Networks

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As commerce and big money have taken over the Internet the nature of networking has changed from a way of linking together some CS departments to a multi-billion (trillion?) pound enterprise

Thus a good knowledge of what networks are and how they work is essential to any good Computer Scientist

Networks

And also to anyone who uses networks as part of their everyday activities

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If more people realised quite how open, fragile and subvertable the Internet is, they would be a lot more circumspect in what they do on it!

Networks

The Internet is familiar to everyone here

Networks

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But networks have been around for a long time

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A network is any means to connect entities together so they can communicate

Networks

Reasons to network include:

Networks

Reasons to network include:

- Resource sharing

Networks

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- Communication and collaboration

Networks

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Networks

Reasons to network include:

- Resource sharing
- Communication and collaboration
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- Reliability through replication
- Entertainment

Networks

Existing networks include:

- The telephone system
- The mobile phone system
- TV and radio
- System control networks, e.g., Controller Area Network (CAN bus) in cars (and bicycles!)
- Sensor control networks, e.g., Bluetooth and ANT
- Cable (TV) networks
- The Internet

Networks

Metcalfe's Law

> *The value of a network expands exponentially as the number of users increases*

Networks

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The bigger the network, the more links it has

Networks

There are many different kinds of network, thus meaning we need classifications to put things into easy boxes

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But there are many classifications to choose from

Networks

Classification by size

- LAN Local Area Network

Networks

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- LAN Local Area Network
- MAN Metropolitan Area Network

Networks

Classification by size

- LAN Local Area Network
- MAN Metropolitan Area Network
- WAN Wide Area Network

Networks

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- LAN Local Area Network
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Networks

Classification by size

- LAN Local Area Network
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- PAN Personal Area Network, WPAN (wireless PAN)
- and so on

Networks

Classification by speed

- Narrowband
- Broadband

Networks

Classification by ~~speed~~ technology

- Narrowband
- Broadband

Actually these technical terms do not denote speed: their real meanings have been distorted by marketing

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Optical fibre, while very fast, is actually technically narrowband

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Exercise Find the technical meanings for narrowband and broadband

Networks

Marketing terms include:

Networks

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- Broadband (xDSL)

Networks

Marketing terms include:

- Broadband (xDSL)
- Fibre Broadband (xDSL)

Networks

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- Broadband (xDSL)
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- Full Fibre (fibre)
- Fast (?)
- Superfast (above 30Mbs)
- Ultrafast (above 300Mbs)

Networks

Classification by technology

Networks

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Classification by technology

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- Medium distance wired. ADSL (ADSL2, ADSL2+, . . .)

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- Power line

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- Longer distance wireless (3G, 4G/LTE, 5G, WiMAX, . . .)
- Very long distance wireless: satellite
- Power line
- etc.

Networks

Continuing Exercise Find the meanings for the various acronyms

Exercise Read some adverts for Internet connectivity products and determine what they actually are offering (e.g., “Superfast broadband fibre”)

