IP Next Generation (IPv6)

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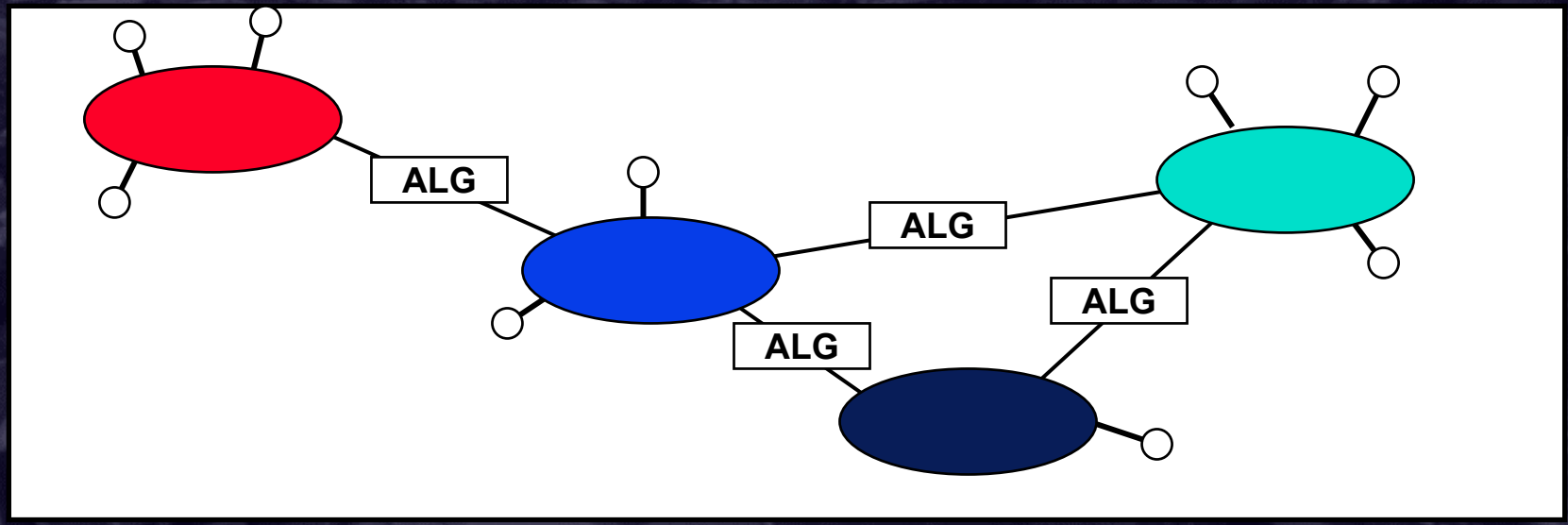
Based in part upon slides of Prof. Raj Jain (OSU), S.Deering (Cisco), C. Huitema (Microsoft)

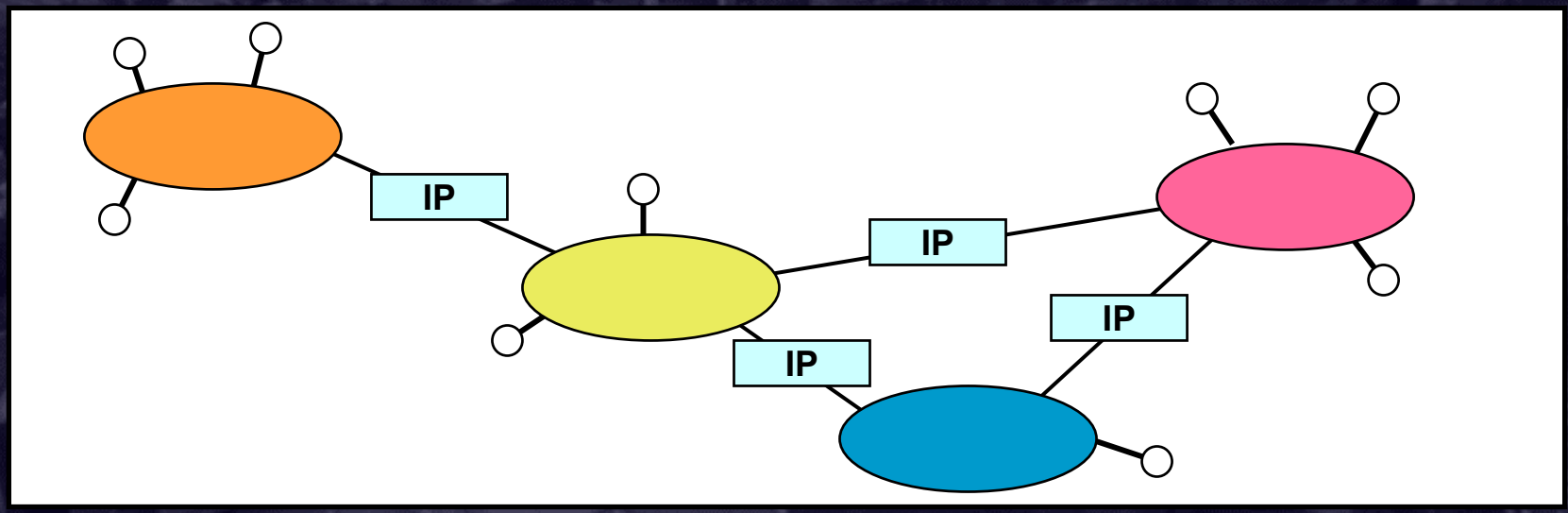
- Limitations of current Internet Protocol (IP)
- How many addresses do we need?
- IPv6 Addressing
- IPv6 header format
- IPv6 features: routing flexibility, plug-n-play, multicast support, flows

Pre-IP: Translation, ALGs



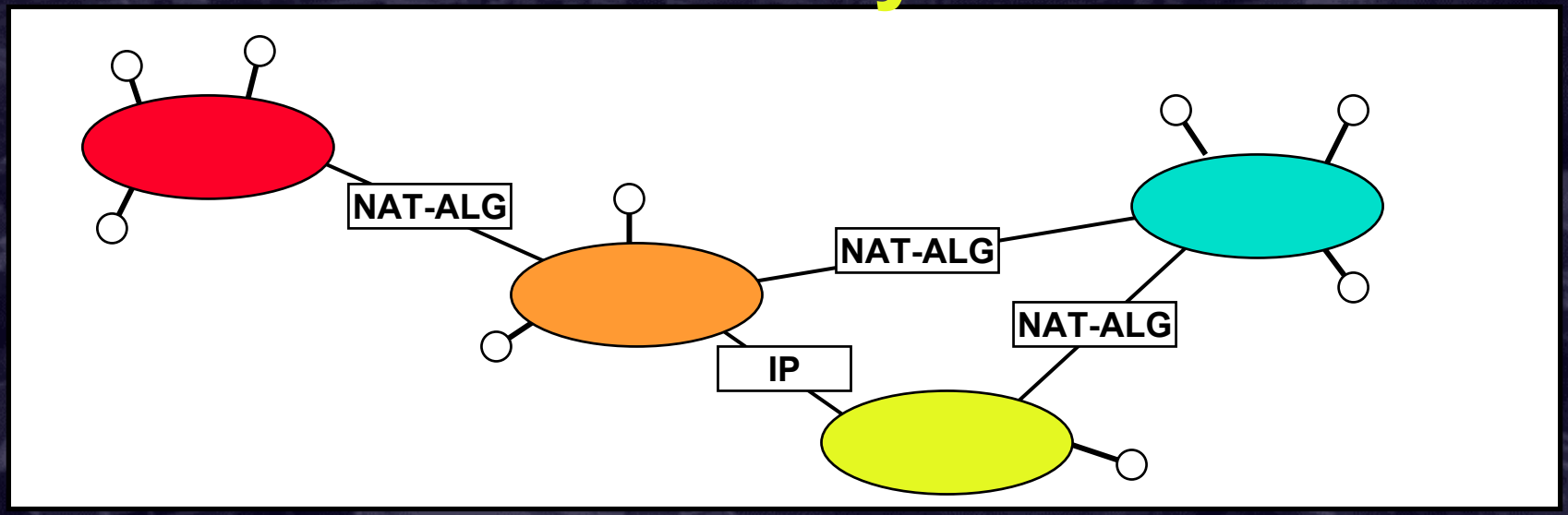
- application-layer gateways
  - inevitable loss of some semantics
  - difficult to deploy new internet-wide applications
  - hard to diagnose and remedy end-to-end problems
  - stateful gateways=> hard to route around failures
- no global addressability
  - ad-hoc, application-specific solutions

The IP Solution …



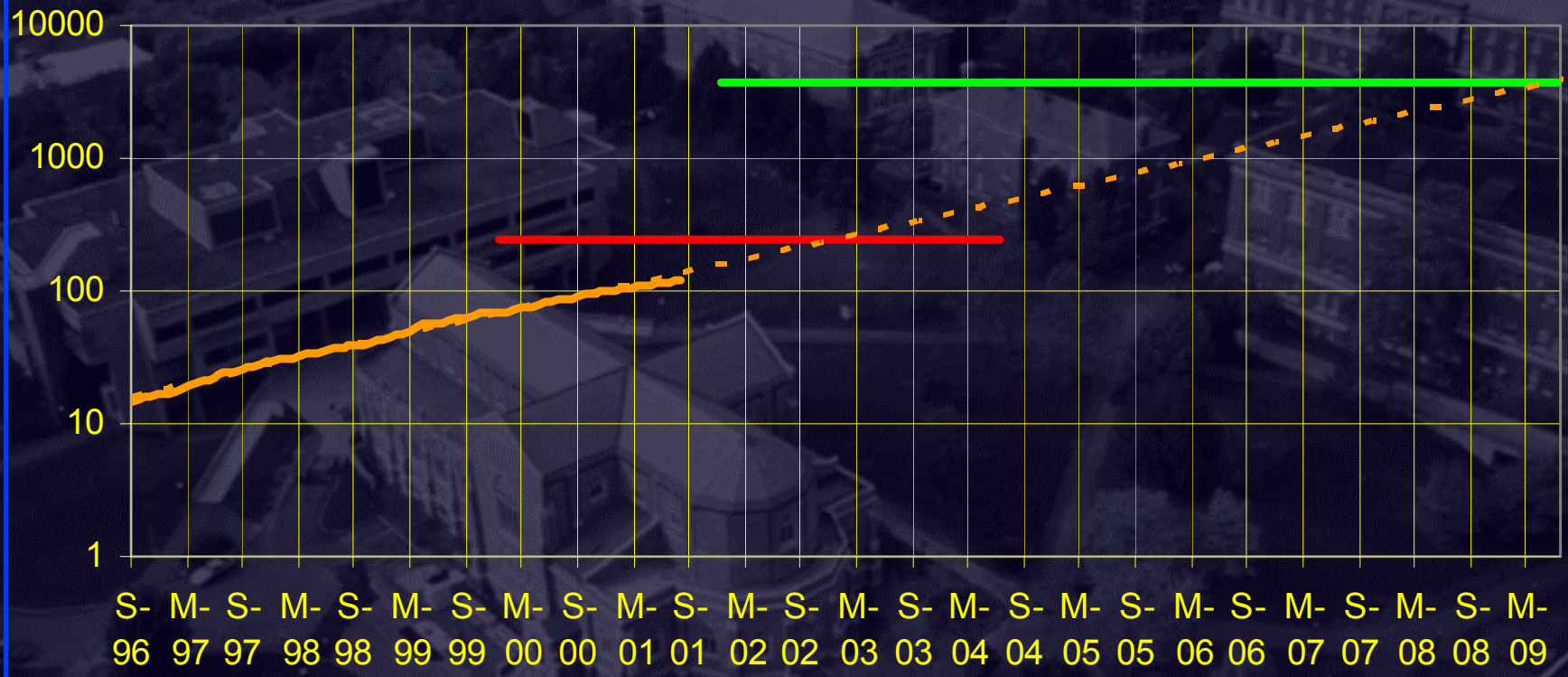
- internet-layer gateways & global addresses
- simple, application-independent, lowest denominator network service: best-effort datagrams
- stateless gateways could easily route around failures
- with application-specific knowledge out of gateways:
  - NSPs no longer had monopoly on new services
  - Internet: a platform for rapid, competitive innovation

