Internet Protocol: The Next Generation

Raj Jain

Raj Jain is now at
Washington University in Saint Louis
Jain@cse.wustl.edu
http://www.cse.wustl.edu/~jain/

- Limitations of current Internet Protocol (IP)
- How many addresses do we need?
- Features of new IP
  - Address Allocation
  - Provider selection
  - Mobility
  - Autoconfiguration

IP 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

IP Address

- Class A:

0	Network	Local
1	7	24 bits

- Class B:

10	Network	Local
2	14	16 bits

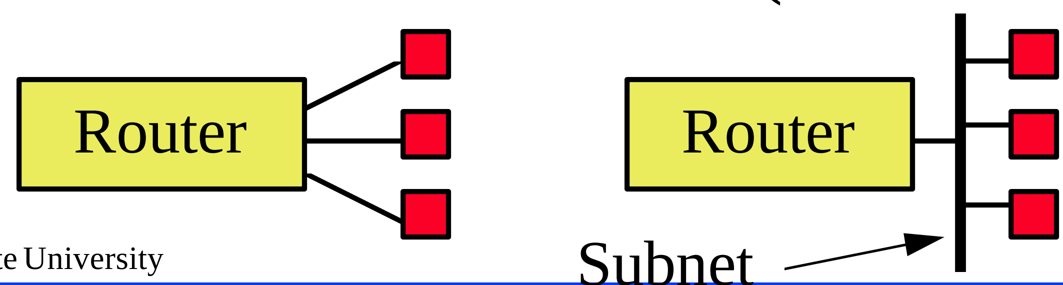
- Class C:

110	Network	Local
3	21	8 bits

- Class D:

1110	Host Group (Multicast)
4	28 bits

- Local = Subnet + Host (Variable length)



IP Address Format

- Three all-zero network numbers are reserved
- 127 Class A + 16,381 Class B + 2,097,151 Class C networks = 2,113,659 networks total
- Class B is most popular.
- 20% of Class B were assigned by 7/90 and doubling every 14 months ⇒ Will exhaust by 3/94
- Question: Estimate how big will you become?
  Answer: More than 256!
  Class C is too small. Class B is just right.

Band-Aids

- Allow a network to have multiple class C addresses
  - Routers keep routes for each network
    $\Rightarrow$ Multiple addresses $\Rightarrow$ long routing tables
  - Many routers were unable to keep track of all address
  - Long routing update messages
- Subdivide one Class A address among regional providers
- Recycle unused addresses
  (only 2.5% of Class B network space was used)
- Whole address space will be exhausted by 2008 to 2018
- CIDR Route Aggregation

Three Possible IP Death Scenario

Year	Networks	Computers
1980	10	10^2
1990	10^3	10^5
1997	10^6	10^8

- No more addresses
- No more network numbers
- Too big routing tables and routing messages
- Band-aids for mobility, integrated services, security
- In 12/1987: Network number shortage [Callon]

How Many Addresses Do We Need?

- 10 Billion people by 2020
- Each person will be served by 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

Address Size

- H Ratio = $\log_{10}$(number 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 ⇒ H = 0.26 (assuming 3.3 bits/digit)
- US telephone expanded area codes with 10^8 subscribers ⇒ H = 0.24
- SITA expanded 7-character address at 64k nodes ⇒ H = 0.14 (assuming 5 bits/char)
- Physics/space science net stopped at 15000 nodes using 16-bit addresses ⇒ H = 0.26
- 3 Million Internet hosts currently using 32-bit addresses ⇒ H = 0.20 ⇒ A few more years to go

IPv6 Addresses

- 128-bit long. Fixed size
- $2^{128} = 3.4\times10^{38}$ addresses
  $\Rightarrow 665\times10^{21}$ 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
  $8\times10^{17} \Rightarrow$ 1,564 address per sq. m
- Assigned to Interfaces. 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
    ::3243:0000:0000:ABCD
    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:BA23:7000::/40

