Aggregation for Measurement Efficiency in the ENABLE Service

Karthik Balasubramanian

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Committee:

Dr.Joseph B. Evans (Chair)

Dr.Victor Frost

Dr.Arvin Agah

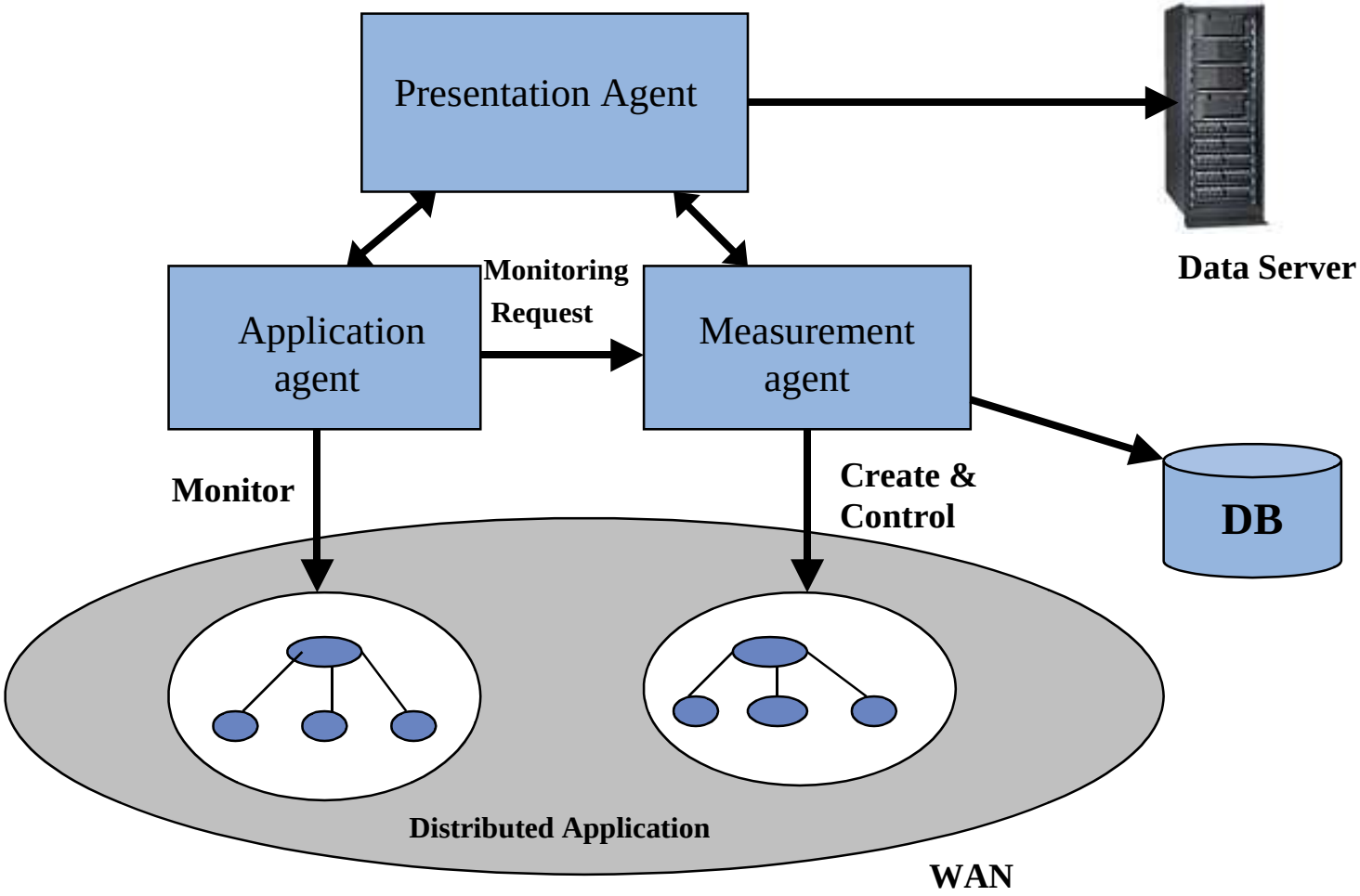
Overview

- Introduction
- ENABLE Architecture
- Scalability Issues in the ENABLE Service
- Aggregation Schemes Implemented
- Results and Evaluation
- Summary & Future Work

Introduction

- Ever-growing increase in the size of networks and speed of the Internet backbone
- Need for networks to function well
- Distributed applications unable to take advantage of high-speed networks
- The Focus: To implement a network monitoring infrastructure to improve the performance of distributed applications

