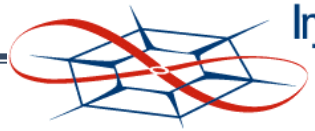
Scalable Emulation of IP networks through Virtualization

Amit Kucheria

Masters Thesis Defense
University of Kansas, Lawrence
May 9th 2003

Committee:
Dr. Douglas Niehaus (Chair)
Dr. Victor Frost
Dr. Jeremiah James



Information and Telecommunication Technology Center

Talk Content

- Introduction
- Virtual Network Framework
- Design of Virtual Network Elements
- Evaluation of Virtual networks
- Summary

Introduction – Problem

- Ubiquitous IP networks – Data, Video & Voice
- Need to study and test new protocols
- Large scale networks
- Current testing methods:
  - Simulation
  - Physical testing

Introduction – Existing methods

- Simulation
  - ns2, OPNET
  - Side-effects of OS interactions ignored
  - Management complexity ignored
  - Change in focus
- Physical Testing
  - Equipment/Infrastructure costs
  - Erroneous extrapolations of small tests

Introduction - Goals

- Design & Implement Network Emulation Framework to solve current problems
- Test with realistic network loads
  - Generated by real utilities (e.g. ttcp, ftp, telnet, etc.)
  - Synthesized loads through Netspec
- Compare results with results from physical network

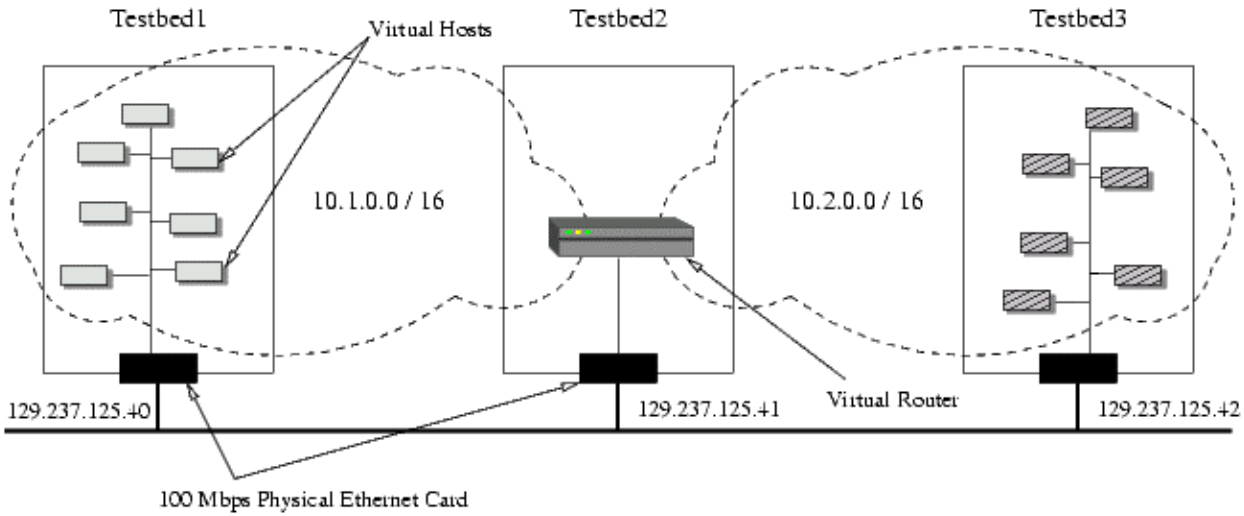
Introduction – Virtual Network Elements

- Definition:

  A virtual network element (VNE) is a software object that emulates the functions of network elements such as hosts and routers.

- Modules inserted into the Linux network protocol stack transparently
- New layer added to protocol processing sequence: *Virtual Network layer* (VNL)

Introduction - VNE



- Simple application of virtual network
- Virtual network traffic multiplexed over physical interface(s)
- VNL handles mux/demux

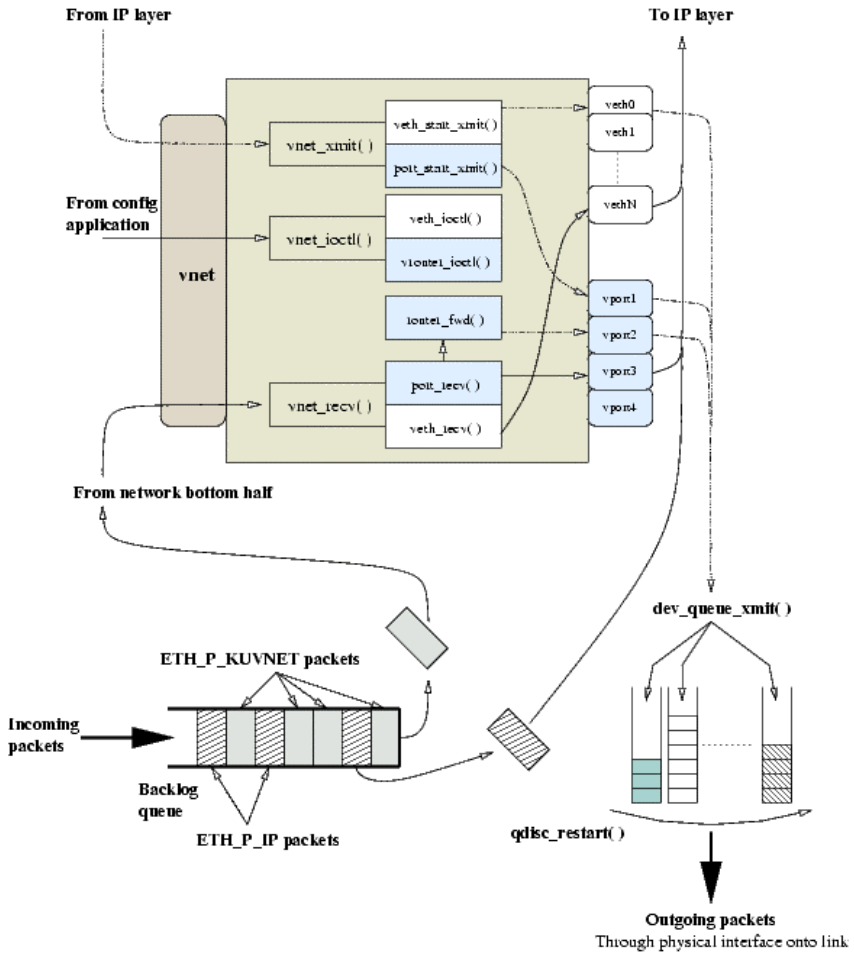
Virtual Network Framework (VNF)

- Three basic elements of a network: host, router & link
- Host and Router emulated by virtual host and virtual router code in VNL
- Virtual link implemented using link throttling techniques of Linux traffic control
- Σ throughput(virtual elements) $\leq \Sigma$ throughput(physical interfaces)

VNF: Design Considerations

- Socket-layer compatibility
- Creation/Deletion/Configuration
- Arbitrary mapping of virtual elements to physical hosts
- Virtual routing decisions
- Network emulation ability

