Impact of Proactive Temperature Management on Performance of NoCs

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Outline

- Motivation
- Temperature
- Proactive management
- Impact on performance

Motivation

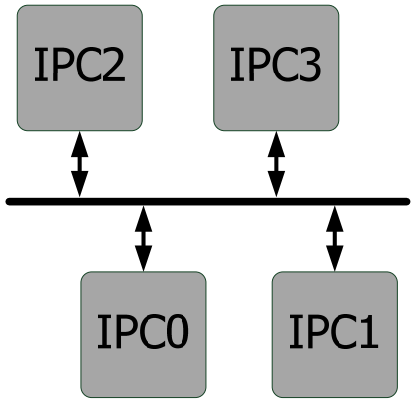
Technological progress

Requirements:

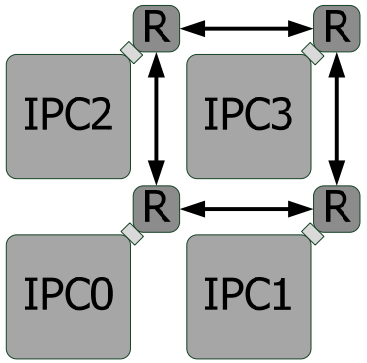
- performance, versatility
- energy efficiency, size
- reliability, robustness

Bus-based system

- synchronous (clock skew)
- centralized
- consecutive com.



Network-on-Chip



- GALS
- decentral
- parallel com.

Motivation

Challenges

Critical trends:

- power density
- probability of defects (# structures)
- susceptibility to environmental influences (structural size of ICs)

temperature related issues increasingly dominant (power → heat)

Impact of temperature

Problem:

- thermal stress (hot spots, imbalances)
- physical effects abetted by high temperatures (TDDB, EM, …)
- behavior of ICs temperature-dependent (U_{th}, ΔT_{switch})

Impairment:

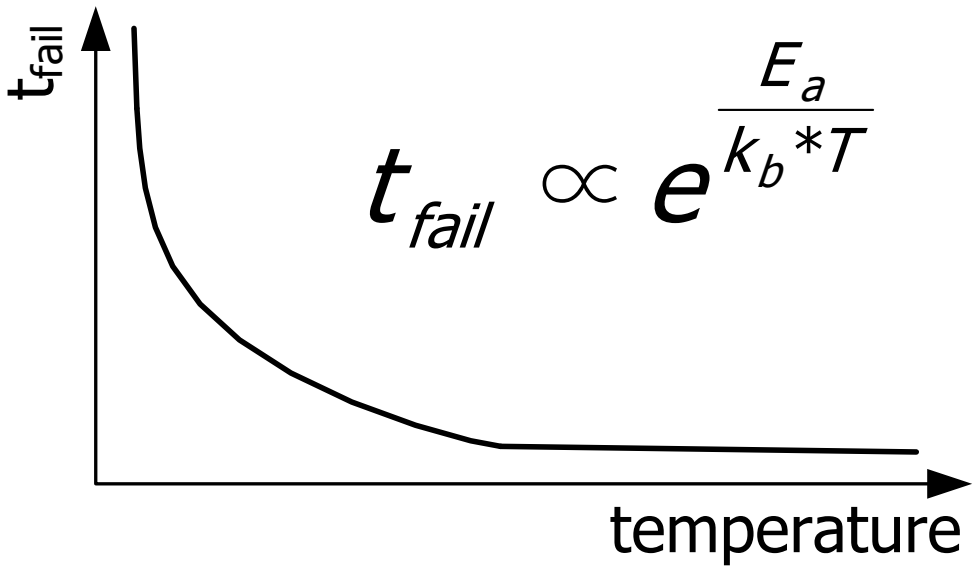
- lifetime
- operability
- performance

need for management
of on-chip temperature

Temperature

Arrhenius-Model

- link between temperature and physical effects
- dependency of velocity of chemical reactions on temperature



