Advanced Networking for Reliable Energy Delivery Systems

Dependable End-to-End Delay Constraints for EDS Control Networks using SDNs

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OVERVIEW

- EDS control networks require dependable delay guarantees on delivery of network packets
  - Packets must be delivered between hosts with *guaranteed upper bounds on end-to-end delays*
  - Should be resilient to flooding or other network level denial-of-service (DoS) attempts
- Traditional approaches (*e.g.,* CAN [1], AFDX [2]):
  - Not suitable for commercial off-the-shelf (COTS) systems
    - Require expensive custom hardware and software
    - Proprietary, complex, expensive
- Our approach:
  - Leverages the capabilities of **software-defined networking** (SDN)
    - Reduces the management and integration overheads
  - Guarantees timing constraints for traffic in hard real-time systems
    - Can easily be integrated with COTS SDN hardware
  - Isolates flows into different queues
    - Provide *stable* quality of experience (*e.g.,* end-to-end delays) even in the presence of heterogeneous (*e.g.,* best-effort) traffic

SOFTWARE DEFINED NETWORKS

- Communication network components:
  - *Control* planes (decide packet forwarding rules)
  - *Data* planes (perform the actual actions on packets)
- SDN simplifies access to the network configuration
  - *Controller*:
    - Logically centralizes the control-plane state
  - *Switch*:
    - Contains a table processing pipeline and a collection of physical *ports*

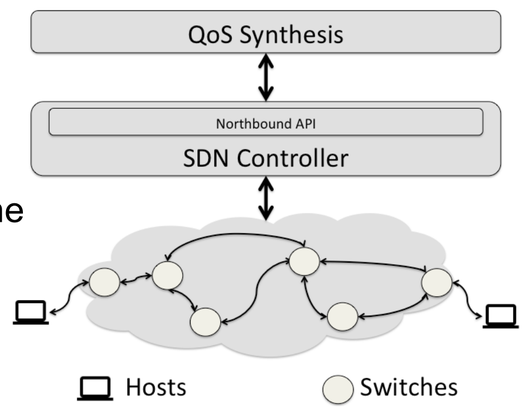


Figure: An SDN with a six switch topology

PROBLEM OVERVIEW & SOLUTION SKETCH

- EDS control networks often include *high priority/critical* traffic flows
  - Essential for the correct and safe operation of the system
  - Have stringent timing requirements
    - Can tolerate *little to no* loss of packets
  - *Examples*: sensors for closed loop control and actual control commands in power grid systems

How to develop mechanisms to *guarantee end-to-end delays for high-criticality flows* on networks constructed using SDN switches?

- Given an SDN topology:
  - Switches and controller
  - A set of real-time flows with specified delay and bandwidth guarantee requirements
  - The problem is to
    - *Find paths for the flows and*
    - *Map the flows to the queues of switch ports*

    such that the *end-to-end delays can be guaranteed* for the maximum number of critical flows
- Our proposal:
  - Develop a *criticality-aware constrained* path selection algorithm
  - Allocate *each flow to an individual queue*
  - Intuition:
    - Overprovision the bandwidth
    - Critical real-time flows do *not* experience queueing delays even in the presence of increased packet flow on non critical flows

PATH LAYOUT AND FLOW MAPPING

- The selection of an optimal path for each flow subject to delay and bandwidth constraints is NP-complete
  - Extended existing heuristic [3] and developed *polynomial* algorithm
- Isolating flows using *separate queues* results in lower and more stable delays
  - Especially when traffic rate in the flow approaches the configured maximum rates

