CS615 - Aspects of System Administration

Networking I

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## OSI Model

<table>
<thead>
<tr>
<th>Layer</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>Application</td>
</tr>
<tr>
<td>6</td>
<td>Presentation</td>
</tr>
<tr>
<td>5</td>
<td>Session</td>
</tr>
<tr>
<td>4</td>
<td>Transport</td>
</tr>
<tr>
<td>3</td>
<td>Network</td>
</tr>
<tr>
<td>2</td>
<td>Data link</td>
</tr>
<tr>
<td>1</td>
<td>Physical</td>
</tr>
</tbody>
</table>
Networking I

- Political
- Financial
- Application
- Presentation
- Session
- Transport
- Network
- Link
- Physical

You are Here
Layer 1: Repeater Hub

Half-duplex, cheap, obsolete.
Layer 2: Network Switch

MAC bridge, full-duplex, segmentation, STP
Layer 3: Router

connect networks, forward packets, routing tables, BGP
IPv4 Basics

10011011111101100101100101100100

IPv4 addresses are 32-bit numbers.
IPv4 Basics

10011011 11110110 01011001 01100100

Each IPv4 address consists of four octets.
IPv4 Basics

Each IPv4 address consists of four octets.

10011011 11110110 01011001 01100100
155 . 246 . 89 . 100
IPv4 Basics

10011011 11110110 01011001 01100100

IPv4 addresses are divided into a network part and a host part.

Hosts on the same network (broadcast domain) can talk to each other without the help of a router.
IPv4 Basics

There are three different *classes* of IPv4 networks.
IPv4 Basics

There are three different classes of IPv4 networks. Well, five, really.
# IPv4 Basics

<table>
<thead>
<tr>
<th>Class</th>
<th>Leading bits</th>
<th>Size of network number bit field</th>
<th>Size of rest bit field</th>
<th>Number of networks</th>
<th>Addresses per network</th>
<th>Start address</th>
<th>End address</th>
</tr>
</thead>
<tbody>
<tr>
<td>Class A</td>
<td>0</td>
<td>8</td>
<td>24</td>
<td>$128 \times (2^7)$</td>
<td>$16,777,216 \times (2^{24})$</td>
<td>0.0.0.0</td>
<td>127.255.255.255</td>
</tr>
<tr>
<td>Class B</td>
<td>10</td>
<td>16</td>
<td>16</td>
<td>$16,384 \times (2^{14})$</td>
<td>$65,536 \times (2^{16})$</td>
<td>128.0.0.0</td>
<td>191.255.255.255</td>
</tr>
<tr>
<td>Class C</td>
<td>110</td>
<td>24</td>
<td>8</td>
<td>$2,097,152 \times (2^{21})$</td>
<td>$256 \times (2^8)$</td>
<td>192.0.0.0</td>
<td>223.255.255.255</td>
</tr>
<tr>
<td>Class D (multicast)</td>
<td>1110</td>
<td>not defined</td>
<td>not defined</td>
<td>not defined</td>
<td>not defined</td>
<td>224.0.0.0</td>
<td>239.255.255.255</td>
</tr>
<tr>
<td>Class E (reserved)</td>
<td>1111</td>
<td>not defined</td>
<td>not defined</td>
<td>not defined</td>
<td>not defined</td>
<td>240.0.0.0</td>
<td>255.255.255.255</td>
</tr>
</tbody>
</table>
Subnets

\[
\begin{array}{cccc}
10011011 & 11110110 & 01011001 & 01100100 \\
11111111 & 11111111 & 00000000 & 00000000 \\
\end{array}
\]

A *netmask* splits the IPv4 address into *network* and *host* parts.
Subnets

A netmask splits the IPv4 address into network and host parts.
$ ipcalc -n 155.246.89.100/16
Address:  155.246.89.100  10011011.11110110. 01011001.01100100
Netmask:  255.255.0.0 = 16  11111111.11111111. 00000000.00000000
Wildcard:  0.0.255.255  00000000.00000000. 11111111.11111111
=>
Network: 155.246.0.0/16  10011011.11110110. 00000000.00000000
HostMin:  155.246.0.1  10011011.11110110. 00000000.00000001
HostMax:  155.246.255.254  10011011.11110110. 11111111.11111110
Broadcast:  155.246.255.255  10011011.11110110. 11111111.11111111
Hosts/Net: 65534  Class B

