Latency- and Resilience-Aware Networking

Energy-, Latency- and Resilience-Aware Networking (e.LARN)

SPP 1914: “Cyber-Physical Networking”

http://larn.systems

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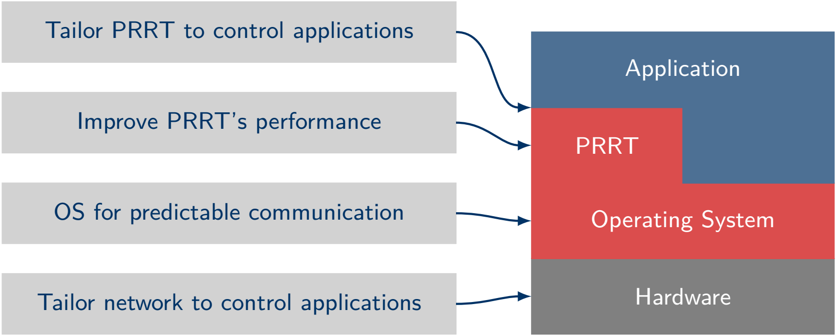
Department of Computer Science 4 (Distributed Systems and Operating Systems)
Friedrich-Alexander-Universität Erlangen-Nürnberg

November 15th, 2022

Recapitulation: Goals



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Software, Hardware & Algorithms

PRRT Predictably Reliable Real-time Transport protocol

- Cross-Layer Pacing + Rate Control
- Improved timing precision and accuracy

Software, Hardware & Algorithms

PRRT	Predictably Reliable Real-time Transport protocol
	- Cross-Layer Pacing + Rate Control
	- Improved timing precision and accuracy
X-LEEP	Cross-Layer Pacing for Energy Efficiency
	- Adjust CPU voltage and frequency

Software, Hardware & Algorithms

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	- Cross-Layer Pacing + Rate Control
	- Improved timing precision and accuracy
X-LEEP	Cross-Layer Pacing for Energy Efficiency
	- Adjust CPU voltage and frequency
DEEPHEC	Deep Learning for Hybrid Error Coding
	- Adaptive error control
	- Provide predictable adaptation time

Status

Cross Layer Pacing

X-LEEP

DeepHEC

Conclusion

Bufferbloat

Jim Gettys; Kathleen Nichols: **Bufferbloat: Dark Buffers in the Internet**, CACM, 2012

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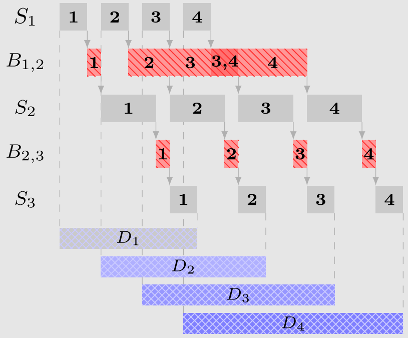
Unpaced