$$t_{fail} \propto e^{\frac{E_a}{k_b * T}}$$

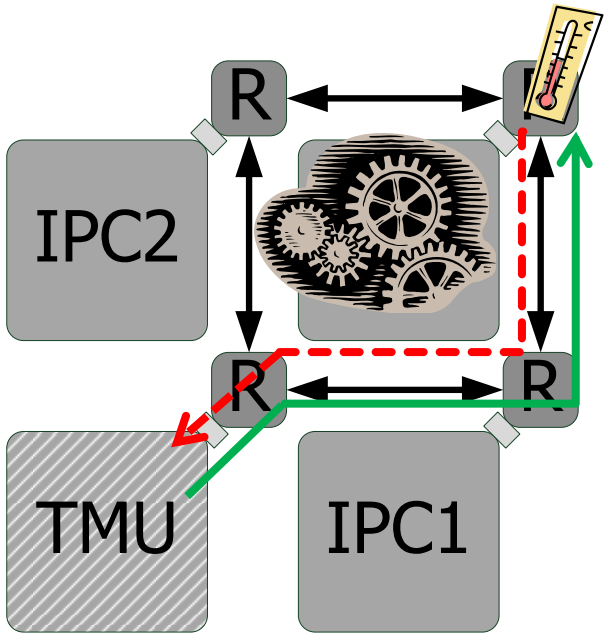
lifetime decreased exponentially

Temperature

Reactive management

State-of-the-art:

- (switching) activity
- temperature change
- detection (sensors)
- forwarding to TMU
- reaction (DFS, DVS, TR, CG)



$$\Delta T_{react} = \Delta T_{activity}(\tau_{th}) + 2 * \Delta T_{trans}$$

- long response times (due to τ_{th})
- additional traffic
- high frequency & long periods of reduced performance mode

$\Delta T_{trans} \approx$ 25...30 cycles (4x4 NoC)

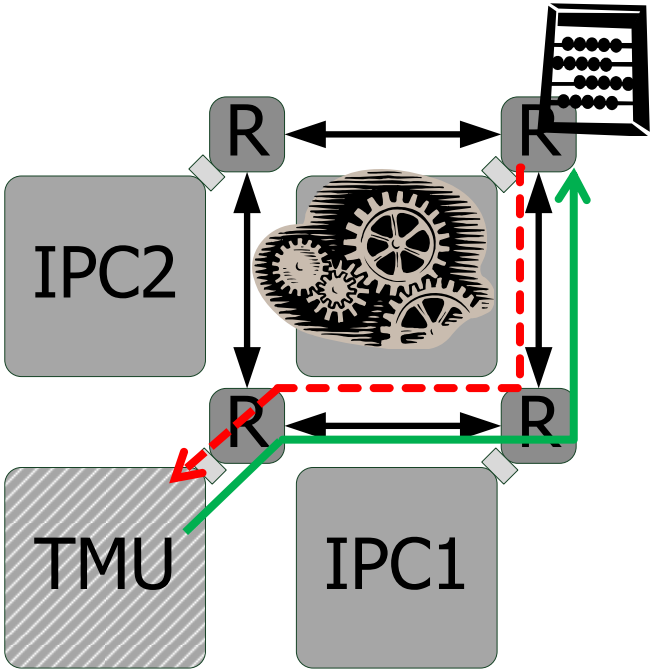
$(\tau_{th} = R_{th} * C_{th})$

Temperature

Proactive management

Approach:

- (switching) activity
- detection (counter)
- forwarding to TMU
- compute temperature change
- countermeasures (DFS, DVS, TR, CG)



$$\Delta T_{react} = \Delta T_{compute} + 2 * \Delta T_{trans}$$

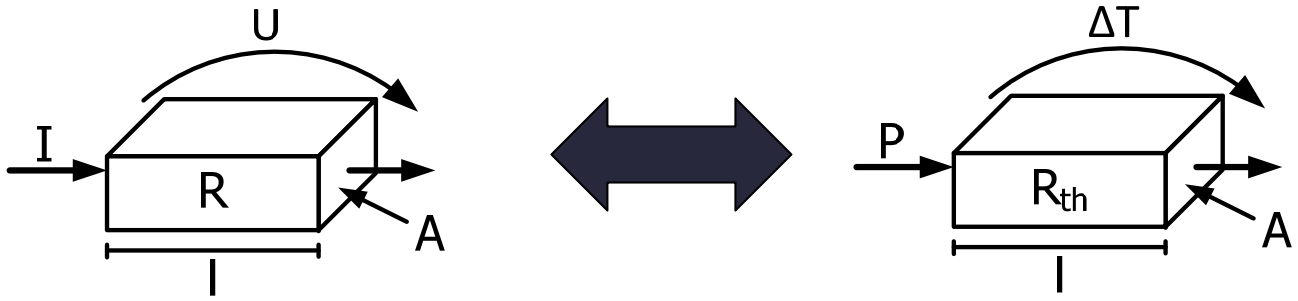
- shortened response times
- reduced additional traffic
- **impact on performance and temperature?**