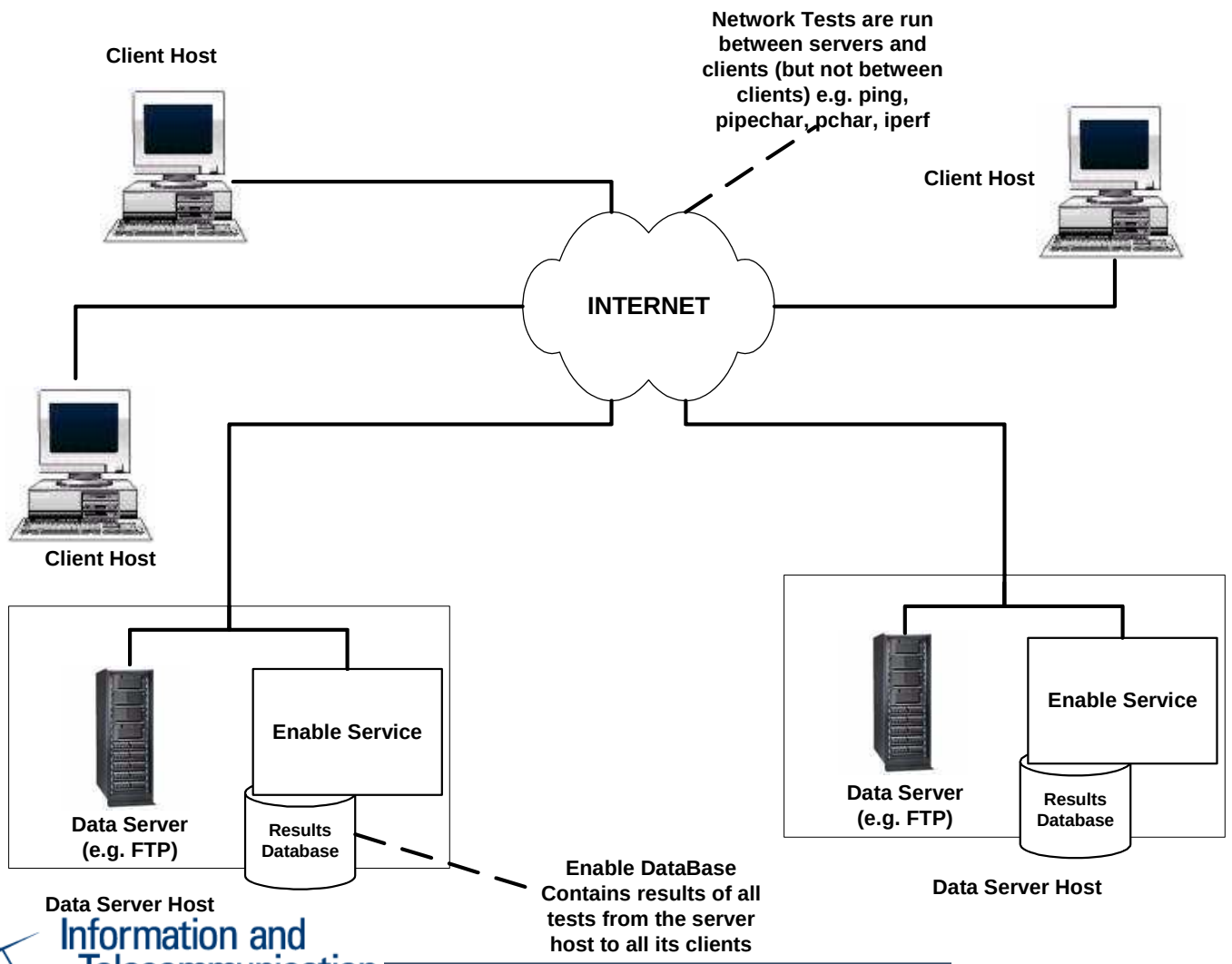
Monitoring Infrastructure



What is ENABLE ?

- Enhancing of Network-Aware Applications and BottLeneck Elimination
- Why “ENABLE” ?
  - Enables clients to achieve much higher throughput from a data server
- What does “Network-Aware” mean ?
  - Applications that adjust their resource demands in response to changes in resource availability

ENABLE Architecture



Scalability Issues in the ENABLE Service

- To time out clients from the database if the server does not get a connection from a client for a particular period of time
- Controlling the tests frequency
- To reduce the amount of redundant testing between the server and client hosts
  - A single Pipechar test uses approx. 100 Kbits/sec
- To define Aggregation techniques