VNF: Architecture

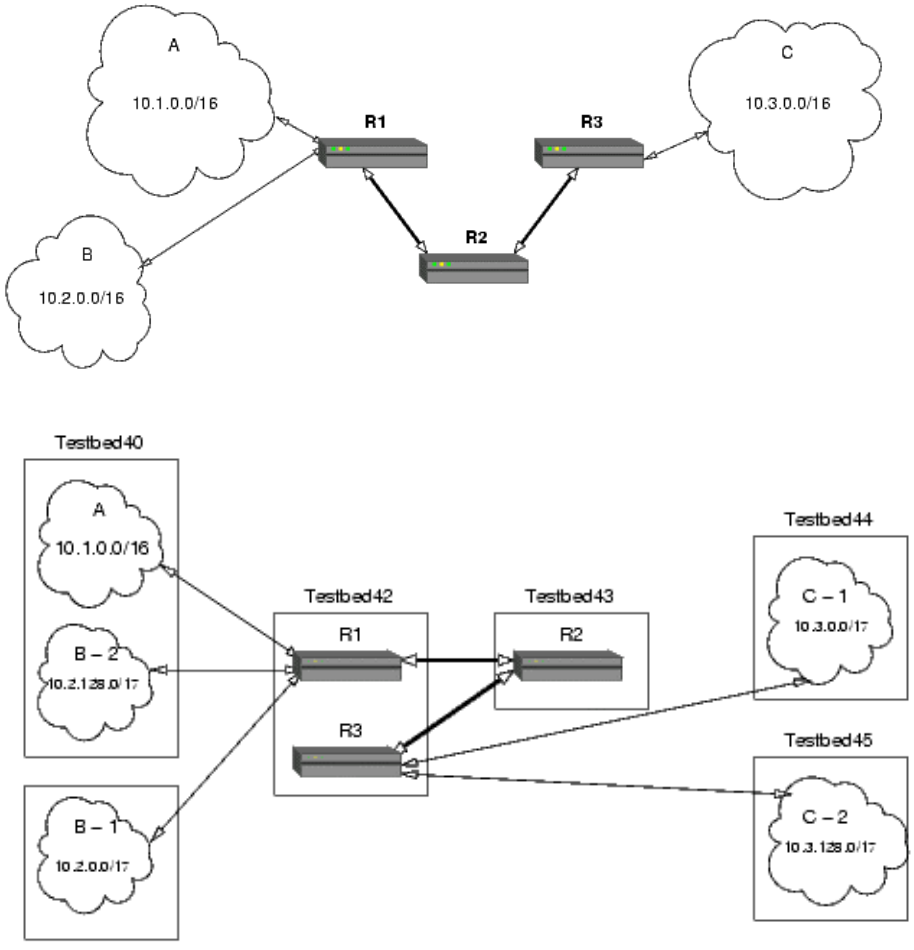


- Multiple virtual hosts and virtual routers share VNL
- ETH_P_KUVNET is the packet type
- Each of the virtual devices can have a queue attached

VNF: Capabilities

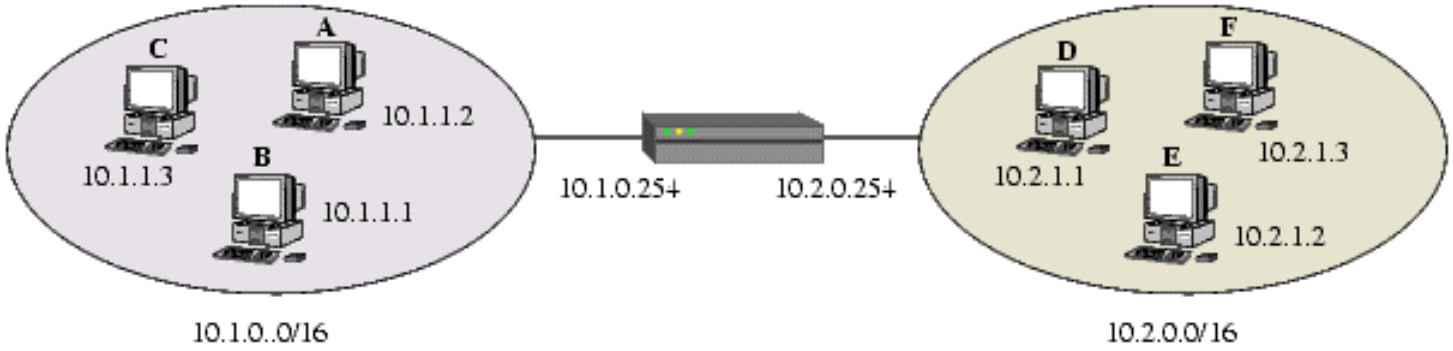
- Multi-homed (virtual) hosts
- Split subnets across physical machines
- Supports almost arbitrary mapping of virtual elements to physical hosts through *subnet maps*
- Subnet map identical to routing table
- VNL inserts a new header: VNET header between IP and MAC header

VNF: Capabilities: Split-subnet



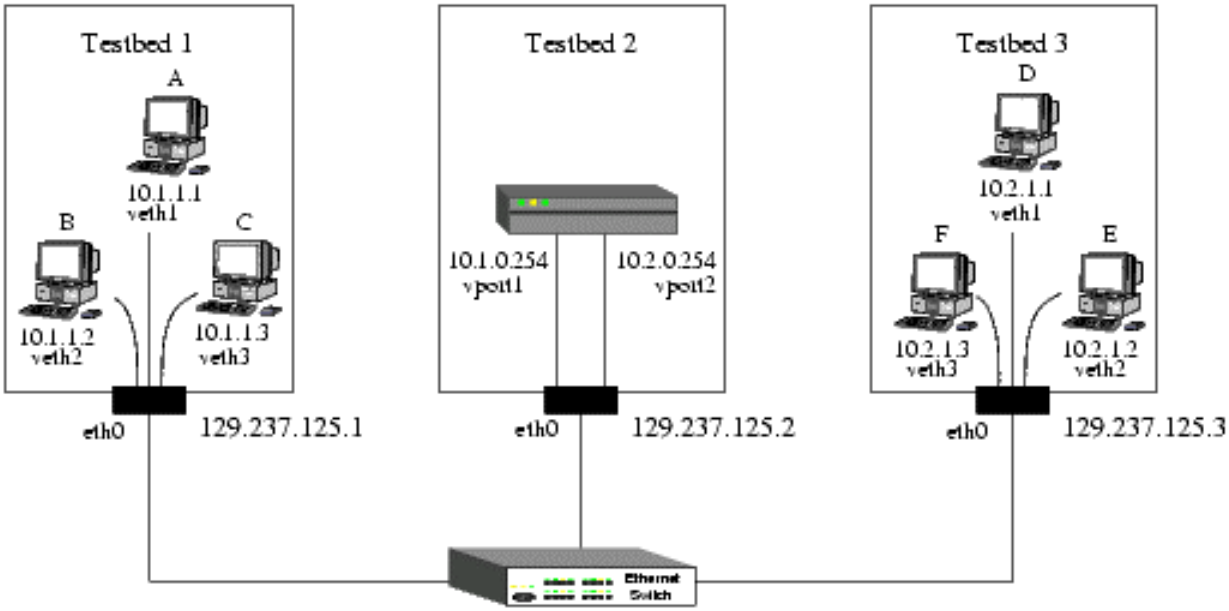
- Flexibility in placing VNEs on physical machines
- Load/Application /Characteristic-based mapping

VNF: Example



- Depicts virtualization based on network application
- Depicts working of *split-subnet* mapping
- A, D: Servers
- A $\leftrightarrow$ (E, F), D $\leftrightarrow$ (B, C)

VNF: Example (continued)



