Approaches for Resilience- and Latency-Aware Networking

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Motivation

- Cyber-Physical Systems (CPS) require different networking approaches.
- Latency-aware components have an awareness for time. Operations execution time is bounded and can be predicted upfront.
- Resilience-aware systems cope with shortcomings of the environment, e.g. physical loss, as well as software problems, e.g. crashes.
- These traits can be provided by optimization on network core and edge, as well as cross-layer design and cooperation with operating systems.

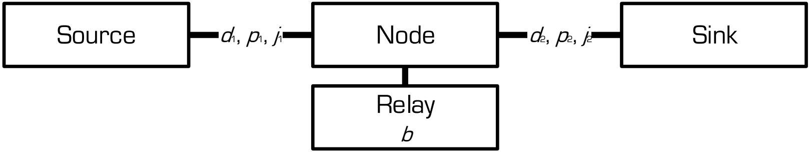
Transparent Transmission Segmentation (TTS)

- End-to-end network functions (error and congestion control, etc.) perform better when working on local segments of a split transmission.
- By deploying relays to a network, it is possible to transparently segment the transmission path, hence without the end-hosts noticing.
- Relaying itself can be implemented in any language and system with access to network hardware.
- Rewriting is done by the network itself, through the use of Software-Defined Networking. Thereto, switches are reprogrammed.

Evaluation

- Scenario: Two links, one split using one relay.
- Parameters: Delay (d [ms]]), Jitter (j [ms]), Packet Loss Rate (p [%]), Relay Buffer Size (b [Byte]).
- Measured Metric: Transmission time for all data of a TCP stream.
- Performance Metric: A_{12} score (stochastic superiority) [Vargha2000] ($A_{12} < 0.5$: E2E better, $A_{12} > 0.5$: TTS better)

Scenario



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Results

Case	d_1	j_1	p_1	d_2	j_2	p_2	b	A_{12}
Buffer (Very Small)	50	5	1e-06	10	1	1e-06	16	0.065
Buffer (Small)	50	5	1e-06	10	1	1e-06	64	0.729
Buffer (Big)	50	5	1e-06	10	1	1e-06	1024	0.892
High Error Rate	50	5	1e-06	10	1	3	1024	0.917
No Errors	50	5	0	10	1	0	1024	0.901
High Jitter	50	50	1e-06	50	50	1e-06	1024	0.688
Natural	50	5	0.0001	5	1	0.0001	1024	0.841

Interpretation

- TTS improves performance and ensures faster deliveries.
- Improvement (between 18% to 41%) of additional cases in which TTS is superior to E2E.
- Buffer size at relay has to be large enough.
- Link parameters have an impact on degree of improvement.
- Low p-values ($< 10^{-4}$ for all cases) indicate likelihood of significant effect.

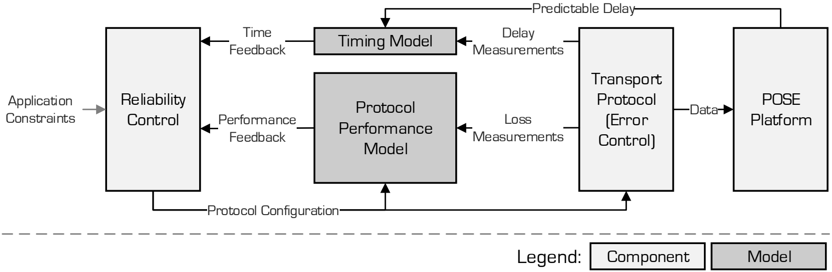
State of the Art

- Industry continuously adopts Internet protocols (e.g. Ethernet, IP).
- Internet-based protocols lack traits required for CPS:
  - Latency-Awareness (no protocol stack gives bounds for processing time).
  - Resilience-Awareness (TCP is 100% reliable, but delay unbound).
  - Exploitation of Fault-Tolerance (e.g. missing sample: next one suffices).

PRRT

- Replaces traditional socket implementations, e.g. UDP/TCP.
- API extended by methods to state application requirements:
  - Tolerable maximal error rate (e.g. $< 10^{-6}$).
  - Tolerable maximal delivery time (e.g. $< 10ms$).
  - Maximum throughput (e.g. $< 1Mbps$).
- Models are maintained:
  - Network Model (what does the channel look like?).
  - Timing Model (when do we need to send packets?).
  - Performance Model (how well is error control performing?).
- These models combined with search algorithms provide:
  - Coding configuration to meet the latency and resilience constraints.
  - Packet transmission pacing to ensure loss caused by congestion is avoided.

PRRT and Integration with Predictable Operating System Executive (POSE)



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- Thoroughly optimize network and operating system, dissolving layers at compile and run time while they are still present at design time.
- Improve and extend systems calls, so they better fit requirements of the transport layer stack.
- Minimize and limit time that is required until data from the application layer is transmitted via the network card as well as the time needed to deliver the data to the application.

Outlook

Latency- and Resilience-Aware Networking (LARN) funded as a project in the DFG priority programme 1914: “Cyber-Physical Networking”.

A) Research Questions:

- **Cross-Layer Design**: How well can combinations of operating and network stack improve transmissions?
- **Segmentation Selection**: What are feasible heuristics for locations and number of splits?
- **Soft Performance Guarantees**: To which extent can we give guarantees of efficiency? How tight can time and residual error rate be bound?

B) Practical Tasks:

- **Integrated Network Stack**: Bring together networking and operating system stack into a flexible, reusable component.
- **Use Case Diversity**: Cooperate with other projects in the priority programme and provide the networking unit as a basis for their tasks.
- **Protocol Diversity**: Investigate effects of TTS on RTP and PRRT transmissions, to show how general this approach is.