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CS2003: Internet and the Web

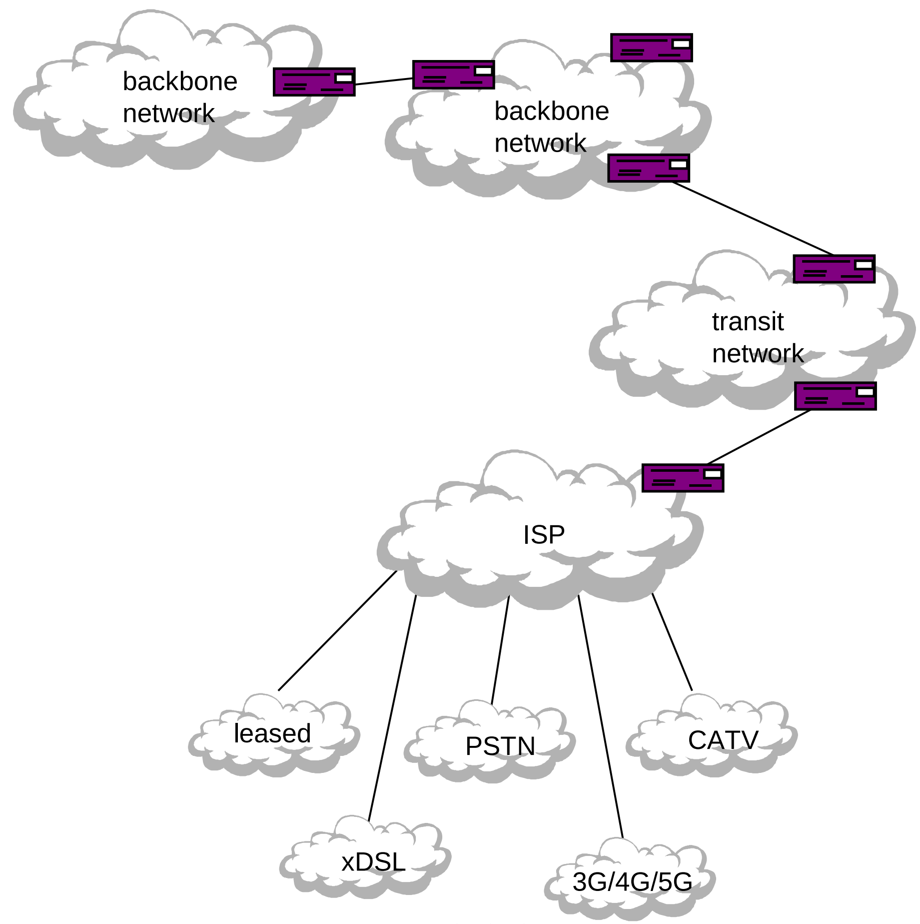
Internet Protocol

Internet Protocol overview

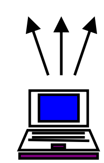
1. **IP best effort service model.**
2. IP addresses.
3. Names and the DNS.

Internet: global connectivity

- Connectivity between network clouds:
  - internal workings hidden
  - IP provides convergence
- Backbone providers:
  - commercial network operators
- Transit networks:
  - may be IP-aware
  - may provide basic connectivity only (possibly not IP-aware)