Pipechar

- Simple, user-level tool
- Probes the network to find out a bottleneck link
- “Sender-only” network probing program
- Reports Bandwidth and RTT information
- Reports two kinds of Bandwidth metrics
  - Capacity of the link
  - Available Bandwidth

```
raphael [12] % pipechar -l www-didc.lbl.gov
0: localhost [10 hops]
 1: NoNameNode                          (10.10.127.254)   1.11  -0.09   3.67ms
 2: ks-2-a10-52.r.greatplains.net       (164.113.234.206) 1.21   1.70   8.66ms
 3: ks-2-abilene-ks.r.greatplains.net   (164.113.238.193) 1.15   1.31   9.02ms
 4: dnvr-kscy.abilene.ucaid.edu         (198.32.8.13)     1.06   0.99  21.25ms
 5: snva-dnvr.abilene.ucaid.edu         (198.32.8.1)      1.04   1.04  43.51ms
 6: esnet-snva.abilene.ucaid.edu        (198.32.11.94)    9.30 -10.92  85.29ms
 7: lbl-snv-oc48.es.net                 (134.55.209.6)    1.01   3.83  87.17ms
 8: lbnl-ge-lbl2.es.net                 (198.129.224.1)   1.05  -9.47  85.10ms
 9: ir1000gw.lbl.gov                    (131.243.128.210) 1.42  -3.53  54.75ms
10: george.lbl.gov                      (131.243.2.12)    1.23  -0.78  50.24ms

PipeCharacter statistics: 91.36% reliable
From localhost:
|       64.865 Mbps  100BT (97.0672 Mbps)

1: NoNameNode                       (10.10.127.254)
|
|       58.451 Mbps    !!! ??? congested bottleneck <40.3480% BW used>
2: ks-2-a10-52.r.greatplains.net    (164.113.234.206)
|
|       61.276 Mbps    !!! ??? congested bottleneck <59.7124% BW used>
3: ks-2-abilene-ks.r.greatplains.net(164.113.238.193)
|
|       66.632 Mbps    !!! ??? congested bottleneck <56.2190% BW used>
4: dnvr-kscy.abilene.ucaid.edu      (198.32.8.13 )
|
|       147.294 Mbps             <2.0733% BW used>
*******************************************************************************
5: snva-dnvr.abilene.ucaid.edu      (198.32.8.1  )
|
|       6.377 Mbps    !!! ??? congested bottleneck <95.8395% BW used>
6: esnet-snva.abilene.ucaid.edu     (198.32.11.94)
*******************************************************************************
|
|       151.314 Mbps    !!!      <90.9448% BW used>
7: lbl-snv-oc48.es.net              (134.55.209.6)
|
|       153.667 Mbps             <4.0800% BW used>
8: lbnl-ge-lbl2.es.net              (198.129.224.1)
|
|       49.778 Mbps    !!! ??? congested bottleneck <67.2414% BW used>
9: ir1000gw.lbl.gov                 (131.243.128.210)
|       58.727 Mbps  100BT (96.4499 Mbps)

10: george.lbl.gov                   (131.243.2.12)
```

Looking Glass Server

- Gives routing information with regard to network prefixes in question
- Useful in resolving Internet operational problems like connectivity and routing
- Deployed by a network-provider
- Provides a subset of common router commands
- Publicly accessible

Aggregation Schemes Implemented

- Aggregation based on Subnet Information
- Aggregation based on AS Number and Traceroute Information
- Aggregation based on AS Number and Ping Statistics

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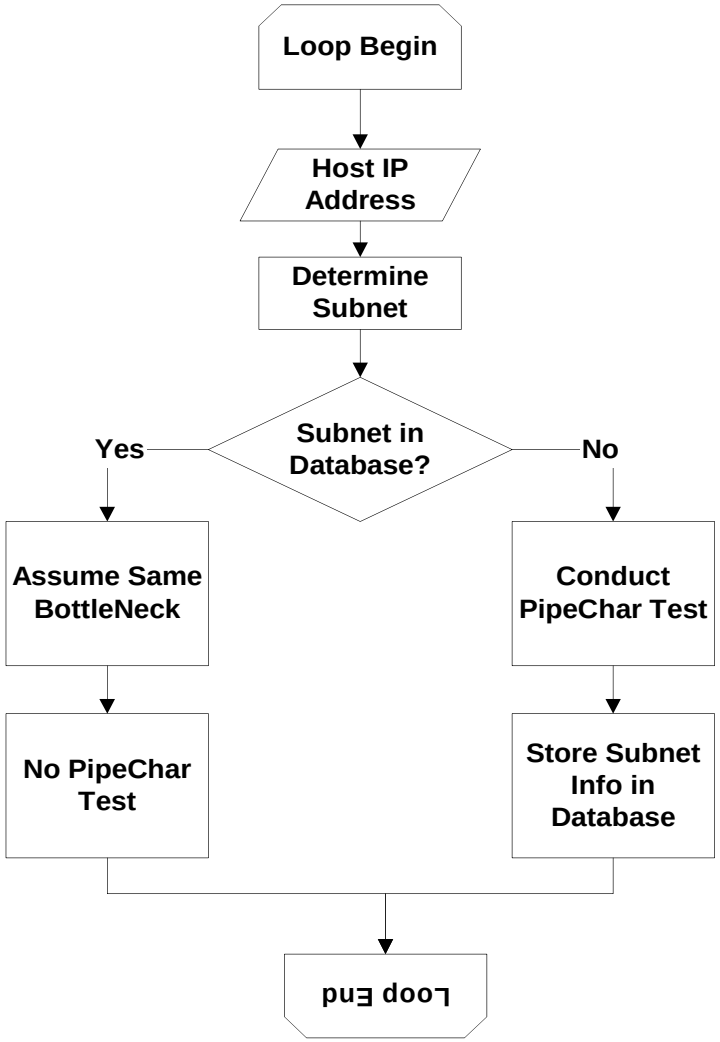
Aggregation Based on Subnet Information

