UNIT–II:

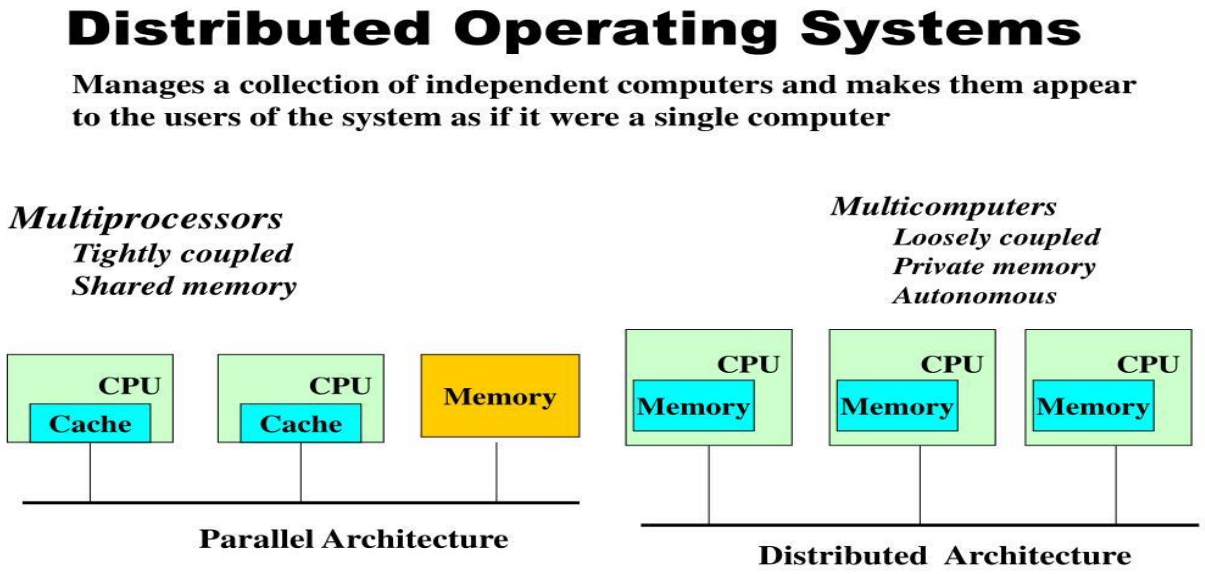
Communication in Distributed Systems, Lay red Protocols, ATM networks, The Client – server model, Remote Procedure call, Group communication

Communication in Distributed Systems:

2.1 COMMUNICATION IN DISTRIBUTED SYSTEMS:

The most important difference between a distributed system and a uniprocessor system is the interprocess communication.

Interprocess communication (IPC) is a set of programming interfaces that allows a programmer to coordinate activities among different program processes that can run concurrently in an operating system.



1. In a uniprocessor system, interprocess communication assumes the existence of shared memory whereas in a distributed system, there‟s no shared memory, so the entire nature of interprocess communication must be completely reframed from scratch.

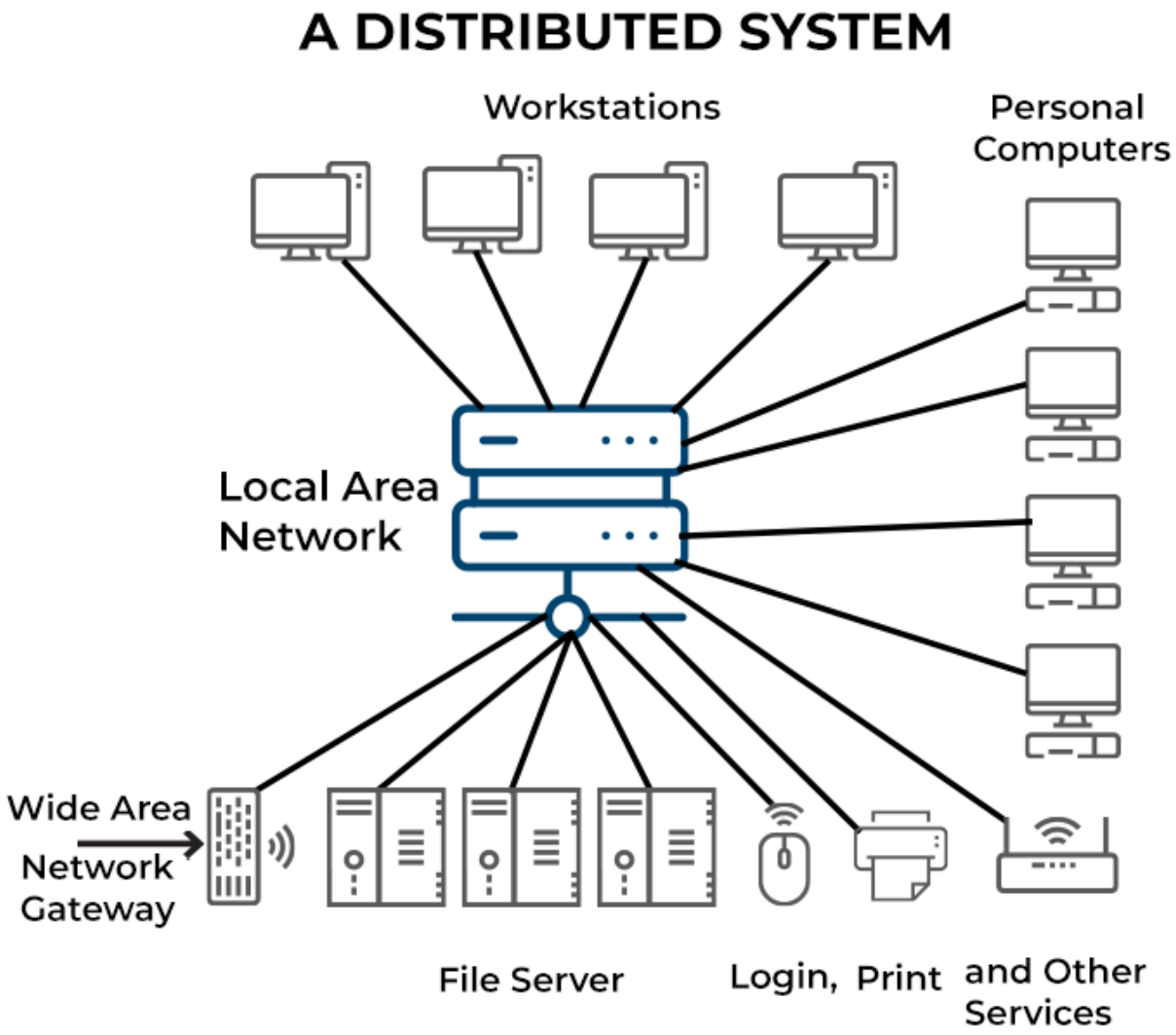
***. All communication in distributed system is based on message passing.**

***. The processes run on different machines and they exchange information through**

message passing.

