IPv6 at FNAL

(Where We Are; Where We are Going)

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U.S. DEPARTMENT OF ENERGY

Fermilab

Outline

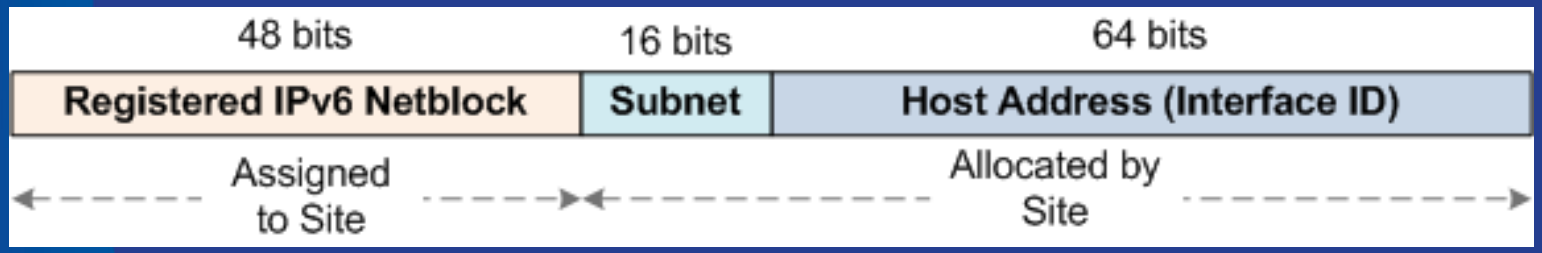
- IPv6 Basics
- Current Status of IPv6 (and IPv4…)
- IPv6 at FNAL Today
- Plans for Moving Forward
- Major Issues to be Addressed

What is IPv6? Why do we want/need it?

- The latest version of the Internet Protocol (IP)
  - Successor to IPv4
- Drafted to alleviate address limitations of IPv4
  - Internet Registry agencies have run out of IPv4 addresses
- 128 bits of address space
  - Versus 32 bits for IPv4
  - Provides 340 undecillion addresses
  - Much more flexible than IPv4 for mobility support
- Designed to be self-configuring
  - Address auto-configuration capabilities
  - Capability to tunnel through IPv4 networks

IPv6 Addressing (I) - IPv6 Address Format

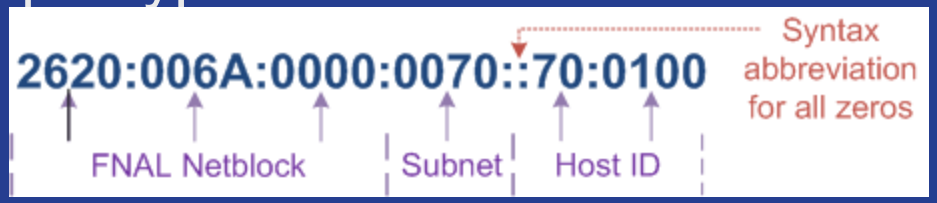
- Default IPv6 address block allocation is /48
  - Host ID is normally left at 64bits
  - Leaving 16 bits for the IPv6 subnet



- No need to be IPv4-like in subnet allocation…
  - Additional address block assignments available as well

IPv6 Addressing (II) - Types of Addresses

- IPv6 interfaces use multiple types of addresses
  - Global addresses:
    - Used for internet communications



  - Link-Local addresses
    - Used for communications within the local subnet

  - Unique local addresses (ULAs):
    - Rough equivalent of IPv4 RFC1918 addresses
  - Privacy address extensions (for SLAAC):
    - Global address that doesn't use MAC address to derive host field
    - Host field component changes regularly
    - Configurable option

IPv6 Addressing (I) - Address Block Types

- Two types of address blocks
  - Provider-Assigned (PA)
    - Service provider issues your IPv6 address block
    - Facilitates more efficient routing from a global perspective
  - Provider-Independent (PI)
    - Obtain your own IPv6 address block from address authority
    - “Needed” for multi-homed sites (multiple ISPs)
    - Minimizes transition difficulties of changing ISPs
- FNAL has two IPv6 /48 address blocks:

ARIN-assigned (PI) block: **2620:006A:0000::/48** **<production network>**

ESnet-assigned (PA) block: **2001:0400:2410::/48** **<used in IPv6 test bed>**

IPv6 Auto-Configuration

- IPv6 addresses can be statically or dynamically configured
- Three dynamic configuration options for global addresses
  - Stateless address auto-configuration (**SLAAC**)
    - End systems configure their own address based on router advertisements (RAs) from neighboring IPv6 router
    - By default, most systems & devices use SLAAC
  - Stateful DHCPv6:
    - Essentially an IPv6 version of DHCP
    - DHCPv6 server implementations emerging; client support varies
  - Stateless DHCPv6 (hybrid):
    - Use SLAAC for global address
    - Use DHCPv6 for additional configuration info (DNS, etc.)
  - Bit fields in RA header determine how clients auto-configure

Dual Stack Operation

- IPv6 and IPv4 address formats are incompatible:
  - An IPv6 system and an IPv4 system can not communicate directly
  - IPv4 systems expected to be around for a long time
- Transition strategy is to run both network stacks on a system (**dual stack**)
- Typical sequence:
  - Dual stack system requests an A (IPv4) record from DNS for a remote system, and also a AAAA (IPv6) record
  - If a AAAA record is returned, the system will normally try IPv6 first:
    - Falling back to trying IPv4 if the IPv6 connection fails
  - Preference of which stack to try first may be configurable, but varies by O/S

Ifconfig on IPv6-enabled Laptop (WinXP)

