Benchmarking the Ethernet-Federated Datacenter

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Overview

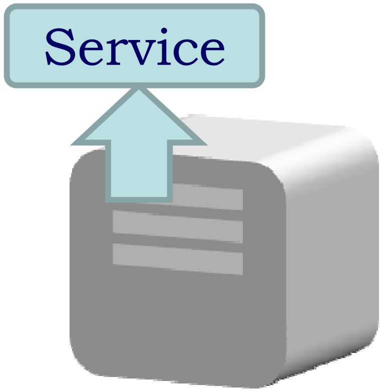
- Why DC Benchmarks?
  - networking in scalable DC and Clouds

- The 3 pillars of DC benchmarking
  1. Workload characterization and monitoring
     - workload, traffic, metrics
     - transaction tracing
  2. Simulation
     - Mercury/Venus environment
     - QCN case study
  3. Analytics
     - DC formulated as a feedback control problem

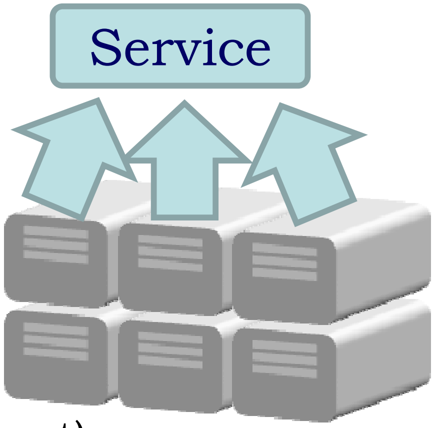
- Conclusion

Note: Animated features not available in the PDF version.

Benchmarking (Cloud) Datacenters



- **Traditional DC**
  - **low cost** of computing power
  - mostly **under-utilized** servers, storage, and network



- **Cloud Computing DC**
  - apps provided as standardized offerings
  - run on **virtualized resources**
  - **dynamically reconfigurable** resources

- **DC Network is the key**
  - LAN (Ethernet), StAN (FibreChannel), SAN (InfiniBand, Myrinet) converge into one integrated Datacenter Network fabric of 10-100 Gbit/s

- **Aim: Holistic view of the Cloud DC, with rigorous benchmarking and monitoring.**

Why DC/Cloud Benchmarks?

- Can’t improve what we can’t measure

- Today’s DC performance is not measurable beyond W and %
  - TPC-xyzW benchmarks are box-oriented, neither DC nor Cloud
  - HPC benchmarks are system-oriented, but not valid for commercial workload

- DC/Cloud operators care about power, cooling and utilization
  - average server utilization: 12-17% [IDC, Gartner]
    - Amazon wants > 80%
  - DC network utilization?

- VM: seems the key to better (server) utilization, yet…
  - Google doesn’t use virtualization
  - How about the network: Is VLAN the equivalent of server VM?
  - Does VM serve the customer or the operator ?

- Customers care about SLA … [+ privacy, phy. separation, price, mgnt.]
  - SLA: measured service ➔ managed demand
    - e.g. algorithmic/arbitrage trading measure latency in M$, not us…

Characterizing the Commercial/Analytic DC Workload

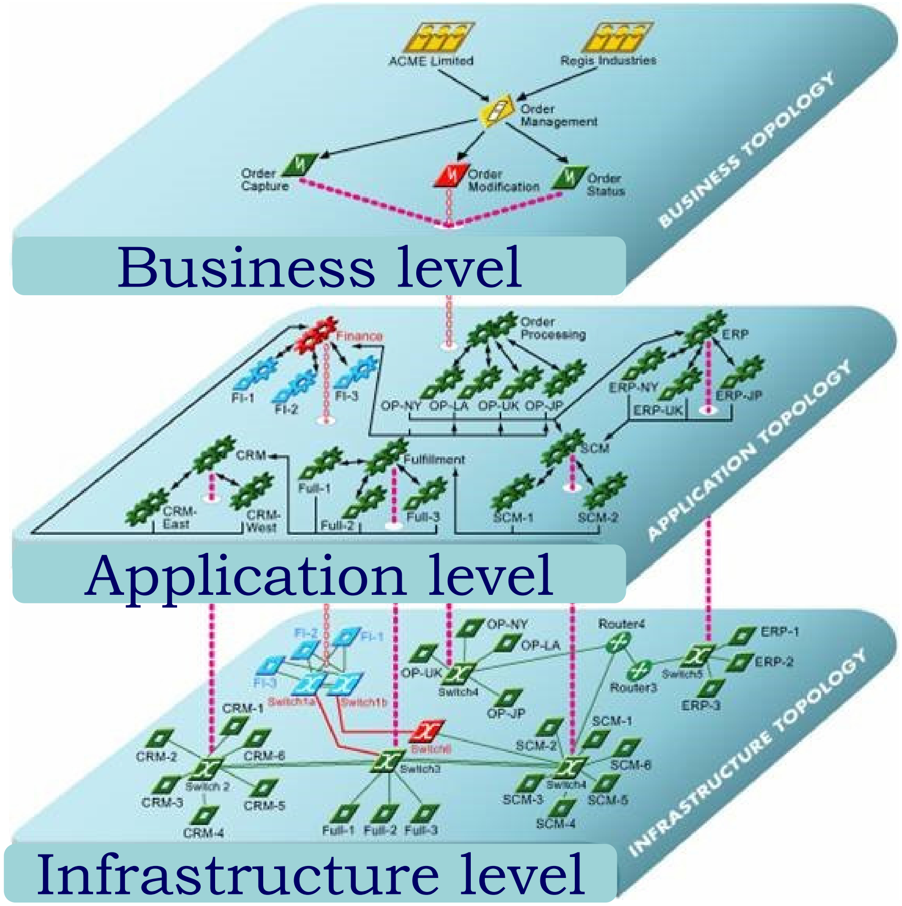
- **Mapping business transactions to application and infrastructure level events** (to functions calls, network packet transfers)
  - Assemble **causal paths,**
  - Observe **distributions**,
  - Detect **patterns**

