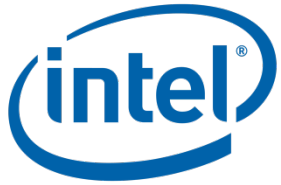

Fast Prototyping Network Data Mining Applications

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Intel Research Berkeley

Motivation

- Developing new network monitoring apps is **unnecessarily time-consuming**
- Familiar development steps
  - Need deep understanding of data sets (including details of the capture devices)
  - Need to develop tools to extract information of interest
  - Need to evaluate accuracy and resolution of data (e.g., timestamps, completeness of data, etc.)
- …and all this happens before one can really get started!

Motivation (cont'd)

- Developers tend to find shortcuts
  - Quickly assemble bunch of ad-hoc scripts
  - Not **"designed-to-last"**
  - Well known consequences
    → hard to debug
    → hard to distribute
    → hard to reuse
    → hard to validate
    → suboptimal performance
- End result: many papers, very little code

Can we solve this problem by design?

- Yes, and it has been done before in other areas.
- Solution: Define declarative language and data model for network monitoring
- What is specific to network measurements?
  - Large variety of networking devices (i.e. potential data sources) such as NIC cards, capture cards, routers, APs, …
  - Need native support for distributed queries to correlate observations from a large number of data sources.
  - Data sets tend to be extremely large for which data shipping is not feasible.

Existing Solutions

- AT&T's GigaScope
- UC Berkeley's TelegraphCQ and Pier
- Common approach (stream databases):
  - Define subset of SQL adding new operators (e.g., 'window' for time bins of continuous query)
  - Gigascope supports hardware offloading by static analysis of the GSQL query

Benefits and Limitations

+ Decouple what is done from how it is done.
+ Amenable to optimizations in the implementation
- Limited expressiveness.
- Need workaround to implement what is not in the language losing the advantages above
- Entry barrier for new users is relatively high.

Alternative Design: The CoMo project

- Users write "monitoring plugins"
  - Shared objects with predefined entry points.
  - Users can write code in C or higher level languages (support for C#, Java, Python, and others)
- The platform provides
  - one single, extensible, network data model.
  - support for a wide variety of network devices.
  - abstraction of monitoring device internals.
  - enforcement of programming structure in the plug-ins to allow for optimization.

Design Challenges

- Fast Prototyping
  - Network Data and Programming Model
- Resource Management
  - Local monitoring node (Load Shedding)
  - Global network of monitors (“Network-wide Sampling”)

Network Data Model

- Unified data model with quality and lineage information.
  - Allows the definition of ad-hoc metadata (i.e., labels defined by the users)
- Software sniffers understand native format of each device and translate to our common data model
  - support so far for PCAP, DAG, NetFlow, sFlow, 802.11 w/radio, any CoMo monitoring plug-in.
- Sniffers describe the packet stream they generate
  - Provide multiple templates if possible
  - Describe the fields in the schema that are available
  - Plug-ins just have to describe what they are interested in and the system finds the most appropriate matching

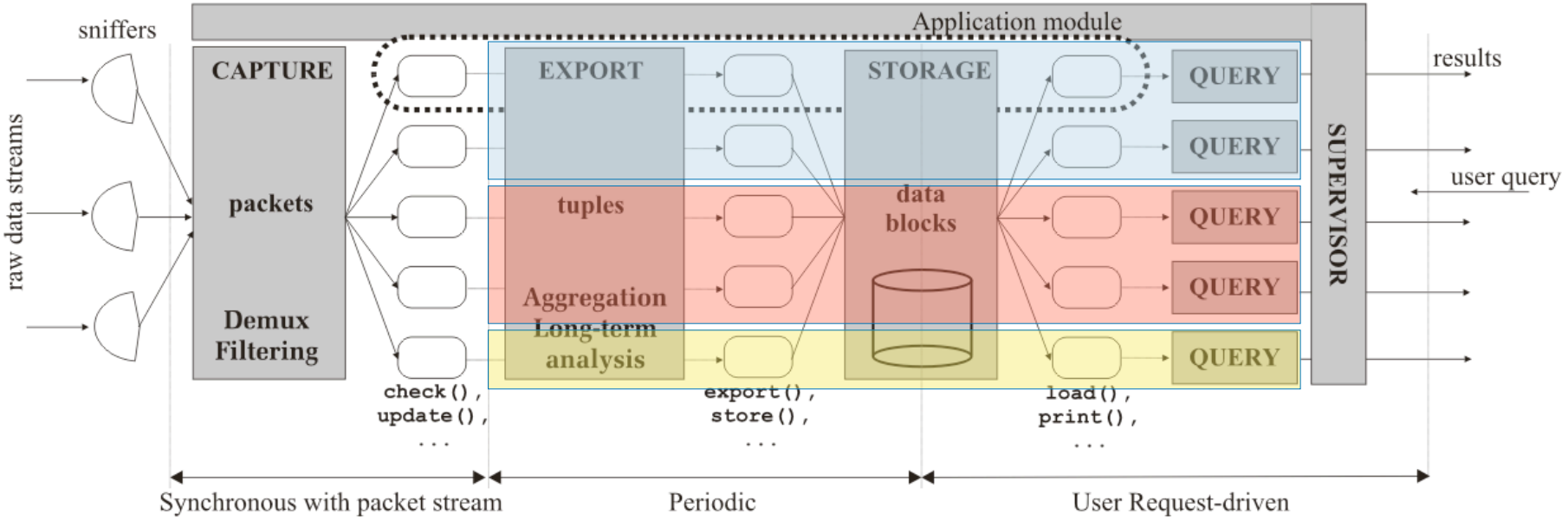
Programming Model

- Application modules made of two components:
  <filter>:<monitoring function>
- Filter run by the core, monitoring function contained in the plug-in written by the user
  - set of pre-defined callbacks to perform simple primitives
  - e.g., update(), export(), store(), load(), print(), replay()
  - callback are closures (i.e., the entire state is defined in the call). they can be optimized in isolation and executed anywhere.
- No explicit knowledge of the source of the packet stream
  - Modules specify what they need in the stream and access fields via standard macros
  - e.g., IP(src), RADIO(snr), NF(src_as)

Hardware Abstraction

- Goals: scalability and distributed queries
  - support large number of data sources and high data rates
  - support a heterogeneous environment (clients, APs, packet sniffers, etc.)
  - allow applications to perform partial query computations in remote locations
- To achieve this we…
  - hide to modules where they are running
  - enforce a programming structure
  - … basically try to partially re-introduce declarative queries

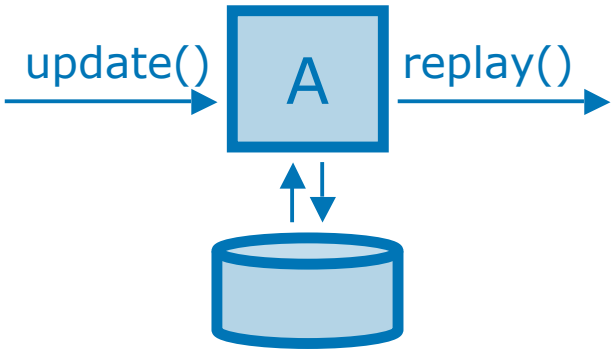
Hardware Abstraction (cont'd)



- EXPORT/STORAGE can be replicated for load balancing
- CAPTURE is the main choke point
  - It periodically discards all state to reduce overhead and maintain a relative stable operating point