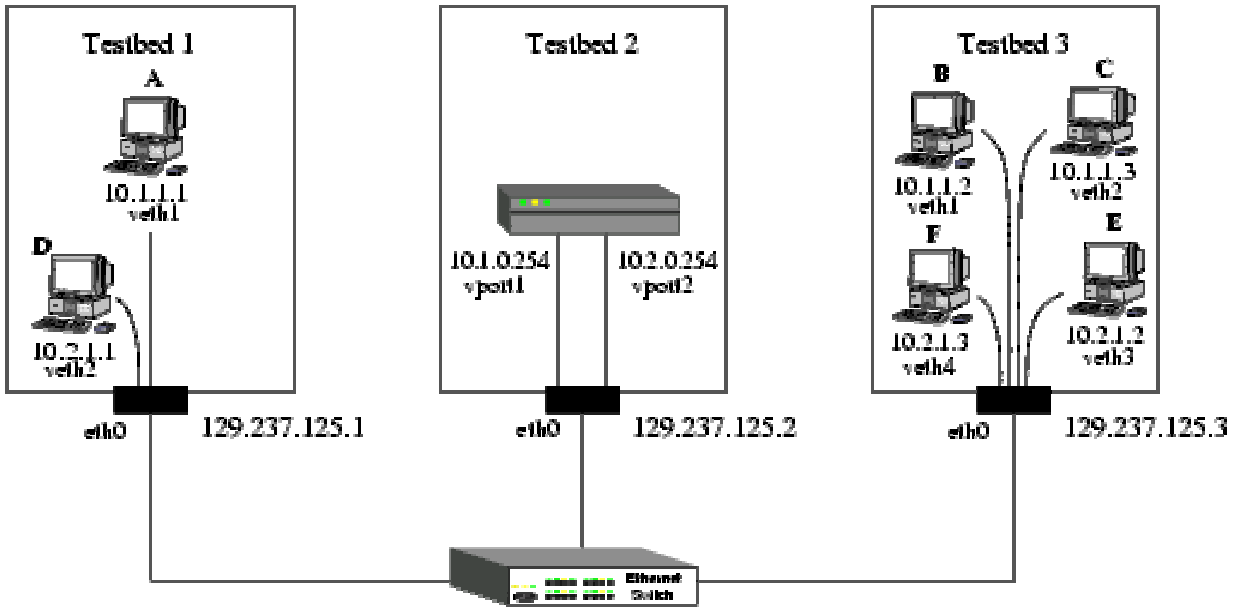
Virtual routing table of virtual host A

Destination	Gateway	Netmask	Flag	Interface
10.1.1.1	0.0.0.0	255.255.255.255	H	Veth1
10.1.0.0	0.0.0.0	255.255.255.0	U	Veth1
0.0.0.0	10.1.0.254	0.0.0.0	G	Veth1

Subnet map of virtual hosts

Destination	Gateway	Netmask	Flag	Interface
10.1.1.1	0.0.0.0	255.255.255.255	H	Veth1
10.1.0.0	129.237.125.1	255.255.0.0	U	Veth1
10.1.0.0	0.0.0.0	255.255.255.255	N	Veth1

VNF: Example (continued)



- Alternative mapping of VNE to physical machines

Design of Virtual Network Elements

- Implemented as Linux network device driver
- Configured through `ioctl()s`
- Netspec-based configuration
- Shows virtual interface statistics through tools such as `ifconfig`, `ip`, etc.
- Supports packet capture tools such as `tcpdump`

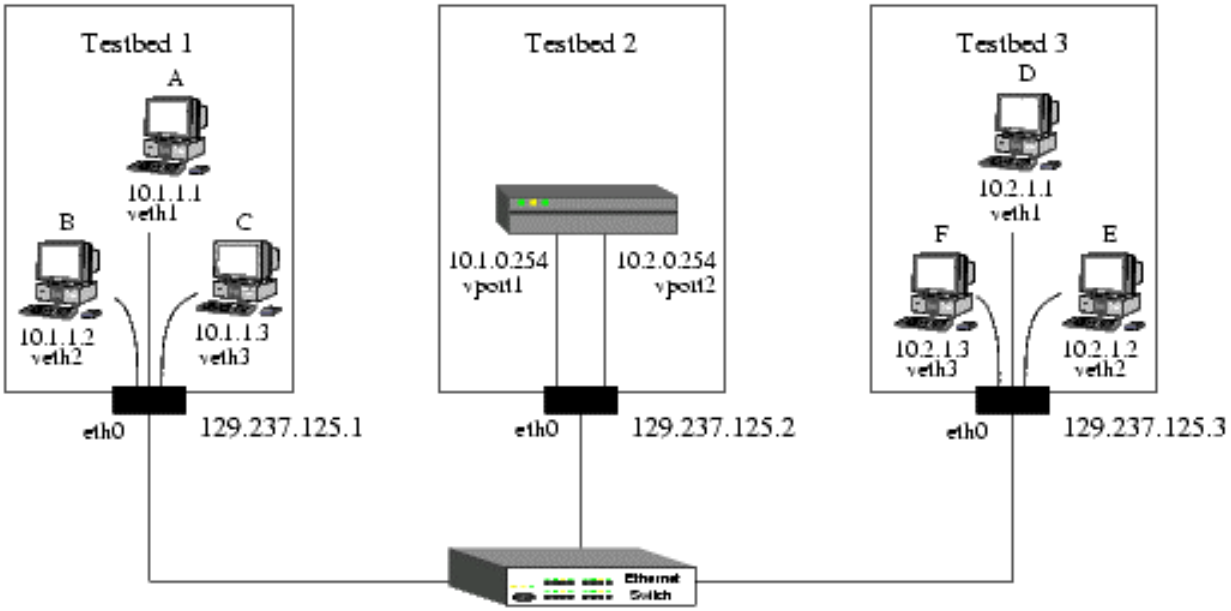
VNE design: Virtual Host

- Has an IP address
- Virtual routing table contains gateway entry
- Subnet map table contains location of virtual router emulating the gateway
- Acts as source or sink
- Socket applications bind to it

VNE: Virtual Router

- Each port has an IP address
- Virtual routing table contains entries to other routers or to subnets
- Subnet map table contains location of virtual router and subnets
- Only a gateway for the packets
- Socket applications typically don’t bind to it (exception: RSVP daemon)

VNF: Example (continued)



Virtual routing table of virtual router

Destination	Gateway	Netmask	Flag	Interface
10.1.0.254	0.0.0.0	255.255.255.255	H	Vport1
10.2.0.254	0.0.0.0	255.255.255.255	H	Vport2
10.1.0.0	129.237.125.1	255.255.0.0	N	Vport1
10.2.0.0	129.237.125.3	255.255.0.0	N	Vport1
10.2.0.0	0.0.0.0	255.255.0.0	N	Vport2

Subnet map of virtual router

Destination	Gateway	Netmask	Flag	Interface
10.1.0.254	0.0.0.0	255.255.255.255	H	Vport1
10.2.0.254	0.0.0.0	255.255.255.255	H	Vport2
10.1.0.0	129.237.125.1	255.255.0.0	N	Vport1
10.2.0.0	129.237.125.3	255.255.0.0	N	Vport1
10.2.0.0	0.0.0.0	255.255.0.0	N	Vport2

