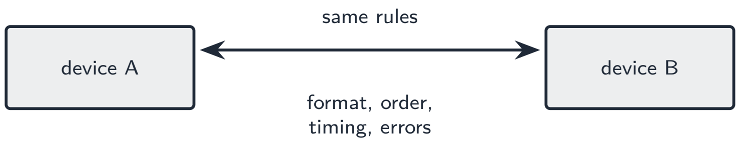
Communication and internet technologies

A-Level Computer Science

Why protocols are needed

A **protocol** 协议 is a **set of rules** for how devices **communicate**. Both ends must follow the same rules, or one side's signals are meaningless to the other. Protocols define the **format** of the data (where addresses and payload sit), the **order** of messages (who speaks first, when to acknowledge), the **meaning** of each message, the **timing** (timeouts, retransmits), and **what to do on error**. Without an agreed protocol, communication fails — like two people speaking different languages with no translator.

"Explain why protocols are essential for communication between computers" (three marks). (1) A protocol is a **set of rules** agreed by both the sender and the receiver; (2) without it the two computers would **interpret the data differently** (format, order, meaning of each part), so the message could not be understood; (3) it allows computers of **different types and manufacturers** to communicate, because everyone implements the same standard. Mention what the rules cover: the format of the data, the order of messages, error detection and recovery, and speed or timing.



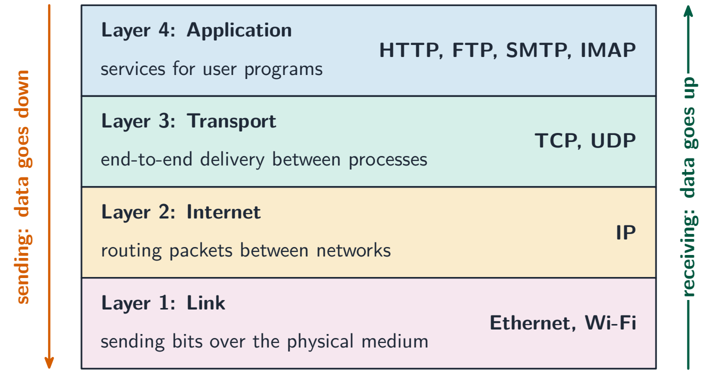
A protocol is the shared rules: format, order, timing and errors

Layered protocols

Networking is complex, so it is split into **layers** 层, each with one focused job, talking only to the layer above and below. Benefits: **modularity** 模块化 (replace one layer — say Ethernet with Wi-Fi — without touching the others), standardisation (vendors interoperate), and **abstraction** 抽象 (you ignore details handled elsewhere). The internet uses the **TCP/IP protocol suite** 协议栈 (4 layers).

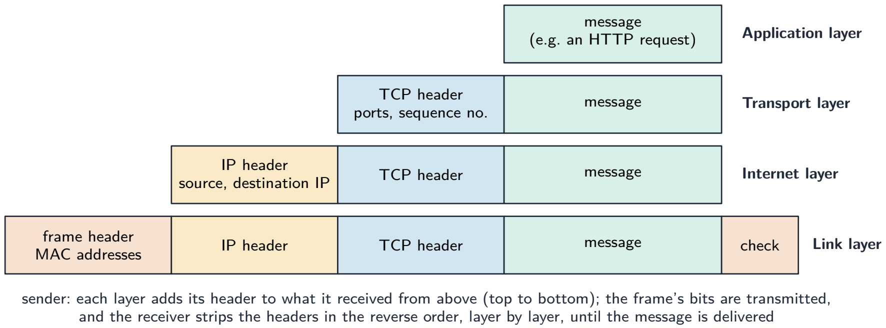
TCP/IP protocol suite

Layer	Purpose	Examples
Application	what the user program does	HTTP, FTP, SMTP, IMAP
Transport	end-to-end delivery between processes	TCP, UDP
Internet	routing packets between networks	IP
Link	sending bits over the physical medium	Ethernet, Wi-Fi