Try also: sipcalc -a 155.246.89.100/16
Subnets

$ ipcalc -n 155.246.89.100/24

Address: 155.246.89.100 10011011.11110110.01011001. 01100100
Netmask: 255.255.255.0 = 24 11111111.11111111.11111111. 00000000
Wildcard: 0.0.0.255 00000000.00000000.00000000. 11111111

=>

Network: 155.246.89.0/24 10011011.11110110.01011001. 00000000
HostMin: 155.246.89.1 10011011.11110110.01011001. 00000001
HostMax: 155.246.89.254 10011011.11110110.01011001. 11111100
Broadcast: 155.246.89.255 10011011.11110110.01011001. 11111111
Hosts/Net: 254 Class B

Try also: sipcalc -a 155.246.89.100/24
CIDR cheat sheet

A.B.C.D/N

- $N$ = bits describing network portion of address
- $M = 32 - N$ = bits in host portion of address
- $2^M$ = number of addresses on this subnet
- $2^M - 2$ = number of possible hosts
  - first address on subnet = network address
  - last address on subnet = broadcast address

subnet division need not occur on dotted boundary only
  - for example, you can divide 155.246.89.0/24 into four /26 networks
  - networks starting at .0, .64, .128, .192

Which of the following is not a valid netmask?
255.255.253.0, 255.255.250.0, 255.255.240.0
Mommy, where do IP addresses come from?

The Internet Assigned Numbers Authority (IANA) oversees global IP address/AS number allocation, root zone management etc.

https://www.iana.org/
Mommy, where do IP addresses come from?

Regional Internet Registries (RIR) manage the allocation and registration of Internet number resources within a region of the world.

XXX: put this in here somewhere https://www.xkcd.com/195/
Mommy, where do IP addresses come from?

RIRs assign blocks of IP addresses to the Local Internet Registries (LIR).

LIRs are either ISPs, enterprises using a lot of addresses, or academic institutions.
IPv4 Subnets: Common CIDRs

10011011 11110110 01011001 01100100

|   |   |   |   |   |   /32 Host route
|   |   |   |   |   /30 "Glue network" (Point-to-point)
|   |   |   |   |   /29 Smallest multi-host network
|   |   |   |   /28 Small LAN
|   |   |   /27 Small LAN
|   |   /26 Small LAN
|   /25 Large LAN
| /24 Large LAN
| /20 Small ISP / Large business
| /19 LIR / ISP / Large business
| /18 LIR / ISP / Large business
| /17 LIR / ISP / Large business
| /16 LIR / ISP / Large business
| /8 RIR
IPv4 Exhaustion

Some researchers wanted a 128-bit space for the binary address, Cerf (recalled) ...
But others said, "That's crazy," because it's far larger than necessary, and they
suggested a much smaller space. Cerf finally settled on a 32-bit space that was
incorporated into IPv4 and provided a respectable 4.3 billion separate addresses.

"It's enough to do an experiment," he said. "The problem is the experiment never
ended."
IPv4 Exhaustion

IPv4 address space depletion:

- private IP space (RFC1918): 10.0.0.0/8, 172.16.0.0/12, 192.168.0.0/16
- class D (224.0.0.0/4) and E (240.0.0.0/4)
- class As (16M addresses each!) initially handed out liberally (ATT, Apple, MIT, Stanford, Xerox, ...)
- subnetting often inefficient
- more and more devices added
IPv4 Exhaustion

IPv4 address space depletion:

Total theoretically available IP addresses: $2^{32}$

RFC1918: 10.0.0.0/8, 172.16.0.0/12, 192.168.0.0/16

RFC5735 etc.: 0.0.0.0/8, 100.64.0.0/10, 127.0.0.0/8, 169.254.0.0/16, 192.0.0.0/24, 192.0.2.0/24, 192.88.99.0/24, 198.18.0.0/15, 198.51.100.0/24, 203.0.113.0/24

Class D/E: 224.0.0.0/4, 240.0.0.0/4

"Limited broadcast": 255.255.255.255/32

What is the percent/number of actually available IP addresses?
IPv4 Exhaustion

Past and predicted:

IANA Address Pool Exhaustion: 2011-02-03
APNIC reached final /8: 2011-04-19
RIPENCC reached final /8: 2012-09-14
LACNIC reached final /8: 2014-06-10
ARIN reached final /8: 2015-09-15
AFRINIC(predicted): 2019-01-09

http://www.potaroo.net/tools/ipv4/
http://www.iana.org/assignments/ipv4-address-space/
IPv6 Basics

10011011111101100101100101100100

IPv4 addresses are 32-bit numbers.
IPv6 Basics

IPv6 addresses are 128 bits.
IPv6 Basics

IPv4: 32 bits $\Rightarrow 2^{32}$ addresses

IPv6: 128 bits $\Rightarrow 2^{128}$ addresses
IPv6 Basics

IPv4: 32 bits $\Rightarrow$ 4, 294, 967, 296 addresses

IPv6: 128 bits $\Rightarrow$ $2^{128}$ addresses
IPv6 Basics

IPv4: 32 bits => 4, 294, 967, 296 addresses

IPv6: 128 bits =>
340, 282, 366, 920, 938, 463, 463, 374, 607, 431, 768, 211, 456 addresses
IPv6 Basics

\[ \frac{2^{128}}{\text{number of atoms in human body}/ \text{number of people on earth}} \]

Input interpretation:

\[ \frac{2^{128}}{\text{estimated number of atoms in a typical human body}} \]

world population

Results:

6.82 per person per atom (2013 estimate)

<table>
<thead>
<tr>
<th>estimated number of atoms in a typical human body</th>
<th>7 \times 10^{27} \text{ atoms}</th>
</tr>
</thead>
<tbody>
<tr>
<td>(assuming a body mass of roughly 70 kilograms)</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>world population</th>
<th>7.13 billion people</th>
</tr>
</thead>
<tbody>
<tr>
<td>(2013 estimate)</td>
<td></td>
</tr>
</tbody>
</table>

https://is.gd/94ve91
IPv6 Basics

- 8x16 bit fields (words) in case insensitive colon hexadecimal representation

```
2031:0000:0000:030F:0000:0000:0000:130B
```
IPv6 Basics

- 8x16 bit fields (words) in case insensitive colon hexadecimal representation

2031:0000:0000:030F:0000:0000:0000:130B

- Leading zeros in a field are optional:

2031:0:0:30F:0:0:0:130B
IPv6 Basics

- 8x16 bit fields (words) in case insensitive colon hexadecimal representation

  2031:0000:0000:030F:0000:0000:0000:130B

- Leading zeros in a field are optional:

  2031:0:0:30F:0:0:0:130B

- Successive fields of 0 represented as ::, but only once in an address:

  2031::30F:0:0:0:130B      ok
  2031:0:0:30F::130B       ok
  2031::30F::130B          not ok
IPv6 Basics

- 8x16 bit fields (words) in case insensitive colon hexadecimal representation

\[2031:0000:0000:030F:0000:0000:0000:130B\]

- Leading zeros in a field are optional:

\[2031:0:0:30F:0:0:0:130B\]

- Successive fields of 0 represented as ::, but only once in an address:

\[
\begin{align*}
2031::30F:0:0:0:130B & \quad \text{ok} \\
2031:0:0:30F::130B & \quad \text{ok} \\
2031::30F::130B & \quad \text{not ok}
\end{align*}
\]

- \[0000:0000:0000:0000:0000:0000:0000:0001 \Rightarrow 0:0:0:0:0:0:0:1 \Rightarrow ::1\]
IPv6 Basics - Address Oddities

- Address may include a link name:

  2001:470:1f07:3d1::1%eth0
IPv6 Basics - Address Oddities

- Address may include a link name:

  2001:470:1f07:3d1::1%eth0

- IPv4-mapped addresses

  0:0:0:0:0:ffff:66.163.162.9
  ::ffff:66.163.162.9
IPv6 Basics - Address Oddities

- Address may include a link name:

  2001:470:1f07:3d1::1%eth0

- IPv4-mapped addresses

  0:0:0:0:0:ffff:66.163.162.9
  ::ffff:66.163.162.9

- You need brackets to distinguish a port from an address:

  **IPv4:** 66.163.162.9:22
  **IPv6:** [2001:470:1f07:3d1::1]:22
IPv6 Basics – Address Scope

- Link-Local (example: fe80::e276:63ff:fe72:3900%xennet0)
  - Used on a single link
  - Packets with link-local source or destination addresses are not forwarded to other links
IPv6 Basics – Address Scope

