22AIE305

# 22AIE305: CLOUD COMPUTING

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# “Cloud” refers to the Internet

**Cloud**

The “Cloud” is the default symbol of the Internet in diagrams.

**Computing**

The broader term of “Computing” encompasses:
- Computation
- Coordination logic
- Storage

**Cloud Computing is about moving computing from the single desktop PC/Laptop/data centers to commercial service providers on the Internet.**

# Evolution of Computing

- Classical Computing
  - Buy, Own & Operate
    - Hardware,
    - System Software,
    - Applications often to meet peak needs.
  - Install, Configure, Test, Verify
  - Manage locally, troubleshoot
  - ..
  - Finally, use it
  - $$$$....$(High CapEx)

- Cloud Computing
  - Subscribe
  - Use when needed
  - Forget about centralized computing problems
  - $ - pay for what you use, based on QoS

# Cloud Computing

Cloud computing is the delivery of different services through the Internet.

These resources include tools and applications like data storage, servers, databases, networking, and software.

Information is found remotely in the cloud or on a virtual space. Companies that provide cloud services enable users to store files and applications on remote servers and then access all data via the Internet.

This means the user is not required to be in a specific place to gain access to it, allowing the user to work remotely.

# Types of Cloud Services

- Email
- Storage, backup, and data retrieval
- Creating and testing distributed apps
- Shared data analytics
- Audio and video streaming
- Delivering on-demand software and services
- Multi-person online games

# Cloud Applications

- **Scientific/Tech Applications**
- **Business Applications**
- **Customer/Social Applications**

***Science and Technical Applications***


***Business Applications***


***Customer/Social Applications***

# Characteristics of Cloud computing

- On-demand usage/flexibility: These can be used almost instantly and can easily be scaled up and down.
- External data storage: A customer's data is usually stored externally at the location of the cloud computing vendor.
- Multi-tenancy: It resources are shared between different users and customers.
- Rented service delivery model: Customers pay for the service instead of buying software licenses and hardware.

# Advantages of cloud computing

1. Security: A cloud host's full-time job is to carefully monitor security from external and as well as internal threats to data, which is significantly more efficient than a conventional in-house system.
   RapidScale claims that 94% of businesses saw an improvement in security after switching to the cloud, and 91% said the cloud makes it easier to meet government compliance requirements. Dell reports that companies that invest in big data, cloud mobility, and security enjoy up to 53% faster revenue growth than their competitors.
2. Cost Savings: It eliminates the capital expenditure by allowing the customers to move from CAPEX to OPEX.

# Advantages of cloud computing

3. Flexibility: A cloud-based service can meet that demand instantly, rather than undergoing a complex (and expensive) update to your IT infrastructure. This improved freedom and flexibility can make a significant difference to the overall efficiency of your organization.

4. Reliability: Cloud systems are more reliable as they take care of disaster recovery, business continuity and data backups, etc.

# Advantages of cloud computing

5. Mobility: Cloud computing allows mobile access to corporate data via smartphones and devices.
Through the cloud, information is accessible to sales staff who travel, freelance employees, or remote employees, for better work-life balance, and also in case of emergencies like lockdown due to emergency (CORONA). Therefore, it's not surprising to see that organizations with employee satisfaction listed as a priority are up to 24% more likely to expand cloud usage.

6. Performance: All latest resources are made available that drastically improve the performance and also take care of obsolescence.

# Advantages of cloud computing

7. Quality Control: All documents are stored in one place and in a single format. With everyone accessing the same information, you can maintain consistency in data, avoid human error, and have a clear record of any revisions or updates.

8. Disaster Recovery: Cloud-based services provide quick data recovery for all kinds of emergency scenarios, from natural disasters to power outages. While 20% of cloud users claim disaster recovery in four hours or less, only 9% of non-cloud users could claim the same. In a recent survey, 43% of IT executives said they plan to invest in or improve cloud-based disaster recovery solutions.

# What is Mobile Cloud Computing?

*Mobile cloud computing (MCC)* refers to an infrastructure where both the data storage and data processing happen outside of the mobile device.

