

Topic 14: Communication and Internet Technologies

How the Internet is stitched together, why TCP speed is limited by round-trip time and how CDNs beat distance.

Optional stretch material. This goes beyond the 9618 syllabus, so you will not be asked about it directly in the exam. Its purpose is to deepen ideas you already know. **Builds on:** 14.1 Protocols, 14.2 Circuit switching and packet switching. Try the challenge questions on the last pages before you read the answers.

Routing between networks: BGP

The Internet is thousands of independently run networks called **autonomous systems** (ISPs, universities, large companies). Inside one network, routers use *interior* protocols such as RIP or OSPF, which find the cheapest path. Between networks, the **Border Gateway Protocol (BGP)** exchanges which address ranges each network can reach.

BGP chooses routes mostly by **business policy** (who pays whom, who peers with whom), not simply the shortest path. It relies on trust: a network that wrongly announces routes can pull traffic towards itself, and such mistakes have knocked large sites offline for hours.

TCP flow and congestion control

TCP does not send as fast as it can. It keeps two limits and obeys the smaller: the **receive window** (how much unacknowledged data the receiver can buffer: *flow control*) and the **congestion window** (how much the network can carry without loss: *congestion control*).

- **Slow start:** begin with a small window and double it every round trip while all is well.
- **Congestion avoidance:** past a threshold, grow by only one segment per round trip.
- **On packet loss:** assume congestion and cut the window (typically halve it), then grow again: *additive increase, multiplicative decrease*.

Since a sender can have at most one window of data in flight per round-trip time (RTT), the throughput limit is **window ÷ RTT**. A 64 KB window with a 100 ms RTT gives at most $65\,536 \div 0.1 \approx 655\text{ KB/s} \approx 5.2\text{ Mbit/s}$, however fast the link is. This is why high-latency connections need large windows.

Latency, CDNs and the speed of light

Light in optical fibre travels at about 200 000 km/s (two-thirds of c). A one-way trip of 15 000 km therefore takes at least 75 ms, whatever the bandwidth. **Bandwidth** (how much per second) can be bought; **latency** (how long one bit takes) is limited by physics and distance.

A **content delivery network (CDN)** places copies of popular content on servers near users, and directs each user to a nearby one (via DNS or **anycast**, where many servers share one IP address and routing picks the nearest). Newer protocols attack delay too: **HTTP/3** runs over **QUIC** (built on UDP) to set up connections in fewer round trips and stop one lost packet blocking unrelated streams.

Challenge questions

1. A TCP connection has a 128 KB (131 072 byte) window and a 40 ms RTT. What is the maximum throughput in Mbit/s?
2. In slow start the congestion window begins at 1 segment and doubles every RTT. After how many RTTs does it first reach at least 100 segments?

3. The one-way fibre distance between two cities is 15 000 km. What is the minimum round-trip time? Why can buying faster broadband not reduce it?

Worked answers

Only look once you have had a proper go at each question.

1. $131\,072 \text{ bytes} \div 0.04 \text{ s} = 3\,276\,800 \text{ bytes/s}$; $\times 8 = 26.2 \text{ Mbit/s}$. **About 26 Mbit/s**, regardless of link capacity.
2. Window after n RTTs = 2^n segments: 1, 2, 4, 8, 16, 32, 64, 128. It first exceeds 100 after **7 RTTs**.
3. One way: $15\,000 \div 200\,000 = 0.075 \text{ s} = 75 \text{ ms}$; round trip **at least 150 ms**. Broadband speed is bandwidth: it changes how quickly a large amount of data can be sent but not how long a signal takes to travel. Only a shorter path (or a nearer server, e.g. via a CDN) helps.