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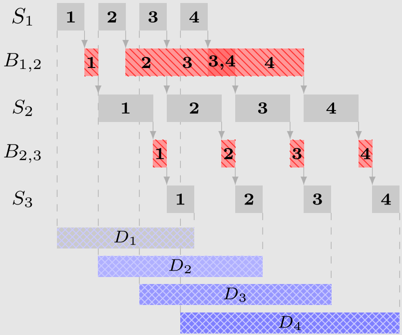
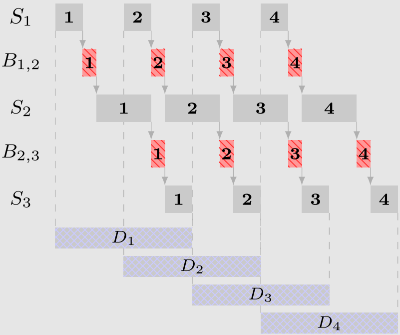
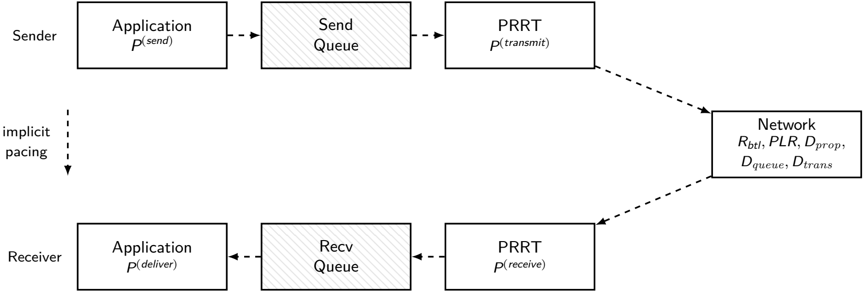
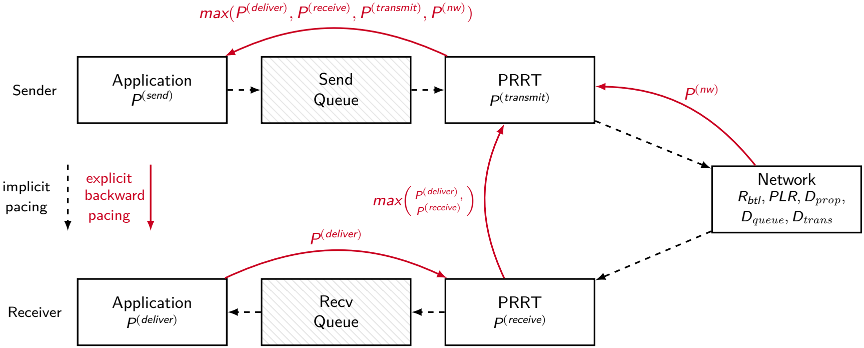


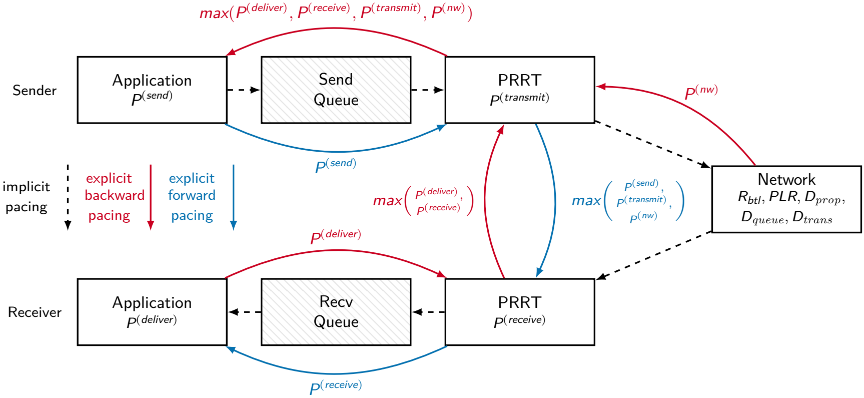
Paced



Cross-Layer Pacing & X-Pace




max(P^(deliver), P^(receive), P^(transmit), P^(nw))
Sender
Application
P^(send)
Send
Queue
PRRT
P^(transmit)
P^(nw)
implicit
pacing
explicit
backward
pacing
max(P^(deliver), P^(receive))
Network
R_btl, PLR, D_prop,
D_queue, D_trans
P^(deliver)
Receiver
Application
P^(deliver)
Recv
Queue
PRRT
P^(receive)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Network
Rbtl, PLR, Dprop,
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Receiver
Application
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Recv
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PRRT
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Real-World Internet Experiment

