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In collaboration with Wolfgang Kellerer and Zoran Despotovic at DOCOMO Euro-Labs,
Volker Hilt at Bell Labs/Alcatel-Lucent and Srini Seetharaman at Deutsche Telekom

NETSERV: PROGRAMMING NETWORKS (AGAIN)

What is NetServ?

- In-network service container
- Java-programmable, signal-driven router
- “GENI Lite” – deploy modules, not VMs
- Active networking that works ™

Overview

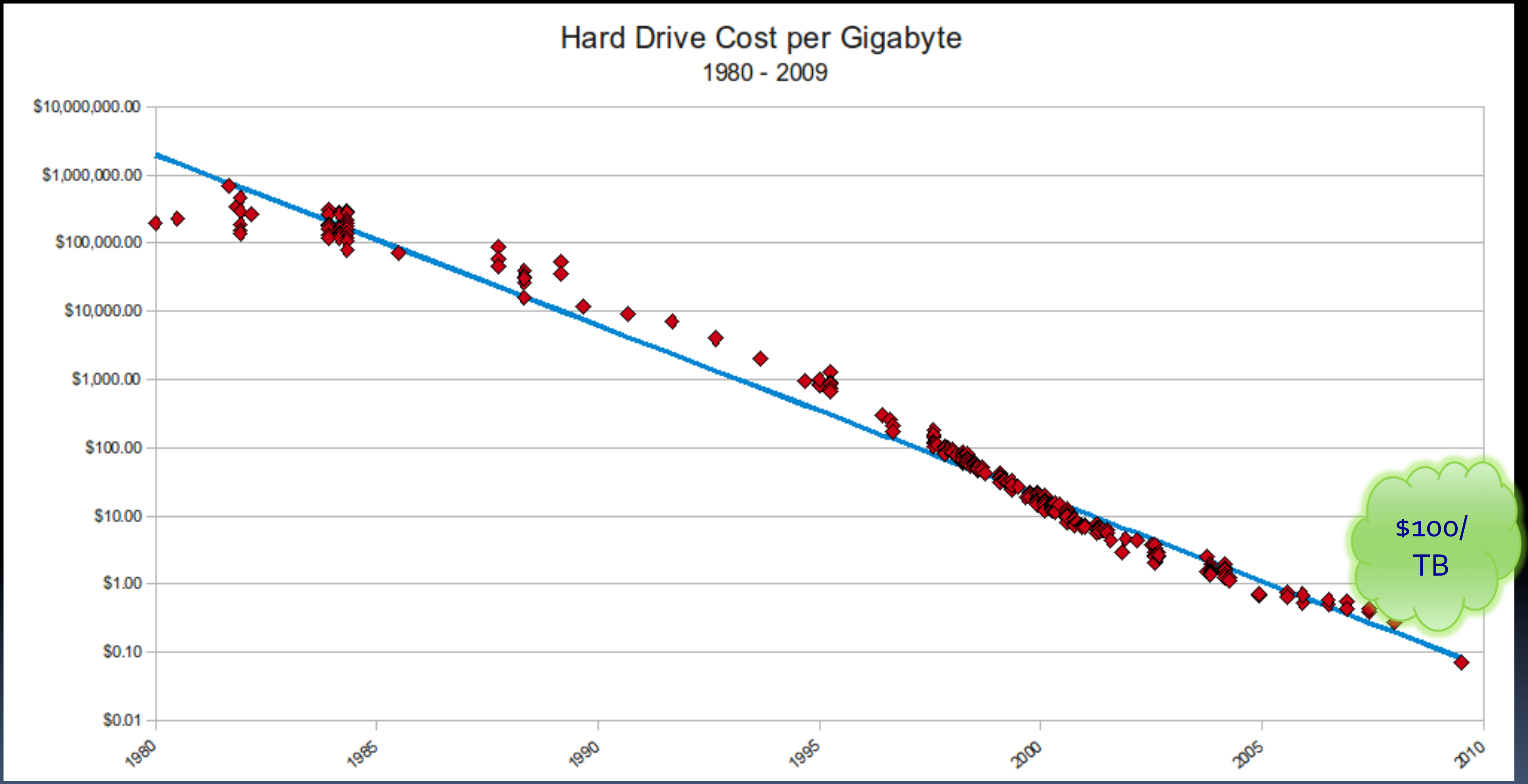
- Old world
  - (computation, storage) ←→ forwarding
- 1990s: active networking
  - no good isolation infrastructure
  - limited applications
- Exploring new opportunities
  - providing additional services in the current Internet → NetServ
  - future Internet architecture

Two worlds

10+ interfaces
0 GB disk
1 low-end processor

1 interface
TB disk
1-32 multi-core processors

Storage costs

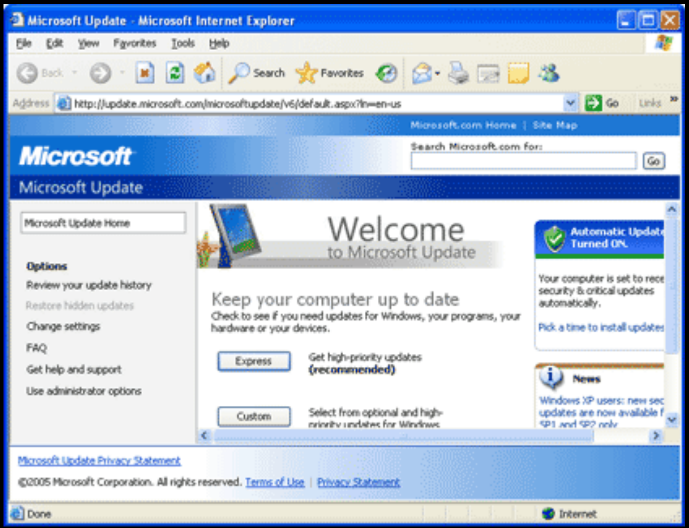


http://www.mkomo.com/cost-per-gigabyte

Bandwidth costs

- Amazon EC2
  - $100/TB in, $100/TB out
- CDN (Internet radio)
  - $600/TB (2007)
  - $100/TB (Q1 2009 – CDNpricing.com)
- NetFlix (7 GB DVD)
  - postage $0.70 round-trip → $100/TB
- FedEx – 2 lb disk
  - 5 business days: $6.55
  - Standard overnight: $43.68
  - Barracuda disk: $91 - $116/TB

Software: from floppy to autonomous


Microsoft Update - Microsoft Internet Explorer

File Edit View Favorites Tools Help

Address http://update.microsoft.com/microsoftupdate/v6/default.aspx?ln=en-us

Microsoft.com Home | Site Map

Search Microsoft.com for:

Microsoft

Microsoft Update

Microsoft Update Home

Options

Review your update history

Restore hidden updates

Change settings

FAQ

Get help and support

Use administrator options

Welcome to Microsoft Update

Keep your computer up to date

Check to see if you need updates for Windows, your programs, your hardware or your devices.

Express — Get high-priority updates (recommended)

Custom — Select from optional and high-priority updates for Windows

Automatic Updat Turned ON.

Your computer is set to rece security & critical updates automatically.

Pick a time to install updates

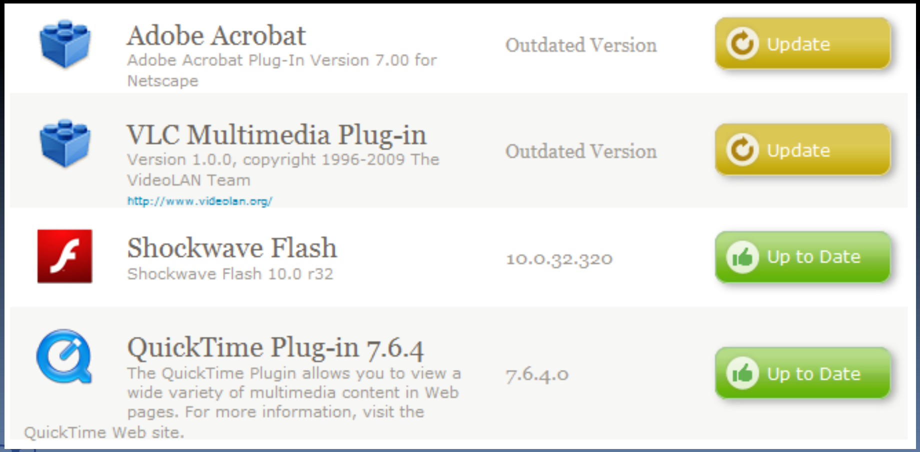
News

Windows XP users: new sec updates are now available f SP1 and SP2 only

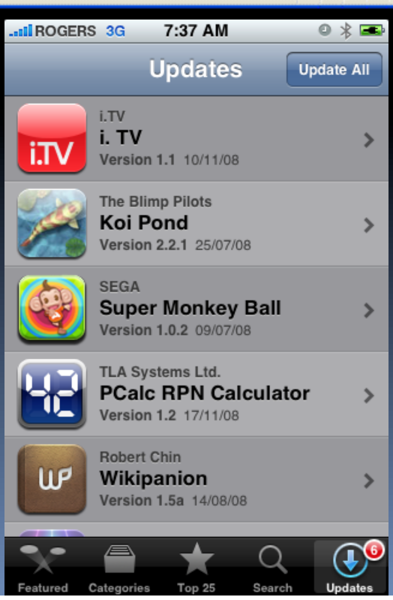
Microsoft Update Privacy Statement

©2005 Microsoft Corporation. All rights reserved. Terms of Use | Privacy Statement

Done — Internet



Adobe Acrobat	Adobe Acrobat Plug-In Version 7.00 for Netscape	Outdated Version	Update
VLC Multimedia Plug-in	Version 1.0.0, copyright 1996-2009 The VideoLAN Team http://www.videolan.org/	Outdated Version	Update
Shockwave Flash	Shockwave Flash 10.0 r32	10.0.32.320	Up to Date
QuickTime Plug-in 7.6.4	The QuickTime Plugin allows you to view a wide variety of multimedia content in Web pages. For more information, visit the QuickTime Web site.	7.6.4.0	Up to Date


ROGERS 3G 7:37 AM

Updates — Update All

i.TV	i. TV	Version 1.1	10/11/08
The Blimp Pilots	Koi Pond	Version 2.2.1	25/07/08
SEGA	Super Monkey Ball	Version 1.0.2	09/07/08
TLA Systems Ltd.	PCalc RPN Calculator	Version 1.2	17/11/08
Robert Chin	Wikipanion	Version 1.5a	14/08/08

Featured — Categories — Top 25 — Search — Updates

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NetServ overview

Extensible architecture for core network services

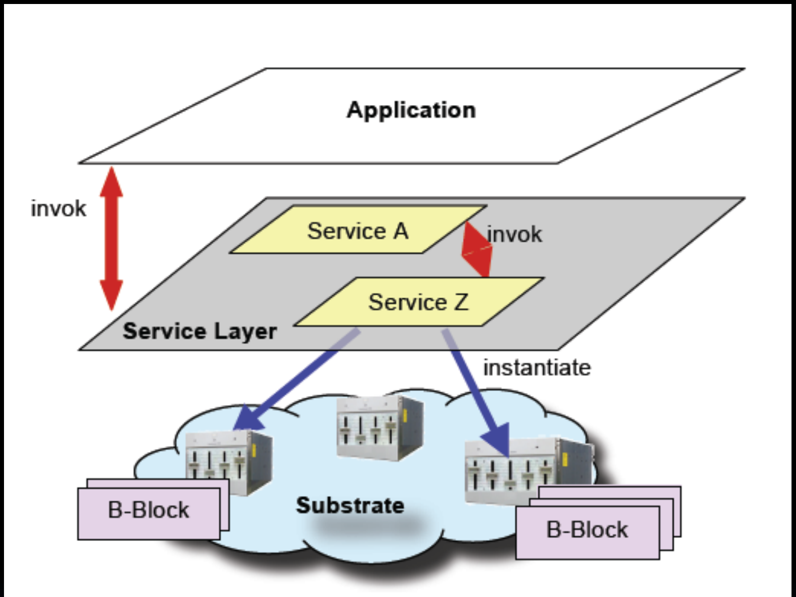

Figure 3: Instantiation of services over tunable building blocks.