Distributed queries

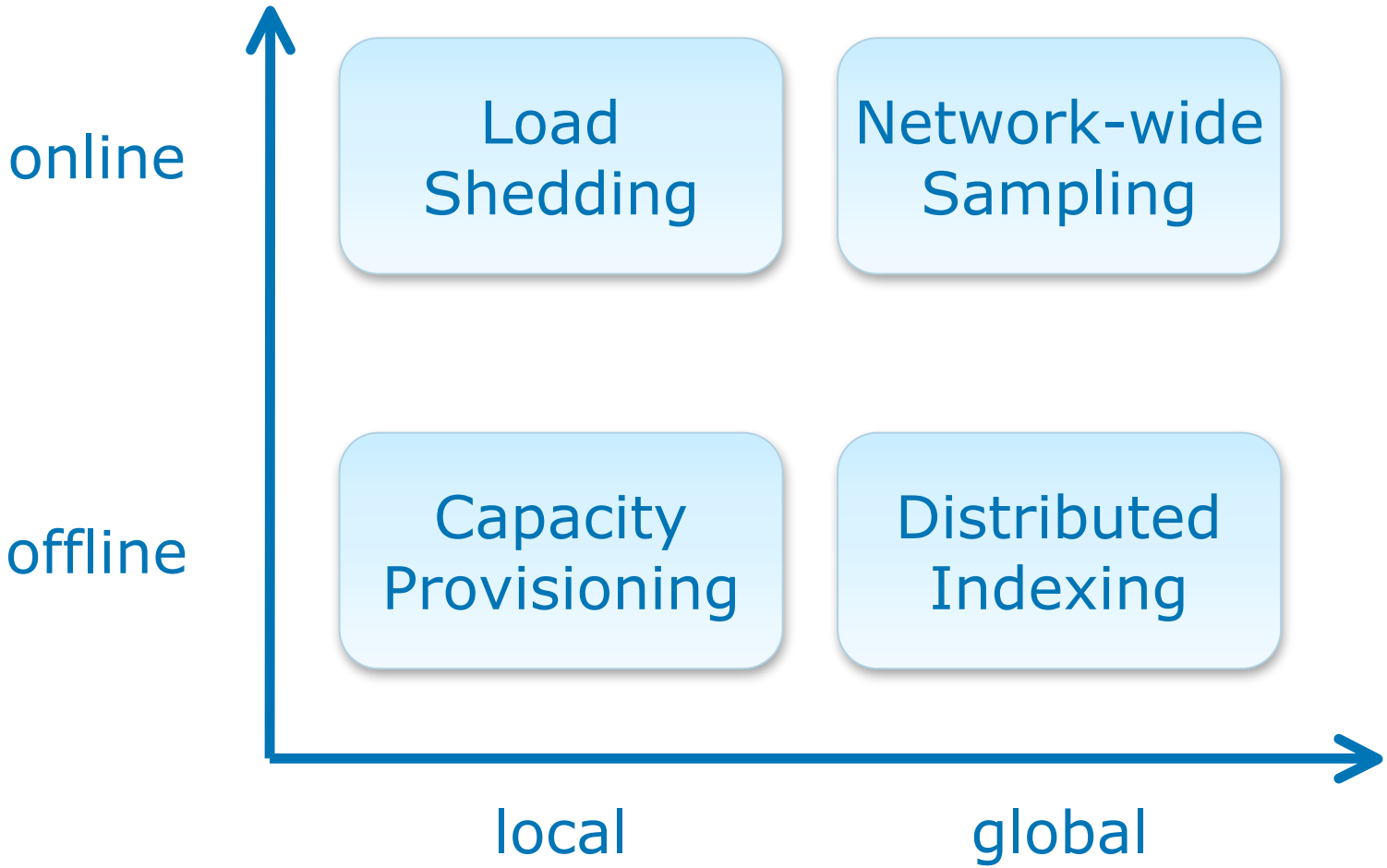
- Modules behave as software sniffers themselves
  - replay() callback to generate a packet stream out of module stored data
  - e.g., snort module generates stream of packets labeled with the rule they match; module B computes correlation of alerts
- This way computations can be distributed but also modules can be pipelined (to reduce the load on CAPTURE)



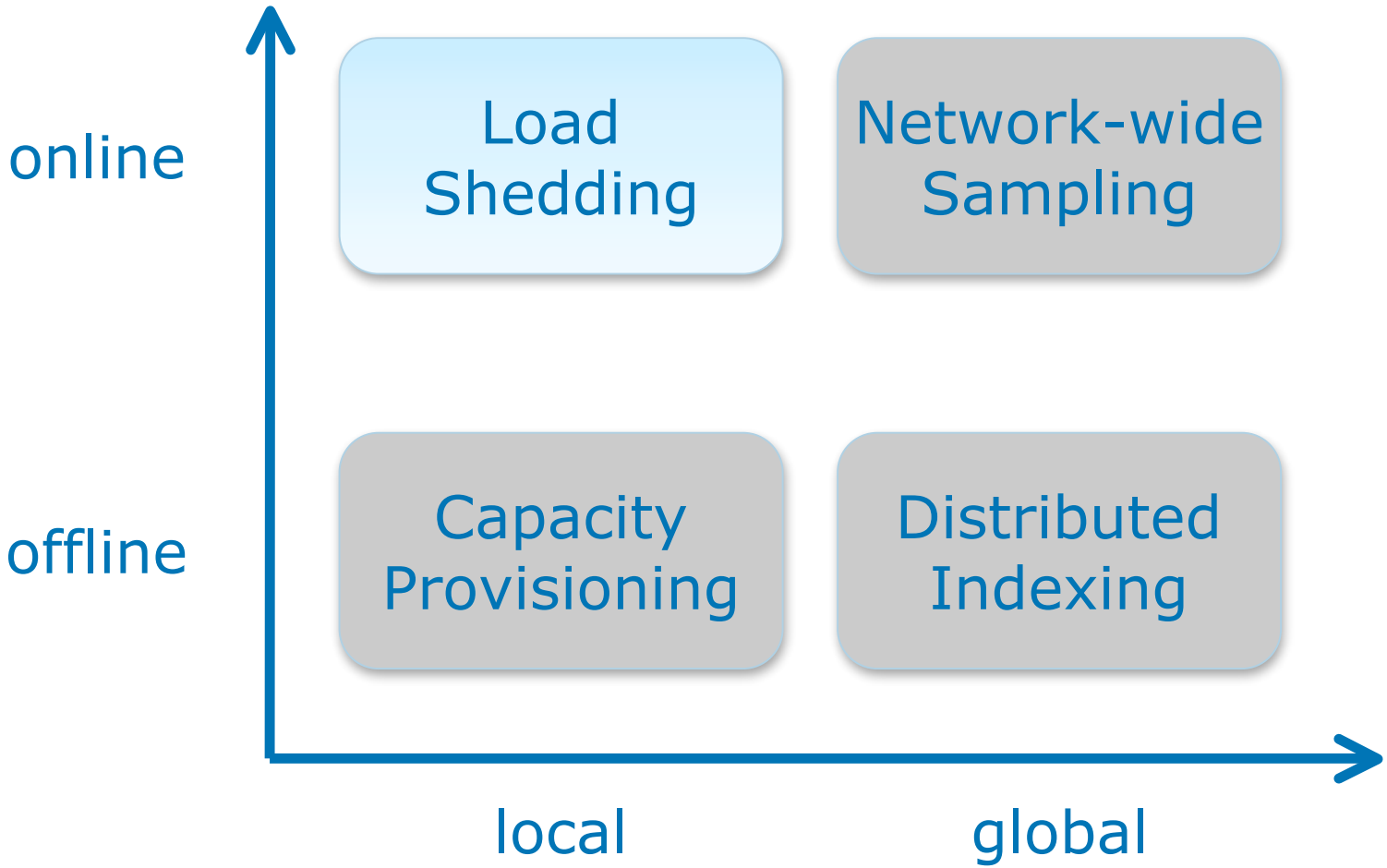
Design Challenges

- Fast Prototyping
  - Network Data and Programming Model
- Resource Management
  - Local monitoring node (Load Shedding)
  - Global network of monitors ("Network-wide Sampling")

Resource Management



Resource Management



Predictive Load Shedding

- Building robust network monitoring apps is hard
  - Unpredictable nature of network traffic
  - Anomalous traffic, extreme data mixes, highly variable data rates
- Operating Scenario
  - Monitoring system running multiple arbitrary queries
  - Single resource to manage: CPU cycles
- Challenge:
  "How to efficiently handle overload situations?"

