A Flexible Model for Resource Management in Virtual Private Networks

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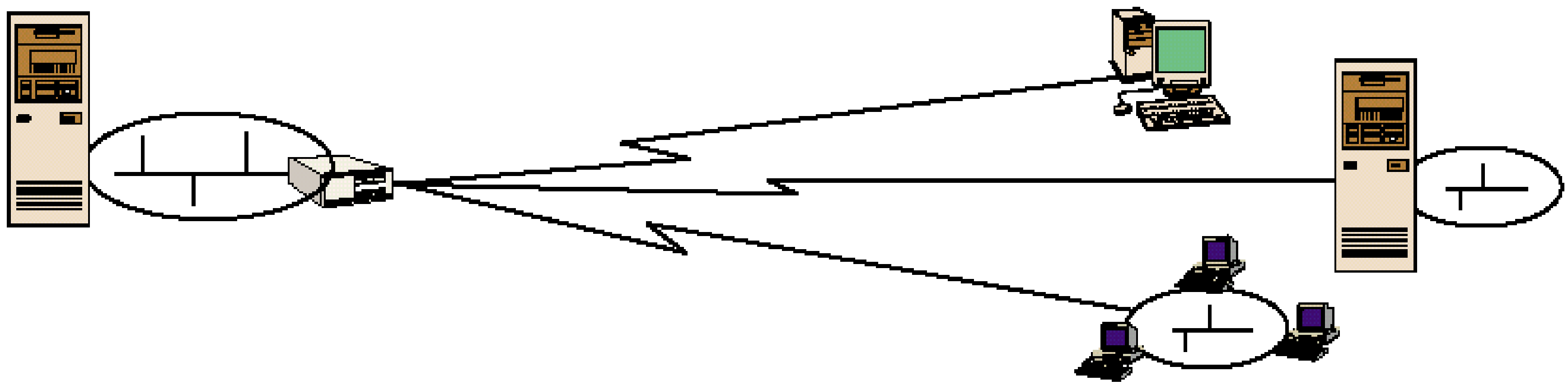
Overview

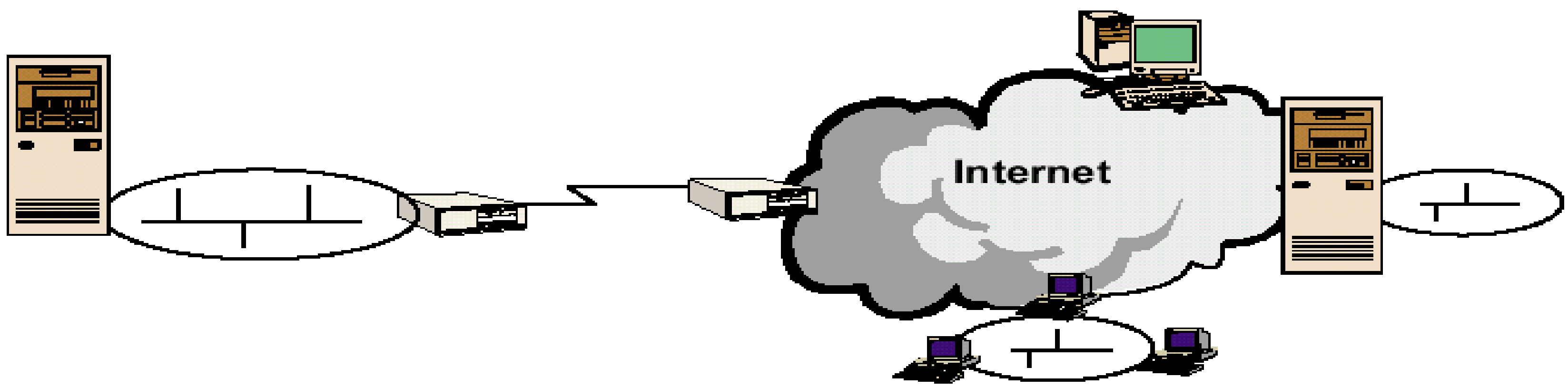
- Introduction of VPN
- Hose model
- Implementation scenarios
- Simulation experiments
- Simulation results
- conclusions

What Is a Virtual Private Network?

Virtual private networks (VPN) provide an encrypted connection between a user's distributed sites over a public network (e.g., the Internet). By contrast, a private network uses dedicated circuits and possibly encryption.

Public Internet instead of Private Network





A VPN replaces all of the above utilizing public internet, Performance and availability depends on your ISP and internet

Benefit - $$$$$

Traditional Private Networks:-

- High fixed cost
- Low variable costs

  (with respect to varying capacity)

=> collection of VPNs sharing a common communication channel are cheaper to build than the equivalent collection of smaller physically discrete networks.

Requirements for IP-based VPNs

- Opaque packet transport
  - VPN traffic no relation to rest of IP backbone traffic
  - VPN may use private IP address
- Data security
  - By customer (firewall + encryption)
  - Secure managed VPN service by providers
- Quality of service
  - Leased and dial-up lines provide guarantee on the bandwidth and latency
- Tunneling mechanism
  - A way to implement opaque transport and security

Resource Management in VPN?

- Isolation from other flows
- Guaranteed bandwidth, loss and delay characteristics
- Over an existing public network
- Yet, same performance assurances as a private network!

QoS Support

- Service Level Agreement (SLA) between a customer & a service provider
  - traffic characteristics and QoS requirements
- Two ways to support different QoS classes within VPN:
  - resources are managed on a VPN specific basis, i.e. SLAs would be for the overall VPN rather than for each specific QoS class
  - resources are managed on an individual QoS basis

Hose Model

- Customer's interface into the network
- Performance guarantee based on the "aggregate" traffic
- To and from a given endpoint to the set of all other endpoints

Hose Model

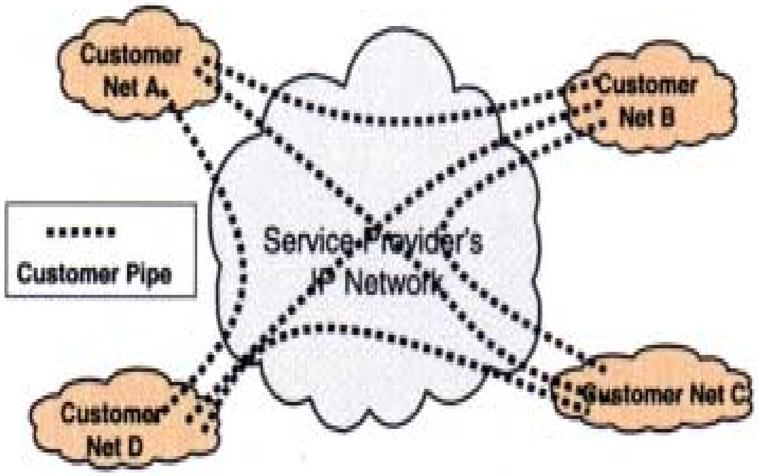


Figure 1: A VPN Based on the Customer-Pipe Model. A mesh of customer-pipes is needed, each extending from one customer endpoint to another. A customer endpoint must maintain a logical interface for each of its customer-pipes.

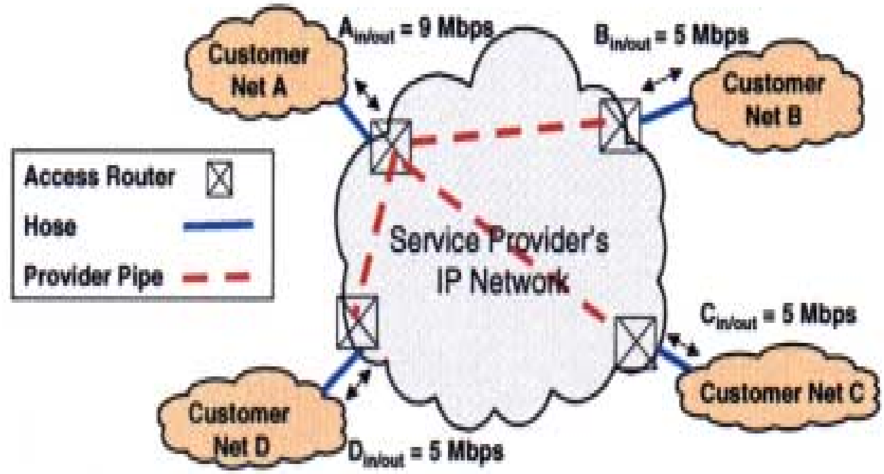


Figure 2: A VPN Based on the Hose Model. A customer endpoint maintains just one logical interface, a hose, to the provider access router. In the Figure, we show the implementation of one hose (based at A) using provider-pipes.

