Networking
CM30078/CM50123

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### 1. Networks

Networks form a central role in the way computers are used today: these days it is very hard to do anything that is not networked

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

### 2. Networks

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

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!

### 3. Networks

The Internet is familiar to everyone here

But networks have been around for a long time

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

### 4. Networks

Reasons to network include:

* Resource sharing
* Communication and collaboration
* Information gathering
* Reliability through replication
* Entertainment

### 5. 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

### 6. Networks

Metcalfe’s Law

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

The bigger the network, the more links it has

### 7. Networks

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

But there are many classifications to choose from

### 8. Networks

Classification by size

* LAN Local Area Network
* MAN Metropolitan Area Network
* WAN Wide Area Network
* PAN Personal Area Network, WPAN (wireless PAN)
* and so on

### 9. Networks

Classification by speed~~speed~~ technology

* Narrowband
* Broadband

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

Optical fibre, while very fast, is actually technically narrowband

**Exercise** Find the technical meanings for narrowband and broadband

### 10. Networks

Marketing terms include:

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

### 11. Networks

Classification by technology

* Voiceband modem (V series of standards, V.92)
* Local Wired (Ethernet)
* Medium distance wired. ADSL (ADSL2, ADSL$2+$, …)
* Optical Fibre (FTTP)
* Hybrid (VDSL with FFTC, G.fast with FTTdp, …)
* Cable Data Over Cable Service Interface Specification (DOCSIS)
* Local Wireless (Wi-Fi, Bluetooth, …)
* Longer distance wireless (3G, 4G/LTE, 5G, WiMAX, …)
* Very long distance wireless: satellite
* Power line
* etc.

### 12. 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

### 13. Networks

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

**Exercise** And what about Interplanetary networks?

### 14. Networks

So what does a typical network look like?

### 15. U of Bath Campus Network



U of Bath Campus network

### 16. Networks

* No hosts shown: this is just the connectivity
* Multiple paths between points
* Gigabit and 10Gb links
* Other big networks, e.g., in CS, are not shown
* Connection to rest of world not shown

### 17. South West Regional Network



South West Regional Network (SWERN)

### 18. Joint Academic Network



Joint Academic Network (JANET)

### 19. JANET



JANET Topology

### 20. Networks



JANET connections to Internet

### 21. GÉANT



GÉANT European Network

### 22. CANARIE



CANARIE network in Canada

### 23. Hierarchy

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

* department
* university
* region
* country
* world

for example

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

### 24. Networks

#### Important Points

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

An “internet” (lower “i”), an abbreviation of “internetwork”, is just some collection of networks

An “intranet” (with an “a”) is some collection of networks belonging to a single organisation

The Web is not the Internet

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

### 25. Networks



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

### 26. Networks



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

### 27. Networks

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

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

### 28. 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
13 youtube.com.hk (208.65.153.238) 165.972 ms 165.825 ms 165.815 ms

gblx: Global Crossing; SJC: San José, California

<youtube.com.hk> is in San José

### 29. Networks

This was done just after a major problem with the route to Youtube (a mistake in Pakistan lead to chaos, February 2008)

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

A little later things settled down again…

### 30. 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) 0.205 ms 0.210 ms 0.091 ms
 2 gw.cs.bath.ac.uk (138.38.108.254) 0.446 ms 0.431 ms 0.341 ms
 3 swan-wren-10g1.bath.ac.uk (138.38.255.1) 1.185 ms 0.841 ms 0.648 ms
 4 7200-bath.bath.ac.uk (138.38.1.1) 1.247 ms 1.062 ms 1.214 ms
 5 fren-bath-ph.swern.net.uk (194.83.94.65) 2.808 ms 2.438 ms 2.653 ms
 6 so-1-3-0.read-sbr1.ja.net (146.97.42.157) 7.839 ms 8.265 ms 7.798 ms
 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
 te7-3.mpd02.lon01.atlas.cogentco.com (130.117.2.26) 9.685 ms
11 <snip>
19 \* \* \*
20 youtube.com (208.65.153.238) 154.886 ms 156.732 ms 156.480 ms

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>

### 31. 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

Google are using a local server, probably in London

### 32. 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!

### 33. Networks

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

A “misconfiguration” meant that its name servers (converting names like <facebook.com> to addresses) were not accessible

This took out Facebook, Whatsapp, Instgram, Oculus, Messenger, etc., and any site that uses Facebook to login

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!

### 34. Networks

#### History

The reason for this cooperative design comes from the history of the Internet

* 1957: The Soviet Union launches Sputnik
* mid 1960s: Advanced Research Projects Agency (ARPA) formed. A project to share expensive resources: namely their computers
* The network design was to be non-centralised to avoid single points of failure, particularly nuclear attacks
* So there is no single point of coordination or oversight of the network
* And there must be multiple paths between hosts

### 35. Networks

#### History

Using simple *circuits* (such as the telephone system used) between machines would be too vulnerable, so *packet switching* was devised

Data is chopped into small chunks, called *packets*, and each packet is sent individually, possibly over different paths

Individual packets might get lost, but others will get through

The original data are reconstructed at the receiving host

### 36. Networks

#### Warning

The word is “packet”, *not* “package”

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

### 37. Networks

* 1969 First Internet has just four nodes
* Runs NCP *Network Control Program*

### 38. Networks

#### History



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

### 39. Networks



An Arpanet IMP (Wikipedia)