- Simplest of the 3 schemes proposed
- IP Addresses of client hosts are stored in a configuration file
- Subnet found using Looking Glass Server

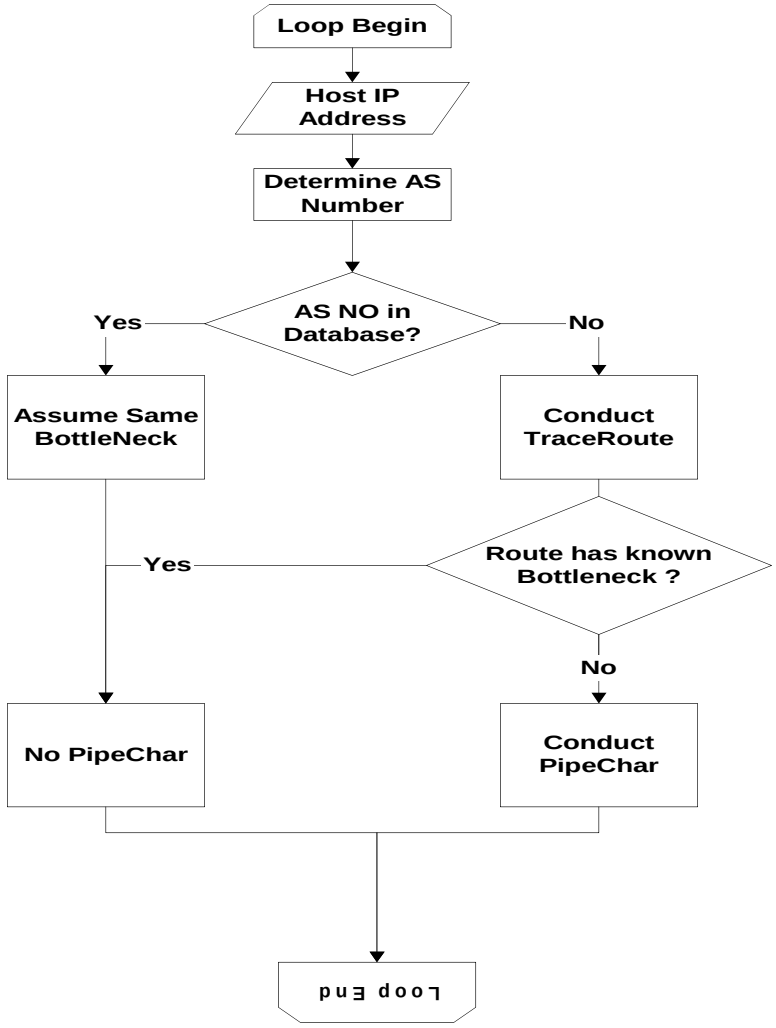


Aggregation Schemes Implemented

- Aggregation based on Subnet Information
- Aggregation based on AS Number and Traceroute Information
- Aggregation based on AS Number and Ping Statistics

Aggregation based on AS Number and Traceroute Information

- AS Number found using Looking Glass Server
- Traceroute test conducted
- Database contains already existing bottlenecks



Aggregation Schemes Implemented

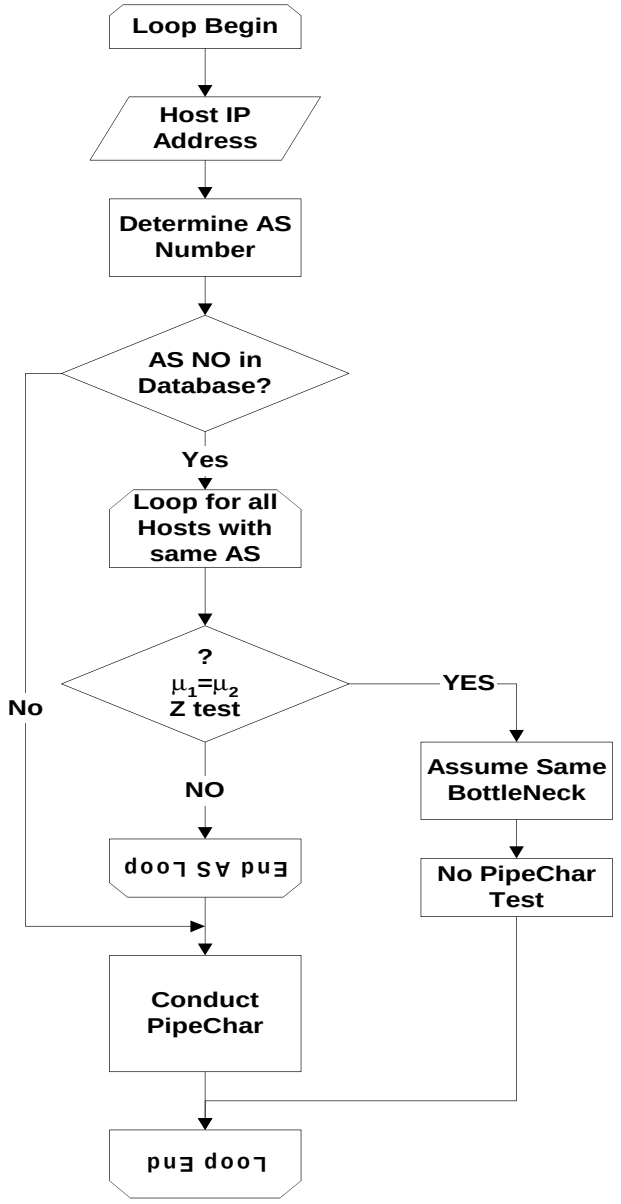
- Aggregation based on Subnet Information
- Aggregation based on AS Number and Traceroute Information
- Aggregation based on AS Number and Ping Statistics