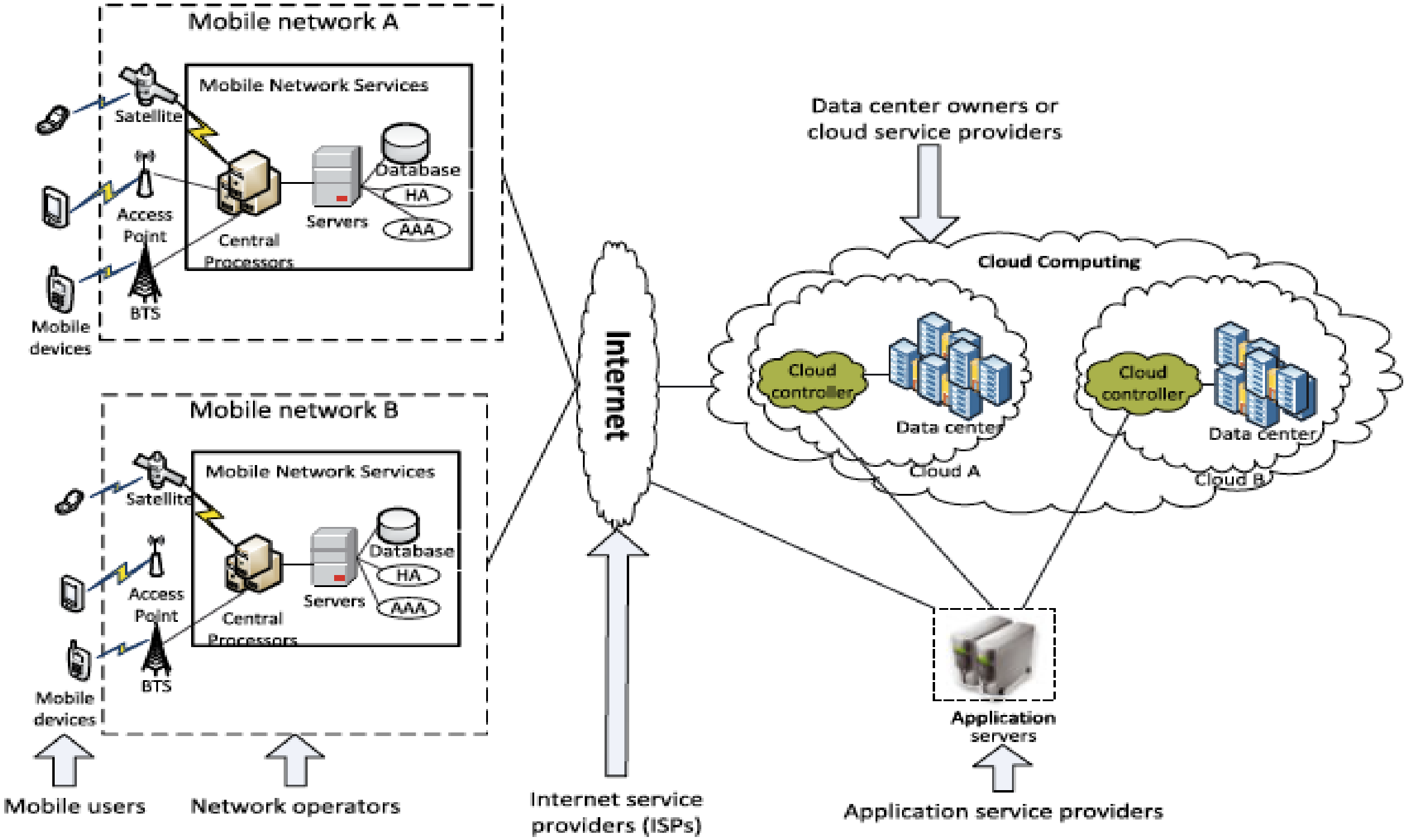
Mobile cloud applications move the computing power and data storage away from the mobile devices and into powerful and centralized computing platforms located in clouds, which are then accessed over the wireless connection based on a thin native client.

# Why Mobile Cloud Computing?

- Mobile devices face many resource challenges (battery life, storage, bandwidth, signal strength, etc.)
- Cloud computing offers advantages to users by allowing them to use infrastructure, platforms and software by cloud providers at low cost and in an on-demand fashion.
- Mobile cloud computing provides mobile users with data storage and processing services in clouds, obviating the need to have a powerful device configuration (e.g. CPU speed, memory capacity etc), as all resource-intensive computing can be performed in the cloud.

# MCC Popularity

- According to a recent study by ABI Research, more than 980 million businesses will use cloud services through mobile devices by 2025.
- That traction will push the revenue of mobile cloud computing to $25.2 billion.
- Mobile cloud computing is a highly promising trend for the future of mobile computing.