The Internet Today: with NATs



- network address translators and app-layer gateways
  - inevitable loss of some semantics
  - hard to diagnose and remedy end-to-end problems
  - stateful gateways inhibit dynamic routing around failures
  - no global addressability => brokered with NATs
  - new Internet devices more numerous, and may not be adequately handled by NATs (e.g., mobile nodes)

Address Shortage Causes More NAT Deployment



Address exhaustion date estimate varies from 2009-2019!

IPv4 Addresses

- **Example**: 164.107.134.5
  = 1010 0100 : 0110 1011 : 1000 0110 : 0000 0101
  = A4:6B:86:05 (32 bits)
- Maximum number of address = 2^{32} = 4 Billion
- Class A Networks: 15 Million nodes
- Class B Networks: 64,000 nodes or less
- Class C Networks: 250 nodes or less
- Class B very popular…

- Total allocated address space as seen by routing: ~1Billion

How Many Addresses?

- 10 Billion people by 2020
- Each person has more than one computer
- Assuming 100 computers per person $\Rightarrow 10^{12}$ computers
- More addresses may be required since
  - Multiple interfaces per node
  - Multiple addresses per interface
  - Some believe 2^6 to 2^8 addresses per host
- Safety margin $\Rightarrow 10^{15}$ addresses
- *IPng Requirements $\Rightarrow 10^{12}$ end systems and 10^9 networks. Desirable 10^{12} to 10^{15} networks*

How big an address space ?

- H Ratio = $\log_{10}$(# of objects)/available bits
- 2^n objects with n bits: H-Ratio = $\log_{10}2$ = 0.30103
- French telephone moved from 8 to 9 digits at 10^7 households $\Rightarrow$ H = 0.26 (~3.3 bits/digit)
- US telephone expanded area codes with 10^8 subscribers $\Rightarrow$ H = 0.24
- Physics/space science net stopped at 15000 nodes using 16-bit addresses $\Rightarrow$ H = 0.26
- 3 Million Internet hosts currently using 32-bit addresses $\Rightarrow$ H = 0.20

- Huitema (Nov 01) estimates H = 0.26 next year

IPv6 Addresses

- 128-bit long. Fixed size
- $2^{128} = 3.4 \times 10^{38}$ addresses
  $\Rightarrow 665 \times 10^{21}$ addresses per sq. m of earth surface
- If assigned at the rate of $10^6/\mu s$, it would take 20 years
- Expected to support 8×10^{17} to 2×10^{33} addresses
  $8 \times 10^{17} \Rightarrow$ 1,564 address per sq. m

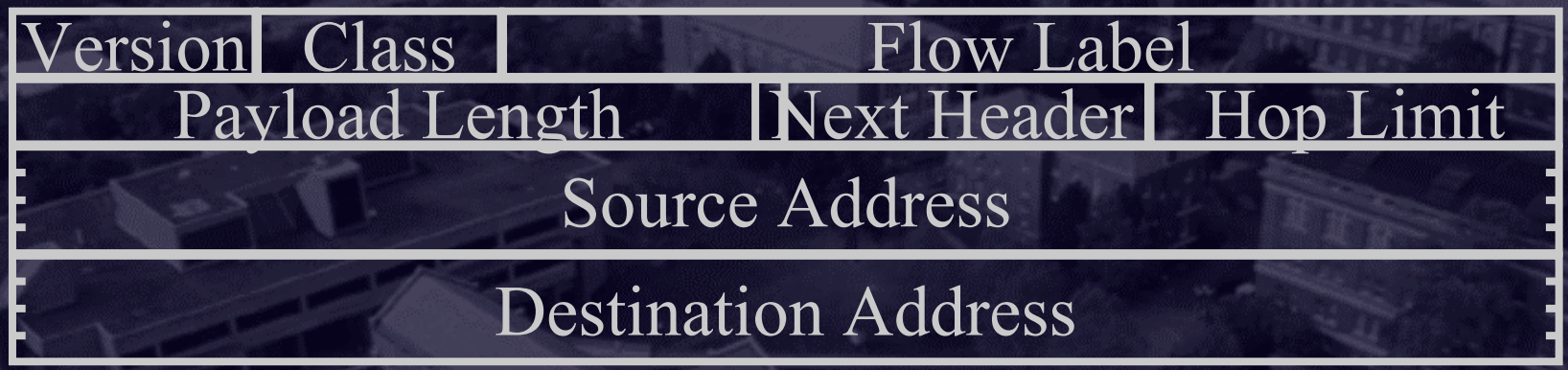
- Allows multiple interfaces per host.
- Allows multiple addresses per interface
- Allows unicast, multicast, anycast
- Allows provider based, site-local, link-local
- 85% of the space is unassigned

Colon-Hex Notation

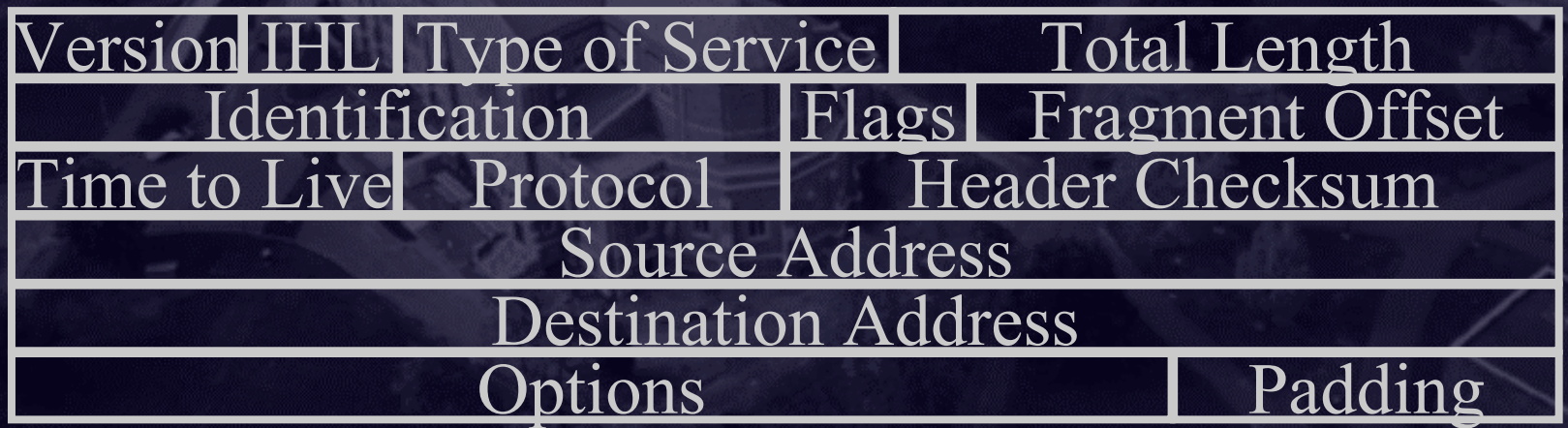
- **Dot-Decimal**: 127.23.45.88
- **Colon-Hex:**
  FEDC:0000:0000:0000:3243:0000:0000:ABCD
  - Can skip leading zeros of each word
  - Can skip one sequence of zero words, e.g., FEDC::3243:0000:0000:ABCD *or* ::3243:0000:0000:ABCD
  - Can leave the last 32 bits in dot-decimal, e.g., ::127.23.45.88
  - Can specify a prefix by /length, e.g., 2345:BA23:7::/40

Header

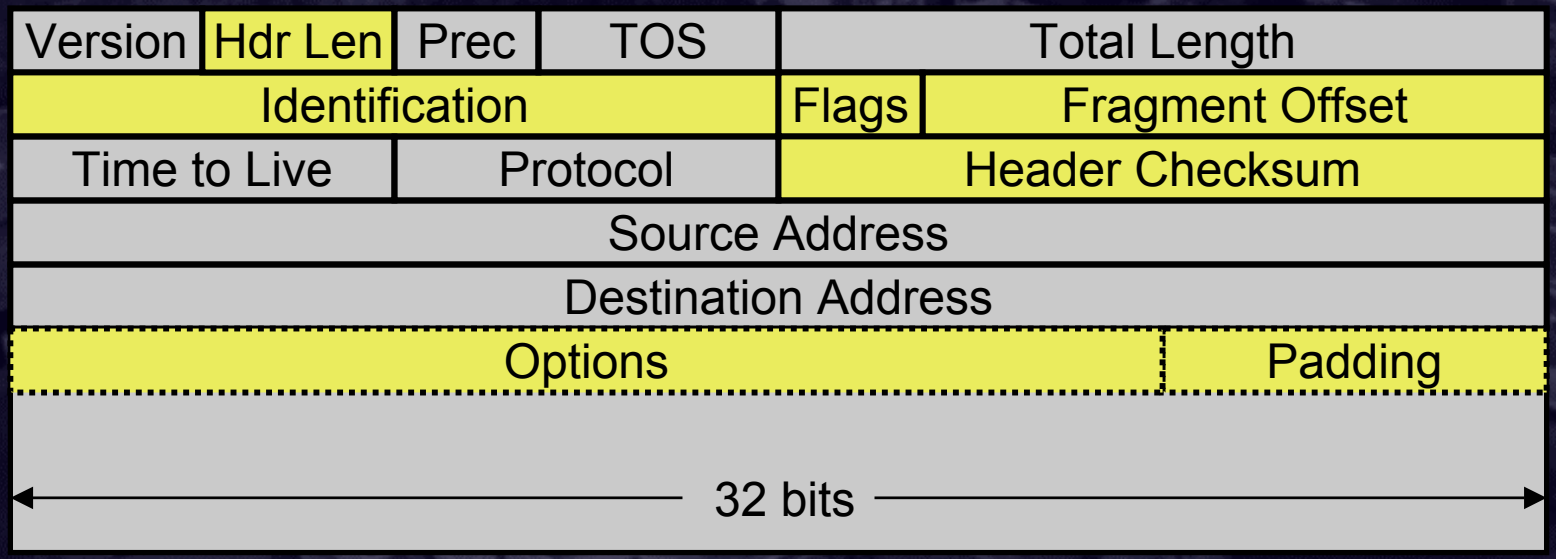
- IPv6:



- IPv4:



The IPv4 Header



shaded fields are absent from IPv6 header

IPv6 vs IPv4

- IPv6 twice the size of IPv4 header
- Version: only field w/ same position and meaning
- ***Removed***:
  - **Header length, fragmentation fields (identification, flags, fragment offset), header checksum**
- ***Replaced***:
  - **Datagram length by payload length**
  - **Protocol type by next header**
  - **Time to live by hop limit**
  - **Type of service by "class" octet**
- ***Added***: flow label
- All fixed size fields.
- No optional fields. Replaced by extension headers.
  - Idea: avoid unnecessary processing by intermediate routers w/o sacrificing the flexibility

Extension Headers

- Most extension headers are examined only at destination
- Routing: Loose or tight source routing
- Fragmentation: one source can fragment
- Authentication
- Hop-by-Hop Options
- Destination Options:

Extension Header (Continued)

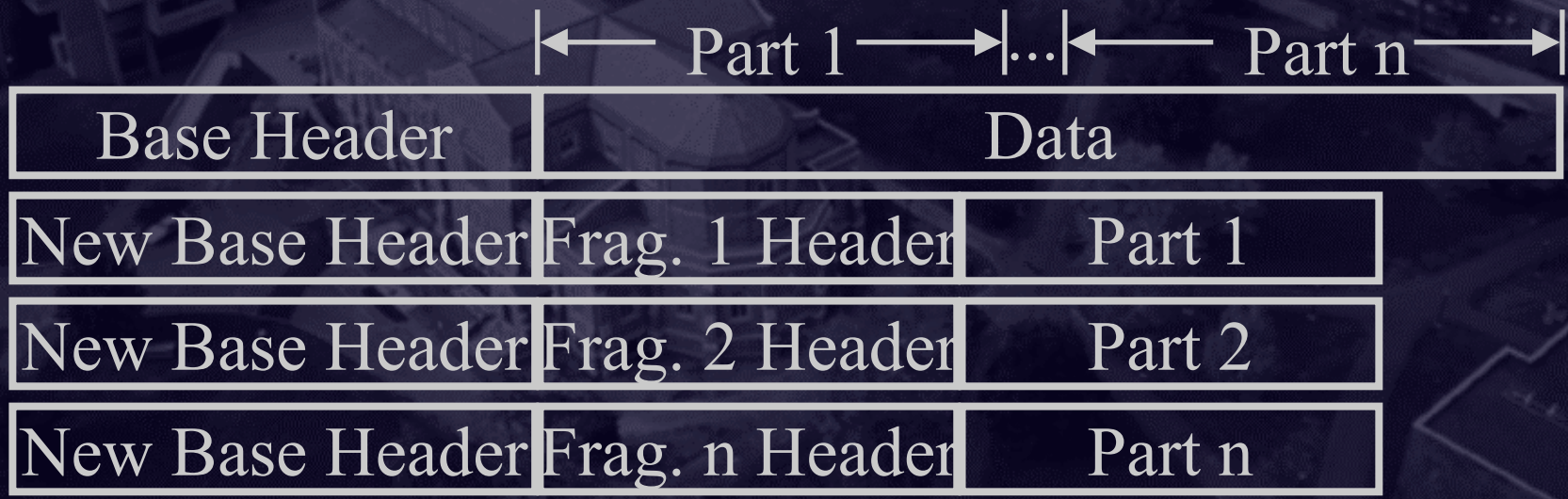
- Only Base Header:

- Only Base Header and One Extension Header:

- Only Base Header and Two Extension Headers:

Fragmentation

- Routers cannot fragment. Only source hosts can.
  ⇒ Need path MTU discovery or tunneling
- Fragmentation requires an extension header
- Payload is divided into pieces
- A new base header is created for each fragment



Initial IPv6 Prefix Allocation

Allocation	Prefix	Allocation	Prefix
Reserved	0000 0000	Unassigned	101
Unassigned	0000 0001	Unassigned	110
NSAP	0000 001	Unassigned	1110
IPX	0000 010	Unassigned	1111 0
Unassigned	0000 011	Unassigned	1111 10
Unassigned	0000 1	Unassigned	1111 110
Unassigned	0001	Unassigned	1111 1110
Unassigned	001	Unassigned	1111 1110 0
Provider-based*	010	Link-Local	1111 1110 10
Unassigned	011	Site-Local	1111 1110 11
Geographic	100	Multicast	1111 1111

*Has been renamed as “Aggregatable global unicast”

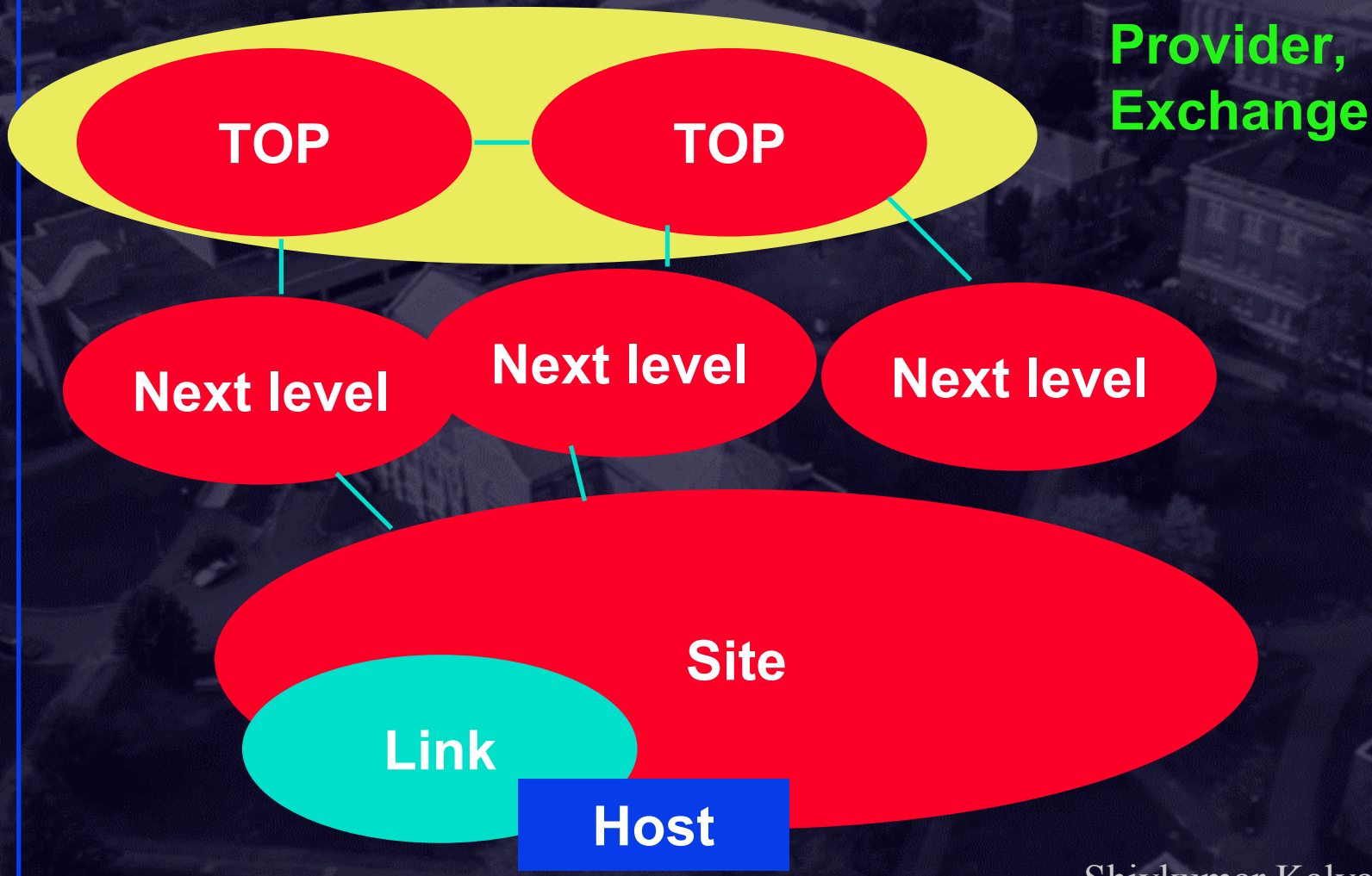
Aggregatable Global Unicast Addresses

- Address allocation:"provider-based" plan
- Format: TLA + NLA + SLA + 64-bit interface ID
- TLA = "Top level aggregator."
  - For "backbone" providers or "exchange points"
- NLA = "Next Level Aggregator"
  - Second tier provider and a subscriber
  - More levels of hierarchy possible within NLA
- SLA = "Site level aggregator"
  - Renumbering:change of provider => change the TLA and NLA. But have same SLA & I/f ID
- Sub-fields variable-length, non-self-encoding (like CIDR)

Aggregatable Global Unicast Addresses (Continued)

- Interface ID = 64 bits
  - Will be based on IEEE EUI-64 format
  - An extension of the IEEE 802 (48 bit) format.
  - Possible to derive the IEEE EUI-64 equivalent of current IEEE 802 addresses

IPv6 Routing architecture



Local-Use Addresses

- Link Local: Not forwarded outside the link, FE:80::xxx
  - Auto-configuration and when no routers are present

- Site Local: Not forwarded outside the site, FE:C0::xxx
- Independence from changes of TLA / NLA*

- Provides plug and play

Multicast Addresses

- 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)
- All IPv6 routers will support native multicast

Eg: Multicast Scoping

- Scoping. Eg: 43 ⇒ NTP Servers
  - FF01::43 ⇒ All NTP servers on this node
  - FF02::43 ⇒ All NTP servers on this link
  - FF05::43 ⇒ All NTP servers in this site
  - FF08::43 ⇒ All NTP servers in this org.
  - FF0F::43 ⇒ All NTP servers in the Internet
- Structure of Group ID:
  - First 80 bits = zero (to avoid risk of group collision, because IP multicast mapping uses only 32 bits)

Address *Auto-configuration*

- Allows plug and play
- BOOTP and DHCP are used in IPv4
- DHCPng will be used with IPv6
- Two Methods: Stateless and Stateful
- Stateless:
  - A system uses *link-local* address as source and multicasts to "All routers on this link"
  - Router replies and provides all the needed prefix info

Address Auto-configuration (Continued)

- All prefixes have a associated *lifetime*
- System can use link-local address permanently if no router
- Stateful:
  - Problem w stateless: Anyone can connect
  - Routers ask the new system to go DHCP server (by setting managed configuration bit)
  - System multicasts to "All DHCP servers"
  - DHCP server assigns an address

ICMPv6: Neighbor Discovery

- ICMPv6 combines regular ICMP, ARP, Router discovery and IGMP.