Aggregation Based on AS Number and Ping Statistics

Hypothesis Testing Procedure: Z Test

- No. of pings conducted for host 1 and host 2 = 100
- **Ping Times:** Host 1 = X_1 to X_{100} & Host 2 Y_1 to Y_{100}
- X and Y samples are independent of one another
- Ping times are assumed to be of normal distribution
- Null Hypothesis: $H_0 : \mu_1 - \mu_2 = \Delta_0$
- μ_i: Mean Ping time of host i (i = 1,2)
- Δ_0 : Null value of the difference in population means
- $\Delta_0 = 0$, Hence null hypothesis becomes: $\mu_1 = \mu_2$
- Hypotheses are: $H_0 : \mu_1 - \mu_2 = 0$

$$H_a : \mu_1 - \mu_2 \neq 0$$



Aggregation Based on AS Number and Ping Statistics

- Motivation for choice of a Test statistic
  - To decide between H_0 and H_a
- Test statistic

$$Z = \frac{\mu_1 - \mu_2}{\sqrt{\frac{\sigma_1^2}{m} + \frac{\sigma_2^2}{n}}}$$

- Define $\alpha = 0.01$
  - Type 1 error probability
- Type 1 error probability
  - Rejecting H_0 when H_0 is true

- Compute $Z_{\alpha/2} = 2.57$
- If $Z < Z_{\alpha/2}$, then H_0 is accepted
  - Mean Ping times of the 2 hosts are equal
- If $Z >= Z_{\alpha/2}$, then H_0 is rejected
  - Mean Ping times of the 2 hosts are NOT equal

Testing Environment

- Tested in an environment similar to the ENABLE service
- Run from 2 different hosts:
  - Host at EDC (Eros Data Center) – 192.41.204.5
  - Host at ITTC – 129.237.126.172
- IP addresses of client hosts stored in a config file

Results and Evaluation

- Results - Based on Subnet scheme
- Results - Based on AS Number & Traceroute scheme
- Results - Based on AS Number & Ping Statistics scheme

Results of Test 1 (EDC Host) & Validation

IP Address	Subnet	Pipechar Test Required?
198.133.219.125	198.133.219.0/24	Yes
66.218.71.83	66.218.64.0/20	Yes
66.218.71.77	66.218.64.0/20	No
198.133.219.25	198.133.219.0/24	No
192.150.14.120	192.150.14.0/24	Yes
66.218.71.81	66.218.64.0/20	No
194.183.224.106	194.183.224.0/19	Yes
192.150.14.110	192.150.14.0/24	No
204.202.132.15	204.202.128.0/19	Yes
194.183.224.114	194.183.224.0/19	No
66.218.71.87	66.218.64.0/20	No
192.150.14.104	192.150.14.0/24	No
204.202.132.25	204.202.128.0/19	No
194.183.224.110	194.183.224.0/19	No

Client IP Address	Congested Bottleneck
198.133.219.125	Hops 3 through 15 equally congested
198.133.219.25	
66.218.71.79	Hops 3 through 16 equally congested
66.218.71.81	
66.218.71.83	
66.218.71.87	
192.150.14.104	gbr5-p51.cgcil.ip.att.net (12.123.4.234)
	gbr3-p100.cgcil.ip.att.net (12.122.5.2)
192.150.14.110	gbr5-p51.cgcil.ip.att.net (12.123.4.234)
	gbr3-p100.cgcil.ip.att.net (12.122.5.2)
192.150.14.120	gbr5-p51.cgcil.ip.att.net (12.123.4.234)
	tbr1-p013801.cgcil.ip.att.net (12.122.10.50)
204.202.132.15	Hops 3 through 15 equally congested
204.202.132.25	
194.183.224.106	Hops 3 through 15 equally congested
194.183.224.110	
194.183.224.114	