Exercise And read about the controversies about how they advertise speeds

Networks

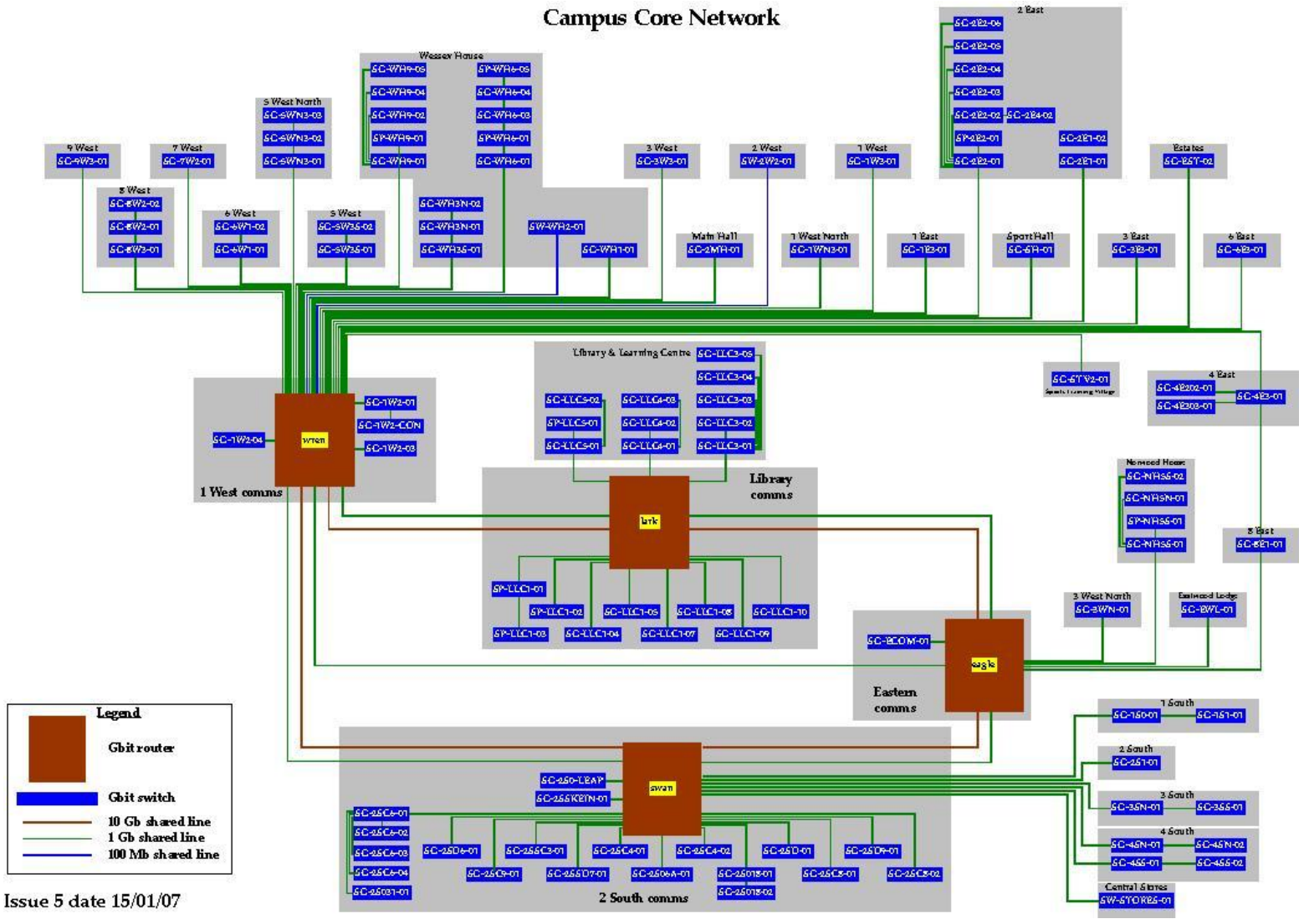
Exercise We use NFC to make contactless payments. Would you regard that as a network?

Exercise And what about Interplanetary networks?

Networks

So what does a typical network look like?