The four layers of the TCP/IP protocol suite

The purpose of each layer, as the mark scheme words it. *Application layer:* provides the **protocols that user applications use** (HTTP for the web, SMTP for email) and the interface between the application and the network; it produces the data to be sent and passes it to the transport layer. *Transport layer:* establishes the **end-to-end connection**, **splits** the data into packets (segments) and adds **port numbers** and **sequence numbers**; on receipt it **reassembles** the packets in order and requests any that are missing (TCP), or sends without those guarantees (UDP). *Internet layer:* adds the **source and destination IP addresses** to form IP packets (datagrams) and **routes** them across networks via routers; it does not guarantee delivery. *Link layer:* adds the **MAC addresses** and error-check bits to form a **frame** and transmits the bits over the **physical** local network (Ethernet or Wi-Fi) through the network interface card. "Complete the stack" means these four, in this order, from the top: Application, Transport, Internet, Link.



Encapsulation: each layer adds its own header 首部 to what it receives from the layer above, so the bits on the wire carry four sets of information; the receiver removes them one layer at a time

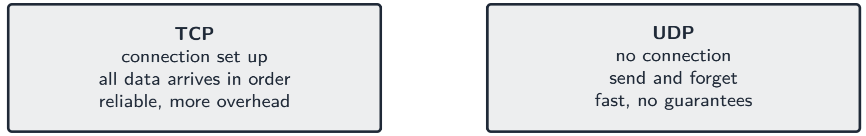
"Describe how the TCP/IP suite is applied when a message is sent from one host to another" (five marks). At the **sender** the message passes **down** the stack: (1) the application layer produces the data using a protocol such as HTTP or SMTP; (2) the transport layer splits it into packets and adds a header with the port numbers and a sequence number; (3) the internet layer adds a header with the source and destination IP addresses and chooses the route; (4) the link layer adds the MAC addresses of the next device and sends the frame over the physical link. Routers along the way read the internet-layer header and forward each packet. At the **receiver** the frame passes **up** the stack: each layer removes and acts on its own header, the transport layer reassembles the packets in sequence-number order and asks for any that are missing, and the application layer presents the message. The same protocol at each layer at both ends is what makes the exchange work.

Application layer

The **application layer** 应用层 gives services to user programs and defines the protocols they speak (HTTP for web, SMTP for email). This is where a programmer most often works.

Transport layer

The **transport layer** 传输层 delivers data **end-to-end** between processes, identified by **port numbers** 端口号. Two protocols:



TCP connects and delivers in order; UDP sends and forgets

- **TCP** 传输控制协议 — **connection-oriented** 面向连接: sets up a connection, ensures **all data arrives in order**, retransmits lost **packets** 数据包, controls flow. Reliable but with overhead. Used by HTTP, HTTPS, SMTP, FTP.
- **UDP** 用户数据报协议 — **connectionless** 无连接: sends and forgets, with no acknowledgements or ordering. Low overhead, no guarantees. Used for streaming, DNS and gaming, where speed beats reliability.

Internet layer

The **internet layer** 网络层 carries packets between hosts using **IP**. Each packet has a source and destination **IP address** IP 地址, and **routers** 路由器 forward it onward. It does not guarantee delivery — that is TCP's job.

A home router does this job for your house: it reads each packet's destination address and sends it on towards the internet, and back to the right device.

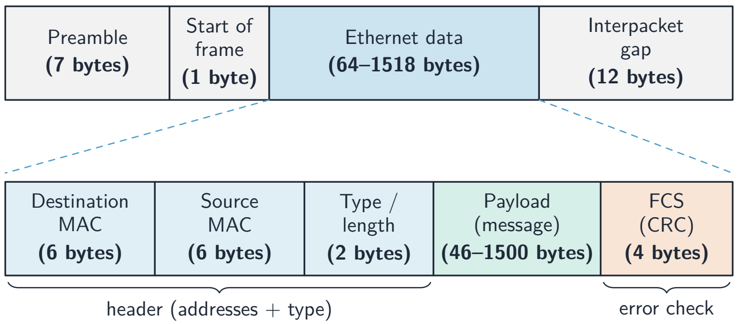
A home Wi-Fi router: it forwards packets between your devices and the internet

Before the router reaches the wider internet, a **modem** 调制解调器 connects the home to the internet provider over the provider's cable or phone line. Its lights show the link is up and online.