Mobile network A
Mobile Network Services
Satellite
Access Point
Central Processors
Servers
Database
HA
AAA
BTS
Mobile devices
Mobile network B
Mobile Network Services
Satellite
Access Point
Central Processors
Servers
Database
HA
AAA
BTS
Mobile devices
Internet
Data center owners or cloud service providers
Cloud Computing
Cloud controller
Data center
Cloud A
Cloud controller
Data center
Cloud B
Application servers
Mobile users
Network operators
Internet service providers (ISPs)
Application service providers

# MCC Architecture

- Mobile devices are connected to the mobile networks via base stations that establish and control the connections and functional interfaces between the networks and mobile devices.
- Mobile users' requests and information are transmitted to the central processors that are connected to servers providing mobile network services.
- The subscribers' requests are delivered to a cloud through the Internet.
- In the cloud, cloud controllers process the requests to provide mobile users with the corresponding cloud services.

# Advantages of MCC

- Extending battery lifetime:
  - Computation offloading migrates large computations and complex processing from resource-limited devices (i.e., mobile devices) to resourceful machines (i.e., servers in clouds).
  - Remote application execution can save energy significantly.
  - Many mobile applications take advantages from task migration and remote processing.

# Advantages of MCC

- Improving data storage capacity and processing power:
  - MCC enables mobile users to store/access large data on the cloud.
  - MCC helps reduce the running cost for computation intensive applications.
  - Mobile applications are not constrained by storage capacity on the devices because their data now is stored on the cloud.

# Advantages of MCC

- Improving reliability and availability:
  - Keeping data and application in the clouds reduces the chance of lost on the mobile devices.
  - MCC can be designed as a comprehensive data security model for both service providers and users:
    - Protect copyrighted digital contents in clouds.
    - Provide security services such as virus scanning, malicious code detection, authentication for mobile users.
  - With data and services in the clouds, then are always(almost) available even when the users are moving.

# Advantages of MCC

- Dynamic provisioning:
  - Dynamic on-demand provisioning of resources on a fine-grained, self-service basis
  - No need for advanced reservation
- Scalability:
  - Mobile applications can be performed and scaled to meet the unpredictable user demands
  - Service providers can easily add and expand a service

# Advantages of MCC

- Multi-tenancy:
  - Service providers can share the resources and costs to support a variety of applications and large no. of users.

- Ease of Integration:
  - Multiple services from different providers can be integrated easily through the cloud and the Internet to meet the users' demands.

# MCC Applications

- Mobile Commerce:
  - M-commerce allows business models for commerce using mobile devices.
  - Examples: Mobile financial, mobile advertising, mobile shopping…
  - M-commerce applications face various challenges (low bandwidth, high complexity of devices, security, …)
  - Integrated with cloud can help address these issues
  - Example: Combining 3G and cloud to increase data processing speed and security level.

# MCC Applications

- Mobile Learning:
  - M-learning combines e-learning and mobility
  - Traditional m-learning has limitations on high cost of devices/network, low transmission rate, limited educational resources
  - Cloud-based m-learning can solve these limitations
  - Enhanced communication quality between students and teachers
  - Help learners access remote learning resources
  - A natural environment for collaborative learning

# MCC Applications

- Mobile Healthcare:
  - M-healthcare is to minimize the limitations of traditional medical treatment (eg. Small storage, security/privacy, medical errors, …)
  - M-healthcare provides mobile users with convenient access to resources(eg. medical records)
  - M-healthcare offers hospitals and healthcare organizations a variety of on-demand services on clouds
  - Examples:
    - Comprehensive health monitoring services
    - Intelligent emergency management system
    - Health-aware mobile devices (detect pulse-rate, blood pressure, level of alcohol etc)
    - Pervasive access to healthcare information
    - Pervasive lifestyle incentive management (to manage healthcare expenses)

# MCC Applications

- Mobile Gaming:
  - M-game is a high potential market generating revenues for service providers.
  - Can completely offload game engine requiring large computing resource (e.g., graphic rendering) to the server in the cloud.
  - Offloading can also save energy and increase game playing time (eg. MAUI allows fine-grained energy-aware offloading of mobile codes to a cloud)
  - Rendering adaptation technique can dynamically adjust the game rendering parameters based on communication constraints and gamers' demands

# MCC Applications

- Assistive technologies:
  - Pedestrian crossing guide for blind and visually-impaired
  - Mobile currency reader for blind and visually impaired
  - Lecture transcription for hearing impaired students
- Other applications:
  - Sharing photos/videos
  - Keyword-based, voice-based, tag-based searching
  - Monitoring a house, smart home systems
  - …