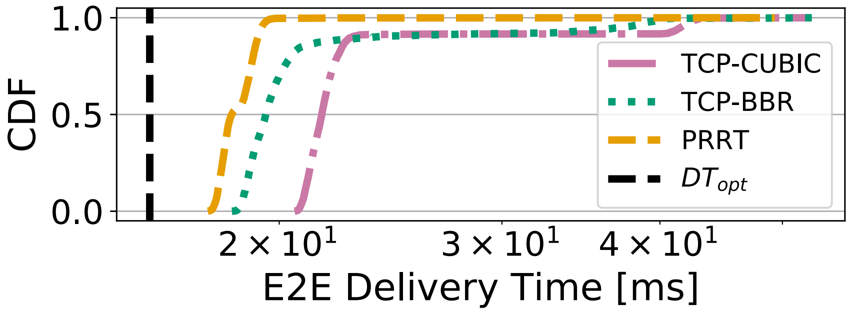

Figure: PRRT with X-Pace vs. Optimized Low-Latency TCP Variants

Status

Cross Layer Pacing

X-Leep

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Implementation

- Goal: Adapt application and operating system to run-time behaviour of the network layer
- Approach: Adjust voltage and frequecy of the CPU

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- Approach: Adjust voltage and frequecy of the CPU
- Application interface to obtain:
  - Data sampling period (t_{period})
  - Last execution time ($t_{execution}$)

$$f_{opt} = f_{cur} \cdot \frac{t_{execution}}{t_{period}}$$

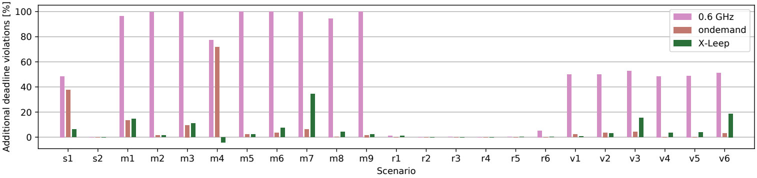
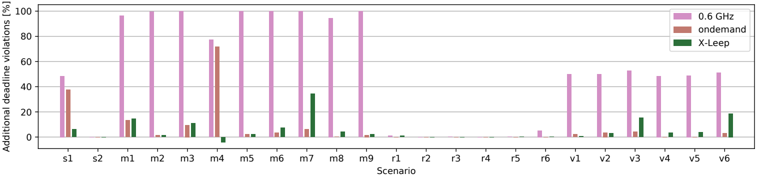


Figure: Increase in deadline violations, normalised to the execution at 1.4 GHz fixed



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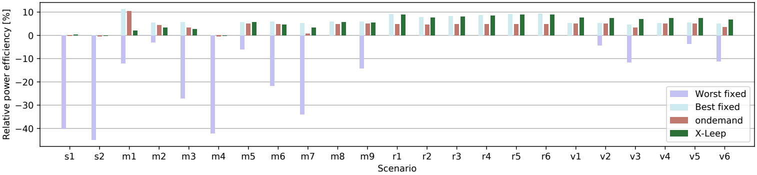

Figure: Power efficiency comparison, normalised to the execution at 1.4 GHz fixed

Status

Cross Layer Pacing

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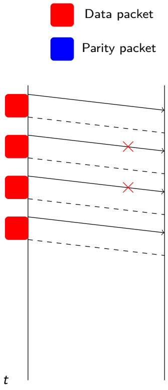
Predictable Reliability

- Goal: meet the **application loss rate** and **latency constraints** using the **minimum** possible **redundancy information**



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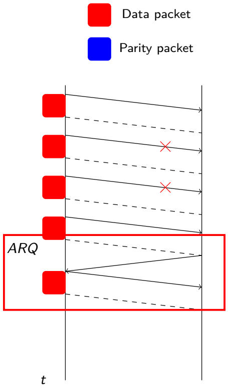

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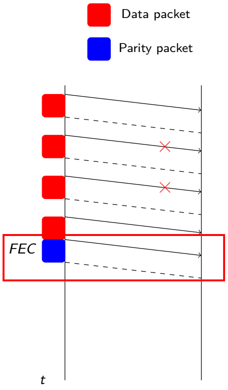

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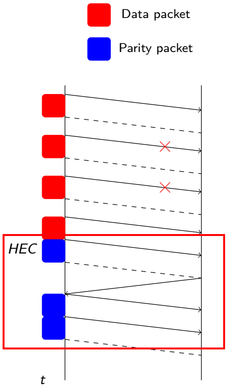
Predictable Reliability