- The "neighbor discovery" is a generalization of ARP & router discovery.
- Source maintains several caches:
  - destination cache: dest -> neighbor mapping
  - neighbor cache: neighbor IPv6 -> link address
  - prefix cache: prefixes learnt from router advertisements
  - router cache: router IPv6 addresses

Neighbor Discovery (Continued)

- Old destination => look up destination cache
- If new destination, match the prefix cache. If match => destination local!
- Else select a router from router cache, use it as the next-hop (neighbor).
  - Add this neighbor address to the destination cache
- Solicitation-advertisement model:
  - Multicast solicitation for neighbor media address if unavailable in neighbor cache
  - Neighbor advertisement message sent to soliciting station.

IPv6 Auto-configuration: 7 problems

- 1. End-node acquires L3 address:
  - Use link-local address as src and multicast query for advts
  - Multiple prefixes & router addresses returned
- 2. Router finds L3 address of end-node: same net-ID
- 3. Router finds L2 address of end-node: neighbor discovery (generalization of ARP, w/ several caches)
- 4. End-nodes find router: solicit/listen for router advt
- 5. End-nodes send directly to each other: same prefix (prefix cache) => direct
- 6. Best router discovery: ICMPv6 redirects
- 7. Router-less LAN: same prefix (prefix cache) => direct. Link-local addresses + neighbor discovery if no router.

- Integrated several techniques from CLNP, IPX, Appletalk etc

Auto-Reconfiguration ("Renumbering")

- Problem: providers changed => old-prefixes given back and new ones assigned THROUGHOUT the site
- Solution:
  - 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

Other Features of IPv6

- Flow label for more efficient flow identification (avoids having to parse the transport-layer port numbers)
- Neighbor un-reachability 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

If IPv6 is so great, how come it is not there yet?

- Applications
  - Need upfront investment, stacks, etc.
  - Similar to Y2K, 32 bit vs. “clean address type”
- Network
  - Need to ramp-up investment
  - No “push-button” transition

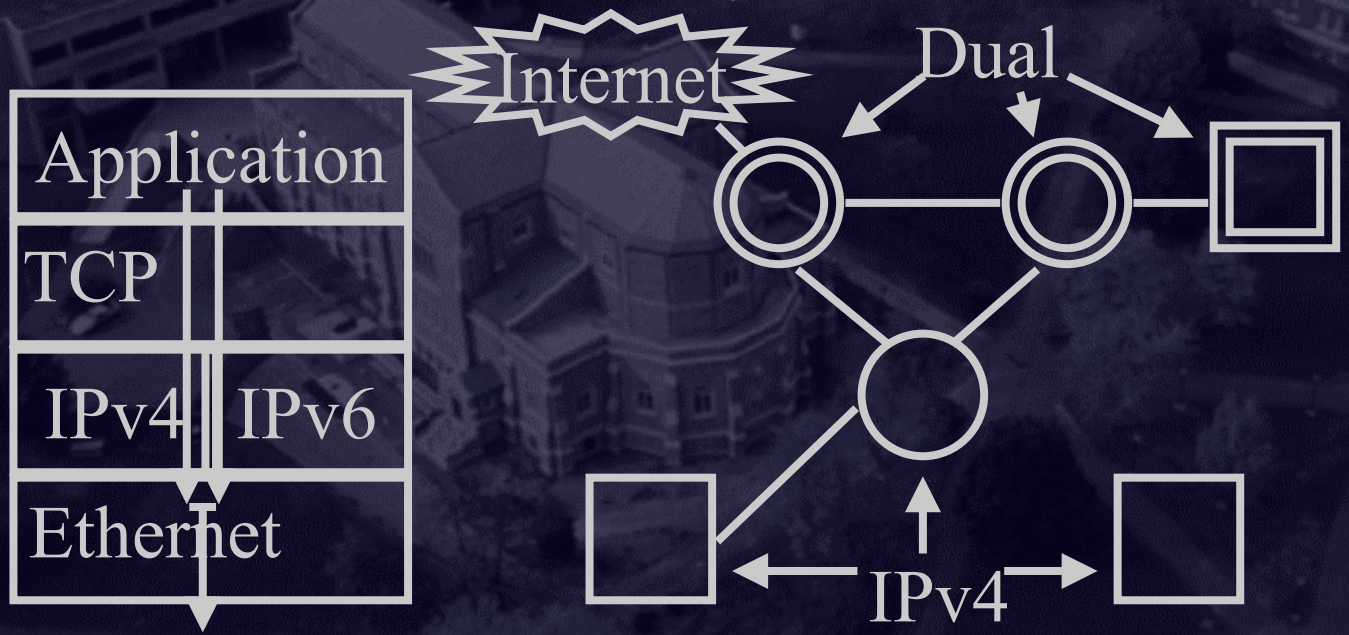
Transition Issues: Protocol upgrades

- Most application protocols will have to be upgraded: FTP, SMTP, Telnet, RIogin
- Several full standards revised for IPv6
- Non-IETF standards: X-Open, Kerberos, ... will be updated… Hosts, routers … the works!

- With a suite of "fixes" to IPv4, what is compelling in IPv6?
  - Sticks: tight address allocation (3G going to IPv6), NAT becomes too brittle…
  - Incentives (carrots): stateless autoconf simplifies mobility, if p2p and multimedia grow, then NATs may pose a problem

Transition Mechanisms

- 1. Recognize that IPv4 will co-exist with IPv6 indefinitely
- 2. Recognize that IPv6 will co-exist with NATs for a while
- Dual-IP Hosts, Routers, Name servers
- Tunneling IPv6-over-IPv4 (6-over-4), IPv4 as link (6-to-4)
- Translation: allow IPv6-only hosts to talk to IPv4-only hosts



IPv4-IPv6 Co-Existence / Transition

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

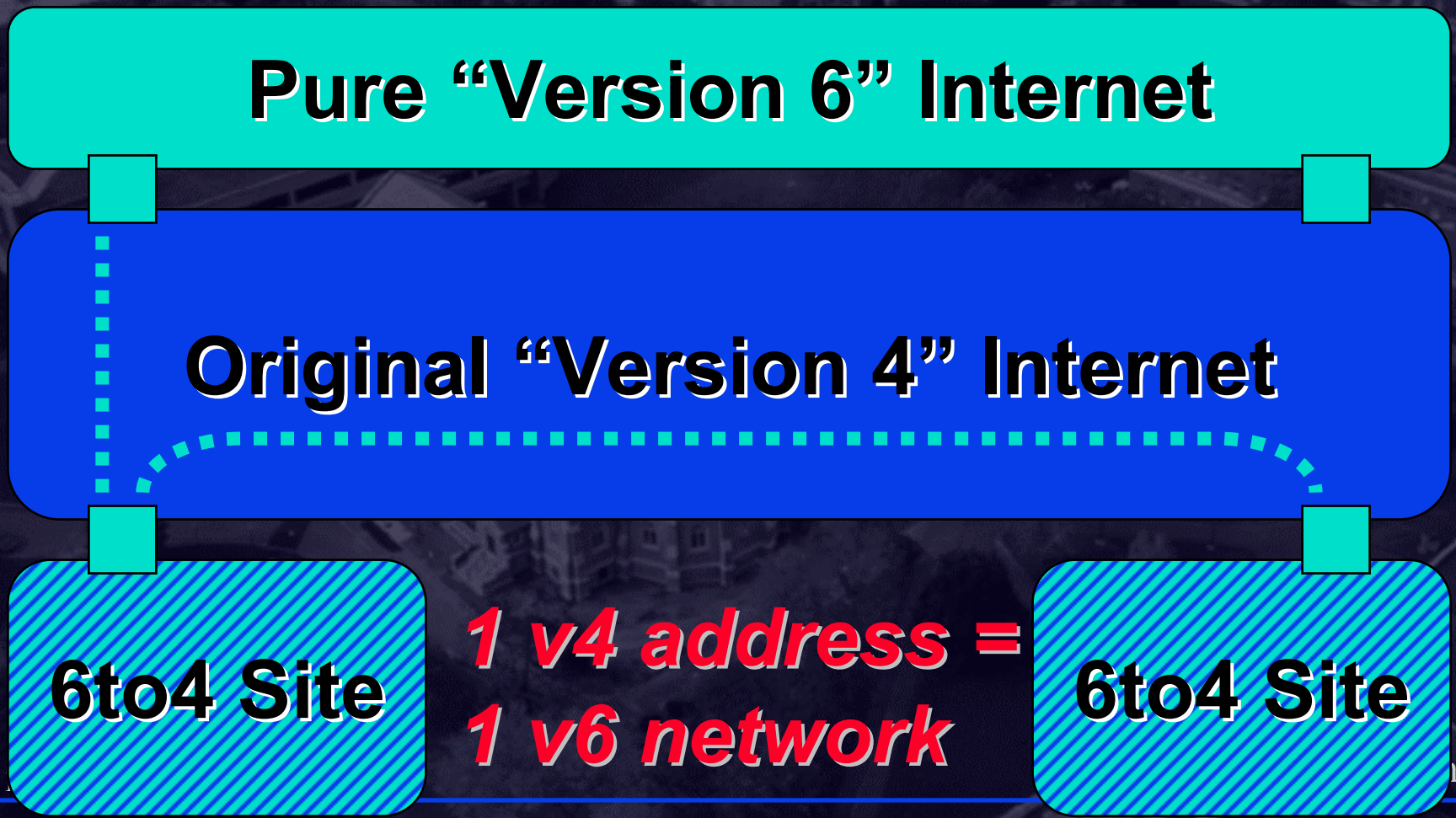
Tunnels

- Encapsulate IPv6 inside IPv4 packets (or MPLS).Methods:
  - 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)

