IPv6:
Why, What, When, How?

Steve Deering
Cisco Systems, Inc.
deering@cisco.com

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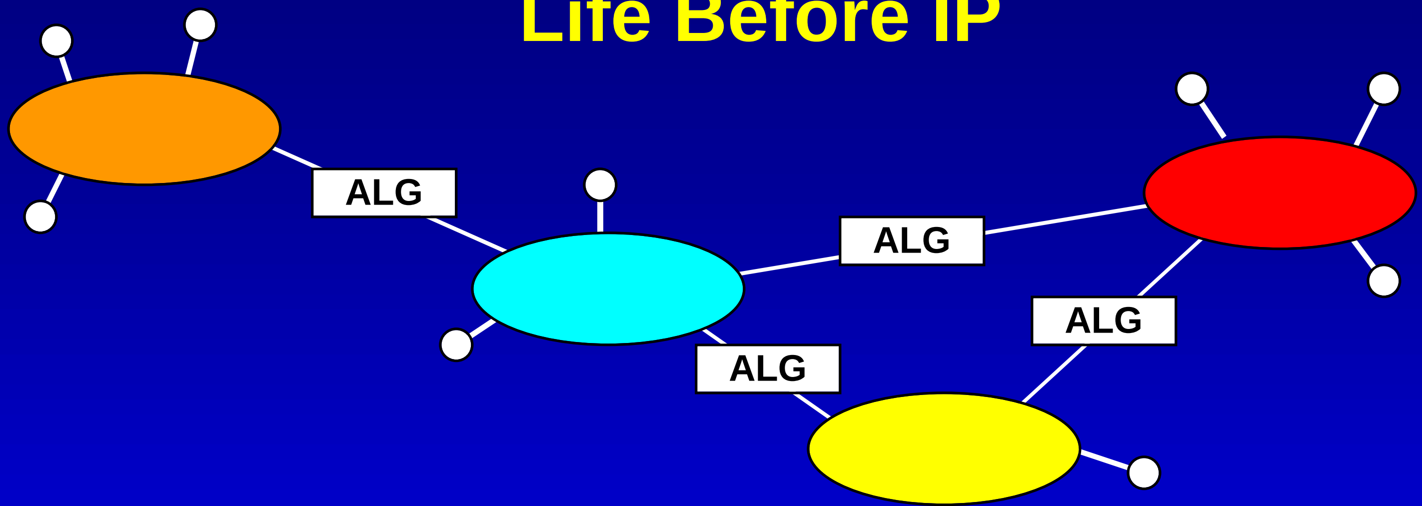
Why?

Life Before IP



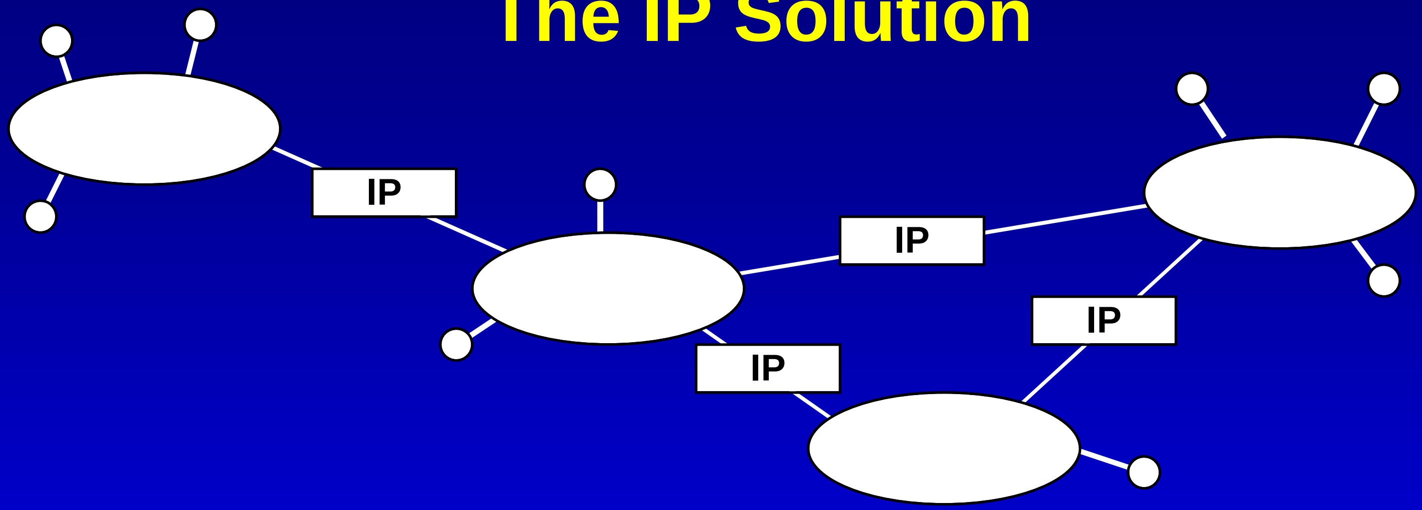
application-layer gateways

- inevitable loss of some semantics
- difficult to deploy new internet-wide applications
- hard to diagnose and remedy end-to-end problems
- stateful gateways inhibited dynamic routing around failures