Wireless Interface

Hardwire Interface

Command Prompt

```
Wireless LAN adapter Wireless Network Connection:

   Connection-specific DNS Suffix  . : dhcp.fnal.gov
   Description . . . . . . . . . . . : Intel(R) Centrino(R) Advanced-N 6205
   Physical Address. . . . . . . . . : 8C-70-5A-87-A4-F8
   DHCP Enabled. . . . . . . . . . . : Yes
   Autoconfiguration Enabled . . . . : Yes
   Link-local IPv6 Address . . . . . : fe80::d46d:5958:345b:2a06%16(Preferred)
   IPv4 Address. . . . . . . . . . . : 131.225.173.28(Preferred)
   Subnet Mask . . . . . . . . . . . : 255.255.252.0
   Lease Obtained. . . . . . . . . . : Thursday, November 01, 2012 10:53:31 AM
   Lease Expires . . . . . . . . . . : Thursday, November 01, 2012 5:23:30 PM
   Default Gateway . . . . . . . . . : 131.225.172.1
   DHCP Server . . . . . . . . . . . : 1.1.1.1
   DHCPv6 IAID . . . . . . . . . . . : 529297498
   DHCPv6 Client DUID. . . . . . . . : 00-01-00-01-17-AB-15-44-24-B6-FD-FA-A8-B4

   DNS Servers . . . . . . . . . . . : 131.225.0.254
   Primary WINS Server . . . . . . . : 131.225.9.1
   Secondary WINS Server . . . . . . : 131.225.110.15
   NetBIOS over Tcpip. . . . . . . . : Enabled

Ethernet adapter Bluetooth Network Connection:

   Media State . . . . . . . . . . . : Media disconnected
   Connection-specific DNS Suffix  . :
   Description . . . . . . . . . . . : Bluetooth Device (Personal Area Network)
   Physical Address. . . . . . . . . : D0-DF-9A-40-DB-44
   DHCP Enabled. . . . . . . . . . . : Yes
   Autoconfiguration Enabled . . . . : Yes

Ethernet adapter Local Area Connection:

   Connection-specific DNS Suffix  . : dhcp.fnal.gov
   Description . . . . . . . . . . . : Intel(R) 82579LM Gigabit Network Connecti
on
   Physical Address. . . . . . . . . : 24-B6-FD-FA-A8-B4
   DHCP Enabled. . . . . . . . . . . : Yes
   Autoconfiguration Enabled . . . . : Yes
   IPv6 Address. . . . . . . . . . . : 2620:6a:0:87:71b5:7aba:7a5f:b7e5(Preferre
d)
   Temporary IPv6 Address. . . . . . : 2620:6a:0:87:68fc:c6c:2783:d537(Preferred
)
   Link-local IPv6 Address . . . . . : fe80::71b5:7aba:7a5f:b7e5%12(Preferred)
   IPv4 Address. . . . . . . . . . . : 131.225.82.200(Preferred)
   Subnet Mask . . . . . . . . . . . : 255.255.248.0
   Lease Obtained. . . . . . . . . . : Monday, October 22, 2012 8:50:52 AM
   Lease Expires . . . . . . . . . . : Friday, November 02, 2012 12:18:26 PM
   Default Gateway . . . . . . . . . : fe80::20b:45ff:feb0:7c80%12
                                       131.225.87.200
   DHCP Server . . . . . . . . . . . : 131.225.8.120
   DNS Servers . . . . . . . . . . . : 131.225.0.254
   Primary WINS Server . . . . . . . : 131.225.9.1
   Secondary WINS Server . . . . . . : 131.225.110.15
   NetBIOS over Tcpip. . . . . . . . : Enabled
```

Link-Local IPv6 Address

Global IPv6 Addresses

IPv6 Default Gateway

Tunnels

- IPv6 has native tunneling capabilities to work across IPv4-only networks
- Regarded as a transition tool to assist islands of IPv6
- Intended to work automatically & transparently
- IPv6 tunnels come in many flavors:
  - Router-to-Router
  - Host-to-Router
  - Router-to-Host
  - Host-to-Host

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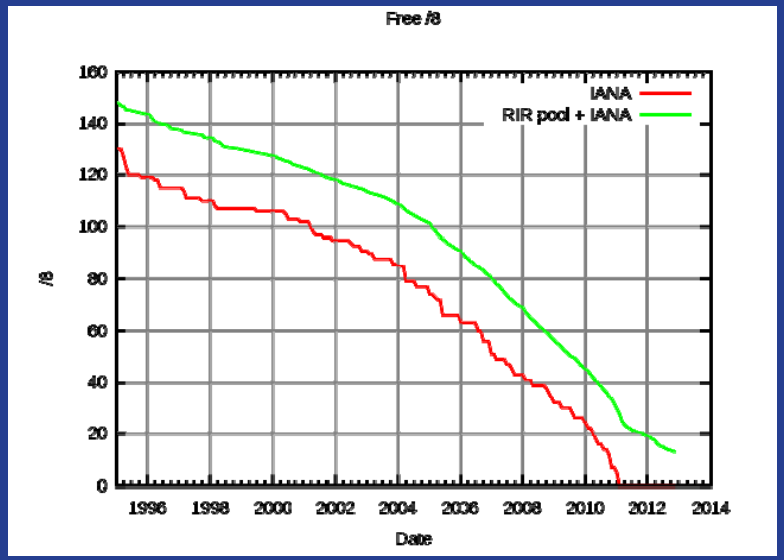
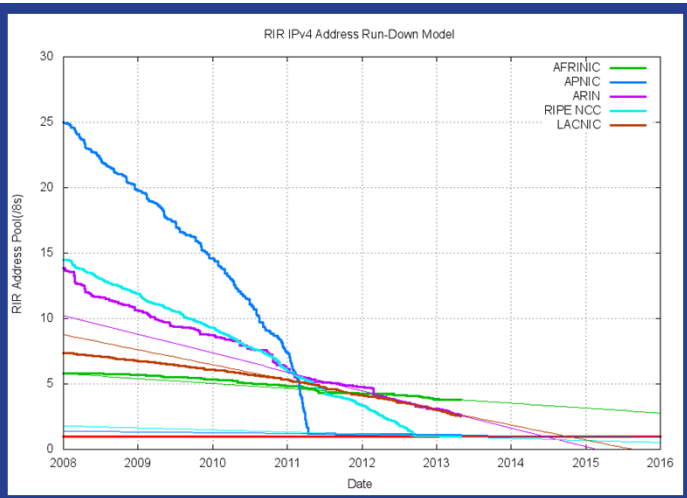
IPv4 Address Exhaustion is Happening…