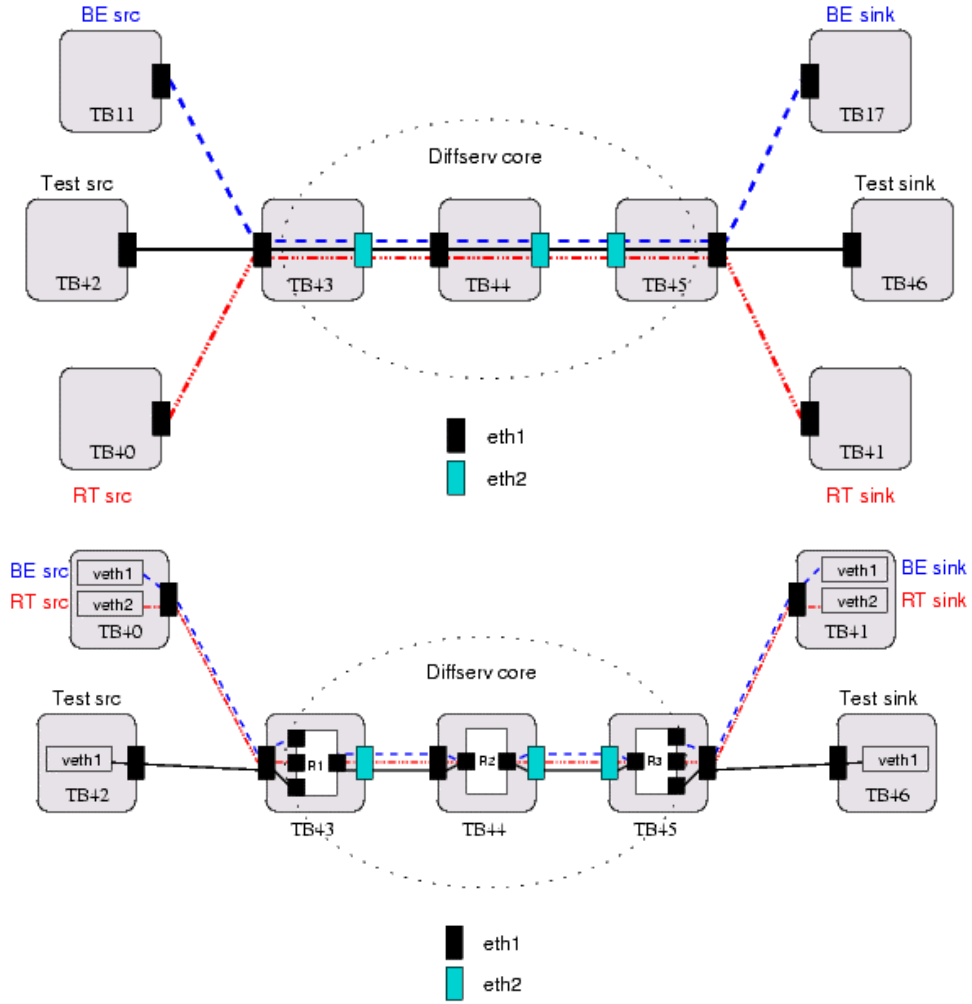
Evaluation of Virtual Networks

- Control plane of emulated network remains the same as physical network
  - Identical software
  - Identical signaling costs
- Need to confirm verity of data plane results
- Results of Physical tests vs. Emulation tests
- Diffserv and Intserv networks used for exercising VNF

Evaluation of Virtual Networks

- Diffserv relies on Linux traffic control(*tc*), hence works with VNE with minor modifications
- Intserv relies on *tc* and RSVP signaling, RSVP required some porting to understand virtual routing

Diffserv - Network Topology (9 elements)



- Link bandwidth – 100Mbps in access network & 10Mbps inside core
- Routers – Emulated on high speed Pentium III, 1GHz, 1GB RAM Linux systems

Diffserv - Network Topology (9 elements)

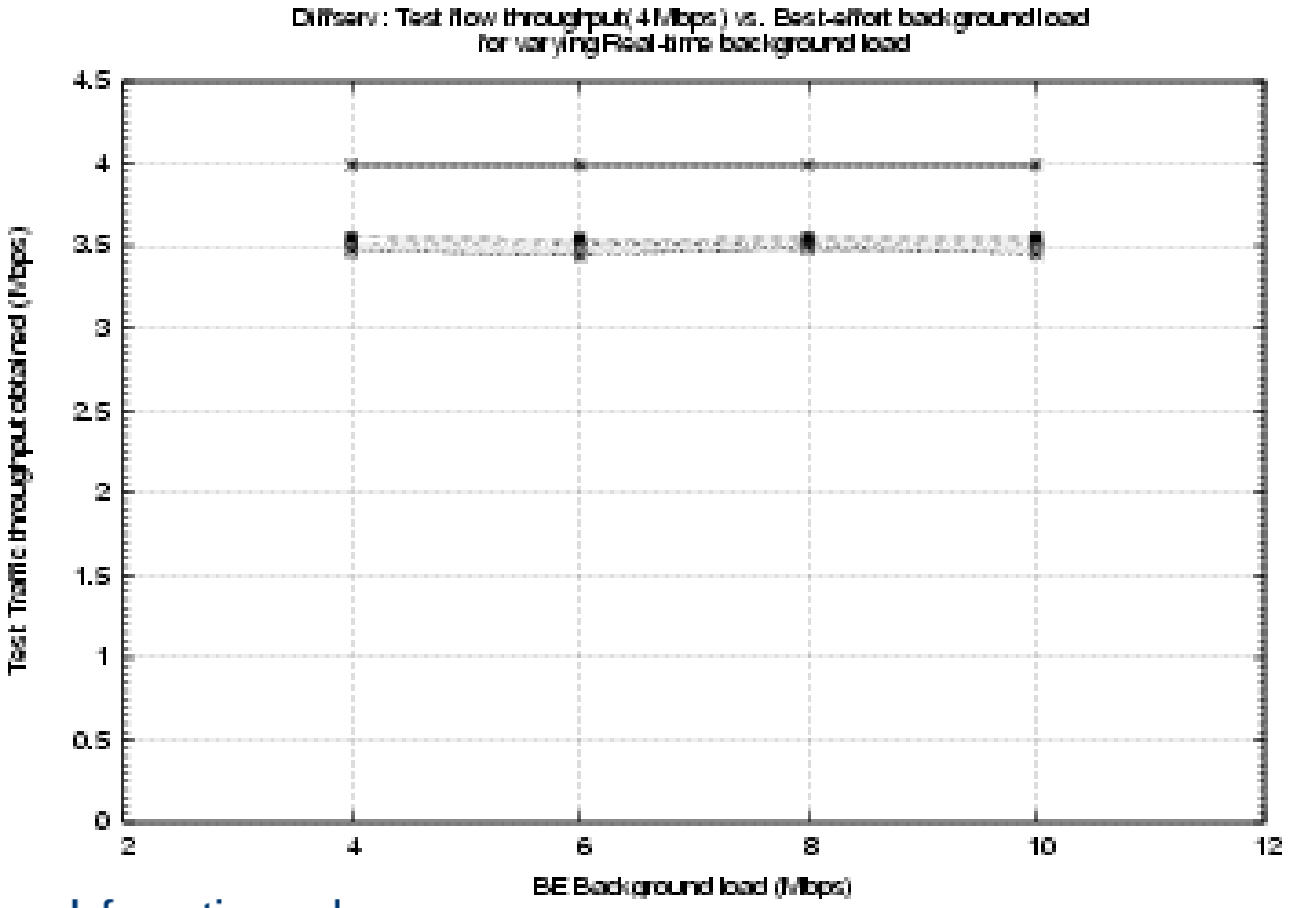
- Used to validate working of Diffserv
- Throughput of ‘Test’ stream measured in presence of background RT and BE load
- Netspec-generated CBR traffic using UTIME patches
- `tcpdump` output captured at source and sink, merged and diff’ed

Diffserv - Network Test parameters

Traffic	• BG-BE traffic = 4-10Mbps • BG-RT traffic = 0-10Mbps • Test CBR traffic = 4Mbps
Diffserv Parameters (core routers)	• Real time AF class = 6Mbps • Best Effort class = 4Mbps • HTB queuing discipline
Data Plane	• Throughput • Delay