***. Successful distributed systems depend on communication models that hide or simplify message passing.**

Communication in distributed systems involves exchanging information between processes or nodes located on different machines within a network. It is one of the most critical aspects of distributed computing because it underpins the coordination, resource sharing, and functionality of the entire system. Below are some key points on communication in distributed systems:



1. Types of Communication Models

- **Message Passing: This is the most common communication mechanism, where nodes exchange messages. It can be synchronous or asynchronous.**
    - ***Synchronous*: Sender waits for a response from the receiver before proceeding.**
    - ***Asynchronous*: Sender sends the message and continues without waiting for a response.**
- **Remote Procedure Call (RPC): A function call to a procedure that runs on a remote node as if it were local. The underlying system hides the complexity of network communication.**
- **Remote Method Invocation (RMI): Extends RPC by allowing object-oriented interaction where methods of remote objects are invoked, commonly used in Java systems.**
- **Shared Memory: A communication model where distributed systems share a common memory space (virtual or physical), although this is rare and typically implemented via some abstraction (e.g., Distributed Shared Memory - DSM).**

2. Challenges in Communication

- **Latency: Time delays in sending and receiving messages across a network.**
- **Bandwidth: The capacity of a communication link, which can be a bottleneck when transferring large amounts of data.**
- **Fault Tolerance: Communication systems need to handle node failures, message loss, and network partitioning.**
- **Concurrency: Multiple nodes may attempt to communicate simultaneously, leading to potential conflicts or resource contention.**
- **Consistency: Inconsistent views of the system due to network delays or partitioning can create challenges for maintaining system state.**
- **Message Ordering: Ensuring the correct sequence of message delivery is crucial, especially for systems that require strong consistency or transactional integrity.**

3. Protocols and Standards

- **Transmission Control Protocol (TCP): A reliable, connection-oriented protocol that ensures data is transmitted in order and without loss.**
- **User Datagram Protocol (UDP): A faster, connectionless protocol that does not guarantee message delivery or order, suitable for real-time or time-sensitive applications.**
- **HTTP/HTTPS: Commonly used for web-based distributed systems, particularly for client-server architectures.**

- **gRPC: A high-performance, open-source RPC framework that uses HTTP/2 for communication and supports a wide variety of programming languages.**
- **Message Queuing Protocols: In some systems, message queues (e.g., Kafka, RabbitMQ) are used to decouple producers and consumers, allowing for asynchronous and reliable message delivery.**

4. Communication Paradigms

- **Client-Server: The most basic paradigm where a server provides services and a client consumes them. Requests are initiated by the client, and responses come from the server.**
- **Peer-to-Peer (P2P): All nodes are equal, and they communicate directly with each other without a centralized server. P2P networks are highly scalable and fault-tolerant but introduce complexities like data consistency and security.**
- **Publish-Subscribe: In this model, messages are categorized into topics. Publishers send messages without knowing the receivers, and subscribers listen to topics of interest. This decouples message producers and consumers.**

5. Security in Communication

- **Encryption: Ensuring confidentiality by encrypting messages using protocols like TLS (Transport Layer Security) or SSL (Secure Sockets Layer).**
- **Authentication: Verifying the identity of nodes communicating in the system, often through digital certificates or token-based mechanisms.**
- **Authorization: Controlling access to system resources and ensuring that only authorized users or nodes can access specific services or data.**
- **Integrity: Preventing tampering with messages by using checksums, digital signatures, or hashing algorithms.**

6. Synchronization Mechanisms

- **Clock Synchronization: Distributed systems often rely on synchronized clocks for ordering events. Algorithms like Network Time Protocol (NTP) or more sophisticated mechanisms such as Lamport clocks are used.**
- **Leader Election: In some systems, one node is elected as the leader to coordinate activities. Algorithms like Paxos or Raft handle this process.**

7. Reliability and Fault Tolerance

- **Replication: Data or processes are replicated across multiple nodes to ensure that the system remains operational even if one node fails.**
- **Quorum Systems: Used to ensure consistency in distributed systems by requiring that a majority (quorum) of nodes agree on the state of the system before a change is accepted.**

8. Examples of Distributed Communication Systems

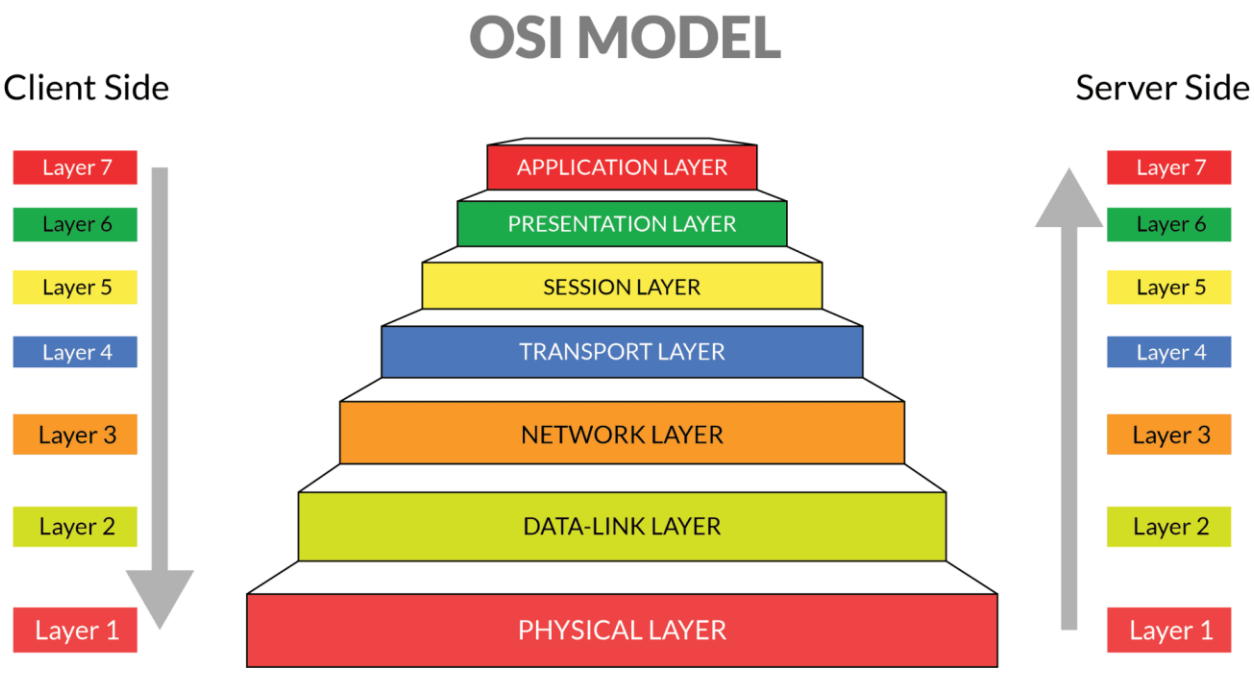
- **Apache Kafka: A distributed messaging system that provides high-throughput, fault-tolerant communication between producers and consumers.**
- **Google's gRPC: A high-performance, open-source RPC framework used in microservices architectures for efficient and flexible communication.**
- **Amazon SQS (Simple Queue Service): A distributed message queuing service that enables decoupled communication between components of a system.**

