# Chapter 1

# L12 – Network System Calls & the Internet

## 1.1 From End–Systems to Processes

Every computer attached to the Internet that exchanges messages is called an **end-system**.

- **Client process**: issues *requests*.
- **Server process**: generates *responses*.

Thus, the words *client* and *server* are used both for the *processes* and for the *machines* executing them.

### 1.1.1 Naming a Process

A process is uniquely identified by the pair

`IP address` : `port number`

**IP address** (e.g. `8.8.8.8`) – identifies the end-system.

**Port number** (e.g. `53`) – identifies the process on that end-system. Certain services have *well-known ports* (DNS uses port 53).

#### Some definitions

**End-system** A host connected to the Internet that can send/receive packets.

**Socket** A file descriptor returned by `socket()`; used with `sendto()` and `recvfrom()` instead of `read()` and `write()`.

**Well-known port** A globally agreed port number reserved for a specific application-level protocol (e.g. port 53 for DNS).

### 1.1.2 Network System Calls

The following POSIX calls allow a user process to exchange messages with a remote peer:

#### Server-side calls

1. `socket()` – create a network endpoint and obtain a **socket**, a special file descriptor.
2. `bind()` – register the local process name `[IP, port]` with the kernel (e.g. `[8.8.8.8,53]`).
3. `recvfrom()` – retrieve an arriving request; the kernel fills in the client's `[IP, port]`.
4. `sendto()` – transmit a response back to the requesting client.
5. `close()` – release the socket when no more requests should be served.

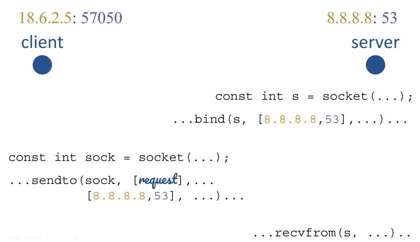
#### Client-side calls

1. `socket()` – create a socket (no fixed port required).
2. `sendto()` – hand the kernel the request packet and the server's address (e.g. `[8.8.8.8,53]`).
3. `recvfrom()` – wait for (or poll for) the matching response.
4. `close()` – terminate communication once all responses are received.

**Blocking vs. Non-blocking** Each call (most notably `recvfrom()`) may be invoked in **blocking** mode (the kernel puts the process to sleep until data arrives) or **non-blocking** mode (the call returns immediately with an error code such as `EAGAIN` if no data is ready).

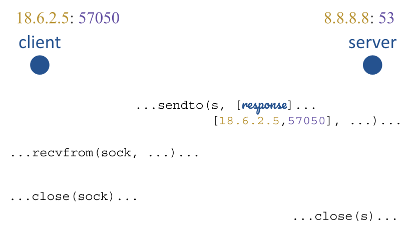
### 1.1.3 Example Network Flow

#### Client → Server (Request)




1. Client issues `socket()` then `sendto()`(*request*, [8.8.8.8,53]).
2. Kernel consults its routing tables and places the UDP datagram on the wire.
3. Server's NIC receives the packet; the kernel matches `[8.8.8.8,53]` to the waiting socket produced by `bind()`.
4. Server process unblocks from `recvfrom()` and obtains both the request data and the client's return address.

#### Server → Client (Response)



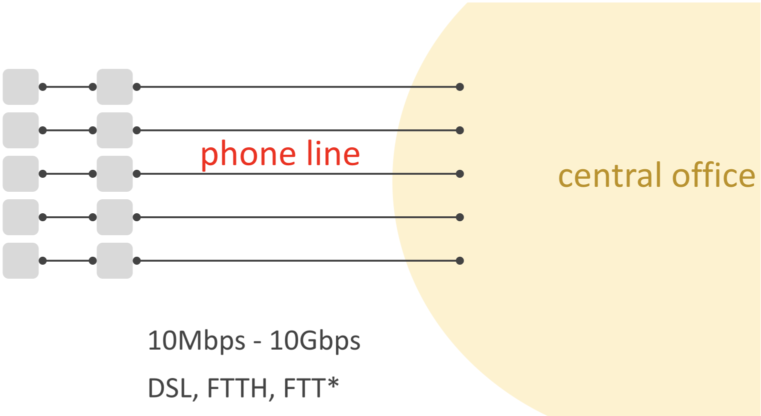

1. Server calls `sendto()`(*response*, [18.6.2.5,57050]).
2. Packet traverses the network back to the client.
3. Client's kernel delivers the datagram to the waiting socket; `recvfrom()` returns the response.
4. Client invokes `close()`. (Whether any data is sent upon `close()` depends on the socket type—topic for a later lecture.)
5. Server eventually calls `close()` when it no longer wishes to serve further requests.