Proactive management

Temperature model

thermal model	symbol	electrical model	symbol
heat flow	P [W]	current	I [A]
temperature	T [K]	voltage	U [V]
resistance	R_{th} [K/W]	resistance	R [V/A]
capacitance	C_{th} [J/K]	capacitance	C [As/V]

dualism of electrical and thermal energy flows



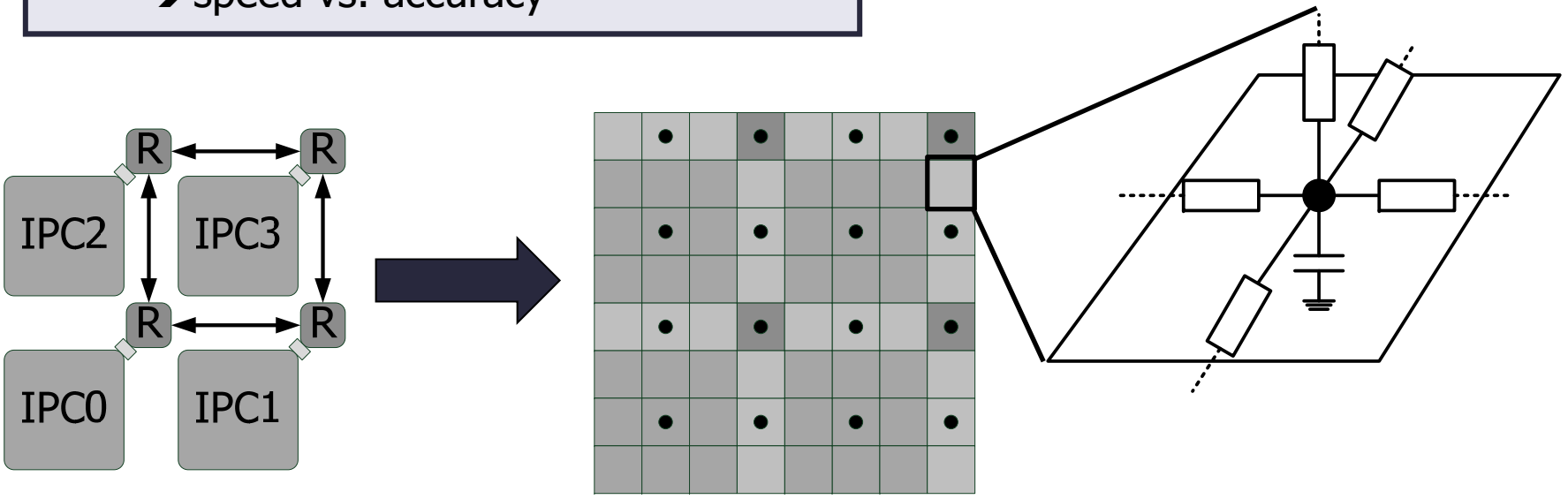
$$R = \frac{l}{\sigma * A}$$

$$R_{th} = \frac{l}{\lambda * A}$$

Proactive management

Temperature model

- mapping NoC to model
  - ➔ regular grid of RC-tiles (incl. links)
- granularity of the RC-network
  - ➔ speed vs. accuracy