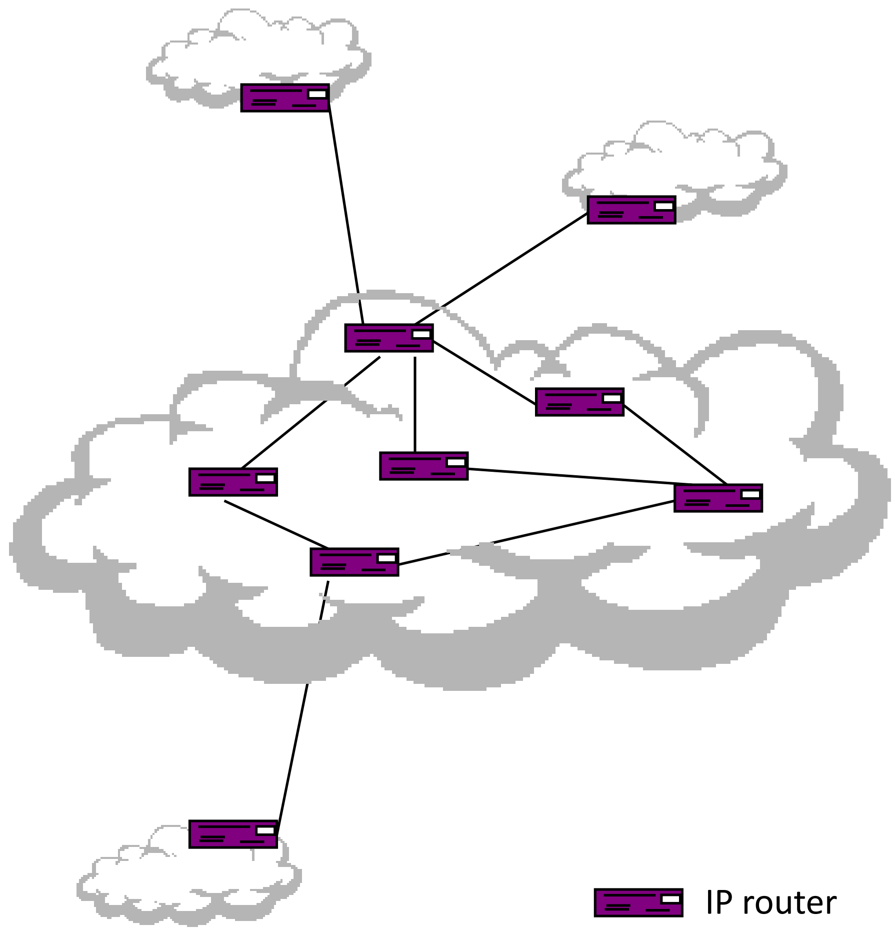
3G/4G/5G	Global System for Mobile communication
CATV	cable TV network
leased	fixed, leased line services (business)
PSTN	public switched telephone network
xDSL	digital subscriber line