9.Scalability Considerations

- **Load Balancing: Distributing the communication workload evenly across servers to prevent any single node from becoming a bottleneck.**
- **Sharding: Dividing a large data set into smaller, manageable parts (shards), with each shard managed by a different server or group of servers.**

Layered Protocols in Distributed Systems

Layered protocols in distributed systems follow a hierarchical approach where communication tasks are divided into distinct layers. Each layer has a specific role and interacts with the layer directly above and below it. The most common model to represent layered protocols is the OSI model (Open Systems Interconnection), but in practice, the TCP/IP model is more commonly implemented. Below is a detailed breakdown of each layer, including protocols commonly used in distributed systems.



1. Application Layer

This is the top-most layer where high-level protocols operate. It is responsible for end-user services and direct interactions with applications.

- **HTTP (Hypertext Transfer Protocol): Used for transmitting web pages over the internet. It is stateless and uses TCP for reliable transmission.**
- **HTTPS (HTTP Secure): The secure version of HTTP, which uses TLS (Transport Layer Security) or SSL (Secure Sockets Layer) to encrypt communication between clients and servers.**
- **FTP (File Transfer Protocol): A standard network protocol for transferring files between a client and server on a network.**
- **SMTP (Simple Mail Transfer Protocol): Used for sending emails across networks.**
- **gRPC (Google Remote Procedure Call): An open-source high-performance RPC framework that uses HTTP/2. It is highly efficient and supports multiple languages.**
- **DNS (Domain Name System): Resolves domain names to IP addresses, allowing users to access services using human-readable names.**
- **High-level protocols focus on user services and data formatting.**
- **Provides interfaces for communication with lower layers.**
- **Can handle multiple network services simultaneously (email, web, file transfer, etc.).**

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2. Transport Layer

The transport layer ensures reliable or fast delivery of data between devices. It handles data flow control, error correction, and packet retransmission.

- **TCP (Transmission Control Protocol): A connection-oriented protocol that ensures reliable, ordered, and error-checked delivery of a stream of data between applications. It is used for applications that require reliability, such as web services, email, and file transfers.**
- **UDP (User Datagram Protocol): A connectionless protocol that sends data without guaranteeing delivery or order. It is faster than TCP and is commonly used in real-time applications such as video conferencing, streaming, and gaming.**
- **Reliability (TCP): Provides error-checking, retransmission of lost data, and in-sequence delivery.**
- **Speed (UDP): Low-latency communication without guarantees, used where speed is critical and minor data loss is acceptable.**
- **Flow Control: Manages the rate of data transmission to prevent a fast sender from overwhelming a slower receiver.**

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3. Network Layer

The network layer is responsible for routing packets across multiple networks (hence, the term internetworking). It provides addressing and manages the delivery of packets across networks.

- **IP (Internet Protocol): The fundamental protocol for addressing and routing. It provides logical addresses (IP addresses) for devices on a network.**
    - ***IPv4*: The most widely used version of IP, using 32-bit addresses.**
    - ***IPv6*: The newer version, using 128-bit addresses to handle more devices and improve efficiency.**
- **ICMP (Internet Control Message Protocol): Used for network diagnostics and error reporting (e.g., the "ping" command uses ICMP to test connectivity).**
- **ARP (Address Resolution Protocol): Resolves IP addresses into MAC (Media Access Control) addresses, allowing network devices to locate each other on the same local network.**
- **Routing: Determines the path packets take from the source to the destination across different networks.**
- **Fragmentation: Breaks down large packets into smaller fragments that can fit the maximum transmission unit (MTU) of the underlying network.**
- **Error Handling: Detects and corrects network-level issues (via ICMP).**

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4. Data Link Layer

The data link layer handles communication between devices on the same local network. It is responsible for ensuring that data is transferred correctly from one node to another over the physical medium.

- **Ethernet: The dominant technology used for wired LANs (Local Area Networks). It operates at both the data link and physical layers.**
- **Wi-Fi (IEEE 802.11): A wireless networking technology that allows devices to connect to a network without physical cables. It uses radio waves to communicate between devices and access points.**
- **PPP (Point-to-Point Protocol): A data link layer protocol used to establish direct connections between two nodes. It is often used in wide area networks (WANs) or between routers.**
- **Frame Construction: Breaks packets into frames for physical transmission.**
- **Error Detection: Detects errors using mechanisms like cyclic redundancy check (CRC) and retransmits faulty frames.**
- **MAC (Media Access Control): Manages access to the physical transmission medium and ensures that multiple devices can communicate over the same network without collisions.**

5. Physical Layer

The physical layer is the lowest layer in the protocol stack. It deals with the actual physical connection between devices and handles the transmission of raw data bits over a communication medium such as cables or radio waves.

- **Transmission Media: Physical materials used to transmit data (e.g., twisted pair cables, fiber optics, and wireless radio signals).**
- **Bit Transmission: Converts data packets into electrical signals, light pulses, or radio waves for physical transmission.**
- **Modulation/Demodulation: Converts digital data into signals suitable for transmission and then back to digital data at the receiver.**
- **Signal Encoding: Translates binary data into physical signals that can be transmitted over a medium.**
- **Data Rate: Controls the speed at which data can be transmitted, measured in bits per second (bps).**
- **Physical Topology: Defines the arrangement of devices and how they are connected, whether using star, ring, bus, or mesh topologies.**

6.Session Layer :

Session Layer, which is the 5th layer in the OSI model, uses the services provided by The transport layer, enables applications to establish and maintain sessions and to synchronize the sessions.

Now, in order to establish a session connection

7.Presentation Layer:

Presentation Layer is the 6th layer in the Open System Interconnection (OSI) model. This layer is also known as Translation layer, as this layer serves as a data translator for the network. The data which this layer receives from the Application Layer is extracted and manipulated here as per the required format to transmit over the network. The main responsibility of this layer is to provide or define the data format and encryption

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How Data Flows Through Layers :

When a message is sent from one node to another, the data passes through each layer of the protocol stack, starting at the Application Layer and moving downward to the Physical Layer for transmission. Each layer adds its own header information, a process known as encapsulation. Upon receiving the message, the destination device performs decapsulation, stripping away headers at each layer to extract the original message.