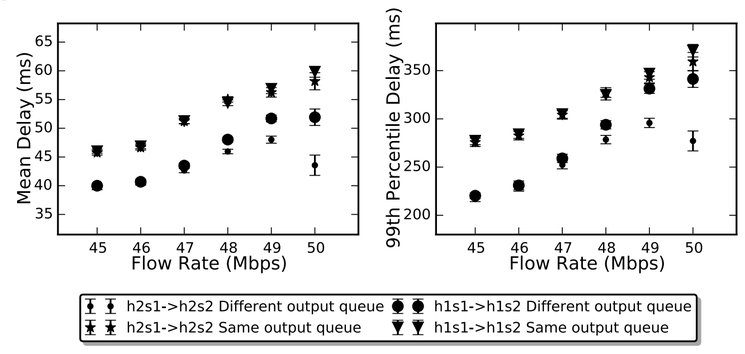
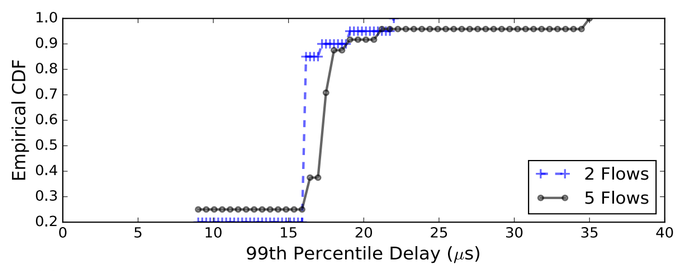


Figure: The measured mean and 99th percentile per-packet delay for the packet the two-switch, four-host topology

EXPERIENCE AND EVALUATION

- Experimental setup:
  - Mininet [4] topology with Open vSwitch [5] configured switches
  - Ryu [6] SDN controller
  - `netperf` [7] to generate the UDP traffic
  - Network with Heterogeneous flows
    - [1, 5] critical flows along with [1, 3] non-critical flows
- Results and Observations:
  - Our flow rules and queue configurations isolate the critical flows from the non-critical traffic
    - Non-critical flows do *not* affect critical flows
    - The mean and 99th percentile delay experienced by the real-time flows *always* meet their delay requirements.



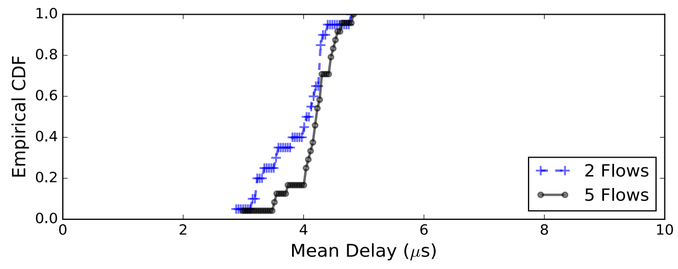


Figure: (a) The empirical CDF of (a) average, (b) 99th percentile delay with different number of flows. For each set of flow f ∈{2,5}, total f × 25 × 5 packet flows (each for 10 seconds) were examined

For our experiments, *we do not observe any instance* for which a set of schedulable flow misses its deadline (i.e., packets arriving after the passing of their end-to-end delay requirements)

CONCLUSION AND FUTURE WORK

- Presented mechanisms
  - that provide end-to-end delays for critical traffic in EDS networks using COTS SDN switches
- Hence, future EDS control networks can be better managed, less complex (fewer network components to deal with) and more cost effective
- This initial effort can be extended in several directions:
  - *Multiplex flows* and yet meet their timing requirements
  - Impose *admission control* policy
  - Prototype and evaluate on actual *hardware switches*

REFERENCES

[1] M Farsi, K Ratcliff, M Barbosa. An overview of controller area network. Computing & Control Engineering Journal, 1999.

[2] ARINC Specification 664, Part 7, Aircraft Data Network, Avionics Full Duplex Switched Ethernet (AFDX) Network. 2003.

[3] S. Chen and K. Nahrstedt. On finding multi-constrained paths. In *IEEE ICC*, 1998.

[4] B. Lantz, B. Heller, and N. McKeown. A network in a laptop: rapid prototyping for software-defined networks. In *ACM SIGCOMM Workshop on Hot Topics in Networks*, 2010.

[5] Open virtual switch. http://openvswitch.org/.

[6] Ryu controller. http://osrg.github.io/ryu/.

[7] Netperf. http://www.netperf.org/netperf/.

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