- Essential to understand the system and to observe how the changes in workload affect internal system functionality.

- Challenge

  I. **No de-facto standard** as MPI in HPC, many protocols in a commercial DC: HTTP, CORBA, JDBC, etc

  II. Correct, instance-level **causal path reconstruction** in a typical multi-tier, heterogeneous architecture **is difficult**



Monitoring and workload characterization

- Commercial DC workloads are not quantitatively known (yet)

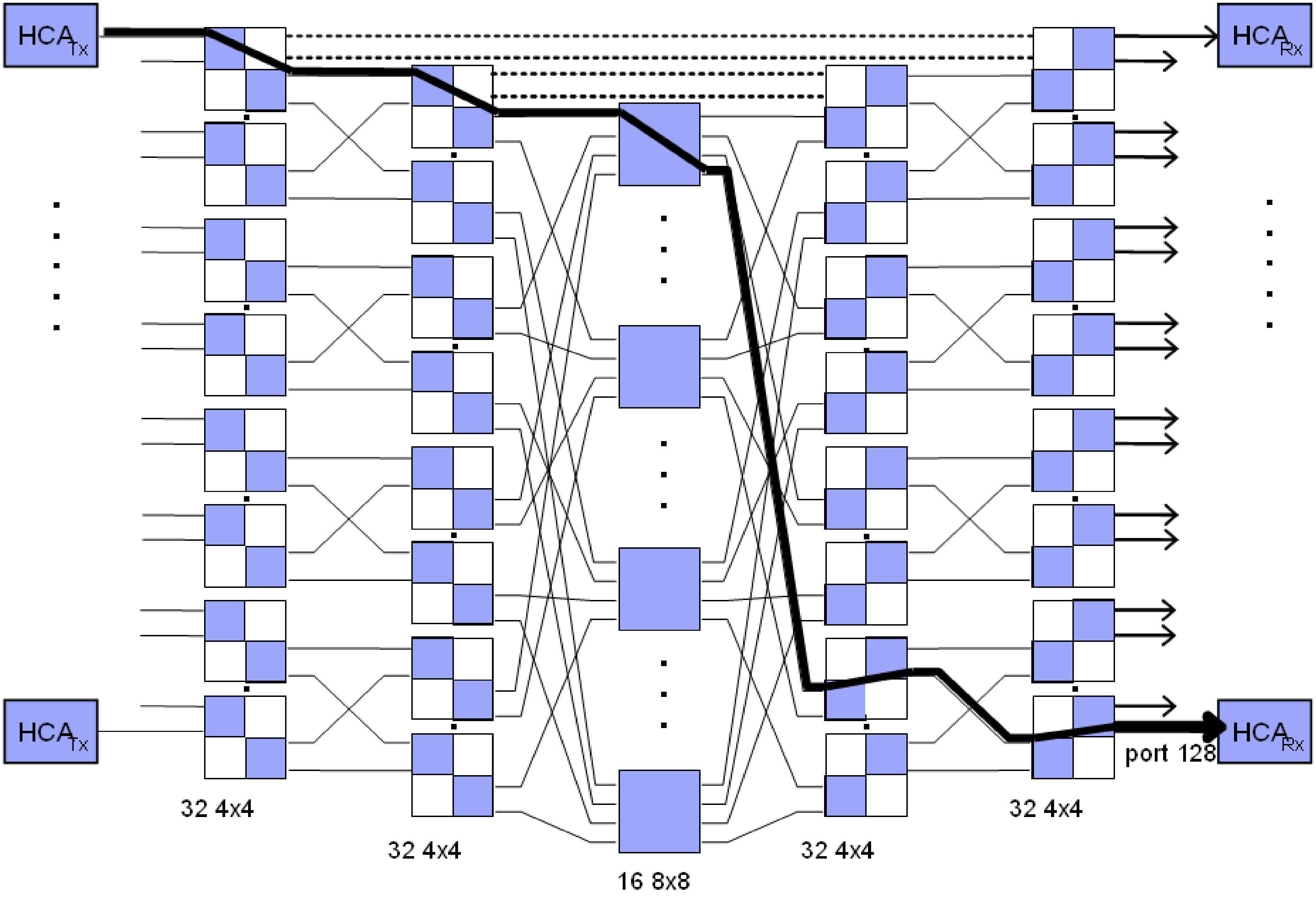
- Wanted
  - Agreed [observable] **workloads**
  - Instrumentation and **monitoring** tools
  - Detailed performance **models** for the **<u>full DC</u>**