## 1.2 Internet Components

This section introduces the most common ways an **end-system** (e.g. your laptop) reaches the global Internet. For every access technology we list the physical path, the achievable data rate, and the main engineering trade-offs.

### 1.2.1 Access via the Public Switched Telephone Network

A typical home setup places the laptop behind a *DSL/Fiber modem–router* that terminates the household telephone line and relays traffic to the *central office* a few kilometres away.



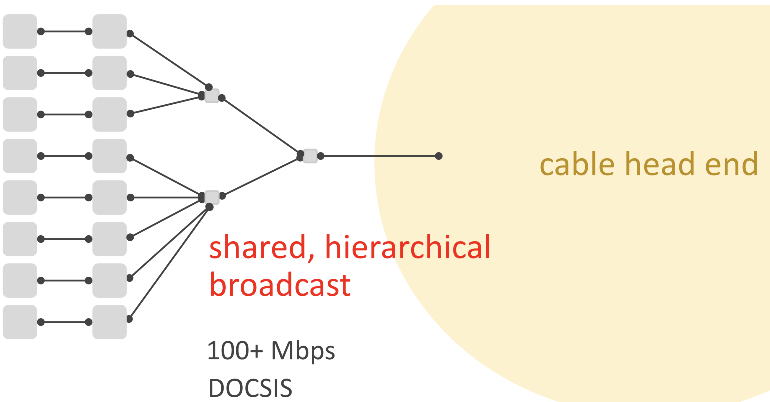

1. **Path**: Laptop → Modem/Router → Copper / Fiber local loop → Central Office → Internet.
2. **Rate**: 10–10,000 Mbps (material and DSL/Fiber technology dependent).
3. **Why legacy copper?**
   - Incumbent telcos *already own* a wire to every household — a compelling business advantage.
   - Pulling new fibre is capital-intensive; upgrades therefore proceed gradually (*FTTH*, *FTTB*, *FTTC*, ...).

**End-system** Any device exchanging packets over the Internet.

**Modem** A specialised *packet switch* that adapts IP packets to the physical characteristics of the telephone line.

### 1.2.2 Access via the Cable TV Network

A second option reuses the coaxial cable that once delivered only television signals.




1. **Path**: Laptop → Cable Modem/Router → Coaxial tree → *Cable Head-End* → Internet.

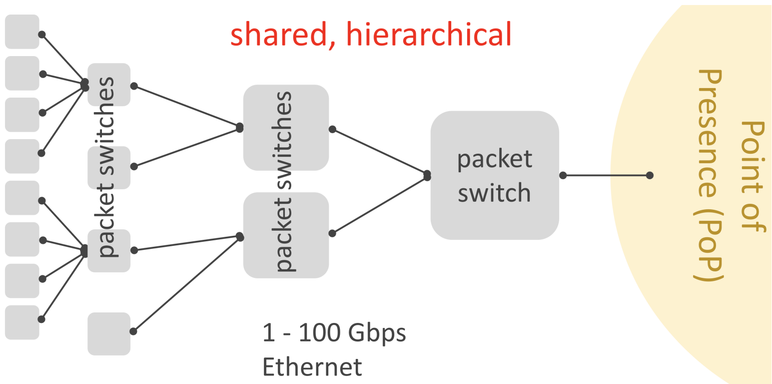
2. **Rate**: Typically 100–1,000 Mbps.
3. **Key differences to DSL**:
   (a) *Shared medium* — the last-mile coax is shared by all subscribers on the tree; throughput per user can drop at peak times (e.g. Saturday night).
   (b) *Broadcast medium* — frames sent by the head-end are physically delivered to *every* household on the tree.

