LARN
Latency- and Resilience-Aware Networking

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SPP 1914: "Cyber-Physical Networking"

http://larn.systems

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Friedrich-Alexander-Universität Erlangen-Nürnberg

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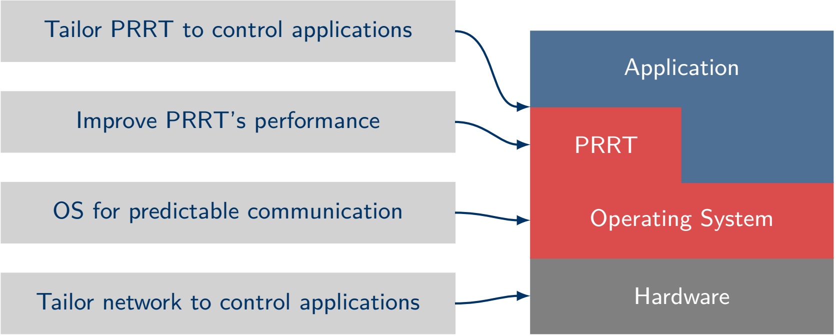
Tailor PRRT to control applications
Improve PRRT's performance
OS for predictable communication
Tailor network to control applications
Application
PRRT
Operating System
Hardware

Software, Hardware & Algorithms

PRRT Predictable Reliable Real-time Transport protocol

- Packet Loss Measurement / Estimation
- BBR-based Congestion Control & Bottleneck Bandwidth Estimation
- Cross-layer Pacing between Application and Network
- API: Ordered Receive Modes, many other improvements

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X-Lap Cross-Layer Timing Analysis

- Automated Detection of Causes of Latency & Jitter
- Automated Control-Flow Graph Extraction
- Energy Evaluations

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RNA Reliable Networking Atom

- Autonomous-Driving Car Scenario (BarCamp II)
- Wireless Embedded Real-Time Video Streaming Experiments

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Definitions

- **Pace** := Time required to apply a certain step to a certain unit of data.
  (e.g. propagation time per packet or sampling time per sensor reading)
- A (sub-)system implements **pacing** iff it ensures that each step is executed at a pace that considers the bottleneck pace in the overall system's chain of processing steps.

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- ... rinse, repeat.

Near Zero Queuing Delay

- Network bottleneck bandwidth measured: Minimal bound on interval between packets of given size.
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- Application pace allows to anticipate a `send()` call.
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Reduced "Waste"

- The operating system and physical computing platform can run exactly at the speed of application and transport layer.
- This allows to reduce clock-cycles, by avoiding polling, or slow-down the processor to prolong the lifetime of battery-driven devices.

Background

- Channel limited by *BtlBw*, which can be measured using BBR [Google'16].
- Application sends packets of size L and with frequency f (data rate $R_{app} = L \cdot f$).

Cross-Layer Pacing ensures $BtlBw \equiv R_{app}$ by controlling f.

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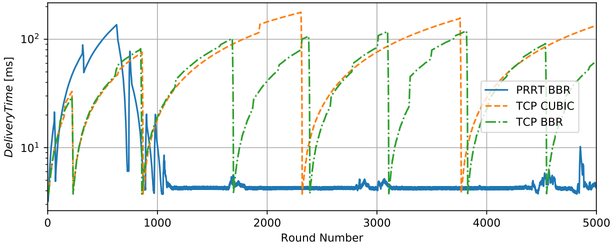
Implementation

- The BBR algorithm paces packets to the bottleneck bandwidth.
- The application is allowed to place one packet in the socket and the next `send()` call block until the packet is sent to the wire (after pacing period has passed).
- Alternatives:
  - The application can query the socket for the bottleneck and adjust its sampling rate or sensor resolution.
  - The operating system "slows down" the application.

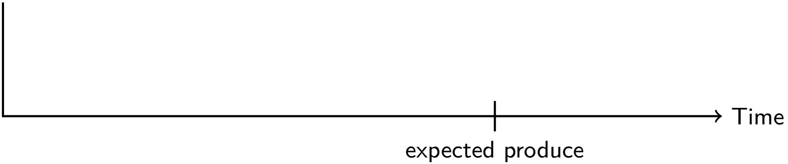


Results

- Delivery times within $1 - 4\times$ the propagation delay for most of the cases.
- PRRT achieves near-zero queueing after startup phase.
- In spite of limited send buffers, TCP cannot achieve this.

PRRT + BBR we can effectively pace an application to the speed of the network.

So far, we only synchronise the pace of the **application** and the **network**.



Operating System

- Pacing-aware scheduling.
- Energy-efficient pacing.

Hardware

- Measure maximum pace.
- Synchronise node-local and global paces (CPU throttling).