no global addressability

- ad-hoc, application-specific solutions

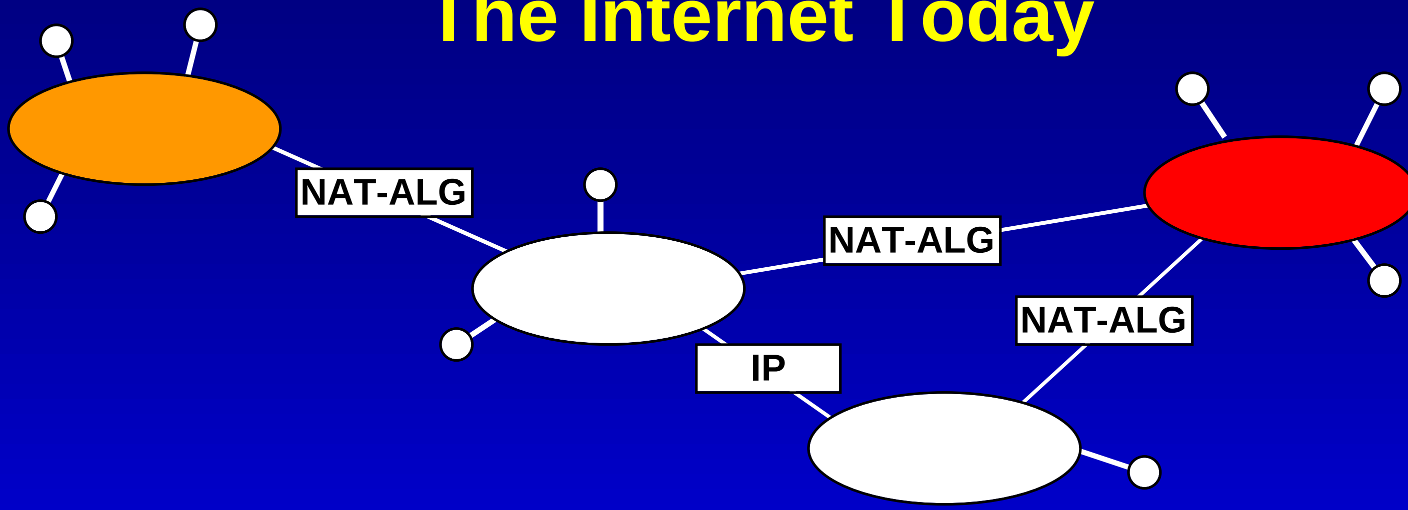
The IP Solution



internet-layer gateways & global addresses

- simple, application-independent, least-common-denominator network service: best-effort datagrams (i.e., packet switching)
- stateless gateways could easily route around failures
- with application-specific knowledge out of the gateways:
  - NSPs no longer had monopoly on providing new services
  - Internet became a platform for rapid, competitive innovation

The Internet Today



network address translators and app-layer gateways

- inevitable loss of some semantics
- difficult to deploy new internet-wide applications
- hard to diagnose and remedy end-to-end problems
- stateful gateways inhibit dynamic routing around failures

no global addressability

- ad-hoc, application-specific (or ignorant!) solutions

But Isn't There Still Lots of IPv4 Address Space Left?

- approx. half the IPv4 space is unallocated today
  - how long does it take for the number of IP devices to double?
- IPv4 addresses are effectively being rationed
  => consumption statistics tell us nothing about the real demand for addresses, or the hardship created by witholding them
  - the difficulty in obtaining addresses is why many (most?) of the NAT-ALGs exist
- new kinds of Internet devices will be much more numerous, and not adequately handled by NATs (e.g., mobile phones, cars, residential servers, ...)

Why Are NATs Not Adequate?

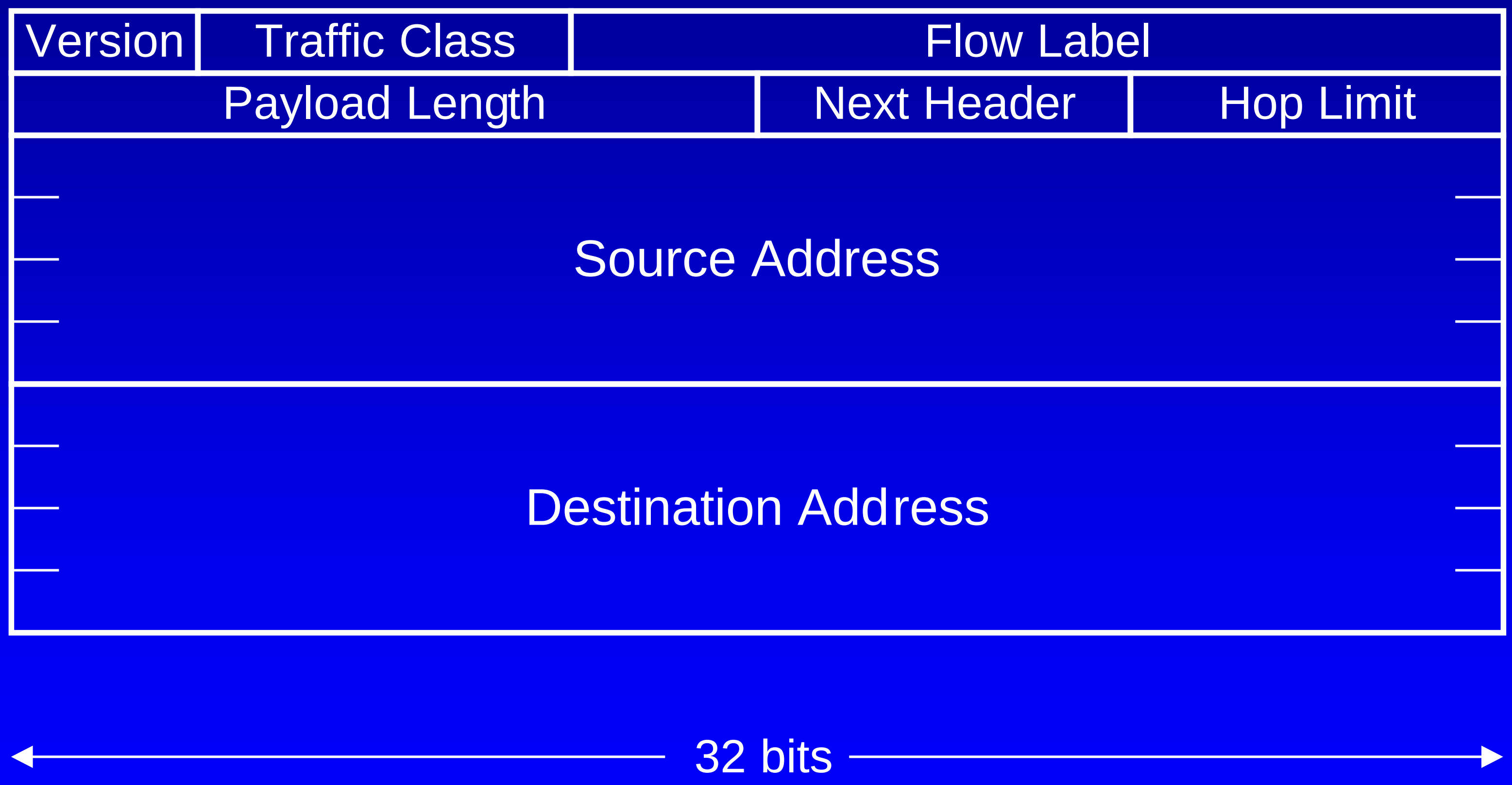
- they won’t work for large numbers of “servers”, i.e., devices that are “called” by others (e.g., IP phones)
- they break most current IP multicast and IP mobility protocols
- they break many existing applications
- they limit the market for new applications and services
- they compromise the performance, robustness, security, and manageability of the Internet

But Can't We Just Make the NATs Better?