**Shared medium** Multiple end-systems contend for the same link.

**Broadcast medium** A single transmission is received by all nodes on the medium.

### 1.2.3 Access via a Point of Presence (PoP)

Enterprise campuses and data-centres aggregate thousands of machines through a switched hierarchy that ultimately connects to an **ISP Point of Presence (PoP)**.




1. **Path**: Workstation → Access switch → Aggregation/Core switch → PoP → Internet.
2. **Rate**: 1–100 Gbps per link inside the site.
3. **Hierarchy**: Many small switches feed fewer, higher-capacity switches, reducing cost while maintaining performance.

**PoP** The interface between a customer network (campus, enterprise, data-centre) and an Internet Service Provider.

#### Summary

- **Access technologies**: DSL/Fiber over phone lines, Cable-TV coax, cellular, satellite, campus PoP, ...
- **Ownership**: Each path segment is operated by an *Internet Service Provider (ISP)* such as a telco (Swisscom), a cable operator (UPC/Sunrise), or a research network (SWITCH).
- **Design heuristic**: When extending connectivity, always ask:
  1. What infrastructure already exists?
  2. Which media are users accustomed to paying for?

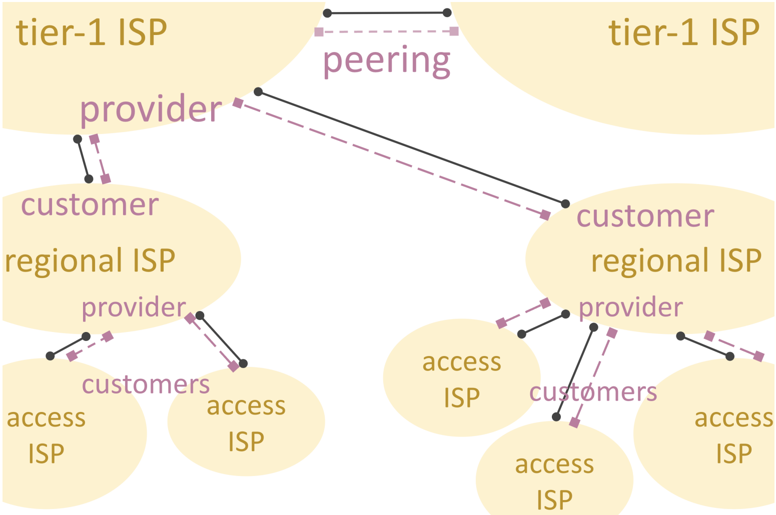
  Leveraging existing assets often yields the most economical solution.

## 1.3 Internet Service Providers (ISPs)

Every end-system ultimately reaches the global Internet through one or more **Internet Service Providers (ISPs)**. To scale worldwide connectivity, ISPs organise themselves in a *three-tier hierarchy* linked by specific business agreements.

### 1.3.1 Why a Hierarchy?

Directly wiring every pair of the world's access networks is infeasible (thousands of telcos, cable operators, universities, enterprises, . . . ). Instead, ISPs form a multi-level structure:




1. **Access ISPs** — interface with end-systems (e.g. Swisscom, Sunrise).
2. **Regional ISPs** — aggregate many access ISPs within a country or region.
3. **Tier-1 ISPs** — few, globe-spanning backbones that can reach every network without paying another provider.

**Definition.** ***Customer–provider relationship****: the lower-tier ISP (*customer*) pays the higher-tier ISP (*provider*) for global reachability.*

### 1.3.2 Peering Agreements

When two ISPs exchange large, roughly balanced traffic volumes, they may bypass providers and interconnect as **peers**:

- *Settlement-free peering*: each party carries the other's traffic at no cost.
- *Paid peering*: one ISP compensates the other if traffic is highly asymmetric.

Peering can occur at *any* tier (access ↔ access, regional ↔ regional, tier-1 ↔ tier-1) whenever it is economically attractive.