Modularization

- Building Blocks
- Service Modules

Virtual services framework

- Security
- Portability

NSF FIND four-year project

- Columbia University
- Bell Labs
- Deutsche Telekom
- DOCOMO Euro-Labs

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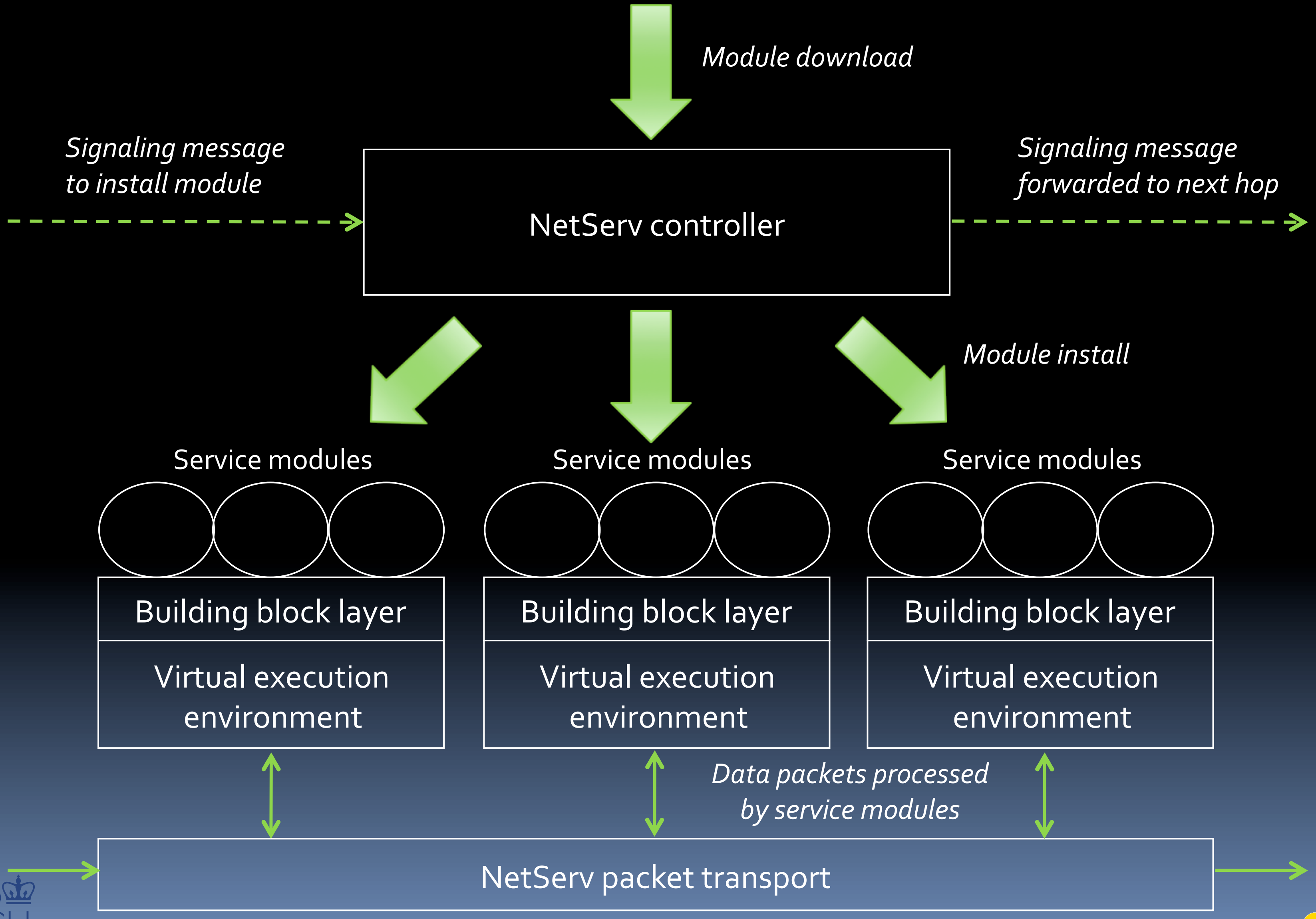
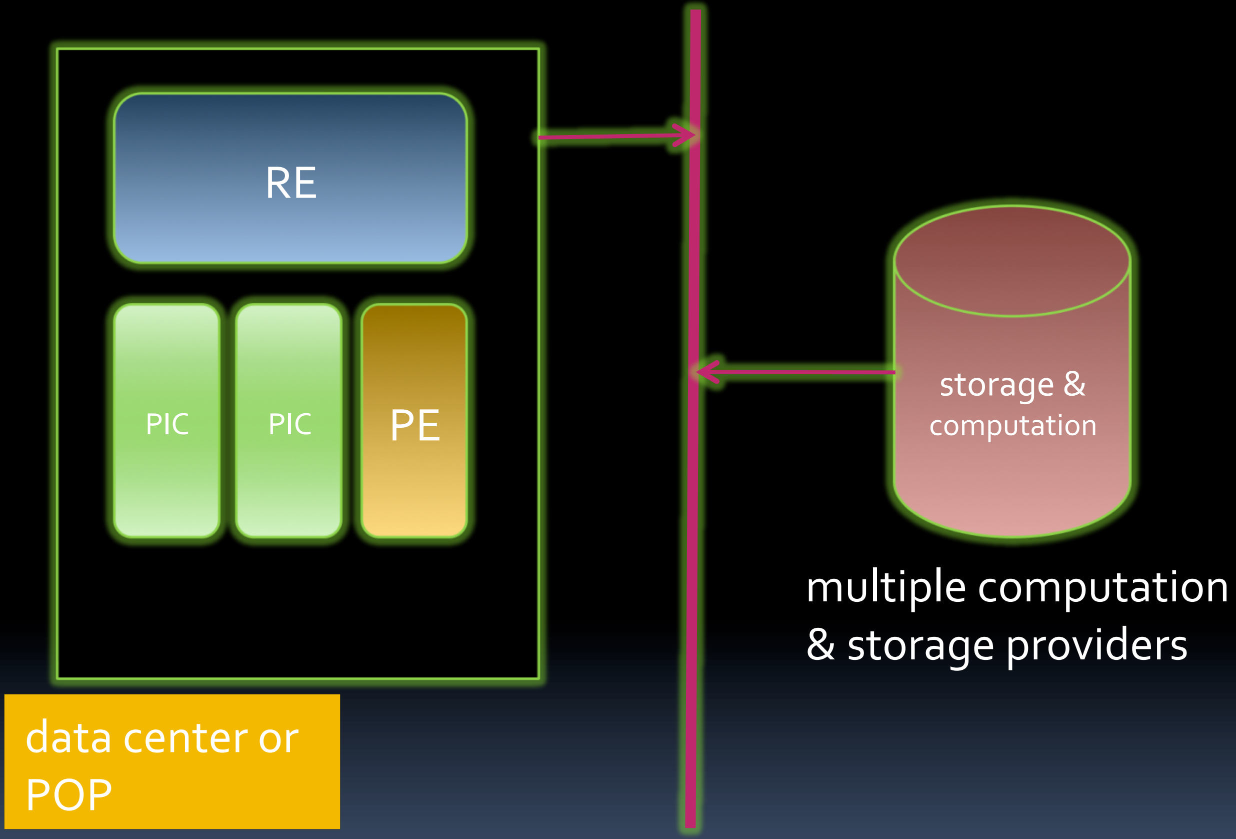
Architecture overview



Module download
Signaling message to install module
NetServ controller
Signaling message forwarded to next hop
Module install
Service modules
Service modules
Service modules
Building block layer
Virtual execution environment
Building block layer
Virtual execution environment
Building block layer
Virtual execution environment
Data packets processed by service modules
NetServ packet transport

Network node example



Different from active networks?

- Active networks
  - Example: Packet contains executable code or pre-installed capsules
    - Can modify router states and behavior
    - Mostly stateless
  - Not successful
    - Per-packet processing too expensive
    - Limited storage (memory expensive)
    - Security concerns
    - No compelling *killer app* to warrant such a big shift
  - Notable work: ANTS, Janos, Switchware
- NetServ
  - Virtualized services on current, passive networks
    - Service invocation is signaling driven, not packet driven
    - Some flows & packets, not all of them
    - Emphasis on storage
  - Service modules are stand-alone, addressable entities
    - Separate from packet forwarding plane
    - Extensible plug-in architecture

How about GENI?