- Acceptable mid-target: Realistic traffic generator…
  - Wherefrom?
    - traces or exec-based models

- Obstacle: DC traffic space-time distribution = ?
  - requires estimation of TopN causal paths (essential transactions)

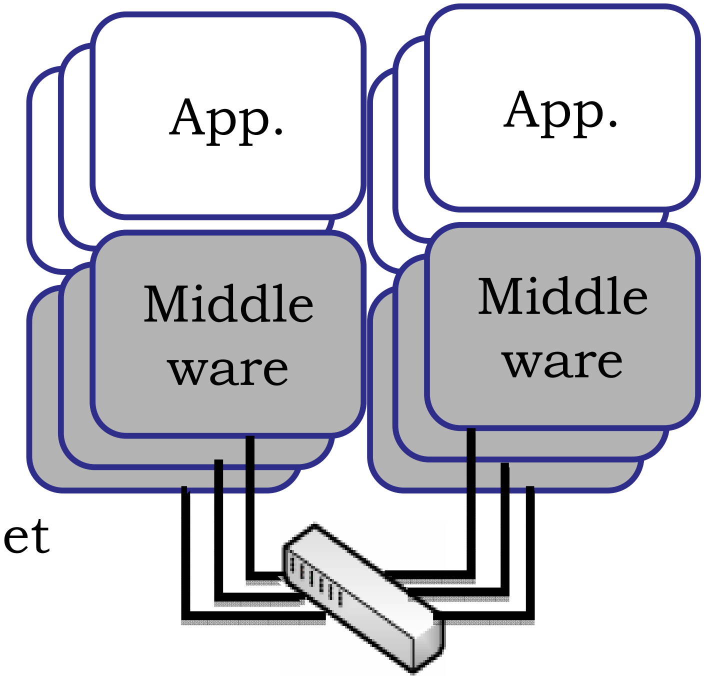
Tracing a Day in the Life of a DC Transaction

Projecting a Transaction on the DC Network (DCN)



Review: White box approaches

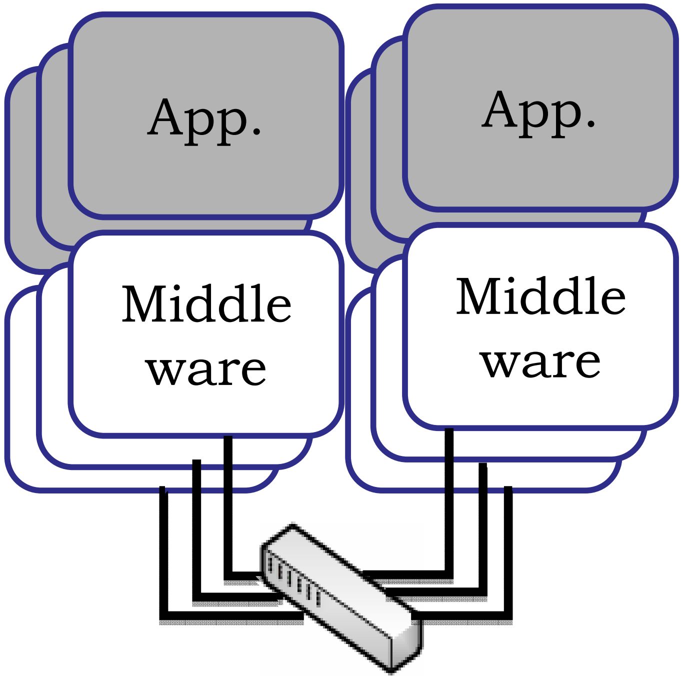
- **Application source code can be modified**
- Tagging transactions with IDs
  - register tag and timestamp when transaction passes boundaries
- Examples:
  - NetLogger (Gunter at al., Berkeley Lab)
  - WebMon: web transaction monitoring with custom JavaScript and cookies for id storage (Gschwind et al, HP Labs)
  - User Programmable Virtual Networks (Meijer et al.)
  - ARM: open standard defining interfaces to insert and track identifiers (http://www.opengroup.org/management/arm)



