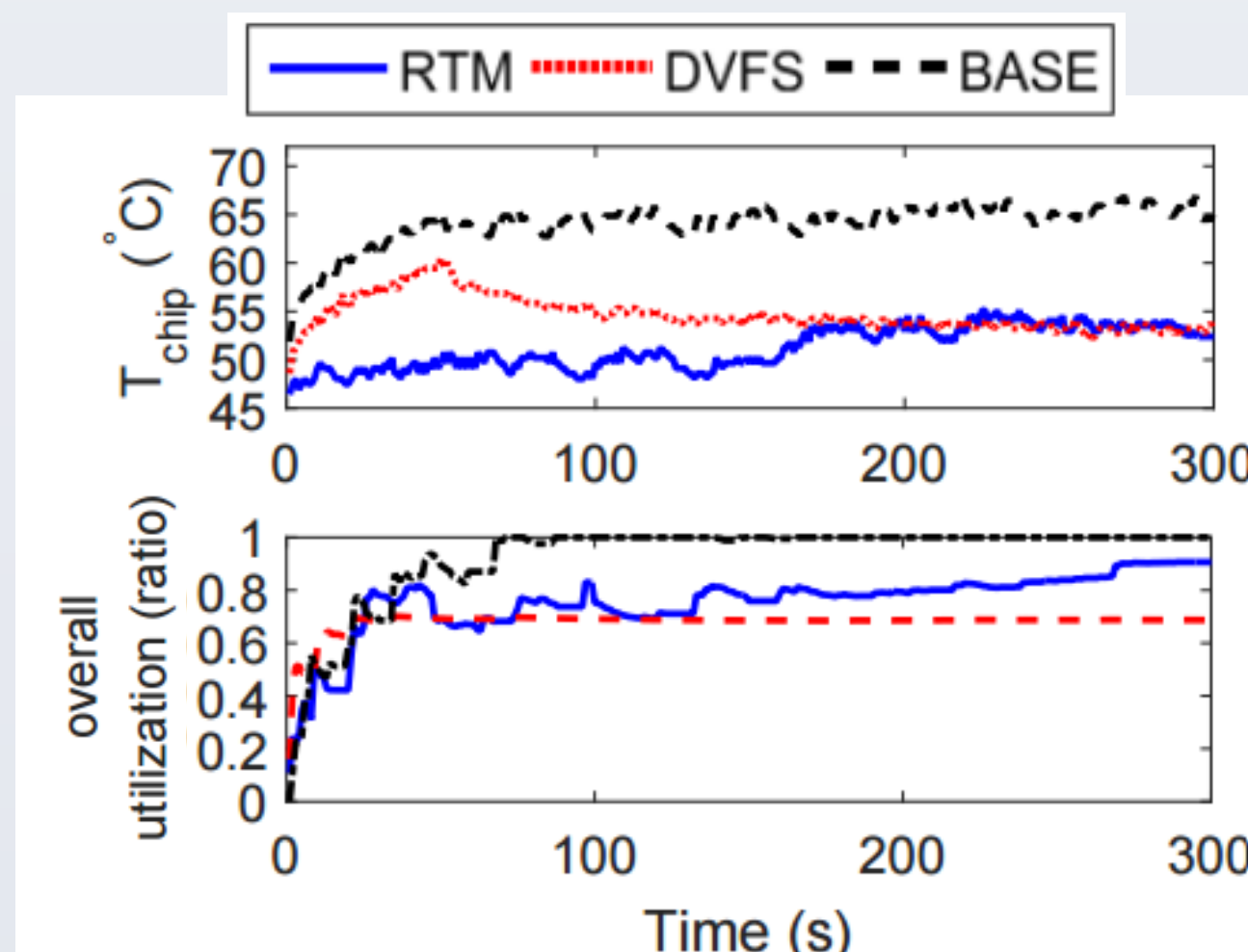
$MTTF(T, \Delta T, V, f, ...)$

Utilization

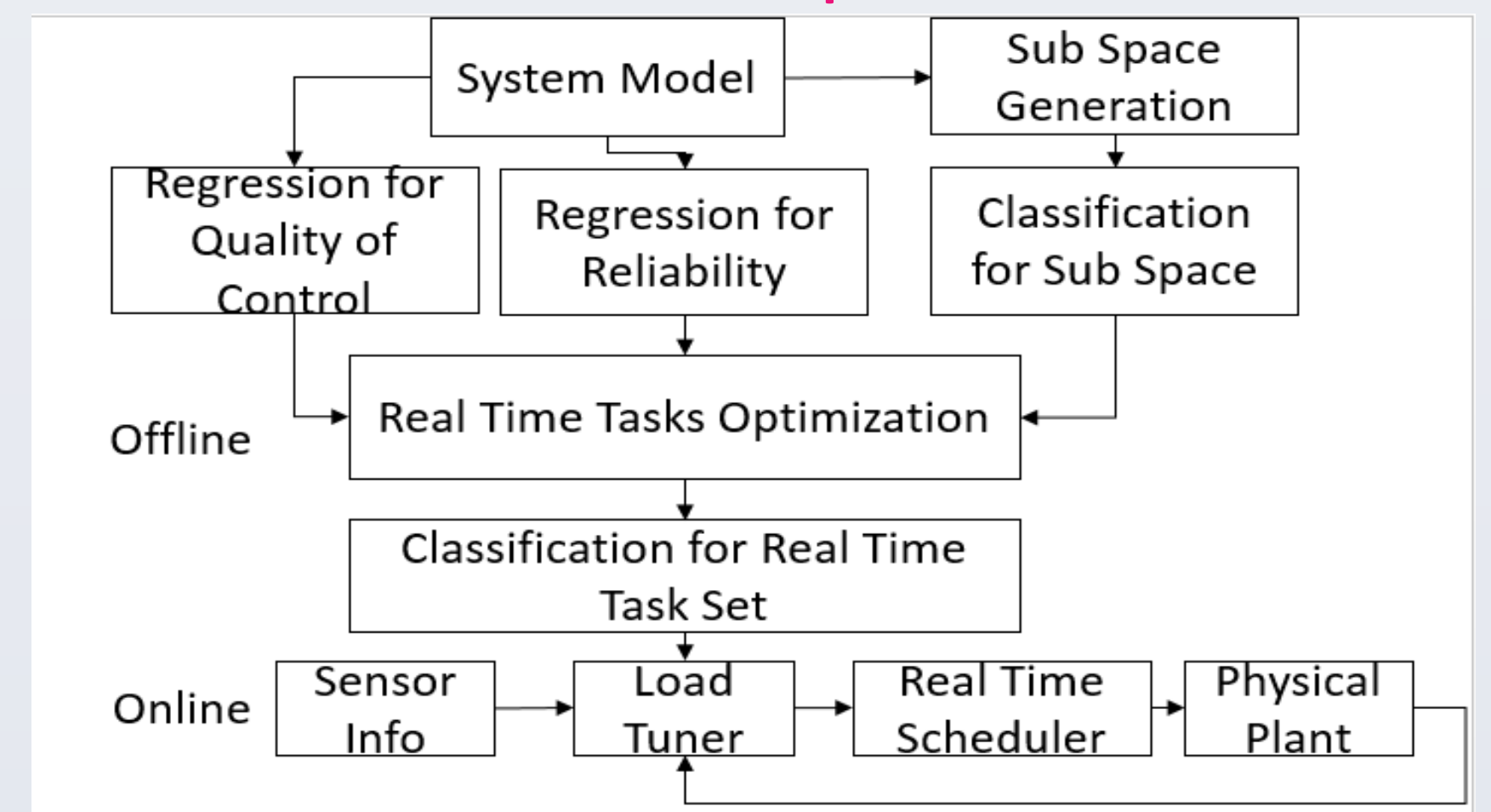
Reliability

CPS 1: Vehicle ECUs