Comparison between Pipe & Hose

- 2 performance service abstractions: Pipe & Hose
  - A pipe provides performance guarantees for traffic between A specific origin and destination pair
  - A hose provides performance guarantees between an origin and a set of destinations, and between a node and a set of origins, i.e. it’s characterized by the “aggregate” traffic coming from or going into the VPN.

Advantages of Hose for customer

- Ease of specification - one rate per endpoint vis-a-vis one rate per pair of endpoints
- Flexibility - traffic to multiple endpoints multiplexed on one hose
- Multiplexing gain - Total of hose rates < Aggregate rate in a Private network
- Characterization - Statistical variability over multiple pairs smoothed into hose
- Billing - Resize hose capacities dynamically

Implementation Scenarios

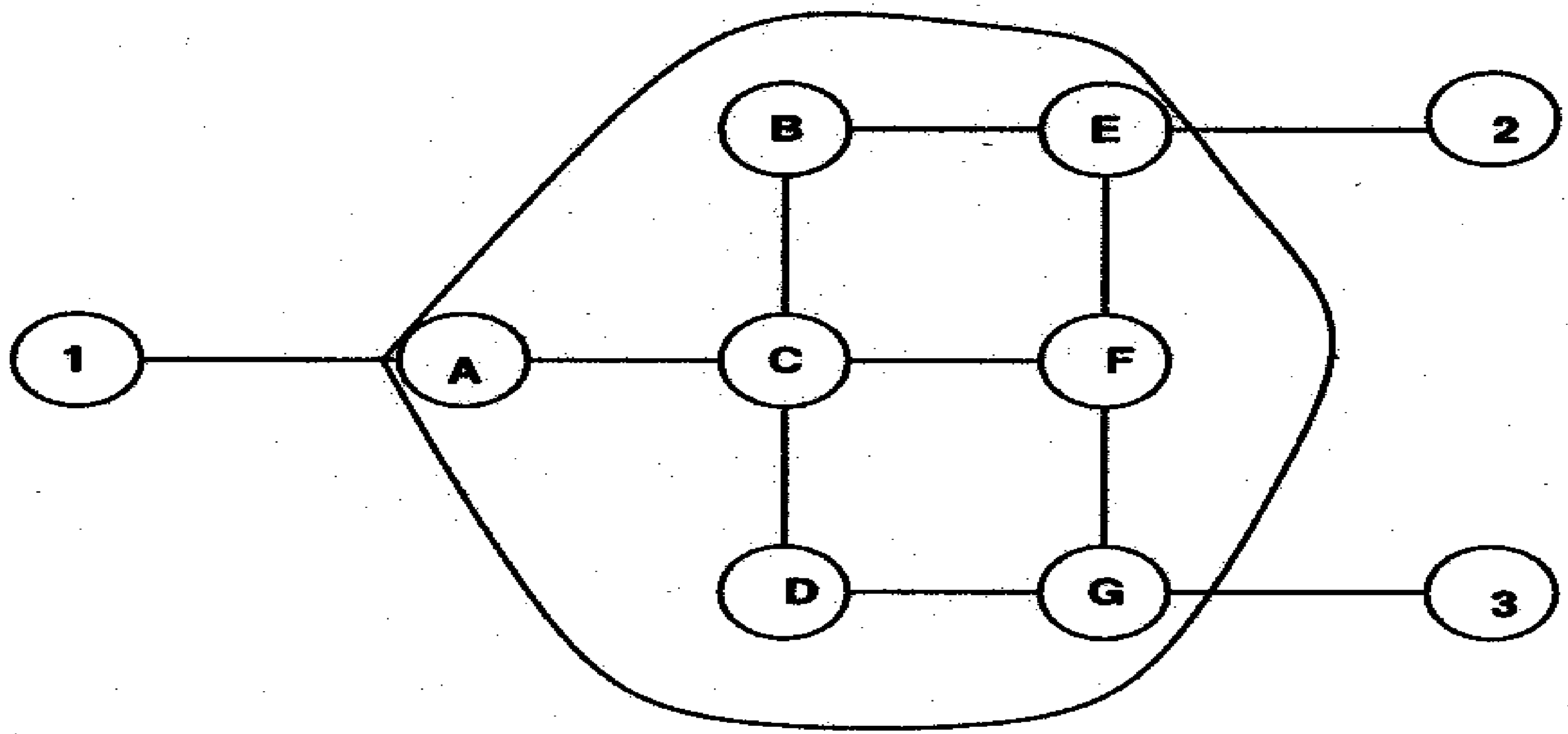


Figure 3: An example network to illustrate various implementation possibilities. 1-3 represent customer routers, and A-G represent provider routers.

Dynamically Resized VPNs

- Disadvantage of provisioned VPNs
  - Reserved capacity may not be used
- Resized provider pipes
- Resized trees
- Resized trees with explicit routing
- Resource aggregation across a VPN

Requirements for Dynamically Resized VPNs

- Prediction of required capacity based on traffic measurement - technique suggested

- Signaling protocols to dynamically reserve resources - future work

Prediction of Traffic Rate

- T_{meas} - measurement window
- T_{ren} - next window for which rate is renegotiated
- T_{samp} - regularly spaced samples
- R_i - average rate over inter-sample intervals
- Local maximum predictor