# MCC Issues

- Mobile communication issues:
  - Low bandwidth: One of the biggest issues, because the radio resource for wireless networks is much more scarce than wired networks
  - Service availability: Mobile users may not be able to connect to the cloud to obtain a service due to traffic congestion, network failures, mobile signal strength problems
  - Heterogeneity: Handling wireless connectivity with highly heterogeneous networks to satisfy MCC requirements (always-on connectivity, on-demand scalability, energy efficiency) is a difficult problem

# MCC Issues

- Computing issues:

  Computation offloading:

  - One of the main features of MCC
  - Offloading is not always effective in saving energy
  - It is critical to determine whether to offload and which portions of the service codes to offload
  - Two types:
    - Offloading in a static environment
    - Offloading in a dynamic environment

# MCC Security Issues

- Protecting user privacy and data/application secrecy from adversaries is key to establish and maintain consumers' trust in the mobile platform, especially in MCC.

- MCC security issues have two main categories:
  - Security for mobile users
  - Securing data on clouds

# Security for Mobile Users

- Mobile devices are exposed to numerous security threats like malicious codes and their vulnerability.
- GPS can cause privacy issues for subscribers.
- Security for mobile applications:
  - Installing and running security software are the simplest ways to detect security threats.
  - Mobile devices are resource constrained, protecting them from the threats is more difficult than that for resourceful devices.

# Mobile User Security Approaches

- Oberheide et al. present an approach to move the threat detection capabilities to clouds.
- An extension of the CloudAV platform consisting of host agent and network service components.
- Host agent runs on mobile devices to inspect the file activity on a system.
- If an identified file is not available in a cache of previous analyzed files, this file will be sent to the incloud network service for verification.
- The second major component of CloudAV is a network service that is responsible for file verification

J. Oberheide, K. Veeraraghavan, E. Cooke, J. Flinn, and F. Jahanian. “Virtualized in-cloud security services for mobile devices,” in Proc 1st Workshop on Virtualization in Mobile Computing (MobiVirt), pp. 31-35, June 2008.

# Mobile User Security Approaches

- Portokalidis et al. present a paradigm in which attack detection for a smartphone is performed on a remote server in the cloud.
- The smartphone records only a minimal execution trace, and transmits it to the security server in the cloud.

G. Portokalidis, P. Homburg, K. Anagnostakis, and H. Bos, “Paranoid Android: versatile protection for smartphones,” in Proc 26th Annual Computer Security Application Conference (ACSAC), pp. 347-356, September 2010.

# Privacy Issues in MCC

- Location based services (LBS) faces a privacy issue on mobile users' provide private information such as their current location.

- This problem becomes even worse if an adversary knows user's important information.

# Privacy Issues in MCC

- Zhangwei and Mingjun propose the location trusted server (LTS) approach.
- After receiving mobile users' requests, LTS gathers their location information and cloaks the information called "cloaked region" to conceal user's information.
- The "cloaked region" is sent to LBS, so LBS knows only general information about the users but cannot identify them.


- H. Zhangwei and X. Mingjun, "A Distributed Spatial Cloaking Protocol for Location Privacy," in Proc 2nd Intl Conf on Networks Security Wireless Communications and Trusted Computing (NSWCTC), vol. 2, pp. 468, June 2010.

# Context-aware Mobile Cloud Services

- It is important to fulfill mobile users' satisfaction by monitoring their preferences and providing appropriate services to each of the users.

- Context-aware mobile cloud services try to utilize the local contexts (e.g., data types, network status, device environments, and user preferences) to improve the quality of service (QoS).

# Mobile Service Clouds

- Samimi et al. build the Mobile Service Cloud model.
- When a customer uses a service, the request firstly goes to a service gateway which will choose an appropriate primary proxy to meet the requirements and then sends the result to the user.
- In disconnection, MSCs will establish transient proxies for mobile devices to monitor the service path, and support dynamic reconfiguration.
- The model addresses the disconnection issue and can maintain the QoS at an acceptable level.

F. A. Samimi, P. K. Mckinley, and S. M. Sadjadi, “Mobile Service Clouds: A Self-Managing Infrastructure for Autonomic Mobile Computing Services,” in Proceedings of the 2nd International Workshop on Self-Managed Networks, Systems & Services (SelfMan), vol. 3996, pp. 130-141, 2006.