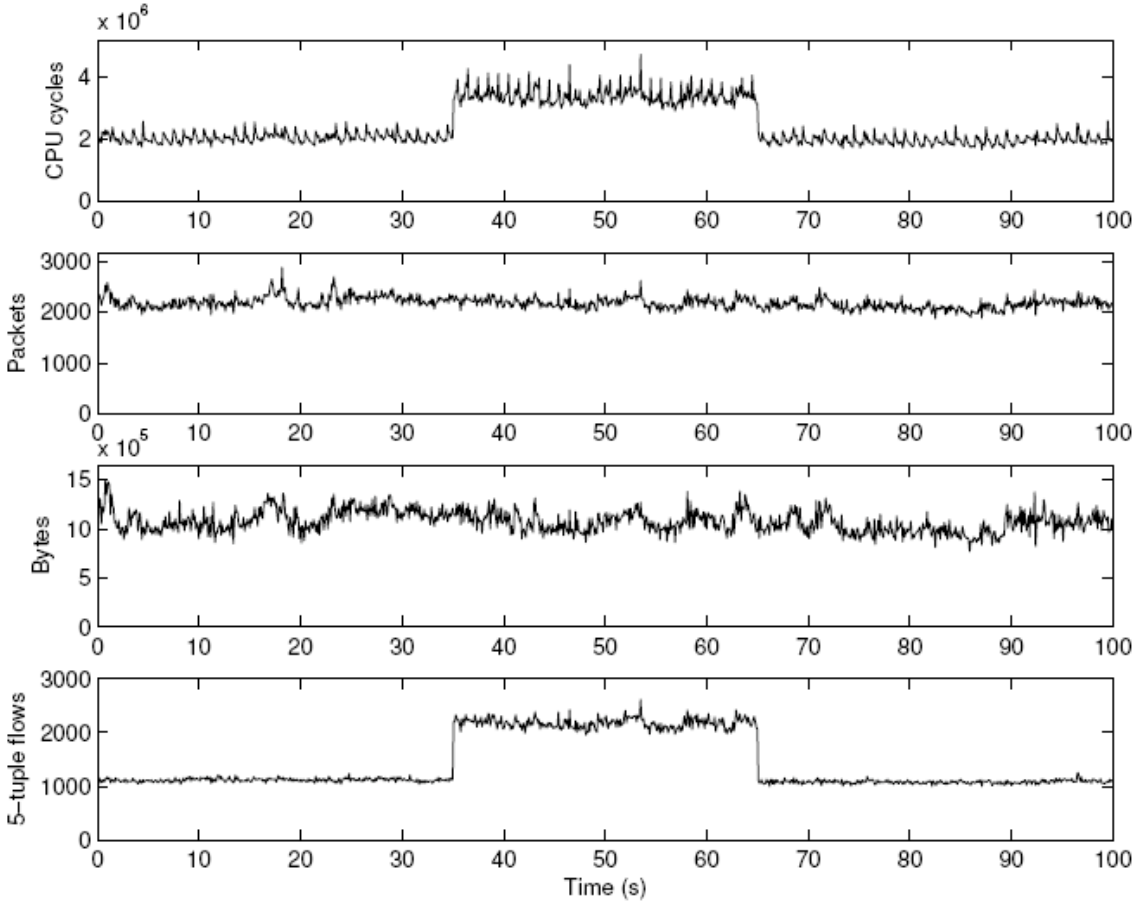
Approach

- Real-time modeling of the queries' CPU usage
  1. Find correlation between traffic features and CPU usage
     - Features are query agnostic with deterministic worst case cost
  2. Exploit the correlation to predict CPU load
  3. Use the prediction to guide the load shedding procedure
- Main Novelty:
  No a priori knowledge of the queries is needed
  - Preserves high degree of flexibility
  - Increases possible applications and network scenarios

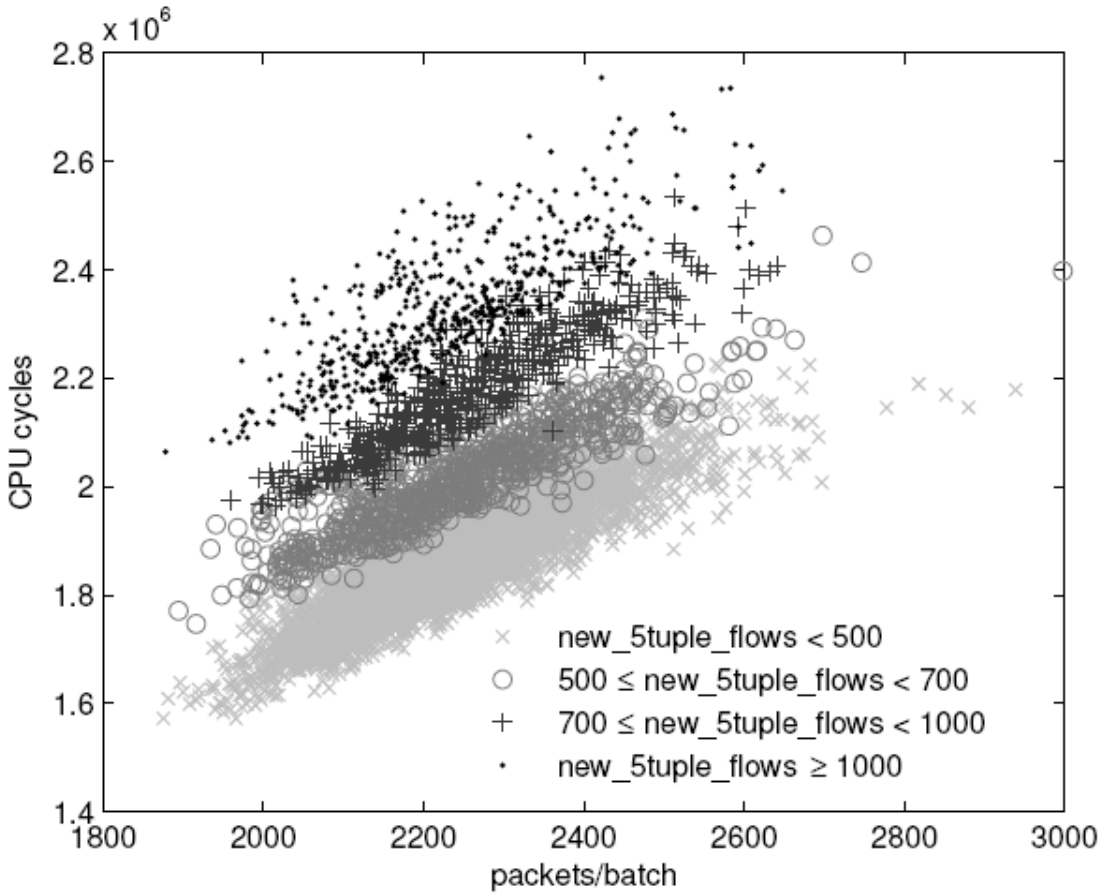
Key Idea

- Cost of maintaining data structures needed to execute a query can be modeled looking at a basic set of traffic features
- Empirical observation
  - Updating state information incurs in different processing costs
    - E.g., creating or updating entries, looking for a valid match, etc.
  - Type of update operations depend on the incoming traffic
  - Query cost is dominated by the cost of maintaning the state
- Our method
  - Find the **right set** of traffic features to model queries' cost