  $R_{ren} = max\{R_i\}$
- Local Gaussian predictor

  $R_{ren} = m + \alpha\sqrt{v}$

  m = mean of R_i

  v = variance of R_i

  α = Multiplier

Simulation Experiments

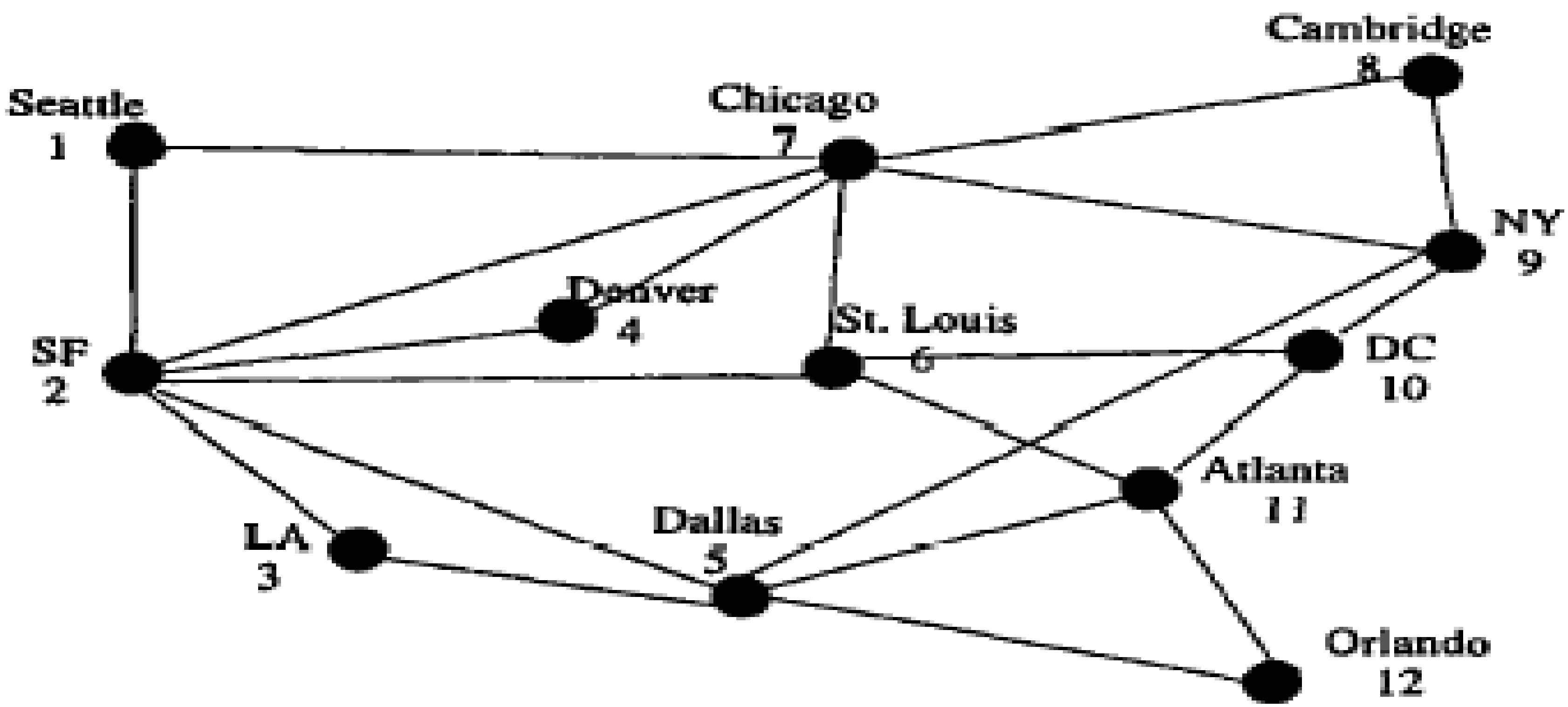


Figure 4: Physical Topology of IP Backbone

Simulation Experiments

- 2 sets of traces – voice and data
- PSTN traffic == IP telephony traffic?
- Experiments
  - The stability of VPN traffic matrices
  - Evaluation the usefulness of the hose model
  - A mesh of provider-pipes in the network vs. a source based tree
  - The relationship between short term capacity management by resizing and the longer term admission control algorithms

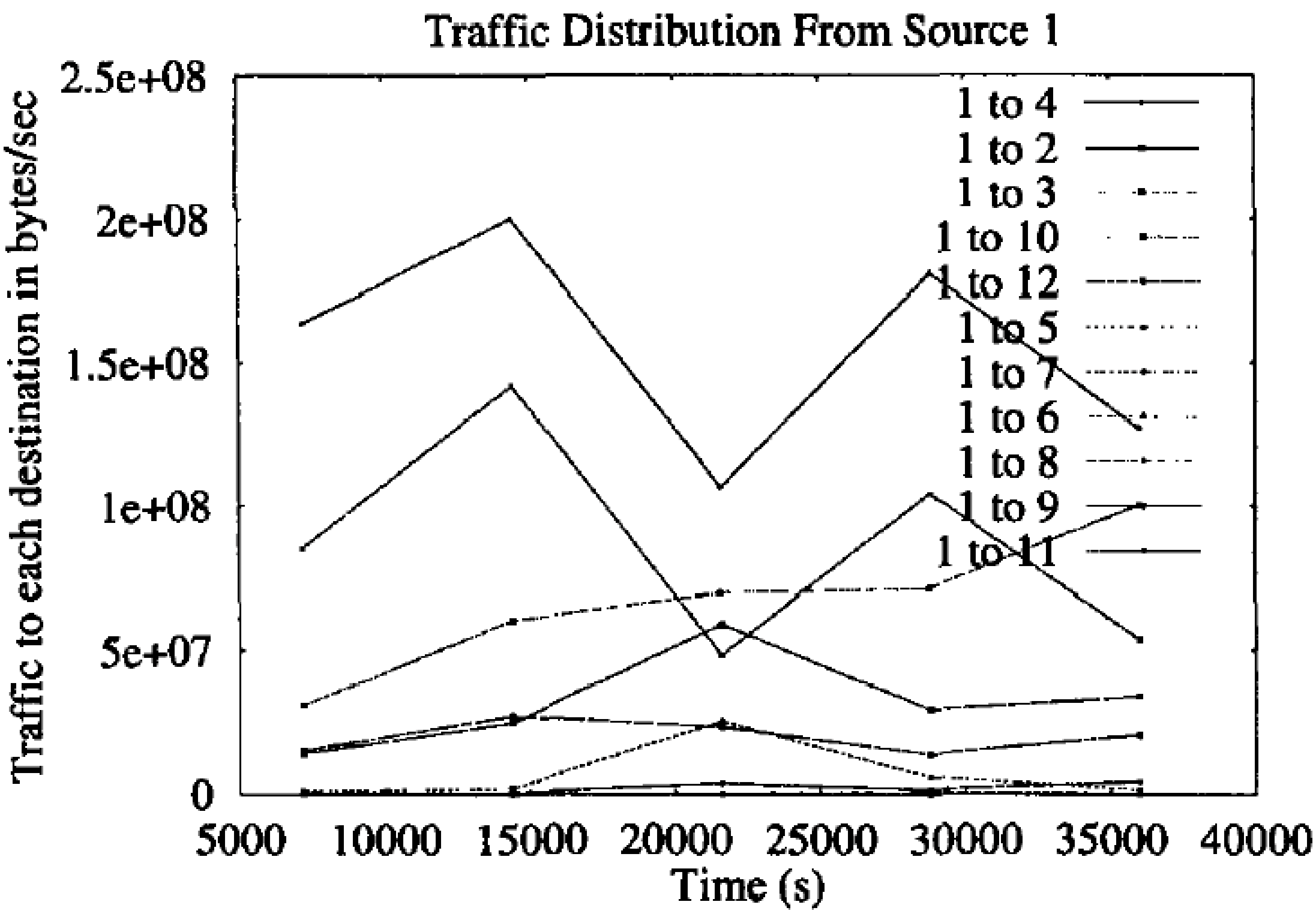


Figure 5: VARIABILITY IN THE DATA TRAFFIC MATRIX: Capacity for each destination of a selected hose

Performance Benefit of Hoses for the Customer

- **Customer-Pipe Requirement** = $\sum_{j \in E_l(i)} S(r_{ij})$
- **Hose Requirement =** $S(\sum_{j \in E_l(i)} r_{ij})$
- **Statically provisioned access host-gain**

= Customer-Pipe Requirement / Hose Requirement

Provisioning the Access Link

- The capacity required by a customer on each access link depends on the service model being offered to the VPN customer
- If customer's service interface into the network is

Customer-Pipe:

adequate capacity would need for each such pipe

Hose:

capacity that needed is the maximum traffic demand for the hose

Statically Provisioned Access Hose Gain for Data Traffic

Hose Source	Static Requirement (kB/sec)		Static prov. hose gain
	Customer-Pipe	Hose	
1	2229	1164	1.92
2	2873	1379	2.08
3	13379	12538	1.07
4	4925	2031	2.43
5	619	255	2.42
6	86	79	1.08
7	112	59	1.88
8	3104	2538	1.22
9	1483	416	3.57
10	752	251	2.99
11	778	303	2.56
12	1606	771	2.08

Table 1: STATICALLY PROVISIONED ACCESS HOSE GAIN FOR DATA TRAFFIC: static requirements for customer-pipes and hoses.