- GENI = global-scale test bed for networking research
  - parallel experiments in VMs
- ➔ long-term, "heavy" services
- Demonstrated NetServ on GENI during GEC8

Related work

- Cisco's Programmable Overlay Router
- Juniper's JUNOS SDK
- DaVinci project
- OpenFlow
- ShadowNet (AT&T) – virtual routers
- MillionNode GENI (end systems)

NetServ service containers

- NetServ service container
  - User-level processes
  - Embeds a Java Virtual Machine
  - Runs OSGi
  - Service modules are dynamically installed and removed
- NetServ Service Modules
  - OSGi-compliant Java code
  - Can be stand-alone server (i.e., listens on a port)
  - Or can be packet processor
    - Packets are first routed from kernel to container using kernel queue (Netfilter queue in Linux and pseudo-device in Click Router)
    - Packets are then passed to Java using Java Native Interface (JNI)

Service modules

- Full-fledged service implementations
  - Use building blocks and other service modules
  - Can be implemented across multiple nodes
  - Invoked by applications
- Examples:
  - Routing-related services
    - Multicast, anycast, QoS-based routing
  - Monitoring services
    - Link & system status, network topology
  - Identity services
    - Naming, security
  - Traffic engineering services
    - CDN, redundancy elimination, p2p network support

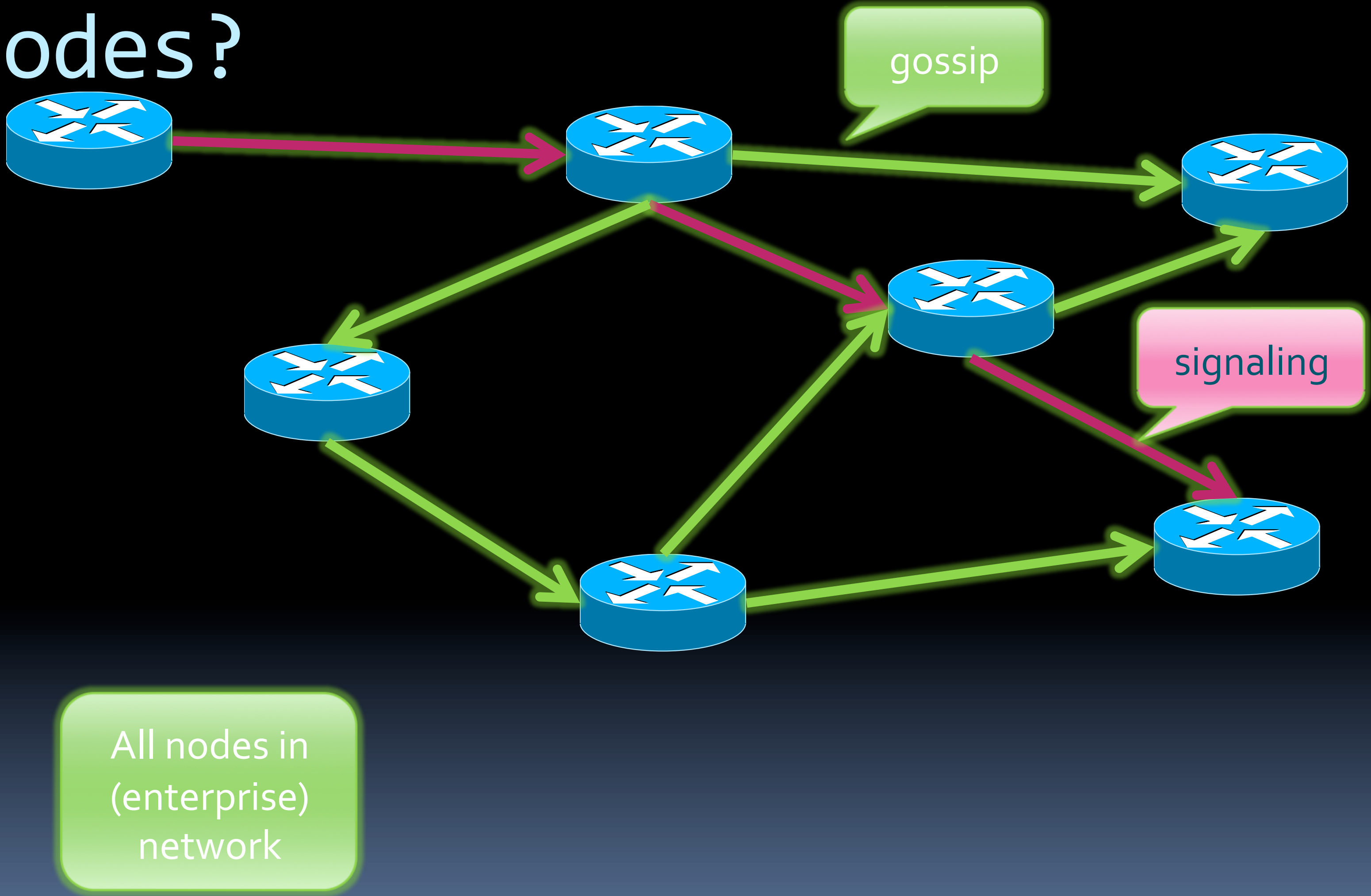
Deployment scenarios

- Three actors
  - Content publisher (e.g. youtube.com)
  - Service provider (e.g. ISP)
  - End user
- Model 1: Publisher-initiated deployment
  - Publisher rents router space from providers (or end users)
- Model 2: Provider-initiated deployment
  - Publisher writes NetServ module
  - Provider sees lots of traffic, fetches and installs module
  - Predetermined module location (similar to robots.txt)
- Model 3: User-initiated deployment
  - User installs NetServ module to own home router or PC
  - *or on willing routers along the data path*

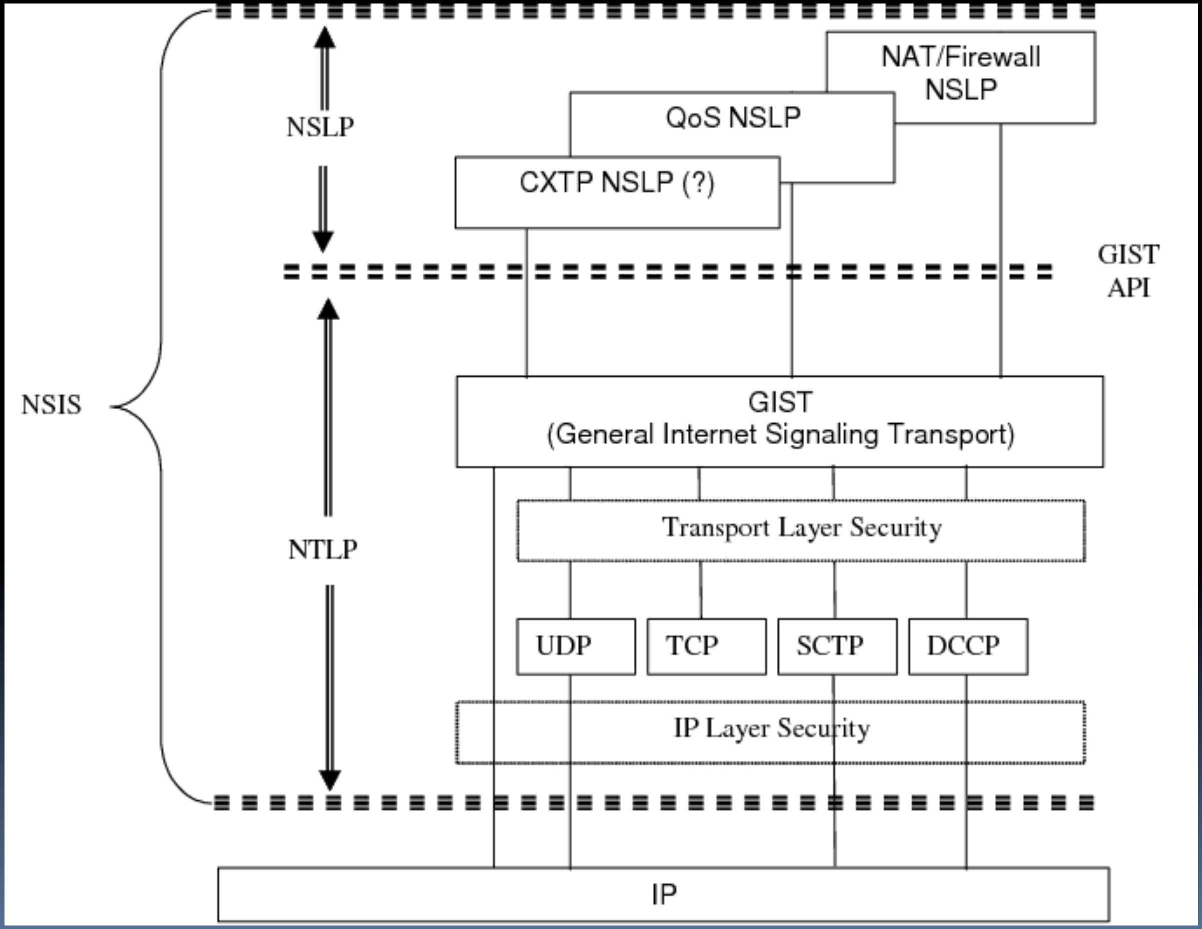
Where does code run?

- All (or some?) nodes in a network
  - AS, enterprise LAN
- Some or all nodes along path
  - data path from source to destination
- Selected nodes by property
  - e.g., one in each AS

How does code get into nodes?



How does code get into nodes?



NSIS

- Progress along data path
  - with RAO-based discovery
- Designed to transport large objects
  - supports TCP and UDP
- Security mechanisms

NetServ signaling daemons

- NetServ signaling daemons
  - NSIS (RFC 4080) compliant
  - Two layers: Generic GIST and NetServ-specific NSLP
  - Receive signaling packets to setup/remove/probe modules
  - Command in signal packet handed to NetServ Controller
  - Node can be on-path – signal forwarded to next hop
  - Currently based on FreeNSIS implementation

Module management: OSGi

- "Dynamic module system for Java"
  - originally for set top boxes
- Why OSGi? Why not just JAR files?
  - More than just JAR files
    - much richer encapsulation
    - metadata in manifest
  - Automatic dependency resolution
  - Version management
  - Provides systems services (logging, configuration, user authentication, device access, ...)
  - ~ Debian's apt-get or Apple's App Store methods of installation

OSGi features

- Dynamic module system for Java
    - Modules loaded and unloaded at runtime
    - *Bundle:* self-contained JAR file with specific structure
    - Open-source implementations: Apache Felix, Eclipse Equinox
- Security and accounting
    - Security built on Java 2 Security model
        - Permission-based access control
        - No fine-grained control or accounting for CPU, storage, bandwidth
        - Can load native code with appropriate permission
    - Strict separation of bundles
        - Classpath set up by Bundle class loader
        - Inter-bundle communication only through published interfaces

OSGi architecture

- Architecture
  - **Bundles**: JAR files with manifest
  - **Services**: Connects bundles
  - **Services Registry**: Management of services
  - **Modules**: Import/export interfaces for bundles
- Possible to "wrap" existing Java apps and JARs
  - Add additional manifest info to create OSGi bundle
  - E.g.: Jetty web server now ships with OSGi manifest; now extensively used with OSGi containers and custom bundles
  - For NetServ, we created a OSGi bundle for the Muffin HTTP proxy server

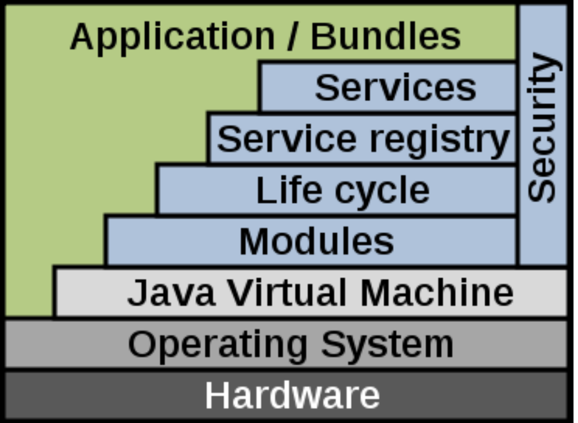


Image credit: Wikipedia

OSGi implementation

- Many core frameworks
  - Eclipse Equinox, Apache Felix, Knoplerfish
- Real-world examples
  - Eclipse IDE uses OSGi for plugin architecture
- Mostly finds use in enterprise applications needing plugin functionality
  - E.g.: IBM Websphere, SpringSource (now VMWare) dm server, Red Hat's JBoss