Results of Test 2 (ITTC Host) & Validation

IP Address	Subnet	Pipechar Test Required?
216.136.131.71	216.136.128.0/22	Yes
64.58.76.224	64.58.76.0/22	Yes
216.136.131.83	216.136.128.0/22	No
204.202.132.15	204.202.128.0/19	Yes
204.202.132.25	204.202.128.0/19	No
216.136.130.54	216.136.128.0/22	No
64.58.77.41	64.58.76.0/22	No
204.202.132.19	204.202.128.0/19	No

Client IP Address	Congested Bottleneck	
216.136.131.71	cust-int.level3.net	(64.152.81.62)
	ge-1-2-.msr2.sc5.yahoo.com	(216.115.101.230)
	Bandwidth = 31.162 Mbps	
216.136.131.83	cust-int.level3.net	(64.152.69.18)
	ge-0-2-0.msr2.sc5.yahoo.com	(216.115.100.237)
	Bandwidth = 33.628 Mbps	
216.136.130.54	cust-int.level3.net	(64.152.69.18)
	ge-0-2-0.msr2.sc5.yahoo.com	(216.115.100.237)
	Bandwidth = 35.112 Mbps	
64.58.77.41	bbr01-p6-0.stng01.exodus.net	(209.1.169.197)
	dcr03-g9-0.stng01.exodus.net	(216.33.96.145)
	Bandwidth = 33.441 Mbps	
64.58.76.224	bbr01-p6-0.stng01.exodus.net	(209.1.169.197)
	dcr03-g9-0.stng01.exodus.net	(216.33.96.145)
	Bandwidth = 35.579 Mbps	
204.202.132.15	ks-1-a400-51.r.greatplains.net	(164.113.232.202)
	ksca01-edge12.mo.inet.qwest.net	(65.120.164.237)
	Bandwidth = 36.724 Mbps	
204.202.132.25	ks-1-a400-51.r.greatplains.net	(164.113.232.202)
	ksca01-edge12.mo.inet.qwest.net	(65.120.164.237)
	Bandwidth = 39.856 Mbps	
204.202.132.19	ks-1-a400-51.r.greatplains.net	(164.113.232.202)
	ksca01-edge12.mo.inet.qwest.net	(65.120.164.237)
	Bandwidth = 35.222 Mbps	

Results and Evaluation

- Results - Based on Subnet scheme
- Results - Based on AS Number and Traceroute scheme
- Results - Based on AS Number and Ping Statistics scheme

Results of Traceroute Test

raphael [20] % perl Traceroute_scheme2.pl

IP address is 131.243.2.20
AS number is 16

IP address is 64.58.76.224
AS number is 17110

IP address is 140.173.170.11
AS number is 4

IP address is 131.243.2.14
AS number is 16

IP address is 131.243.2.28
AS number is 16

IP address is 64.124.237.130
AS number is 6461

IP address is 208.185.204.181
AS number is 14673

traceroute to 131.243.2.20 (131.243.2.20), 30 hops max, 38 byte packets
Known Bottleneck Found in Traceroute Path of 131.243.2.20

129.237.127.254
164.113.234.218
164.113.238.193
198.32.8.13
***198.32.8.1* Known Bottleneck**
***198.32.11.94* Known Bottleneck**
134.55.209.6
198.129.224.1
198.129.224.6
131.243.128.210

traceroute to 64.58.76.224 (64.58.76.224), 30 hops max, 38 byte packets

traceroute to 140.173.170.11 (140.173.170.11), 30 hops max, 38 byte packets
Known Bottleneck Found in Traceroute Path of 140.173.170.11

129.237.127.254
164.113.234.218
164.113.238.193
198.32.8.13
198.32.8.1
198.32.8.18
198.32.248.85 Known Bottleneck
198.32.16.33 Known Bottleneck
198.32.16.82
140.173.155.5
140.173.1.86

traceroute to 64.124.237.130 (64.124.237.130), 30 hops max, 38 byte packets

traceroute to 208.185.204.181 (208.185.204.181), 30 hops max, 38 byte packets

Results Based on AS Number and Traceroute Scheme

IP Address	AS Number	Pipechar Test Required ?
131.243.2.20	16	No
64.58.76.224	17110	Yes
140.173.170.11	4	No
131.243.2.14	16	No
131.243.2.28	16	No
64.124.237.130	6461	Yes
208.185.204.181	14673	Yes

Results Validation

- Pipechar tests conducted to verify actual bottlenecks

IP Addresses	Bottleneck Links
131.243.2.20	snva-dnvr.abilene.ucaid.edu (198.32.8.1) esnet-snva.abilene.ucaid.edu (198.32.11.94) Bandwidth = 20.5 Mbps
64.58.76.224	bbr01-p6-0.stng01.exodus.net (209.1.169.197) dcr03-g9-0.stng01.exodus.net (216.33.96.145) Bandwidth = 35.6 Mbps
140.173.170.11	USC--abilene.ATM.calren2.net (198.32.248.85) guest-b4.isi.edu (198.32.16.33) Bandwidth = 51.7 Mbps
131.243.2.14	snva-dnvr.abilene.ucaid.edu (198.32.8.1) esnet-snva.abilene.ucaid.edu (198.32.11.94) Bandwidth = 38 Mbps
131.243.2.28	snva-dnvr.abilene.ucaid.edu (198.32.8.1) esnet-snva.abilene.ucaid.edu (198.32.11.94) Bandwidth = 34.5 Mbps
64.124.237.130	iah-core-02.inet.qwest.net (205.171.8.126) iah-core-01.inet.qwest.net (205.171.31.1) Bandwidth = 29.5 Mbps
208.185.204.181	svl-brdr-01.inet.qwest.net (205.171.14.106) pos4-1.cr7.sjc2.us.mfnx.net (208.185.175.73) Bandwidth = 33.4 Mbps