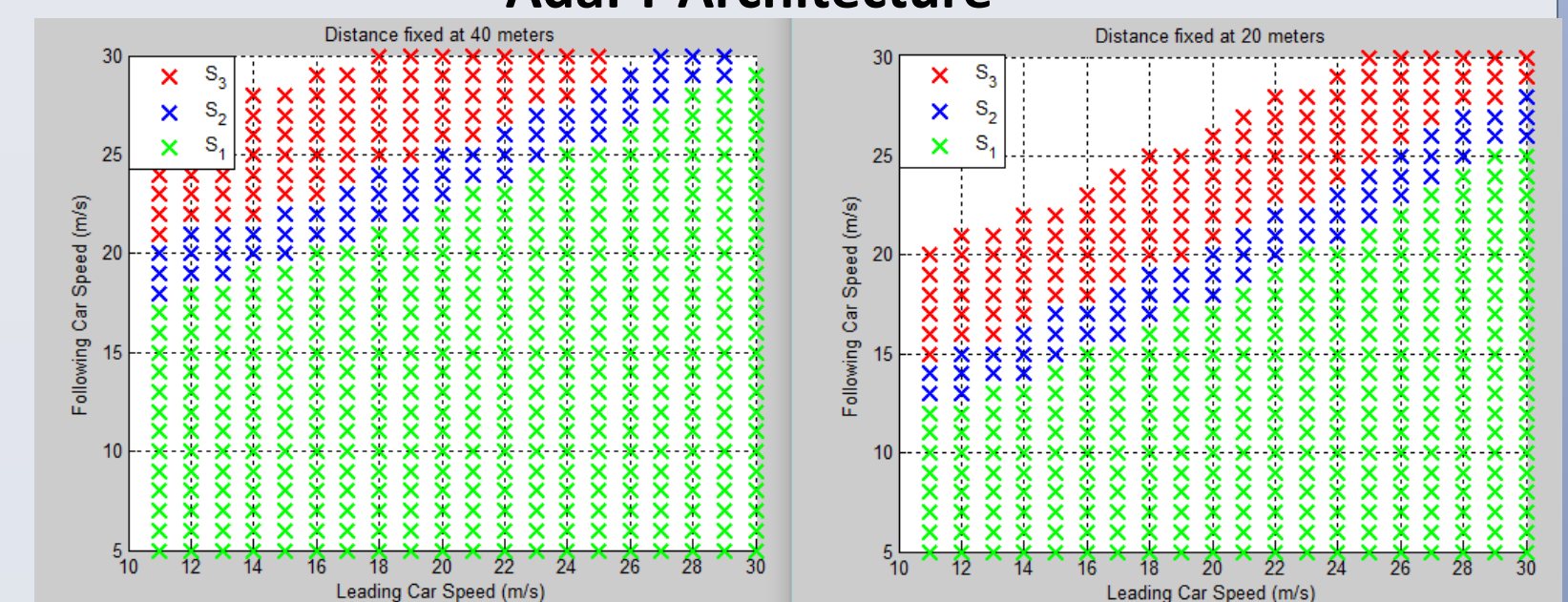
- Task characterization
- Maximizing utilization
- Temporal/spatial temperature gradient constraints
- Improving utilization 32% and lifetime 63%