- IANA = global IP address body
  - Issued remaining address blocks in Feb' 2011



- RIRs = regional address bodies:
  - APNIC = Asia
  - RIPE = Europe
  - ARIN = North America
  - LACNIC = Latin/South America
  - AFRINIC = Africa



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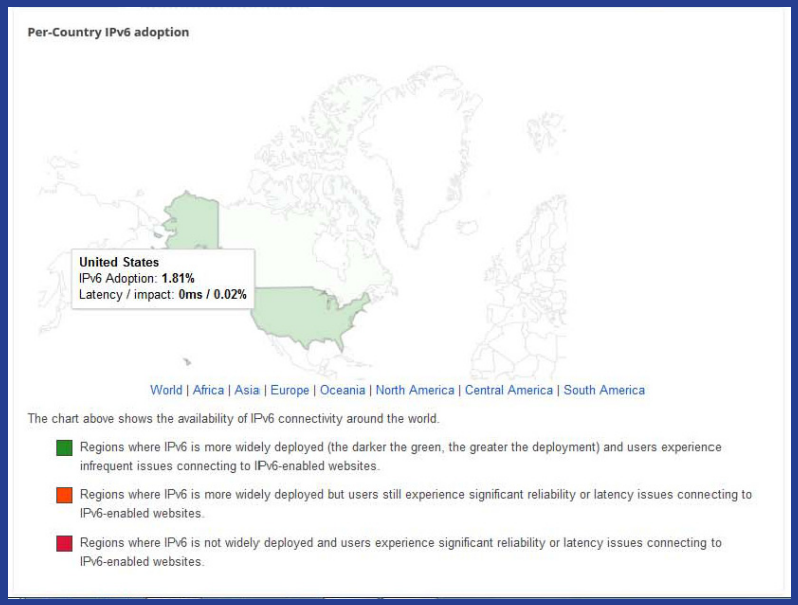
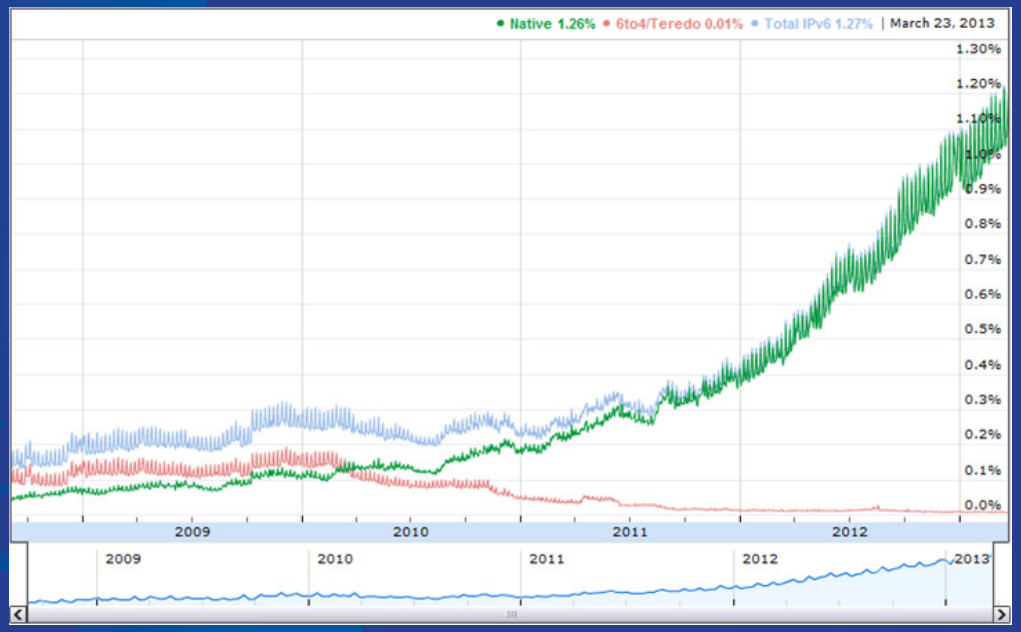
Current status of IPv6 deployment