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

Provider-based Unicast Addresses

3	n bits	m bits	o bits	p bits	125-m-n-o-p
010	Registry ID	Provider ID	Subscriber ID	Subnet ID	Interface ID

- 5-bit Registry: 18 ⇒ InterNIC, 8 ⇒ RIPE NCC, 14 ⇒ APNIC, 10 ⇒ IANA
- Variable size partitions
- Multiple subnets per physical links
- One subnet cannot span multiple physical links

Local-Use Addresses

- Link Local: Not forwarded outside the link, FE:80::xxx

10 bits	n bits	118-n
1111 1110 10	0	Interface ID

- Site Local: Not forwarded outside the site, FE:C0::xxx

10 bits	n bits	m bits	118-n-m bits
1111 1110 11	0	Subnet ID	Interface ID

- Provides plug and play

Multicast Addresses

8 bits	4 bits	4 bits	112 bits
1111 1111	Flags	Scope	Group ID

Flags:

0	0	0	T

- T = 0 ⇒ Permanent (well-known) multicast address, 1 ⇒ Transient
- Scope:
  - 1 Node-local
  - 2 Link-local
  - 5 Site-local
  - 8 Organization-local
  - E Global
- Predefined: 1 ⇒ All nodes, 2 ⇒ Routers, 1:0 ⇒ DHCP servers

Multicast Addresses (Cont)

- Example: 43 ⇒ Network Time Protocol 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 organization
  - FF0F::43 ⇒ All NTP servers in the Internet

IP Version Numbers

- Assigned by Internet Assigned Number Authority (IANA)
- Version 1-3 were never formally assigned
- IPv4: Current IP
- IPv5: ST
- IPv6: IP - The Next Generation (based on a TV show)
- IPv7: Initial next generation (One of the IAB documents incorrectly reported current version as 6)

Header

- IPv6:

Version	Priority	Flow Label
Payload Length	Next Header	Hop Limit
Source Address		
Destination Address		

- IPv4:

Version	IHL	Type of Service	Total Length
Identification	Flags	Fragment Offset	
Time to Live	Protocol	Header Checksum	
Source Address			
Destination Address			
Options	Padding		

IPv6 vs IPv4

- 1995 vs 1975
- IPv6 only twice the size of IPv4 header
- Only version number has the same position and meaning as in IPv4
- Removed: header length, type of service, identification, flags, fragment offset, header checksum
- Redefined: length, protocol type, time to live
- Added: Priority and flow label
- All fixed size fields.
- No optional fields. Replaced by extension headers.
- 8-bit hop limit = 255 hops max (Limits looping)
- Next Header = 6 (TCP), 17 (UDP),

Protocol and Header Types

Decimal	Keyword	Header Type
	HBH	Hop-by-hop (IPv6)
1	ICMP	Internet Control Message (IPv4)
2	IGMP	Internet Group Management (IPv4)
2	ICMP	Internet Control Message (IPv6)
3	GGP	Gateway-to-Gateway
4	IP	IP in IP (IPv4 Encaptulation)
5	ST	Stream
6	TCP	
17	UDP	
29	ISO-TP4	
43	RH	Routing Header (IPv6)
44	FS	Fragmentation Header (IPv6)
45	IDRP	Interdomain Routing
51	AH	Authentication header (IPv6)
52	ESP	Encrypted Security Payload
59	Null	No next header
60	ISO-IP	CLNP
88	IGRP	
89	OSPF	Open Shortest Path First

Extension Headers

Base Header	Extension Header 1		Extension Header *n*	Data

- Most extension headers are examined only at destination
- Routing: Loose or tight source routing
- Fragmentation: All IPv6 routers can carry 536 Byte payload
- Authentication
- Security Encaptulation: Confidentiality
- Hop-by-Hop Option: Special options that require processing at every node, e.g., jumbogram option for packets longer than 64 kB
- Destination Options:

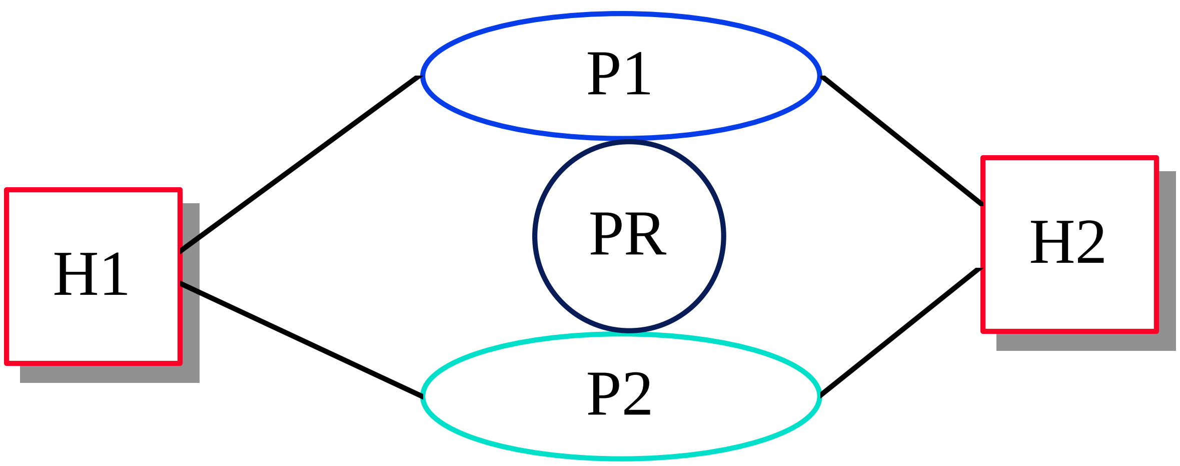
Routing Header

Next Header	Routing Type	Num. Address	Next Address
Reserved	Strict/Loose bit mask		
Address 1			
Address 2			
...			
Address n			

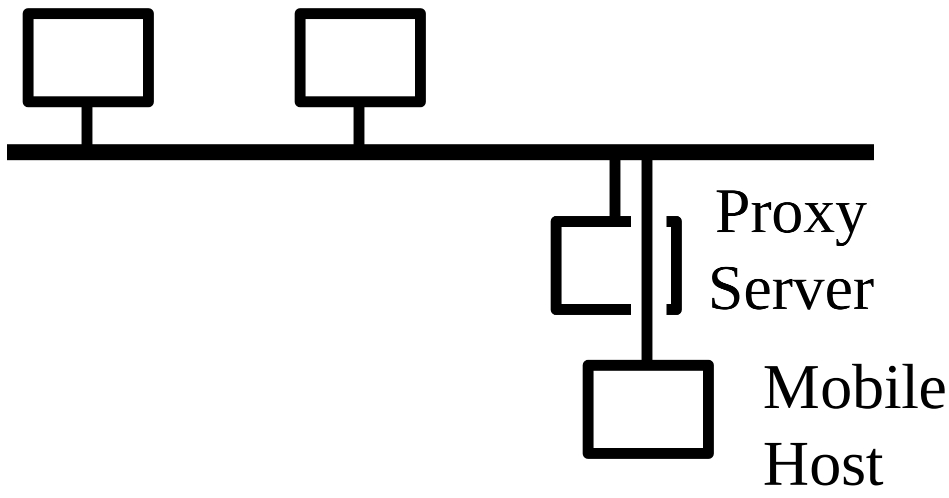
- Strict $\Rightarrow$ Discard if Address[Next-Address] $\neq$ neighbor
- Type = 0 $\Rightarrow$ Current source routing
- Type > 0 $\Rightarrow$ Policy based routing (later)
- New Functionality: Provider selection, Host mobility, Auto-readdressing (route to new address)

Provider Selection

- Possible using routing extension header
- Source specified intermediate systems
- No preference: H1, H2
- P1 Preferred: H1, P1, H2
- H1 becomes Mobile: H1, PR, P1, H2



Proxy Servers



- Mobile hosts asks another node(s) to serve as a proxy
- Multiple proxy servers should synchronize their behavior