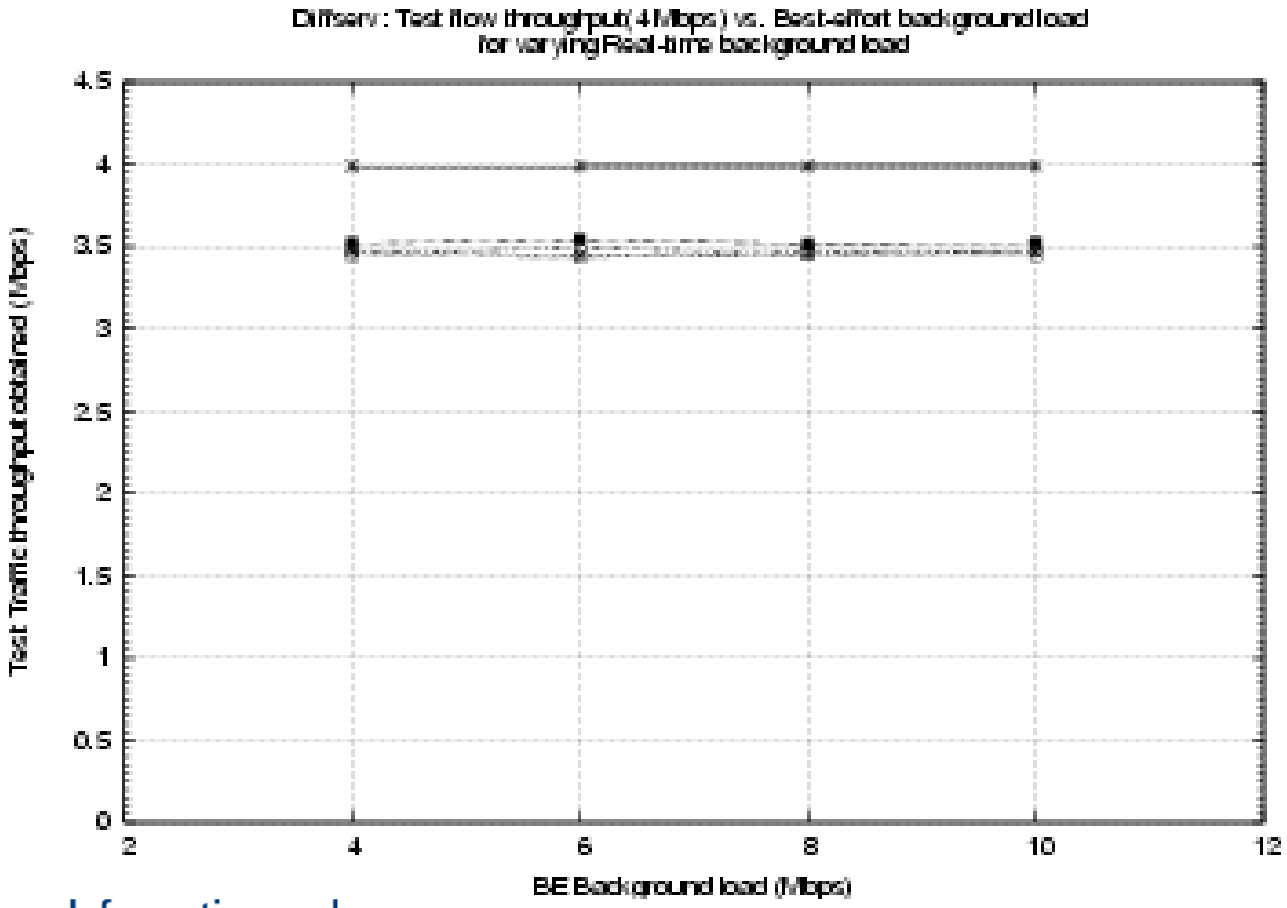
Diffserv – Throughput Comparison (9 elements)

Physical network results



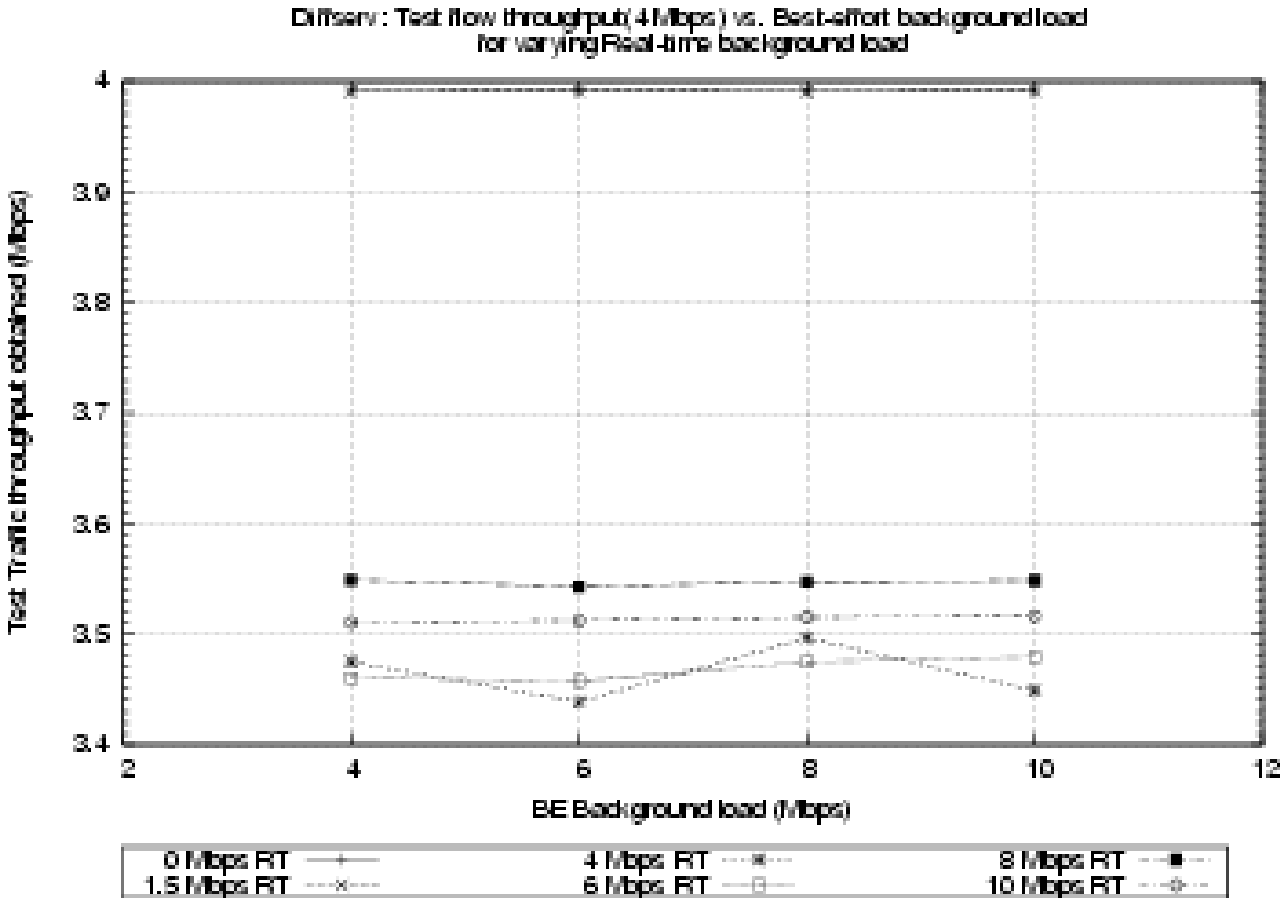
Diffserv – Throughput Comparison (9 elements)