U of Bath Campus Network



U of Bath Campus network

Networks

- No hosts shown: this is just the connectivity

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- Multiple paths between points
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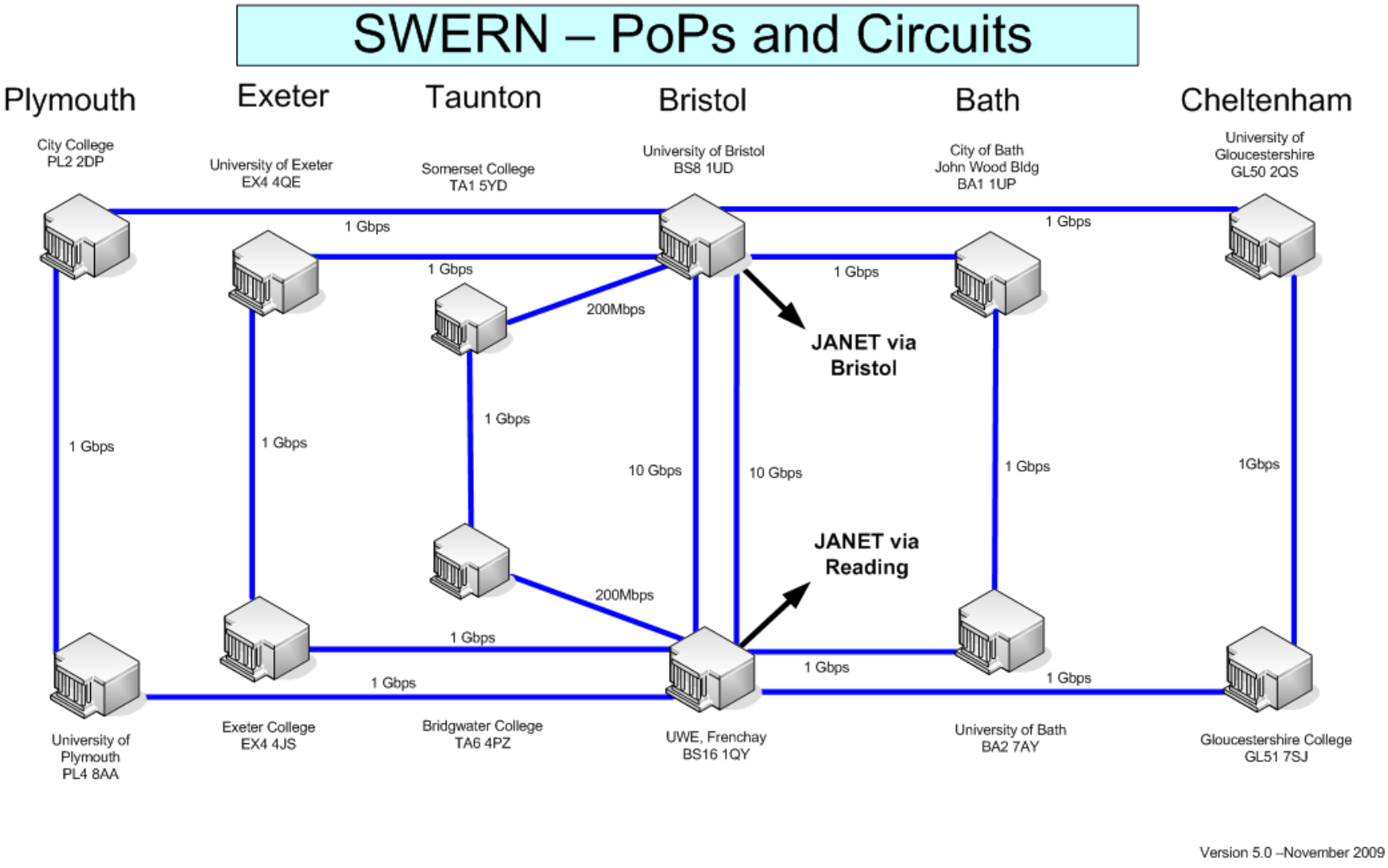
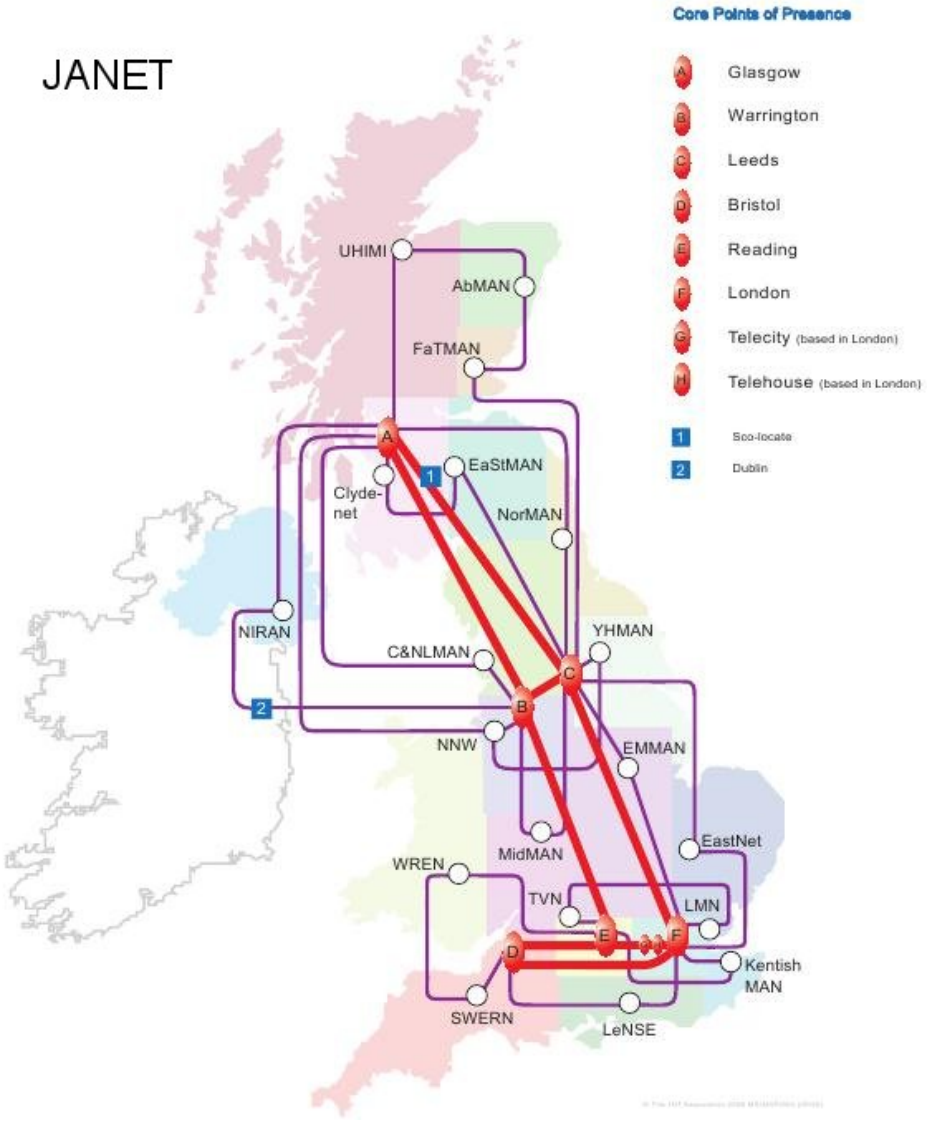
- Other big networks, e.g., in CS, are not shown
- Connection to rest of world not shown