# Context-aware Mobile Cloud Services

- La and Kim propose an algorithm to choose a context-aware adapter.
- The algorithm first determines the gaps occurring in the given contexts. A gap is defined as a result of context changes.
- Then, the algorithm determines a cause of predefined gaps before saving the current states of the service invocation for disconnection.
- For each identified gap, this algorithm will choose an appropriate adapter for the mobile user.

H. H. La and S. D. Kim, “A Conceptual Framework for Provisioning Context-aware Mobile Cloud Services,” in Proceedings of the 3rd IEEE International Conference on Cloud Computing (CLOUD), pp. 466, August 2010.

# Open Issues in MCC

- Network Access Management:
  - An efficient network access management not only improves link performance but also optimizes bandwidth usage.
  - Cognitive radio can be expected as a solution to achieve the wireless access management.
  - Can automatically changes its transmission or reception parameters, in a way where the wireless communications can have spectrum agility in terms of selecting available wireless channels opportunistically.
  - Integrated with MCC for better spectrum utilization

# Open Issues in MCC

- Quality of Service:
  - How to ensure QoS is still a big issue, especially on network delay.
  - CloneCloud and Cloudlets are expected to reduce the network delay.
  - CloneCloud uses nearby computers or data centers to increase the speed of smart phone applications.
  - The idea is to clone the entire set of data and applications from the smartphone onto the cloud and to selectively execute some operations on the clones, reintegrating the results back into the smartphone.

# Open Issues in MCC

- Quality of Service:
  - A cloudlet is a trusted, resource-rich computer or cluster of computers which is well-connected to the Internet and available for use by nearby mobile devices with on one-hop wireless connection.
  - Mobile users may meet the demand for real-time interactive response by low-latency, one-hop, high-bandwidth wireless access to the cloudlet.
  - Can help mobile users overcome the limits of cloud computing as WAN latency and low bandwidth.

# Open Issues in MCC

- Pricing:
  - MCC involves with both mobile service provider (MSP) and cloud service provider (CSP) with different services management, customers management, methods of payment and prices.
  - This will lead to many issues.
  - The business model including pricing and revenue sharing has to be carefully developed for MCC.