A cable modem connects a home network to the internet provider

Link layer

The **link layer** 链路层 sends bits over one physical link (Ethernet, Wi-Fi). It adds a frame header with **MAC addresses** MAC 地址 and handles medium access (e.g. **CSMA/CD** 载波侦听多路访问/冲突检测 on Ethernet).

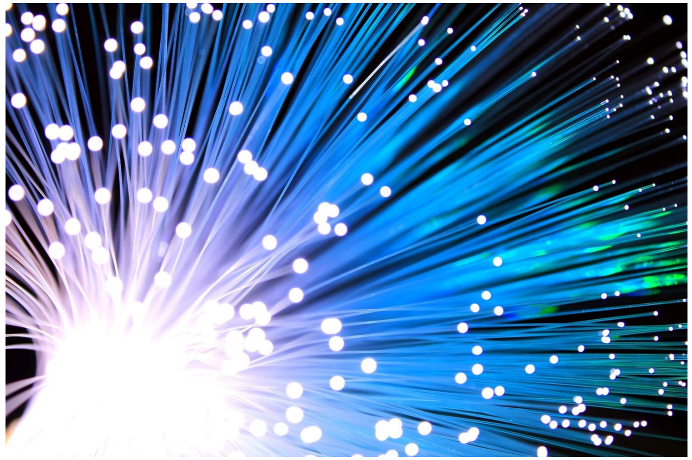


The parts of a typical Ethernet frame

On a wired local network, a **switch** 交换机 joins many devices together. Each device plugs into a port with an Ethernet cable (an RJ45 plug), and the switch uses the MAC addresses in each frame to send it only to the correct port.

A network switch connects many wired devices on a local network

The physical link can be a copper wire, a radio signal (Wi-Fi), or a **fibre-optic cable** 光纤. In a fibre-optic cable, the bits travel as flashes of light through very thin strands of glass, which is fast and carries data a long way.



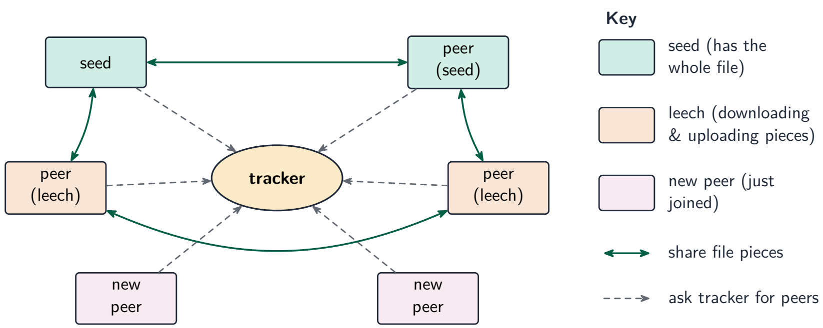
A fibre-optic cable: data travels as light through thin glass strands

A radio link can reach much further. A **satellite dish** 卫星天线 sends and receives radio signals to and from a satellite, carrying data to places that wired links cannot easily reach.

A satellite dish sends and receives data by radio over a long distance

Common application-layer protocols

- **HTTP** 超文本传输协议 — browsers fetch web pages from servers (over TCP, port 80). **HTTPS** is HTTP over TLS — encrypted, port 443.
- **FTP** 文件传输协议 — transfer files between client and server.
- **SMTP** 简单邮件传输协议 — **send** email between client and server, and between servers. Receiving uses POP3 or IMAP.
- **POP3** — downloads email and usually deletes it from the server. **IMAP** — leaves email on the server and syncs across devices, so the same inbox appears everywhere.
- **BitTorrent** — a **peer-to-peer** 对等网络 protocol; a file is split into pieces downloaded from many peers in parallel, so no single server carries all the load.



BitTorrent: a tracker helps peers find each other, then they share file pieces directly

The purpose of each protocol, in the words that score.