South West Regional Network



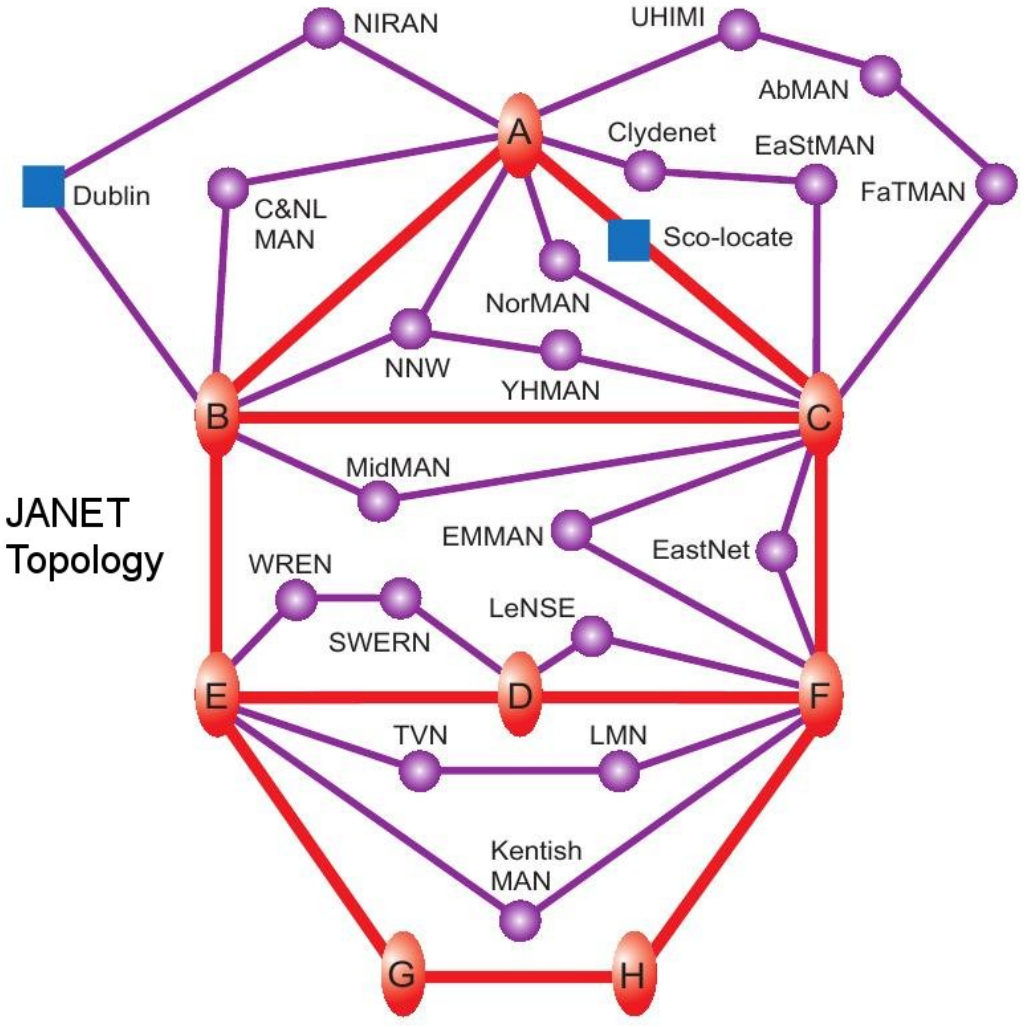
South West Regional Network (SWERN)

Joint Academic Network



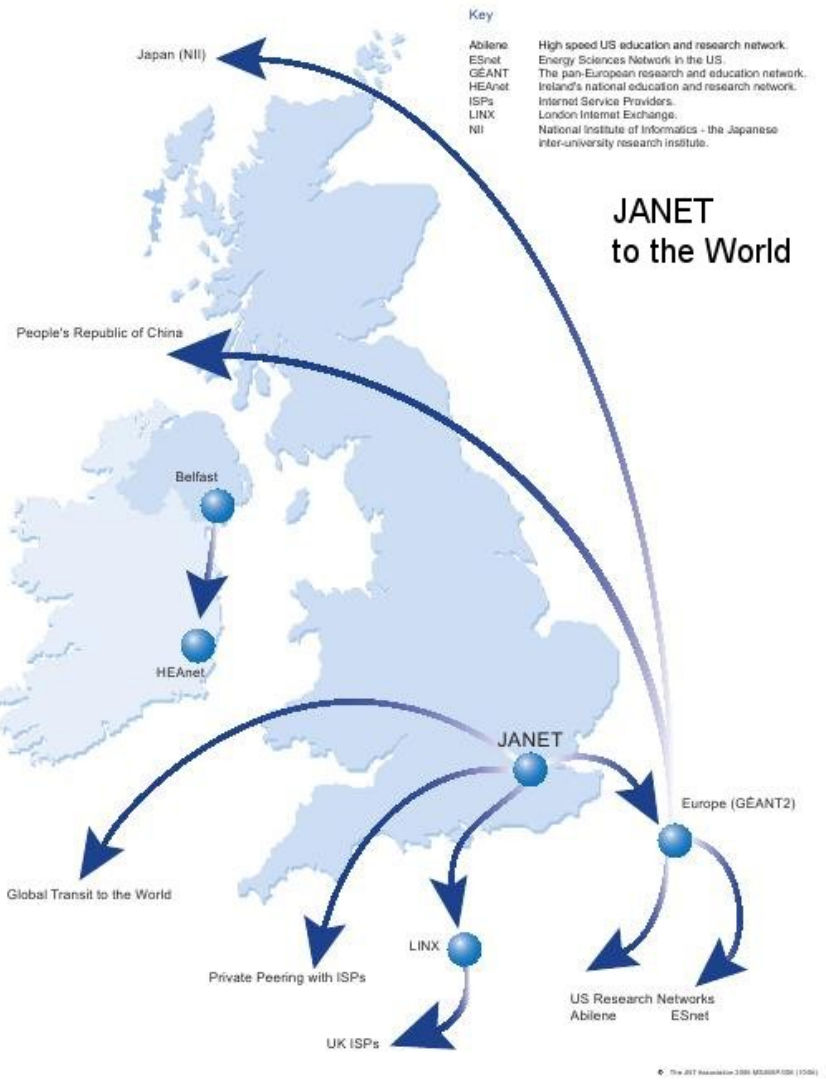
Joint Academic Network (JANET)