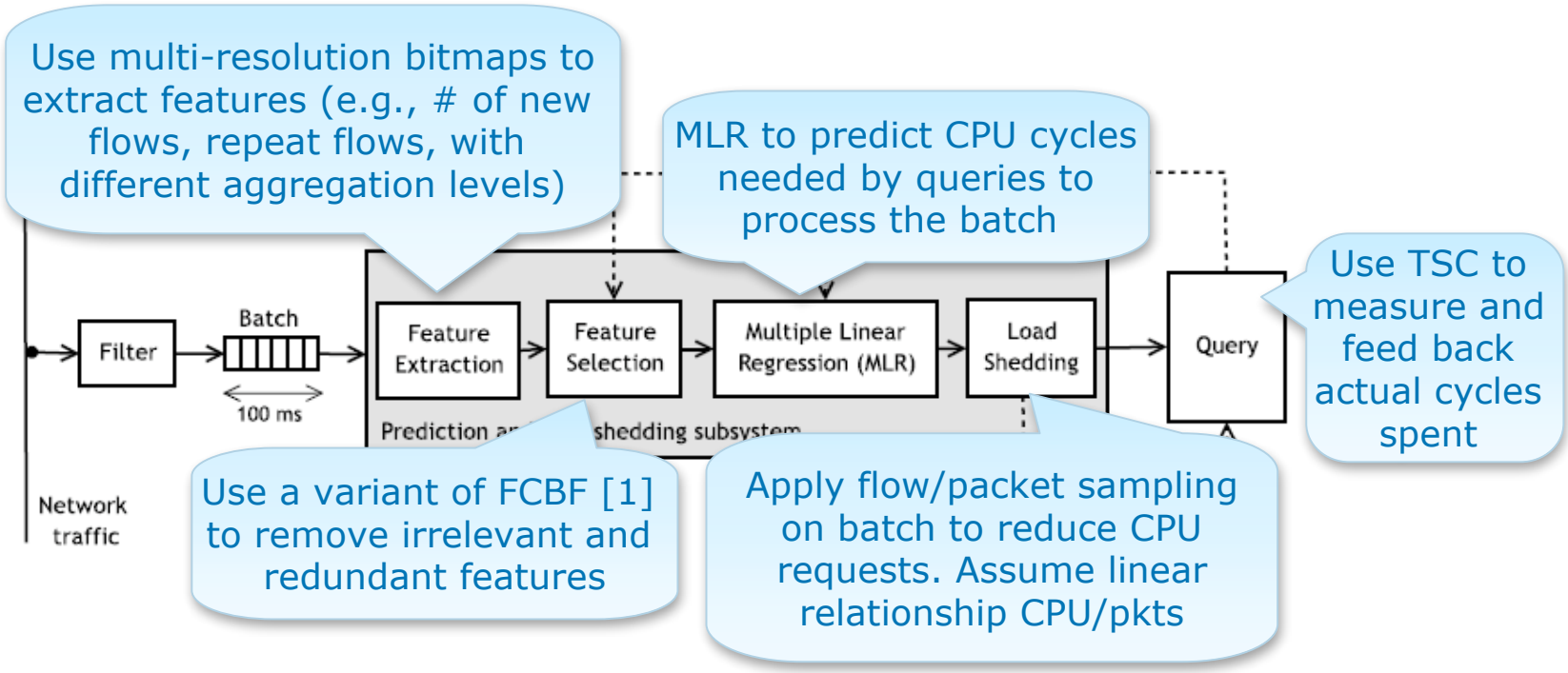
Example


x 10^6
CPU cycles
0
2
4
0 10 20 30 40 50 60 70 80 90 100
Packets
0
1000
2000
3000
0 10 20 30 40 50 60 70 80 90 100
x 10^5
Bytes
0
5
10
15
0 10 20 30 40 50 60 70 80 90 100
5–tuple flows
0
1000
2000
3000
0 10 20 30 40 50 60 70 80 90 100
Time (s)

Example

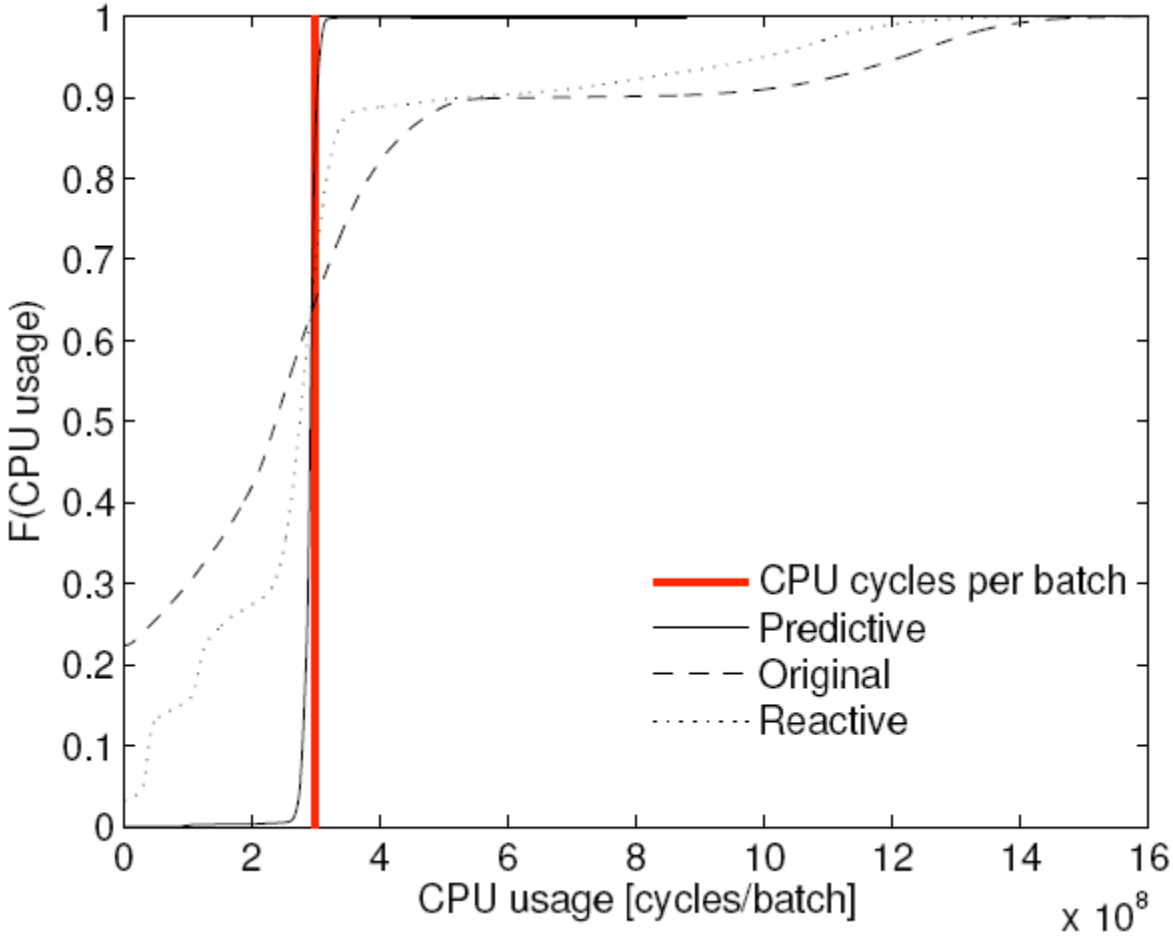

x 10^6
2.8
2.6
2.4
2.2
2
1.8
1.6
1.4
CPU cycles
1800
2000
2200
2400
2600
2800
3000
packets/batch
new_5tuple_flows < 500
500 ≤ new_5tuple_flows < 700
700 ≤ new_5tuple_flows < 1000
new_5tuple_flows ≥ 1000

System overview

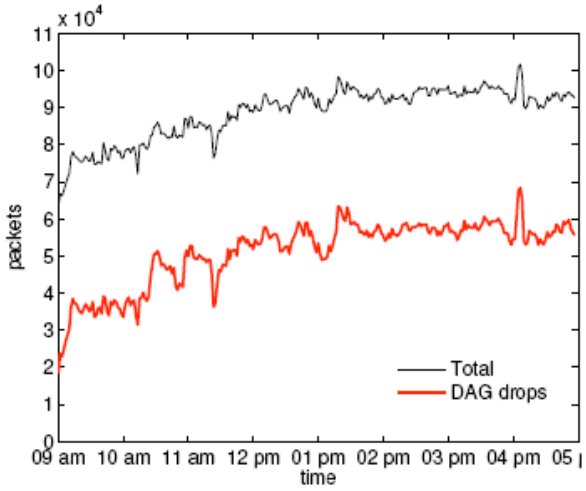


[1] L. Yu and H. Liu. Feature Selection for High-Dimensional Data: A Fast Correlation-Based Filter Solution. In Proc. of ICML, 2003.