Review cont': Gray box approaches

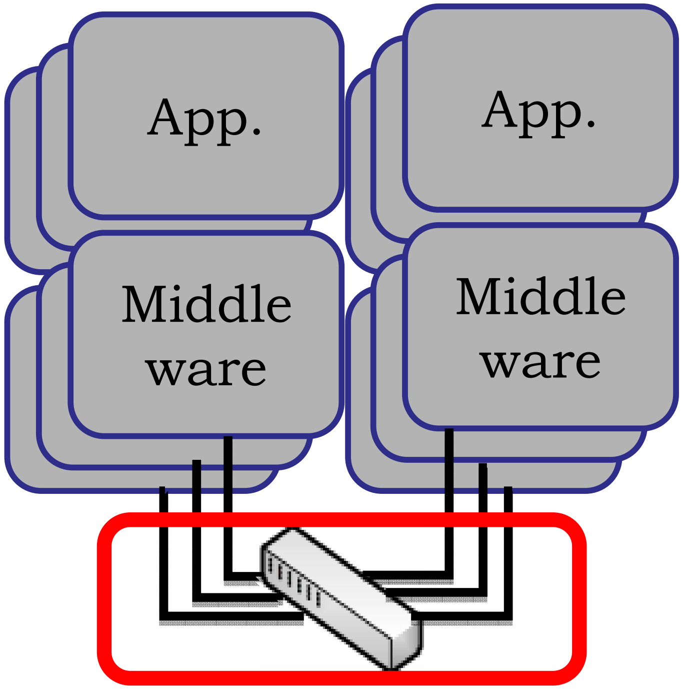
- The **middleware platform** keeps track of transactions by **built-in interceptors**, JIT-compiled tracing instructions

- Examples:
  - Magpie (Microsoft Research), built on the Event Tracing for Windows framework with additional platform modifications
  - IBM's ITCAM for Transactions with ARM-based transaction tracking
  - Java 2 EE component instrumentation (PinPoint, Chen et al.)
  - Java VM agent-insertion (Mirgorodskiy et al.)
  - Various approaches using CORBA interceptors (Moe et al.; Debusmann et al.; Li et al.)
  - Near system kernel solutions: observe processes communication through shared memory, „data tagging" (Whodunit, Chanda et al.; Mysore et al.)

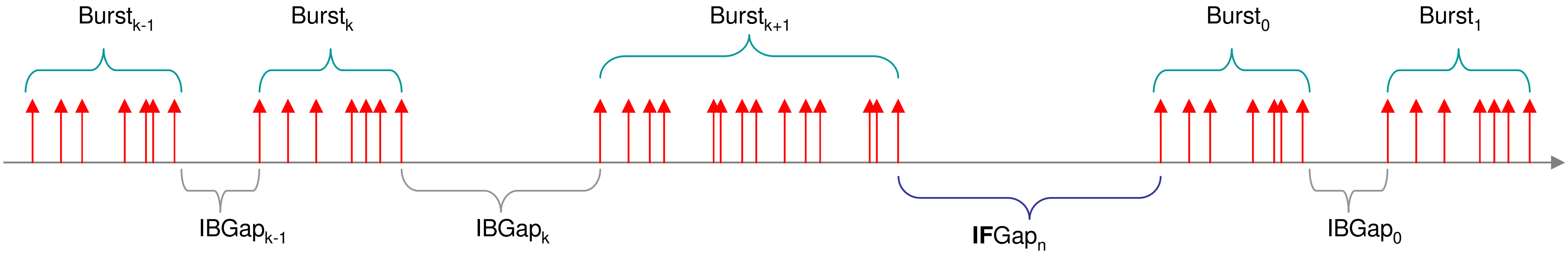


Review cont': Black box approaches

- Only **network traffic** is observed (passively)
  - Probabilistic models
- Examples:
  - Aguilera et al. (HP Labs)
    - **1st method:** assume: call-return message pairs; find possible parent-child relations and evaluate likelihood
    - **2nd method:** consider message traces as time signals; apply convolution to find messages with similar time shift
  - Anandkumar et al. (IBM Watson)
  - assume independent, identically distributed servicing times,
    - and use maximum-likelihood to match events and re-build transactions