- **Link-Local** (example: `fe80::e276:63ff:fe72:3900%xennet0`)
  - Used on a single link
  - Packets with link-local source or destination addresses are not forwarded to other links

- **Unique-Local** (`fc00::/7`)
  - Used for private IPv6 networks
  - Not globally routable
  - Applications similar to RFC 1918
IPv6 Basics – Address Scope

- **Link-Local** (example: `fe80::e276:63ff:fe72:3900%xennet0`)
  - Used on a single link
  - Packets with link-local source or destination addresses are not forwarded to other links
- **Unique-Local** (`fc00::/7`)
  - Used for private IPv6 networks
  - Not globally routable
  - Applications similar to RFC 1918
- **Global** (example: `2001:470:1f07:3d1::1`)
  - A globally unique address
  - Packets with global addresses can be forwarded to any part of the global network

Networking I

April 6, 2018

[IPV6 INFO]
Subnet prefix (masked) - 2001:470:30:84:0:0:0:0/64
Address ID (masked) - 0:0:0:0:e276:63ff:fe72:3900/64
Prefix address - ffff:ffff:ffff:ffff:0:0:0:0
Prefix length - 64
Address type - Aggregatable Global Unicast Addresses
IPv6 Subnets: Common CIDRs

2001:0db8:0123:4567:89ab:cdef:1234:5678

/128 Single end-points and loopback
/124
/120
/116
/112
/110
/108
/104
/100
/96
/92
/88
/84
/80
/76
/72
/68
/64
/60
/56
/52
/48
/44
/40
/36
/32
/28
/24
/20
/16
/12
/8

Single End-user LAN (default prefix size for SLAAC)
Proposed minimal end sites assignment
Default end sites assignment
Local Internet registry minimum allocations
Local Internet registry medium allocations
Local Internet registry large allocations
Local Internet registry extra large allocations
Regional Internet Registry allocations from IANA
Networking Buzzwords

“The network is the computer.”

John Gage, Sun Microsystems
Networking Buzzwords

“The network is the network, the computer is the computer - sorry about the confusion.”

Joe on Computing
Networking Buzzwords
Networking

http://www.chrisharrison.net/index.php/Visualizations/InternetMap
Networking

/X?
Networks
Networking
WHOIS ASN?

The Internet Assigned Numbers Authority (IANA) oversees global IP address/AS number allocation, root zone management etc.

https://www.iana.org/
WHOIS ASN?

Autonomous System Numbers (ASNs) are assigned by IANA to the RIRs, see e.g. ftp://ftp.arin.net/pub/stats/arin/

You can query databases on the internet about e.g. IP block or ASN information via the WHOIS protocol:

$ whois 155.246.89.100 | more

NetRange: 155.246.0.0 - 155.246.255.255
CIDR: 155.246.0.0/16
NetName: STEVENS
NetHandle: NET-155-246-0-0-1
Parent: NET155 (NET-155-0-0-0-0)
NetType: Direct Assignment
Organization: Stevens Institute of Technology (SIT)
RegDate: 1991-12-31
Updated: 2007-01-29
Ref: https://whois.arin.net/rest/net/NET-155-246-0-0-1
WHOIS ASN?

Carriers connect their Autonomous Systems at *Internet Exchange Points* (IXPs) to route traffic between the different networks.

This *peering* happens amongst carriers on a tiered basis.

Examples:

https://peeringdb.com/net?asn=6939
https://peeringdb.com/net/27
https://peeringdb.com/net/433
https://peeringdb.com/net/457
WHOIS ASN?