JANET



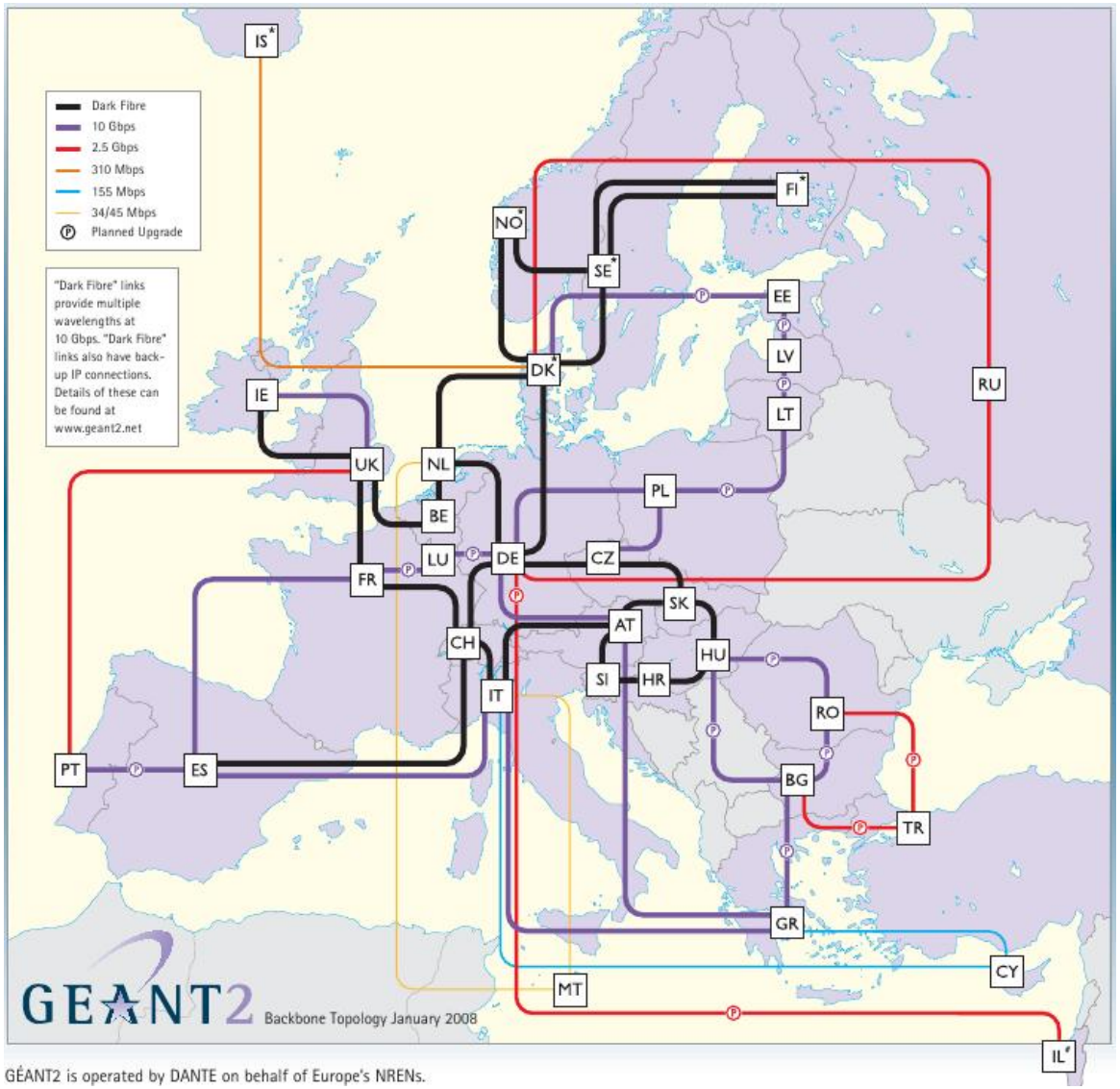
JANET Topology

Networks



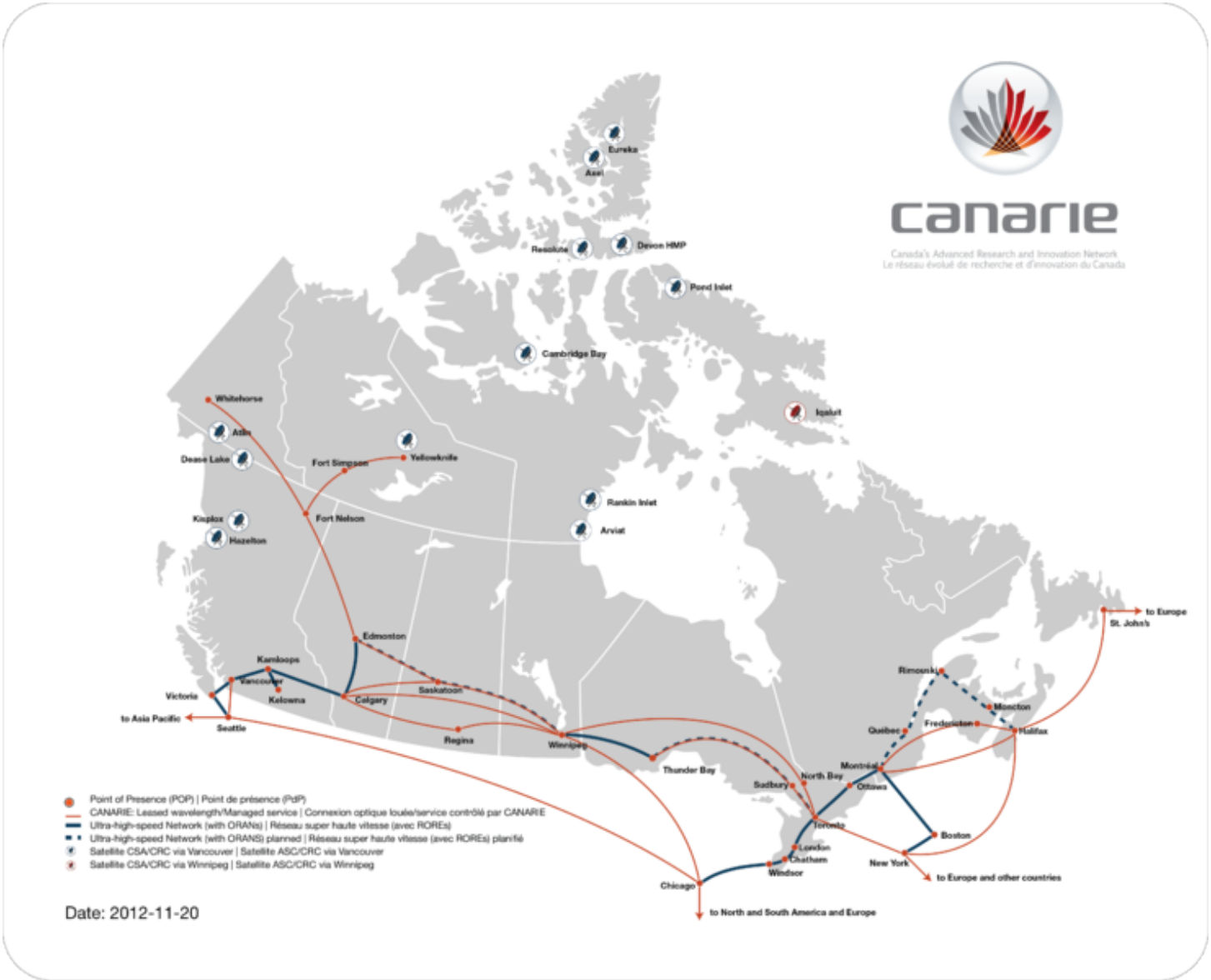
JANET connections to Internet

GÉANT



GÉANT European Network

CANARIE



CANARIE network in Canada

Hierarchy

We can see the Internet is a hierarchy of networks, managed by different groups

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- department

Hierarchy

We can see the Internet is a hierarchy of networks, managed by different groups

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- university

Hierarchy

We can see the Internet is a hierarchy of networks, managed by different groups

- department
- university
- region

Hierarchy

We can see the Internet is a hierarchy of networks, managed by different groups

- department
- university
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- country

Hierarchy

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- department
- university
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- world

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for example

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And this delegation of control is essential to the way the Internet works