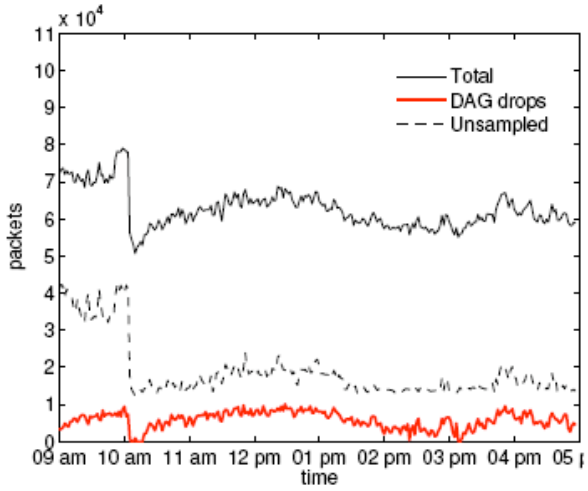
Performance: Cycles per batch



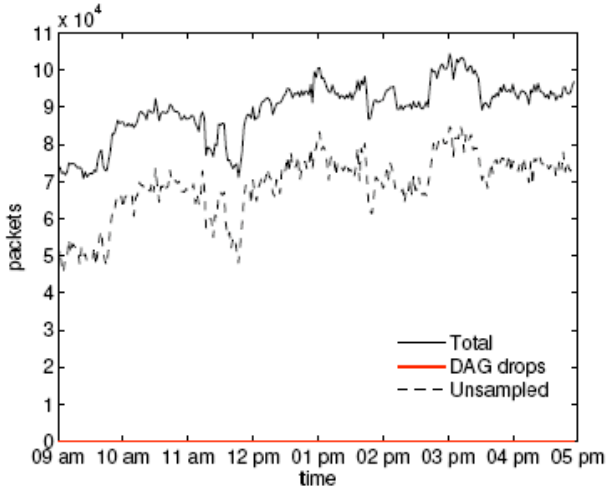
Performance: packet losses



No load shedding



Reactive



Predictive

Performance: Accuracy

- Queries estimate their unsampled output by multiplying their results by the inverse of the sampling rate

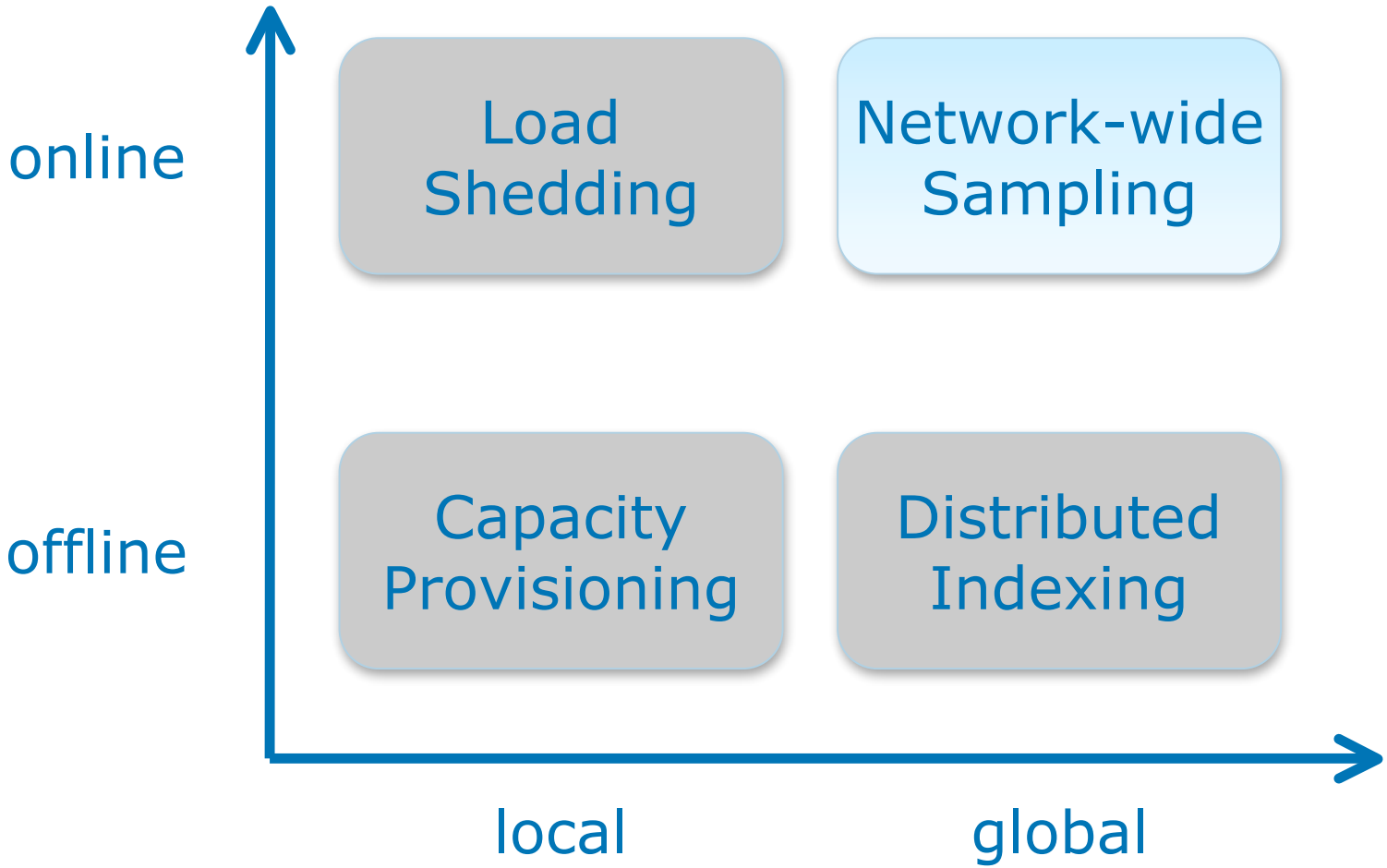
Query	*original*	*reactive*	*predictive*
application (pkts)	55.38% ±11.80	10.61% ±7.78	1.03% ±0.65
application (bytes)	**55.39% ±11.80**	**11.90% ±8.22**	**1.17% ±0.76**
flows	38.48% ±902.13	12.46% ±7.28	2.88% ±3.34
high-watermark	8.68% ±8.13	8.94% ±9.46	2.19% ±2.30
link-count (pkts)	55.03% ±11.45	9.71% ±8.41	0.54% ±0.50
link-count (bytes)	55.06% ±11.45	10.24% ±8.39	0.66% ±0.60
top destinations	21.63 ±31.94	41.86 ±44.64	1.41 ±3.32