Proactive management

Temperature model

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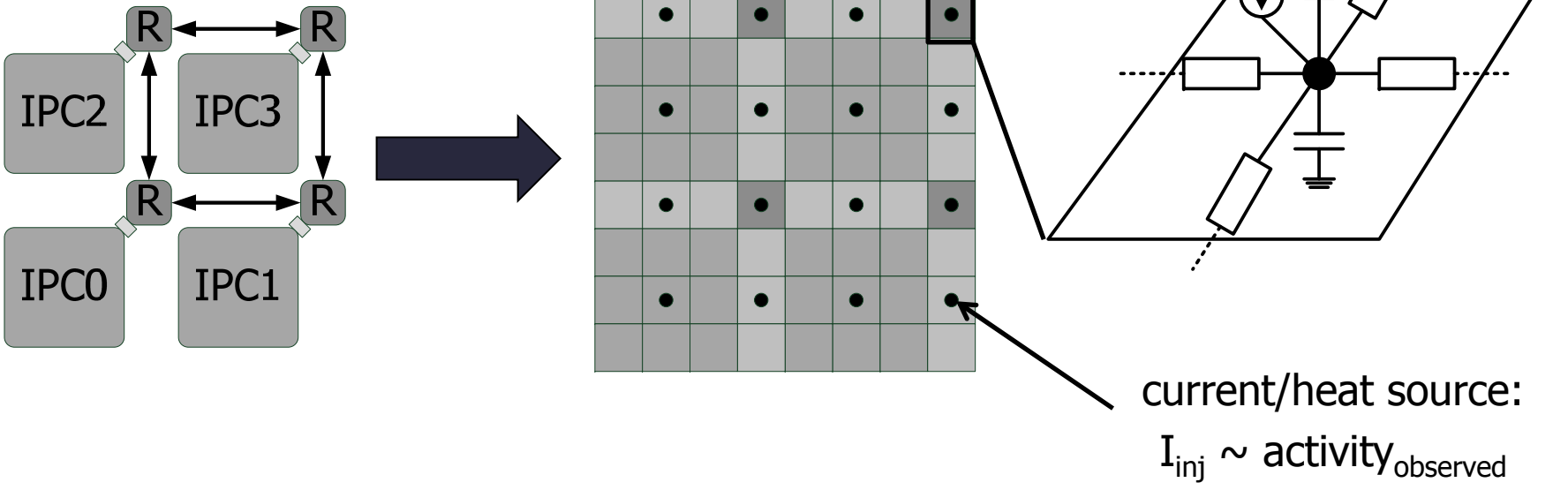