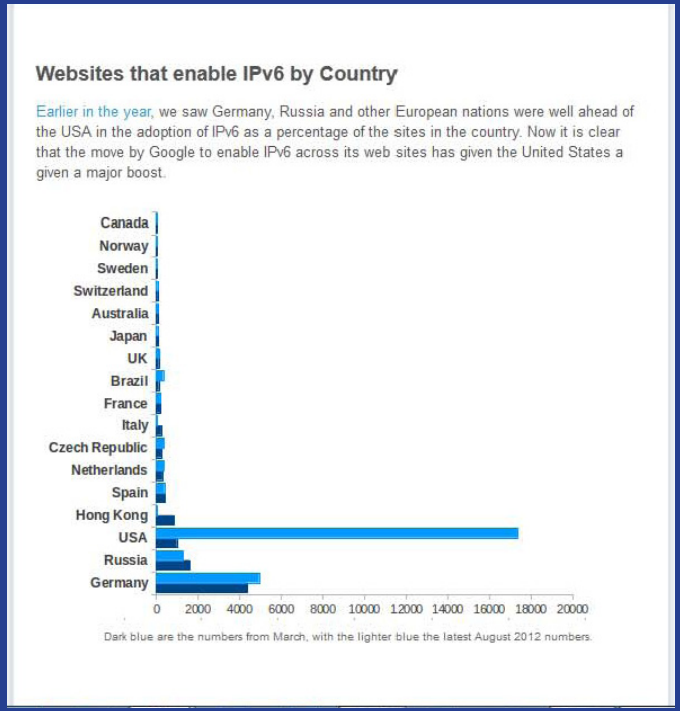
- World-wide IPv6 deployment has been slow
  - Difficult to overcome “IPv4 works; why change?” issue
  - A few countries have established strategic government policies
    - US joined that list
    - European countries looking to emulate US policies



Use of IPv6 Starting To Get Traction

- Google tracks its IPv6 versus IPv4 accesses
  - Worldwide use is at ~1.25%
    - Interpret trend as you wish….
  - Use in US is ~2.4%





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Vendors & Service Providers Move to IPv6

- Network OEMs provide full IPv6 support now
  - In US, all federal network procurements must be IPv6 compliant
  - CPE vendors now supporting IPv6 on home routers as well
  - Implementations now in ASICs
- Operating systems:
  - Windows 7 & MacOS 10.6 enable IPv6 **by default**
  - Linux has IPv6 support for 5+ years (but not enabled by default)
- Tablets & smart phones have IPv6 support
- Internet service providers:
  - Comcast targeting 100% IPv6 availability to homes
  - AT&T, Verizon, Time-Warner, & others are also deploying
- Content service providers:
  - Google, Facebook, Yahoo, Youtube, Wikipedia support IPv6

OMB IPv6 “Mandates” for 2012 & 2014

- End of FY12: Public-facing servers to support native IPv6
  - For DOE, this means e-mail, DNS, & web services
  - “Public-facing” interpreted as “intended for the general public”
- End of FY14: Internal client systems to support IPv6
  - Essentially, this means all desktops
- Labs are not included in DOE IPv6 compliance reporting
  - Current DOE interpretation: Labs aren’t bound to OMB mandate
- “Mandate” lacks enforcement element
  - NIST dashboard for agency compliance:

http://fedv6-deployment.antd.nist.gov/cgi-bin/generate-gov

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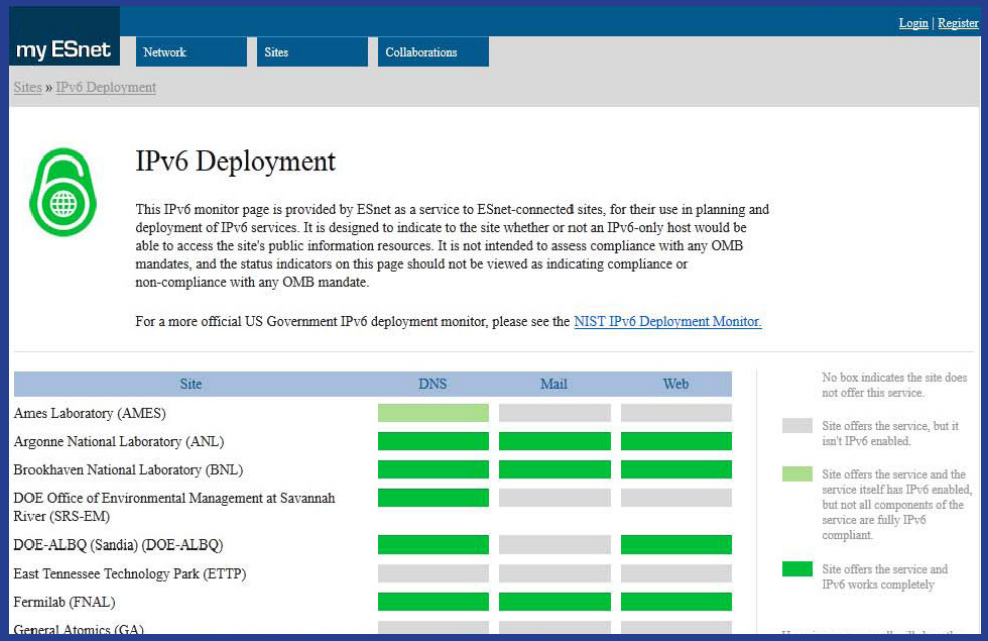
FNAL & the OMB 2012 IPv6 Milestones

- We're done:
  - DNS in March '12
  - Email in Aug. '12
  - Central web in Oct. '12