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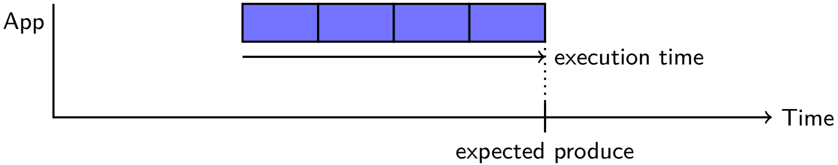

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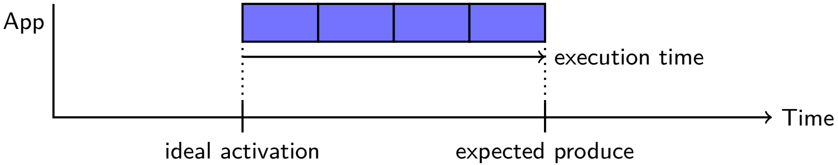

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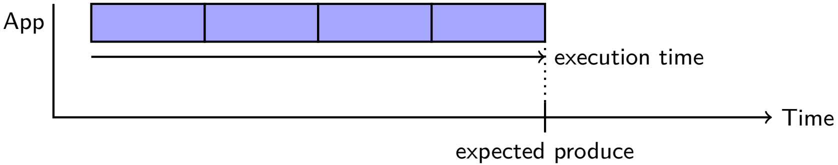

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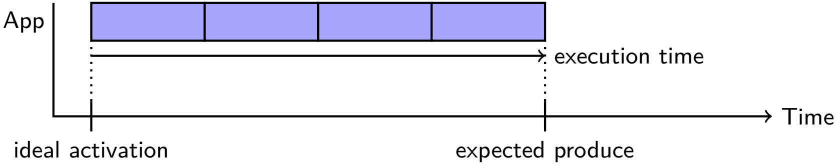

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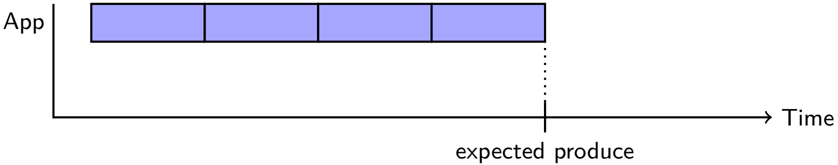

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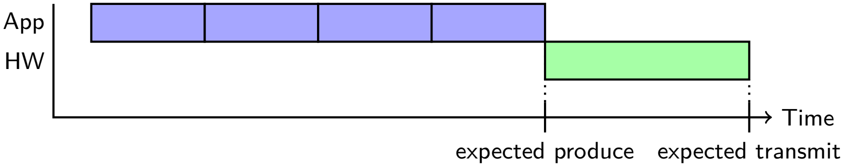

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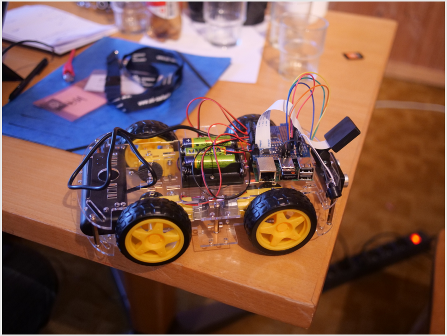
- Raspberry Pi 3 (w/ 802.11n)
- Pi Camera
- Chassis and Motor HAT
- Ultrasonic Sensors



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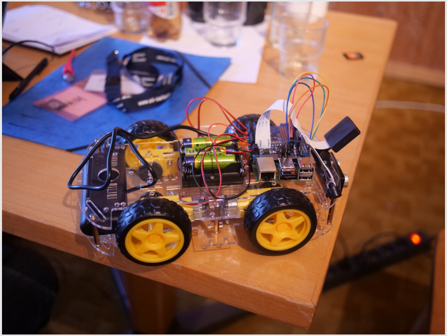

Line-Following ("Autonomous Driving")

- Camera captures line and transmits video via PRRT.
- Edge controller extracts line, determines angle, and determines control outputs.
- Target speed transmitted back and applied on the motor.

Edge2Car Communication

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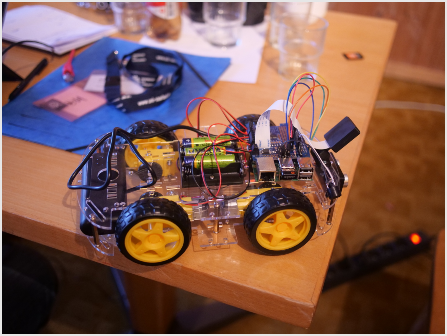

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Edge2Car Communication

Car-Following ("Platooning")

- First car follows line.
- Second car follows but keeps distance to first car.

Car2Car Communication

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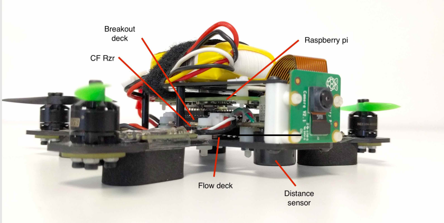
- Pi Zero W + Pi Camera
- CrazyFlie (from BitCraze.io)
  - Optical flow sensor (X,Y position).
  - Laser-based ranging (Z position).



