Team Members
Kalyan K – AP22110011624
Teja P – AP23110010591
Vivek A – AP23110011615
Venkatesh M – AP23110011626
Abhisek J – AP23110011668

# Peer-to-Peer (P2P) Networking
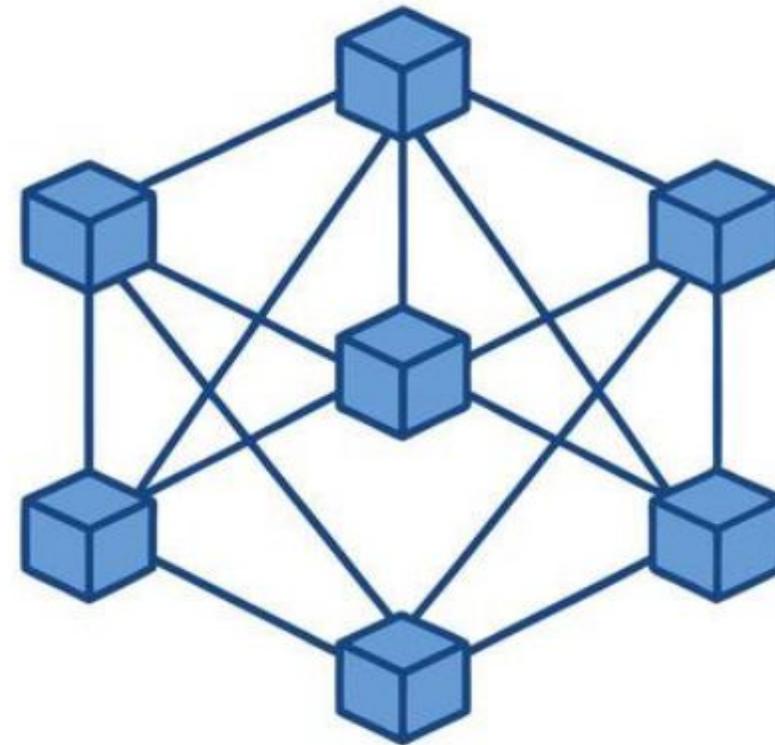
A Decentralized Approach to Communication

What is Peer-to-Peer?

A P2P network is a distributed system where participants, called **"peers,"** make a portion of their resources (processing power, storage, or bandwidth) directly available to other network participants.

Unlike the traditional client-server model, there is no single central server required to manage the network or broker connections.

Each node in the network acts as both a **"client"** (requesting resources) and a **"server"** (providing resources) simultaneously.

The Core Contrast: P2P vs. Client-Server

Client-Server Model

Relies on a central, dedicated server to manage, store, and distribute data and resources.

Clients send requests to the server, and the server responds. Communication is centralized.

Weakness: Creates a single point of failure. If the server goes down, the entire network stops working.

Peer-to-Peer Model

A decentralized architecture where all nodes (peers) share the workload and resources.

Peers request resources from and provide resources directly to other peers in the network.

Strength: Highly resilient and fault-tolerant. There is no single point of failure.

Types of P2P Architectures

Unstructured

Peers connect arbitrarily. Content discovery (like in Gnutella) floods the network with queries, which is simple but can be inefficient.

Structured

Uses a specific topology (like a Distributed Hash Table – DHT) to organize peers, ensuring efficient and scalable content discovery.

Hybrid

Combines a central server (for indexing or bootstrapping) with P2P for data transfer, balancing efficiency with decentralization (e.g., Spotify).