- we could keep adding more protocols and features to try to alleviate some of their shortcomings
  - might improve their functionality, but will increase their complexity, fragility, obscurity, unmanagability,...
  - new problems will arise when we start needing inter-ISP NAT
- doing one thing (moving to IPv6) will avoid the need to continue doing many other things to keep the Internet working and growing
- (no, IPv6 is not the only possible solution, but the most mature, feasible, and widely agreed-upon one)

What?

The IPv6 Header



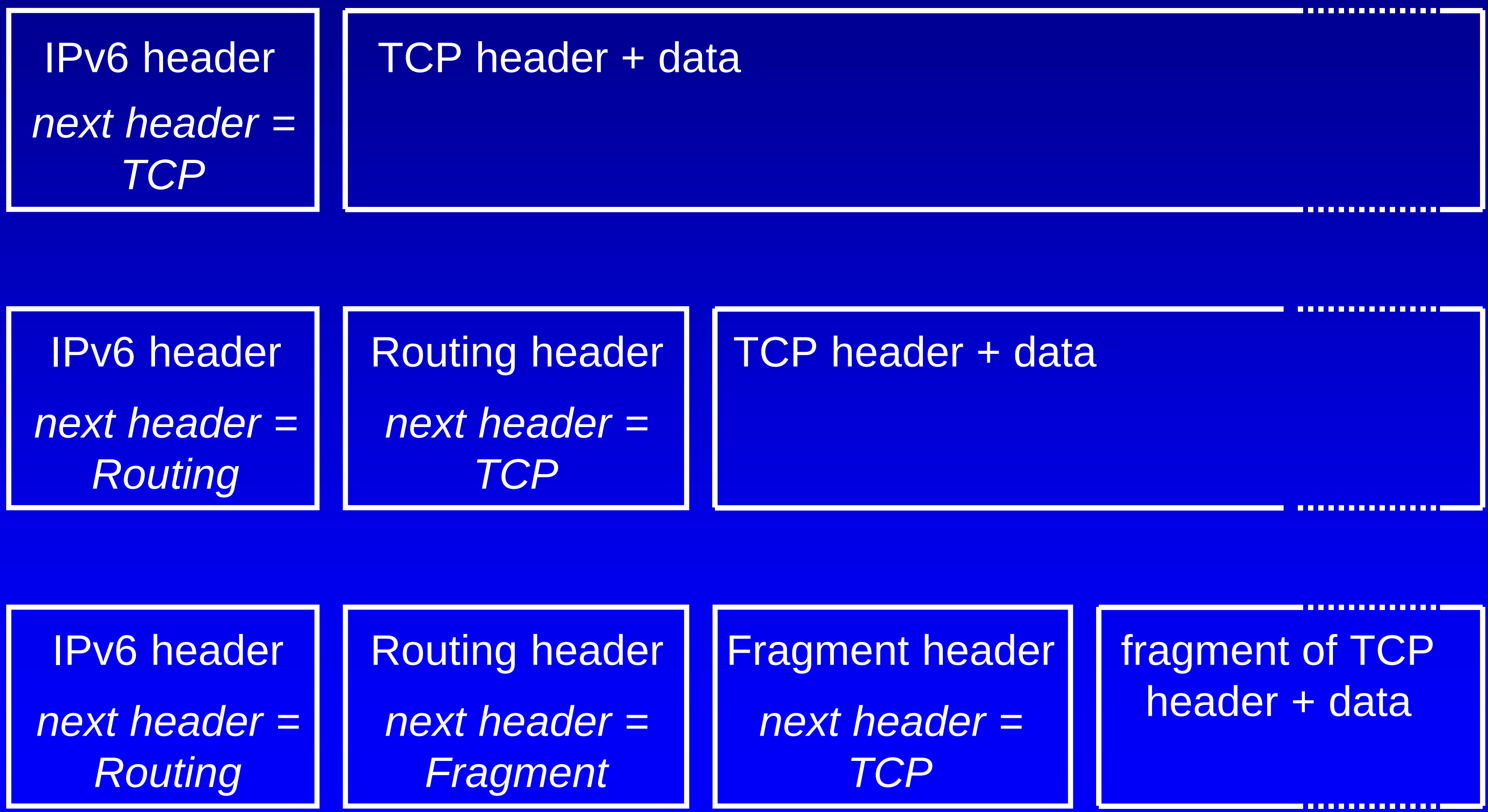
The IPv4 Header

<table>
<tr><td>Version</td><td>Hdr Len</td><td>Prec</td><td>TOS</td><td colspan="3">Total Length</td></tr>
<tr><td colspan="4">Identification</td><td>Flags</td><td colspan="2">Fragment Offset</td></tr>
<tr><td colspan="2">Time to Live</td><td colspan="2">Protocol</td><td colspan="3">Header Checksum</td></tr>
<tr><td colspan="7">Source Address</td></tr>
<tr><td colspan="7">Destination Address</td></tr>
<tr><td colspan="6">Options</td><td>Padding</td></tr>
</table>

← 32 bits →

shaded fields are absent from IPv6 header

Extension Headers



Address Types

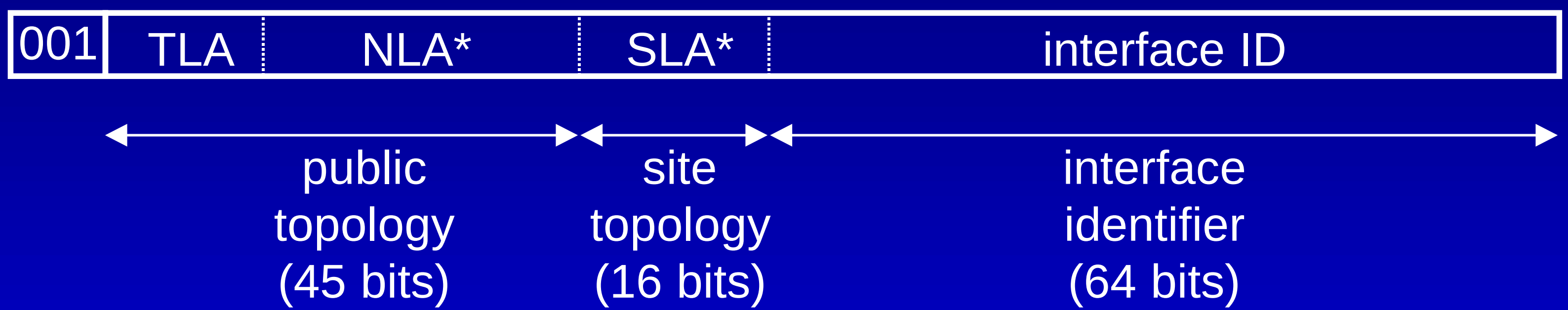
- unicast (one-to-one)
  - global
  - link-local
  - site-local
  - compatible (IPv4, IPX, NSAP)
- multicast (one-to-many)
- anycast (one-to-nearest)
- reserved