Networks

Important Points

The “Internet” (capital “I”) is the world-wide collection of networks

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The Web is not the Internet

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The Web is not the Internet

Anyone caught saying so will be laughed at and will lose marks in the exam

Networks

Tim Berners-Lee and Vint Cerf Front (photos from W3C)

Networks

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Networks

The basis of the Internet is *collaboration* between its member networks

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Data travels from source to destination by being passed from machine to machine; from network to network

Networks

```
traceroute to www.youtube.com (208.65.153.238), 30 hops max, 40
byte packets
 1 fire.cs.bath.ac.uk (172.16.0.1) 0.166 ms 0.171 ms 0.216 ms
 2 gw.cs.bath.ac.uk (138.38.108.254) 0.570 ms 0.448 ms 0.337 ms
 3 swan-wren-10g1.bath.ac.uk (138.38.255.1) 0.430 ms 0.470 ms 0.352 ms
 4 7200-bath.bath.ac.uk (138.38.1.1) 1.190 ms 1.431 ms 1.356 ms
 5 fren-bath-ph.swern.net.uk (194.83.94.65) 3.198 ms 2.548 ms 2.515 ms
 6 so-1-3-0.read-sbr1.ja.net (146.97.42.157) 7.978 ms 7.859 ms 8.305 ms
 7 so-1-0-0.lond-sbr3.ja.net (146.97.33.142) 9.287 ms 9.468 ms 9.207 ms
 8 195.219.100.13 (195.219.100.13) 9.320 ms 9.553 ms 9.760 ms
 9 195.219.195.21 (195.219.195.21) 9.458 ms 9.401 ms 9.407 ms
10 ge4-1-0-1000M.ar3.LON2.gblx.net (64.208.110.81) 14.544 ms 17.433 ms
   13.969 ms
11 te1-1-10G.ar2.SJC2.gblx.net (67.17.109.102) 165.984 ms 167.465 ms
   169.402 ms
12 YOUTUBE-LLC.po1.401.ar2.SJC2.gblx.net (64.212.108.162) 165.040 ms
   167.189 ms 165.938 ms
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```

`gblx`: Global Crossing; `SJC`: San José, California

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`youtube.com.hk` is in San José

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Allegedly, the Pakistan government was trying to censor a Youtube video by blocking all routes to Youtube in that country, but the block escaped to the whole Internet

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A little later things settled down again. . .

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 4 7200-bath.bath.ac.uk (138.38.1.1) 1.247 ms 1.062 ms 1.214 ms
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 7 so-1-0-0.lond-sbr3.ja.net (146.97.33.142) 9.526 ms 9.520 ms 9.726 ms
 8 po1-0.lond-gw-ixp2.ja.net (146.97.35.250) 9.672 ms 9.338 ms 9.089 ms
 9 195.66.226.185 (195.66.226.185) 9.804 ms 9.840 ms 9.926 ms
10 te7-3.mpd02.lon01.atlas.cogentco.com (130.117.2.26) 9.823 ms
   te2-1.3493.mpd02.lon01.atlas.cogentco.com (130.117.2.18) 10.223 ms
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Step 10: multiple probes go different routes

Step 19: a machine that refuses to respond to the probes

Host `208.65.153.238` is now named `youtube.com`

Networks

And again on 25 Sept 2017:

```
traceroute to www.youtube.com (216.58.204.14), 30 hops max, 60 byte packets
 1  fire-private.cs.bath.ac.uk (172.16.0.1)  0.109 ms  0.097 ms  0.088 ms
 2  gw-palo.cs.bath.ac.uk (138.38.108.254)  1.055 ms  1.048 ms  1.041 ms
 3  bath-gw-1-palo.bath.ac.uk (193.63.64.174)  1.608 ms  1.800 ms  1.703 ms
 4  xe-1-2-0.bathub-rbr1.ja.net (146.97.144.33)  1.287 ms  1.332 ms  1.330 ms
 5  xe-1-2-0.briswe-rbr1.ja.net (146.97.67.65)  2.286 ms  2.720 ms  2.707 ms
 6  ae22.londpg-sbr2.ja.net (146.97.37.201)  5.189 ms  4.652 ms  4.648 ms
 7  ae29.londhx-sbr1.ja.net (146.97.33.1)  5.089 ms  5.037 ms  5.012 ms
 8  193.62.157.22 (193.62.157.22)  5.270 ms  5.263 ms  5.246 ms
 9  108.170.246.225 (108.170.246.225)  5.938 ms  5.928 ms  5.869 ms
10  108.170.238.145 (108.170.238.145)  5.907 ms
    108.170.238.147 (108.170.238.147  6.141 ms  6.129 ms
11  lhr35s07-in-f14.1e100.net (216.58.204.14)  5.818 ms  5.820 ms  5.798 ms
```

Networks

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 9  108.170.246.225 (108.170.246.225)  5.938 ms  5.928 ms  5.869 ms
10  108.170.238.145 (108.170.238.145)  5.907 ms
    108.170.238.147 (108.170.238.147  6.141 ms  6.129 ms
11  lhr35s07-in-f14.1e100.net (216.58.204.14)  5.818 ms  5.820 ms  5.798 ms
```