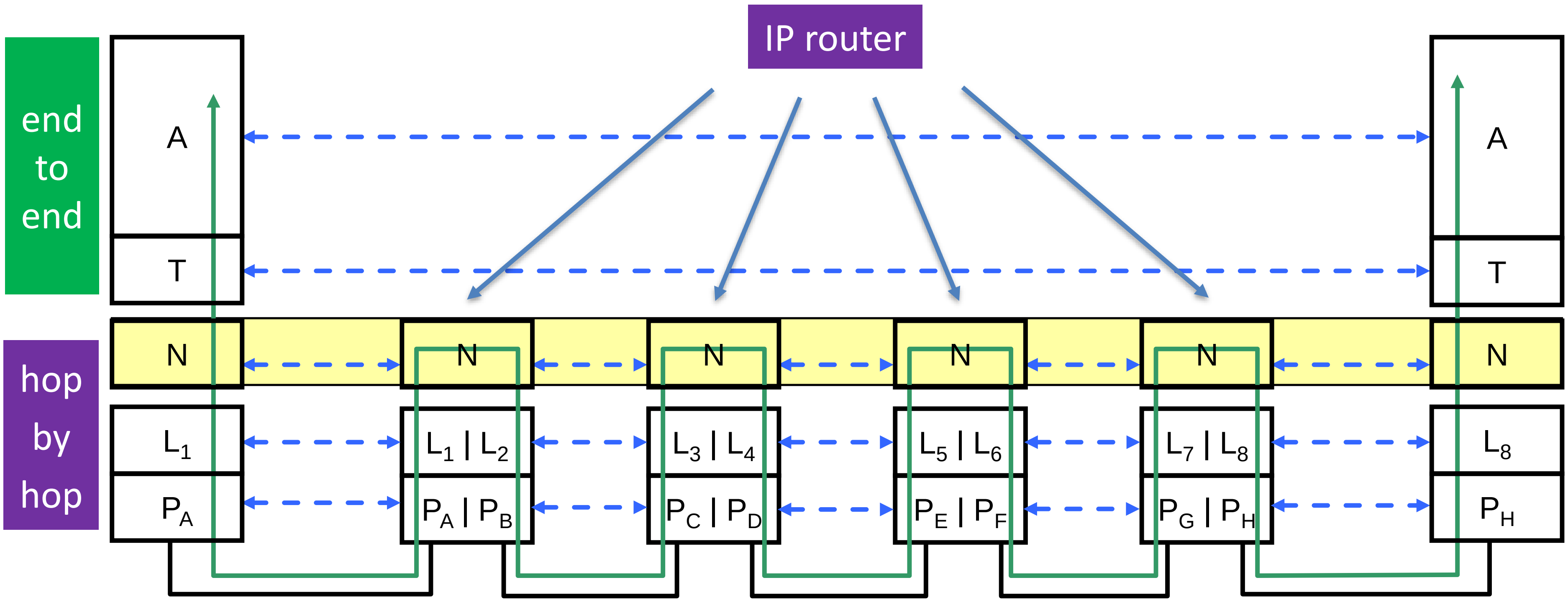
IP router

Network topology – WAN

- **Connectivity between sites:**
  – "interconnection units"
- Use public or private networks:
  – data rate?
- Network "clouds":
  – need cloud-to-cloud connectivity.
  – point-to-point links.
- Interconnection of different networks:
  – IP routeing
- **Addressing and routeing** (more later in the course).



Internet Protocol: common internetworking layer



A	application	N	- - →	network	logical (peer-to-peer) communication
T	transport	L	——→	(data) link	actual end-to-end message path
P	physical				

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IP is independent of sub-network technology.
(needs to work over “anything”)

IP is the common layer for internetworking.
(the “waist” of the hourglass)

Internetworking: simplest service?

- To work over “anything” implies we cannot expect much of the underlying technology
  - See IETF RFC 1149!
- Reliability?
  - Errors in transmission?
  - Packet loss?
- Ordering?
  - Correct sequence of delivery of packets?
- Delay?
  - Consistent end-to-end path?
- **The IP service is referred to as Best Effort:**
  - **“whatever you can get at the time of transmission”.**
  - **“no guarantees”**

IP is Connection-less (CL)

- Send and receive data:
  - datagrams (packet).
  - no connection set-up.
- Simple data/user interface.
- “Send and forget”:
  - Unconfirmed.
  - “Unreliable” (depends on network path).
- Suitable for “bursty” data:
  - Data source is not constrained on transmission.
- No direct access normally:
  - Access via transport protocol.
  - Some applications access IP directly. (Should they? Think of the first practical)