- Goal: meet the **application loss rate** and **latency constraints** using the **minimum** possible **redundancy information**
- Approach: combine proactive and reactive redundancy with Hybrid Error Coding (HEC)



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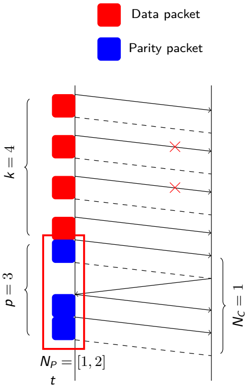

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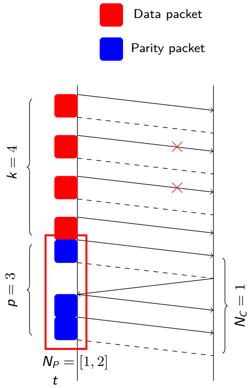

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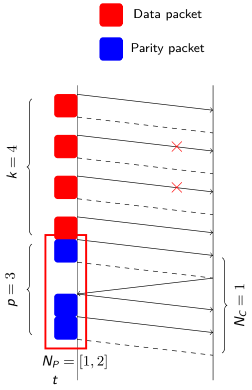
- Problem: **unpredictable reaction time** since the search space depends on channel state and application requirements



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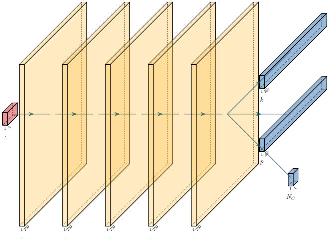
Architecture

- Input: channel state information and application requirements
- 5 fully connected hidden layers with 250 neurons each
- NN output: (k, p, N_C)
- Algorithmic output: N_P



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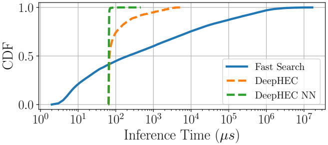
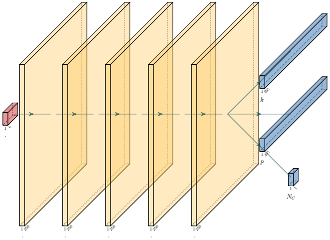


Figure: Inference Time Cumulative Distribution Function (CDF)



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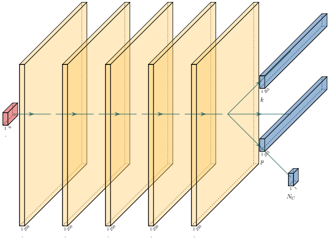

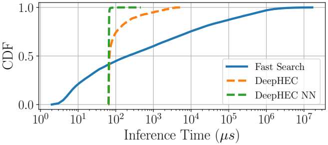

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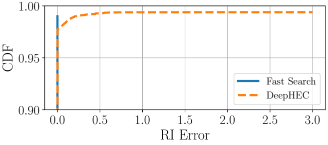

Figure: Redundancy Information error Cumulative Distribution Function (CDF)

Status

Cross Layer Pacing

X-LEEP

DeepHEC

Conclusion

Outcome (since November 2018)

Summary

- 2023: 2 publications (CCNC)
- 2022: 3 publications (in CCNC, TECS, EDCC)
- 2021: 7 publications (in CCNC, EuroSec, LCTES, e-Energy, WEEE, PLOS)
- 2020: 5 publications (in WEEE, IFAC, DCOSS Wi-DroIT, ISORC, APSys)
- 2019: 2 publications (in EuroSys EdgeSys Workshop, InfoCOM ULLWN Workshop)