Address Autoconfiguration

- 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
  - All prefixes have a associated lifetime
  - System can use link-local address permanently if no router

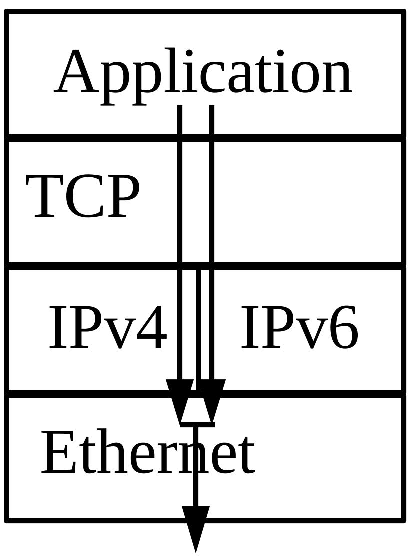
Address Autoconfiguration (Cont)

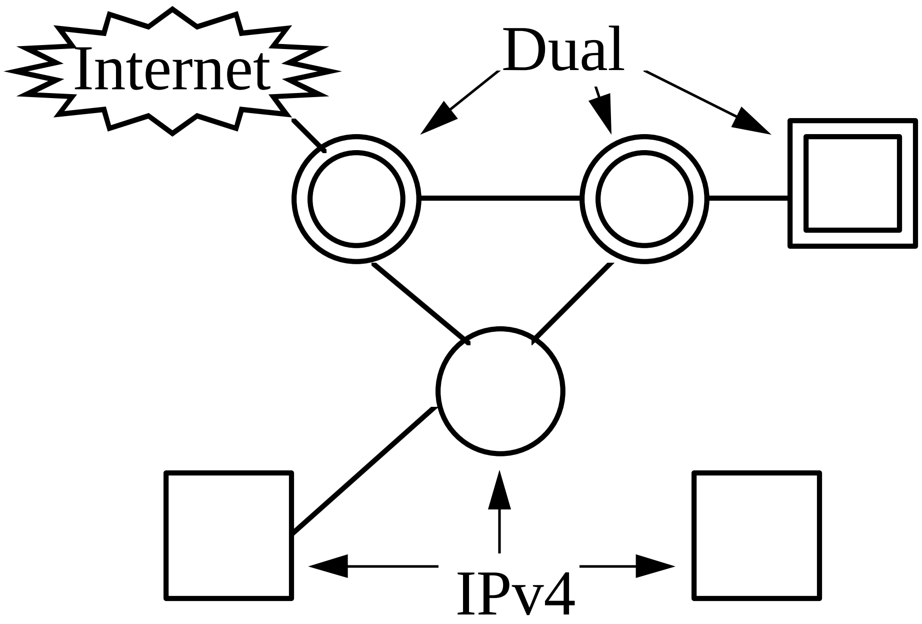
- Two lifetimes: Valid > preferred
- Prefix cannot be used after valid lifetime expires
- Prefix can be used after preferred lifetime expires but it is better to choose other addresses

- Duplicate Detection: Send to self
- 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

Transition Mechanisms

- Dual-IP Hosts, Routers, Name servers
- Tunneling IPv6 over IPv4
- Hosts and Routers can be gradually upgraded to IPv6
- It is better (though not required) to upgrade routers before upgrading hosts





Transition Mechanisms (Cont)

- Domain Name Server (DNS) records will tell hosts which IP to use for a destination
- IPv4 addresses use record type "A" with 32-bit addresses
- IPv6 will use record type "AAAA" (quad-A) with 128-bit addresses
- DNS servers may be upgraded to provide the new record type but may use IPv4 for communication
- IPv6 hosts may also use manually configured host tables if no upgraded DNS server