6to4

Automated tunneling across IPv4…

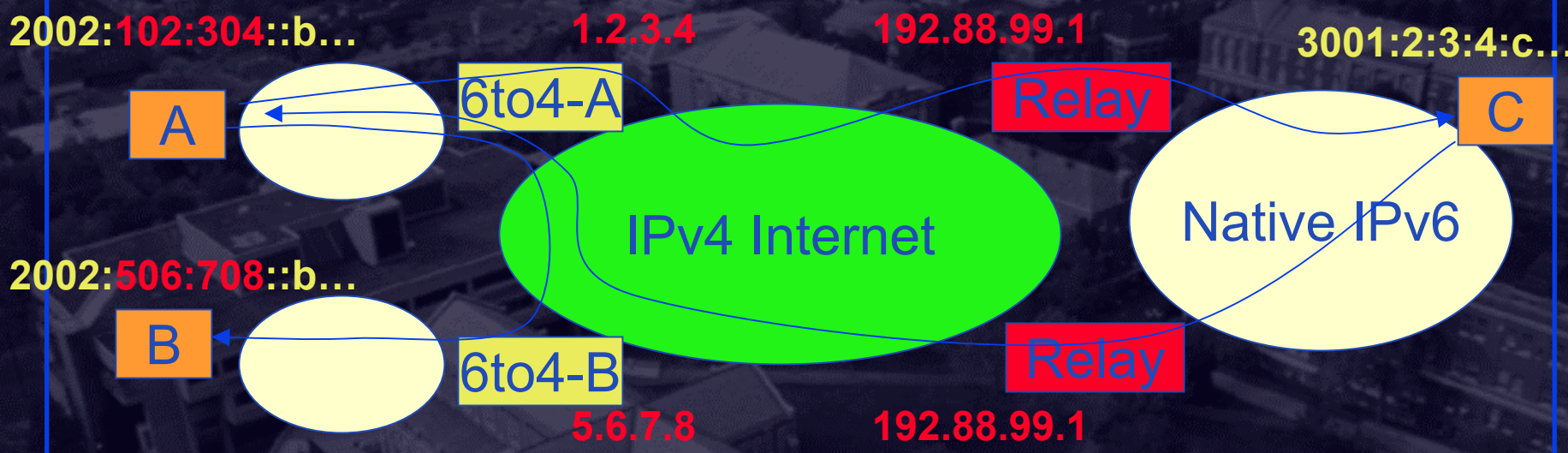


6to4 addresses:
1 v4 address = 1 v6 network

FP (3bits)	TLA (13bits)	IPv4 Address (32bits)	SLA ID (16bits)	Interface ID (64bits)
001	0x0002	ISP assigned	Locally administered	Auto configured

- Stateless tunnel over the IPv4 network without configuration
  - The IPv6 address contains the IPv4 address
  - Entire campus infrastructure fits behind single IPv4 address

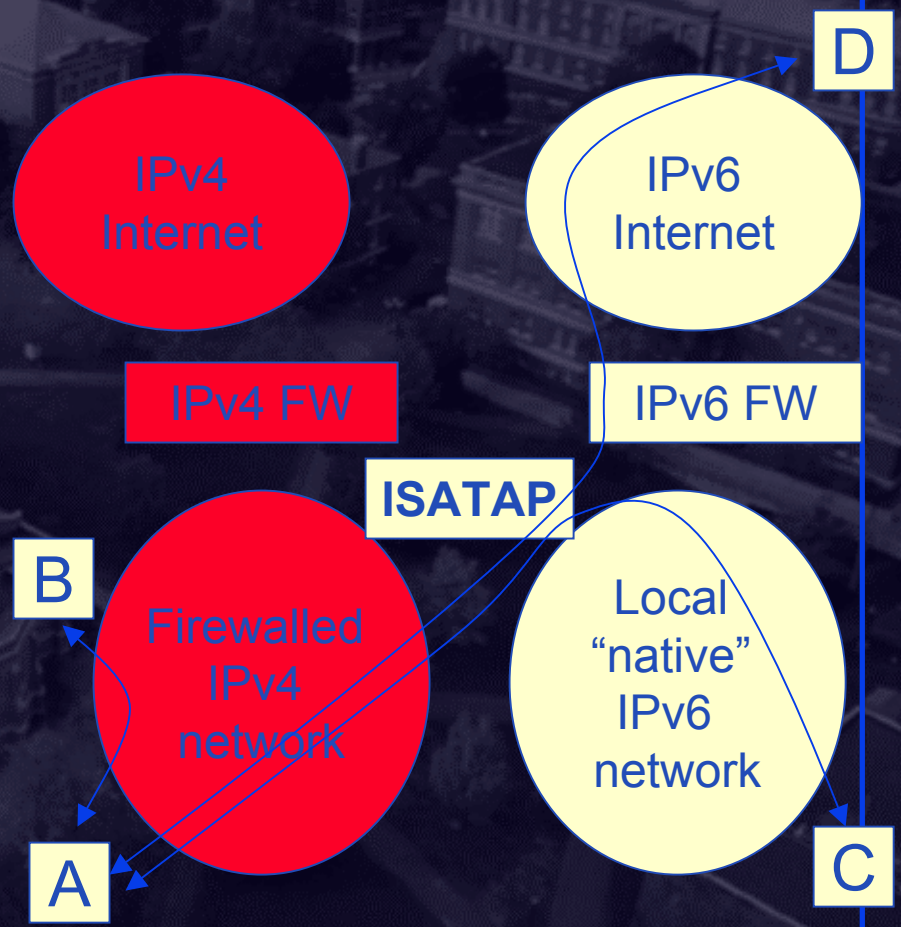
6to4: tunnel IPv6 over IPv4



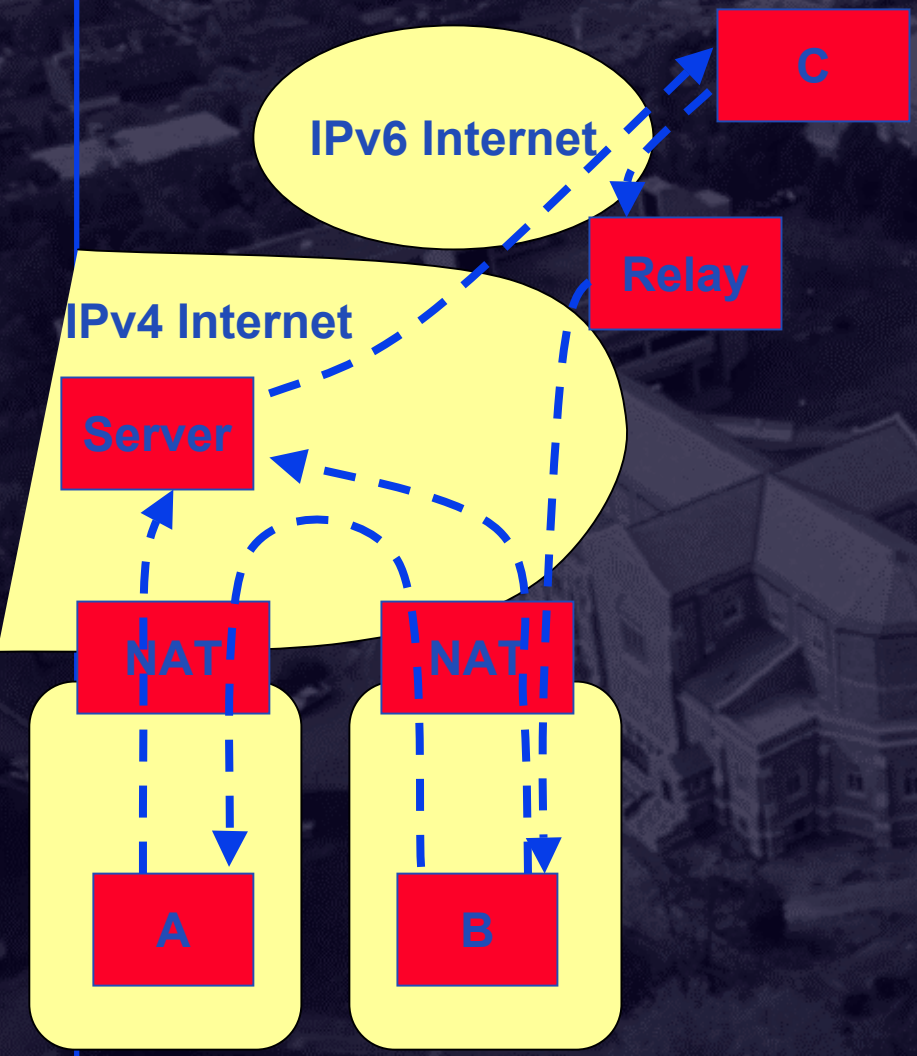
- 6to4 router derives IPv6 prefix from IPv4 address,
- 6to4 relays advertise reachability of prefix 2002::/16
- Automatic tunneling from 6to4 routers or relays
- Single address (192.88.99.1) for all relays

ISATAP: IPv6 behind firewall

- ISATAP router provides IPv6 prefix
- Host complements prefix with IPv4 address
- Direct tunneling between ISATAP hosts
- Relay through ISATAP router to IPv6 local or global



Shipworm: IPv6 through NAT

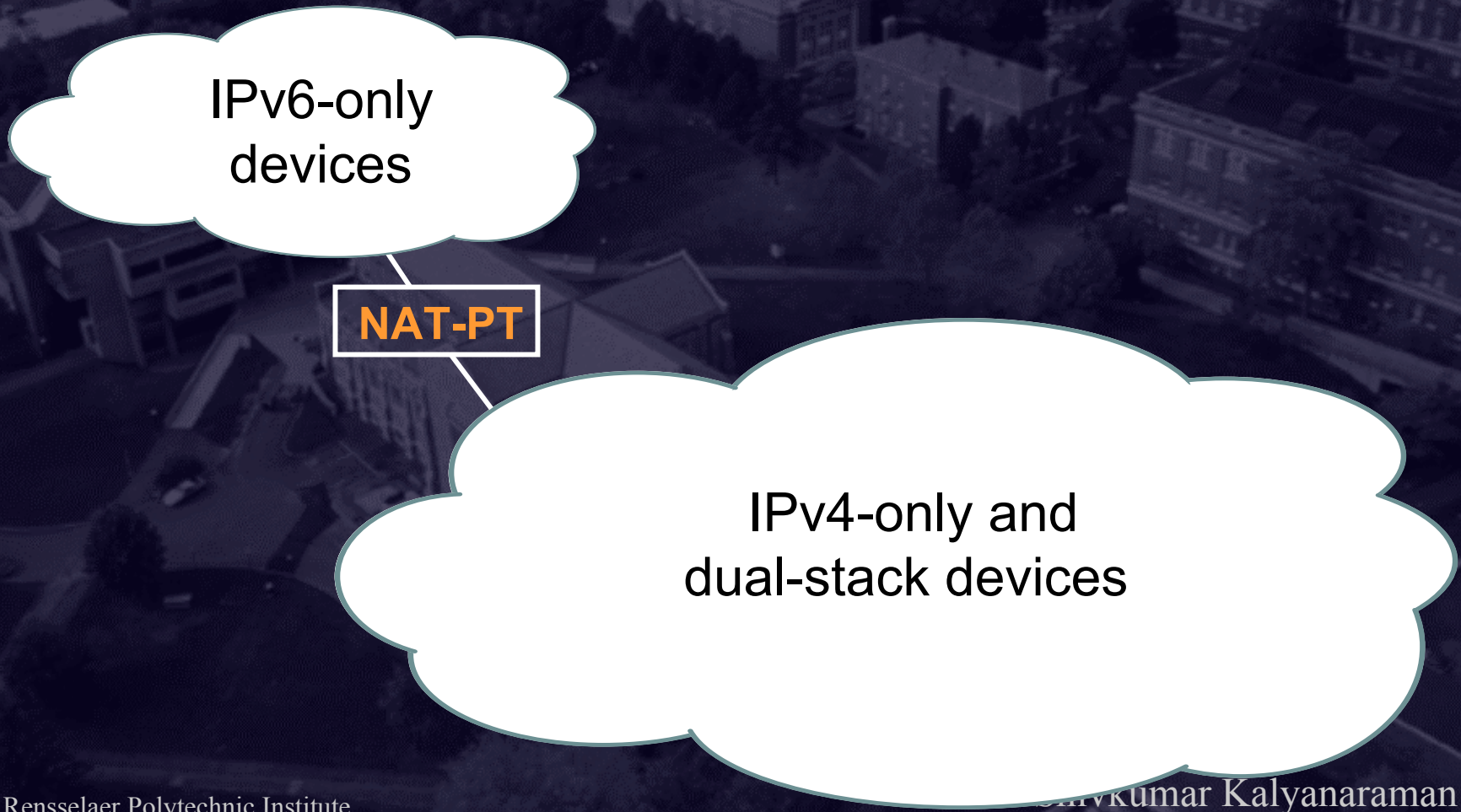


- Shipworm: IPv6 / UDP
  - IPv6 prefix: IP address & UDP port
- Shipworm servers
  - Address discovery
  - Default “route”
  - Enable “shortcut” (A-B)
- Shipworm relays
  - Send IPv6 packets directly to nodes
- Works for all NAT