Errors in the query results (*mean* ± *stdev)*

Limitations

- Current method works only with queries that support packet/flow sampling
  - Working on custom load shedding support
- Results shown when applying same sampling rate across all queries.
  - Need to accommodate for varying needs of queries
  - Maximize the overall system utility by guaranteeing queries a fair access to CPU (and packet streams)
- Consider other resources (e.g., memory, disk)

Resource Management



Network-wide Sampling

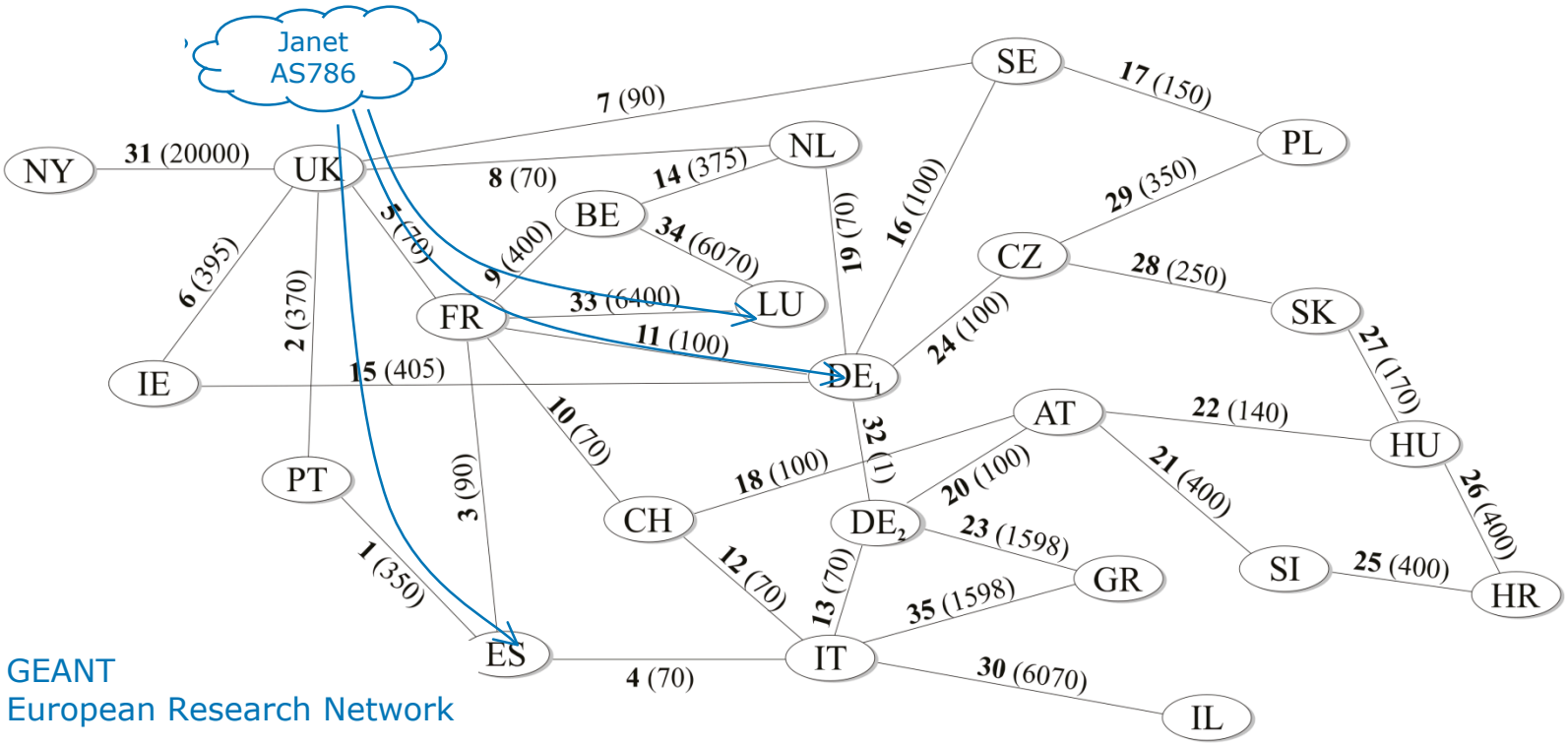
- Given a network of monitors, select the ones that need to participate in a measurement task
  - The task is unknown a priori
- Operating scenario
  - Routing is known. Relationship between pairs of monitoring nodes is known
- Challenge:
  how to configure a network-wide monitoring infrastructure with hundreds of viewpoints?

Our objective

- Given a measurement task and a target accuracy, find a method that:
  - sets the sampling rates on all monitors
  - guarantees optimal use of resources (in terms of processed packets)
  - requires minimum configuration
  - can adapt quickly to changes in the traffic
- Method should apply to a general class of measurement tasks

A case study

- Estimate amount of traffic flowing among a subset of origin-destination pairs
- Common task for traffic engineering apps



GEANT
European Research Network

Problem formulation

Choose vector of sampling rates *p* that maximizes

utility function for OD pair k

"effective" sampling rate for OD pair k

$$\sum_{k \in \mathcal{F}} M\left(\rho_k\left(\boldsymbol{p}\right)\right),$$

sampling rate on monitor i

$$p_i \geq 0$$

max sampling rate for monitor i

$$p_i \leq \alpha_i \quad \text{for all } i \in \mathcal{L}$$

$$\sum_{i \in \mathcal{L}} p_i U_i \leq \theta,$$

packets traversing monitor i

system capacity (in packets)

- Effective sampling rate approximated by sum of sampling rates
- All constraints are linear and define a convex solution space
- Unique maximizer exists as long as M() is strictly concave

Algorithm

- Solve system defined by KKT conditions
  - select set active/inactive constraints (equivalent to switching off/on a monitor)
  - use gradient projection method to explore space
  - use KKT conditions to check optimality of solution
- Selection of active/inactive constraints is NP-hard
  → no guarantee of convergence
- Limit algorithm runs to 2,000 iterations
  → 98.6% optimum found (for our task)

The utility function

- Measures quality of sampling an OD pair
- "Well behaved" to make the algorithm run fast
- Square relative error good candidate
  - SRE = $(X/p - S) / S)^2$
- Utility is 1 - E[SRE]
  - $M(p) = 1 - E[1/S] * (1/p - 1)$;
  - minor tweaking to force it to be zero when p = 0
  - needs E[1/S] where S is the size of the OD pair

Evaluation

- Consider NetFlow data from GEANT
  - Collected using Juniper's Traffic Sampling
  - 1/1000 periodic sampling
  - We scale the measurement by 1000
    (we just need a realistic mix of OD pair sizes)
- Results based on one run of the algorithm
  - One five minute snapshot of the network traffic
  - Compute OD pair sizes and link loads
  - Assume E[1/S] is known