Google are using a local server, probably in London

Networks

And again on 3 October 2019:

```
traceroute to www.youtube.com (216.58.198.174), 30 hops max, 60 byte packets
 1  fire-private.cs.bath.ac.uk (172.16.0.1)  0.197 ms  0.174 ms  0.149 ms
 2  gw-palo.cs.bath.ac.uk (138.38.108.254)  0.708 ms  0.682 ms  0.661 ms
 3  bath-gw-1-palo.bath.ac.uk (193.63.64.174)  1.776 ms  1.531 ms  1.856 ms
 4  xe-1-2-0.bathub-rbr1.ja.net (146.97.144.33)  1.074 ms  1.061 ms  1.047 ms
 5  xe-1-2-0.briswe-rbr1.ja.net (146.97.67.65)  2.113 ms  2.103 ms  2.092 ms
 6  ae22.londpg-sbr2.ja.net (146.97.37.201)  4.314 ms  4.329 ms  4.274 ms
 7  ae29.londhx-sbr1.ja.net (146.97.33.1)  5.163 ms  5.878 ms  5.854 ms
 8  193.62.157.22 (193.62.157.22)  5.587 ms  5.586 ms  5.544 ms
 9  * * *
10  172.253.71.200 (172.253.71.200)  7.069 ms
    108.170.238.118 (108.170.238.118)  6.627 ms
    172.253.68.210 (172.253.68.210)  6.284 ms
11  74.125.242.114 (74.125.242.114)  8.502 ms
    108.170.232.99 (108.170.232.99)  4.818 ms
    74.125.242.82 (74.125.242.82)  5.622 ms
12  lhr25s10-in-f14.1e100.net (216.58.198.174)  4.574 ms
    216.239.57.207 (216.239.57.207)  6.150 ms
    209.85.250.185 (209.85.250.185)  7.028 ms
```

Now much more variation in routes and multiple servers!

Networks

Mistakes in routing are not just ancient history: 4th October 2021 Facebook dropped off the Internet for 6 hours

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To the extent that the keycards on the doors to the machine rooms that Facebook engineers needed to get into to fix the problem were also not working

And the engineers couldn’t message the security guards with the backup keys, either!

Networks

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- So there is no single point of coordination or oversight of the network
- And there must be multiple paths between hosts

Networks

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The original data are reconstructed at the receiving host

Networks

Warning

The word is “packet”, *not* “package”

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Take care never to use the word “package” in a technical context

Networks

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Networks

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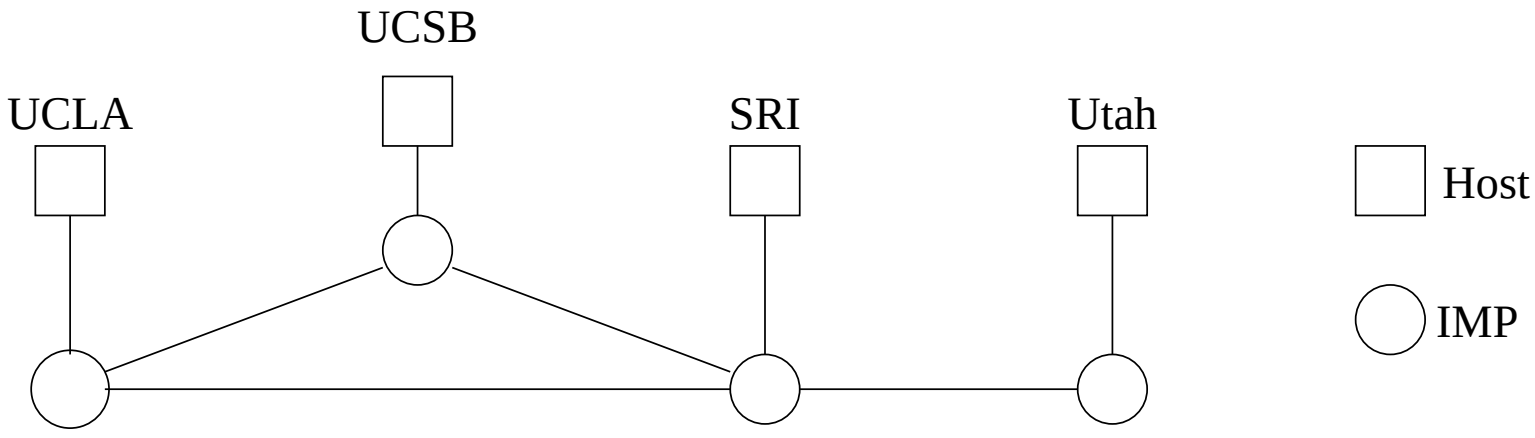
- Runs NCP *Network Control Program*

Networks

History



The Original Arpanet, 1969; Separate *Interface Message Processors*

Networks

An Arpanet IMP (Wikipedia)