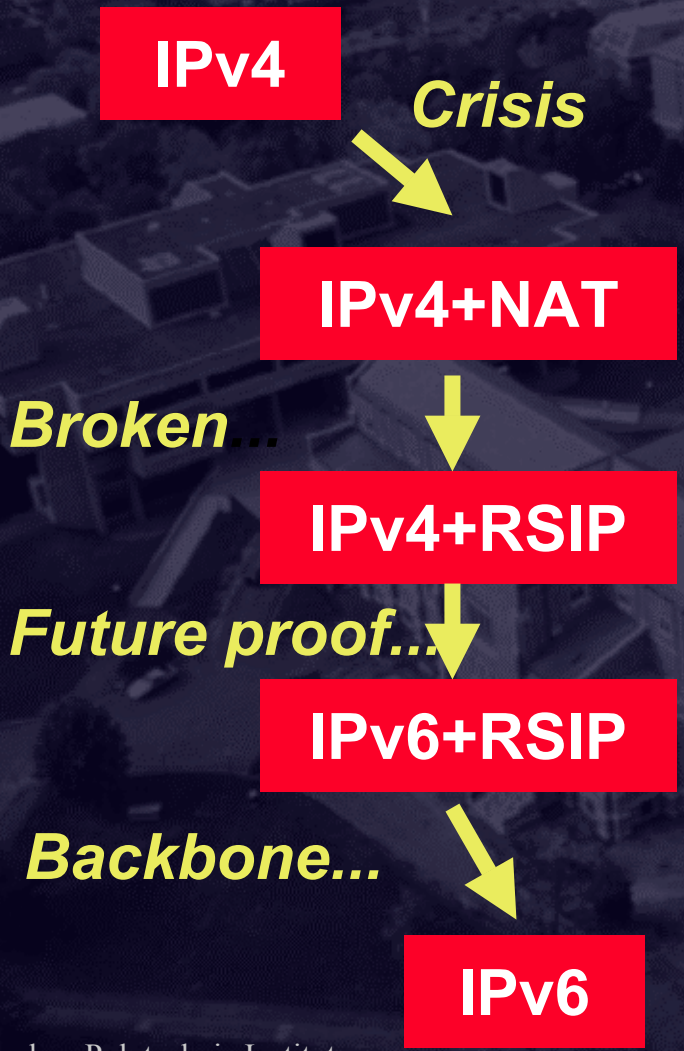
Translation: path from NATs

- 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. autoconfig)
- 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)



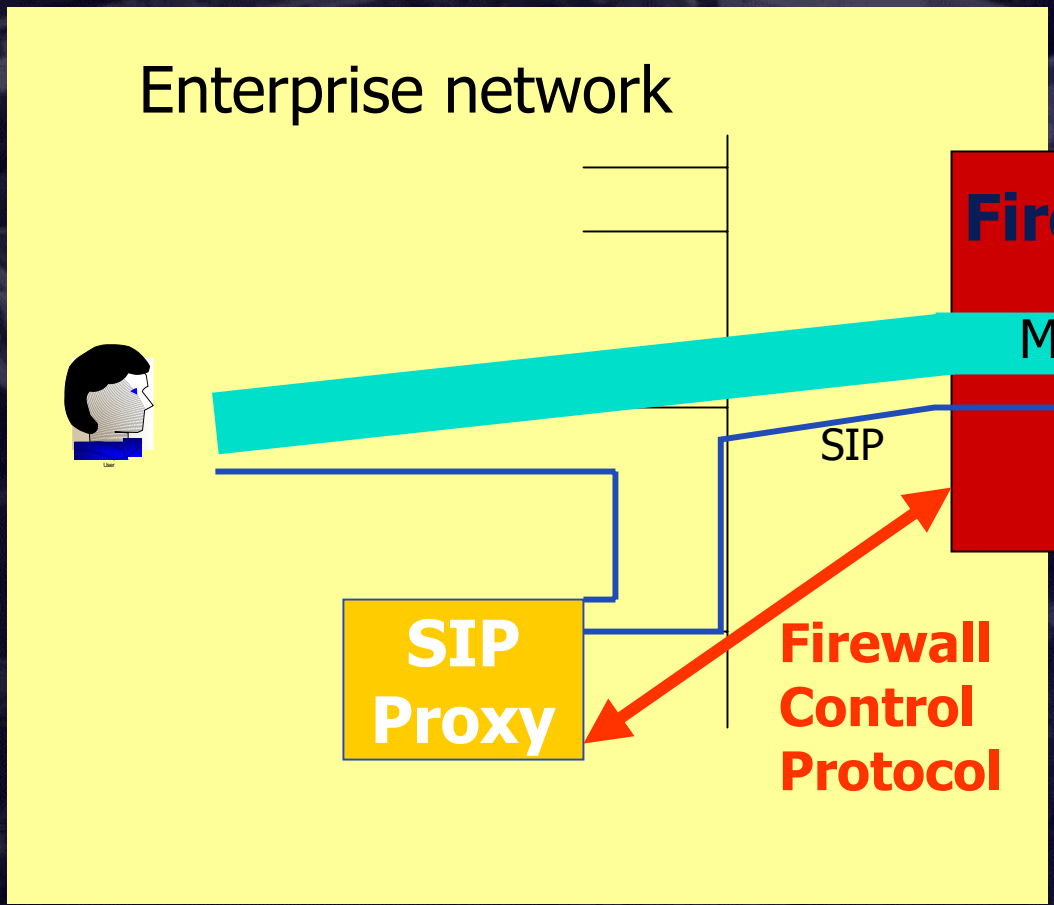
RSIP-based evolution leads to IPv6



Unlikely direction…

Since RSIP is not gaining traction

Firewall Control Protocol (FCP)



Work in progress: IETF "MIDCOM"

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
    - e.g., Apple, Bull, Mentat, Novell, SGI

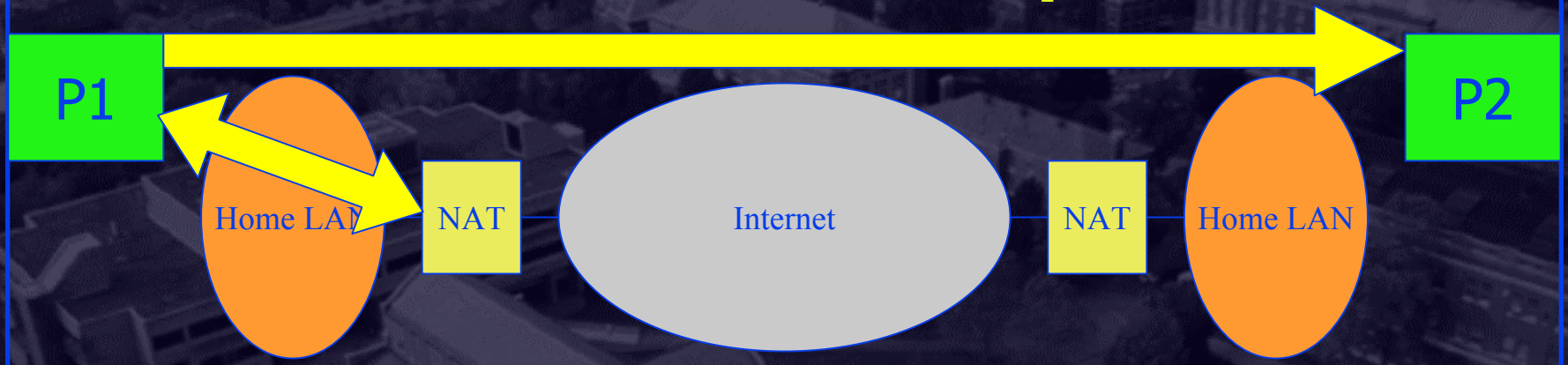
  (see playground.sun.com/ipng for most recent status reports)
- good attendance at frequent testing events

6-bone etc…

- 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
- 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
- Few commercial trials by ISPs announced

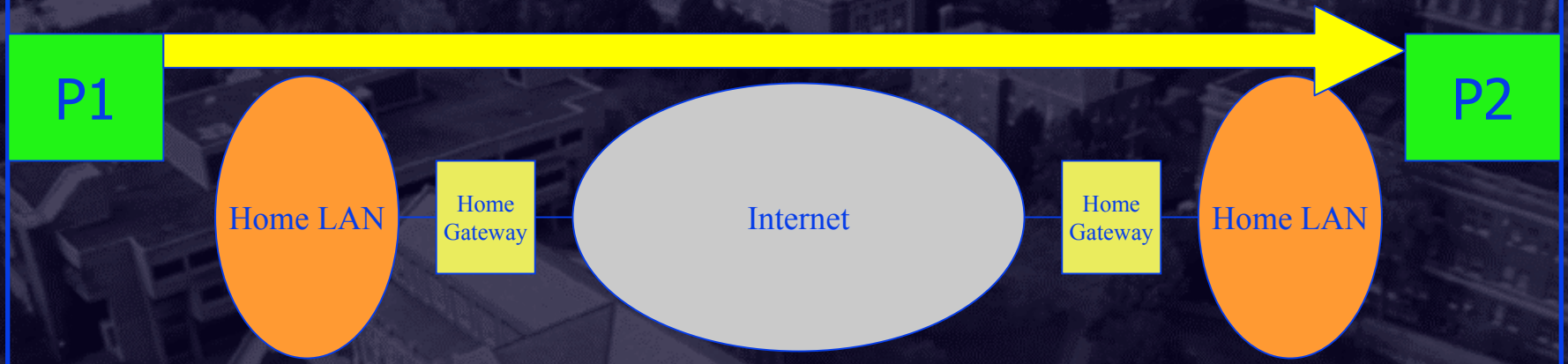
Incentive: Peer-to-peer applications?