Address Type Prefixes

address type	**binary prefix**
IPv4-compatible	0000...0 (96 zero bits)
global unicast	001
link-local unicast	1111 1110 10
site-local unicast	1111 1110 11
multicast	1111 1111

- all other prefixes reserved (approx. 7/8ths of total)
- anycast addresses allocated from unicast prefixes

Global Unicast Addresses



- TLA = Top-Level Aggregator
  NLA* = Next-Level Aggregator(s)
  SLA* = Site-Level Aggregator(s)
- all subfields variable-length, non-self-encoding (like CIDR)
- TLAs may be assigned to providers or exchanges

Link-Local & Site-Local Unicast Addresses

link-local addresses for use during auto-configuration and when no routers are present:

1111111010	0	interface ID

site-local addresses for independence from changes of TLA / NLA*:

1111111010	0	SLA*	interface ID

Multicast Addresses

11111111	flags	scope	group ID
8	4	4	112 bits

- low-order flag indicates permanent / transient group; three other flags reserved
- scope field:
  1 - node local
  2 - link-local
  5 - site-local
  8 - organization-local
  B - community-local
  E - global

  (all other values reserved)

Routing

- uses same “longest-prefix match” routing as IPv4 CIDR
- straightforward changes to existing IPv4 routing protocols to handle bigger addresses
  unicast: OSPF, RIP-II, IS-IS, BGP4+, …
  multicast: MOSPF, PIM, …
- can use Routing header with anycast addresses to route packets through particular regions
  e.g., for provider selection, policy, performance, etc.

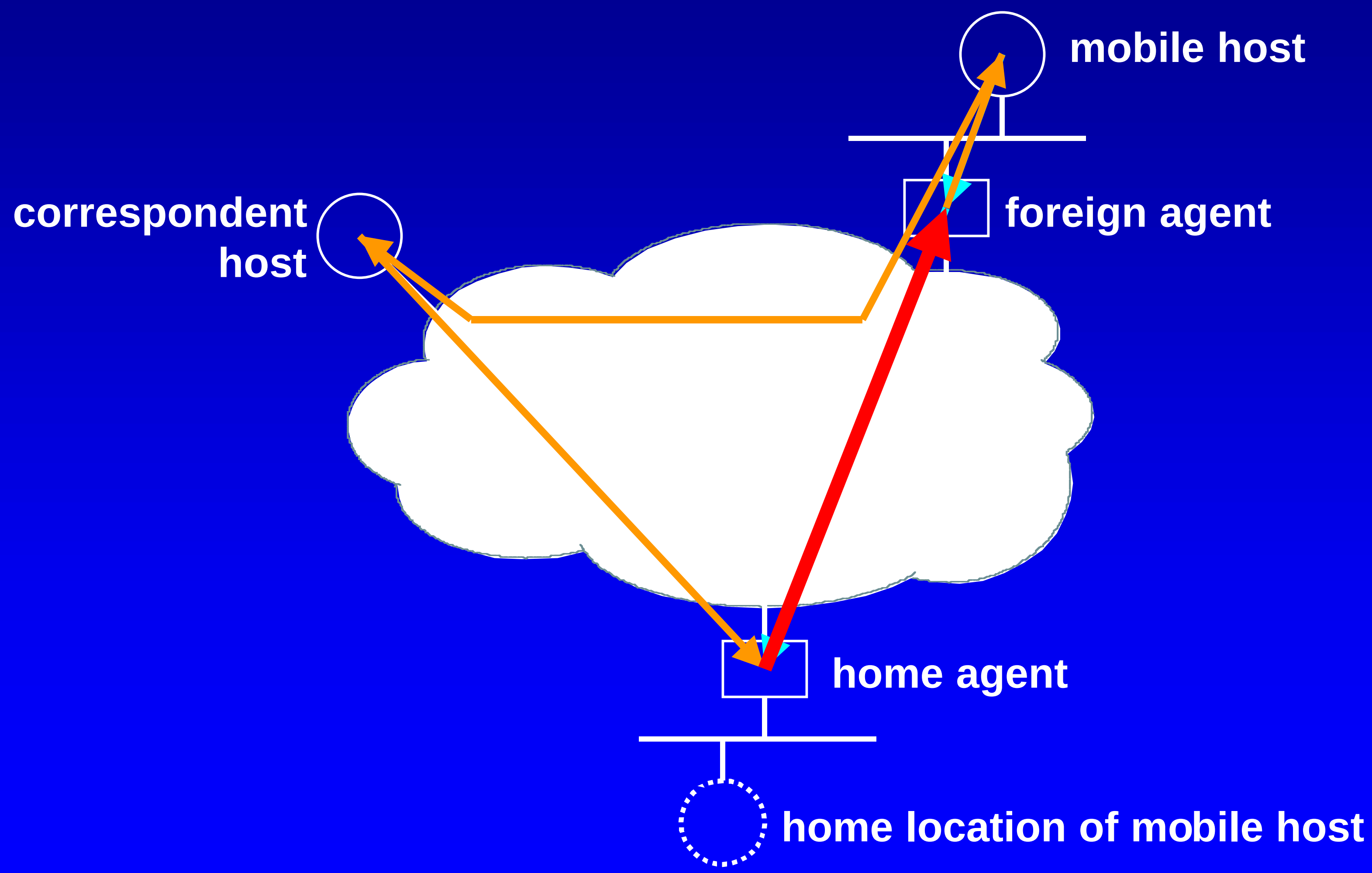
Serverless Autoconfiguration (“Plug-n-Play”)