Statically Provisioned Access Hose Gain for Voice Traffic

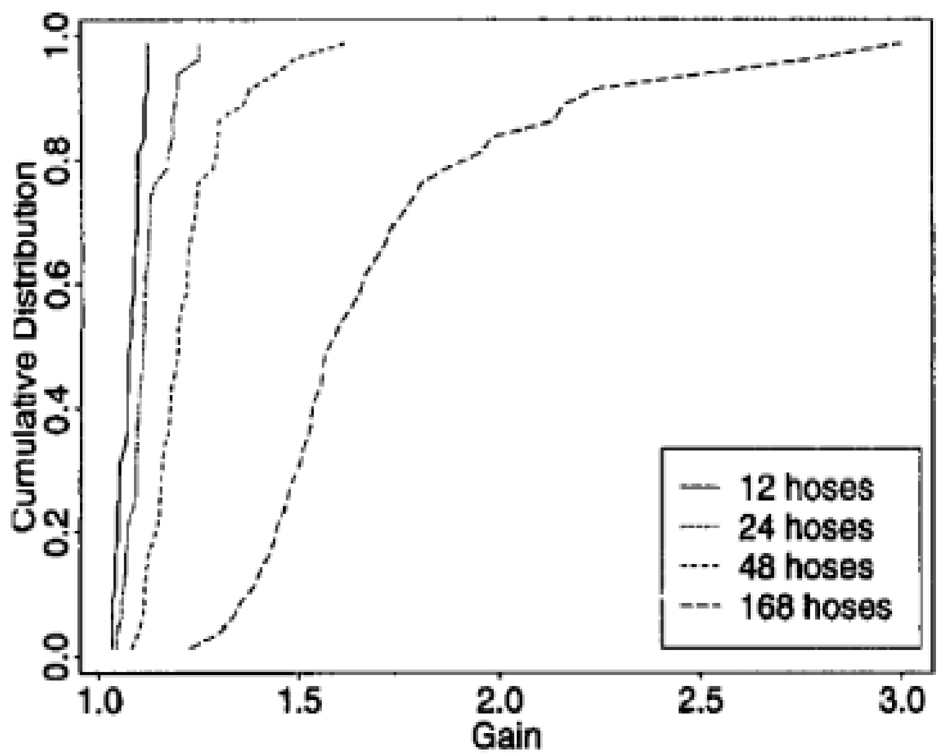


Figure 6: STATICALLY PROVISIONED ACCESS HOSE-GAIN FOR VOICE TRAFFIC: CDF of hose-gain for different aggregation levels

Resizing the Access Link

- The capability to renegotiate hose capacities is provided to customers
- The renegotiation is based on demand predictions derived from measurement that track the fluctuations in the offered traffic

Benefit of Resizing the Access Link for Voice Traffic

	number of hoses			
	12	24	48	168
Max. resizing gain	2.15	2.17	2.22	3.08
Mean resizing gain	1.94	1.95	1.98	2.06
Min. resizing gain	1.80	1.79	1.77	1.82

Table 2: HOSE RESIZING GAIN FOR VOICE TRAFFIC: maximum, mean and minimum across hoses at different aggregation levels. Renegotiation at 1 minute intervals .

Effect of Reducing the Resizing Frequency

Resize Freq.	12 hoses	24 hoses	48 hoses	168 hoses
1 minute	2.34, 0.40	2.37, 0.39	2.53, 0.39	3.55, 0.47
5 minute	2.72,0.88	2.73, 0.86	2.88, 0.86	3.96, 0.98
10 minute	3.11,1.42	3.11, 1.38	3.25, 1.37	4.36, 1.49
30 minutes	4.72,3.54	4.64, 3.40	4.72, 3.36	5.76,3.48

Table 3: BLOCKING ABOVE HOSE REQUIREMENT FOR VOICE TRAFFIC: Impact of resizing interval on performance. Each table entry represents the percentage overallocation and percentage of calls blocked.

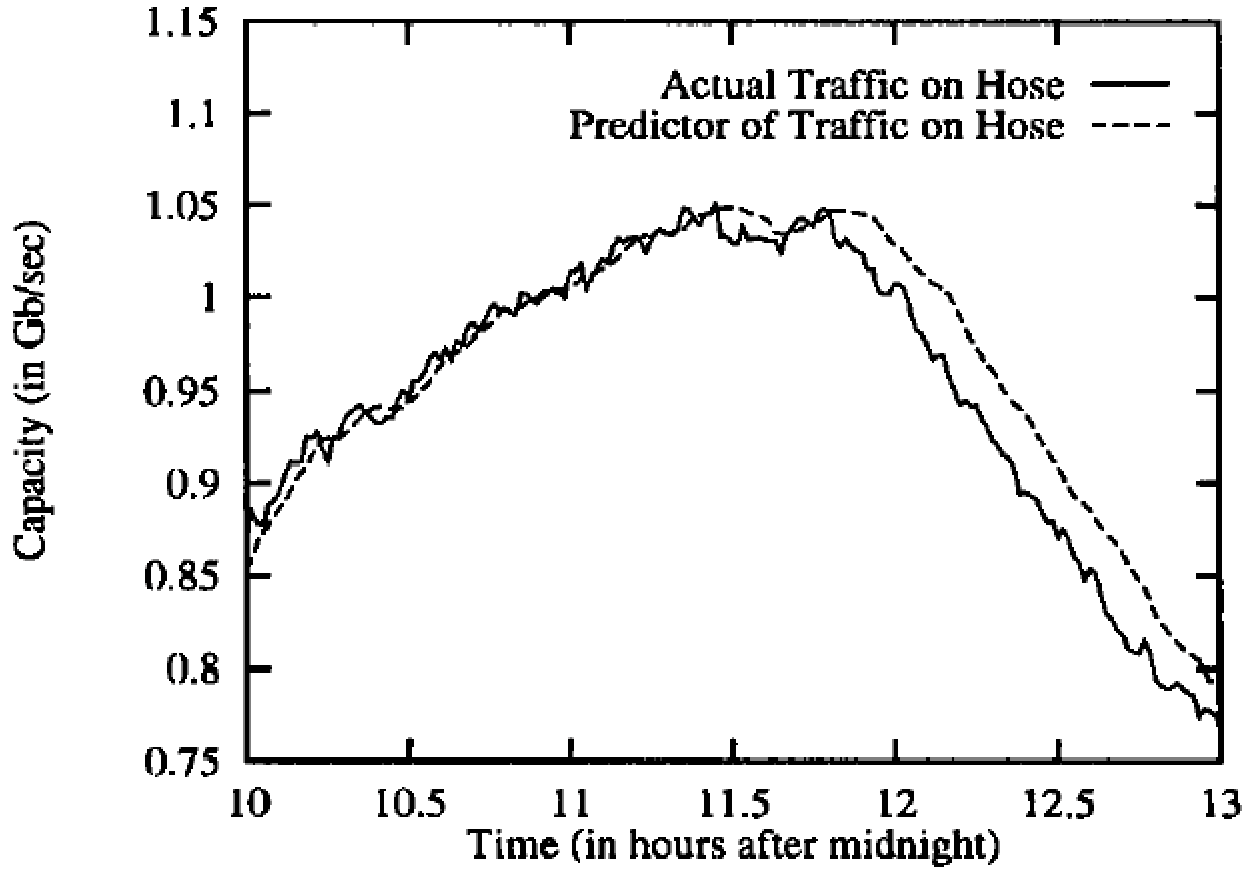


Figure 7: TIME SERIES OF VOICE TRAFFIC: actual traffic and hose prediction for a single hose.

Benefit of Resizing the Access Link for Data Traffic

Resizing Interval	1 min.	5 min.	10 min.	30 min
Max. resizing gain	62.9	49.8	44.4	37.8
Mean resizing gain	15.5	11.9	10.7	9.23
Min. resizing gain	1.95	1.84	1.80	1.75

Table 4: HOSE RESIZING GAIN FOR DATA TRAFFIC: maximum, mean and minimum across hoses for different resizing intervals T_{ren}.