Problem 1: Peer-to-peer RTP audio example



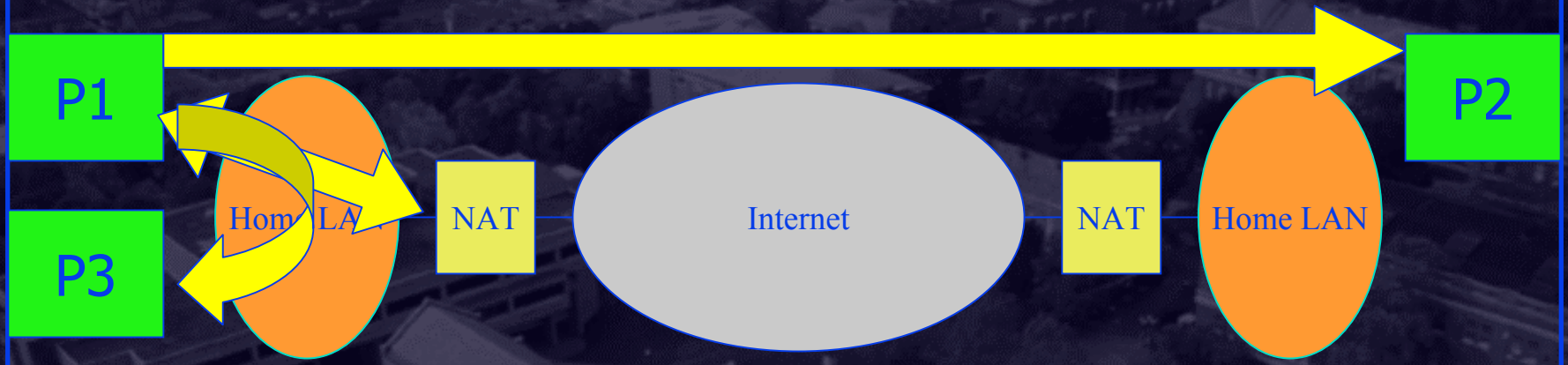
- With NAT:
  - Need to learn the address "outside the NAT"
  - Provide that address to peer
  - Need either NAT-aware application, or application-aware NAT
  - May need a third party registration server to facilitate finding peers

Solution 1: Peer-to-peer RTP audio example



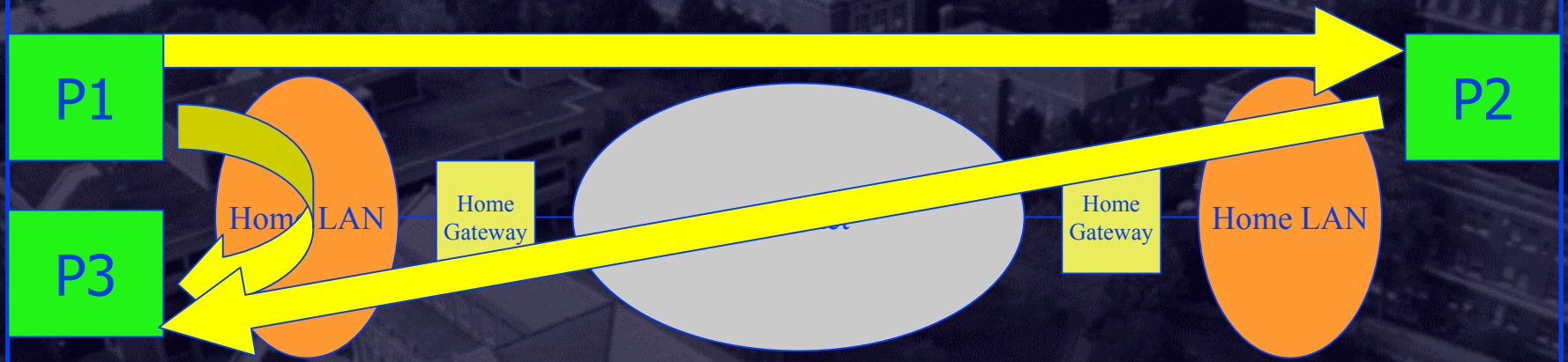
- With IPv6:
  - Just use IPv6 address

Problem: Multiparty Conference



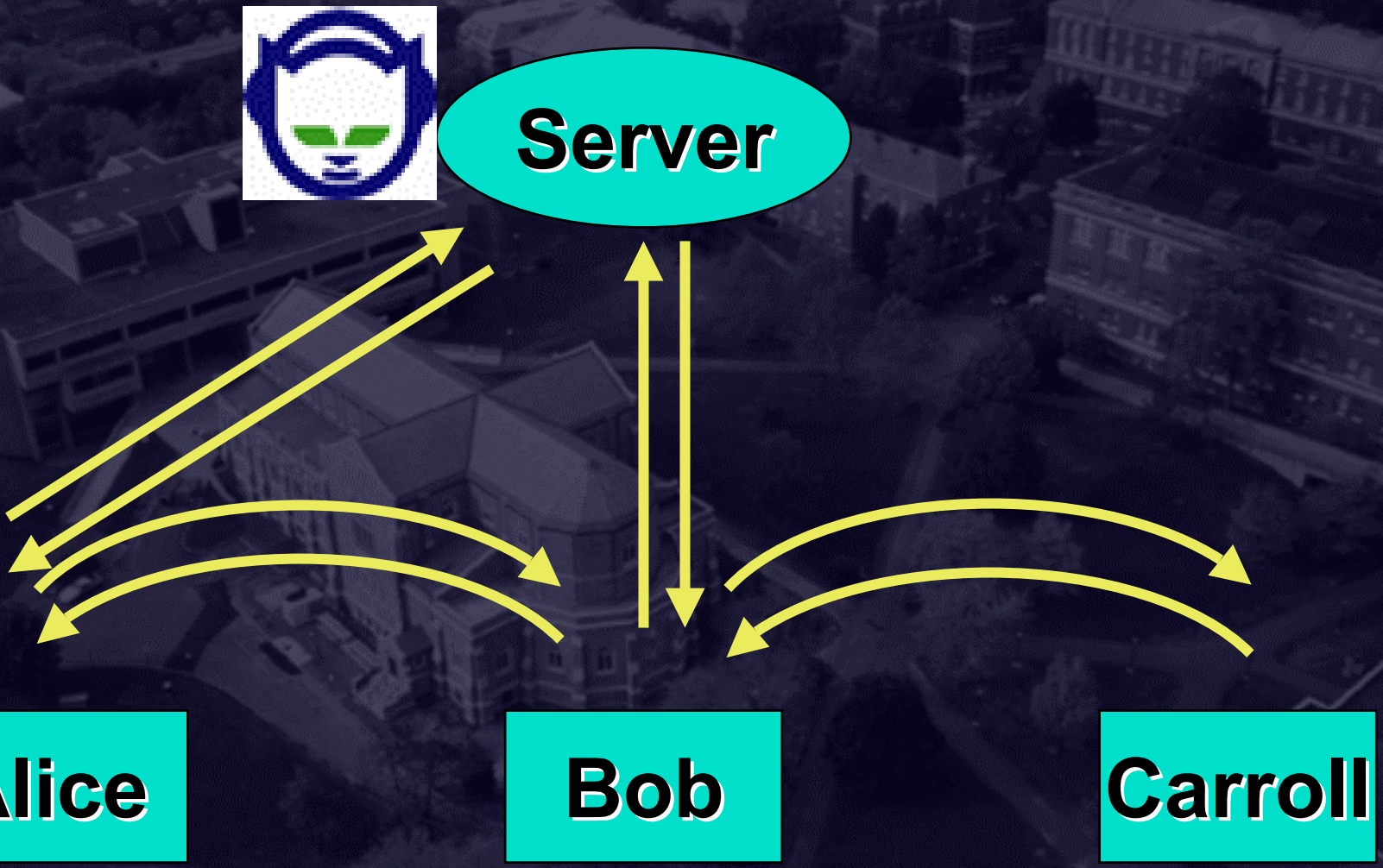
- With NAT, complex and brittle software:
  - 2 Addresses, inside and outside
  - P1 provides "inside address" to P3, "outside address" to P2
  - Need to recognize inside, outside
  - P1 does not know outside address of P3 to inform P2

Multiparty IPv6 Conference



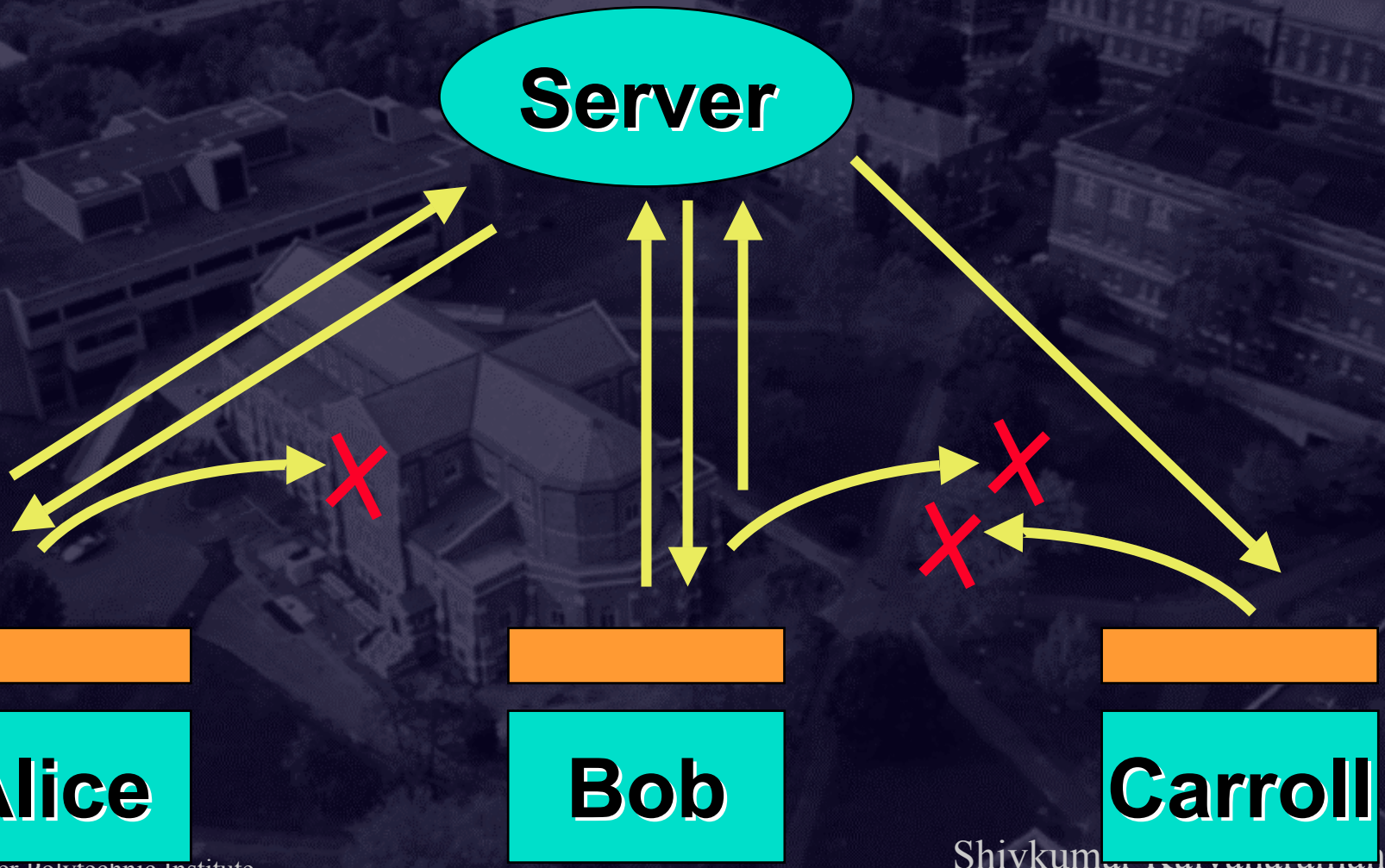
- With IPv6:
  - Just use IPv6 addresses

