TCP/IP Deep Dive – Technical Explanation

TCP/IP Model (4 Layers)
The TCP/IP architecture consists of four abstraction layers enabling interoperable end-to-end communication across heterogeneous networks:

1. **Application Layer** – Includes higher-level protocols (HTTP, FTP, DNS). Provides user-facing services and formats data for transport.
2. **Transport Layer** – Ensures end-to-end delivery and flow control.
    - TCP provides reliable, connection-oriented service using sequence numbers, acknowledgements, windows.
    - UDP offers connectionless datagrams with minimal overhead.
3. **Internet Layer** – Provides logical addressing and routing via the IP protocol. Manages fragmentation, TTL, best-effort forwarding.
4. **Network Access Layer** – Implements link-specific framing, MAC addressing, and physical signaling (Ethernet, Wi-Fi).

Packet Encapsulation & Headers

As data descends through the protocol stack, each layer prepends its own header:

Application Data
↓ add TCP header
↓ add IP header
↓ add link-layer (Ethernet) header
→ forms a transmitted frame

At the receiver, decapsulation removes each header in reverse order. Encapsulation enables multiplexing, modularity, and independent evolution of layers.

TCP Connection Establishment (3-Way Handshake + Termination)

A reliable TCP connection is established using control flags and sequence numbers:

1. Client → **SYN** segment proposes seq number.
2. Server → **SYN + ACK** acknowledges client and proposes its own seq number.
3. Client → **ACK** confirms receipt.

Once established, full-duplex data transmission begins. TCP ensures ordered delivery, retransmissions, and congestion control.

Termination uses FIN/ACK exchanges enabling graceful teardown and avoiding half-open connections.

IP Routing Process

Routers forward packets hop-by-hop using the destination IP address:

1. Router extracts destination IP from the packet header.
2. Performs a **Longest Prefix Match** lookup in the routing table.
3. Determines:
    - next hop router
    - outbound interface
4. Decrements Time-To-Live (TTL) to prevent loops.
5. Forwards packet to next hop.

If no matching route is found:

- use default route if configured
- otherwise send ICMP Destination Unreachable

Routing protocols (OSPF, BGP, RIP) dynamically exchange network reachability updates to compute optimal paths.

Summary

The TCP/IP stack modularizes networking by separating application services, transport reliability, logical addressing, and physical framing. Encapsulation enables interoperability between media types and routing infrastructures. TCP handshakes guarantee reliable stateful communication, while routers apply prefix-based forwarding and TTL safety mechanisms, enabling scalable packet delivery across global IP networks.