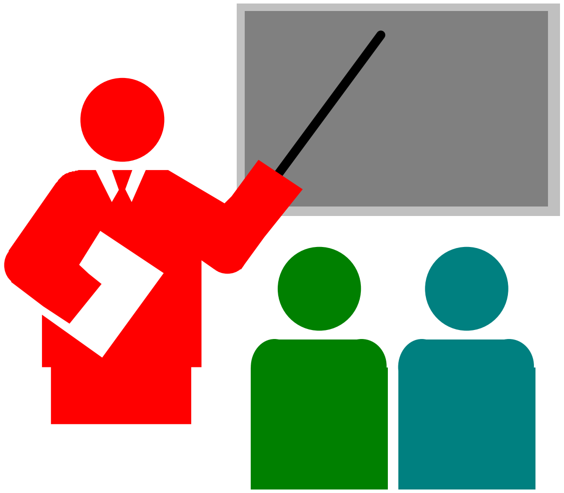
Application Issues

- Most application protocols will have to be upgraded FTP, SMTP, Telnet, Rlogin
- 27 of 51 Full Internet standards, 6 of 20 draft standards, 25 of 130 proposed standards will be revised for IPv6
- No checksum ⇒ checksum at upper layer is mandatory, even in UDP
- non-IETF standards: X-Open, Kerberos, ... will be updated
- Should be able to request and receive AAAA DNS records
- May want to take advantage of new features: Security, flow control, encryption, ...
- Extension to TCP socket interface has already been developed

Implementations

- 4.4-lite BSD by US Naval Research Laboratory (NRL)
- UNIX, OPEN-VMS by Digital Equipment Corporation.
- DOS/WINDOWS by FTP Software
- HP-UX SICS (Swedish Institute of Computer Science)
- Linux
- NetBSD by INRIA Rocquencourt
- Solaris 2 by Sun
- Streams by Mentat
- Routers: BayNetworks, Cisco, Penril Datability Networks
- Complete list in http://www.playground.sun.com/pub/ipng/html/ipng-implementations.html

Summary



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

Books

- C. Huitema, "IPv6: The New Internet Protocol," Prentice-Hall, 1996, 188 pp.
- S. Bradner, A. Mankin, Ed., "IPng: Internet Protocol Next Generation," Addison-Wesley, 1995, 307 pp.
- D. E. Comer, "Internetworking with TCP/IP, Vol 1: Principles, Protocols, and Architecture," Chapter 29, 3rd Ed., Prentice-Hall, 1995, pp. 489-510.

RFCs

RFCs can be obtained via ftp://ds.internic.net/rfc/rfcnnnn.txt, where nnnn is the RFC number in [] below.

- [1897] R. Hinden, J. Postel, "IPv6 Testing Address Allocation", 01/25/1996, 4 pp.
- [1887] Y. Rekhter, T. Li, "An Architecture for IPv6 Unicast Address Allocation", 01/04/1996, 25 pp.
- [1885] A. Conta, S. Deering, "Internet Control Message Protocol (ICMPv6) for the Internet Protocol Version 6 (IPv6)", 01/04/1996, 20 pp.
- [1883] S. Deering, R. Hinden, "Internet Protocol, Version 6 (IPv6) Specification", 01/04/1996, 37 pp.

- [1881] I. IESG, "IPv6 Address Allocation Management", 12/26/1995, 2 pp.
- [1809] C. Partridge, "Using the Flow Label Field in IPv6", 06/14/1995, 6 pp.
- [1753] J. Chiappa, "IPng Technical Requirements Of the Nimrod Routing and Addressing Architecture", 01/05/1995, 18 pp.
- [1726] F. Kastenholz, C. Partridge, "Technical Criteria for Choosing IP:The Next Generation (IPng)", 12/20/1994, 31 pp.
- [1719] P. Gross, "A Direction for IPng", 12/16/1994, 5 pp.
- [1710] R. Hinden, "Simple Internet Protocol Plus White Paper", 10/26/1994, 23 pp.