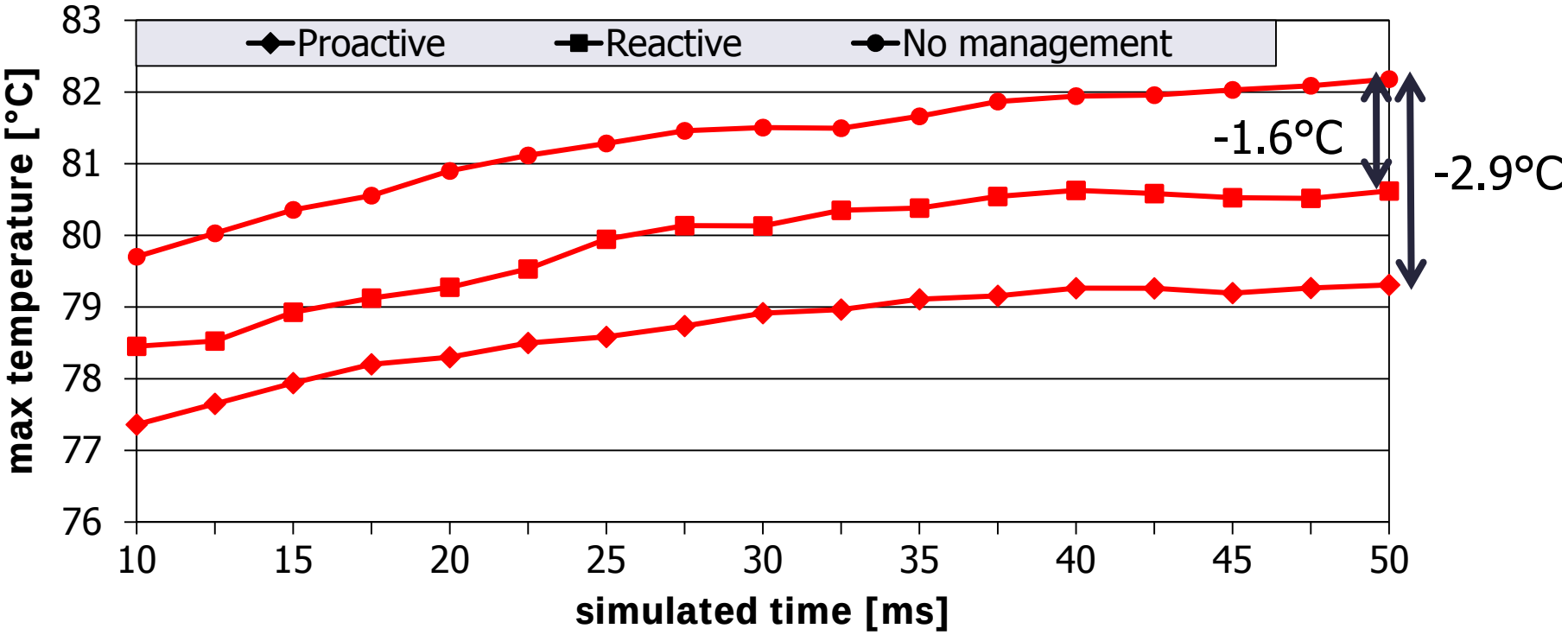
Proactive management

Temperature simulation - overview

- complete package (incl. heat spreader & sink)
- modeling granularity: 1 RC-tile per component
- NoC-Simulator = SystemC + OSCI TLM + SystemC AMS
  - SystemC + TLM: functional simulation
  - SystemC AMS: simulation of thermal behavior
- IPC traffic generation: random packet generation with different load factors
- temperature monitoring: IPCs, routers, links
- temperature control: DFS (active comp.), TR (IPCs)