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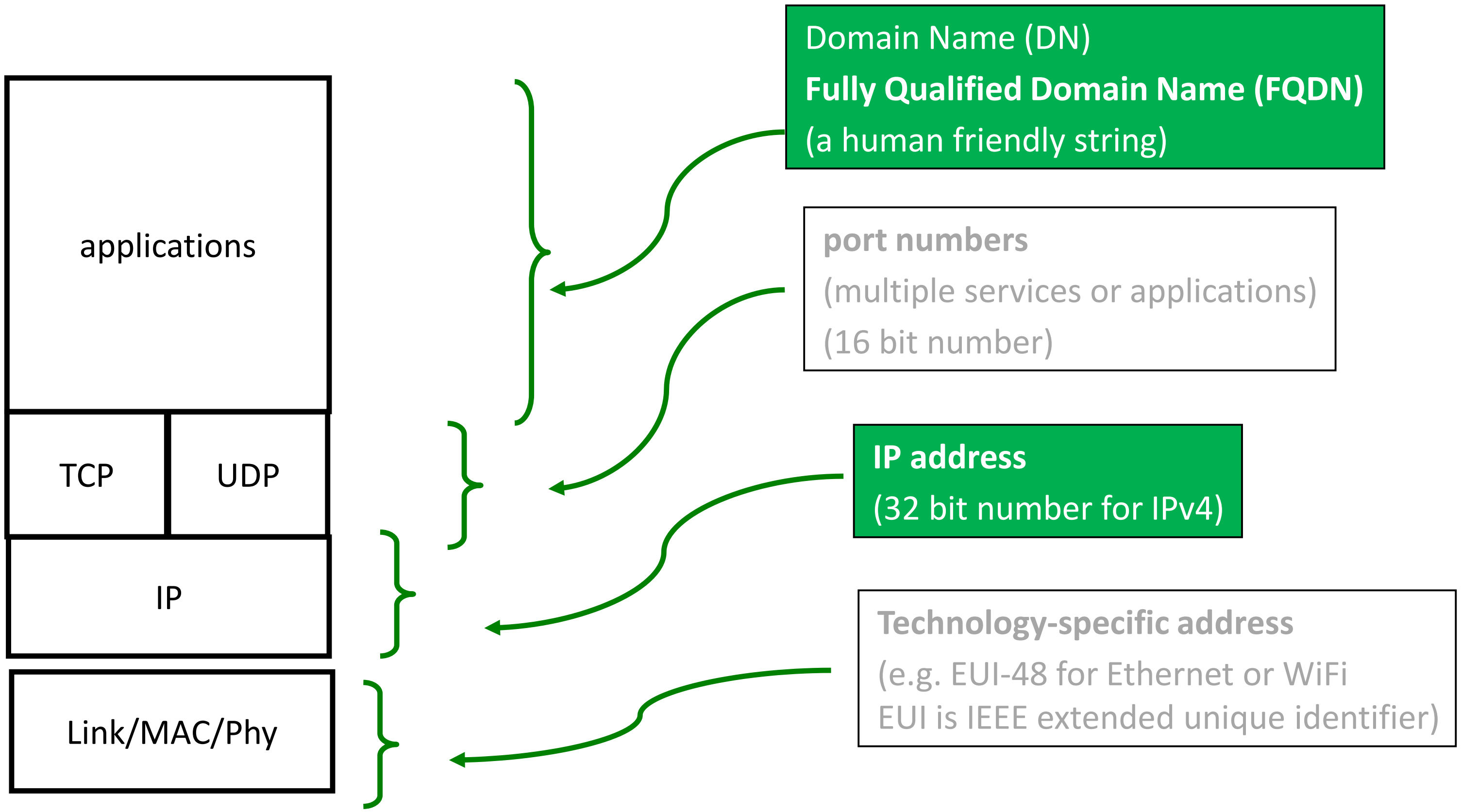
Naming and Address Bindings



A FQDN is looked up in a global directory service (the **Domain Name System**) and a corresponding IP address is found.

Strictly speaking, an IP address identifies an **interface on a host** (such as an Ethernet interface or wireless LAN interface) and **not** the host itself.

IPv4 header

```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|Version|  IHL  |Type of Service|          Total Length         |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|         Identification        |Flags|      Fragment Offset    |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|  Time to Live |    Protocol   |         Header Checksum       |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                       Source Address                          |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                    Destination Address                        |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

IP Header Format (from http://www.faqs.org/rfcs/rfc791.html , p11)

IPv4 address

`138.251.195.61     1000 1010 1111 1011 1100 0011 0011 1101`

- Dotted decimal – easier to read and write
- 32 bit binary – what is sent over the wire

IPv6 header