Layer Interaction

Each layer in the protocol stack has a clearly defined role and interacts only with the adjacent layers. For example:

- **The Transport Layer uses the Network Layer for routing packets.**
- **The Application Layer uses the Transport Layer to reliably send data.**
- **The Data Link Layer uses the Physical Layer to transmit frames over the physical medium.**

Layered Protocols in Distributed Systems

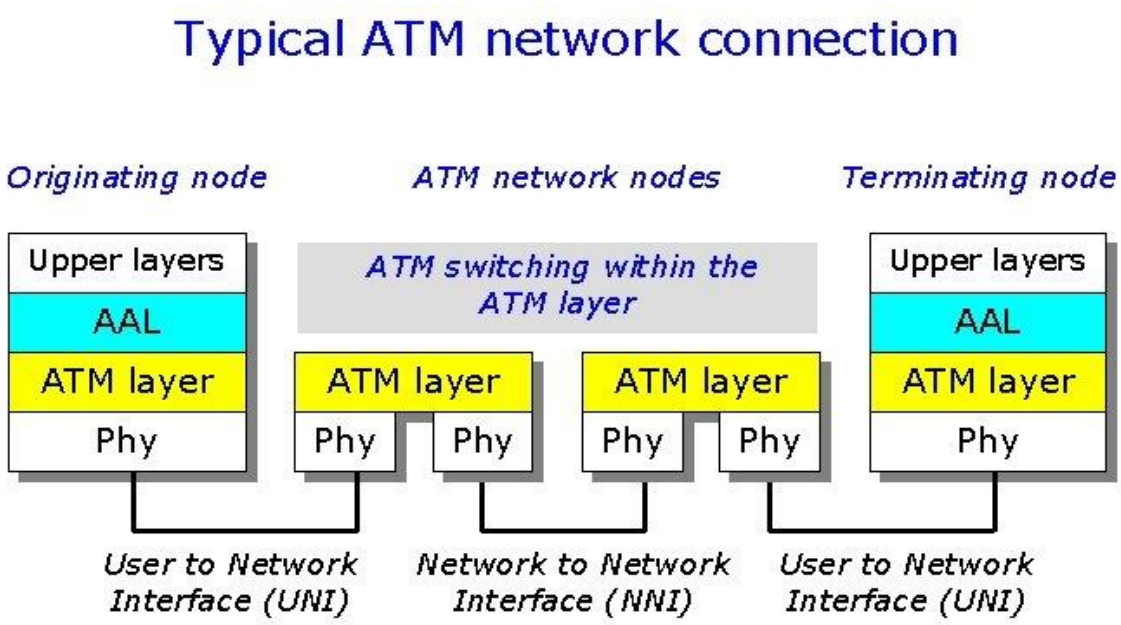
In distributed systems, different layers and protocols work together to enable seamless communication between nodes spread across various networks and geographies. Each layer abstracts complexity from the layers above, providing a modular structure that simplifies development, debugging, and system scalability.

Benefits of Layered Protocols

- **Modularity: Each layer is independent, so changes in one layer don't affect the others.**
- **Standardization: Protocols are standardized, making it easier to design and implement systems that can interoperate.**
- **Scalability: Layers enable distributed systems to grow and scale by allowing abstraction and separation of concerns.**
- **Interoperability: Layered protocols enable systems from different vendors and platforms to communicate seamlessly.**

ATM (Asynchronous Transfer Mode) Networks:

Asynchronous Transfer Mode (ATM) is a network technology designed for high-speed, low-latency transmission of voice, video, and data across both local and wide area networks. ATM is often considered a high-performance, cell-based switching technology that integrates various types of network traffic.



1. Basic Concepts of ATM Networks

ATM is a connection-oriented technology that uses fixed-size cells to transmit data. These cells are 53 bytes in size, with 5 bytes used for the header and 48 bytes for the payload. ATM was designed to support a wide variety of traffic types, including real-time (voice and video) and non-real-time (data) services.

Key Characteristics:

- **Cell-based transmission: Unlike packet-switched networks (like IP) that use variable-length packets, ATM transmits fixed-size cells.**
- **Connection-oriented: Before data transmission can occur, a virtual circuit must be established between sender and receiver.**
- **Quality of Service (QoS): ATM offers different service classes, allowing the network to prioritize certain types of traffic based on the application's requirements.**

2. ATM Cell Structure

An ATM cell consists of two parts: a header and a payload.

- **Header (5 bytes): Contains information needed for routing and managing the cell (e.g., virtual path identifier (VPI) and virtual channel identifier (VCI)).**

- **Payload (48 bytes): Carries the actual data from the application or service.**

3. ATM Layers

ATM uses a layered architecture similar to the OSI model but optimized for high-speed networks. The three main layers in ATM are:

a. ATM Adaptation Layer (AAL)

This layer is responsible for segmenting higher-layer data into ATM cells and reassembling them at the destination. It is also responsible for managing error correction, timing, and synchronization. There are different types of AAL depending on the application:

- **AAL1: Used for constant bit-rate (CBR) services like voice and video, which require low latency and steady transmission.**
- **AAL2: Supports variable bit-rate (VBR) services that are delay-sensitive but tolerate some variability in transmission rates.**
- **AAL3/4: Combines two AALs that were initially designed for connectionless data services.**
- **AAL5: The most commonly used AAL, especially for data communications like IP over ATM. It is simpler and more efficient.**

b. ATM Layer

The ATM layer is responsible for cell multiplexing and switching. It provides services for managing virtual paths (VP) and virtual channels (VC), enabling multiple connections to be handled simultaneously over the same physical link.

- **Virtual Path (VP): A collection of virtual channels (VC) that share a common path across the network.**
- **Virtual Channel (VC): A specific connection between two endpoints, identified by the VPI/VCI in the cell header.**

c. Physical Layer

The physical layer deals with the transmission of ATM cells over the physical medium. It ensures that cells are properly transmitted and received between devices. ATM can run over different types of physical media, including fiber optics and twisted-pair copper.