Benefit of Resizing the Access Link for Data traffic

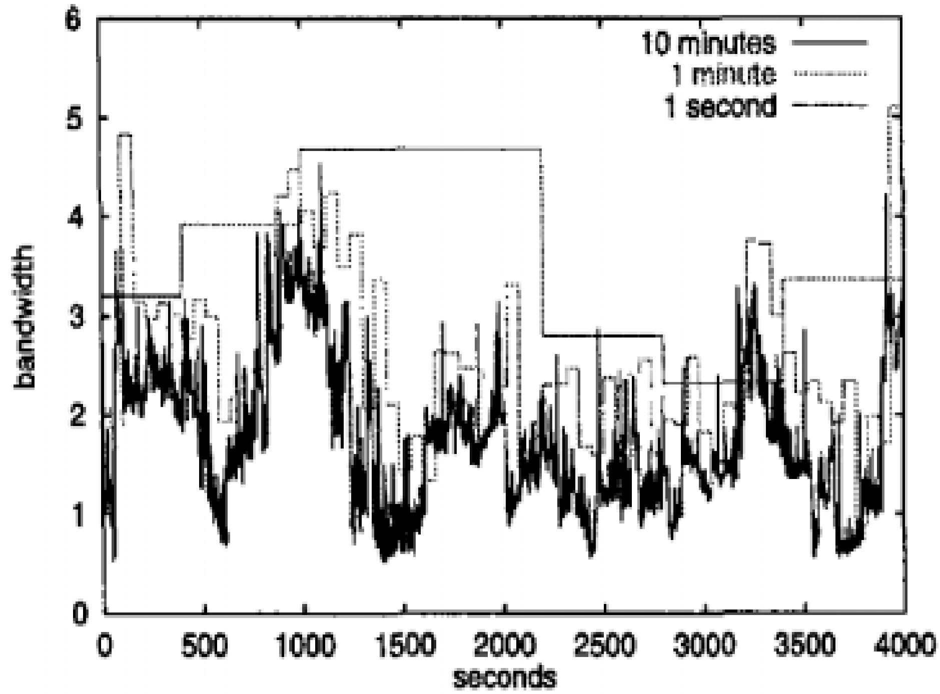


Figure 8: HOSE PREDICTORS FOR DATA TRAFFIC: variance-based predictors for data over 1 second, 1 minute and 10 minute windows. Bandwidth is shown in nominal units.

Comparison of Benefits of Resized Hoses and Customer-Pipes

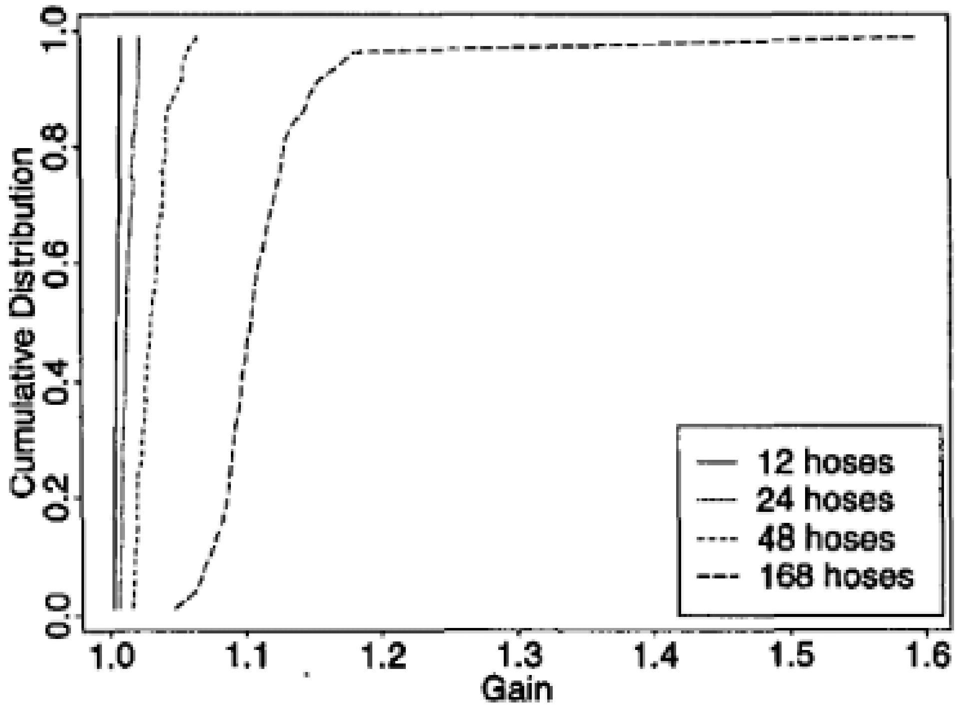


Figure 9: DYNAMICALLY-RESIZED ACCESS HOSE GAIN FOR VOICE TRAFFIC. CDF (across access links) of the gain in capacity in going from dynamically resized customer-pipes to dynamically resized hoses.

Comparison of Benefits of Resized Hoses and Customer-Pipes (cont.)

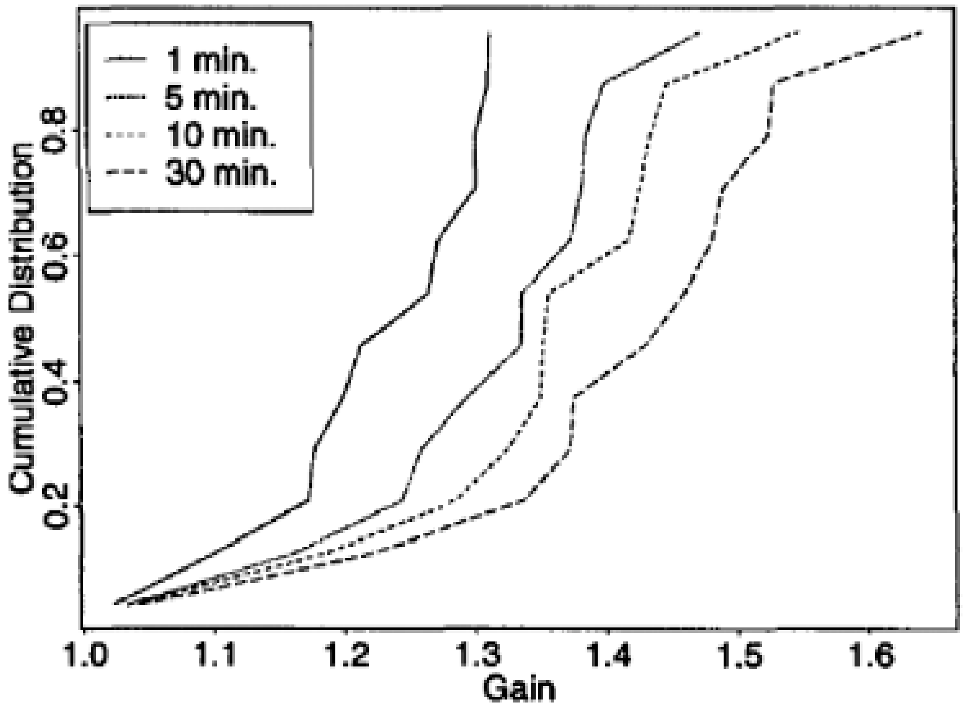


Figure 10: DYNAMICALLY-RESIZED ACCESS HOSE GAIN FOR DATA TRAFFIC. CDF (across access links) of the gain in capacity in going from dynamically resized customer-pipes to dynamically resized hoses.