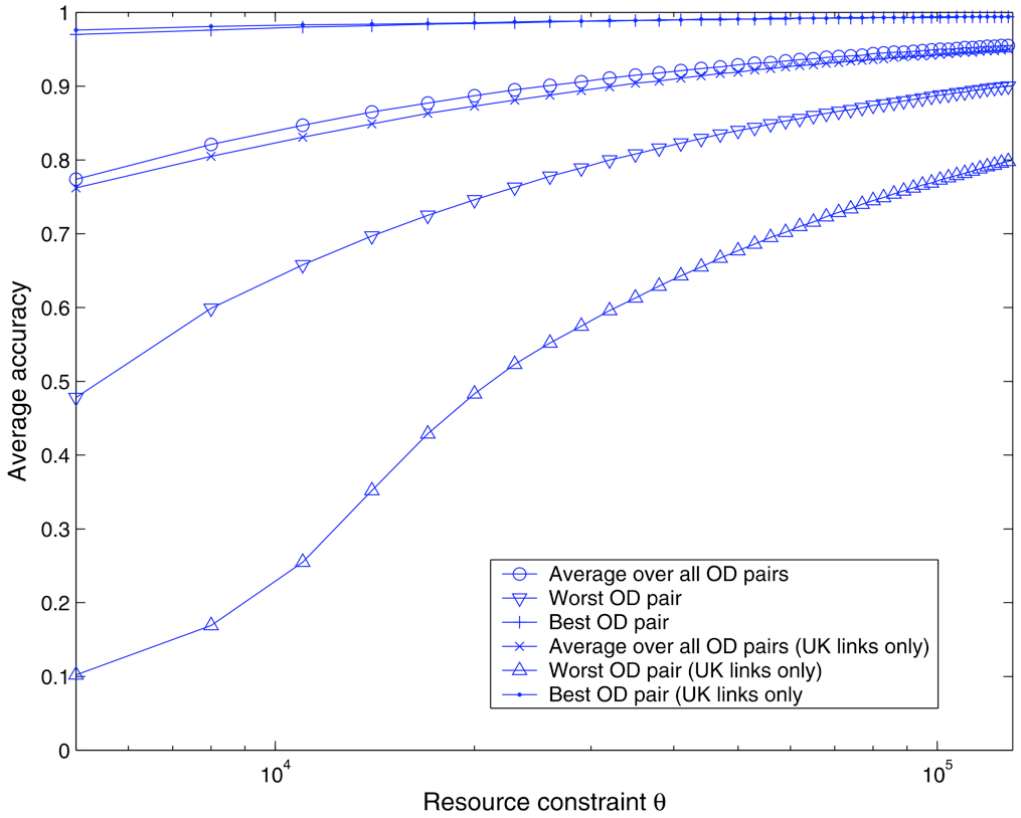
Results highlights

- Measuring relative accuracy
  - Defined as one minus relative error (not squared)
  - Allows to validate manipulation of utility function and the use of effective sampling rate
- Accuracy is in the range 89-99%
  - Worst accuracy for JANET – LU (it has just 20 pkts/sec)
- Measurement spread across 10 links
- Max sampling rates is 0.92% (lightly loaded links)
  - Most links are around 0.1%
  - No OD pair is monitored on more than two links

Comparing to "naive" solutions

- Why not just monitoring JANET access link?
  - All the monitored traffic would be relevant!
  - To achieve same accuracy over all OD pairs we need ~1% sampling rate
    → 70% more packets are processed
  - It's not always possible to monitor both directions of access links
- Why not just monitoring all UK links?
  - There are just 6 links leaving the UK
  - Straightforward algorithm to set sampling rate (each OD pair is present on just one link), but...

Monitoring all UK links

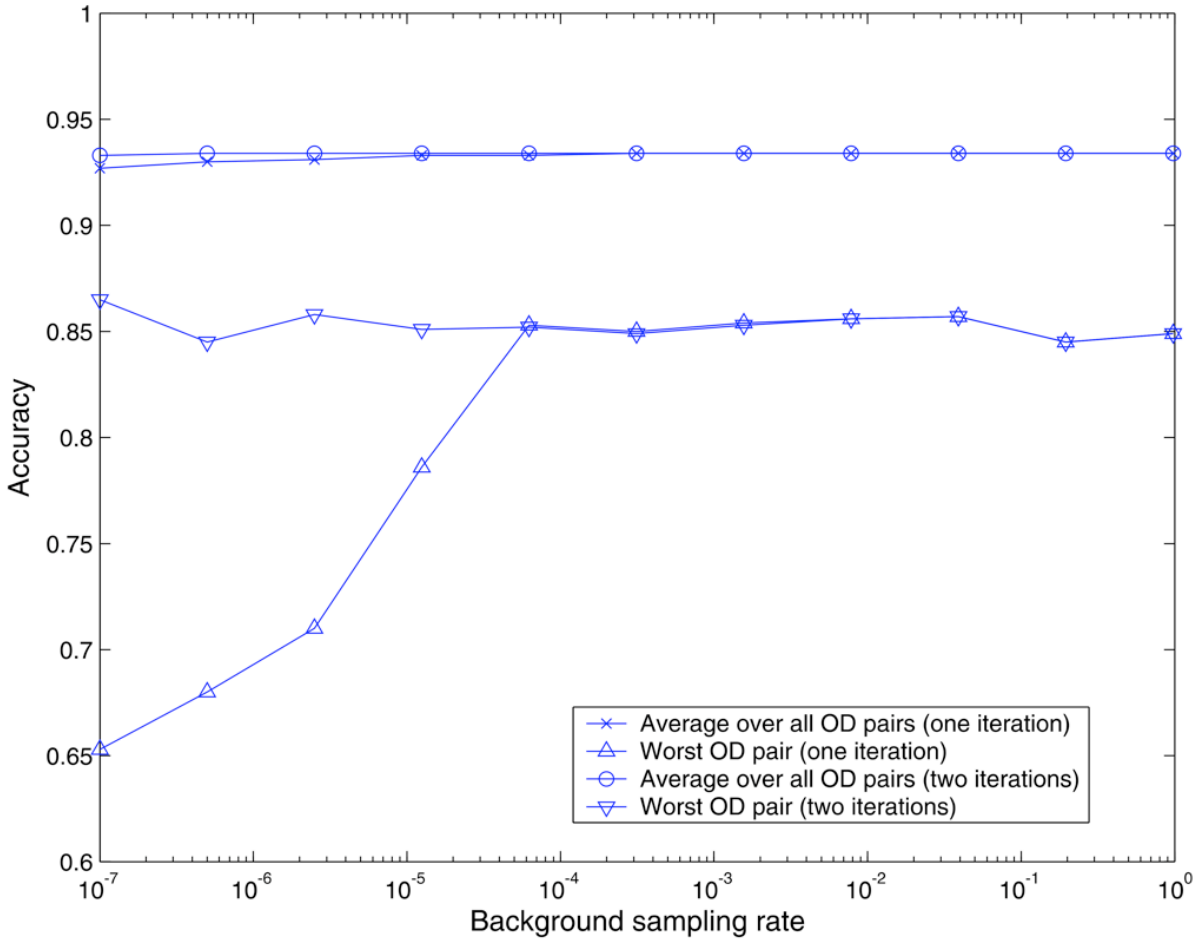


- Why does our method work better?
  - It looks across the entire network to find where small OD pairs manifest themselves without hiding behind large flows

Deployment on real networks

- Two aspects need to be addressed
- Bootstrap:
  What prior knowledge about the network does the method need?
  - need routing information
  - need estimate of E[1/S] for each OD pair
- Adaptation:
  How does the method perform over time?
  - time of day effect change E[1/S] and Ui
  - routing event change path taken by OD pairs

Bootstrapping phase



Adapting to traffic fluctuations

- Three different cases that require different approaches
- Link load increases
  - more sampled packets, exceeding capacity

  → find new sampling rates to enforce target capacity
- OD pair decreases in volume
  - poor accuracy because of bad E[1/S] estimate