- Seven SC Labs are "all green" today

ESnet IPv6 Dashboard:
https://my.es.net/sites/ipv6

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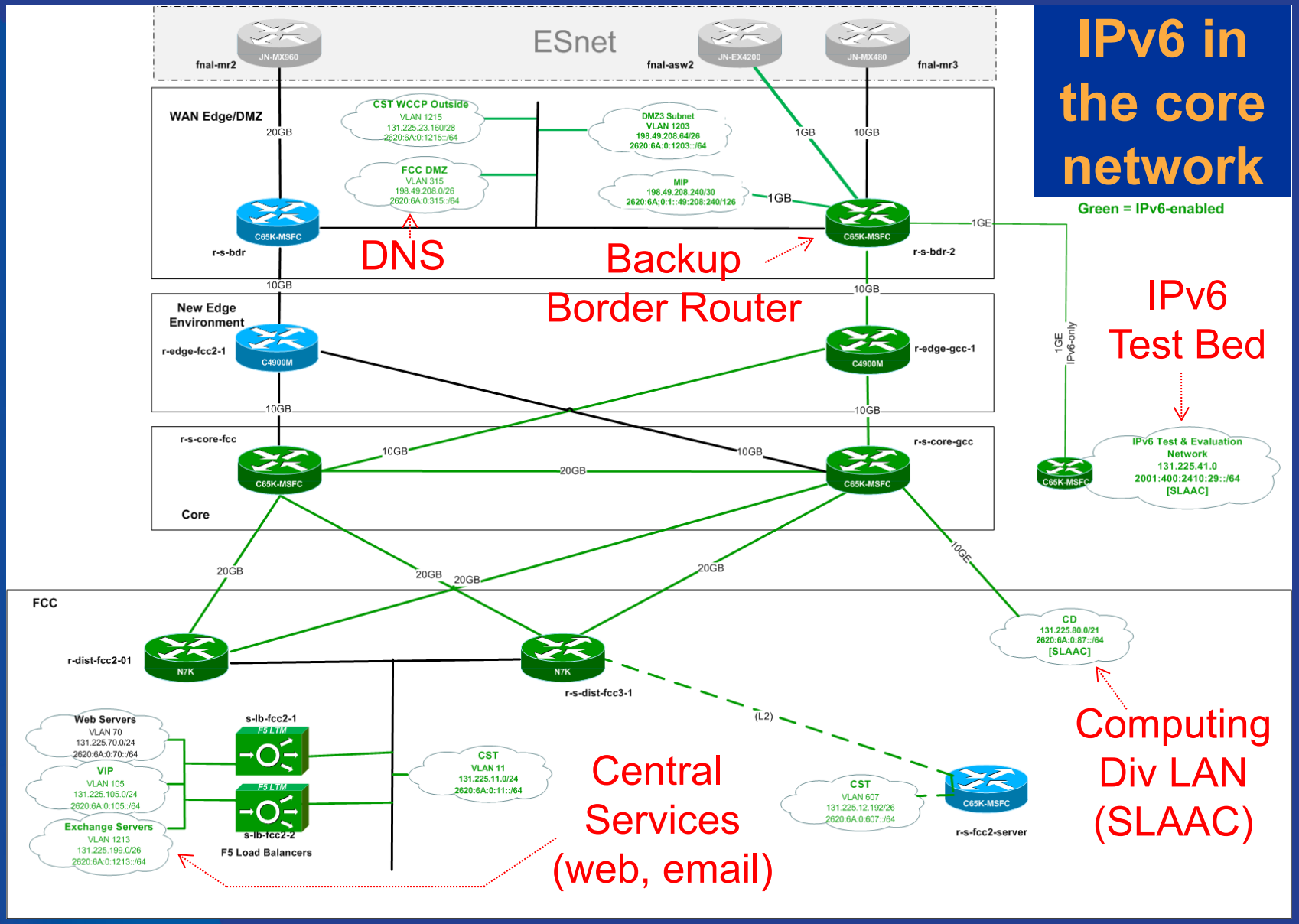
Accomplishments in Conjunction with OMB 2012 Milestones

- Provider-Independent (PI) address space procured
- Addressing model adopted & plan written
  - Will overlay IPv4 addressing that's in place
- Test bed environment deployed
- IPv6 Routing in place within core network
- Flow data collection adapted for IPv6 (NetFlow v9)
- Quasi-production IPv6 evaluation with real users
  - Computing Division staff ( )
  - In place since ~2007

Will become the "foundation" of our future IPv6 efforts

IPv6 in the core network



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IPv6 Address Plan – Subnet Allocation Model

- Map to current IPv4 subnet assignments
- /64s for all non point-to-point subnets
  - Point-to-point subnets = /126, not /64
- Based on VLAN assignment
- Decimal equivalents (ie., not in hex)
  - Vlan 87 = IPv6 subnet 87, not 57[hex]

IPv6 Address Assignments - Static

- IPv6 assignment based on IPv4 assignment – last two bytes
  - Again, using decimal equivalents (ie., not in hex)
  - IPv6-only systems – same model; last byte higher than 256
- Examples:

vLAN 70; IPv4 subnet 131.225.70.0/24:

IPv4 addr **131.225.70.100** → IPv6 addr **2620:006A:0000:0070::70.0100**

vLAN 87; IPv4 subnet 131.225.80.0/21:

IPv4 addr **131.225.80.100** → IPv6 addr **2620:006A:0000:0087::80:0100**

IPv4 addr **131.225.87.100** → IPv6 addr **2620:006A:0000:0087::87:0100**

Routing Model & Issues

- Routing Protocols:
  - EGP = BGP4 (just extension to MBGP)
  - IGP = OSPFv3 (ships in the night with IPv4 OSPFv2)
  - Router ID = existing IPv4 loopback address
- Routing Model:
  - Map to the existing IPv4 routing configuration
- OSPFv3 Routing Authentication:
  - Requires complex configuration of IPsec tunnel today
    - Not doing authentication right now
  - Cisco scheduled to implement simple CLI command for IPsec ESP authentication tunnel later this year