Results and Evaluation

- Results - Based on Subnet scheme
- Results - Based on AS Number and Traceroute scheme
- Results - Based on AS Number and Ping Statistics scheme

Results of Ping Stats. Test 1 - ITTC Host

	Test 1 : ITTC Host	$Z_{\alpha/2} = 2.57$
Z Factor	192.65.185.145 & 192.65.185.2 is 0.79	
	192.65.185.33 & 192.65.185.2 is 1.48	
	194.25.7.252 & 192.65.185.2 is 4.14	
	192.65.185.40 & 192.65.185.2 is 1.65	

	Test 1 (a) ITTC Host .. Different Time	Test 1 (b) ITTC Host .. Different Day
Z Factor	192.65.185.145 & 192.65.185.2 is 0.99	192.65.185.145 & 192.65.185.2 is 0.74
	192.65.185.33 & 192.65.185.2 is 1.91	192.65.185.33 & 192.65.185.2 is 1.77
	194.25.7.252 & 192.65.185.2 is 8.76	194.25.7.252 & 192.65.185.2 is 10.97
	192.65.185.40 & 192.65.185.2 is 1.97	192.65.185.40 & 192.65.185.2 is 1.43

Results Based on AS Number and Ping Statistics

IP Address	AS Number	Pipechar Test Required?
192.65.185.2	3320	Yes
192.65.185.145	3320	No
192.65.185.33	3320	No
194.25.7.252	3320	Yes
192.65.185.40	3320	No

Results Validation

- Pipechar tests conducted to verify actual bottlenecks
- Script was run at different times and on different days
- Results consistent

Client (IP address)	AS number	Bottleneck Link
192.65.185.2	3320	ks-2-abilene-ks.r.greatplains.net(164.113.238.193) ipls-kscy.abilene.ucaid.edu (198.32.8.6) Bandwidth = 71.6 Mbps
192.65.185.145	3320	ks-2-abilene-ks.r.greatplains.net(164.113.238.193) ipls-kscy.abilene.ucaid.edu (198.32.8.6) Bandwidth = 71.8 Mbps
192.65.185.33	3320	ks-2-abilene-ks.r.greatplains.net(164.113.238.193) ipls-kscy.abilene.ucaid.edu (198.32.8.6) Bandwidth = 58 Mbps
194.25.7.252	3320	Traceroute path differs altogether
192.65.185.40	3320	ks-2-abilene-ks.r.greatplains.net(164.113.238.193) ipls-kscy.abilene.ucaid.edu (198.32.8.6) Bandwidth = 78.8 Mbps

Results of Ping Stats. Test 2 - ITTC Host

	Test 2 : ITTC Host	$Z_{\alpha/2} = 2.57$
Z Factor	216.136.226.6 & 216.136.131.71 is 5.69	
	216.136.129.1 & 216.136.131.71 is 3.43	
	216.136.129.1 & 216.136.226.6 is 1.01	
	216.136.130.54 & 216.136.131.71 is 2.49	
	Test 2 (a) ITTC Host .. Different Time	**Test 2 (b) ITTC Host .. Different Day**
Z Factor	216.136.226.6 & 216.136.131.71 is 6.24	216.136.226.6 & 216.136.131.71 is 6.89
	216.136.129.1 & 216.136.131.71 is 2.41	216.136.129.1 & 216.136.131.71 is 2.53
	216.136.130.54 & 216.136.131.71 is 0.14	216.136.130.54 & 216.136.131.71 is 0.47
	Results Based on AS Number and Ping Statistics	

IP Address	AS Number	Pipechar Test Required?
216.136.131.71	10310	Yes
216.136.226.6	10310	Yes
216.136.129.1	10310	No
64.58.77.41	17110	Yes
216.136.130.54	10310	No

Results Validation

- Pipechar tests conducted to verify actual bottlenecks
- Inconsistent with algorithm decision for host 216.136.226.6
- 64.58.77.41 being in different AS Number, the bottleneck was different