How P2P Works (Simplified)

2. Resource Query

The peer queries the network (either by flooding or using a DHT) to find which peers have the desired file or resource.
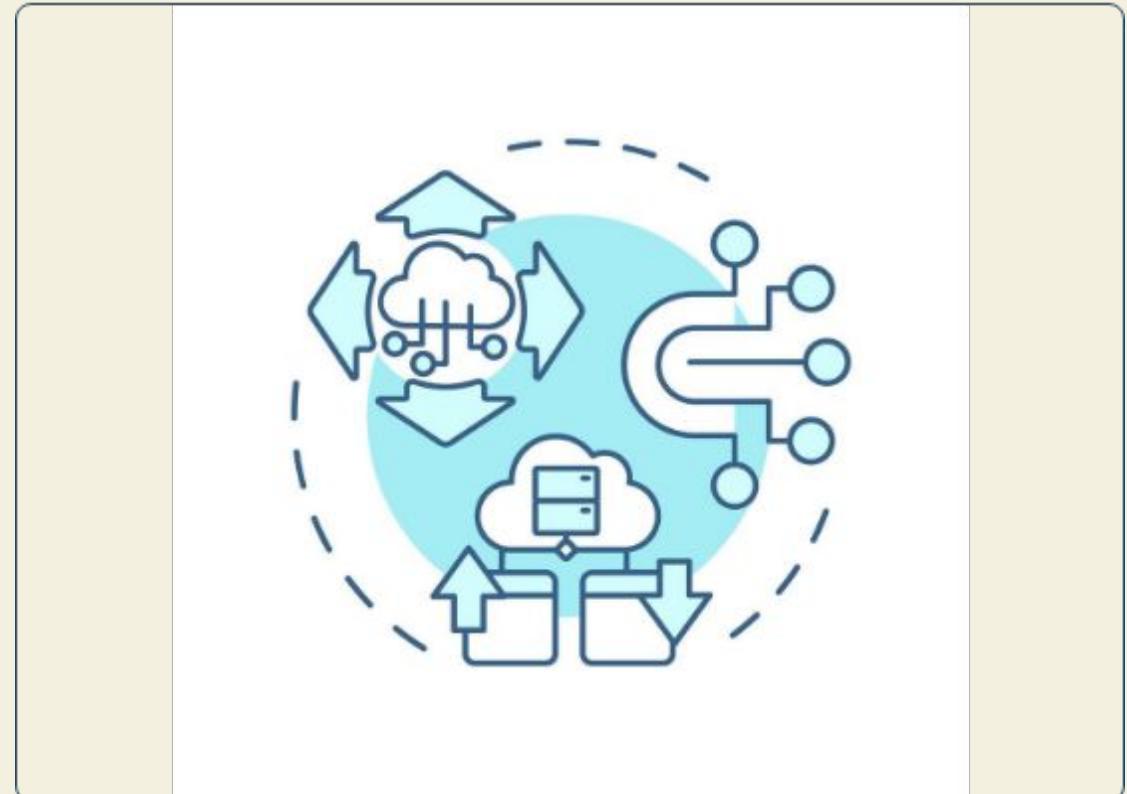
4. Data Transfer

The peer downloads pieces of the file from multiple peers simultaneously and also uploads pieces it already has.

1. Peer Discovery

A new peer joins and must find other peers, often via a "bootstrap" node or a central "tracker" server.

3. Direct Connection

The peer establishes direct connections to the other peers (a "swarm") that hold the resource.

Advantages of P2P

✓ **Scalability:** Network performance often *improves* as more users join, since each new peer is also a resource provider.

✓ **Resilience & Fault Tolerance:** No single point of failure. If one peer goes offline, the network continues to function.

✓ **Cost-Effectiveness:** Eliminates the need for expensive, high-capacity central servers and reduces infrastructure costs.

✓ **Censorship Resistance:** The decentralized nature makes it difficult for any central authority to block or shut down the service.

Disadvantages & Challenges

⚠️ **Security Risks:** No central authority to vet peers, making it easier to spread malware or conduct denial-of-service attacks.

⚠️ **Resource Availability:** Content is only available if a peer holding it is online. This creates the "leecher" problem.

⚠️ **Discovery Inefficiency:** Finding specific, unpopular content can be slow and difficult in large unstructured networks.

⚠️ **Legal & Copyright Issues:** P2P is notoriously used for illegal file sharing, creating significant legal and ethical challenges.