Protocol	Purpose (state this)
HTTP	transfers web pages (hypertext) between a web server and a browser; HTTPS is the encrypted version
FTP	transfers files between a client and a server (uploading to and downloading from a file server)
SMTP	sends email from a client to a mail server, and between mail servers (a "push" protocol)
POP3	downloads email from the server to the client, usually deleting it from the server, so it is read on one device
IMAP	lets the client read and manage email that stays on the server, so the same mailbox is seen on every device
BitTorrent	shares files peer-to-peer: pieces of a file are downloaded from, and uploaded to, many other users at once

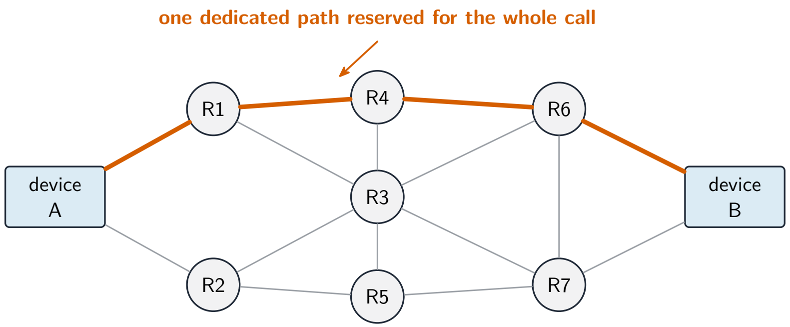
Asked for the two email protocols, give **SMTP** for sending and **POP3 or IMAP** for receiving; asked to describe IMAP, say that the messages **remain on the server** and are **synchronised** across devices, which is the difference from POP3.

"Describe how files are shared using the BitTorrent protocol" (four marks). (1) The file is split into **pieces** (typically 256 KB each), and a small **torrent** file describes them (their hashes) and names a **tracker** 追踪器. (2) A peer wanting the file contacts the tracker, which keeps a list of the peers in the **swarm** 群 currently sharing that file. (3) The peer downloads **different pieces from many peers at the same time**, and as soon as it holds a piece it **uploads** it to others; a peer with the whole file is a **seed** 种子, one still downloading a leech. (4) When all pieces are in, they are reassembled and checked against the hashes. **"Explain what peer-to-peer file sharing means":** there is **no central server** holding the file; every computer is both a **client and a server**, downloading from and uploading to the others, so the load and the bandwidth are spread across the swarm and the more peers there are, the faster it gets.

Circuit switching vs packet switching

Circuit switching

A **dedicated path** is set up between the two ends before any data is sent (**circuit switching** 电路交换), reserved for the whole conversation, then released. It gives **reserved bandwidth** 带宽 and in-order delivery, but is **inefficient** during silences and slow to set up. Classic example: the traditional telephone network.



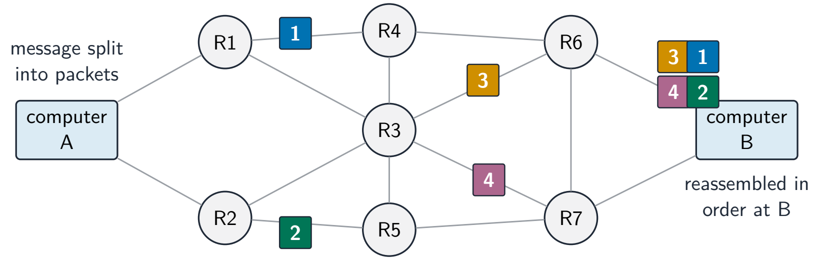
Circuit switching: one dedicated path is reserved end to end

"Describe circuit switching as a method of data transmission" (three marks). (1) A **dedicated** path (circuit) is **set up** between the sender and the receiver **before** any data is sent; (2) the **whole** message is sent along that path, in order, as one continuous stream; (3) the circuit is reserved for the **duration** of the communication and released afterwards.