Benefits of Statically Provisioned Trees

- Moving from the root of a tree corresponding to a given hose towards a leaf, progressively fewer flows are aggregated together and hence we expect the benefit of sharing reservations in the tree to decrease. (Figure 11)

- A tree gain (the ratio of the requirement of the hose to the corresponding sum of the requirements of customer-pipe) of 1 occurs on links where each tree present on the link leads toward a single destination. (Figure 12)

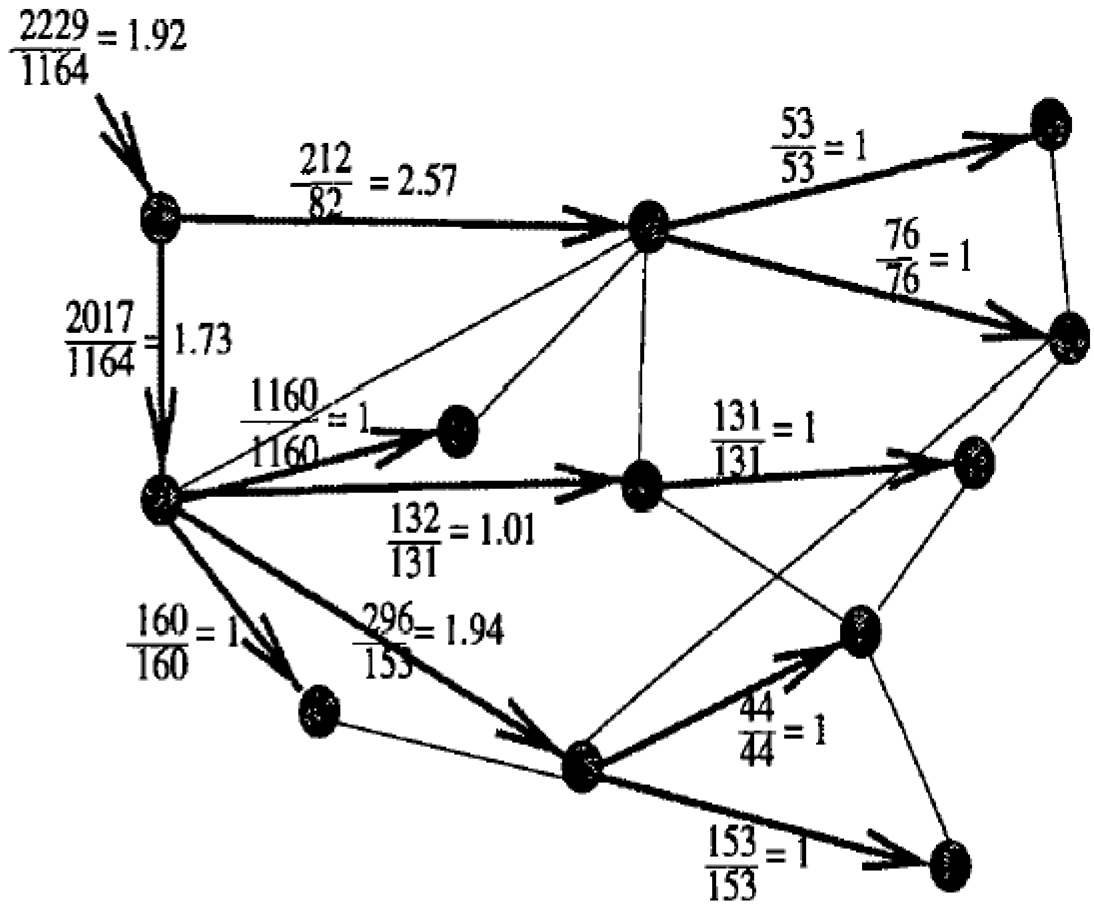


Figure 11: STATICALLY PROVISIONED TREE GAIN FOR DATA TRAFFIC FOR 1 TREE: Ratio of provider-pipe requirements to tree requirements, for each link used by a hose connected to node 1.

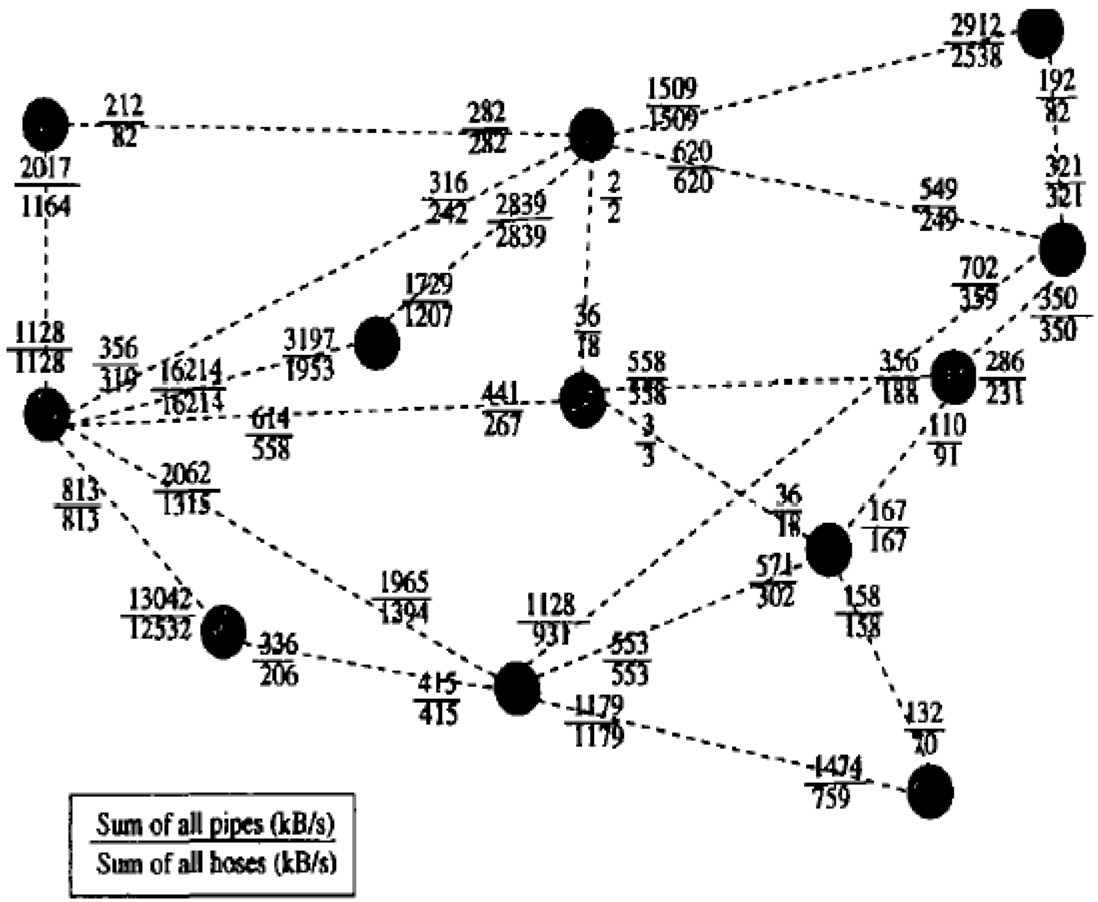


Figure 12: STATICALLY PROVISIONED TREE GAIN FOR DATA TRAFFIC FOR ALL TREES. Ratio of provider-pipe requirements to tree requirements for each link. Each link is labeled with two ratios, as the links are bidirectional. The ratio corresponding to the link from node A to node B is placed nearest to node A.

Benefits of Dynamical Resizing for Voice Traffic

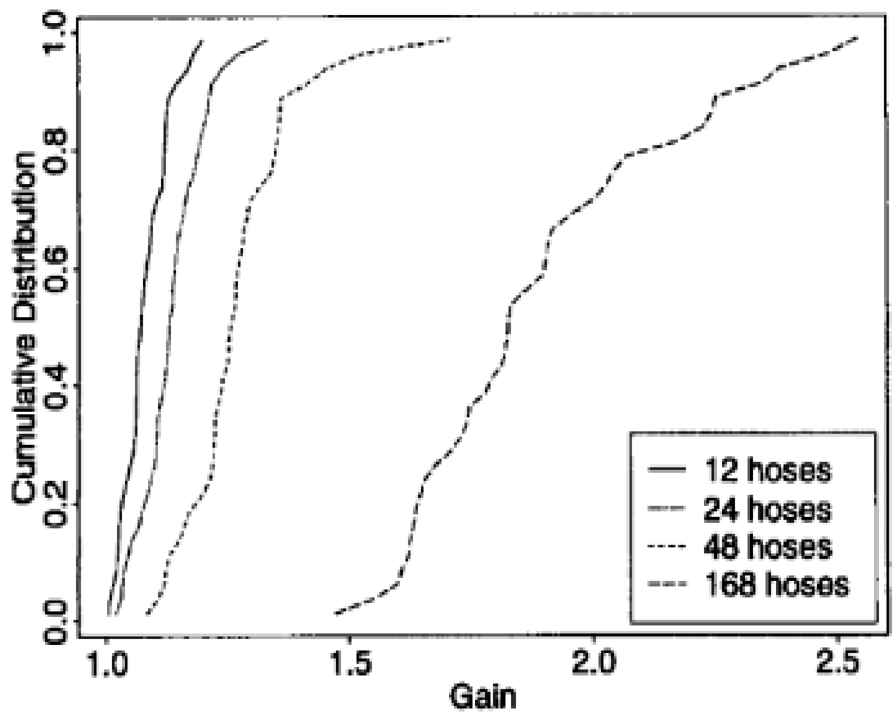


Figure 13: PROVIDER-PIPE RESIZING GAIN FOR VOICE TRAFFIC: CDF (over all provider-pipes) of static to dynamically sized provider-pipe requirements, for different levels of aggregation.