4. Quality of Service (QoS) in ATM

One of ATM's strengths is its ability to support multiple levels of Quality of Service (QoS), making it ideal for applications with varying requirements for bandwidth, delay, and jitter. ATM offers different service categories, such as:

- **Constant Bit Rate (CBR): Guarantees a fixed rate of data transfer, ideal for real-time applications like voice and video that require low delay and jitter.**

- **Variable Bit Rate (VBR): Allows for variability in data rate, used for applications that have bursts of data but still require a level of predictability (e.g., video streaming).**
    - ***Real-time VBR (rt-VBR)*: Optimized for time-sensitive traffic, such as video conferencing.**
    - ***Non-real-time VBR (nrt-VBR)*: Used for applications like file transfer, where timing is less critical.**
- **Available Bit Rate (ABR): Adjusts the data rate dynamically based on the available bandwidth. This is used for applications like data transfer where guaranteed timing is not necessary.**
- **Unspecified Bit Rate (UBR): Provides no QoS guarantees, typically used for non-critical traffic such as email and web browsing.**

5. ATM Addressing and Virtual Circuits

ATM uses a virtual circuit model to establish communication paths between network devices.

- **Virtual Circuit: ATM establishes a virtual connection between endpoints. Two types of virtual circuits are used:**
    - **Permanent Virtual Circuit (PVC): A dedicated path set up by the network administrator.**
    - **Switched Virtual Circuit (SVC): Dynamically created when needed, similar to a telephone call.**

ATM uses a hierarchical addressing scheme that is divided into a Virtual Path Identifier (VPI) and a Virtual Channel Identifier (VCI) to uniquely identify connections within the ATM network.

6. ATM Switching

ATM switches play a critical role in relaying cells between source and destination based on the VPI/VCI in the header. The switch maintains a routing table and updates the VPI/VCI at each hop to ensure that cells are properly forwarded.

7. Advantages of ATM

- **Versatility: ATM supports both real-time (e.g., voice and video) and non-real-time (e.g., data) services over the same network.**
- **High Performance: Fixed-size cells enable efficient processing and switching, reducing delays in high-speed networks.**
- **QoS Support: Multiple service classes allow ATM to provide guaranteed levels of performance for critical applications.**
- **Scalability: ATM can scale across different network sizes, from local area networks (LANs) to wide area networks (WANs).**

8. Disadvantages of ATM

- **Overhead: ATM's fixed cell size introduces significant overhead, especially for small data transmissions, as each 53-byte cell includes a 5-byte header.**
- **Complexity: ATM is more complex to implement and manage compared to other networking technologies such as Ethernet and IP.**
- **Cost: ATM equipment and infrastructure can be more expensive than alternatives.**
- **Competition from IP: As IP-based networks (e.g., Ethernet) improved and offered better support for high-speed data and multimedia traffic, ATM's adoption decreased in favor of cheaper and simpler alternatives.**

9. Applications of ATM

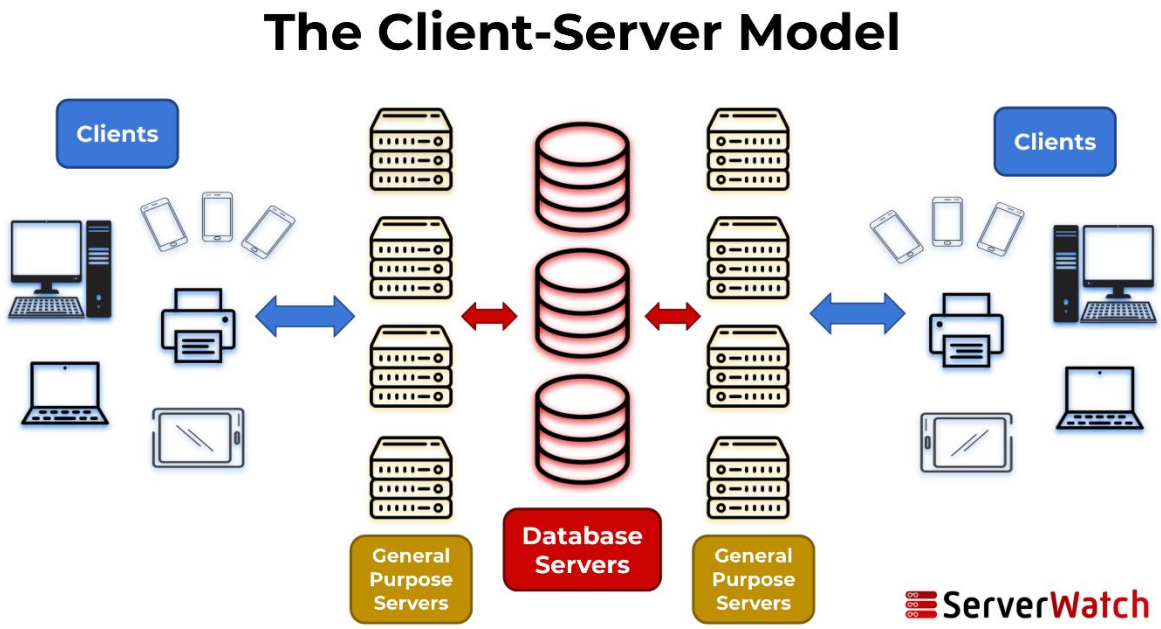
- **Telecommunications: ATM has been widely used by telephone companies for transporting voice and video traffic because of its QoS capabilities.**
- **Corporate Networks: Large organizations used ATM for their private networks due to its support for high-speed data transfer and multiple service classes.**
- **Broadband Networks: ATM has been a backbone technology for broadband networks, supporting DSL and fiber connections.**
- **Multimedia Applications: Its ability to handle voice, video, and data simultaneously made it a good choice for early multimedia applications.**

10. ATM in Modern Networks

Though ATM was a popular technology in the 1990s and early 2000s, it has largely been replaced by more flexible and less costly alternatives, such as Ethernet, MPLS (Multiprotocol Label Switching), and IP-based solutions. However, ATM's influence on modern networking, especially its focus on QoS and efficient switching, can still be seen in newer technologies like MPLS.

Client-Server Model

The Client-Server Model is a distributed application structure that divides tasks or workloads between service providers (servers) and service requesters (clients). This model is widely used in networking, web applications, database systems, and cloud services. It enables efficient resource sharing and centralized control.



1. Basic Concept

In the client-server model, two primary components interact:

- **Client: The client is a device or software that requests services or resources from the server. Clients initiate communication with the server.**
- **Server: The server is a central machine or software that provides services, resources, or data to clients. Servers are always on, waiting to handle client requests.**

The model operates on a request-response cycle where the client sends a request to the server, and the server processes the request and returns a response.