- hosts can construct their own addresses:
  - subnet prefix(es) learned from periodic multicast advertisements from neighboring router(s)
  - interface IDs generated locally, e.g., using MAC addresses
- other IP-layer parameters also learned from router adverts (e.g., router addresses, recommended hop limit, etc.)
- higher-layer info (e.g., DNS server and NTP server addresses) discovered by multicast / anycast-based service-location protocol [details still to be decided]
- DHCP also available for those who want more control

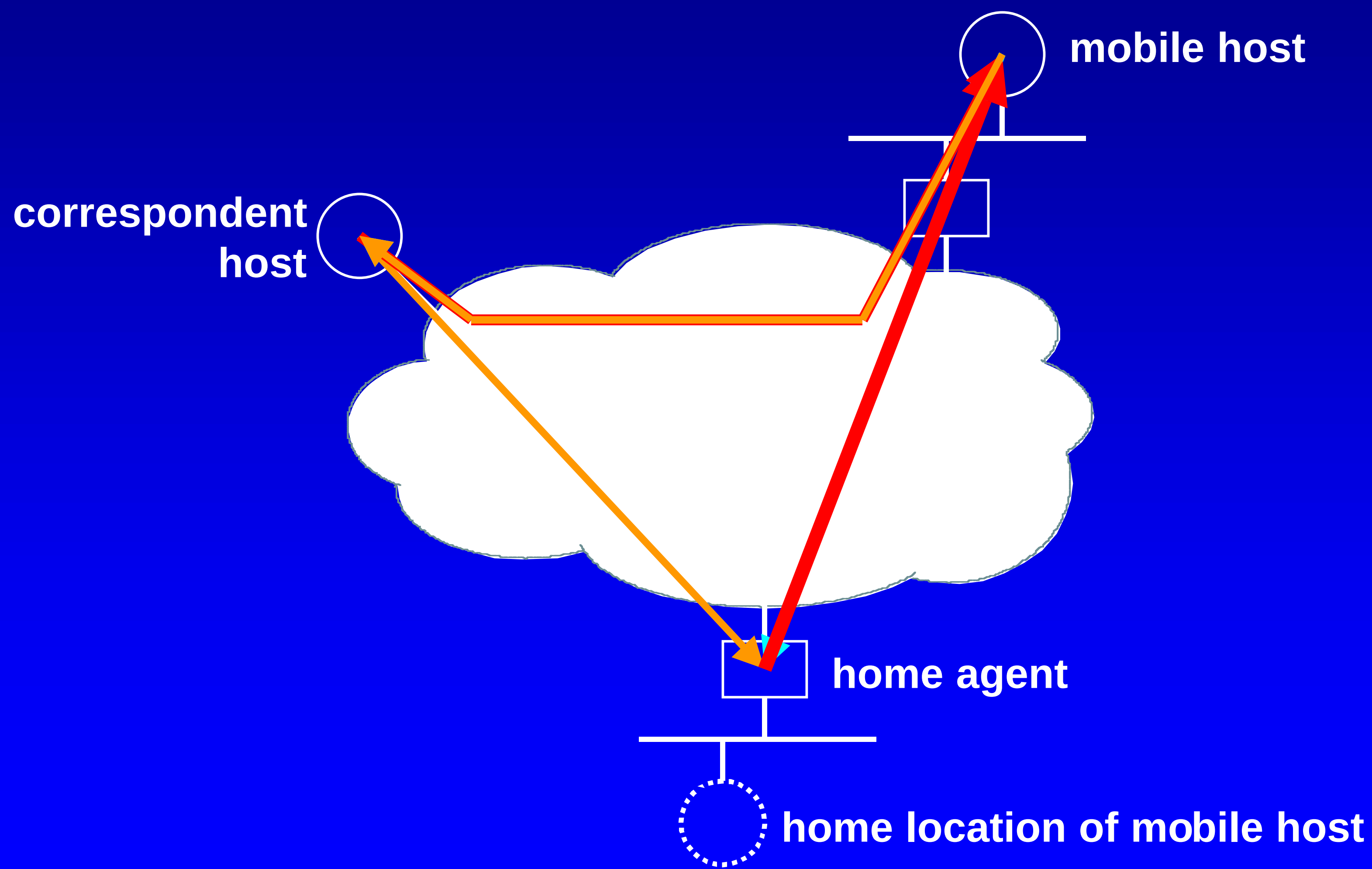
Auto-Reconfiguration ("Renumbering")

- new address prefixes can be introduced, and old ones withdrawn
  - we assume some overlap period between old and new, i.e., no "flash cut-over"
  - hosts learn prefix lifetimes and preferability from router advertisements
  - old TCP connections can survive until end of overlap; new TCP connections can survive beyond overlap
- router renumbering protocol, to allow domain-interior routers to learn of prefix introduction / withdrawal
- new DNS structure to facilitate prefix changes

Mobile IP (v4 version)



Mobile IP (v6 version)



Other Features of IPv6

- flow label for more efficient flow identification (avoids having to parse the transport-layer port numbers)
- neighbor unreachability detection protocol for hosts to detect and recover from first-hop router failure
- more general header compression (handles more than just IP+TCP)
- security ("IPsec") & differentiated services ("diff-serv") QoS features — same as IPv4

How?

IPv4-IPv6 Co-Existence / Transition

a wide range of techniques have been identified and implemented, basically falling into three categories:

(1) dual-stack techniques, to allow IPv4 and IPv6 to co-exist in the same devices and networks

(2) tunneling techniques, to avoid order dependencies when upgrading hosts, routers, or regions

(3) translation techniques, to allow IPv6-only devices to communicate with IPv4-only devices

expect all of these to be used, in combination

Dual-Stack Approach

- when adding IPv6 to a system, do not delete IPv4
  - this multi-protocol approach is familiar and well-understood (e.g., for AppleTalk, IPX, etc.)
  - note: in most cases, IPv6 will be bundled with new OS releases, not an extra-cost add-on
- applications (or libraries) choose IP version to use
  - when initiating, based on DNS response:

    if (dest has AAAA or A6 record) use IPv6, else use IPv4
  - when responding, based on version of initiating packet
- this allows indefinite co-existence of IPv4 and IPv6, and gradual, app-by-app upgrades to IPv6 usage