AdaFT: Resource Aware Framework for Adaptive Fault Tolerance in CPS



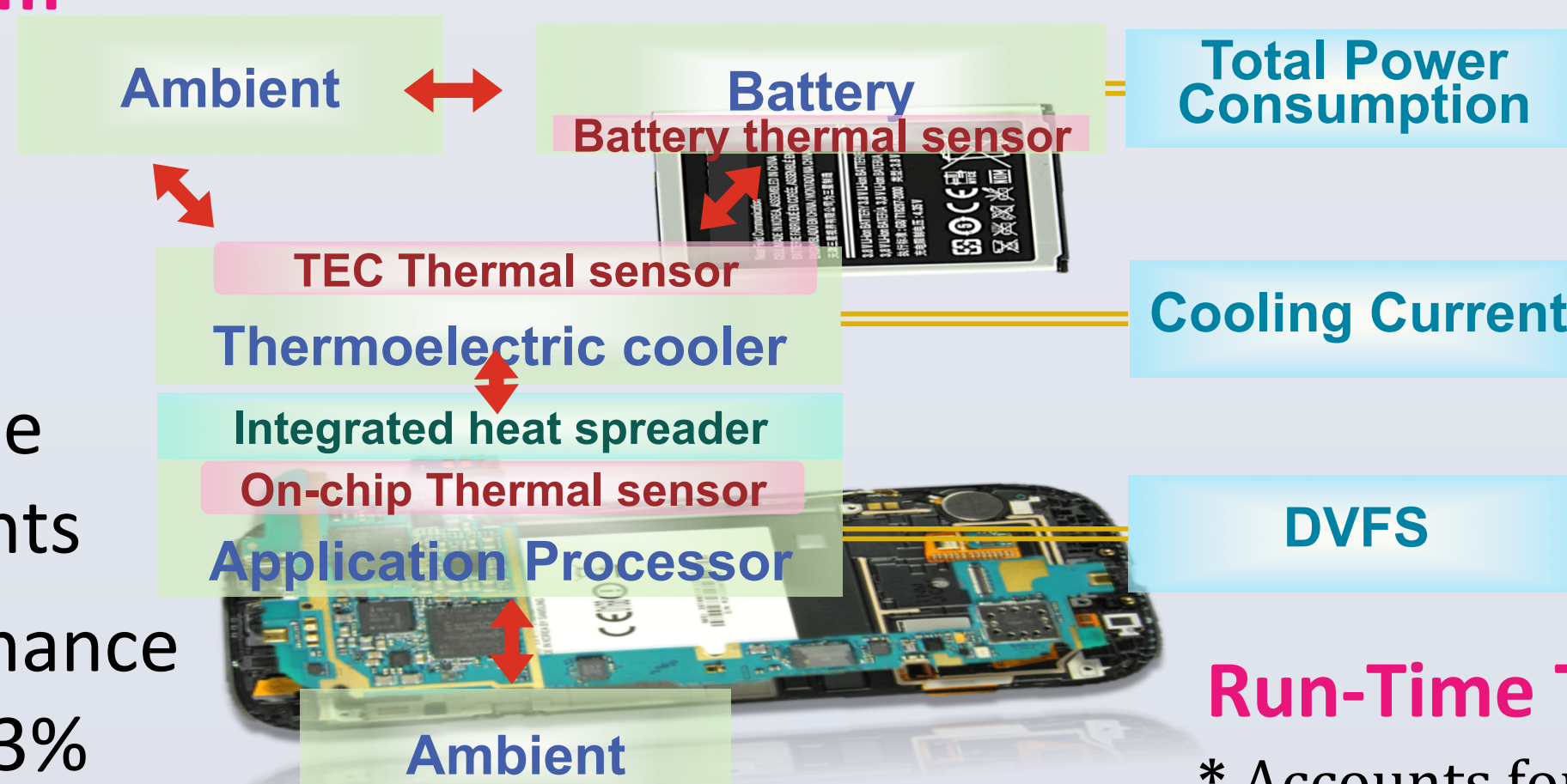
AdaFT Architecture



AdaFT Sub Space for 2-Car Platoon System

CPS 2: Mobile System

- CPU-battery thermal coupling
- Optimize power
- Real-time deadline Thermal constraints