IPv6 Tools in Use

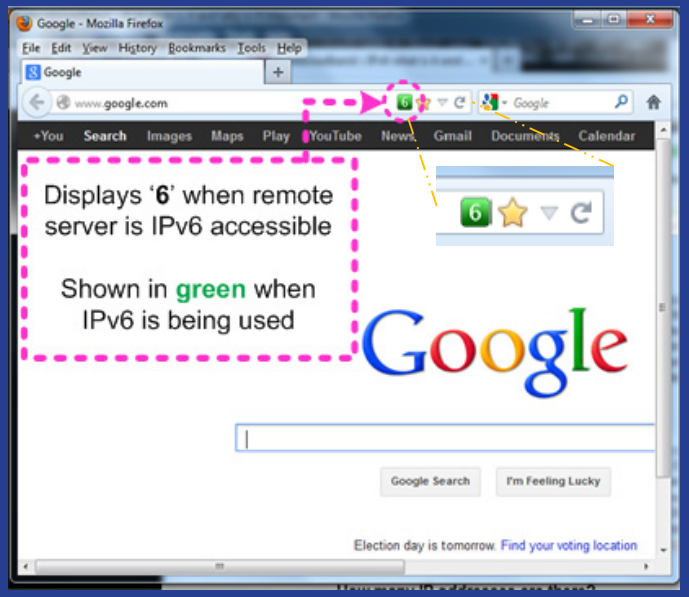
- Ping & Traceroute:

O/S	Ping	Traceroute
Windows XP	**Ping6**	**Tracert6**
Windows 7	**Ping** *<-4;-6 >*	**Tracert** *<-4;-6>*
MacOS	**Ping6**	**Traceroute6**
Linux	**Ping6**	**Traceroute6**

```
Terminal — bash — 138×37
cd-117052m:~ vyto$ traceroute6 -I www.isc.org
traceroute6 to www.isc.org (2001:4f8:0:2::d) from 2620:6a::87:c62c:3ff:fe3c:9a4f,
 1  r-s-fapl-ge2-5.fnal.gov  0.934 ms  0.513 ms  0.466 ms
 2  vlan371.r-s-bdr-2.fnal.gov  0.680 ms  0.517 ms  0.502 ms
 3  2001:400:2402:8::1  0.531 ms  0.472 ms  0.458 ms
 4  chicsdn2-ip-fnalmr3.es.net  1.907 ms  1.967 ms  1.956 ms
 5  eqxchirt1-10g-chicsdn2.es.net  2.078 ms  2.074 ms  2.233 ms
 6  chi-ibx.r1.ord1.isc.org  3.292 ms  3.881 ms  3.248 ms
 7  int-0-0-1-8.r1.pao1.isc.org  53.760 ms  53.833 ms  53.544 ms
 8  www.isc.org  53.028 ms  53.194 ms  53.323 ms
cd-117052m:~ vyto$ ping6 www.isc.org
PING6(56=40+8+8 bytes) 2620:6a::87:c62c:3ff:fe3c:9a4f --> 2001:4f8:0:2::d
16 bytes from 2001:4f8:0:2::d, icmp_seq=0 hlim=53 time=53.708 ms
16 bytes from 2001:4f8:0:2::d, icmp_seq=1 hlim=53 time=53.490 ms
16 bytes from 2001:4f8:0:2::d, icmp_seq=2 hlim=53 time=53.539 ms
16 bytes from 2001:4f8:0:2::d, icmp_seq=3 hlim=53 time=53.425 ms
16 bytes from 2001:4f8:0:2::d, icmp_seq=4 hlim=53 time=53.616 ms
^C
--- www.isc.org ping6 statistics ---
5 packets transmitted, 5 packets received, 0.0% packet loss
round-trip min/avg/max/std-dev = 53.425/53.556/53.708/0.098 ms

cd-117052m:~ vyto$
```

- Firefox **Sixornot**: add-on that indicates IPv6 accessibility/use:
  - **IPvFoo** (Google Chrome) & **IPvFox** (Firefox) are very similar
  - Haven't found counterpart for IE…



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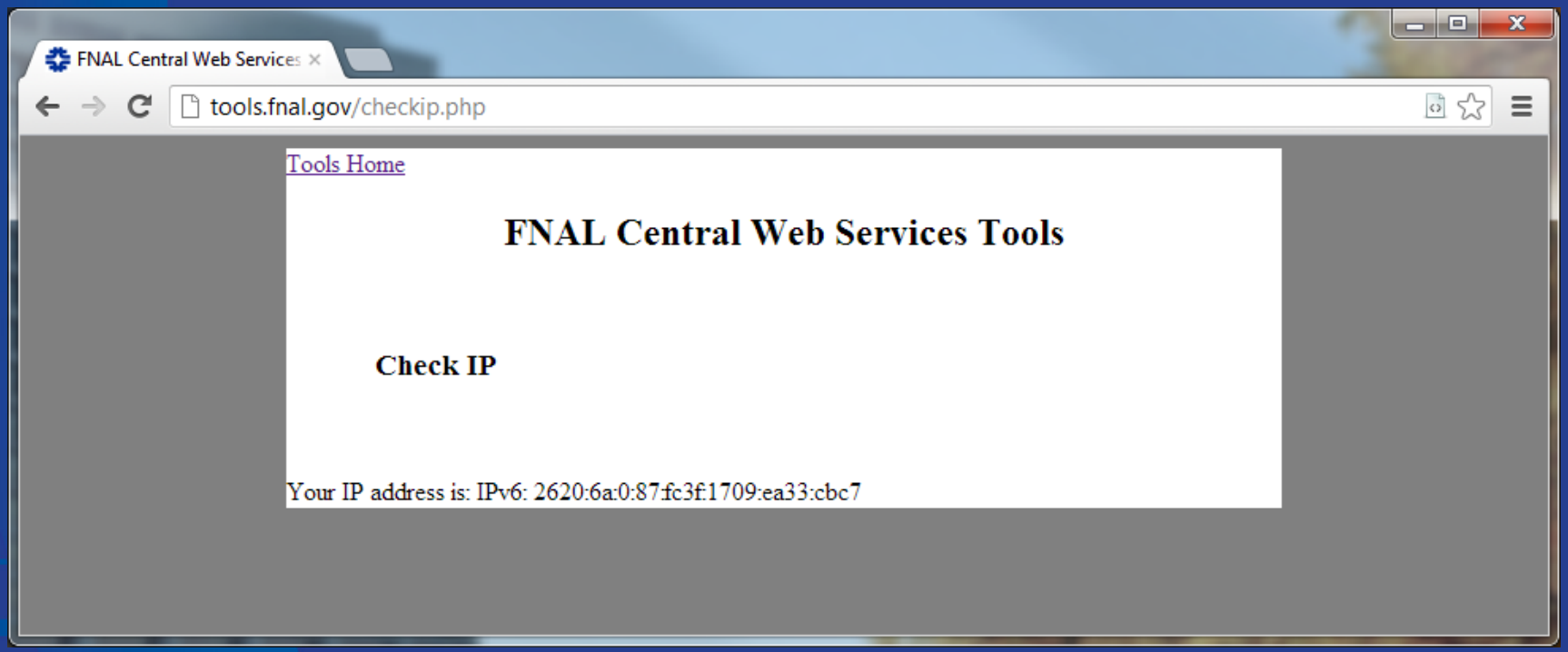
IPv6 Address Verification Service