```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|Version| Traffic Class |           Flow Label                  |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|         Payload Length        |  Next Hdr     |   Hop Limit   |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                                                               |
+                                                               +
|                                                               |
+-                     Source IPv6 Address                     -+
|                                                               |
+                                                               +
|                                                               |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                                                               |
+                                                               +
|                                                               |
+-                  Destination IPv6 Address                   -+
|                                                               |
+                                                               +
|                                                               |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

from RFC8200 https://tools.ietf.org/html/rfc8200 , page 6

IPv6 address

```
2001:48d0:0101:0501:0000:0000:0000:0122
2001:48d0:101:501::0122

0010000000000001 0100100011010000 0000000100000001
0000010100000001 0000000000000000 0000000000000000
0000000000000000 0000000100100010
```

- Colon-delimited hexadecimal – easier to read and write (?)
- 128 bit binary – what is sent over the wire

IPv4 address exhaustion

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The RIPE NCC has run out of IPv4 Addresses

Today, at 15:35 (UTC+1) on 25 November 2019, we made our final /22 IPv4 allocation from the last remaining addresses in our available pool. We have now run out of IPv4 addresses.

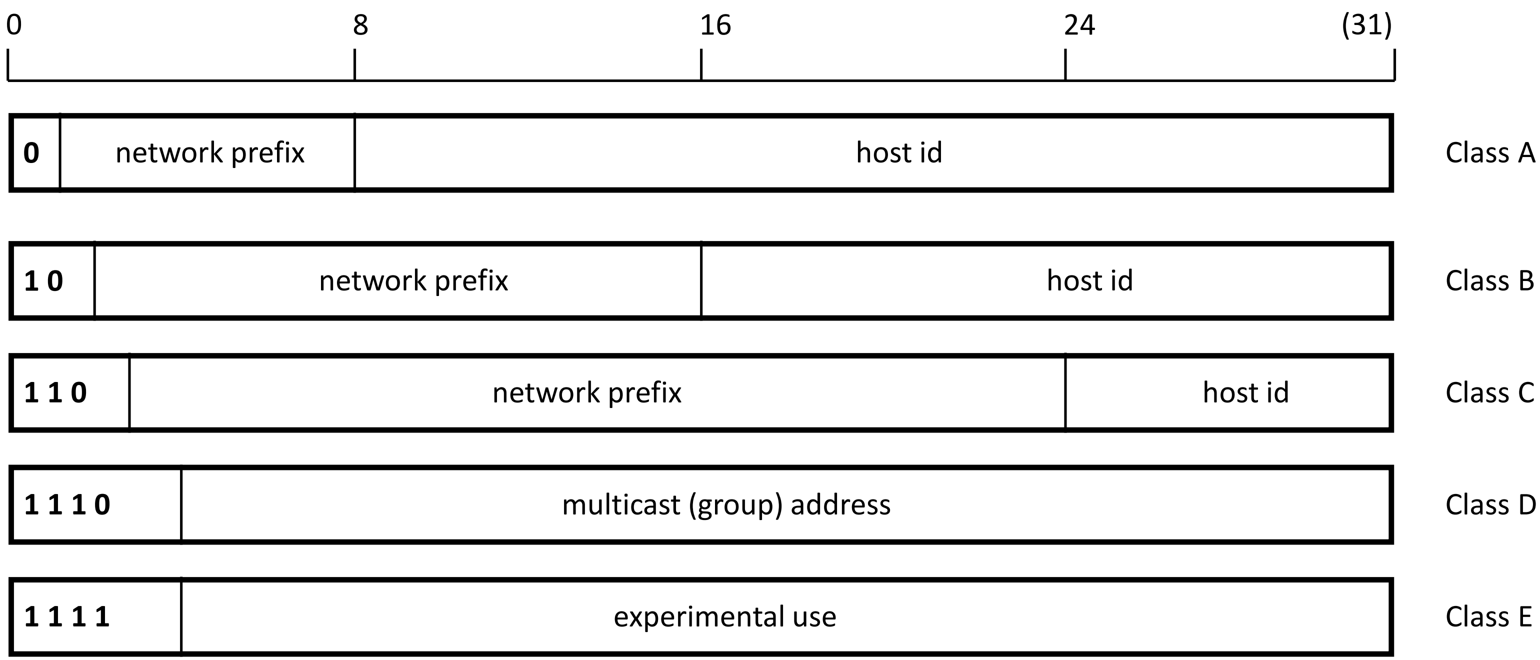
Our announcement will not come as a surprise for network operators - IPv4 run-out has long been anticipated and planned for by the RIPE community. In fact, it is due to the community's responsible stewardship of these resources that we have been able to provide many thousands of new networks in our service region with /22 allocations after we reached our last /8 in 2012.