- [1707] M. McGovern, R. Ullmann, "CATNIP: Common Architecture for the Internet", 11/02/1994, 16 pp.
- [1705] R. Carlson, D. Ficarella, "Six Virtual Inches to the Left: The Problem with IPng", 10/26/1994, 23 pp.
- [1688] W. Simpson, "IPng Mobility Considerations", 08/11/1994, 9 pp.
- [1687] E. Fleischman, "A Large Corporate User's View of IPng", 08/11/1994, 13 pp.
- [1686] M. Vecchi, "IPng Requirements: A Cable Television Industry Viewpoint", 08/11/1994, 14 pp.
- [1683] R. Clark, M. Ammar, K. Calvert, "Multiprotocol Interoperability In IPng", 08/11/1994, 12 pp.
- [1682] J. Bound, "IPng BSD Host Implementation Analysis", 08/11/1994, 10 pp.

- [1681] S. Bellovin, "On Many Addresses per Host", 08/08/1994, 5 pp.
- [1680] C. Brazdziunas, "IPng Support for ATM Services", 08/08/1994, 7 pp.[1679] D. Green, P. Irey, D. Marlow, K. O'Donoghue, "HPN Working Group Input to the IPng Requirements Solicitation", 08/08/1994, 10 pp.
- [1678] E. Britton, J. Tavs, "IPng Requirements of Large Corporate Networks", 08/08/1994, 8 pp.
- [1677] B. Adamson, "Tactical Radio Frequency Communication Requirements for IPng", 08/08/1994, 9 pp.
- [1676] A. Ghiselli, D. Salomoni, C. Vistoli, "INFN Requirements for an IPng", 08/11/1994, 4 pp.
- [1675] S. Bellovin, "Security Concerns for IPng", 08/08/1994, 4 pp.

- [1674] M. Taylor, "A Cellular Industry View of IPng", 08/08/1994, 3 pp.
- [1673] R. Skelton, "Electric Power Research Institute Comments on IPng", 08/08/1994, 4 pp.
- [1672] J. Brownlee, "Accounting Requirements for IPng", 08/08/1994, 2 pp.
- [1671] B. Carpenter, "IPng White Paper on Transition and Other Considerations", 08/08/1994, 8 pp.
- [1670] D. Heagerty, "Input to IPng Engineering Considerations", 08/08/1994, 3 pp.
- [1669] J. Curran, "Market Viability as a IPng Criteria", 08/08/1994, 4 pp.
- [1668] D. Estrin, T. Li, Y. Rekhter, "Unified Routing Requirements for IPng", 08/08/1994, 3 pp.

- [1667] S. Symington, D. Wood, J. Pullen, "Modeling and Simulation Requirements for IPng", 08/08/1994, 7 pp.
- [1622] P. Francis, "Pip Header Processing", 05/20/1994, 16 pp.
- [1621] P. Francis, "Pip Near-term Architecture", 05/20/1994, 51 pp.
- [1561] D. Piscitello, "Use of ISO CLNP in TUBA Environments", 12/23/1993, 25 pp.
- [1550] S. Bradner, A. Mankin, "IP: Next Generation (IPng) White Paper Solicitation", 12/16/1993, 6 pp.
- [1526] D. Piscitello, "Assignment of System Identifiers for TUBA/CLNP Hosts", 09/30/1993, 8 pp.
- [1475] R. Ullmann, "TP/IX: The Next Internet", 06/17/1993, 35 pp.

- [1347] R. Callon, "TCP and UDP with Bigger Addresses (TUBA), A Simple Proposal for Internet Addressing and Routing", 06/19/1992, 9 pp.

Internet Drafts [As of 1/28/95]

All internet drafts can be obtained via
ftp://ds.internic.net/internet-drafts/xxx
where xxx is the file name given below in <> . Unless renewed, internet drafts expire after 6 months of issue date.