Virtual network results



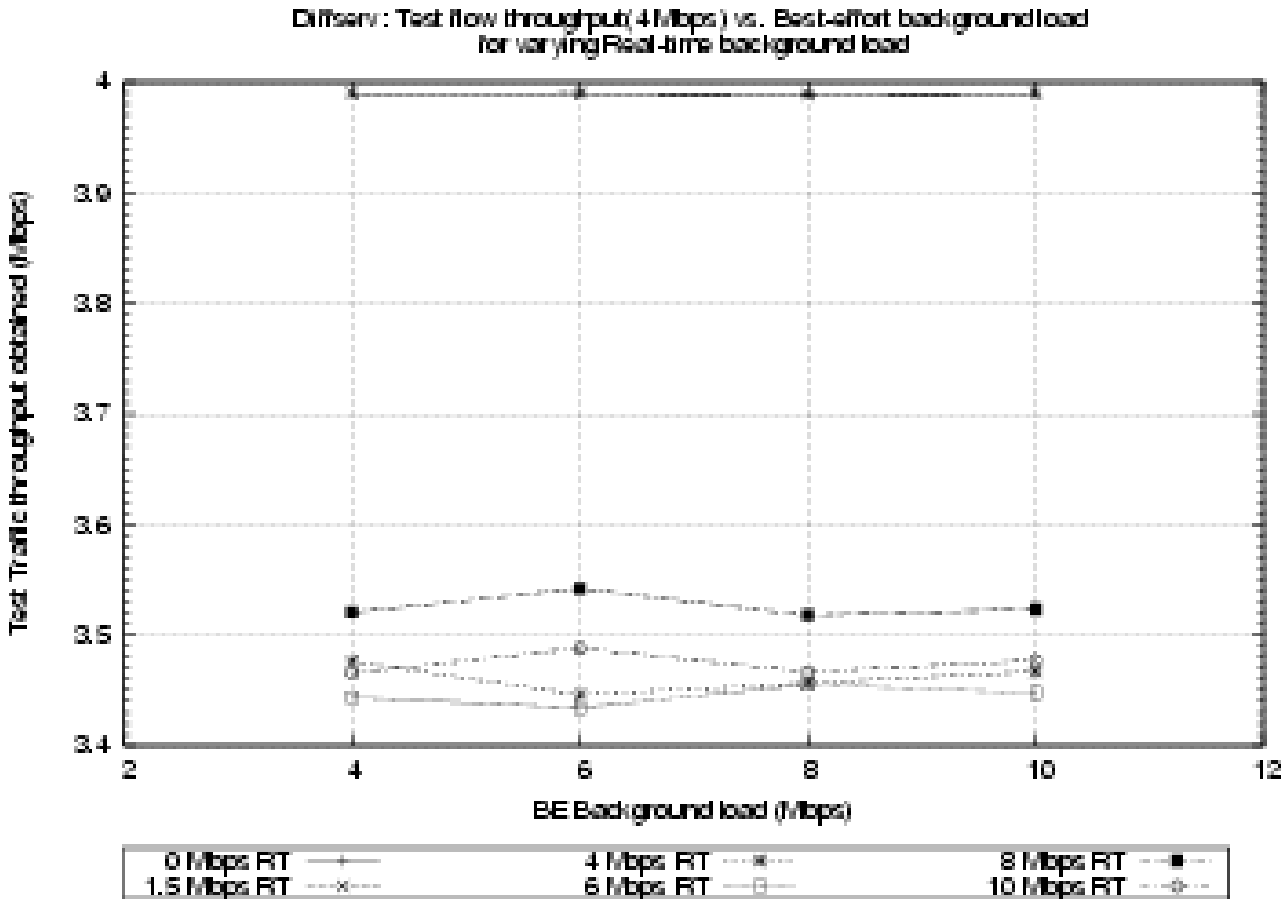
Diffserv – Throughput Comparison (9 elements)

Physical network zoomed results

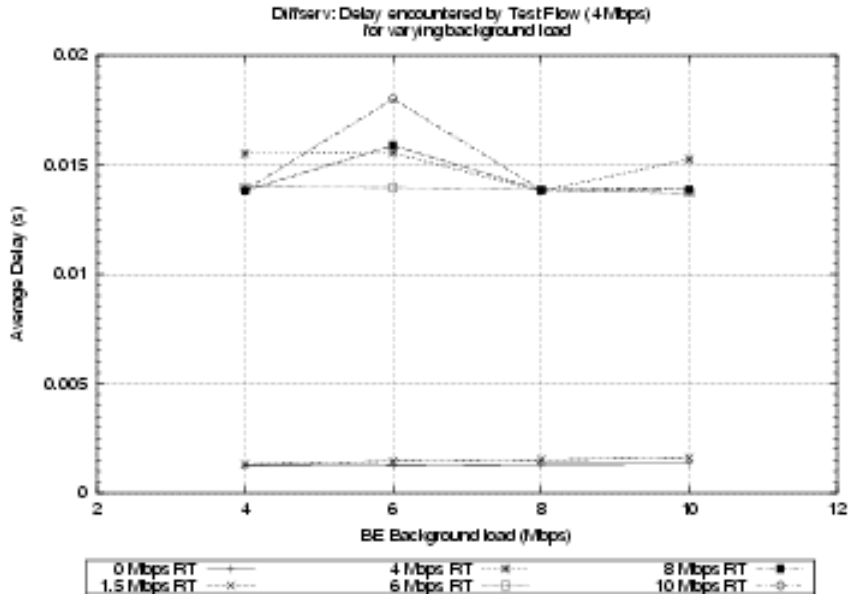


Diffserv – Throughput Comparison (9 elements)

Virtual network zoomed results



Diffserv – Delay Comparison (9 elements)

