End-To-End Performance Guarantees in Computer Networks Using NetLets

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Outline of Presentation

- Present-day Networks - Need for QoS
- NetLets: Basic Concepts
- Distributed Computing Environments
- Analytical Model and Performance Guarantees

Present-Day Networks: Internet

Very little Quality of Service (QoS) Guarantees:

- Internet packets are routed according to best-effort mechanism
- All packets are the same - control packet from PC to a waiting teraflop machine
- Once packet is sent, very little can be done about how it is sent

QoS is Needed Now:

- Large distributed simulations
- Data transfers to and from high performance machines
- Control of sensors and robots over networks

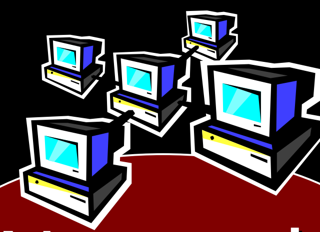
State and configuration of network must be exploited to achieve best performance

What type of QoS is Desired:

1. End-to-end guarantees on delay, jitter, etc., for various types of messages

2. Must be provided in a transparent manner to the application programmer

NetLets: Basic Idea



data packets

Application

Network

Currently, no control once data reaches the network

data packets

data packets

Application

NetLets

Network

NetLet Packets

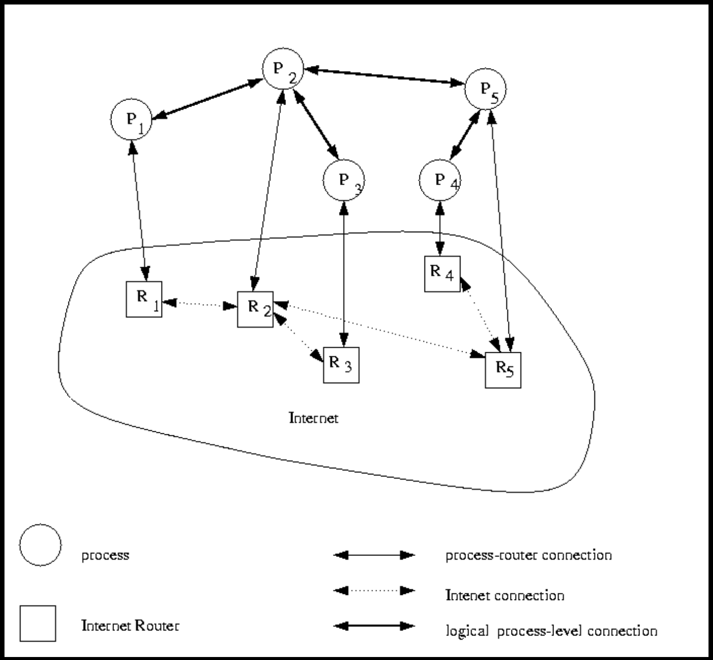
Netlets use both configuration and state of network

Distributed Computing Over IP Networks

At Present:

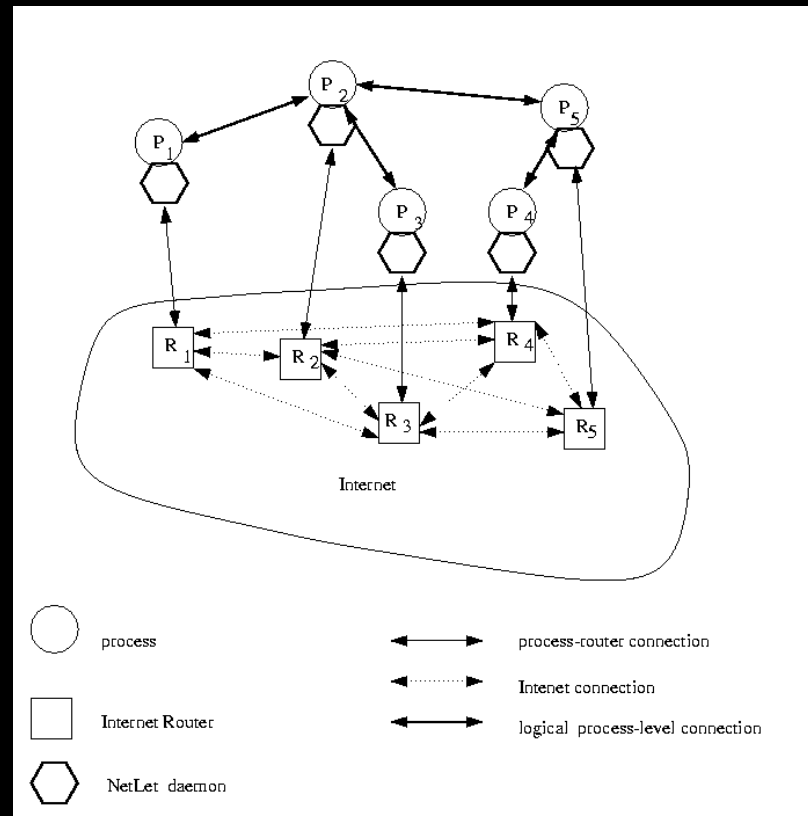
- process-to-process communication is achieved as peer-to-peer mechanism
- parallelism in network is not taken advantage of

e.g. congestion on a link is not bypassed



NetLets Offer Natural Solution:
Increase flow in less congested routes
- Use processes to assist in networking