Metrics for Workload Evaluation



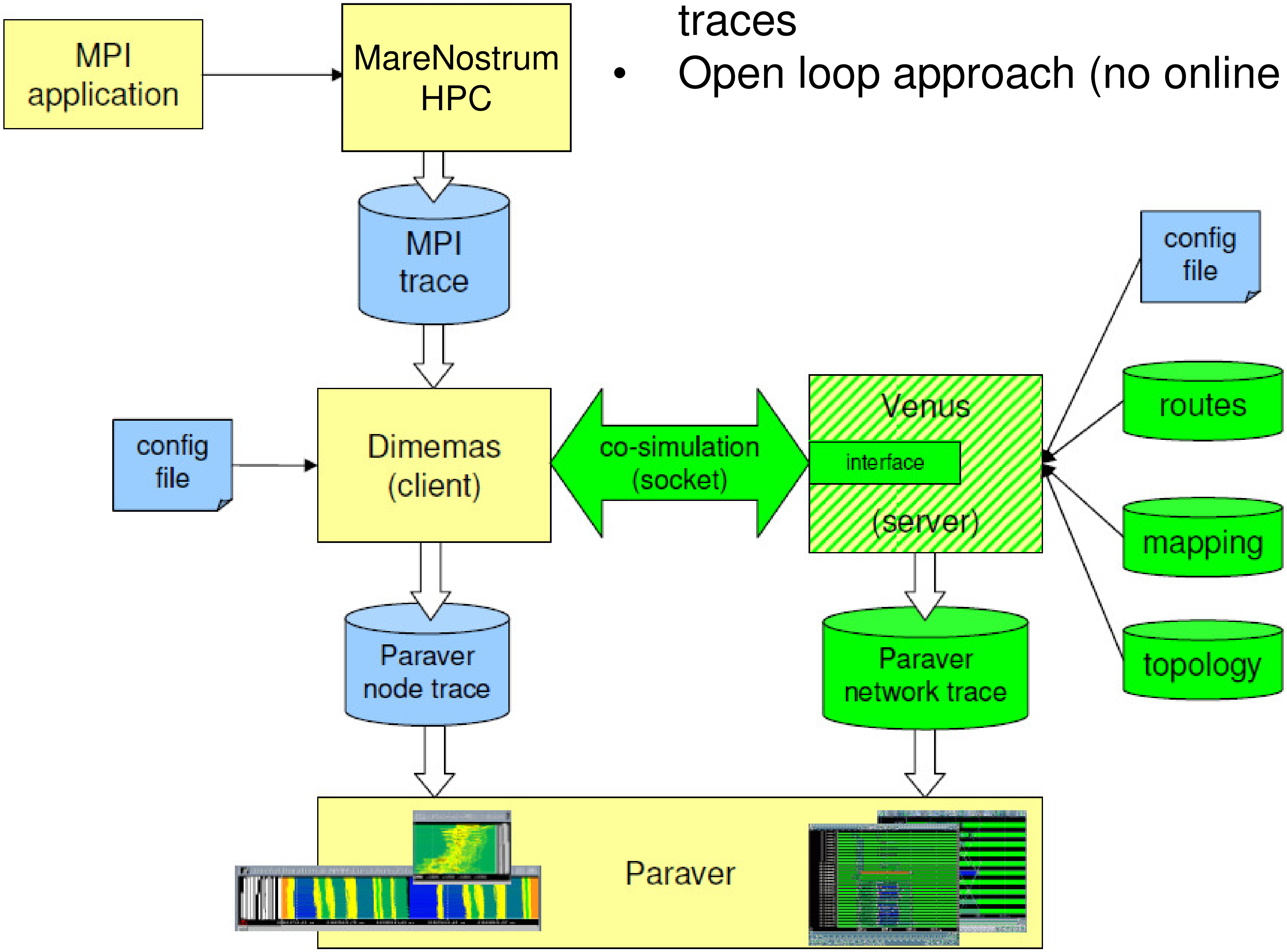
- Workload is a set of the following components, listed hierarchically: **work, job/transaction, flow, burst, and packet (frame, flit).**
- Established **DCN level metrics**:
  - latency (end-to-end (e2e) delay at L7), throughput, jitter, fairness
- Is **Flow Completion Time (FCT)** a good metric?
  - Yes, but sensitive to distributions
    - For example, for Pareto distributions, FCT loses its relevancy because $FCT = \Sigma(t_{\text{inject}} + t_{\text{queue}} + t_{\text{flight}} + t_{\text{RTX}}) \neq L_{\text{e2e}}(X)$, i.e., the central limit theorem does not apply
  - L2 detail of FCT: Flow definition?
    - (1) flows received entirely without any loss;
    - (2) flows received entirely with some loss;
    - (3) flows received partially,
    - (4) flows not yet having arrived at destination.

Simulation for Large-scale Systems

- „Monte Carlo” discrete even simulations
  - synthetic workloads, based on predetermined probabilistic distributions drive accurate functional models
- Trace driven simulations
  - computing nodes are represented by a trace of two kinds of records:
    - computation: wait time
    - communication: fed into the DCN model
- Used in HPC
    - Message Passing Interface (MPI) is a de-facto communication standard
    - MPI libraries instrumented for tracing are available
    - IBM: MARS, VENUS etc. simulation environments

2nd Generation HPC Simulator: Venus-Dimemas

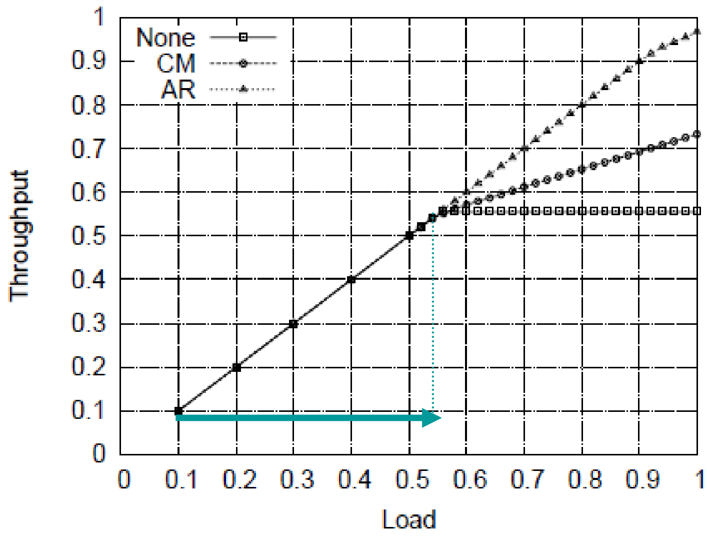
- System models for simulation based on message traces
- Open loop approach (no online feedback)