- Improves performance per energy unit 13%

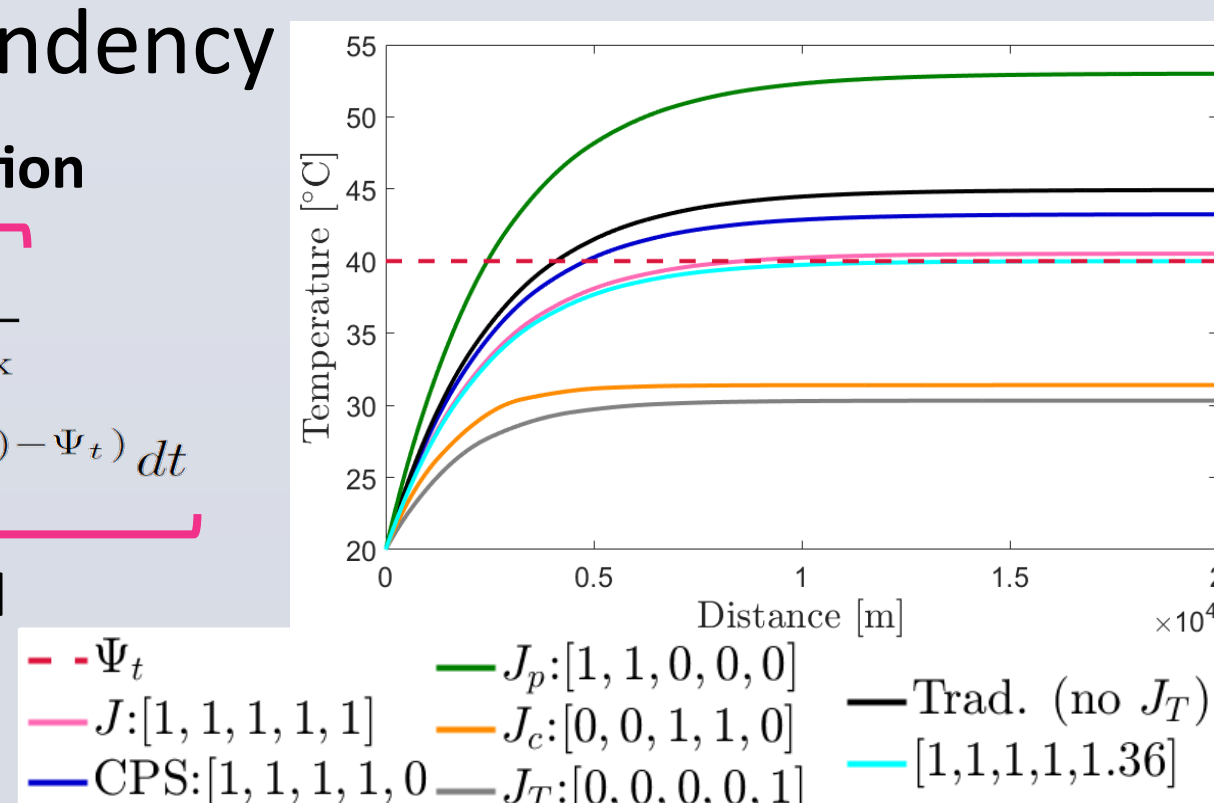


Mobile system architecture

CPS 3: Small Unmanned Aircraft System

- Optimize multi-objective mission performance
- Minimize component thermal degradation
- Model thermal dependency