https://www.ripe.net/publications/news/about-ripe-ncc-and-ripe/the-ripe-ncc-has-run-out-of-ipv4-addresses

IP addresses

- Used for identification:
  - Allow hosts to be uniquely labelled.
- Used by transport protocols:
  - Forms part of the identity of transport packet flow.
- Bound to an **interface** on a IP host:
  - Multiple interfaces, multiple IP addresses.
- Used for **routeing** and **forwarding**:
  - **routeing**: discover network paths between networks.
  - **forwarding**: transmit packets towards their destination.

IPv4 addresses: old class system



Classes A, B and C still in use in some **private** networks, but not used globally.

Class D still in use today, but multicast routeing not supported globally.

Class E possibly still in use today, in private networks, for experiments.

IPv4 addresses: old class system

- Class A: 0.0.0.0 to 127.255.255.255
  - 2^24 hosts per network (very large!)
- Class B: 128.0.0.0 to 191.255.255.255
  - 2^16 hosts per network
- Class C:
  - 2^8 hosts per network
- Quite wasteful
  - Should the Ford Motor Company or the Prudential Insurance Company have 2^24 addresses when the address space is finite?
  - https://www.iana.org/assignments/ipv4-address-space/ipv4-address-space.xhtml

IPv4 addresses – classless

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- Special addresses:
  - (also many for IPv6, not shown here)

Address example	Src	Dst	Description
255.255.255.255	No	Yes	Limited broadcast. If the local network supports broadcast then broadcast the datagram. This is never passed on by routers.
138.251.255.255 210.50.160.255	No	Yes	Net directed broadcast. If the target network supports broadcast then broadcast the datagram on it.
127.x.x.x	Yes	Yes	Loopback. Send to yourself.
0.0.42.6	Yes	No	Used by a host which does not know its network prefix.
0.0.0.0	Yes	No	Used by a host that does not know its IP address.

- Classless addressing:
  - remove use of Class A, B and C
  - **address mask** → network prefix
  - IPv4 address plus mask: e.g. 138.251.195.61/24
- More flexibility in address allocation.
- routeing information aggregation:
  - (sub-netting & super-netting)
  - **CIDR: Classless InterDomain**

Bitwise logical operators

Bitwise AND $Z = A.B$

A	B	Z
0	0	0
0	1	0
1	0	0
1	1	1

mask: $1.B = B$

Bitwise OR $Z = A + B$

A	B	Z
0	0	0
0	1	1
1	0	1
1	1	1

Bitwise XOR $Z = A \oplus B$

A	B	Z
0	0	0
0	1	1
1	0	1
1	1	0

IP address netmasks

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- Bit mask for the **network prefix** of the address:
  - e.g. 255.0.0.0 ≡ /8, 255.255.240.0 ≡ /20, etc.
- For example: 138.251.195.61/24

```
/24 → 255.255.255.0

138.251.195.61    1000 1010 1111 1011 1100 0011 0011 1101  address
255.255.255.0     1111 1111 1111 1111 1111 1111 0000 0000  mask
138.251.195.0     1000 1010 1111 1011 1100 0011 0000 0000  prefix
```

138.251.195.61/24 (which is not class C – can you see why?)