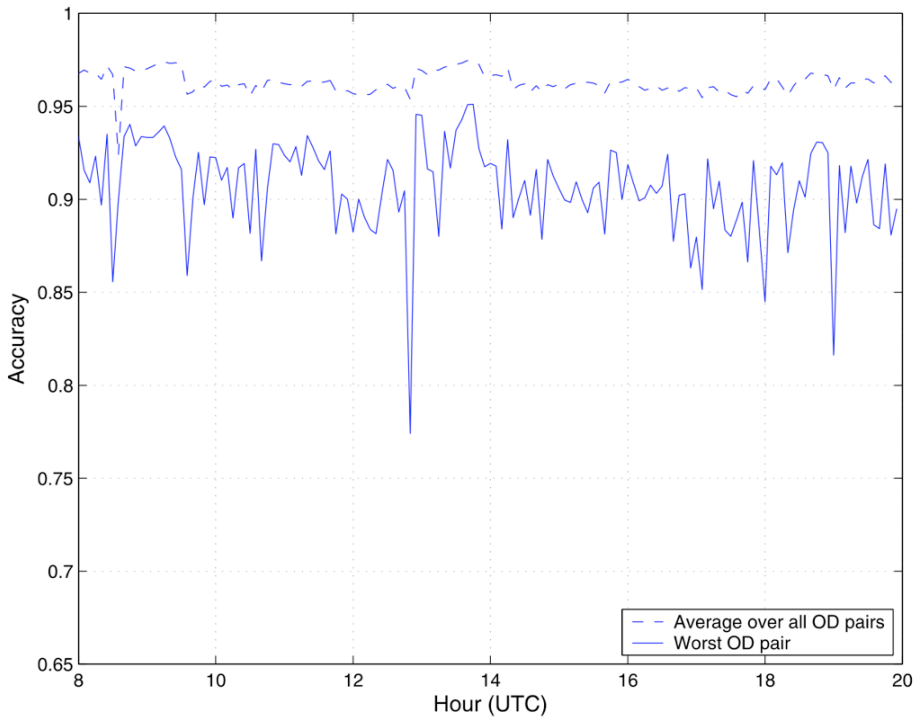
  → adapt capacity Q to keep target accuracy
- OD pair traverses different set of links
  - missing entire OD pair

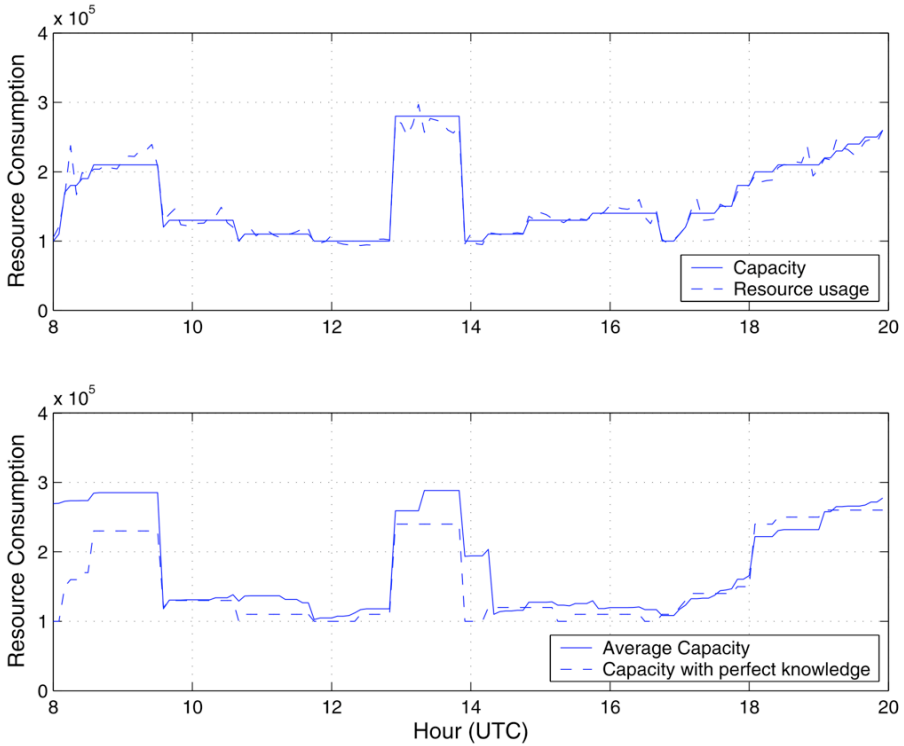
  → monitor routing updates and "re-bootstrap" the algorithm

Fluctuations in OD pairs

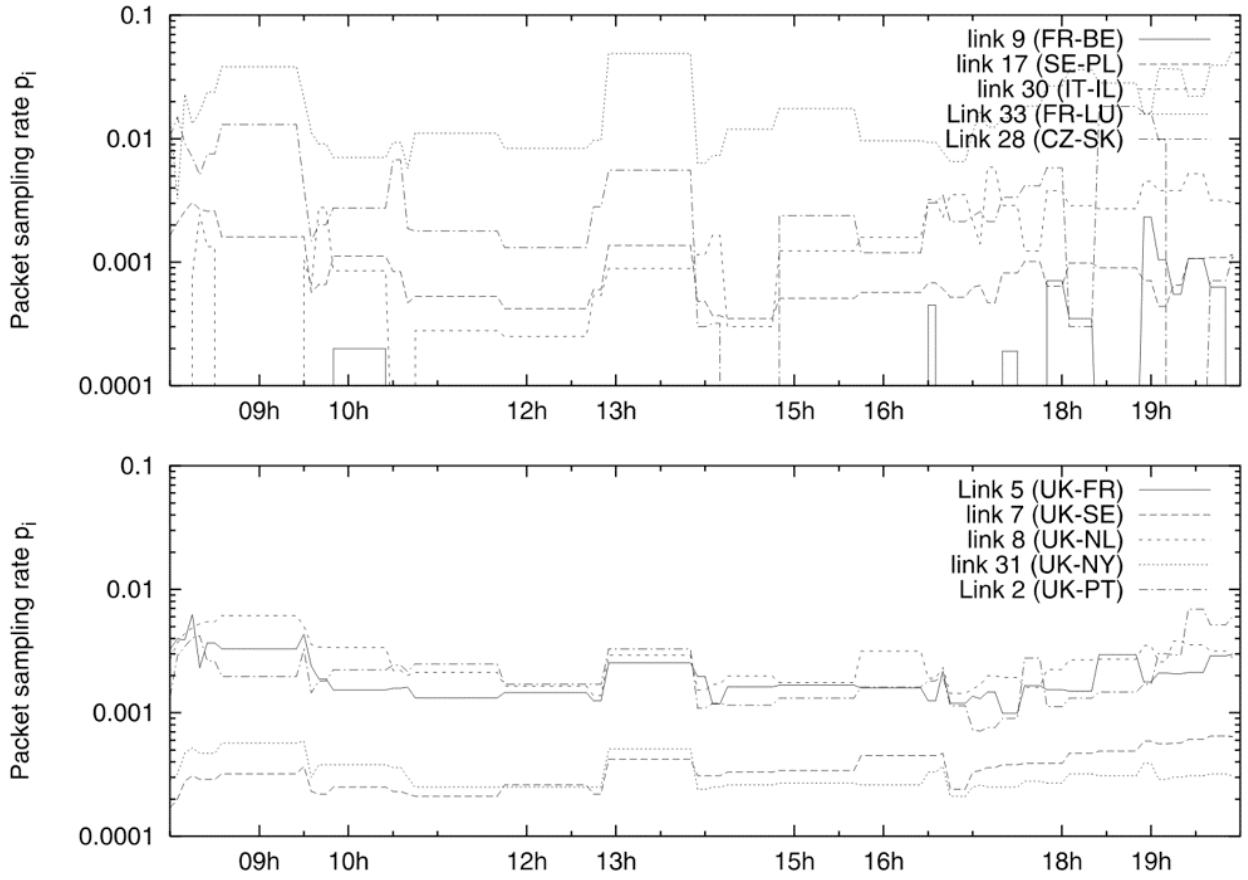
- Monitoring accuracy of OD pairs
  - Accuracy is not known.
  - Need to estimate E[1/S] from sampled data.
  - Use simplest method → Current size of OD pair
- Compute new sampling rates when estimated accuracy drops below target
- If the estimated accuracy is still below target, increase capacity by 10%
- Decrease capacity if estimated accuracy is above target for more than one hour

Fluctuations in OD pairs





Fluctuations in OD pairs (cont'd)



Conclusions

- The CoMo Project
  - Code available at http://como.sourceforge.net
  - Open source, BSD License
  - Currently in the process of being commercialized by Intel (codename Harris Hill)
  - Used by EU Onelab/Onelab2 (Planetlab Europe)