P2P apps: w/ global addresses

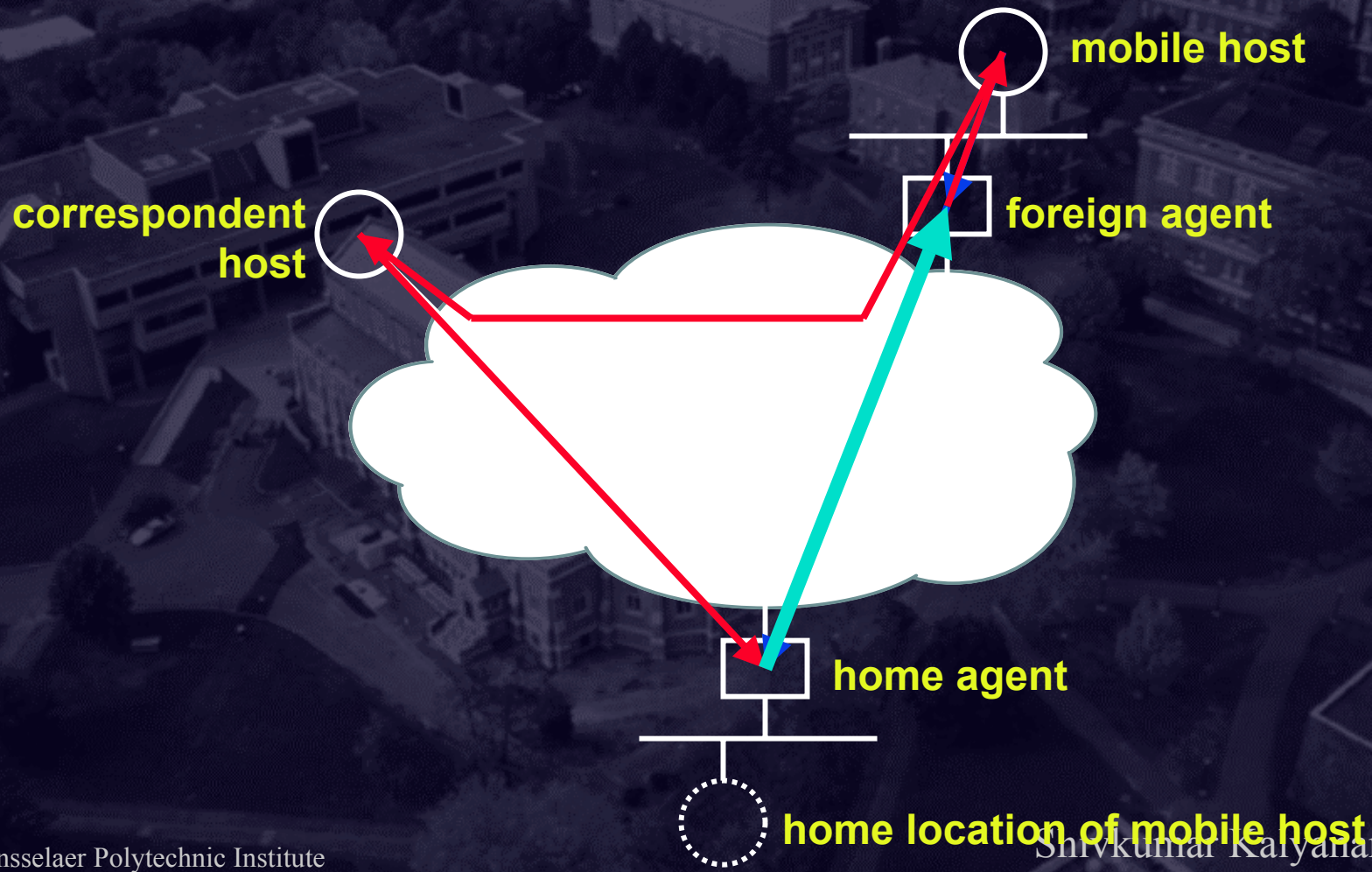


P2P apps w/ some firewalls and NAT.

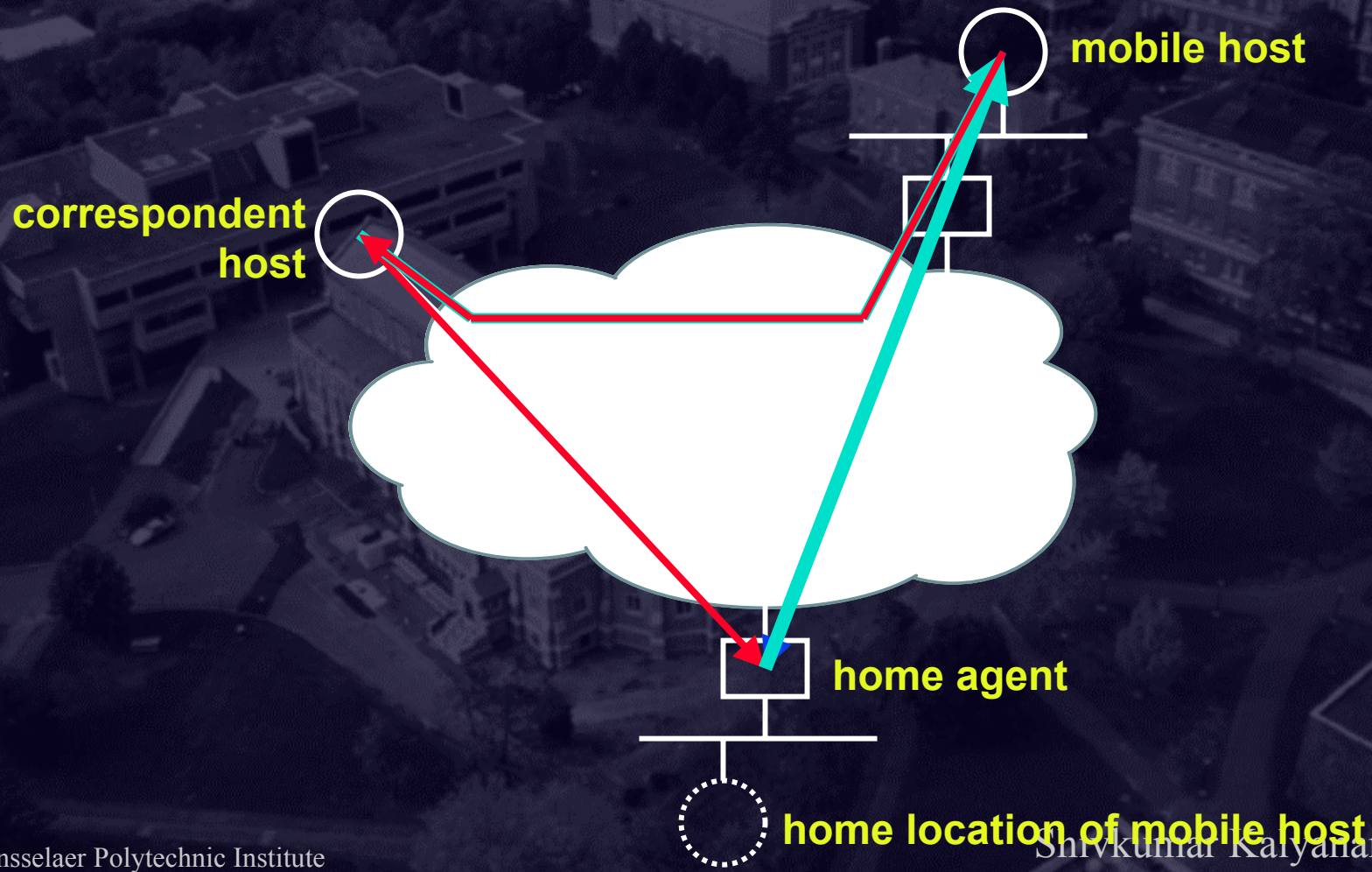
P2P apps: In a world of NAT



Mobility (v4 version)



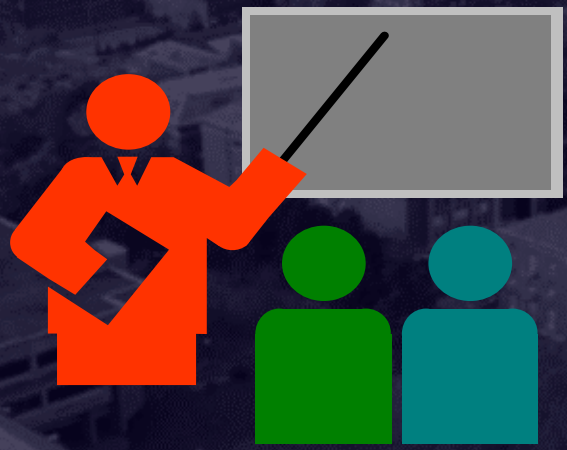
Mobile IP (v6 version)



Key drivers? Parting thoughts …

- Always-on requirement => large number of actively connected nodes online
- 3G, internet appliances
  - large numbers of addresses needed in short order…
  - IPv6 auto-configuration and mobility model better
  - 3GPP already moving towards IPv6
- P2P apps and multimedia get popular and NAT/ALGs/Firewalls break enough of them
- Multi-homed sites and traffic engineering hacks in BGP/IPv4 make inter-domain routing un-scalable
- Dual stack, simpler auto-conf, automatic tunneling (6to4 etc) simplify migration path and provide installed base
  - Applications slowly start self-selecting IPv6

Summary



- IPv6 uses 128-bit addresses
- Allows provider-based, site-local, link-local, multicast, anycast addresses
- Fixed header size. Extension headers instead of options for provider selection, security etc
- Allows auto-configuration
- Dual-IP, 6-to-4 etc for transition