Getting packets: Click router

- Runs as a Linux kernel module or user-level program
- Modules written in C++ (called *Elements*) are configured in a text file
- Elements are arranged in a directed graph, through which packets traverse
- Example:
    - Click router command:

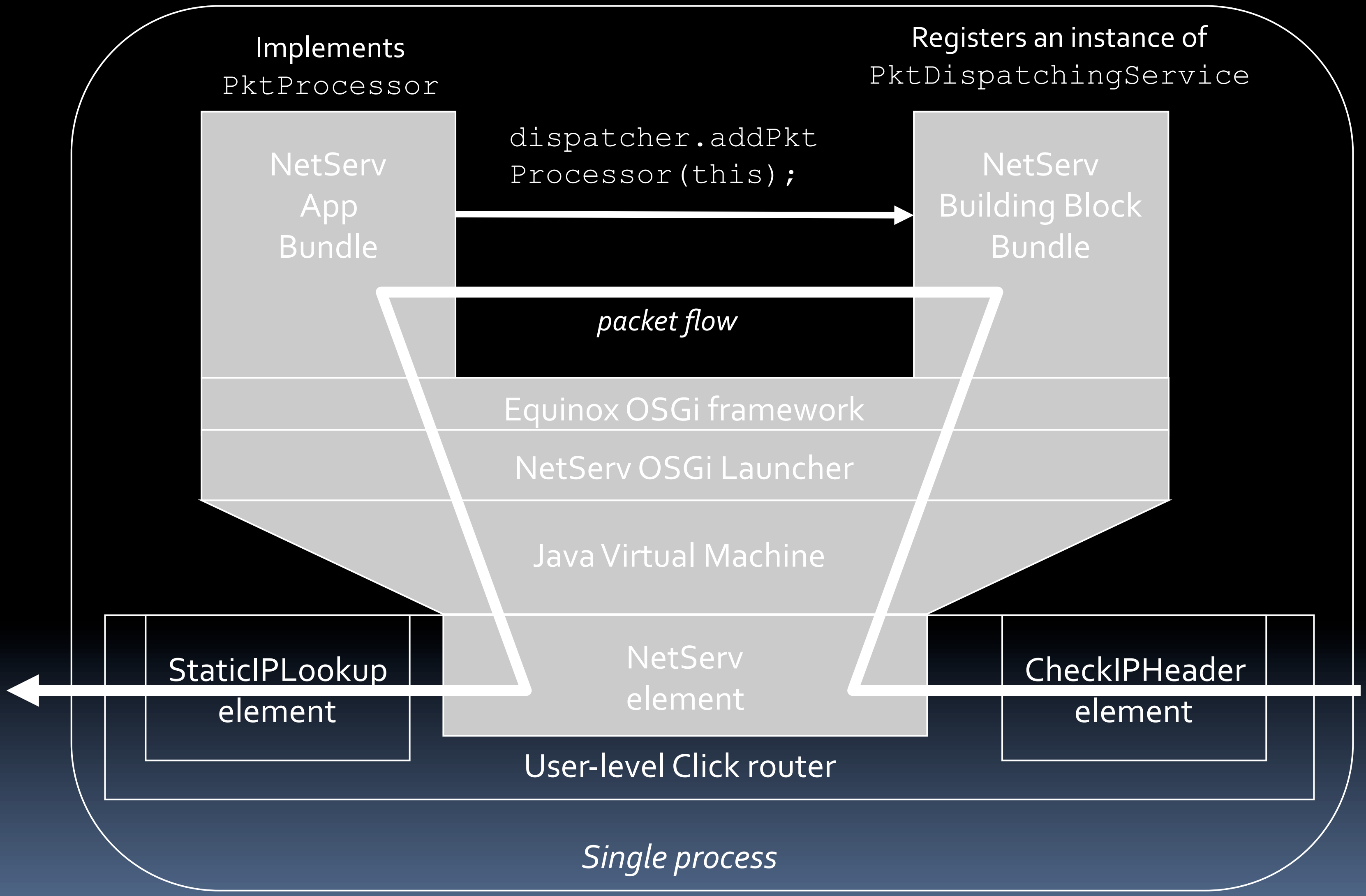
      ```
      sudo click print.click
      ```
    - Configuration file print.click:

      ```
      FromDevice(en0)->CheckIPHeader(14)->IPPrint->Discard;
      ```
- http://www.read.cs.ucla.edu/click/

1st prototype

- Proof-of-concept for dynamic network service deployment
  - Open-source Click modular router
  - Java OSGi dynamic module system
- Promising initial measurement results
  - NetServ overhead acceptable compared to other overhead

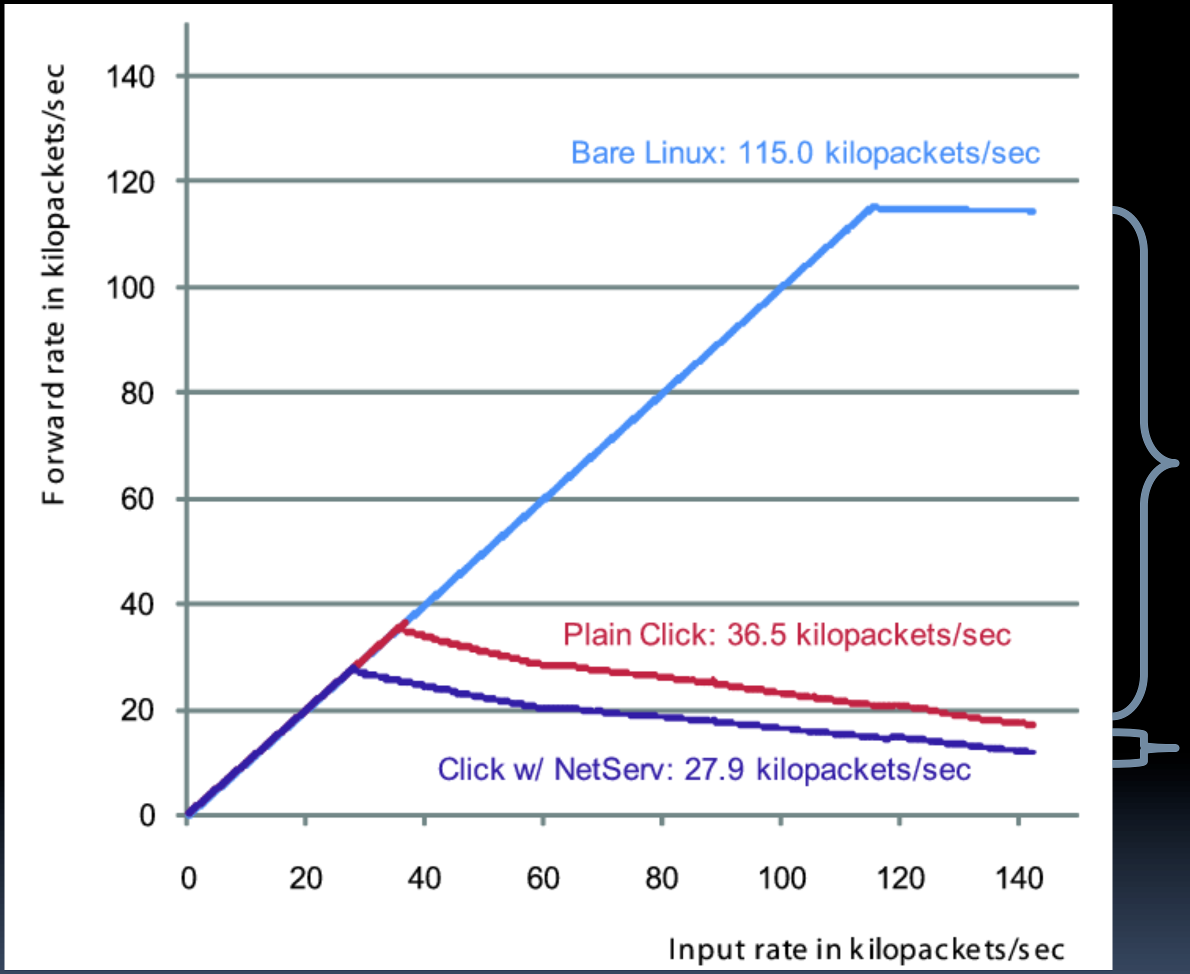
1st implementation



Performance evaluation

- Initial measurements on the first prototype
  - NetServ on user-level Click router
  - Maximum Loss Free Forward Rate (MLFFR)
- Future work on next-generation prototypes
  - NetServ on JUNOS, kernel-mode Click
  - Ping latency
  - Microbenchmarks
  - Throughput for non-trivial services