2. Characteristics of the Client-Server Model

- **Centralization: Servers provide centralized control over data and services. Clients access services but do not manage them.**
- **Scalability: Servers can handle multiple clients, allowing the system to grow as more clients are added.**
- **Modularity: The client and server are separate components, making it easier to update or replace one without affecting the other.**
- **Interactivity: The client and server can interact in real time, with clients requesting data, and servers providing it instantly or after processing.**

3. How the Client-Server Model Works

- **Client Request: The client initiates communication by sending a request to the server. This request can be for data, resources, or services.**
- **Server Response: The server receives the client request, processes it, and sends back the requested information or service.**
- **End of Interaction: Once the server fulfills the client request, the interaction ends. In some cases (persistent connections), the client may keep the connection open for further communication.**

4. Types of Servers

Servers can perform different roles, depending on the services they provide:

- **Web Servers: Handle HTTP requests and serve web pages or web applications (e.g., Apache, Nginx).**
- **Database Servers: Store, manage, and provide access to databases (e.g., MySQL, Oracle).**
- **File Servers: Allow clients to store and retrieve files over a network (e.g., FTP servers).**
- **Application Servers: Host and manage applications that clients interact with (e.g., JBoss, Tomcat).**
- **Proxy Servers: Act as intermediaries between clients and other servers, often used for caching, filtering, or anonymizing requests.**

5. Types of Client-Server Architectures

There are various types of client-server architectures based on how tasks and services are distributed:

a. Two-Tier Architecture

- **In a two-tier architecture, the client directly interacts with the server.**
- **The client handles presentation (e.g., UI), while the server manages data and business logic.**
- **Example: A database system where the client sends SQL queries directly to the database server.**

b. Three-Tier Architecture

- **In a three-tier model, the application is divided into three layers:**
    - **Client Layer: The user interface and presentation logic.**
    - **Application Server Layer: The business logic and processing.**
    - **Database Layer: Manages and stores the data.**

- **This architecture is common in web applications, where the client (browser) interacts with an application server that processes business logic and communicates with the database.**

c. N-Tier Architecture

- **An extension of the three-tier model, with more layers to handle specialized services such as caching, load balancing, security, etc.**
- **This architecture is used in large, scalable enterprise systems and cloud environments.**

6. Communication in Client-Server Model

Client-server communication can occur using different protocols and data formats:

- **HTTP/HTTPS: Commonly used in web-based applications, where the client (browser) communicates with a web server.**
- **TCP/IP: Transport protocol used for reliable, connection-oriented communication between clients and servers.**
- **WebSockets: Enables real-time, two-way communication between clients and servers over a single TCP connection, often used in chat applications or live notifications.**
- **RPC (Remote Procedure Call): Allows a client to execute code on the server as if it were local.**

7. Advantages of the Client-Server Model

- **Centralized Management: Servers provide centralized control, which simplifies management, updates, and security.**
- **Scalability: Servers can handle multiple clients and be scaled vertically (more power) or horizontally (more servers) to meet demand.**
- **Resource Sharing: Clients can access shared resources like files, databases, and services located on the server, reducing redundancy.**
- **Data Integrity: Since the server is a central point, it ensures consistency in data management and integrity.**

8. Disadvantages of the Client-Server Model

- **Single Point of Failure: If the server goes down, all clients lose access to services or data, leading to system downtime.**
- **Performance Bottleneck: If the server is overwhelmed by too many requests, performance may degrade, causing delays for clients.**

- **Cost: Setting up and maintaining dedicated servers and infrastructure can be expensive.**
- **Network Dependency: The model is highly dependent on the network connection between clients and the server. If the network fails or is slow, the client-server interaction suffers.**

9. Client-Server Model in Real-Life Applications

The client-server model is used in a wide variety of applications:

- **Web Browsing: The browser (client) sends an HTTP request to the web server, which returns the requested webpage.**
- **Email: Email clients like Microsoft Outlook or Gmail request messages from an email server (SMTP/IMAP/POP3).**
- **Online Gaming: The game client connects to a central server that manages the game world, players, and actions.**
- **Banking Systems: Banking clients connect to a central server to retrieve account information, make transactions, and perform other banking services.**

10. Security in Client-Server Model

Security is crucial in client-server communication since sensitive data and services are accessed over networks. Some common security measures include:

- **Authentication: Ensures that only authorized clients can access the server's resources (e.g., user login, API tokens).**
- **Encryption: Encrypts the data exchanged between the client and server to prevent eavesdropping or data breaches (e.g., SSL/TLS for HTTPS).**
- **Firewall: Protects servers from unauthorized access or malicious traffic by controlling the flow of data.**
- **Access Control: Servers can enforce access control policies to limit which clients can access specific resources.**

Remote Procedure Call (RPC)

Introduction:

A Remote Procedure Call (RPC) is a communication mechanism used in distributed systems to enable a program to invoke a procedure (or function) on a remote server as if it were a local function call. The complexity of network communication, data serialization, and response handling is abstracted, allowing the developer to work with familiar function call semantics.

Basic Working of RPC

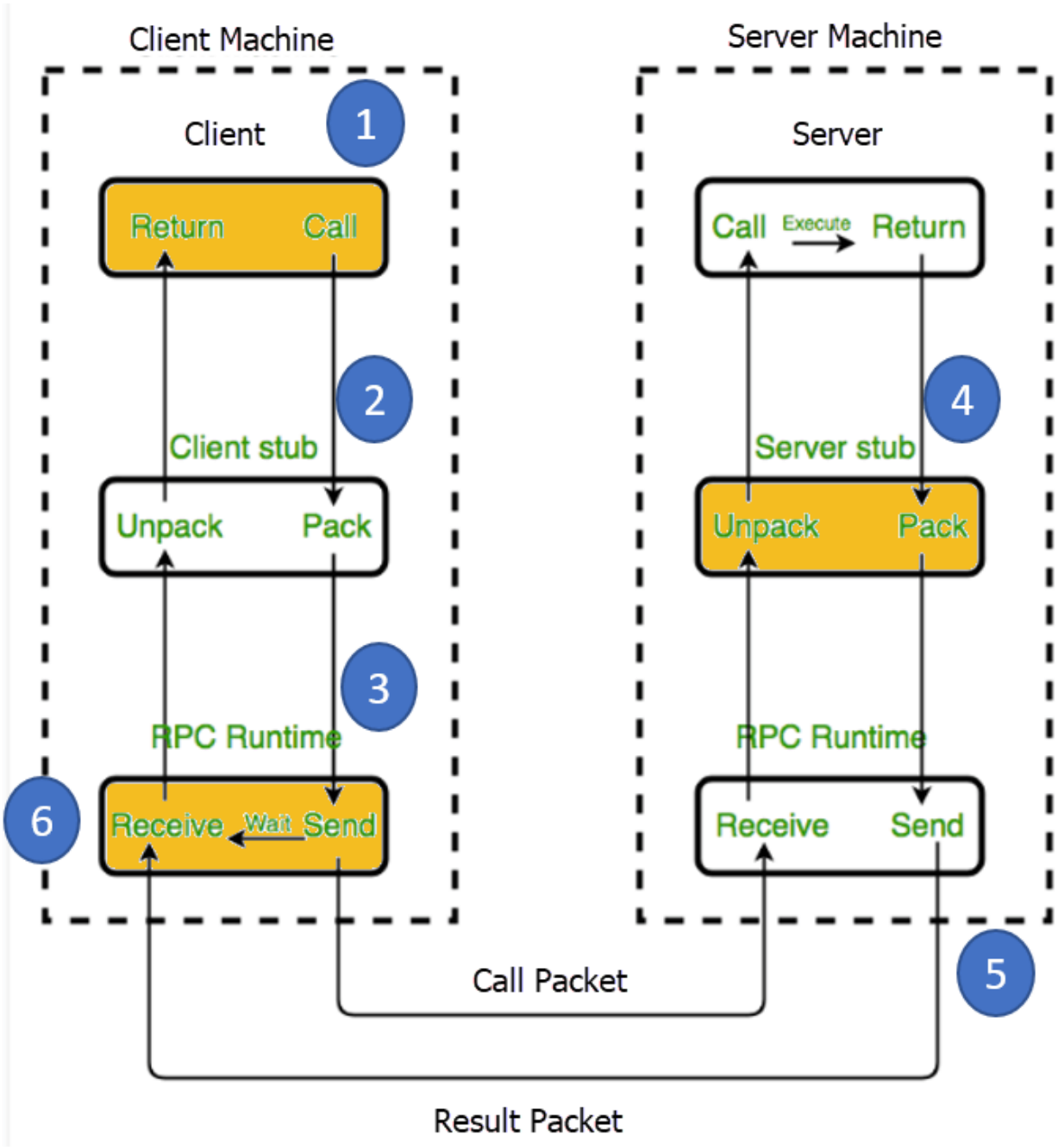
In a typical RPC interaction:

1. **The client makes a procedure call.**
2. **The RPC client stub packages the request into a message (serialization) and sends it to the remote server.**
3. **The server receives the request, deserializes it, and invokes the corresponding function.**
4. **After executing the function, the server serializes the result and sends it back to the client.**
5. **The client stub deserializes the response and returns the result to the client application.**

Components of RPC

- **Client: The program or process that requests a remote service.**
- **Server: The program or process that provides the requested service.**
- **Client Stub: A local proxy for the remote procedure on the client side. It handles parameter serialization and communication.**
- **Server Stub: A proxy on the server side that deserializes requests and forwards them to the actual procedure.**

RPC Architecture



RPC can be viewed as consisting of the following layers:

- **Application Layer: Where the client and server applications reside.**
- **RPC Layer: Contains client and server stubs to handle serialization (marshaling/unmarshaling) and communication.**
- **Transport Layer: Manages the actual message exchange over the network (e.g., via TCP or UDP).**

Synchronous vs Asynchronous RPC

- **Synchronous RPC: The client waits for the server to complete the procedure and return the result before continuing.**
- **Asynchronous RPC: The client sends a request and continues its execution. The result is processed later, when available.**

Advantages of RPC

- **Simplifies communication: Abstracts the details of network communication, providing a simple function-call interface.**
- **Location transparency: Clients don't need to know the physical location of the server; they only need the server's identifier or address.**
- **Language-neutral: RPC systems can be designed to work across different programming languages by using compatible data serialization formats (e.g., JSON, XML).**

Disadvantages of RPC

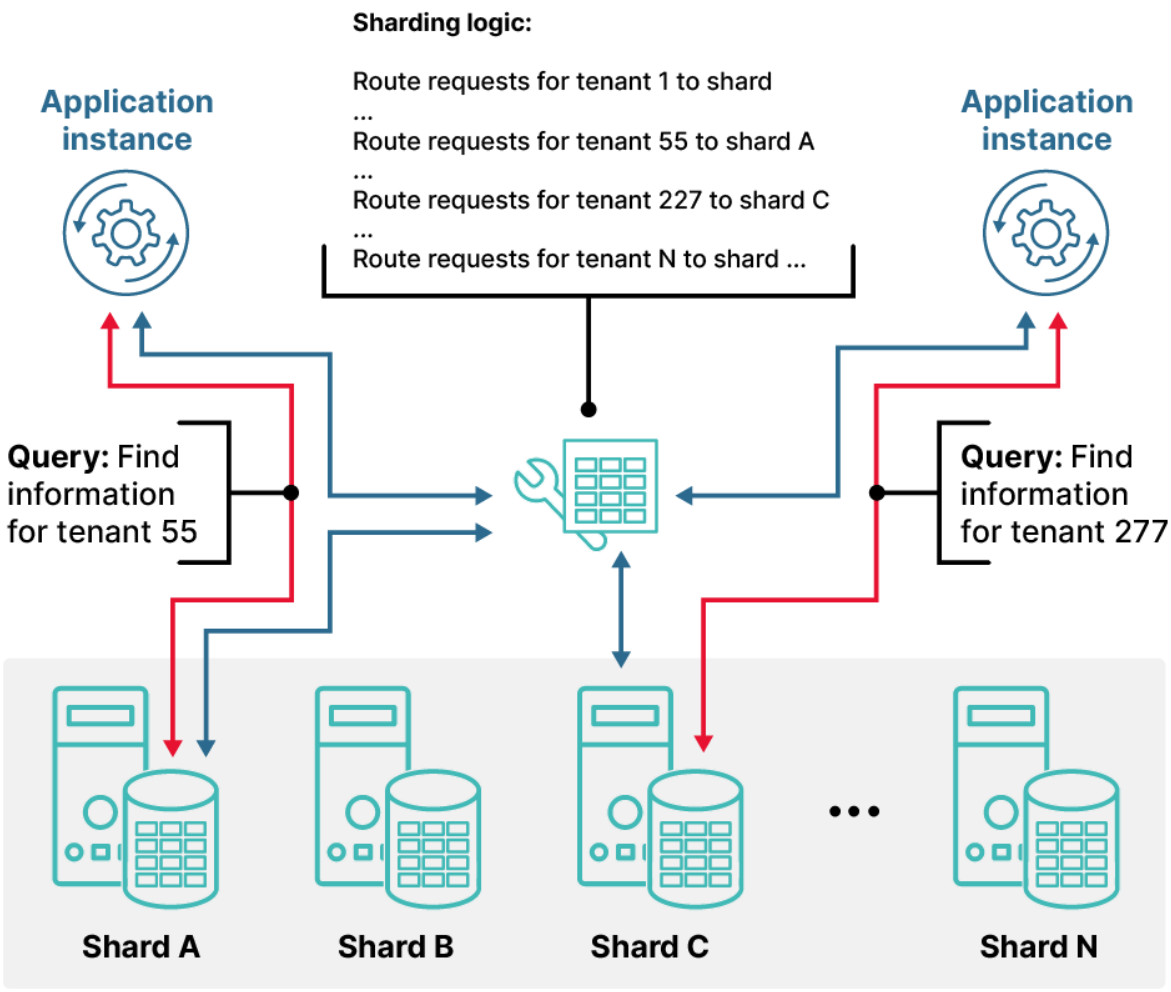
- **Network dependency: Since RPC relies on the network, latency or network failures can lead to delays or errors.**
- **State management: Maintaining state between multiple RPC calls can be complex in stateless environments.**
- **Overhead: Serialization and deserialization (marshaling and unmarshaling) add performance overhead.**

Group Communication

Introduction

Group Communication in distributed systems refers to the process of communicating with multiple recipients simultaneously. It is essential for systems where multiple processes, nodes, or users need to coordinate, share data, or achieve consensus.