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Accepted Publications

- Vogelgesang, Kai; Gil Pereira, Pablo; Herfet, Thorsten: **SHARQ: Scheduled HARQ for Time- and Loss-Rate-Sensitive Networks**, CCNC, 2023
- Vogelgesang, Kai; Herfet, Thorsten: **On Multihop vs. End-to-End Transport**, CCNC, 2023
- Pereira, Pablo Gil; Schmidt, Andreas; Herfet, Thorsten: **DeepHEC: Hybrid Error Coding using Deep Learning**, EDCC, 2022
- B. Herzog, S. Reif, J. Hemp, T. Hönig, and W. Schröder-Preikschat: **Resource-demand estimation for edge tensor processing units**, ACM TECS, 2022
- Gil Pereira, Pablo; Herfet, Thorsten: **Polar Coding for Efficient Transport Layer in Multicast**, CCNC, 2022
- L. Gerhorst, B. Herzog, S. Reif, W. Schröder-Preikschat, and T. Hönig: **AnyCall: Fast and flexible system-call aggregation**, PLOS, 2021
- B. Herzog, F. Hügel, S. Reif, T. Hönig, and W. Schröder-Preikschat: **Automated selection of energy-efficient operating system configurations**, WEEE, 2021
- S. Reif, B. Herzog, J. Hemp, T. Hönig, and W. Schröder-Preikschat: **AI waste prevention: Time and power estimation for edge tensor processing units**, e-Energy 2021, 2021
- B. Herzog, S. Reif, F. Hügel, T. Hönig, and W. Schröder-Preikschat: **Towards automated system-level energy-efficiency optimisation using machine learning**, e-Energy 2021, 2021
- S. Schuster, P. Wägemann, P. Ulbrich, and W. Schröder-Preikschat: **Annotate once — analyze anywhere: Context-aware WCET analysis by user-defined abstractions**, LCTES'21, 2021

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Accepted Publications

- B. Herzog, S. Reif, J. Preis, W. Schröder-Preikschat, and T. Hönig: **The price of meltdown and spectre: Energy overhead of mitigations at operating system level**, EuroSec, 2021.
- Gil Pereira, Pablo; Herfet, Thorsten: **Reducing FEC-Complexity in Cross-Layer Predictable Data Communication**, CCNC, 2021
- S. Reif, B. Herzog, F. Hügel, T. Hönig, and W. Schröder-Preikschat: **Nearly symmetric multi- core processors**, APSys, 2020
- S. Reif and W. Schröder-Preikschat: **Precisely timed task execution**, ISORC, 2020
- Böhmer, Marlene; Schmidt, Andreas; Pereira, Pablo Gil and Herfet, Thorsten: **Latency-aware and-predictable Communication with Open Protocol Stacks for Remote Drone Control**, DCOSS Wi-DroIT, 2020
- Schmidt, Andreas; Pereira, Pablo Gil; Herfet, Thorsten: **Predictably Reliable Real-time Transport Services for Wireless Cyber-Physical Systems**, IFAC World Congress, 2020
- Reif, Stefan; Herzog, Benedict; Pereira, Pablo Gil; Schmidt, Andreas; Büttner, Tobias; Hönig, Timo; Schröder-Preikschat, Wolfgang; Herfet, Thorsten: **X-Leep: Leveraging Cross-Layer Pacing for Energy-Efficient Edge Systems**, WEEE, 2020
- Schmidt, Andreas; Reif, Stefan; Gil Pereira, Pablo; Hönig, Timo; Herfet, Thorsten; Schröder-Preikschat, Wolfgang **Cross-layer Pacing for Predictably Low Latency**, ULLWN, 2019
- Gallenmüller, Sebastian; Glebke, René; Günther, Stephan; Hauser, Eric; Leclaire, Maurice; Reif, Stefan; Rüth, Jan; Schmidt, Andreas; Carle, Georg; Herfet, Thorsten; Schröder-Preikschat, Wolfgang; Wehrle, Klaus: **Enabling Wireless Network Support for Gain Scheduled Control**, EdgeSys, 2019

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Network

- ✓ PRRT – Predictable protocol
- ✓ DeepHEC – Error Control

Operating System

- ✓ X-LEEP – Energy efficiency
- ✓ Precise task execution

+

Reliable Network Atom (RNA)
(Embedded Edge-Server, Car, Drone, ...)

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- Optimisation
- Cross-layer pacing

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Thank you for your attention. Questions?