IPv6 or IPv4 verification is located at:

http://tools.fnal.gov/checkip.php



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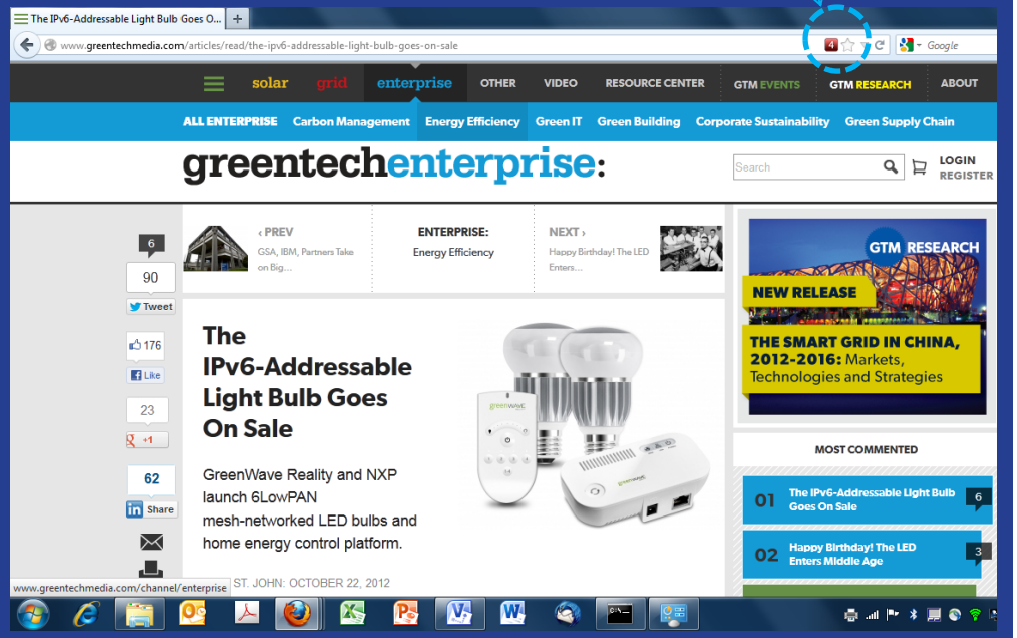
Trying to Think Strategically; Not Tactically

A little irony here…

- IPv6-addressable light bulb (LED)
  - Uses 6LoWPAN over IEEE 802.15.4
  - $200 for the kit
  - $30/light bulb
  - Why we might need an undecillion addresses…



- IPv6 autoconfiguration & address space is enabling technology…

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IPv6 Planning Scope: Taking a Broad View