NetLets for Distributed Processes



ORNL laid initial foundations for NetLets

Process-process communication is handled

through Netlets that

- estimate link statistics (non-linear estimators)

- compute "best" paths

Provide probabilistic end-to-end guarantees

- distribution-free under stationarity conditions

- detailed probabilistic models are not needed:

  measurements are often sufficient

Distributed Computing over IP

We showed

that measurements are sufficient to provide end-to-end delay guarantees

- No need for extensive modeling

We derived probabilistic end-to-end delay guarantees for very general classes of networks

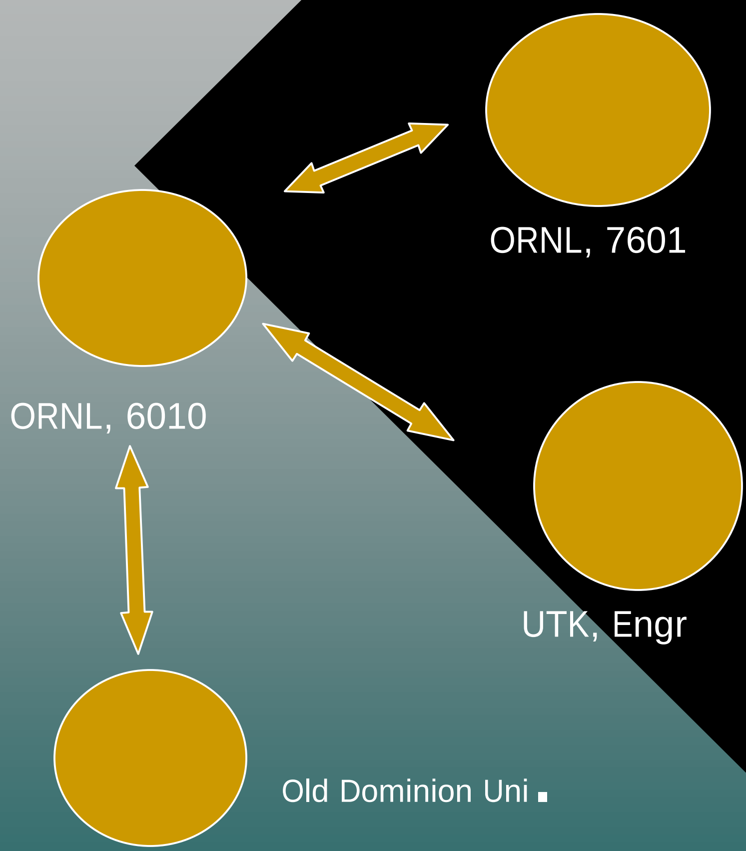
NetLets became possible as a result of unique combination of

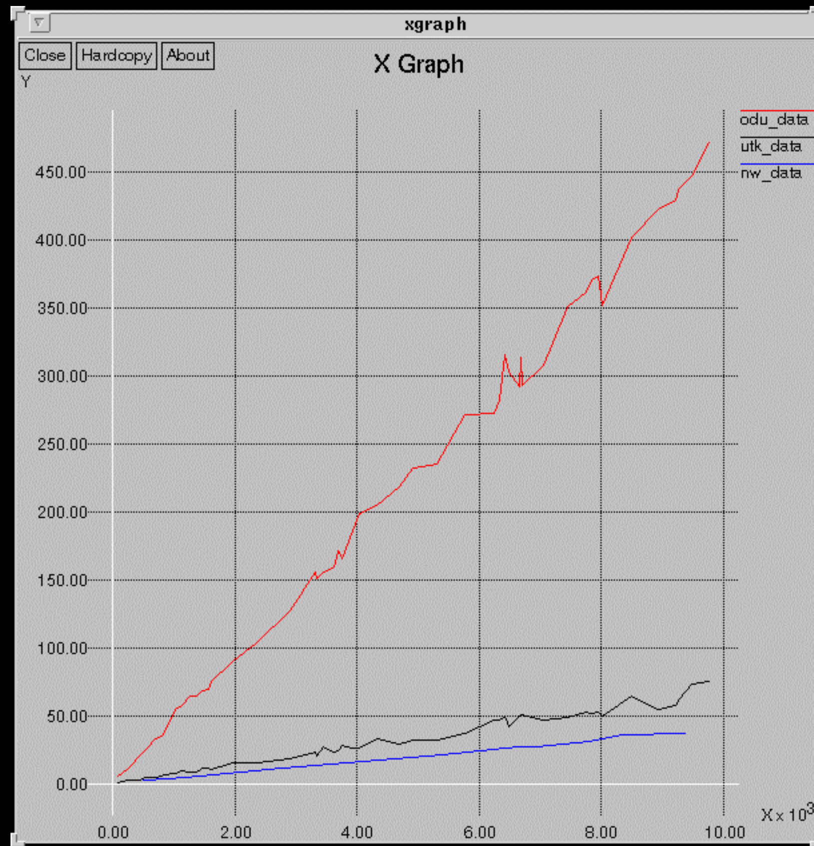
statistical estimation, graph and flow algorithms, and network engineering