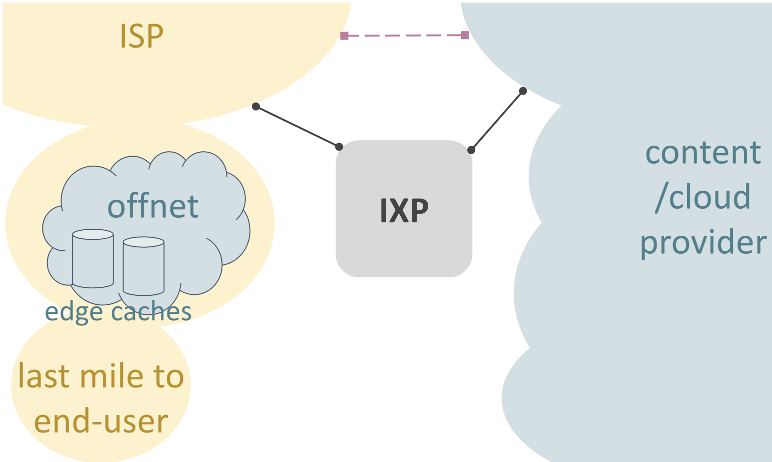
### 1.3.3 Internet eXchange Points (IXPs)

ISPs rarely drag a private cable to every partner. Instead, they each attach *one* high-speed link to a neutral facility called an **IXP**—essentially a massive Ethernet switch where multiple ISPs exchange traffic.

**IXP** Neutral switching fabric that enables many bilateral or multilateral interconnections through a single physical port.

### 1.3.4 Content/Cloud Providers as Networks

Companies such as Google, Microsoft, Amazon, and Meta evolved from regular customers of ISPs into operators of near-global backbones:




1. Directly connect their data-centres to large ISPs and IXPs.
2. Peer with ISPs to minimise transit cost and latency.
3. Deploy **edge caches** *inside* ISP networks to store popular content close to users.
4. Interconnect those caches via an **off-net**—a private overlay that is *logically* theirs but *physically* located within partner ISPs.

### 1.3.5 Edge Caches and Off-nets

**Definition.** ***Edge cache****: server cluster owned and managed by the content provider but* installed within *the ISP's premises; stores the most popular objects for that ISP's subscribers.*

**Definition.** ***Off-net****: the private backbone interconnecting multiple edge caches that reside* outside *the content provider's core network.*
This arrangement improves user experience while reducing upstream traffic for the ISP.

#### Recap

1. The Internet scales through a three-tier ISP hierarchy (access–regional–tier-1) governed by customer–provider contracts.
2. Peering offers a cost-effective shortcut whenever traffic volumes justify it.
3. IXPs simplify physical connectivity by acting as neutral switching hubs.
4. Large content/cloud providers now run quasi-global networks, peer with ISPs, and deploy edge caches/off-nets for performance.

## 1.4 The Network Interface and the CPU

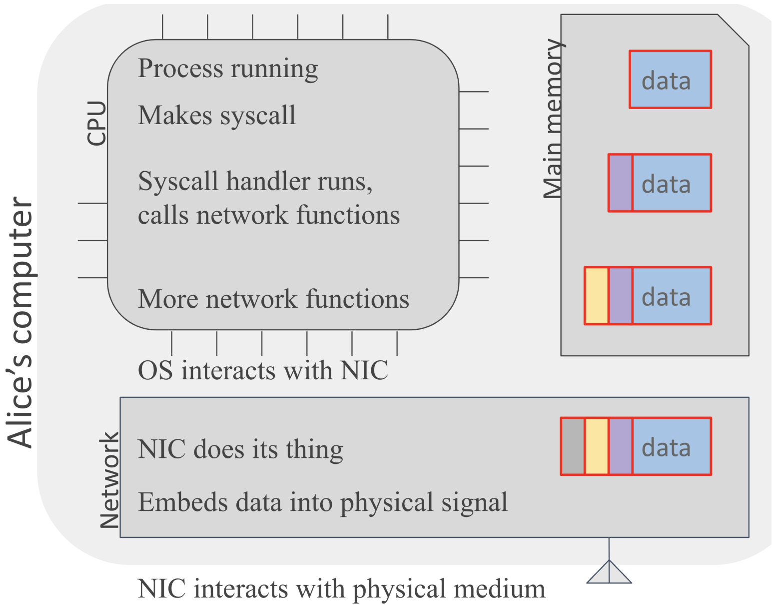
Every Internet message created by a user process must travel from *main memory* to the *Network Interface Card (NIC)*, descend through the five protocol layers, and finally leave the machine as a physical signal. This section shows how the operating system, the NIC, and the layered "network stack" cooperate to make that happen.