Most of these services are available via APIs or text-based interfaces:

```bash
$ host www.google.com
www.google.com has address 172.217.0.36
www.google.com has IPv6 address 2607:f8b0:4006:807::2004
$ whois -h whois.cymru.com 2607:f8b0:4006:807::2004
+AS | IP | AS Name
$ curl -s https://peeringdb.com/api/net?asn=15169 | python -mjson.tool | more
{
  "data": [
    {
      "aka": "Google, YouTube (for Google Fiber see AS16591 record)",
      "created": "2005-02-06T06:41:04Z",
      "id": 433,
      "info_ipv6": true,
      "info_prefixes4": 15000,
      "info_prefixes6": 750,
      "info_ratio": "Mostly Outbound",
    }
  ]
}
```
Networking
To find the path your packets might take, give `traceroute(1)` a go:

```
$ traceroute search.yahoo.com
traceroute to search.yahoo.com (63.250.200.63), 30 hops max, 60 byte packets
 1 155.246.89.2 (155.246.89.2) 0.342 ms postal0.cs.stevens-tech.edu (155.246.89.3)
 2 155.246.89.2 (155.246.89.2) 0.311 ms 0.300 ms gwa.cc.stevens.edu (155.246.151.3)
 3 454a0465.cst.lightpath.net (69.74.4.101) 3.984 ms 3.761 ms 3.735 ms
 4 18267502.cst.lightpath.net (24.38.117.2) 32.559 ms 32.591 ms 32.577 ms
 5 hunt183-154.optonline.net (167.206.183.154) 4.473 ms 4.634 ms 18267502.cst.lightpath.net
 6 451be0a9.cst.lightpath.net (65.19.113.169) 5.170 ms 5.278 ms hunt183-154.optonline.net
 7 nyiix.bas1-m.nyc.yahoo.com (198.32.160.121) 6.928 ms 451be0a9.cst.lightpath.net
 8 ae-1.pat2.bfw.yahoo.com (216.115.111.26) 26.422 ms ae-1.pat1.bfw.yahoo.com (216.115.111.28)
 9 et-18-1-0.msr1.bf2.yahoo.com (74.6.227.37) 17.812 ms et-18-1-0.msr2.bf1.yahoo.com
10 et-0-1-1.clr1-a-gdc.bf1.yahoo.com (74.6.122.15) 18.817 ms et-0-1-1.clr2-a-gdc.bf1.yahoo.com
```
Networking
Networking
Networking
Networking

Stringing cables across the oceans’ floors since 1866!

http://www.submarinecablemap.com/
https://is.gd/Cjan0u
http://www.submarinecablemap.com/
Networking

“The Net interprets censorship as damage and routes around it.”

...except when it can’t.

https://blog.cloudflare.com/how-syria-turned-off-the-internet
https://player.vimeo.com/video/54630037
Networking

http://amzn.com/0061994952
Networking

The internet is a physical place.

https://en.wikipedia.org/wiki/Room_641A
Networking

Now identify the physical and organizational aspects of your network traffic:

$ traceroute search.yahoo.com
traceroute to search.yahoo.com (63.250.200.63), 30 hops max, 60 byte packets
1 155.246.89.2 (155.246.89.2) 0.342 ms postal0.cs.stevens-tech.edu (155.246.89.3)
2 155.246.89.2 (155.246.89.2) 0.311 ms 0.300 ms gwa.cc.stevens.edu (155.246.151.37)
3 454a0465.cst.lightpath.net (69.74.4.101) 3.984 ms 3.761 ms 3.735 ms
4 18267502.cst.lightpath.net (24.38.117.2) 32.559 ms 32.591 ms 32.577 ms
5 hunt183-154.optonline.net (167.206.183.154) 4.473 ms 4.634 ms 18267502.cst.lightpath.net
6 451be0a9.cst.lightpath.net (65.19.113.169) 5.170 ms 5.278 ms hunt183-154.optonline.net
7 nyiix.bas1-m.nyc.yahoo.com (198.32.160.121) 6.928 ms 451be0a9.cst.lightpath.net
8 ae-1.pat2.bfw.yahoo.com (216.115.111.26) 26.422 ms ae-1.pat1.bfw.yahoo.com (216.115.111.28)
9 et-18-1-0.msr1.bf2.yahoo.com (74.6.227.37) 17.812 ms et-18-1-0.msr2 bf1.yahoo.com
10 et-0-1-1.clr1-a-gdc bf1.yahoo.com (74.6.122.15) 18.817 ms et-0-1-1.clr2-a-gdc bf1.yahoo.com
Networking I

- Physical
- Network
- Link
- Transport
- Session
- Presentation
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- Financial
- Political

You are Here
Internet Maps and Architecture

- https://is.gd/C66S8a
- http://www.submarinecablemap.com/
- https://is.gd/tpPNE5
- https://is.gd/B0d3kh
- http://amzn.com/0061994936
- http://bgp.he.net/
- https://www.wired.com/2014/08/shark_cable/
IPv6

- http://bgp.he.net/ipv6-progress-report.cgi
- https://ipv6.he.net/statistics/
- http://tunnelbroker.net/