Anatomy of NetLets

Finite-sample statistics	Flow and graph algorithms	Network Engineering

Network Measurements





- Distributed environment consisting of four sites
- TCP/IP end-to-end delivery times vs message size

Routing Problem

Given: computer network $G = (V, E)$
available bandwidths $b(e)$, for link $e \in E$
link-delays $d(e)$, for link $e \in E$
queuing delay $q_v(r)$, for node $v \in V$, for message size r

Message Transmission Problem:
Compute a path to send message of r units
from s to d with minimum end-to-end delay

Simple Path: $(v_0, v_1), (v_1, v_2), \ldots, (v_{k-1}, v_k)$:
End-to-End delay for message size r:

$$t(r, P) = g\left(r, \min_{j=0}^{k-1} b(e_j)\right) + \sum_{j=0}^{k-1} d(e_j) + \sum_{j=0}^{k-1} q_{v_j}(r)$$

where $e_j = (v_j, v_{j+1})$;
$g\left(r, \min_{j=0}^{k-1} b(e_j)\right)$ is delay due to bandwidth;
$\sum_{j=0}^{k-1} d(e_j)$ is delay due to link-delays; and
$\sum_{j=0}^{k-1} q_{v_j}(r)$ is the queuing delay.

Random Formulation

In practice,

$g(.,.)$ and $d(.)$ can be accurately estimated.

— they depend on links

$q(.,.)$ – queuing delays are hard to estimate

— they depend on other messages

— Message of size R arrives at the source according to an *unknown* distribution P_R

– At any node v:

Q_v: queuing delay distributed according to *unknown* P_{Q_v}

R_v: message size distributed according to *unknown* and P_{R_v}

Measurements:

$(Q_{v:1}, R_{v:1}), (Q_{v:2}, R_{v:2}), \ldots, (Q_{v:l}, R_{v:l})$

independently and identically distributed (iid) according to *unknown* P_{Q_v, R_v}

Fundamental Question:

When *only* measurements are available,

can any guarantees be given on end-to-end delay ?

Optimal Paths

End-To-End Delay of P in transmitting a message of size R:

$$T(P,R) = g(R, b(P)) + d(P) + \sum_{j=0}^{k-1} Q_{v_j|R}$$

Expected Delay of P

$$\bar{T}(P,R) = g(R, b(P)) + d(P) + \sum_{j=0}^{k-1} \int Q_{v_j} dP_{Q_{v_j}|R}$$

Best Expected Path:

P_R^*: path with minimum expected end-to-end delay,

$$\bar{T}(P_R^*, R) = \min_{P \in \mathcal{P}} \bar{T}(P,R)$$

where $\mathcal{P}$ is set of all paths between s and d.

Regression-Based Paths

Empirical End-To-End delay: Based on the estimator $\hat{q}_v(.)$

$$\hat{T}(P,R) = g(R, b(P)) + d(P) + \sum_{j=0}^{k-1} \hat{q}_{v_j}(R)$$

— $\hat{T}(.)$ can be computed since it involves only the measurements

Best empirical end-to-end delay path:

$$\hat{P} = \arg\min_{P \in \mathcal{P}} \hat{T}(P)$$

— computed using our algorithm in $O(m^2 + mn \log n + n f(l))$ time

$f(l)$: cost of computing regression at r

Performance Guarantees

Compute $\hat{P}$ based on vector space method *based entirely* on measurements, such that for sample size

$$l = \frac{8192 n^4 \tau^2}{\epsilon^4}\left[d \ln\left(\frac{512 e \tau n^2}{\epsilon^2} \ln \frac{512 e \tau n^2}{\epsilon^2}\right) + (n+3)\ln 2 + \ln(n/\delta)\right],$$

we have

$$\mathbf{P}\left\{\mathbf{E}_R |\bar{T}(\hat{P}_R, R) - \bar{T}(P_R^*, R)| \geq \epsilon\right\} \leq \delta,$$

where $\sup_v Q_v \leq \tau$

Informally, with high probability $1 - \delta$
expected delay of $\hat{P}$ is within ϵ of optimal expected delay,
irrespective of underlying distributions.

Three Classes of NetLets

- Distributed Computing in IP Networks
  - integrate NetLets into native environments
  - thorough analysis of regression methods and sample sizes
  - path-tables can be used to quickly retrieve paths for given message size
- ATM Networks
  - bandwidths and delays are deterministic
  - routes must be reserved which adds random components
- Active Networks
  - routing code can be sent with messages
  - data-collection programs can be more flexible

Conclusions

- NetLets have potential for networking and network applications
  - offer a capability no one else is able to yet
- Unique Combination - statistics, algorithms, network engineering
  - NetLets are made possible by a unique synergy
- Need to advance theory and implementation to the next level
  - testing on benchmark problems