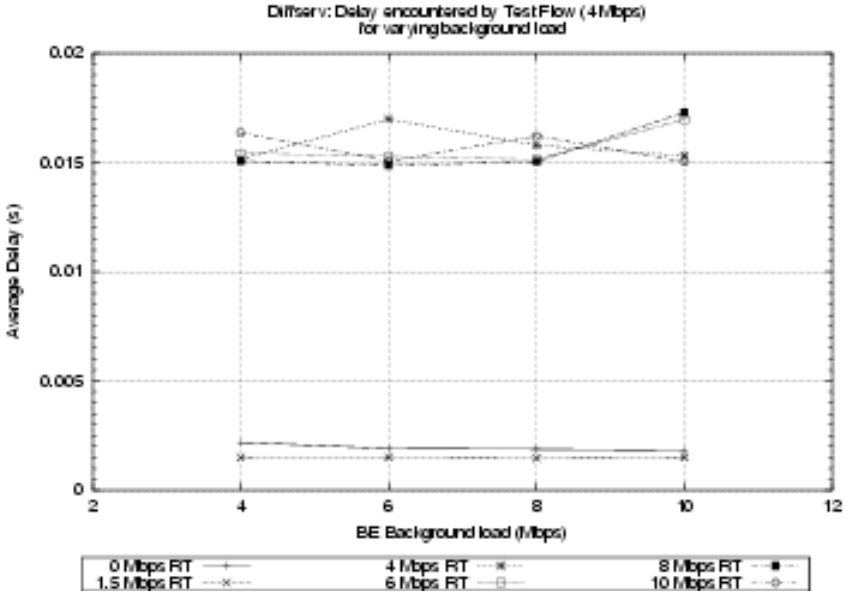


Physical

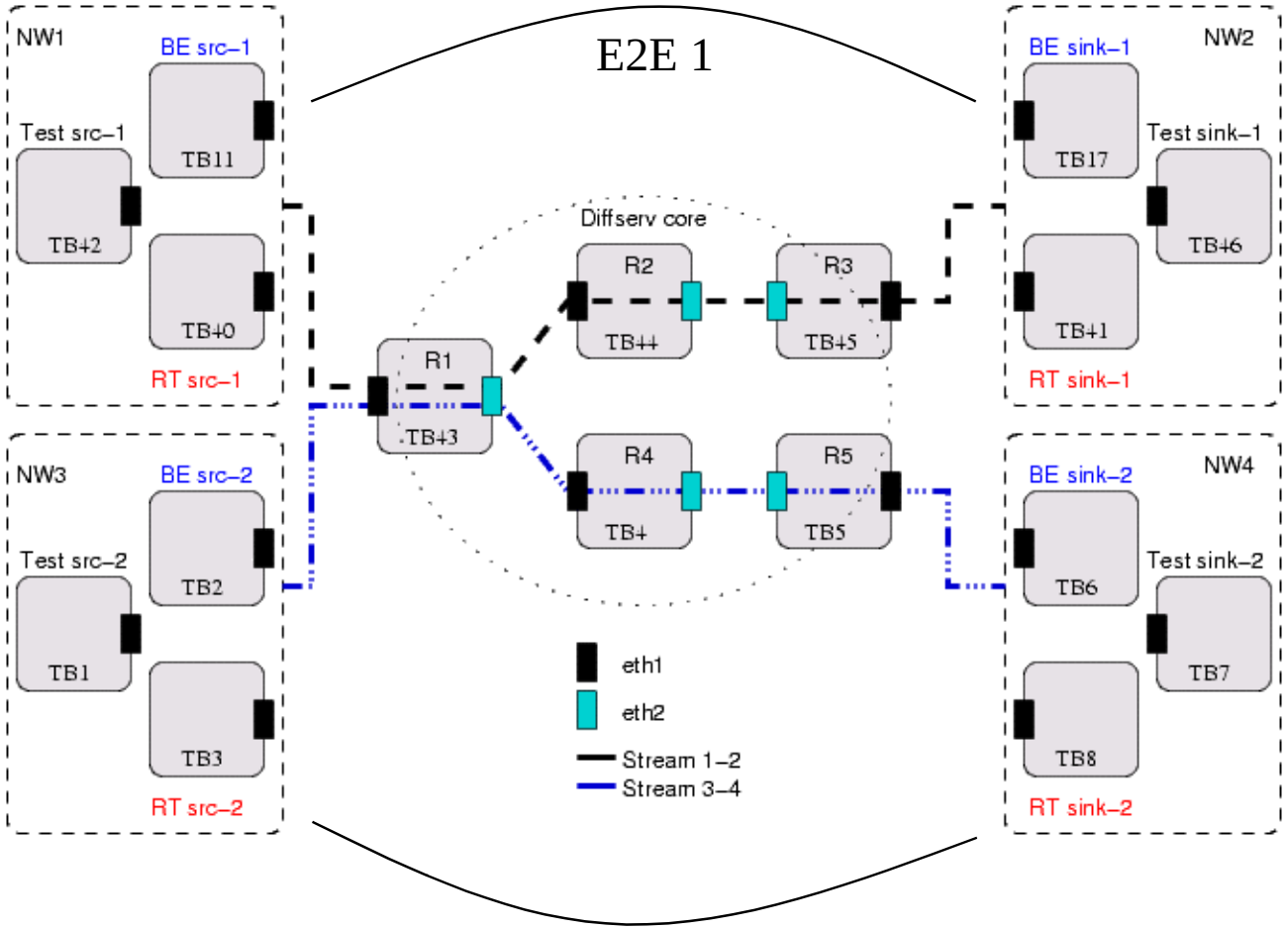
- Uncongested: 2-3 ms
- Congested: 14-18 ms

Virtual

- Uncongested: 2-3 ms
- Congested: 15-17 ms



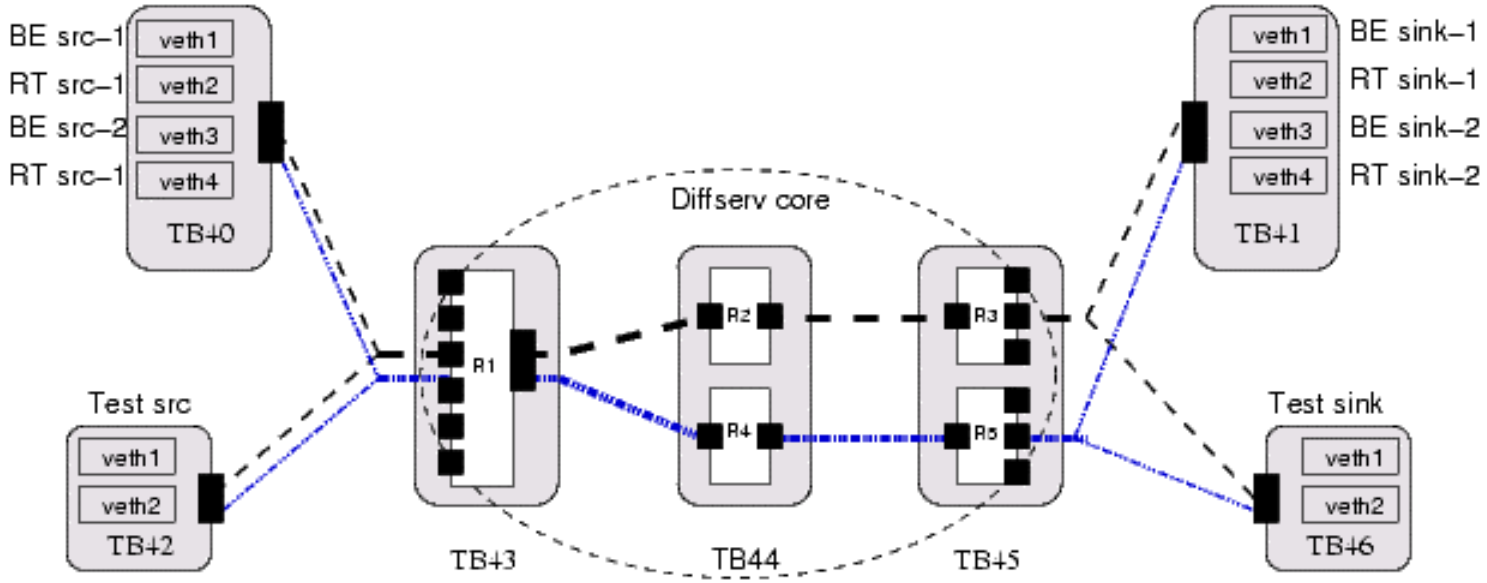
Physical Network Topology – Diffserv - 17 elements



Virtual Network topology – Diffserv – 17 elements

- Physical testing not performed due to shortage of machines
- Ideal case for using VNF
- Need to compare Diffserv properties observed in Physical networks with those observed in Emulated networks

Virtual Network topology – Diffserv – 17 elements



Virtual Network topology – Diffserv – 17 elements

- One greedy customer does not affect other customers of network
- Throughput of 2 ‘Test’ streams measured in presence of background RT and BE load from their respective networks
- `tcpdump` output captured at source and sink, merged and diff’ed

Diffserv - Network Test parameters

Traffic	• BG-BE traffic = 2-6Mbps • BG-RT traffic = 0-6Mbps • Test CBR traffic = 4Mbps
Diffserv Parameters (core routers)	• 2 Real time AF classes = 6Mbps each • Best Effort class = 4Mbps • HTB queuing discipline • 6 Mb RT traffic is threshold (Test + BG)
Data Plane	• Throughput • Delay