Benefits of Dynamical Resizing for Voice Traffic (cont.)

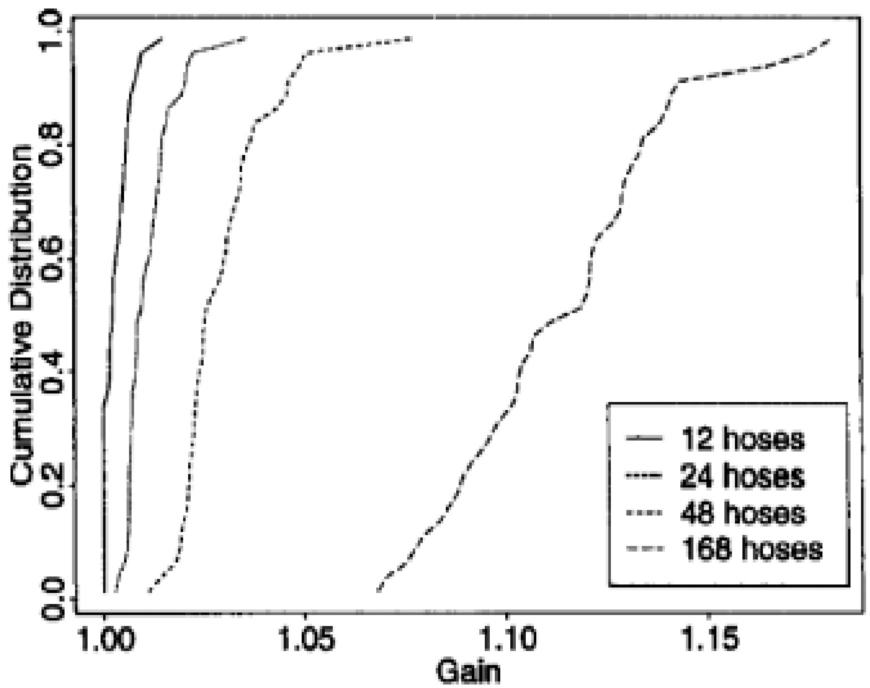


Figure 14: DYNAMICALLY RESIZED TREE GAIN FOR VOICE TRAFFIC: CDF (over all network links) of the ratio of dynamically resized provider-pipe requirement to dynamically resized tree requirement, according to aggregation level.

Benefits of Dynamical Resizing for Data Traffic

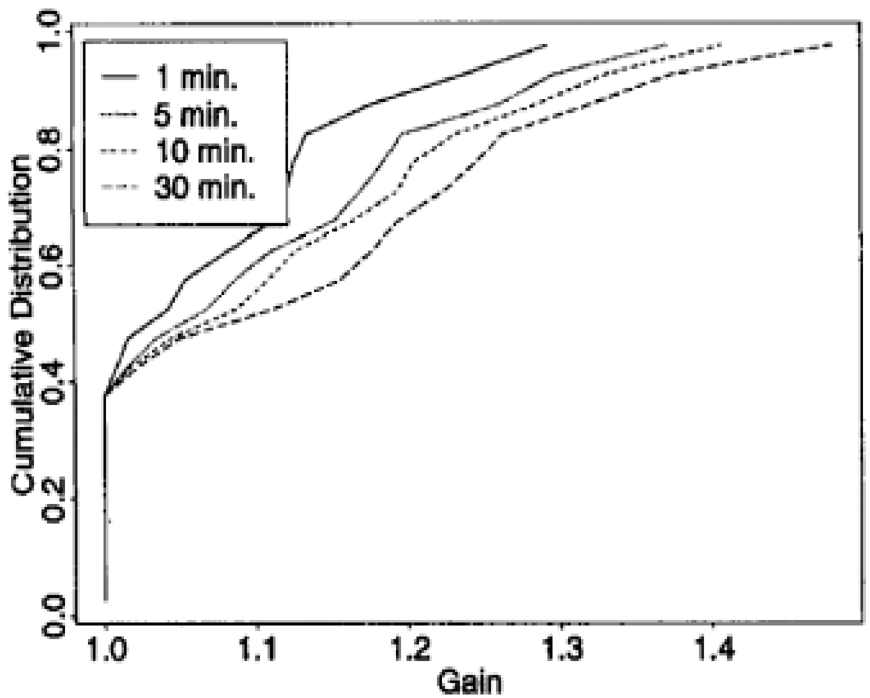


Figure 15: DYNAMICALLY RESIZED TREE GAIN FOR DATA TRAFFIC: CDF (over all network links) of the ratio of dynamically resized provider-pipe requirement to dynamically resized tree requirement, according to resizing window.

Benefits of Dynamical Resizing for Data Traffic

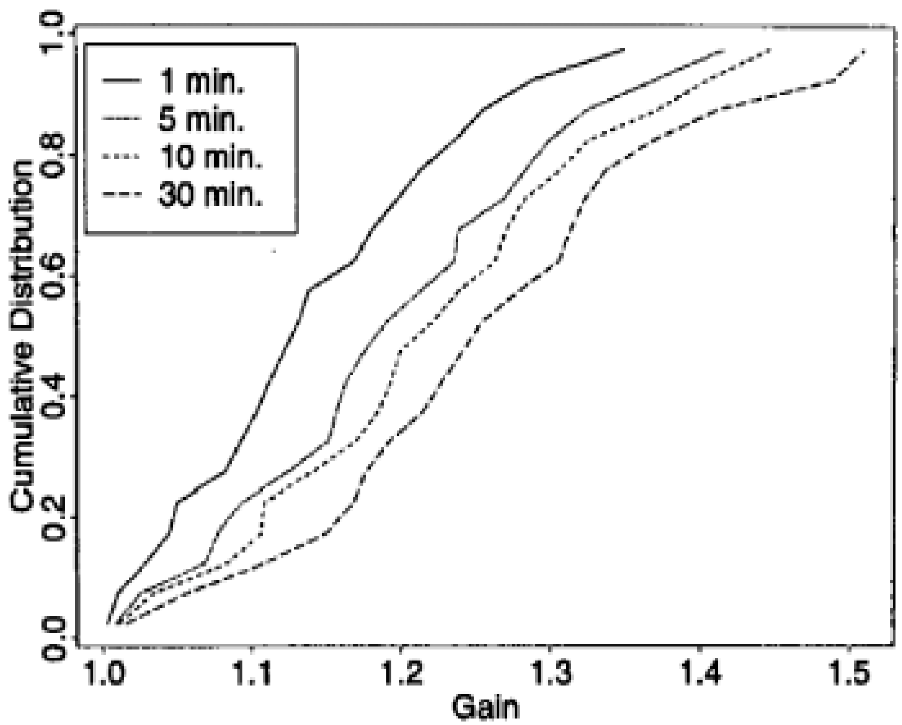


Figure 16: Dynamically Resized VPN Gain for Data Traffic: CDF (across all network links) of ratio of resized VPN requirement to resized provider-pipe requirement, according to resizing interval.