# Key Application: File Sharing
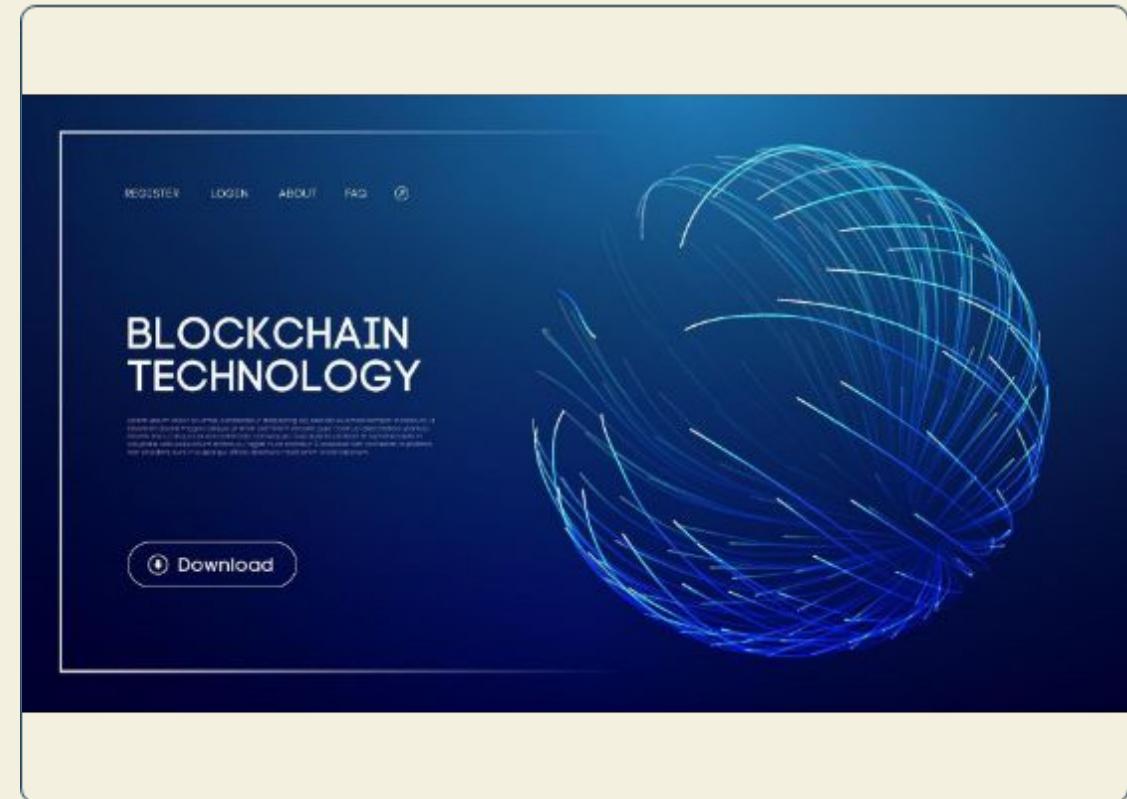
BitTorrent

The most famous P2P application. It allows users to download large files (like Linux distributions or game updates) by pulling "pieces" from a "swarm" of other users (seeders and leechers) simultaneously. This distribution of bandwidth makes transferring large files extremely efficient.

Key Application: Cryptocurrencies

Bitcoin & Blockchain

Cryptocurrencies like Bitcoin operate on a P2P network. The **"blockchain"** is a distributed public ledger (a database) that is maintained and verified by all peers in the network.

Transactions are verified and broadcast by peers, ensuring no central bank or single authority is required to validate or control the currency.

Modern P2P Use Cases

File Sharing | Cryptocurrencies | Communication | Content Delivery

P2P is a foundational technology for many modern decentralized systems, from finance (DeFi) to secure communication (Signal, Skype) and content delivery.

The Future of P2P

Web 3.0 & The Decentralized Web

P2P is the backbone of "Web 3.0," a movement aiming to create a decentralized internet, returning data ownership to users.

Technologies like **IPFS (InterPlanetary File System)** aim to replace HTTP by storing and addressing web content on a global P2P network, making it more resilient and permanent.

Expect continued growth in Decentralized Autonomous Organizations (DAOs) and Decentralized Finance (DeFi), all built on P2P principles.

Thank You

Image Sources

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