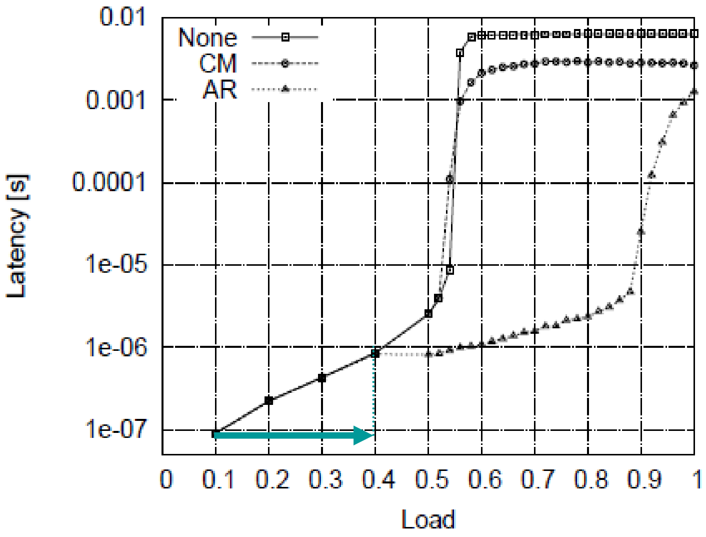


DCB Case Study: 802.1Qau-based Adaptive Routing

CEE Question: Is QCN Needed?

- DCB/CEE: Ethernet + PFC + ETS + QCN + upcoming
- Detroit: Prios->V8; PFC->hand-brake; ETS -> gearbox; QCN -> ABS
  - …where's the Steering/Suspension ?
- Change of DCB Congestion Management: use the QCN load sensor
  - (i) to steer: balance the load by adaptively routing (AR) the traffic around the transient hotspots (absorb shocks);
  - (ii) *iff* all admissible multi-pathing options have been exhausted *and* if the hotspot **persists**, then enable source-injection rate control (ABS)