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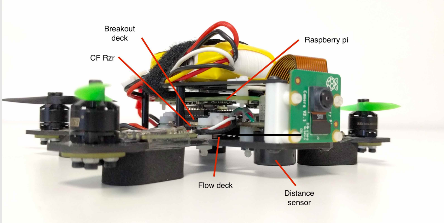

1. Mobile Real-time Video Streaming

- PHY/MAC: 802.11n
- NET: IP
- TRANS: PRRT

Goal: Reliable & Timely Video Stream

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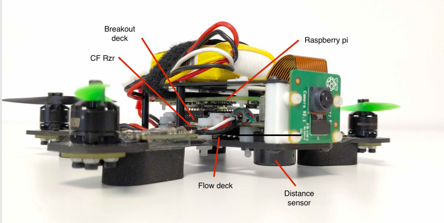

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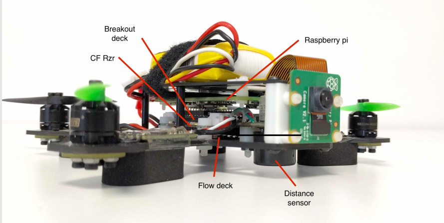

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Currently negotiating/prototyping together with BitCraze.
Evaluation starting **approx. Jun/Jul'18**.

Accepted Publications

- Gil Pereira, Pablo; Schmidt, Andreas; Herfet, Thorsten: **"Cross-Layer Effects on Training Neural Algorithms for Video Streaming"**, 28th ACM SIGMM Workshop on Network and Operating Systems Support for Digital Audio and Video (NOSSDAV), Amsterdam, Netherlands, June 2018
- Reif, Stefan; Schröder-Preikschat, Wolfgang: **"A Predictable Synchronisation Algorithm (Poster)"**, 23rd Annual Symposium on Principles and Practice of Parallel Programming (PPoPP), Vienna, Austria, February 2018

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Publications Under Review

- Reif, Stefan; Schmidt, Andreas; Hönig, Timo; Herfet, Thorsten; Schröder-Preikschat, Wolfgang: **"Differential Energy-Efficiency and Timing Analysis for Real-Time Networks"**, 16th International Workshop on Real-Time Networks (ECRTS RTN), Barcelona, Spain, July 2018
- Schmidt, Andreas; Reif, Stefan; Gil Pereira, Pablo; Hönig, Timo; Herfet, Thorsten; Schröder-Preikschat, Wolfgang: **"Cross-Layer Pacing for Predictable Low-Latency Communication in Edge Computing"**, USENIX Workshop on Hot Topics in Edge Computing (HotEdge), Boston, USA, July 2018.

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- ✔ **PRRT**[1] available for control and video applications as **open source**.
  - Straightforward usage for **C, Python, and Gstreamer** projects.
  - Compatibility with **Linux** on ARM and x86-64 platforms.
- ✔ PRRT packed within the **RNA**, running on different embedded platforms.
- ✔ Fine-grained **analysis** for causes of latency and jitter using **X-Lap**[2].
- ✔ Reduced **network layer latency and jitter** using...
  - hybrid error correction (FEQ + ARQ) by avoiding round-trips and
  - cross-layer pacing with congestion control to avoid queuing delays.
- ✔ Reduced **system layer latency and jitter** by...
  - efficient system architecture, and
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- ✔ **Results** documented in **7 accepted publications** (2 conferences, 3 workshops, 2 posters) and **2 publications under submission**.
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The LARN Team
2 PIs, 1 PostDoc, 3 PhD students and 3 student assistants

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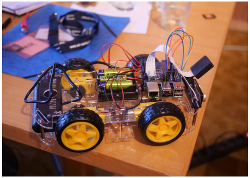
  - Drone for video streaming and control



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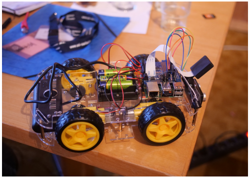

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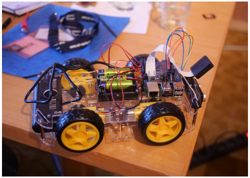

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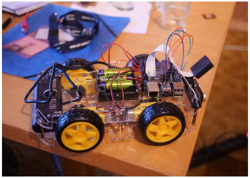

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- Operating System Support
  - Time-predictable synchronisation
  - Cross-layer resource management

- Improve crosscutting system properties
  - focus on **energy efficiency**: impact of runtime adaptations
  - non-functional properties of networked systems (i.e. RNAs)
  - system configuration of individual RNAs (i.e. local scope)

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    energy demand/latency of overall system (i.e. global scope)

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- Identification and proactive avoidance of bottlenecks within system stack
  - build „strain reliefs" to **avoid emergence of bottlenecks**
  - proactively exploit a priori knowledge (i.e. system design)
  - cooperative system-analysis (i.e. ahead of runtime + at runtime)

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- Explore adaptation of Phase 1 research results to related research areas
  - **edge-computing environments** (WIP): improve latency of edge components
  - consider power-demand constraints (i.e. low power IoT devices)
  - extended interweaving of network protocols and operating-system components

Conclusion

Network

- ✔ PRRT – Predictable protocol
- ✔ Network pacing

Operating System

- ✔ X-LAP – Timing measurement
- ✔ Wait-free synchronisation

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

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Thank you for your attention. Questions?