What you see shouldn't sink your ship

What you don't see might…

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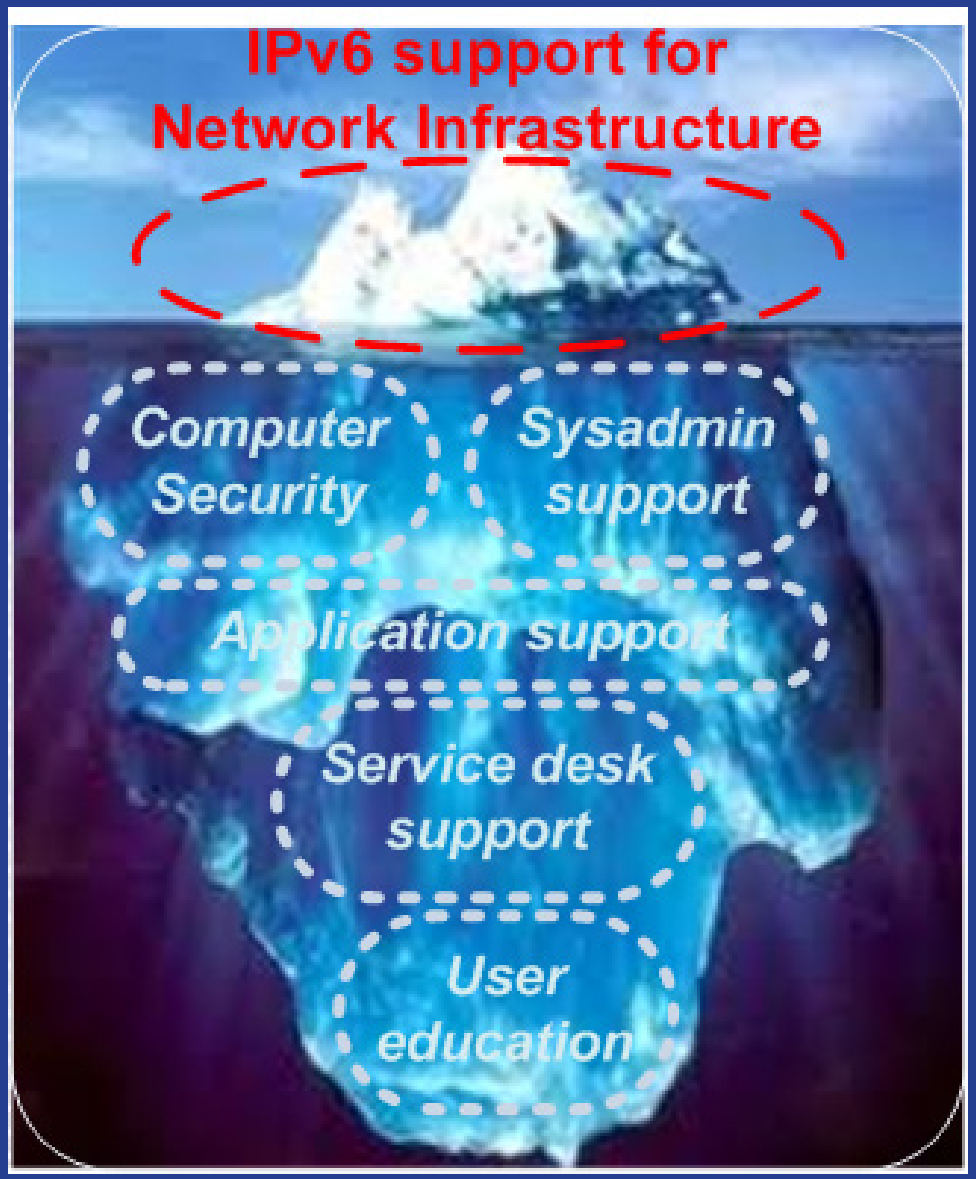
IPv6 support for
Network Infrastructure
Computer Security
Sysadmin support
Application support
Service desk support
User education

FNAL IPv6 Directions (I)

- Planned direction:

  Implement limited deployment of **production-quality** IPv6 user support, consistent with OMB directives

  - Based on Computing Div. wired LAN and volunteer wireless

- Specifically, what does this translate to?
  - Develop:
    - Appropriate addressing configuration mechanisms
    - IP address management (IPAM) support comparable to IPv4
    - IPv6 configuration guidance for common platforms
    - IPv6-based monitoring capabilities
  - Adapt existing networking & computer security tools and utilities to support IPv6 addresses

- Not looking to expand current level of deployment

FNAL IPv6 Directions (II)

- Current planning structure:
  - Small group analyzing key IPv6 deployment issues:
    - Address configuration mechanisms (SLAAC)
    - Router configurations & controls
    - Tunnel controls
    - Dual stack considerations
    - Privacy address considerations
  - Also meeting individually with other support groups on IPv6
- Short term road map:
  - Recommendations on key IPv6 technical issues by August
  - Engage other groups to develop FY14 IPv6 support effort plan
- High-level objective:
  - Meet OMB 2014 milestones within limited IPv6 deployment
  - Position ourselves for wider IPv6 deployment with low effort

What About IPv6 for Scientific Computing?

- Current FNAL IPv6 demands:
  - No known requests from FNAL experiments or collaborations
  - Scientific computing services not in scope of OMB directive
    - Not clear whether this was deliberate or oversight
- Test bed facility for scientific computing R&D includes IPv6
- HEPix IPv6 work group has ongoing testing effort:
  - Focusing on HEP applications/middleware

CERN perturbing HEP IPv6 landscape

- CERN expecting to run out of IPv4 addresses in 2014:
  - VMs blamed as major factor
  - Options under consideration:
    - Private IPv4 address space (NAT)
    - IPv6-only VMs (ie., not dual stack…)
- IPv6 is their preferred solution:
  - Native IPv6 seen as more viable than tunneling options
- Moving forward with plans to provide IPv6 service in 2013
  - Dual stack while IPv4 addresses hold out
- Will push LHC community to adopt IPv6

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StateLess Address Auto-Configuration Support (SLAAC)

- It's simple and it works for all clients
  - Privacy address extensions supported
  - May be necessary in the long run for large-scale addressing
    - Think light bulbs…
- But can cause apoplexy among security types…
  - Absence of access control that DHCP currently provides
- Currently grappling with whether & where to use SLAAC
  - We'd like to know & understand managing SLAAC
  - Leaning toward deployment in Guest environment(s)
  - Developing polling-of-router-adjacencies capability considered desirable with or without SLAAC

Shadow IPv6 Networks

- Shadow IPv6 Networks:

  networks that have IPv6 traffic floating around, but not in a controlled or managed manner

- Auto-configuration capabilities enable IPv6 to just “work”
  - Even without SLAAC, IPv6 hosts auto-configure link local address
    - Tunneling capabilities may work automatically too…
    - Potential for someone to send out router advertisements is real
- Question is how to control IPv6 where its not supported
  - Investigating feasibility of implementing wide-scale RA-guard
  - Risk analysis of this type of vulnerability is needed

Tunnel Control

- IPv6 has a myriad of tunneling options:
  - Windows XP & later have 6-to-4 and Teredo tunneling by default
  - Other O/S vary in default tunneling capabilities
- Observed significant IPv6 tunneling flow records through our perimeter.
- Implemented blocking:
  - 6-to-4 anycast address
  - Teredo UDP port
  - IPv6 tunneling protocol port (41)
- Investigating developing captive IPv6 tunnel capabilities
- Expect this to be an ongoing whack-a-mole problem

?

Questions

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