Basic Concepts in Group Communication



- **Group: A collection of processes or nodes that can communicate with each other. Group communication mechanisms allow messages to be sent to all members of the group simultaneously.**
- **Multicast/Broadcast: The message is sent to all members (broadcast) or a subset (multicast) of the group.**

Types of Group Communication

- **Unicast: Communication between a single sender and a single receiver.**
- **Broadcast: Communication where a message is sent from a single sender to all members of the group.**
- **Multicast: Communication where a message is sent from one sender to a specific subset of the group.**

Key Properties in Group Communication

- **Atomicity: Either all recipients in the group receive the message, or none do. This is crucial for maintaining consistency in distributed systems.**
- **Ordering: The order of messages is important in many applications. There are different types of message ordering:**
    - **FIFO Ordering: Messages from the same sender are delivered in the order they were sent.**
    - **Causal Ordering: Messages are delivered in the causal order (i.e., if message A causes message B, A should be delivered before B).**
    - **Total Ordering: All messages are delivered in the same order to all group members, regardless of sender.**

Types of Group Membership

- **Open Group: Any process can join or leave the group freely.**
- **Closed Group: Only authorized processes can join the group.**

Reliable Group Communication

Reliability is crucial in group communication systems. Some common guarantees include:

- **Reliable delivery: Ensures that if a message is sent, it is eventually received by all non-failing members of the group.**
- **Failure detection: Mechanisms to detect failed members and adjust group membership accordingly.**
- **Acknowledgment-based: In some group communication protocols, each member acknowledges receipt of a message to the sender.**

Multicast Protocols

- **IP Multicast: A protocol that allows efficient distribution of messages to multiple receivers in a local or wide-area network.**
- **Application-level Multicast: Implemented at the application layer, often used when IP Multicast is not feasible (e.g., peer-to-peer networks).**

Advantages of Group Communication

- **Efficiency: Group communication allows simultaneous data transmission to multiple nodes, reducing network overhead.**

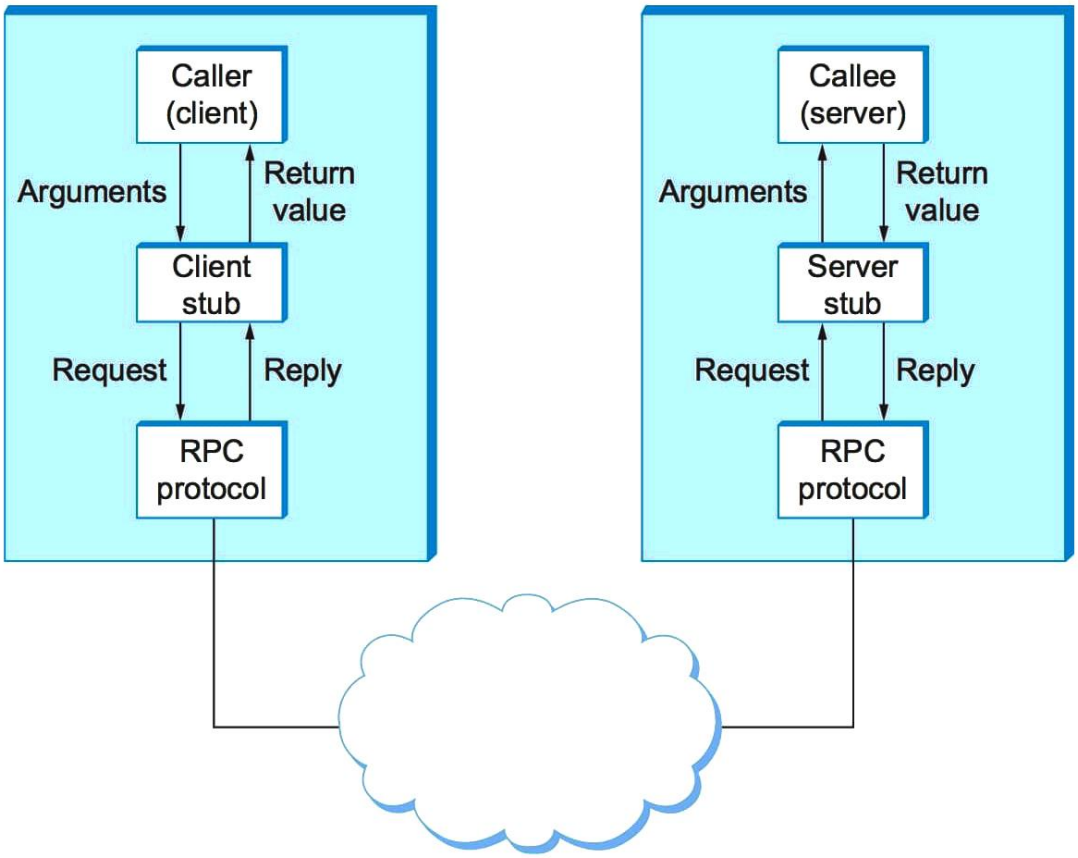
- **Consistency: Enables distributed systems to achieve consistency, as all members receive the same data simultaneously.**
- **Coordination: Facilitates coordination among distributed processes, such as in distributed databases, replication, or collaborative applications.**

Disadvantages of Group Communication

- **Complexity: Managing membership, reliability, and ordering in group communication can be complex.**
- **Scalability: Large groups can generate a lot of network traffic and require efficient protocols to avoid performance degradation.**

Use Cases of RPC and Group Communication

RPC Use Cases:



Remote Procedure Call (RPC)

- **Client-server communication: RPC is commonly used in client-server applications where the client requests services or data from a remote server.**
- **Microservices architecture: RPC enables communication between services in a distributed microservices architecture.**

Group Communication Use Cases:

- **Distributed Databases: Group communication ensures data consistency by broadcasting changes to all replicas.**
- **Collaborative Systems: Real-time collaboration tools (e.g., Google Docs) rely on group communication to synchronize data across multiple users.**
- **Fault-tolerant systems: Systems that replicate data across multiple nodes for fault tolerance use group communication to propagate changes and ensure consistency.**