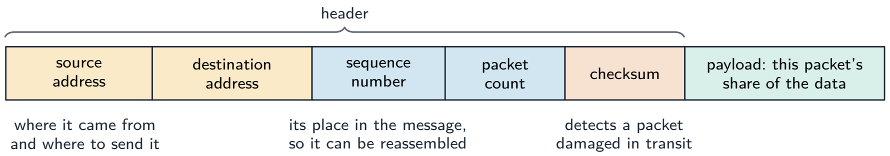
Benefits and drawbacks. *Benefits:* the full **bandwidth** of the circuit is available and guaranteed; data arrives **in order** with no reassembly and no delay once the circuit is up; the route does not change, so timing is predictable (good for real-time voice and video). *Drawbacks:* time is spent **setting up** the circuit before anything is sent; the circuit is reserved even while **no data** is flowing, so bandwidth is wasted and other users cannot share it; both ends must be free at the same time; a **failure anywhere** on the path breaks the whole call, and there is no automatic alternative route. *Where it is appropriate:* a telephone call or a live video link, where a steady, uninterrupted stream matters more than efficiency.

Packet switching

The data is split into **packets**, each sent **independently** (**packet switching** 分组交换). Each packet carries the destination address; routers make per-packet decisions, so packets may take different routes and arrive out of order, and the destination reassembles them. It is **efficient** (one link is **multiplexed** 多路复用 across many conversations), **robust** (reroute around a failure), but has **variable latency** 延迟 and possible loss (TCP handles reliability). Used by the internet.



Packet switching: packets travel independently and may take different routes



What lets a packet travel on its own: the addresses say where, the sequence number says which part of the message it is, and the checksum shows whether it arrived undamaged

"Describe how packet switching is used to pass messages across a network" (four marks). (1) The message is **split into packets** of a fixed maximum size; (2) each packet is given a **header** containing the **source and destination addresses**, a **sequence number** 序号 and an error check; (3) each packet is sent **independently** and may take a **different route**, chosen by the routers it meets; (4) at the destination the packets are **reassembled in order** using the sequence numbers, and any missing packet is requested again. If the question excludes checking and resending, leave out the last clause.

"Describe the function of a router in packet switching" (three marks). A router **receives** a packet, **reads the destination IP address** in its header, and consults its **routing table** 路由表 to decide the **best next hop** towards that destination, taking account of the traffic (congestion) and failed links; it then **forwards** the packet onto that link. Packets of the same message may leave by different routes; the router holds packets in a queue when a link is busy.

"Describe two ways packet switching ensures the complete message is received." (1) Each packet carries a **sequence number**, so the receiver can put the packets in order and can tell that one is **missing**, and (2) the receiver sends an **acknowledgement** 确认 for packets that arrive; a packet not acknowledged within a time limit is **retransmitted** by the sender. A **checksum** 校验和 in each packet lets the receiver detect a corrupted packet and discard it, which then triggers the resend.

Benefits and drawbacks. *Benefits:* no circuit to set up; the network's links are **shared** by many messages, so bandwidth is used efficiently; packets can be **rerouted** around a failed or congested link, so transmission is robust; a lost or damaged packet means resending only **that packet**, not the whole message. *Drawbacks:* packets may arrive **out of order** and must be reassembled, and some may be **lost** or delayed; the **headers** add overhead; the variable delay makes it less suitable for real-time voice and video without extra measures; a heavily loaded network drops packets. *Where it is appropriate:* email, web pages, file downloads and any "bursty" traffic, and the internet in general.

Aspect	Circuit switching	Packet switching
Path	dedicated, reserved	shared, per-packet
Setup time	slow	none
Bandwidth use	inefficient	efficient
Order	in order	may be out of order
Robustness	one failure cuts the circuit	reroute around failures
Suits	constant-rate flows (voice)	bursty flows (web, email)

Modern networks use packet switching for its efficiency and resilience.

Four differences, stated as pairs. (1) Circuit switching sets up a **dedicated path** before sending; packet switching sends **without setting up** a path. (2) In circuit switching the whole message follows **one route**; in packet switching the packets may take **different routes**. (3) Circuit switching delivers the data **in order** without reassembly; packet switching needs **sequence numbers** to reassemble it. (4) Circuit switching **reserves** bandwidth for one conversation even when idle; packet switching **shares** the links between many messages. (Also acceptable: a failed link breaks a circuit but packets are rerouted; circuit switching suits real-time streams, packet switching suits bursty data.) Write each difference as **both** halves; one side alone earns nothing.