Private IPv4 address space

- Private IPv4 networks:
  - IPv4 address exhaustion.
  - Internet access via Network Address Translator (NAT).
- Using IPv4, so need some IPv4 addresses!
  - Could possibly use any address.
  - Hosts **must not** be directly connected to the Internet.
- IPv4 prefixes for private network use (RFC1918):
  - 10/8 prefix.
  - 172.16/12 prefix.
  - 192.168/16 prefix.
  - Not forwarded by routers.
  - NAT (Network Address Translation) maps these to one (or more) public IPv4 addresses.
  - Typical home users will run NAT on their home LAN, as ISPs do not have enough addresses for the (increasing!) number of customer devices

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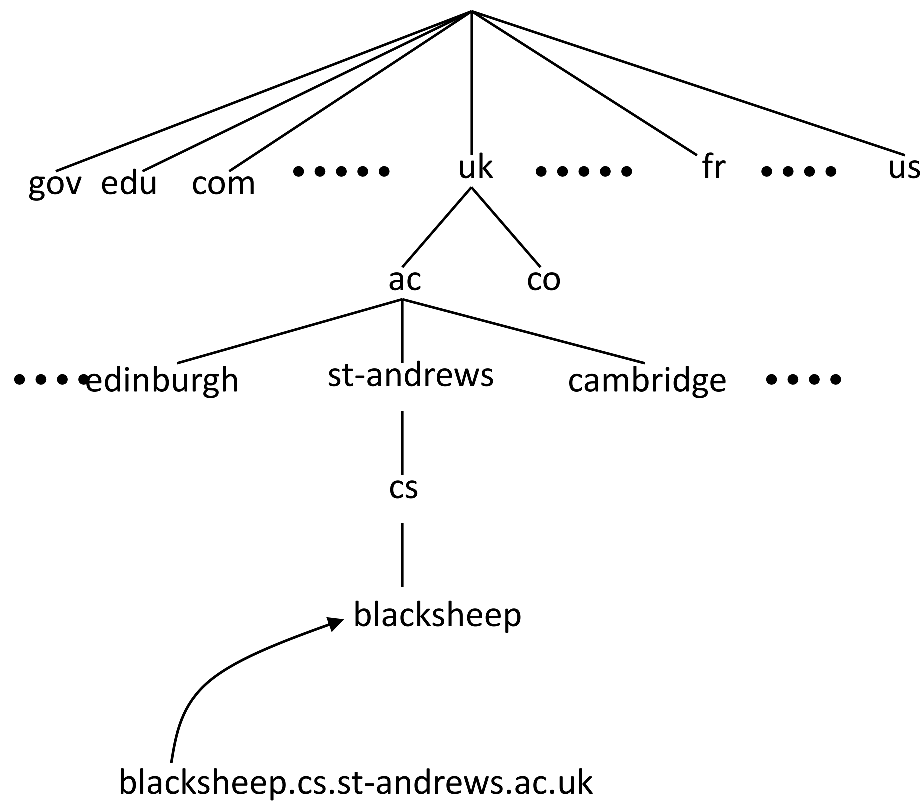
3. **Names and the DNS.**

Domain Name System (DNS)

- Global distributed directory service
- Maps domain names to IP addresses.
- Architecture:
  - name structure
  - administration
  - distribution of data
- client protocol
- Distributed services:
  - nameservers
  - resolvers (clients)
- Global system:
  - must be **scalable**
  - distributed data and admin responsibility
  - **localised caching**

DNS – namespace

- Global, distributed name space
- Nodes through a tree:
  - labels
- Domain:
  - single IP network, e.g.:
    st-andrews.ac.uk
    cs.st-andrews.ac.uk
  - multiple IP networks:
    ibm.com
- DNS servers:
  - servers for each domain
  - administrative area - **zone**