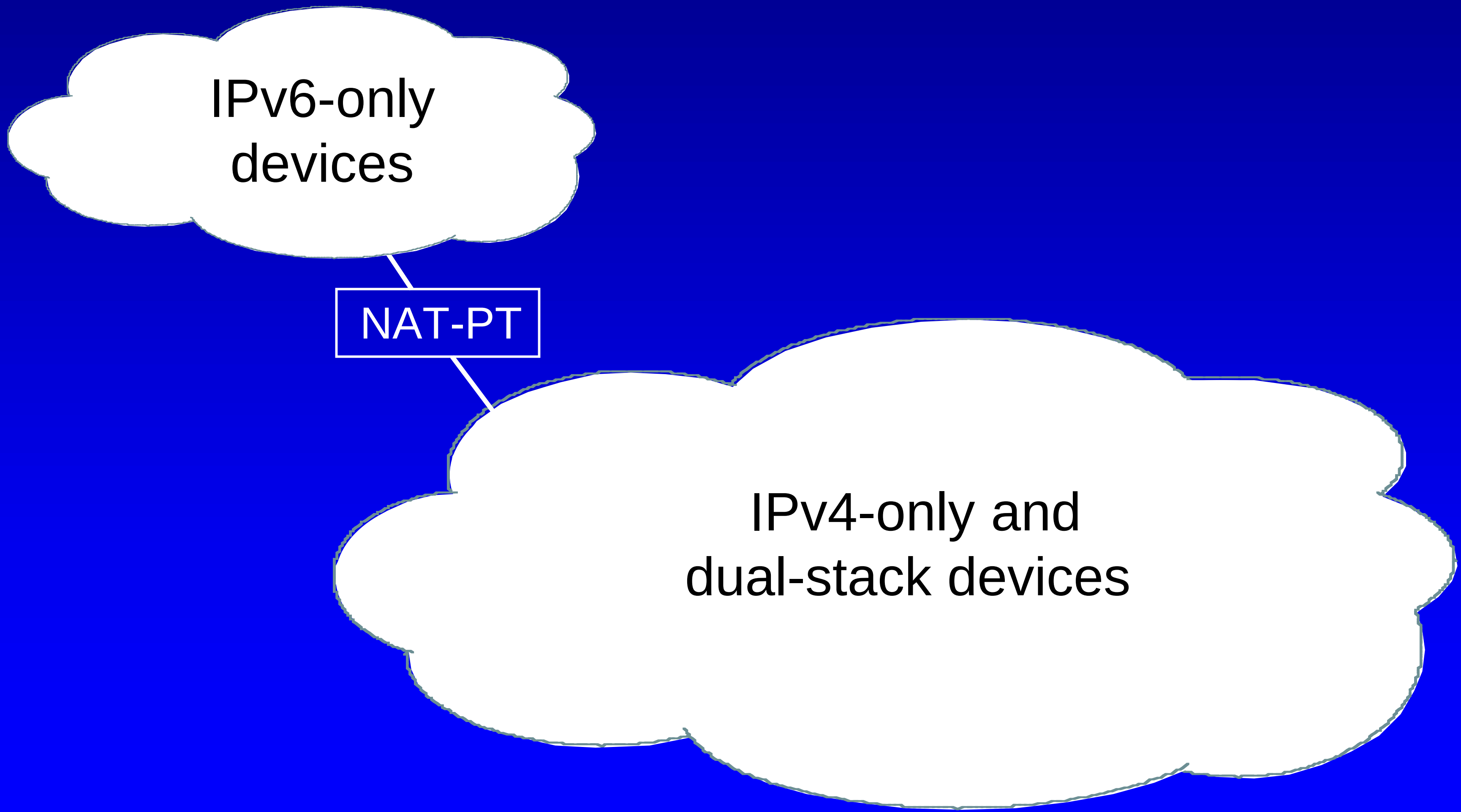
Tunnels to Get Through IPv6-Ignorant Routers / Switches

- encapsulate IPv6 packets inside IPv4 packets (or MPLS frames)
- many methods exist for establishing tunnels:
  - manual configuration
  - “tunnel brokers” (using web-based service to create a tunnel)
  - “6-over-4” (intra-domain, using IPv4 multicast as virtual LAN)
  - “6-to-4” (inter-domain, using IPv4 addr as IPv6 site prefix)
- can view this as:
  - IPv6 using IPv4 as a virtual link-layer, or
  - an IPv6 VPN (virtual public network), over the IPv4 Internet (becoming “less virtual” over time, we hope)