MLFFR comparison

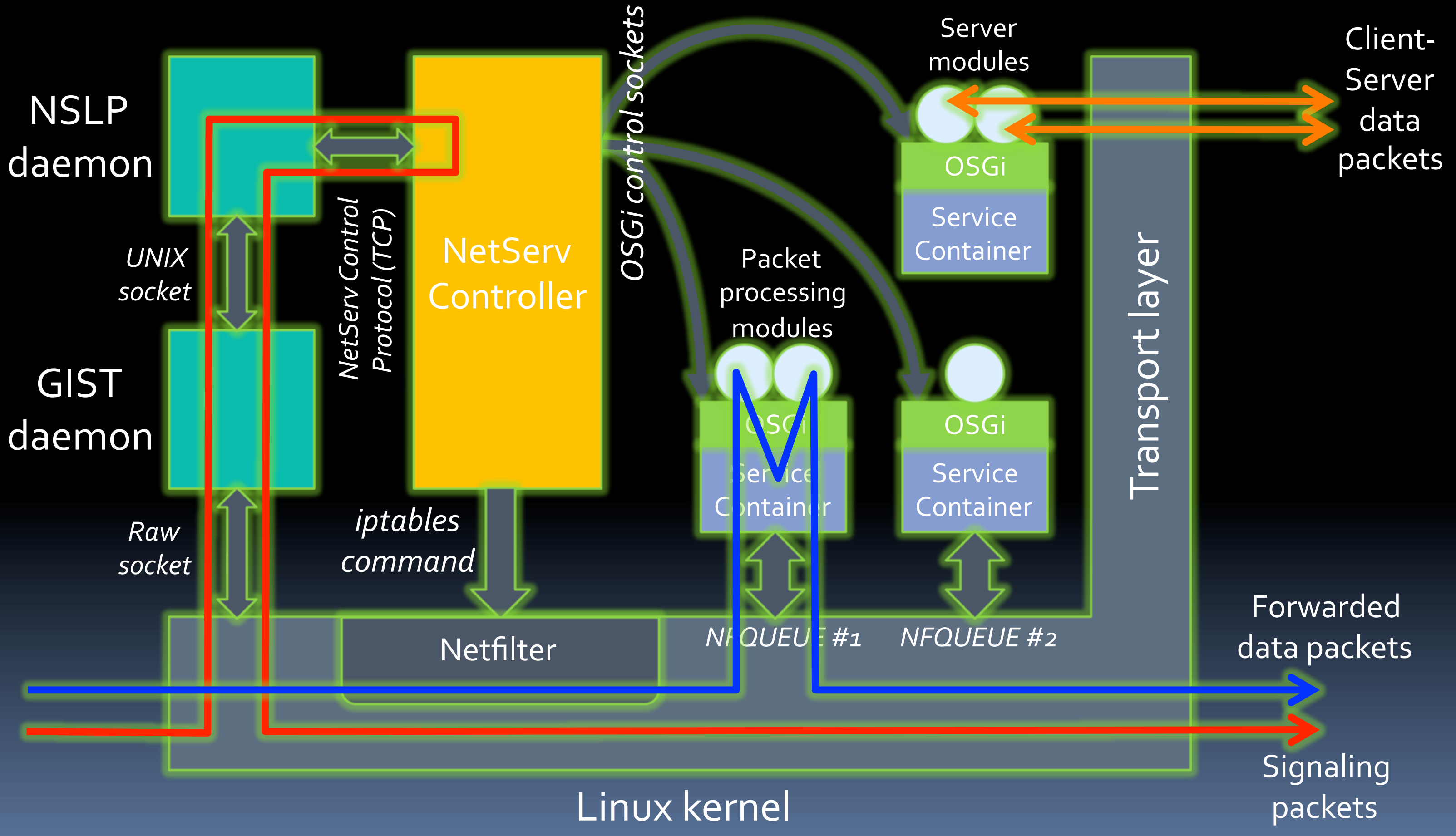


Penalty from kernel-user transition

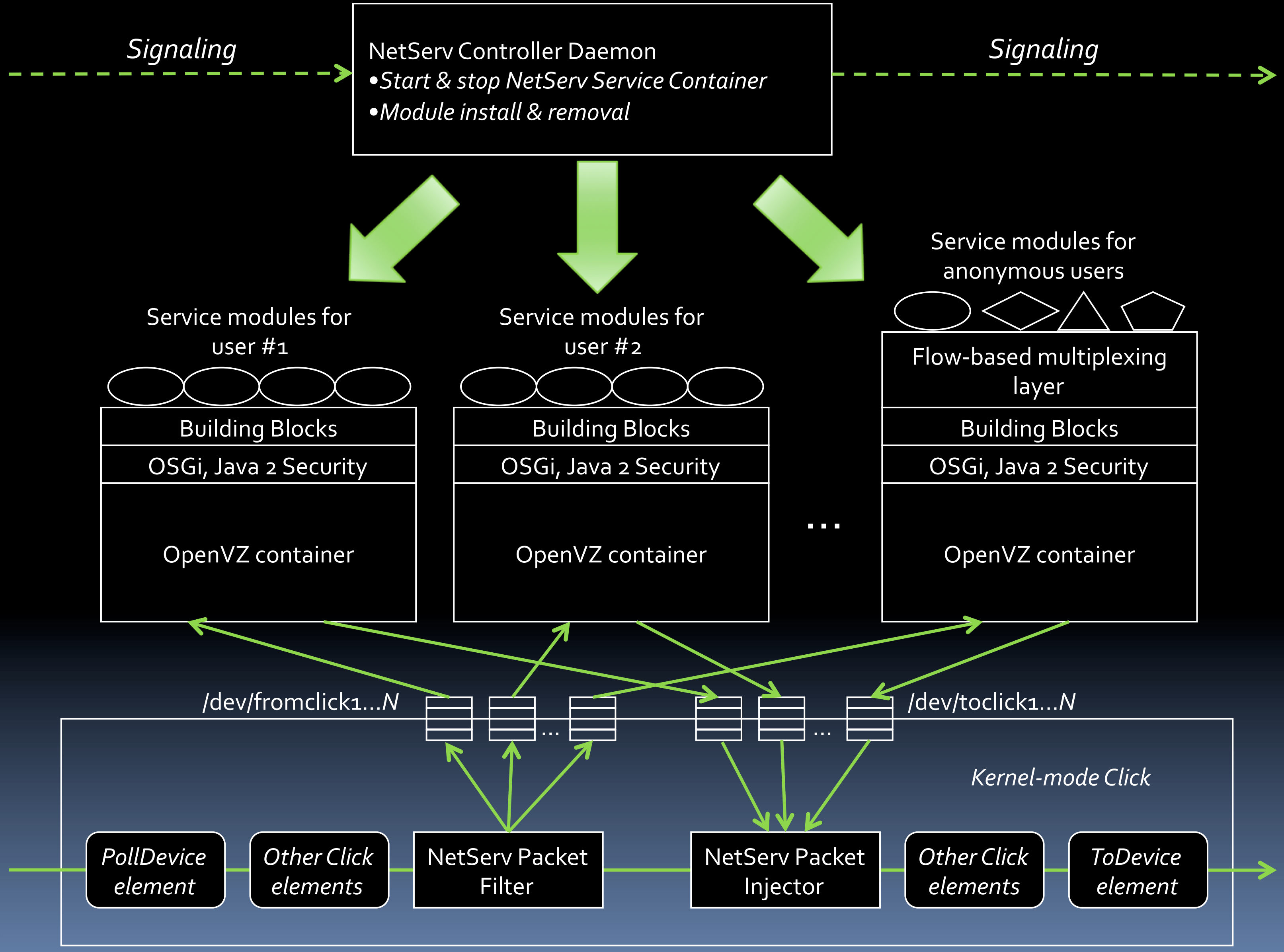
Penalty from trip to Java layer

For a modular architecture, kernel-user transition is unavoidable since putting a module inside a kernel is not an option

Current NetServ node architecture



Next Click architecture



NetServ controller and kernel

- NetServ kernel
  - Pass packets to user-level service container processes
  - Currently Linux kernel with Netfilter queues
  - Click Router version under development
  - Juniper Router version planned
- NetServ controller
  - Coordinates between signaling daemons, kernel, and service container processes
  - Receives setup/remove/probe commands from signaling daemons
  - Insert/remove packet filters into/from the kernel
  - Start/stop service modules in service container processes

Packet intercept

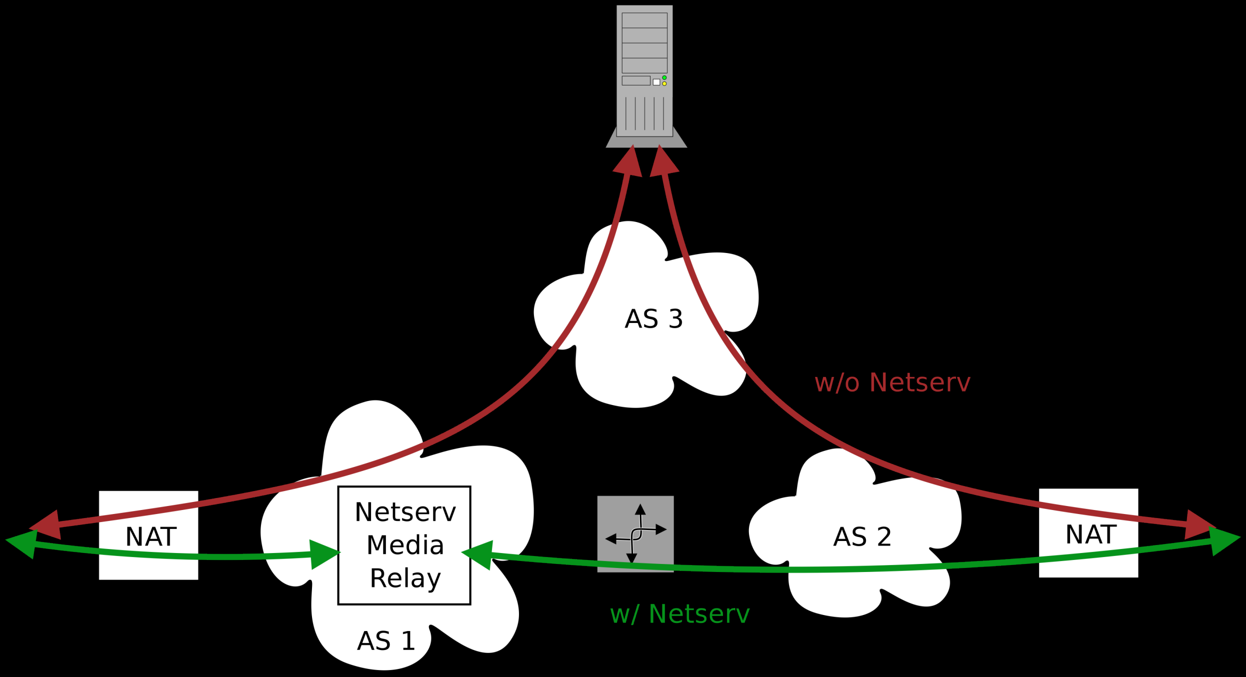
- CLICK
  - more functionality than needed
- pcap
  - capture only
- iptables with NFQUEUE
  - allows filtering of packets into different queues

APIs needed!