Effective Bandwidths for Admission Control

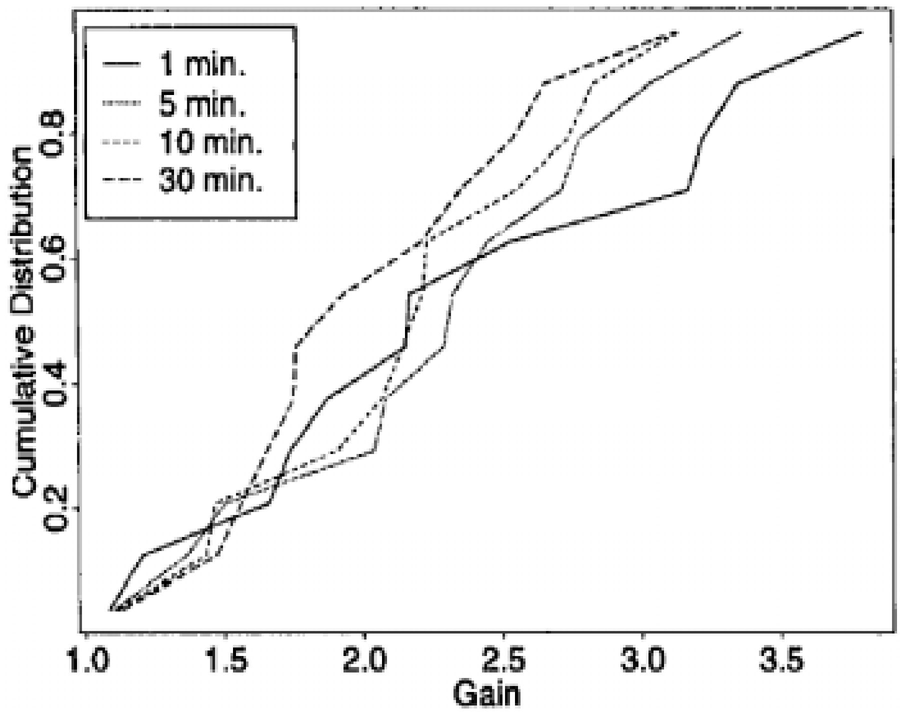


Figure 17: HOSE GAIN FOR EFFECTIVE BANDWIDTH ON ACCESS LINKS FOR DATA TRAFFIC: CDF (over access links) of ratio of maximum pipe requirement to maximum hose requirement, according to renegotiation interval.

Effective Bandwidths for Admission Control

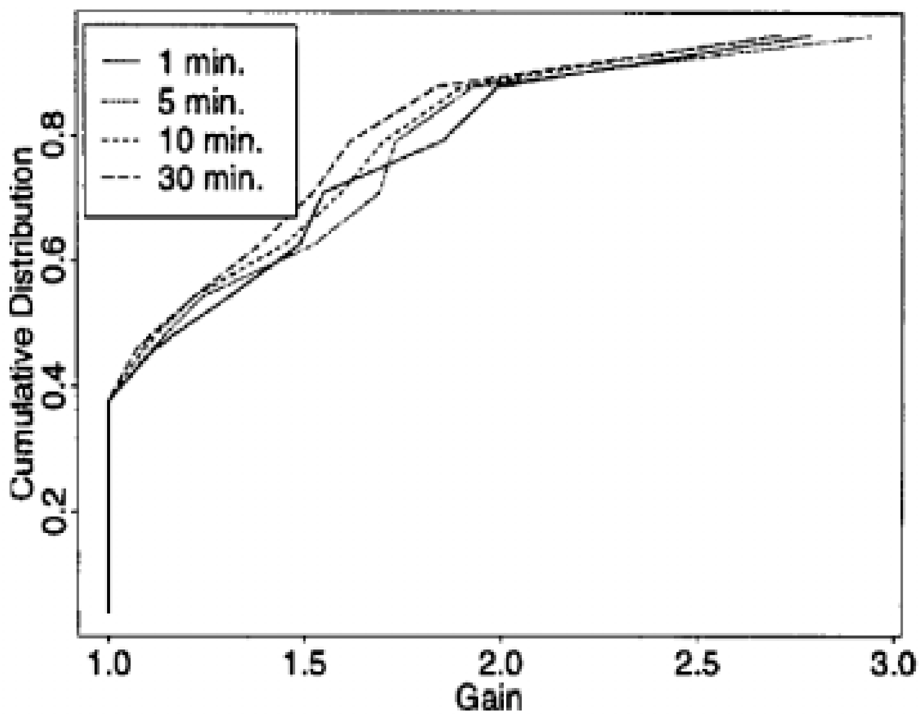


Figure 18: HOSE GAIN FOR EFFECTIVE BANDWIDTH ON INTERNAL LINKS FOR DATA TRAFFIC: CDF (over internal links) of ratio of maximum pipe requirement to maximum hose requirement, according to renegotiation interval.

Effective Bandwidths for Admission Control

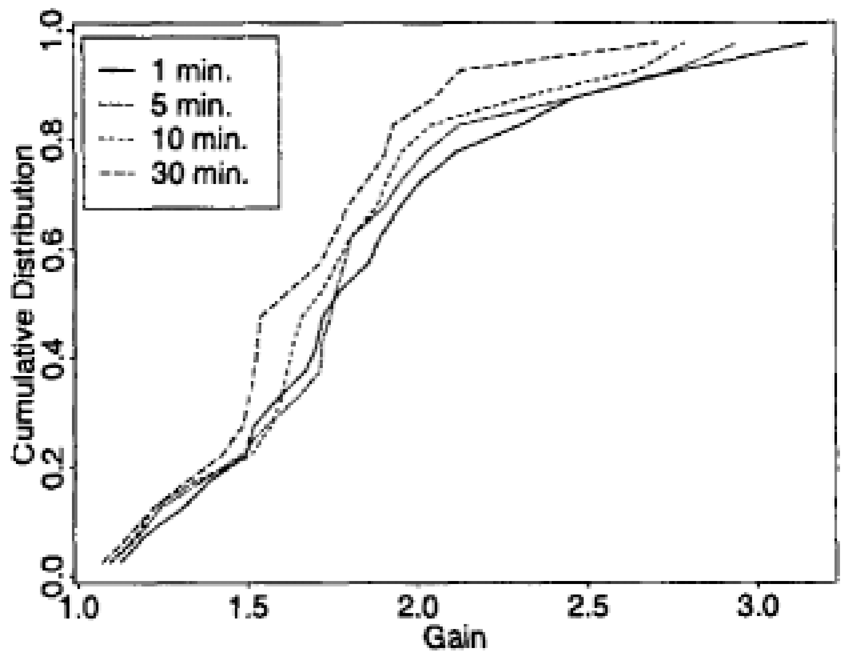


Figure 19: VPN Gain for Effective Bandwidth on Internal Links for Data Traffic: CDF (over internal links) of ratio of maximum pipe requirement to maximum VPN requirement, according to renegotiation interval.

Conclusion

VPNs are undergoing dramatic change owing to at least three interrelated factors:

- Rapid progress in IP network technologies (in overall capacity and the development of diverse network access technologies)
- Progress in IP security (in flexible, dynamic methods for establishing secure associations)
- Rapid change in the diversity and dynamics of communication and collaboration patterns at work and at home

Conclusion (cont.)

- A hose is characterized by the aggregate traffic to and from one endpoint in the VPN to the set of other endpoints in the VPN and by an associated performance guarantee.
- A hose allows a customer to simply buy a logical access link and use it to send traffic to any one of the remote hose endpoints with reliable QoS and with the rates of the customer access links to the only limitation.
- Hoses naturally allow the customer to take advantage of aggregation of the flows to and from access links, reducing required access link capacities.
- Hoses present greater resource management challenges for the provider but it can be addressed by statistical multiplexing or resizing techniques, applied separately or in combination.

Questions?