Describing packet switching in a few sentences

A good exam answer: "The message is broken into small packets. Each packet carries the destination and source addresses and a sequence number. Each packet travels through the network independently, with routers choosing the next hop per packet. Packets may take different paths and arrive out of order. The destination uses the sequence numbers to reassemble the message, and missing packets can be requested again."

Worked example. A phone call and a large file download share a network. Which switching method suits each, and why? A **phone call** needs a steady stream with low delay, and it would suffer badly if pieces arrived late or out of order - so **circuit**

switching suits it: a dedicated path is set up for the whole call and its capacity is reserved for the duration. A **file download** does not care about timing or arrival order, because the receiver reassembles it, and it benefits from using whatever capacity happens to be spare - so **packet switching** suits it: the file is split into packets that travel **independently**, each carrying source and destination addresses and a **sequence number**, with routers choosing a next hop per packet. Name the **property of the traffic** that decides it: reserved capacity and low delay for the call, efficiency and resilience for the download.

Definitions the examiner accepts

A definition question is marked against fixed wording. Learn these exactly, and give one answer only.

Term	Definition
protocol	a set of rules governing how data is transmitted, agreed by sender and receiver so that both interpret it the same way
protocol stack	the layers of protocols, each with its own function, that together carry out communication; each layer communicates only with the layers above and below
application layer	provides the protocols used by applications to exchange data (HTTP, SMTP, FTP, IMAP, POP3)
transport layer	establishes end-to-end communication, splits data into packets with port and sequence numbers, reassembles them and requests missing ones (TCP), or sends without guarantees (UDP)
internet layer	adds IP addresses to form packets and routes them between networks via routers
link layer	adds MAC addresses to form frames and transmits the bits over the physical local network
router	a device that reads a packet's destination address and forwards it along the best available route towards that destination
circuit switching	a dedicated communication path is established between the two ends before data is sent and held for the whole transmission
packet switching	the message is split into packets, each with a header, sent independently over possibly different routes and reassembled at the destination
packet	a unit of data carrying a header (addresses, sequence number, error check) and a payload
peer-to-peer	file sharing without a central server, each computer acting as both client and server

Exam tips

- Why protocols: shared rules, same interpretation, any make of computer. Why layers: each layer has one job and can be changed independently.
- The four layers in order, top to bottom: Application, Transport, Internet, Link. Give each layer's job in one sentence, and the "message from host to host" answer as a walk down the stack and back up.
- Protocol purposes are one-liners: HTTP web pages, FTP files, SMTP sending mail, POP3 downloading mail, IMAP mail kept on the server, BitTorrent peer-to-peer pieces from a swarm.
- Circuit switching: dedicated path first, whole message, held for the duration. Packet switching: split, header with addresses and sequence number, independent routes, reassemble. Benefits and drawbacks come in pairs of opposites.
- A router reads the destination address, consults its routing table, forwards along the best route; it is the packet-switching question the exam asks most.
- "Where appropriate": circuit switching for a phone or live video call; packet switching for email, the web and downloads.

Common mistakes

- Defining a protocol as "a language" or "software"; it is a set of rules.
- Putting the layers in the wrong order, or giving the OSI seven layers instead of the four of TCP/IP.
- Describing the transport layer as "routing" or the internet layer as "splitting into packets"; ports and splitting are transport, IP addresses and routing are internet.
- Confusing POP3 with IMAP, or saying SMTP receives email.
- Describing packet switching without the header (addresses and sequence number) or without reassembly.
- Saying a router "sends the packet everywhere"; it chooses one next hop from its routing table.
- Giving a benefit of packet switching as a drawback of circuit switching without stating the circuit-switching side; each difference needs both halves.
- Claiming packet switching guarantees delivery by itself; the transport layer's sequence numbers and acknowledgements do that.