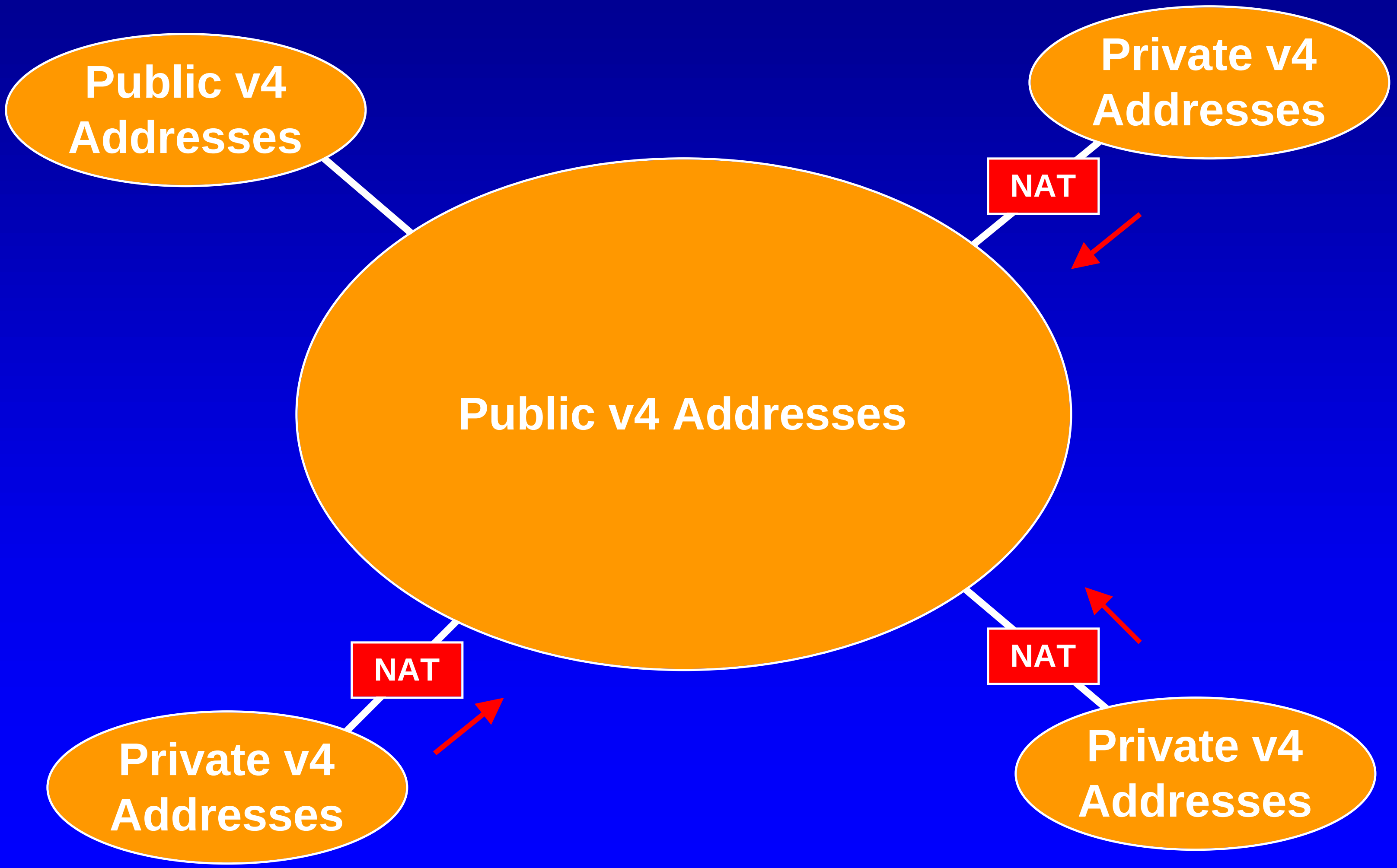
Translation

- may prefer to use IPv6-IPv4 protocol translation for:
  - new kinds of Internet devices (e.g., cell phones, cars, appliances)
  - benefits of shedding IPv4 stack (e.g., serverless autoconfig)
- this is a simple extension to NAT techniques, to translate header format as well as addresses
  - IPv6 nodes behind a translator get full IPv6 functionality when talking to other IPv6 nodes located anywhere
  - they get the normal (i.e., degraded) NAT functionality when talking to IPv4 devices
  - methods used to improve NAT functionality (e.g, ALGs, RSIP) can be used equally to improve IPv6-IPv4 functionality
- alternative: transport-layer relay or app-layer gateways

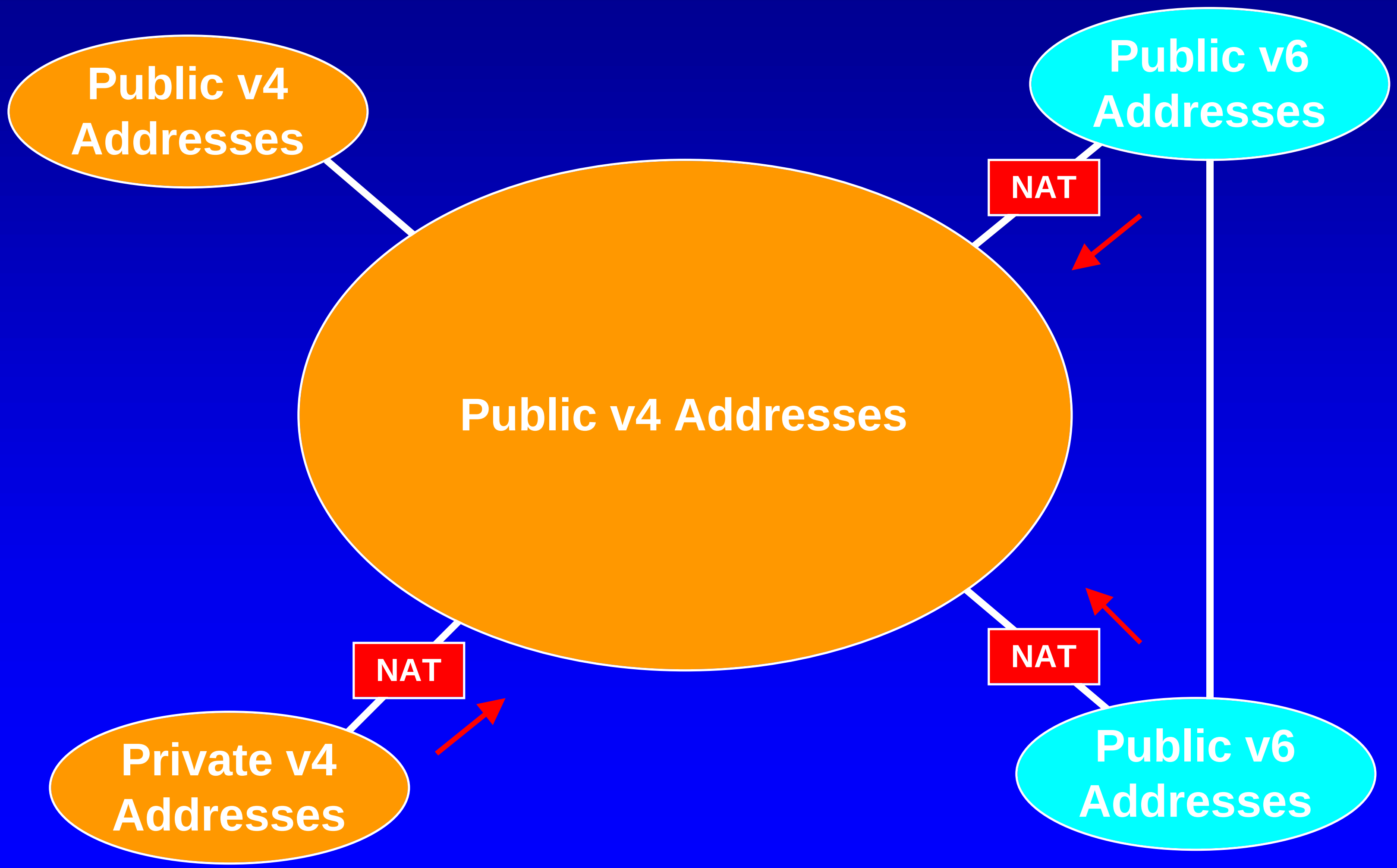
Network Address Translation and Protocol Translation (NAT-PT)