Impact on temperature

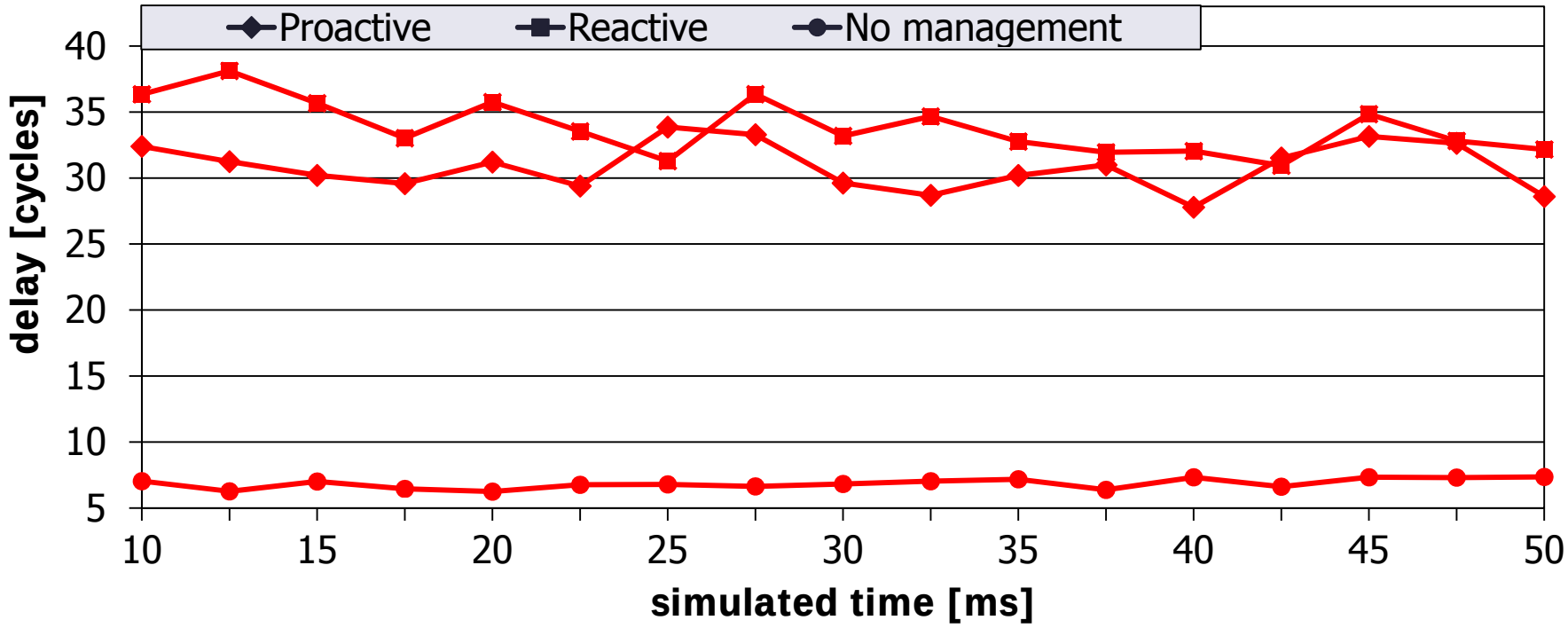
Maximum temperature – 4x4 NoC



approach	avg red. [°C]	avg red. in %
reactive	1.3	1.7
proactive	2.5	3.1

Impact on performance

Router delay – 4x4 NoC

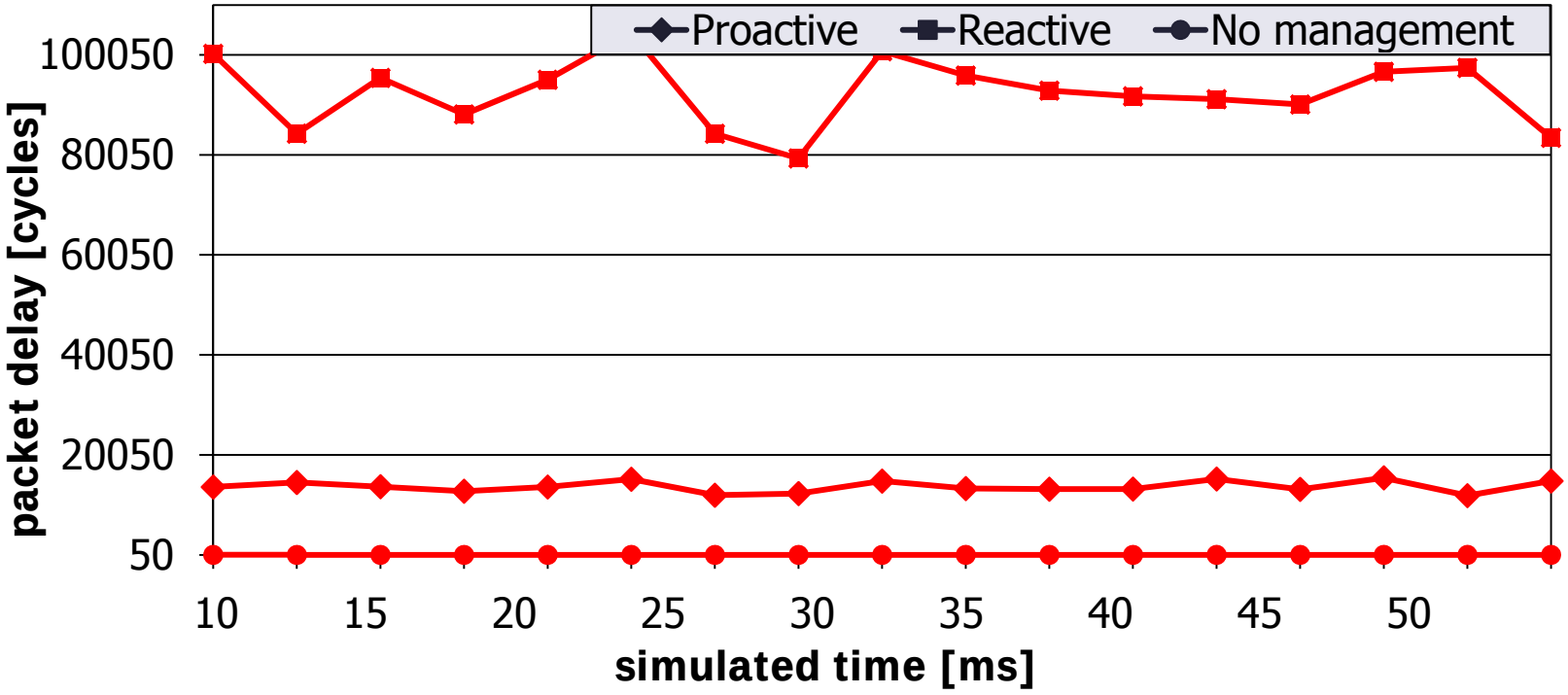


approach	avg penalty	avg penalty in %
reactive	27.2	398
proactive	24.2	353

1 cycle: 1ns

Impact on performance

Packet delay – 4x4 NoC

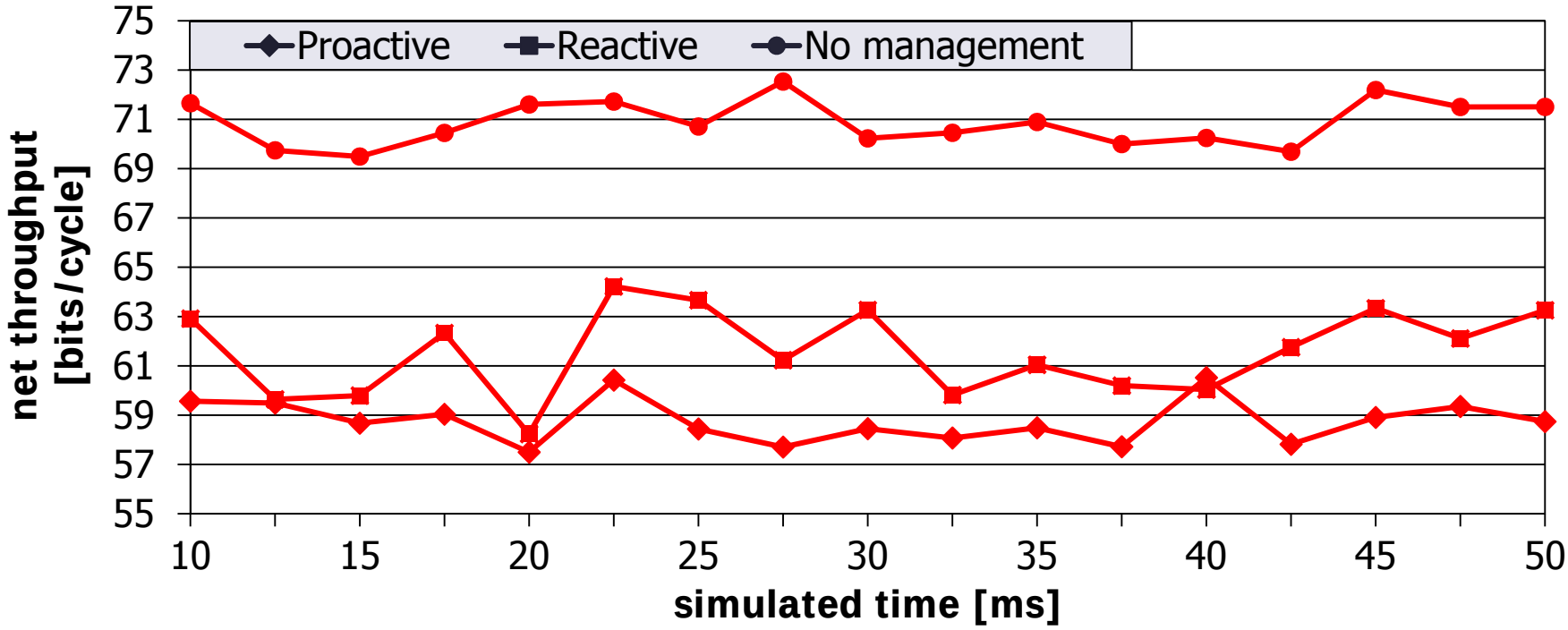


approach	avg penalty	avg penalty in %
reactive	95k	159k
proactive	15k	26k

1 cycle: 1ns

Impact on performance

Net data throughput – 4x4 NoC



approach	avg penalty	avg penalty in %
reactive	9	13
proactive	12	17

1 cycle: 1ns

Summary

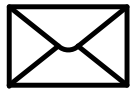
Limitations, open questions:

- no stand-alone alternative for sensors (correction, calibration)
- additional heat due to computation (depends on complexity)?
- impact of technology parameters?
- portability/comparison to other simulators?

- simulation of the temperature profile of NoC-based systems
- proactive temperature management
  - temperature computation based on switching activity
  - speed vs. accuracy
  - effort vs. goal

Thanks for your attention!
Questions?

contact: tim.wegner@uni-rostock.de



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