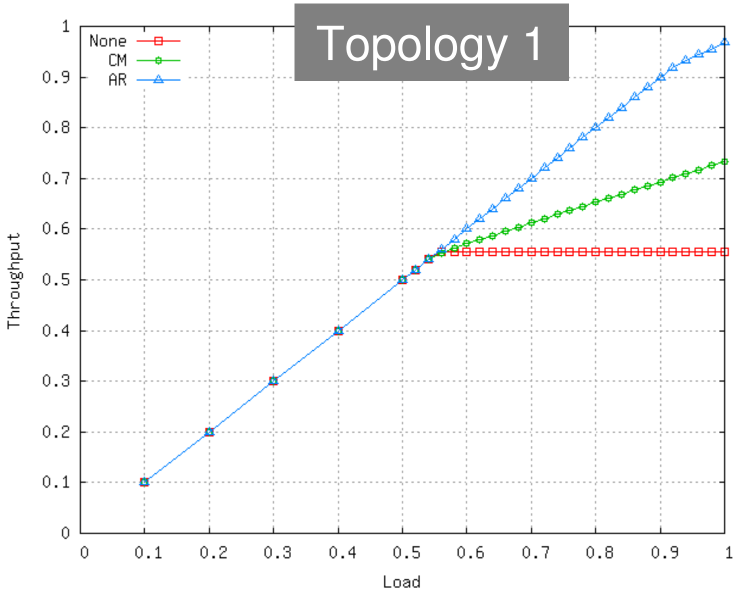


A: QCN is not needed if ρ < 0.4

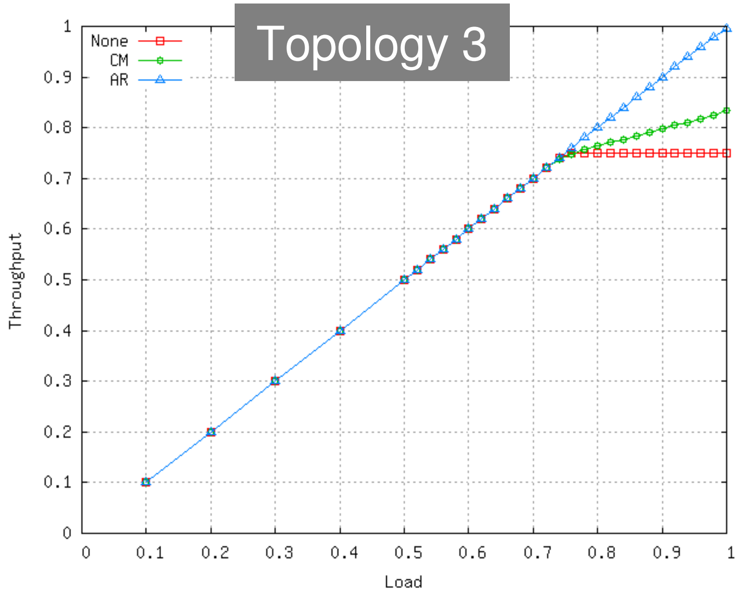
Uniform Bernoulli traffic

Throughput vs. load

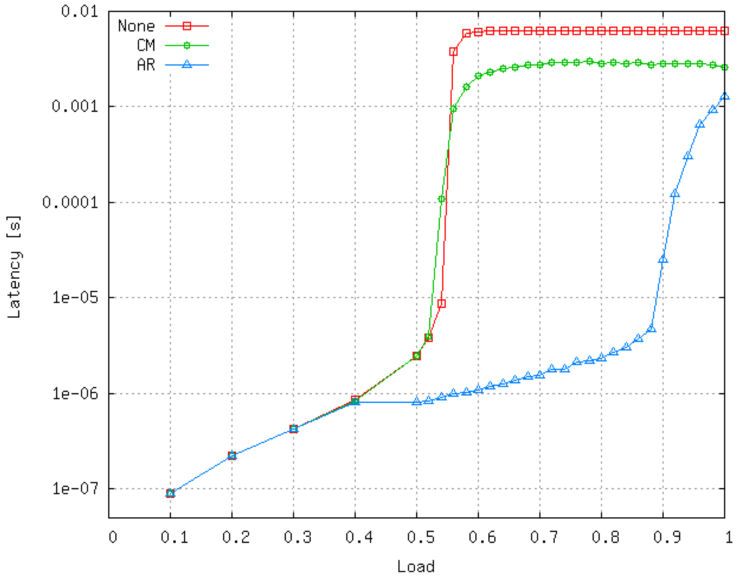
Topology 1

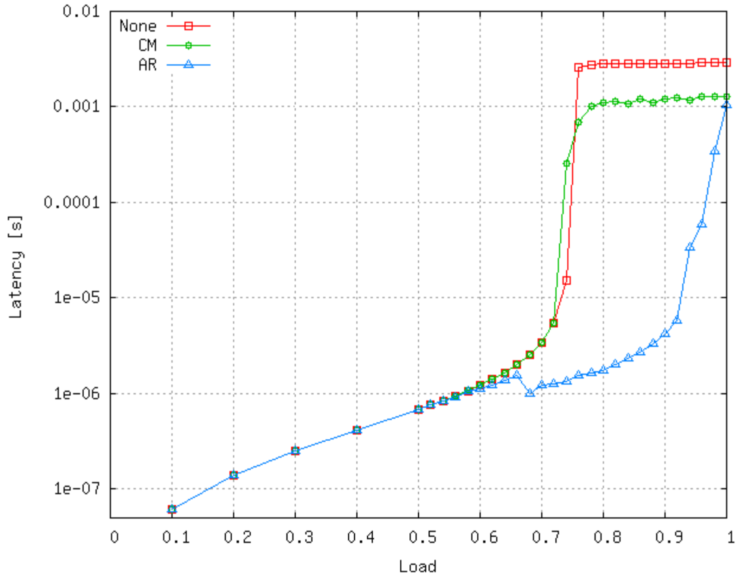


Topology 3



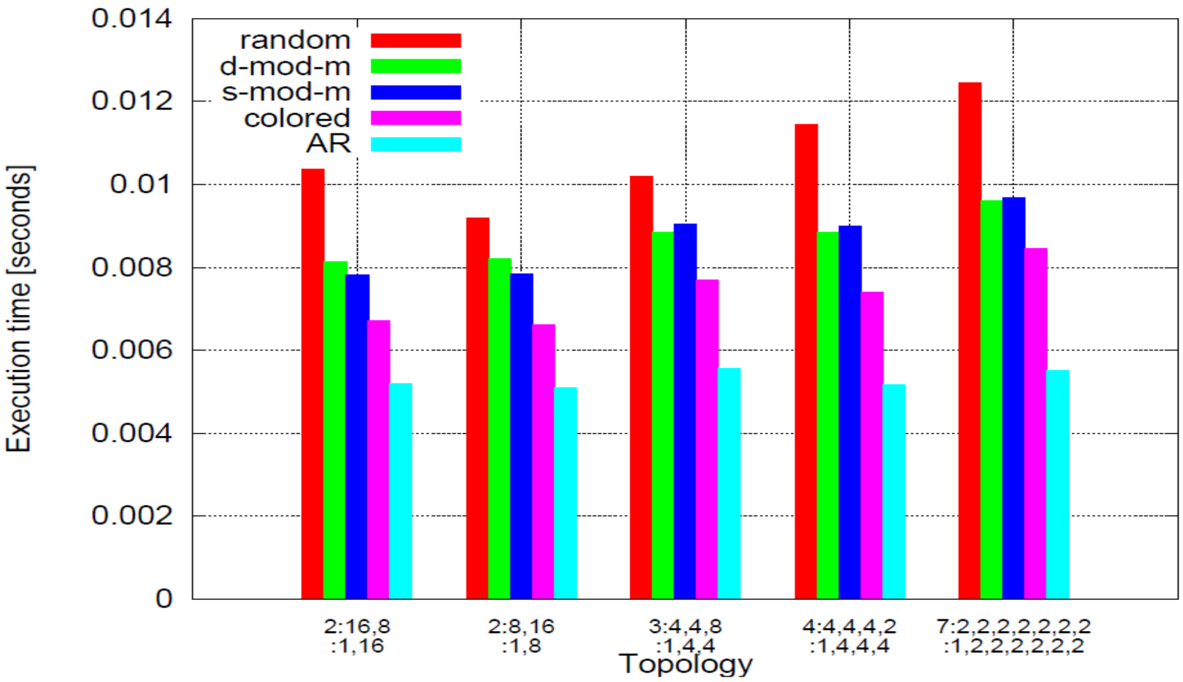
Latency vs. load



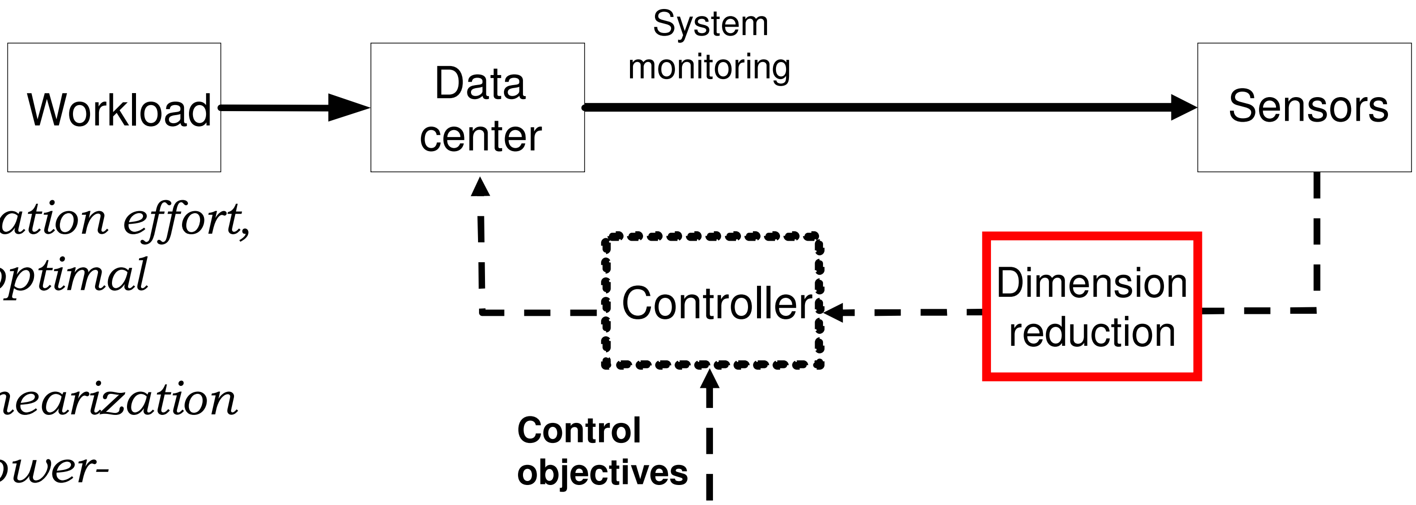


Practical Impact, Benchmarking of Adaptive Routing

- Conjugate Gradient (CG) application from the NAS Parallel Benchmarks (NPB)
- Test run on a *real* 128-node HPC machine to record the trace
- HPC traces files replayed on the VENUS simulator



Analytical Modeling: Online Feedback



- *to reduce the simulation effort, reformulate as an optimal feedback control*
- *apply piece-wise linearization*
- *include the load/power-dependent lag*

$$\dot{x}(t) = A(t)x(t) + B(t)u(t - \tau^{f}(t)) + D(t)w(t)$$
$$y(t) = C(t)x(t - \tau_{tot}(t))$$

- The ultimate goal is a resilient datacenter, that adapts its performance to the workload
  - Feedback required for adaptivity
  - No DC-scale system model yet
- The problem has large dimensionality (10s to 100s)
  - Previous work on dimension reduction for IT infrastructure monitoring
  - Finding simpler models with the least loss of information

Conclusions

- DC benchmarking: everybody wants it, nobody has it...

- DCs and Clouds lack
  - accurate system-level models,
  - rigorous holistic benchmark methodologies
  - agreement on metrics and SLAs ?
  - there's no MPI equivalent for commercial apps (do we need one?)
  - access to operational DCs
    - any volunteers?...☺

- Transaction tracing in DCs remains an open challenge
  - new methods or a breakthrough are needed!

- Simulation and analytics are complementary
  - hard non-linearities (hotspot, server/power overload) need simulation
  - exploring all the sim. dimensions, or finding the worst-case pattern, is not practically feasible via brute force sims ➔ analytics can help

- Scalable simulation environments are tried&true in HPC… no DC/Cloud?
- Can we instrument your datacenter… ? ☺ {That's all, thanks!}