DNS – applications

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Nameservers

- For each zone:
  - primary server
  - secondary server(s)
  - many secondary servers possible for large domain
- Root nameservers:
  - 13 root nameservers
  - .com, .org, .net, etc.
  - {a-m}.rootservers.net

https://www.iana.org/domains/root/servers

Resolvers

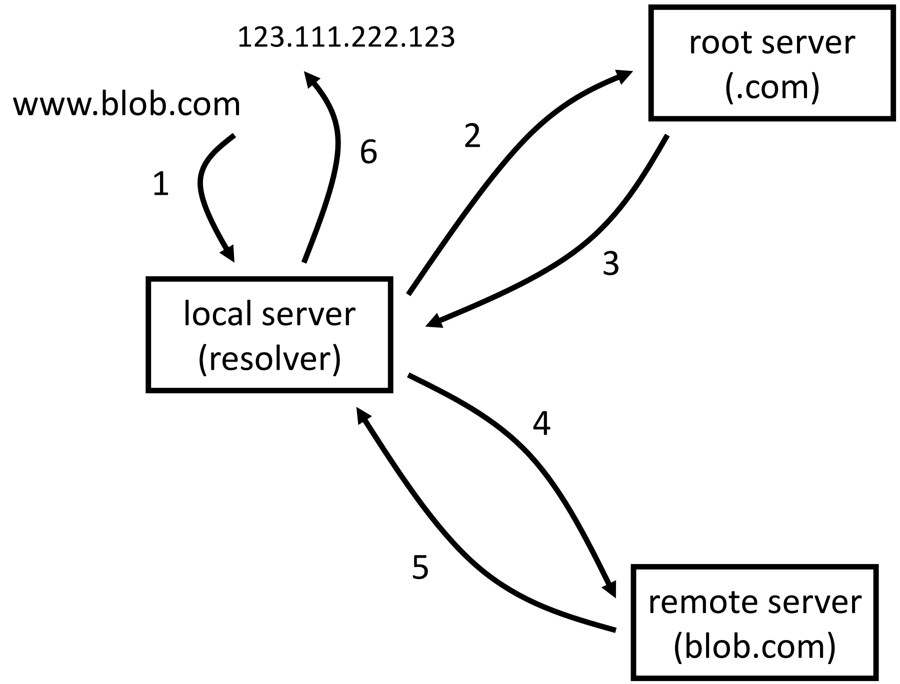
- Client-side library APIs, e.g.:
  - InetAddress.getByName()
  - getaddrinfo(3)
- Client applications:
  - *host*
  - *dig*
  - *nslookup*

Protocol

- DNS messages:
  - in UDP (default), TCP possible.
- DNSsec (secure DNS).
- Dynamic DNS update.

DNS – name resolution (1)

- Query to local server:
  - local server checks cache
  - may query root server
  - root server may redirect query
- **Resource Records (RR)**:
  - A: IPv4 address
  - AAAA: IPv6 address
  - MX: mail record
- **Authoritative** answer:
  - from domain server
- **Non-authoritative** answer:
  - from cache at local server
  - Time To Live (TTL)



DNS – name resolution (2)

- Local (resolving) server is **recursive**:
  - it queries other servers to resolve the request
- Result stored in cache:
  - can be used to answer other queries
  - TTL controls caching
- Within an organisation:
  - recursive for "local" use
  - iterative for others
- Root server is (always) **iterative**:
  - sends a referral to the requester
  - referral gets "closer" to the actual server that holds the mapping
- Why not recursive?
  - load and security.
- Within an organisation:
  - for "external" users.

Summary

- The service offered by the Internet Protocol:
  - **Best Effort** model.
- Addressing:
  - IP address structure.
- Naming and name resolution:
  - Domain Name System (DNS).
- Reading: Peterson & Davie Ch 3.3 and 9.3, Kurose & Ross Ch 4.3 and 2.4