- Avoid SNMP retrieval problems
  - all or nothing (typical)
  - hard to do selective triggers
- Flow management
  - counters, measurement
- System information
  - like system MIB: geo location, uptime, interface speeds, ...
  - routing table
  - routing table changes ("tell me if route to X changes")

NetServ service (demo) examples

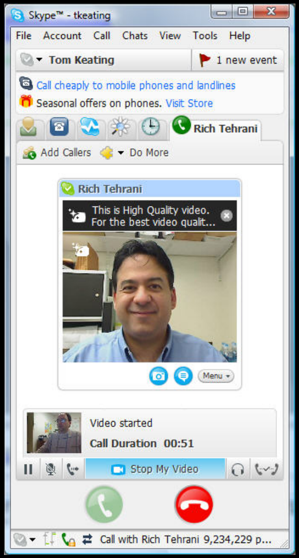
Media relay



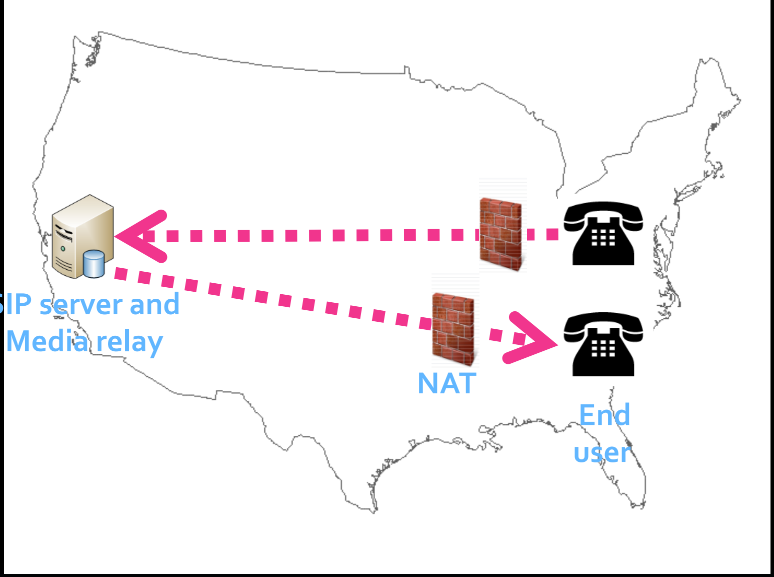
- Standard media relay
  - Required due to NAT
  - Out-of-path
  - Inefficient and Costly
- NetServ media relay
  - Closer to users
  - Improved call quality
  - Reduced cost for ITSP

Media relay

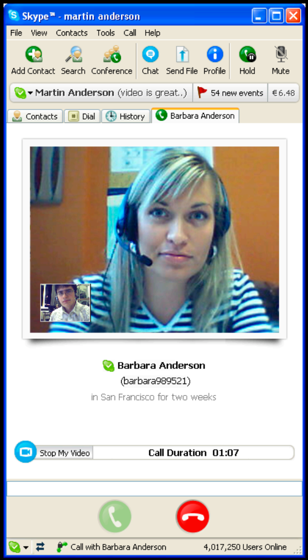
Screen 1


Skype™ - tkeating
File Account Call Chats View Tools Help
Tom Keating
1 new event
Call cheaply to mobile phones and landlines
Seasonal offers on phones. Visit Store
Rich Tehrani
Add Callers
Do More
Rich Tehrani
This is High Quality video. For the best video qualit...
Menu
Video started
Call Duration 00:51
Stop My Video
Call with Rich Tehrani 9,234,229 p...

Screen 2



Screen 3


Skype™ - martin anderson
File View Contacts Tools Call Help
Add Contact Search Conference Chat Send File Profile Hold Mute
Martin Anderson (video is great..)
54 new events
€6.48
Contacts Dial History Barbara Anderson
Barbara Anderson
(barbara989521)
in San Francisco for two weeks
Stop My Video
Call Duration 01:07
Call with Barbara Anderson
4,017,250 Users Online

Tell:

How VoIP calls are relayed today

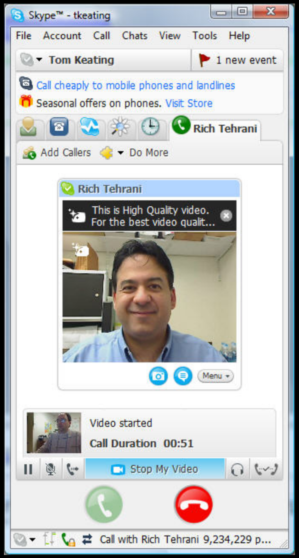
- Media relay needed due to NAT
- But relays are often out-of-path
- Inefficient and high cost for ITSP

Show:

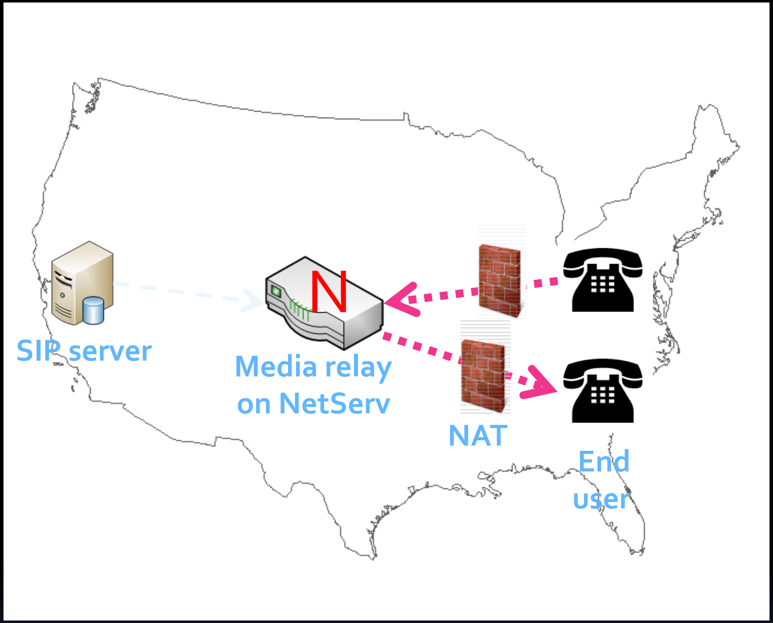
1. Make a video call between screens 1 & 3
2. Call flow displayed on screen 2
3. Bad call quality due to far-away relay

Media relay

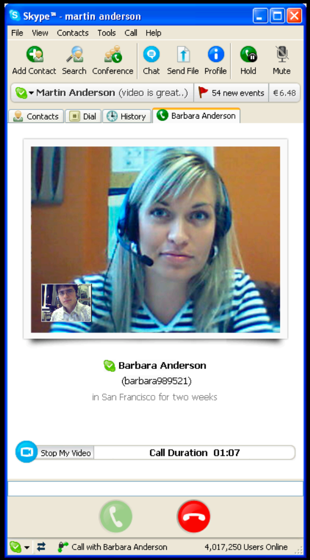
Screen 1


Skype™ - tkeating
File Account Call Chats View Tools Help
Tom Keating
1 new event
Call cheaply to mobile phones and landlines
Seasonal offers on phones. Visit Store
Rich Tehrani
Add Callers
Do More
Rich Tehrani
This is High Quality video. For the best video qualit...
Menu
Video started
Call Duration 00:51
Stop My Video
Call with Rich Tehrani 9,234,229 p...

Screen 2



Screen 3


Skype™ - martin anderson
File View Contacts Tools Call Help
Add Contact Search Conference Chat Send File Profile Hold Mute
Martin Anderson (video is great..)
54 new events
€6.48
Contacts Dial History Barbara Anderson
Barbara Anderson
(barbara989521)
in San Francisco for two weeks
Stop My Video
Call Duration 01:07
Call with Barbara Anderson
4,017,250 Users Online

Tell:

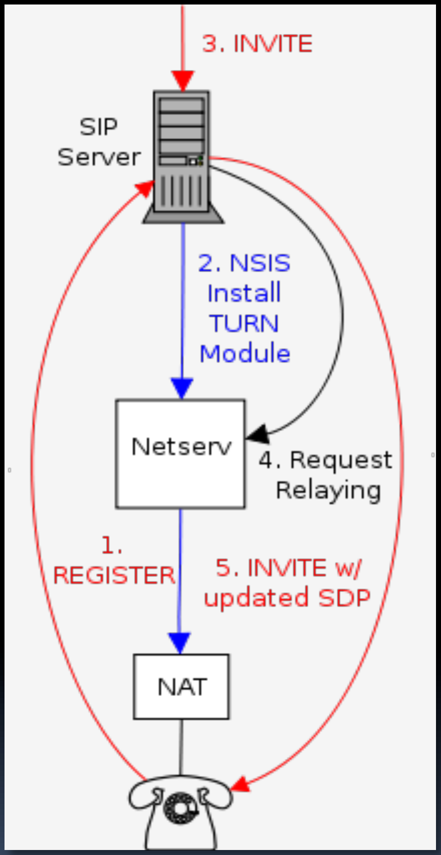
Media relay running in NetServ

- Closer to user agents
- Higher call quality for users
- Reduced cost for ITSP

Show:

1. SIP server sends signal to install module
2. Screen 2 displays module being installed (blue arrow)
3. Make a new video call
4. Call flow through NetServ relay displayed on screen 2
5. Screen 1 & 3 show much better video quality

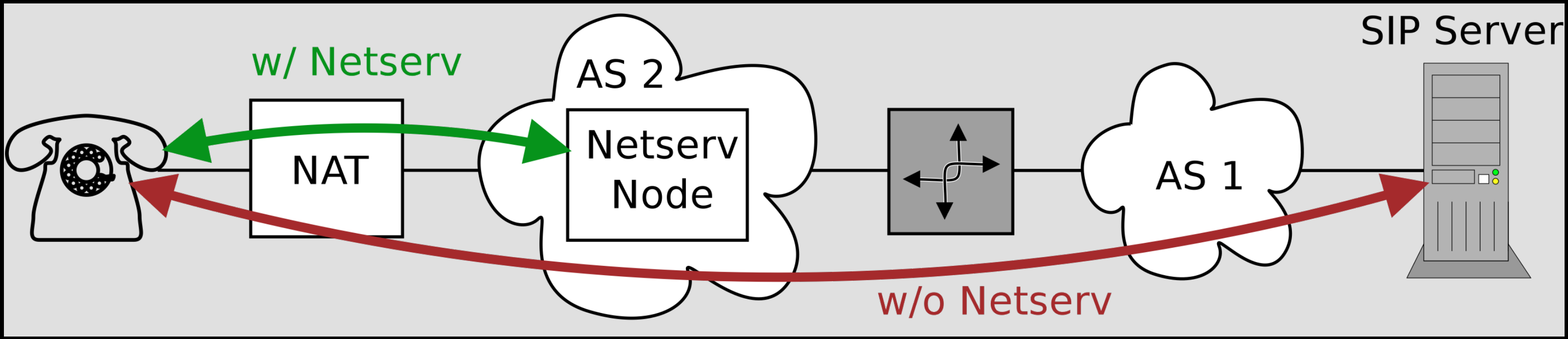
Media Relay Signaling



1. UA registers with SIP server
2. SIP server detects NAT:
   - Sends NSIS signal towards UA
   - Netserv node close to UA is discovered
   - Netserv node installs TURN module
   - SIP server remembers to use the TURN module for the UA
3. An INVITE is received for UA
4. SIP server sends relaying request to the TURN server
5. INVITE with updated SDP is sent to UA

NetServ based TURN module is installed at registration time to speed-up processing of INVITE signaling.