- "IPv6 Stateless Address Autoconfiguration", 12/18/1995, <draft-ietf-addrconf-ipv6-auto-07.txt>
- "Dynamic Host Configuration Protocol for IPv6 (DHCPv6)", 11/13/1995, <draft-ietf-dhc-dhcpv6-03.txt>
- "IPv6 and Neighbour Discovery over ATM", 08/28/1995, <draft-ietf-ipatm-ipv6nd-00.txt>
- "IPv6 Security Architecture", 03/03/1995, <draft-ietf-ipngwg-sec-00.txt>

- "An IPv6 Provider-Based Unicast Address Format", 08/31/1995, <draft-ietf-ipngwg-unicast-addr-fmt-02.txt>
- "A Method for the Transmission of IPv6 Packets over Ethernet Networks", 10/10/1995, <draft-ietf-ipngwg-ethernet-ntwrks-01.txt>
- "OSI NSAPs and IPv6", 08/23/1995, <draft-ietf-ipngwg-nsap-ipv6-00.txt>
- "Path MTU Discovery for IP version 6", 11/07/1995, <draft-ietf-ipngwg-pmtuv6-00.txt>
- "IP Version 6 over PPP", 12/26/1995, <draft-ietf-ipngwg-pppext-ipv6cp-00.txt>
- "Transition Mechanisms for IPv6 Hosts and Routers", 12/27/1995, <draft-ietf-ngtrans-trans-mech-02.txt>

- "Mobility Support in IPv6", 07/07/1995, <draft-perkins-ipv6-mobility-sup-02.txt>
- "Routing Aspects Of IPv6 Transition", 10/11/1995, <draft-ietf-ngtrans-routing-aspects-00.txt>
- "Options for Mobility Support in IPv6", 01/16/1996, <draft-teraoka-ipv6-mobility-sup-02.txt>
- "Mechanisms for OSI CLNP and TP over IPv6", 06/26/1995, <draft-carpenter-ipv6-osi-01.txt>
- "The IPv6 Payload Header", 10/11/1995, <draft-kre-ipv6-payload-01.txt>
- "IPv6 multicast over ATM", 06/21/1995, <draft-armitage-ipatm-ipv6mc-00.txt>
- "Getconninfo(): An alternative to Gethostbyname()", 06/27/1995, <draft-sklower-ipv6-getconninfo-03.txt>

- "A Framework for IPv6 Over ATM", 11/22/1995, <draft-schulter-ipv6atm-framework-00.txt, .ps>
- "RIPng for IPv6", 04/18/1995, <draft-ietf-rip-riping-01.txt>

On-Line References

- IP Next Generation, http://playground.sun.com/pub/ipng/html/ipng-implementations.html
- IP: Next Generation, http://www.cnri.reston.va.us/ipng/ipng.html

Recent Advances in Networking and Telecommunications Seminar Series 1996: Tentative Dates

Last Tuesday of the month (mostly), 3:45-5:15 PM

- January 30, 1996
- February 27, 1996
- March 22 or 26, 1996
- April 30, 1996
- May 28, 1996
- June 18, 1996
- August 27, 1996
- September 24, 1996
- October 15, 1996
- November 26, 1996

Potential Topics for 1996

- Gigabit Networking Standards: Fiber Channel and HIPPI
- Technologies for 6 Mb/s to Home: ADSL, HDSL
- GPS Applications to Networking
- Latest developments in Multimedia over IP
- New Advances in Wireless Networking
- Cellular Digital Packet Data (CDPD)
- Routing on ATM Networks
- Multiprotocol over ATM

Suggestions for topics welcome

Thank You!

- The purpose of the seminar is technology transfer. We want to help Columbus/Ohio businesses be on the leading edge of the technology superhighway. Thank you for attending the seminar.
- If your company would like to sponsor partly, please contact Jain@cis.ohio-state.edu
- Slides of all past seminars and all our papers and reports can be obtained on-line:
  http://www.cis.ohio-state.edu/~jain/
- To get on our list, (if not already on), email requests to netsem@cis.ohio-state.edu

Seminar Registration

If you have not registered before or if your information has changed, please fill this out, tear this part, and leave it with the speaker. We will inform you about our future seminars.

Name: ______________________________________

Position (Title): ______________________________

Company:______________________________________

Address:______________________________________

____

____

Phone: ____________________ Fax: _________________

Email: ______________________________________