Client (IP address)	AS number	Bottleneck Link	
216.136.131.71	10310	cust-int.level3.net	(64.152.81.62)
		ge-1-2-0.msr2.sc5.yahoo.com	(216.115.101.230)
		Bandwidth = 31.2 Mbps	
216.136.226.6	10310	cust-int.level3.net	(64.152.69.18)
		ge-1-2-0.msr1.sc5.yahoo.com	(216.115.101.234)
		Bandwidth = 36.5 Mbps	
216.136.129.1	10310	cust-int.level3.net	(64.152.69.18)
		ge-0-2-0.msr2.sc5.yahoo.com	(216.115.101.234)
		Bandwidth = 34.3 Mbps	
64.58.77.41	17110	bbr01-p6-0.stng01.exodus.net	(209.1.169.197)
		dcr03-g9-0.stng01.exodus.net	(216.33.96.145)
		Bandwidth = 33.4 Mbps	
216.136.130.54	10310	cust-int.level3.net	(64.152.69.18)
		ge-0-2-0.msr2.sc5.yahoo.com	(216.115.100.237)
		Bandwidth = 35.1 Mbps	

Results of Ping Stats. Test 3 - EDC Host

$Z_{\alpha/2} = 2.57$

	Test 3 : EDC Host		
Z Factor	64.14.118.212 & 209.1.169.197 is 0.22		
	216.34.183.97 & 209.1.169.197 is 80.99		
	216.35.210.126 & 209.1.169.197 is 1.45		
	Results Based on AS Number and Ping Statistics		
	IP Address	**AS Number**	**Pipechar Test Required?**
	209.1.169.197	3967	Yes
	64.14.118.212	3967	No
	216.34.183.97	3967	Yes
	216.35.210.126	3967	No

Results Validation

- Pipechar tests conducted to verify actual bottlenecks
- No distinct bottleneck
- Hops 3 through 13 equally congested for all hosts
- Inconsistent with algorithm decision for 216.34.183.97

```
3: NoNameNode                    (152.61.100.40)
|
|     11.974 Mbps    !!! ??? congested bottleneck <73.1589% BW used>
4: 66-128-169-21.du.sdnet.net      (66.128.169.21)
|
|     12.555 Mbps    !!! ??? congested bottleneck <71.7115% BW used>
5: border2-fe0-0.siouxfalls.sdnet.net(63.65.236.3 )
|
|     12.699 Mbps    !!! ??? congested bottleneck <71.1348% BW used>
6: Serial2-7.GW7.MSP1.ALTER.NET    (157.130.105.33)
|
|     12.491 Mbps    !!! ??? congested bottleneck <70.7816% BW used>
7: 113.at-2-0-0.CL2.MSP1.ALTER.NET (152.63.69.102)
|
|     11.903 Mbps    !!! ??? congested bottleneck <72.9775% BW used>
8: 0.so-1-1-0.XL2.CHI2.ALTER.NET   (146.188.136.58)
|
|     12.884 Mbps    !!! ??? congested bottleneck <70.3319% BW used>
9: 0.so-7-1-0.BR6.CHI2.ALTER.NET   (152.63.71.98)
|
|     13.250 Mbps    !!! ??? congested bottleneck <69.6797% BW used>
10: bpr1-so-6-0-0-0.ChicagoEquinix.cw.net(208.174.226.1)
|
|     12.319 Mbps    !!! ??? congested bottleneck <71.4030% BW used>
11: agr1-loopback.Chicago.cw.net    (208.172.2.101)
|
|     12.339 Mbps    !!! ??? congested bottleneck <71.8607% BW used>
12: dcr1-so-6-0-0.Chicago.cw.net    (208.175.10.49)
|
|     12.391 Mbps    !!! ??? congested bottleneck <71.4642% BW used>
13: ibr02-p6-0.okbr01.exodus.net    (208.175.10.82)
```

Performance Comparison

- Trade-off between precision and scalability
- Aggregation based on Subnet information
  - Simple method of aggregation
  - Useful for hosts that belong to internal networks
  - Extent of aggregation is limited
- Aggregation based on AS number and Traceroute
  - Useful for hosts in the wide-area
  - Precise and highly scalable
- Aggregation based on AS number and Ping
  - Useful for hosts in the wide-area (particularly for hosts in the same AS)
  - Certain loss of Precision, but highly scalable

Summary

- Aggregation Techniques proposed and implemented
  - Aggregation based on Subnet information
  - Aggregation based on AS number and Traceroute information
  - Aggregation based on AS number and Ping Statistics
- Redundant testing reduced
  - Not completely eliminated

Future Work

- Estimate the efficiency of each aggregation scheme
- Choice of Aggregation schemes to be determined
- Needs to be deployed in the actual ENABLE service

Questions ?

Q & A

- Z(alpha/2) formula ?
  - Alpha/2 is used because it's a two-tailed test ie, we r checking if the obtained Z value is greater than alpha/2 or less than (-alpha/2)
  - Alpha/2 = Q(Z)
  - Z = Q inverse (alpha/2)
  - Q(Z) = ½ erfc (Z/sqrt(2))
- Why r u doing this Z test ?
  - To check if the mean of the 2 populations are equal
- Why r u using a two-tailed test ?
  - To check for equality and unequality