$$J(v, r_\tau) = \underbrace{\beta_{p1} \frac{DP(v)}{v}}_{\text{energy}} + \underbrace{\beta_{p2} \frac{D}{v}}_{\text{time}} + \underbrace{\beta_{c1} \frac{Nr_\tau}{r_{\tau, \max}}}_{\text{utilization}} + \underbrace{\beta_{c2} e^{-\alpha \Omega(v, r_\tau)}}_{\text{information}} + \underbrace{\beta_T \int_0^T e^{\gamma(\Psi(v, r_\tau) - \Psi_t)} dt}_{\text{thermal}}$$



Run-Time Temperature Estimation

- * Accounts for thermal inertia.
- * Adaptively switches estimators using performance counters.
- * Low Computational Overhead.

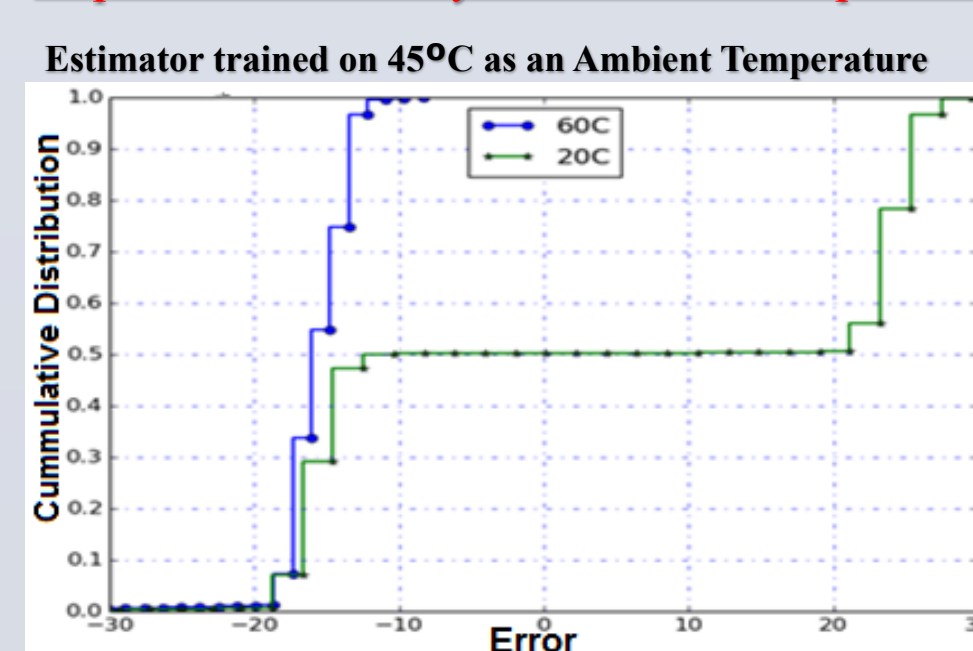
SPEC Suites: [IntReg Unit] Estimation Expression

Dual Estimator ($\tau = \text{Median} = 1.3$)		Baseline Estimator
Below Median	Above Median	
$T_{\text{est}}(n) = 3.13 * \text{IRA} + 0.54 * T_{\text{est}}(n-1) + 24.3$	$T_{\text{est}}(n) = 3 * \text{IRA} + 0.34 * T_{\text{est}}(n-1) + 35.05$	$T_{\text{est}}(n) = 7.05 * \text{IRA} + 56.67$

Temperature Estimation Error Range

IntReg Unit		FPR Unit
SPEC Suite	Baseline Estimator	SPEC Suite
$[-4.5^\circ\text{C}, +4^\circ\text{C}]$	$[-10^\circ\text{C}, +10^\circ\text{C}]$	$[-3.5^\circ\text{C}, 3.5^\circ\text{C}]$

Impact of Variability in Ambient Temperature:



MiBench Suites: IntReg File Thermal Estimator with Sensor Reading