### 1.4.1 Hardware Overview

**NIC controller** On-board processor that handles packet queues and offloads work from the CPU.

**I/O controller** CPU's gateway to peripheral devices.

**DMA controller** Copies data between main memory and device memory *without* CPU intervention.




**Send path (user process → wire):**

1. User process issues a `sendto()` *network syscall*; CPU traps into *kernel mode*.
2. Kernel prepends *transport* and *network* metadata to the user data.
3. Kernel programs the I/O controller; DMA copies the buffer to NIC memory.
4. NIC adds a *link-layer* header, forming a **packet** = *payload* + *all headers*.
5. NIC converts the packet bits into an electrical/optical/radio signal and transmits it onto the medium.

### 1.4.2 The Five-Layer Internet Stack

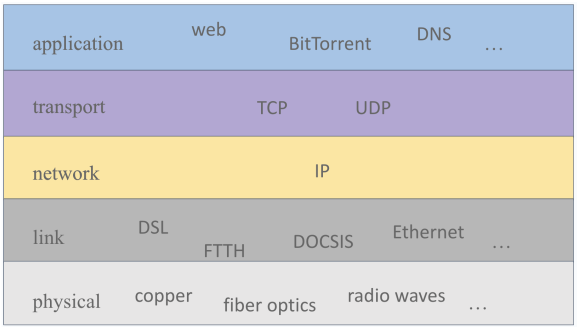
**Application** User programs (web, chat, file-transfer).

**Transport** TCP and UDP.

**Network** IP (Internet Protocol).

**Link** Ethernet, Wi-Fi, DOCSIS, DSL, . . .

**Physical** Copper wire, fibre optics, radio, free-space optics.

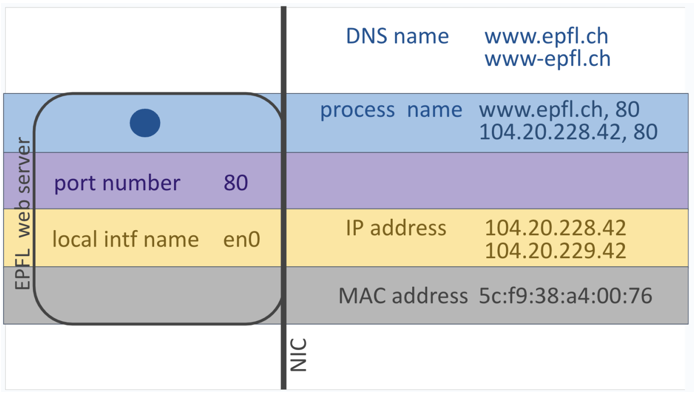



**Layer Properties**

- **Abstraction**: each layer hides lower-level details from the layer above.
- **Encapsulation**: a layer *prepends* its own header.
- **Decapsulation**: a layer *removes* its header on the receiving host.
- **Interfaces**: adjacent layers communicate through a well-defined API (e.g. a *syscall* between Application and Transport).

*Layers reduce complexity and increase flexibility; they do not directly improve raw performance.*

**Example 1.4.2.1** (EPFL Web Server)**.** *Consider the machine that answers HTTP requests for* `www.epfl.ch`*. Important naming facts:*




1. ***Application layer*** *- Runs a web–server* process.
2. ***Transport layer***
   - *Identifies that process with* ***port*** *80.*
   - *Other processes on the same host listen on* different *port numbers.*
3. ***Network layer***
   - *Sees the host's network interface as* `en0`*.*
   - *Associates one or more* ***IP addresses*** *with* `en0` *(e.g.* `104.20.228.42`*).*
4. ***Link layer***
   - *Uses a globally–unique* ***MAC address*** *(e.g.* `5c:f9:38:a4:00:76`*) for the same interface.*

### Name Identifiers

- **Interface identifiers**

  **DNS name** Human-readable alias (`www.epfl.ch`).
  **IP address** Network-layer locator (`104.20.228.42`).
  **MAC address** Link-layer locator (`5c:f9:38:a4:00:76`).
  **OS handle** Local label (e.g. `en0`).

- **Process identifier** *interface–name* , *port*
  A two-tuple: first choose the interface by DNS/IP, then the process by its port number.