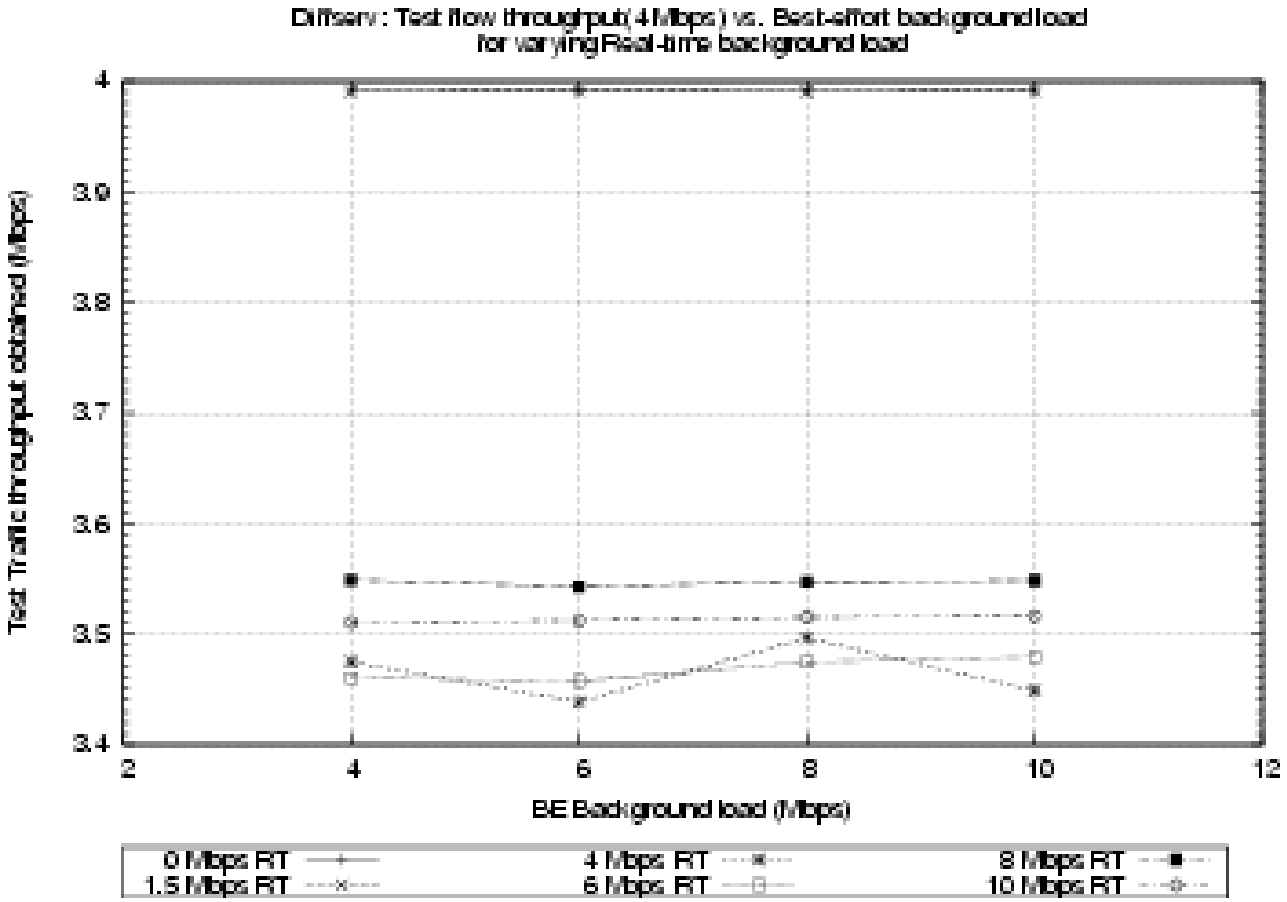
Diffserv – throughput Results (17 elements)

- #1-6 show equal traffic on both networks
- #7-8 show E2E #2 being greedy
- One greedy customer does not affect others in Diffserv

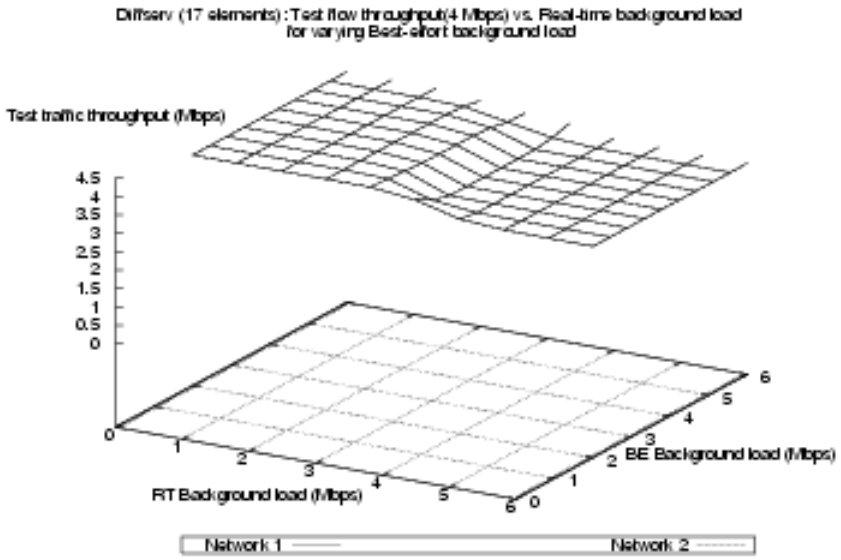
#	E2E	BG-RT (Mbps)	BG-BE (Mbps)	throughput (Mbps)
1	1	0	2	3.9901
	2	0	2	3.9901
2	1	0	4	3.9904
	2	0	4	3.9901
3	1	1.5	2	3.9901
	2	1.5	2	3.9901
4	1	1.5	4	3.9900
	2	1.5	4	3.9897
5	1	4	4	3.4735
	2	4	4	3.4648
6	1	6	6	3.4752
	2	6	6	3.4551
7	1	1.5	2	3.9901
	2	4	4	*3.4799*
8	1	1.5	4	3.9901
	2	6	6	*3.4591*

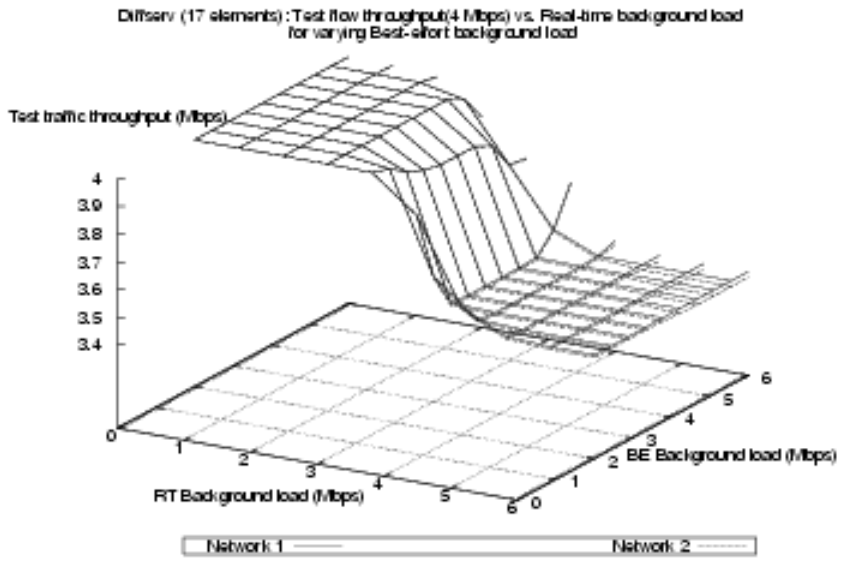
Diffserv – Throughput Comparison (9 elements)

Physical network zoomed results



Diffserv – Throughput Results (17 elements)





Diffserv Data Plane Evaluation – Results

- Diffserv behaves similarly in physical and emulated (virtual) networks
- Results of throughput/delay tests on emulated network similar to those of physical network
- Very minor changes to code to get Diffserv to work with VNEs

Emulating Intserv networks

- Emulated network is identical to Diffserv network
- Diffserv traffic classes replaced by RSVP daemon which does dynamic resource reservation
- RSVP daemon modified:
  - To understand virtual routing
  - To enable many instances to run on a physical machine bound to specific VNEs

Emulating Intserv networks

- Intserv network successfully emulated
- Results on Physical network not reproducible for multiple iterations of tests
  - RSVP daemon uses CBQ
  - Linux CBQ implementation tries *estimation* to schedule packets, does not give consistent results
  - HTB implementation for RSVP non-trivial
- Data plane could not be verified
- Demonstrates clean interface of VNF that allows complex applications to use it

Limitations of VNF

- Sum of throughputs of VNEs on a physical machine must be less than sum of throughput of all physical interfaces; overcome using virtual time techniques introduced by ProTEuS
- Doesn’t allow ‘connected’ NEs to be emulated on same physical machine if packet needs to pass through queuing code; can be overcome by modifying queuing code

Summary

- VNF designed and implemented
- Tested with non-trivial IP networks such as Diffserv and Intserv networks
- Programming model allows easy ‘porting’ of applications to work with VNF
- Larger Diffserv networks successfully emulated
- Intserv networks emulated functionally, but data plane could not be verified

Thank You