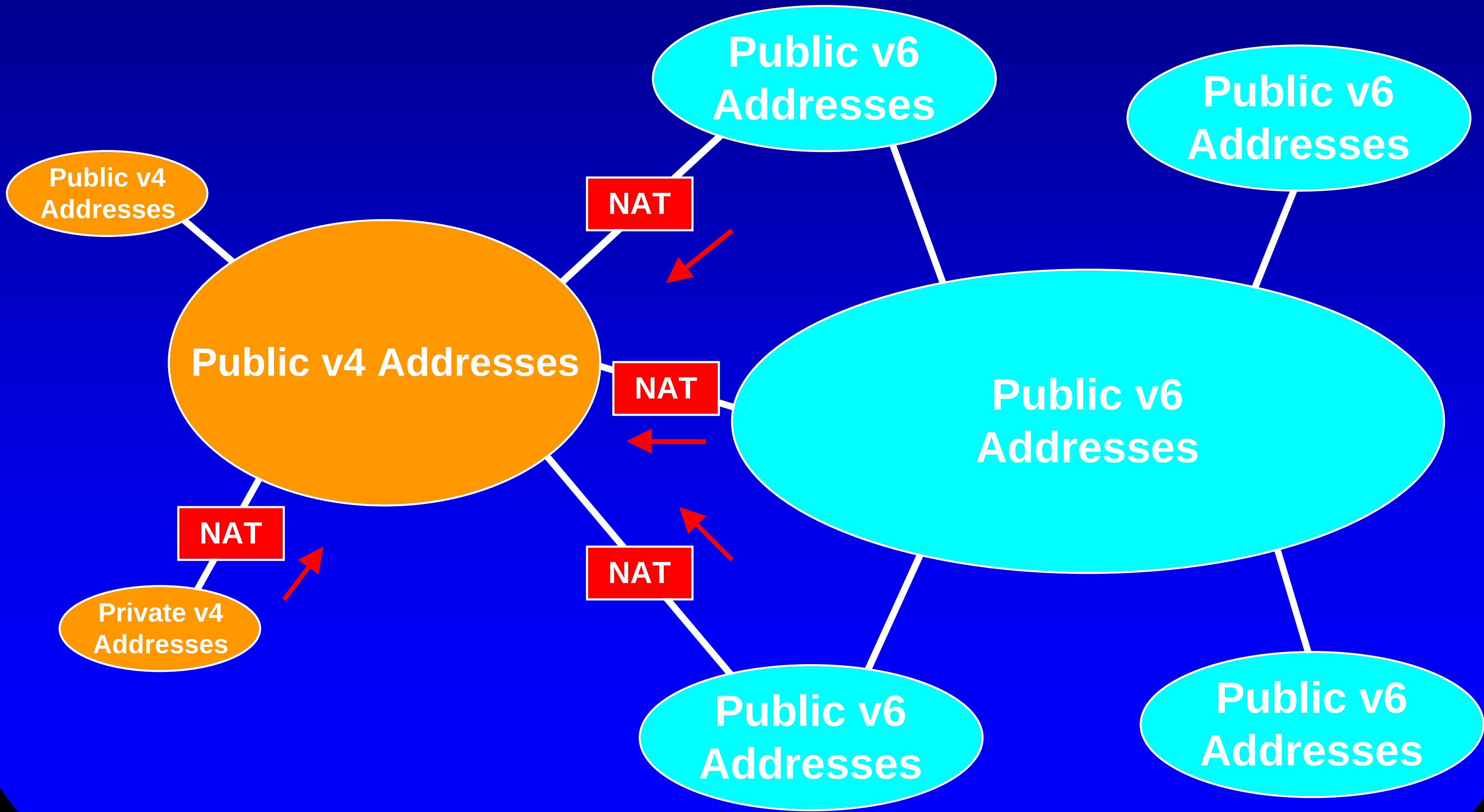
The IPv4 Internet Today



Introducing IPv6 (Simplified View)



Expanding IPv6 (Simplified View)



When?

Standards

- core IPv6 specifications are IETF Draft Standards => well-tested & stable
  - IPv6 base spec, ICMPv6, Neighbor Discovery, Multicast Listener Discovery, PMTU Discovery, IPv6-over-Ethernet,...
- other important specs are further behind on the standards track, but in good shape
  - mobile IPv6, header compression, A6 DNS support, IPv6-over-NBMA,...
  - for up-to-date status: playground.sun.com / ipng
- the 3GPP cellular wireless standards are highly likely to mandate IPv6

Implementations

- most IP stack vendors have an implementation at some stage of completeness
  - some are shipping supported product today, e.g., 3Com, *BSD, Epilogue, Ericsson/Telebit, IBM, Hitachi, KAME, Nortel, Sun, Trumpet
  - others have beta releases now, supported products “soon”, e.g., Cisco, Compaq, HP, Linux community, Microsoft
  - others known to be implementing, but status unkown (to me), e.g., Apple, Bull, Mentat, Novell, SGI

  (see playground.sun.com/ipng for most recent status reports)
- good attendance at frequent testing events

Deployment

- experimental infrastructure: the 6bone
  - for testing and debugging IPv6 protocols and operations
  - mostly IPv6-over-IPv4 tunnels
  - > 200 sites in 42 countries; mostly universities, network research labs, and IP vendors

Deployment (cont.)

- production infrastructure in support of education and research: the 6ren
  - CAIRN, Canarie, CERNET, Chunahwa Telecom, Dante, ESnet, Internet 2, IPFNET, NTT, Renater, Singren, Sprint, SURFnet, vBNS, WIDE
  - a mixture of native and tunneled paths
  - see www.6ren.net, www.6tap.net
- commercial infrastructure
  - a few ISPs (NTT,IIJ, SURFnet, Trumpet) have announced commercial IPv6 service trials

Deployment (cont.)

- IPv6 address allocation
  - 6bone procedure for test address space
  - regional IP address registries (APNIC, ARIN, RIPE-NCC) for production address space
- deployment assistance
  - ipv6.org: contributed FAQs and other info
- deployment advocacy (a.k.a. marketing)
  - IPv6 Forum: www.ipv6forum.com

Other Sources of Information

books:

IPv6, The New Internet Protocol
by Christian Huitema (Prentice Hall)

Internetworking IPv6 with Cisco Routers
by Silvano Gai (McGraw-Hill)

and many more... (14 hits at Amazon.com)

video:

IPv6: the New Internet Protocol
by Steve Deering & Craig Mudge
(University Video Communications, www.uvc.com)