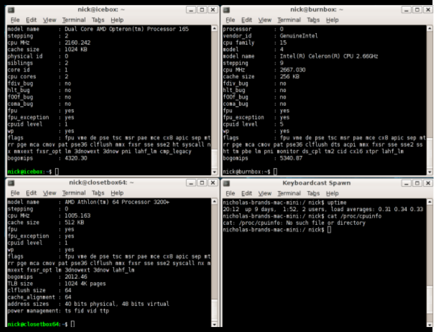
NAT Keep-alive Responder



- NAT Keep-alive responder off
  - UA behind NAT must send keep-alive messages
  - Major bottleneck for SIP server
- NAT Keep-alive responder on
  - Module responds on behalf of SIP server
  - No traffic to server

NAT keep-alive responder

Screen 1



nick@icebox: ~

```
model name      : Dual Core AMD Opteron(tm) Processor 165
stepping        : 2
cpu MHz         : 2160.242
cache size      : 1024 KB
physical id     : 0
siblings        : 2
core id         : 1
cpu cores       : 2
fdiv_bug        : no
hlt_bug         : no
f00f_bug        : no
coma_bug        : no
fpu             : yes
fpu_exception   : yes
cpuid level     : 1
wp              : yes
flags           : fpu vme de pse tsc msr pae mce cx8 apic sep mt
rr pge mca cmov pat pse36 clflush mmx fxsr sse sse2 ht syscall n
x mmxext fxsr_opt lm 3dnowext 3dnow pni lahf_lm cmp_legacy
bogomips        : 4320.30

nick@icebox:~$ 
```

nick@burnbox: ~

```
processor       : 0
vendor_id       : GenuineIntel
cpu family      : 15
model           : 4
model name      : Intel(R) Celeron(R) CPU 2.66GHz
stepping        : 9
cpu MHz         : 2667.030
cache size      : 256 KB
fdiv_bug        : no
hlt_bug         : no
f00f_bug        : no
coma_bug        : no
fpu             : yes
fpu_exception   : yes
cpuid level     : 5
wp              : yes
flags           : fpu vme de pse tsc msr pae mce cx8 apic sep mt
rr pge mca cmov pat pse36 clflush dts acpi mmx fxsr sse sse2 ss
ht tm pbe lm pni monitor ds_cpl tm2 cid cx16 xtpr lahf_lm
bogomips        : 5340.87

nick@burnbox:~$ 
```

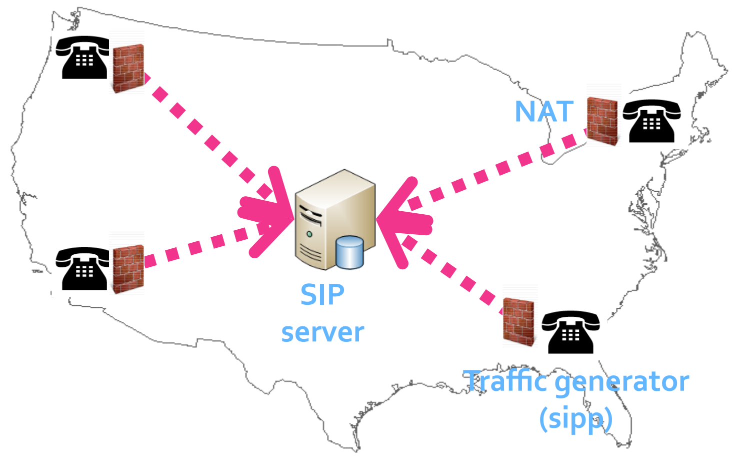
nick@closetbox64: ~

```
model name      : AMD Athlon(tm) 64 Processor 3200+
stepping        : 0
cpu MHz         : 1005.163
cache size      : 512 KB
fpu             : yes
fpu_exception   : yes
cpuid level     : 1
wp              : yes
flags           : fpu vme de pse tsc msr pae mce cx8 apic sep mt
rr pge mca cmov pat pse36 clflush mmx fxsr sse sse2 syscall nx m
mxext fxsr_opt lm 3dnowext 3dnow lahf_lm
bogomips        : 2012.46
TLB size        : 1024 4K pages
clflush size    : 64
cache_alignment : 64
address sizes   : 40 bits physical, 48 bits virtual
power management: ts fid vid ttp

nick@closetbox64:~$ 
```

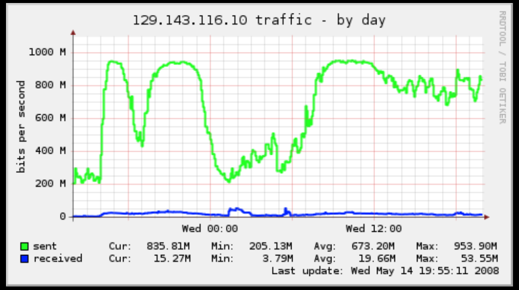
Keyboardcast Spawn

```
nicholas-brands-mac-mini:/ nick$ uptime
20:12  up 9 days,  1:52, 2 users, load averages: 0.31 0.34 0.33
nicholas-brands-mac-mini:/ nick$ cat /proc/cpuinfo
cat: /proc/cpuinfo: No such file or directory
nicholas-brands-mac-mini:/ nick$ 
```

Screen 2



Screen 3



```
🟩 sent        Cur:  835.81M   Min:  205.13M   Avg:  673.20M   Max:  953.90M
🟦 received    Cur:   15.27M   Min:    3.79M   Avg:   19.66M   Max:   53.55M
                                        Last update: Wed May 14 19:55:11 2008
```

High cost for ITSP

$1,344,550

Tell:

- UA behind NAT must keep sending keep-alive message
- Major bottleneck on SIP server today

Show:

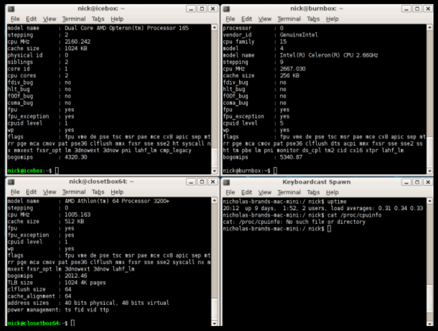
Screen 1: Traffic generators send keep-alive messages to SIP server

Screen 2: Packet flows shown on screen

Screen 3: High traffic volume, thus high cost for ITSP

NAT keep-alive responder

Screen 1



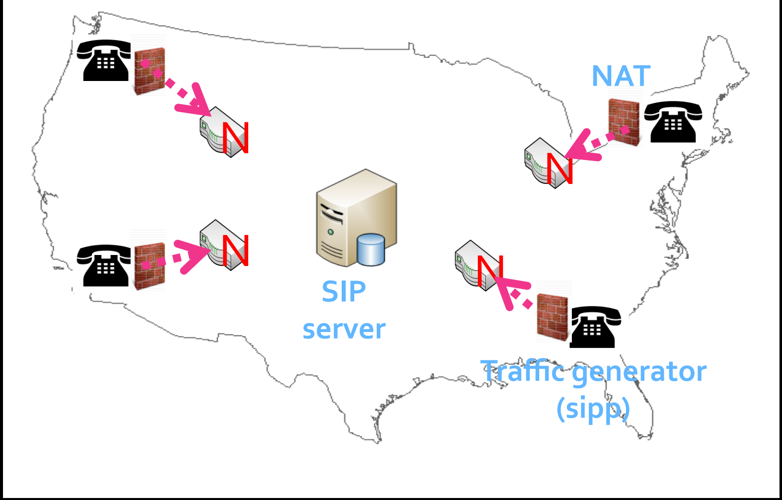
```
model name      : Dual Core AMD Opteron(tm) Processor 165
stepping        : 2
cpu MHz         : 2160.242
cache size      : 1024 KB
physical id     : 0
siblings        : 2
core id         : 1
cpu cores       : 2
fdiv_bug        : no
hlt_bug         : no
f00f_bug        : no
coma_bug        : no
fpu             : yes
fpu_exception   : yes
cpuid level     : 1
wp              : yes
flags           : fpu vme de pse tsc msr pae mce cx8 apic sep mt
rr pge mca cmov pat pse36 clflush mmx fxsr sse sse2 ht syscall n
x mmxext fxsr_opt lm 3dnowext 3dnow pni lahf_lm cmp_legacy
bogomips        : 4320.30

nick@icebox:~$ 
```

```
processor       : 0
vendor_id       : GenuineIntel
cpu family      : 15
model           : 4
model name      : Intel(R) Celeron(R) CPU 2.66GHz
stepping        : 9
cpu MHz         : 2667.030
cache size      : 256 KB
fdiv_bug        : no
hlt_bug         : no
f00f_bug        : no
coma_bug        : no
fpu             : yes
fpu_exception   : yes
cpuid level     : 5
wp              : yes
flags           : fpu vme de pse tsc msr pae mce cx8 apic sep mt
rr pge mca cmov pat pse36 clflush dts acpi mmx fxsr sse sse2 ss
ht tm pbe lm pni monitor ds_cpl tm2 cid cx16 xtpr lahf_lm
bogomips        : 5340.87

nick@burnbox:~$ 
```

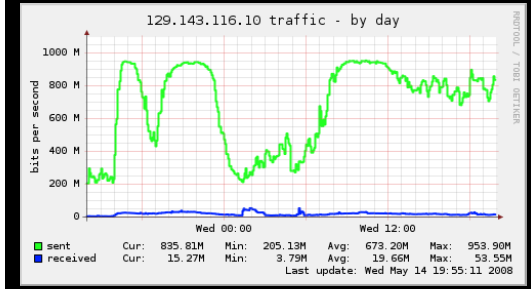
```
model name      : AMD Athlon(tm) 64 Processor 3200+
stepping        : 0
cpu MHz         : 1005.163
cache size      : 512 KB
fpu             : yes
fpu_exception   : yes
cpuid level     : 1
wp              : yes
flags           : fpu vme de pse tsc msr pae mce cx8 apic sep mt
rr pge mca cmov pat pse36 clflush mmx fxsr sse sse2 syscall nx m
mxext fxsr_opt lm 3dnowext 3dnow lahf_lm
bogomips        : 2012.46
TLB size        : 1024 4K pages
clflush size    : 64
cache_alignment : 64
address sizes   : 40 bits physical, 48 bits virtual
power management: ts fid vid ttp

nick@closetbox64:~$ 
```

```
nicholas-brands-mac-mini:/ nick$ uptime
20:12  up 9 days,  1:52, 2 users, load averages: 0.31 0.34 0.33
nicholas-brands-mac-mini:/ nick$ cat /proc/cpuinfo
cat: /proc/cpuinfo: No such file or directory
nicholas-brands-mac-mini:/ nick$ 
```

Screen 2



Screen 3



No keep-alive traffic

$ 0 . 0 0

Tell:

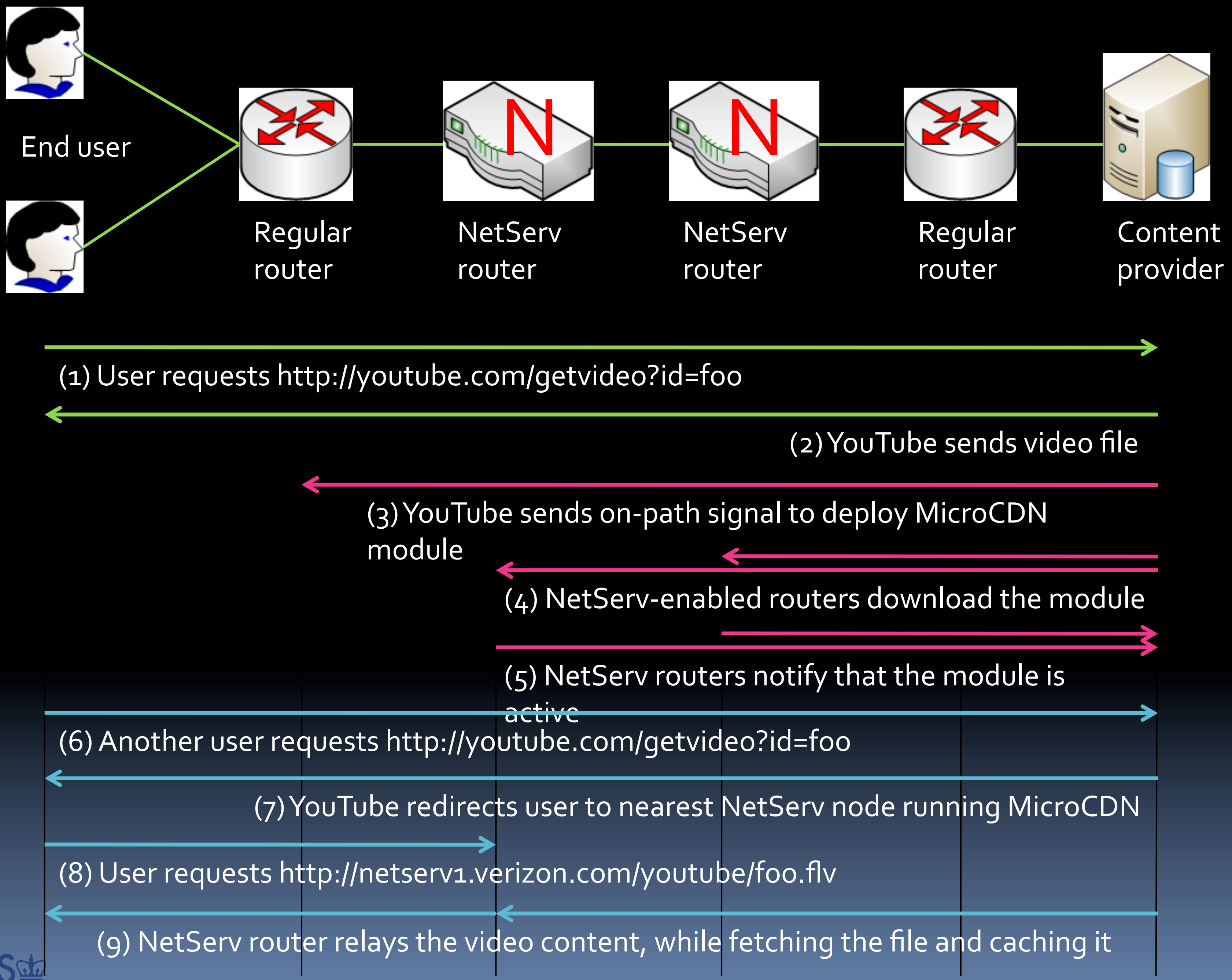
- SIP server installs modules into NetServ nodes closer to users
- Modules respond to keep-alive messages on behalf of SIP server
- Keep-alive messages do not reach SIP server

Show:

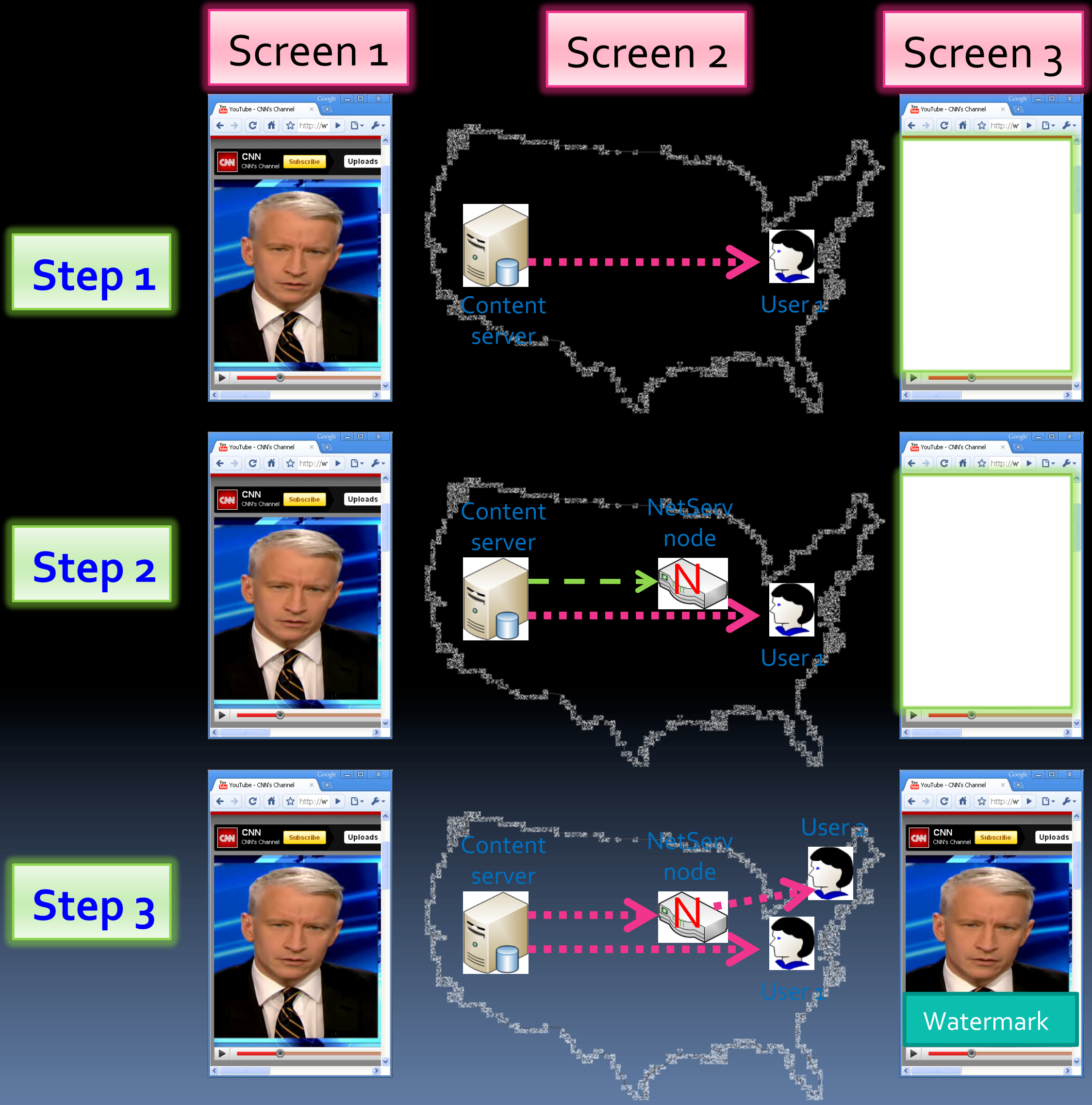
Screen 1: Traffic generators keep sending keep-alive messages to the SIP server

Screen 2: Packet flows terminate at NetServ nodes

Screen 3: SIP server sees no keep-alive traffic, thus no keep-alive cost to ITSP


End user
Regular router
NetServ router
NetServ router
Regular router
Content provider
(1) User requests http://youtube.com/getvideo?id=foo
(2) YouTube sends video file
(3) YouTube sends on-path signal to deploy MicroCDN module
(4) NetServ-enabled routers download the module
(5) NetServ routers notify that the module is active
(6) Another user requests http://youtube.com/getvideo?id=foo
(7) YouTube redirects user to nearest NetServ node running MicroCDN
(8) User requests http://netserv1.verizon.com/youtube/foo.flv
(9) NetServ router relays the video content, while fetching the file and caching it

MicroCDN – watermarking



User 1 downloads and watches video content from provider

Content server sends on-path signal to install MicroCDN module into NetServ router

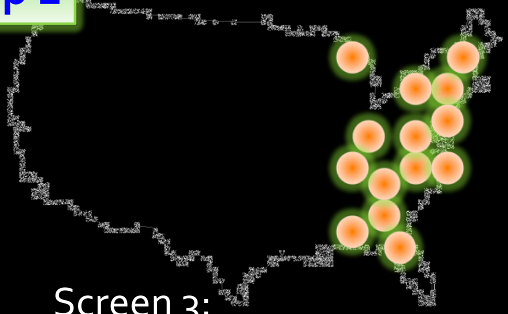
User 2's request gets redirected to NetServ router, which serves processed video

MicroCDN – module migration

Tell:
- •PlanetLab nodes run scripts fetching small files from the web server
- •MicroCDN modules with short TTL keep getting installed and removed
- •PlanetLab scripts are choreographed to make modules *migrate* westward!

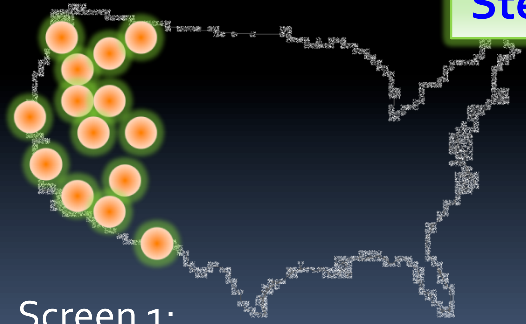
Step 1

Screen 2:
NetServ nodes popping up
In the eastern region



Screen 3:
Web traffic generated from
eastern PlanetLab nodes

Step 2



Screen 1:
Web traffic generated from
western PlanetLab nodes

Screen 2:
(Flickering) NetServ nodes
migrating to the wild west!

This is a rough idea. We are still working out the details to see if this can be done by GEC9.

Looking ahead

Future: NetServ everywhere

- From big to small devices
- Real router: Juniper's JUNOS
- Personal computer: Kernel-mode Click
- Home router: Linux using iptables
- Security and resource control
  - Enable various deployment scenarios
  - Support different economic incentives

The network services fallacy

- We tried adding network services as protocols:
  - multicast
  - QoS
  - mobility
  - security
- All were, more-or-less, failures
  - (or underperformed expectations)
  - hard to secure, not quite right

Thoughts on architecture

- Long-term constant: service model
  - equivalent of railroad track & road width
- Identify core functions we need
  - routing
  - congestion control
  - name lookup
  - path state establishment
  - …
- Learn from history
  - why didn't these get done "right"?
- Need engineering principles
- Requirement list doesn't help

Future Internet architecture?

- Really closer to urban design
  - zoning, fire codes and infrastructure (rail, water)
    - plus oversight (fire marshal & building inspector)
  - architecture changes, urban designs stay
    - see Washington, DC & Berlin
- “Architecture” must be
  - expressible in one sentence
  - avoid limiting options (unknown unknowns)
  - avoid imposing unnecessary costs

Conclusion

NetServ
- rapid on-path services, with storage
- moderate overhead

(GENI) VMs
- Long-term
- Full access, but not composable

OpenFlow
- rule-based packet handling
- can be controlled by NetServ

NetFPGA
- mainly packet processing
- fastest, least flexible