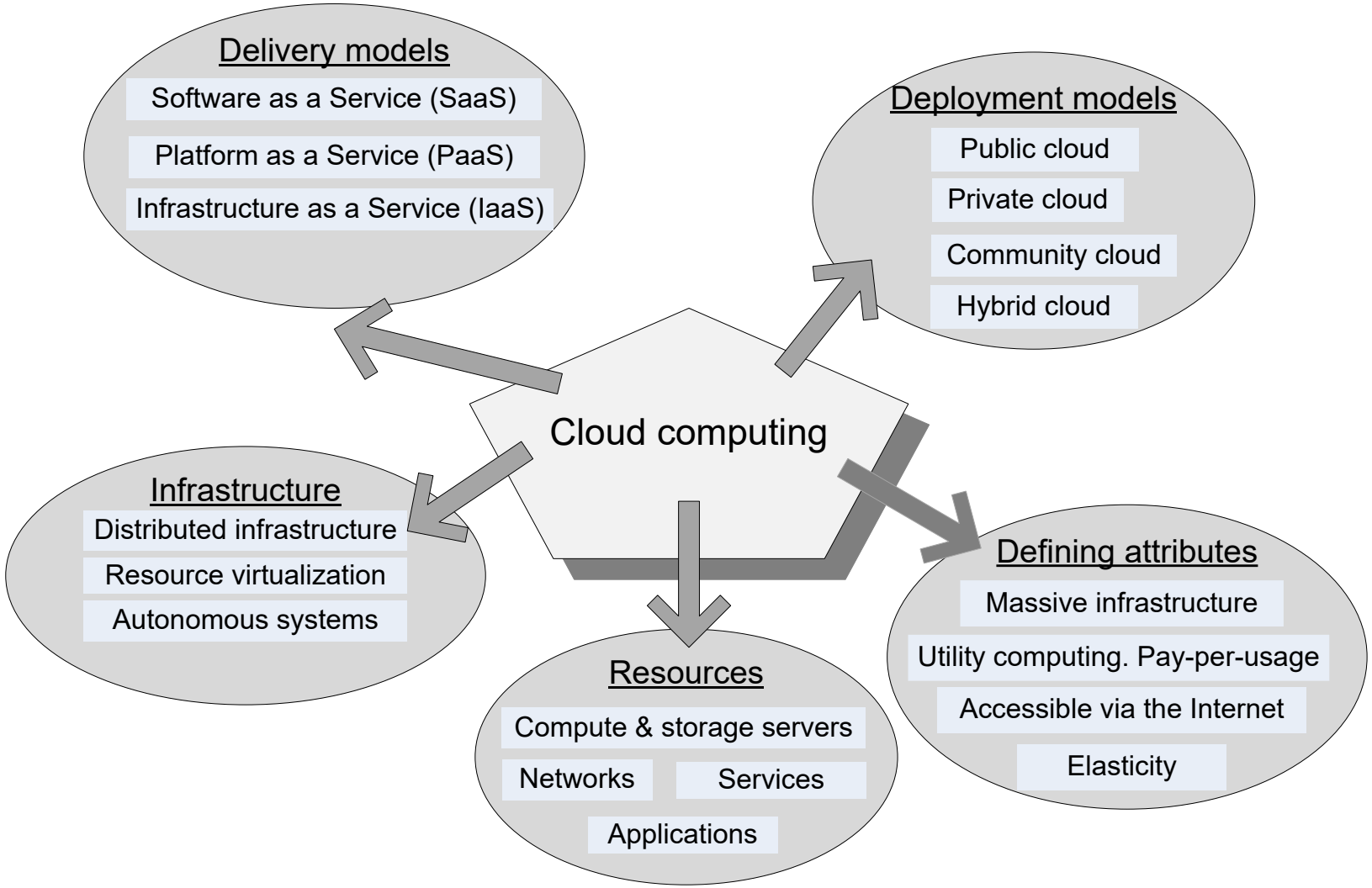
# Open Issues in MCC

- Standard Interface:
  - Interoperability becomes an important issue when mobile users need to interact with the cloud.
  - Web interfaces may not be the best option.
  - It is not specifically designed for mobile devices.
  - May have more overhead.
  - Compatibility among devices for web interface could be an issue.
  - Standard protocol, signaling, and interface for interacting between mobile users and cloud would be required. (HTML5 & CSS3)

# Open Issues in MCC

- Service Convergence:
  - Services will be differentiated according to the types, cost, availability and quality.
  - A single cloud may not be enough to meet mobile user's demands.
  - New scheme is needed in which the mobile users can utilize multiple cloud in a unified fashion.
  - The scheme should be able to automatically discover and compose services for user.
  - Sky computing is a model where resources from multiple clouds providers are leveraged to create a large scale distributed infrastructure.
  - The mobile sky computing will enable providers to support a cross-cloud communication and enable users to implement mobile services and applications.
  - Service integration (i.e., convergence) would need to be explored.

# Cloud Computing Models, Resources, Attributes



# Paradigms for Distributed Applications

- Paradigm means "a pattern, example, or model." In the study of any subject of great complexity, it is useful to identify the basic patterns or models, and classify the detail according to these models. This chapter aims to present a classification of the paradigms for distributed applications.
- Characteristics that distinguish distributed applications from conventional applications which run on a single machine. These characteristics are:
  - ***Interprocess communication***: **A distributed application require the participation of two or more independent entities (processes). To do so, the processes must have the ability to exchange data among themselves.**
  - ***Event synchronization***: **In a distributed application, the sending and receiving of data among the participants of a distributed application must be synchronized.**

# The Peer-to-Peer System Architecture

- In system architecture and networks, **peer-to-peer** is an architecture where computer **resources** and **services** are direct exchanged between computer systems. Each computer has equivalent **capabilities** and **responsibilities**.
- These **resources** and **services** include the exchange of information, processing cycles, cache storage, and disk storage for files.
- In such an architecture, computers, which have traditionally been used solely as clients, **communicate directly** among themselves and can act as both clients and servers, assuming whatever role is most efficient for the network.

# P2P

- “Peer-to-peer (P2P) computing or networking is a distributed application architecture that partitions tasks or workloads between peers.”
- “Peers are equally privileged, equipotent participants in the application. They are said to form a peer-to-peer network of nodes.”

# Client and Server in P2P

In computer science, a client is a computer program that sends a request to another program to perform its actions. The server is a program that receives requests from clients and processes them. By processing the client's request, the client can subsequently execute its actions.

- In a peer-to-peer system, every computer in the network is both client and server. Each computer may send requests or respond to requests and process them.
- In other words, in a P2P system, there is no central server.

# Advantages of P2P

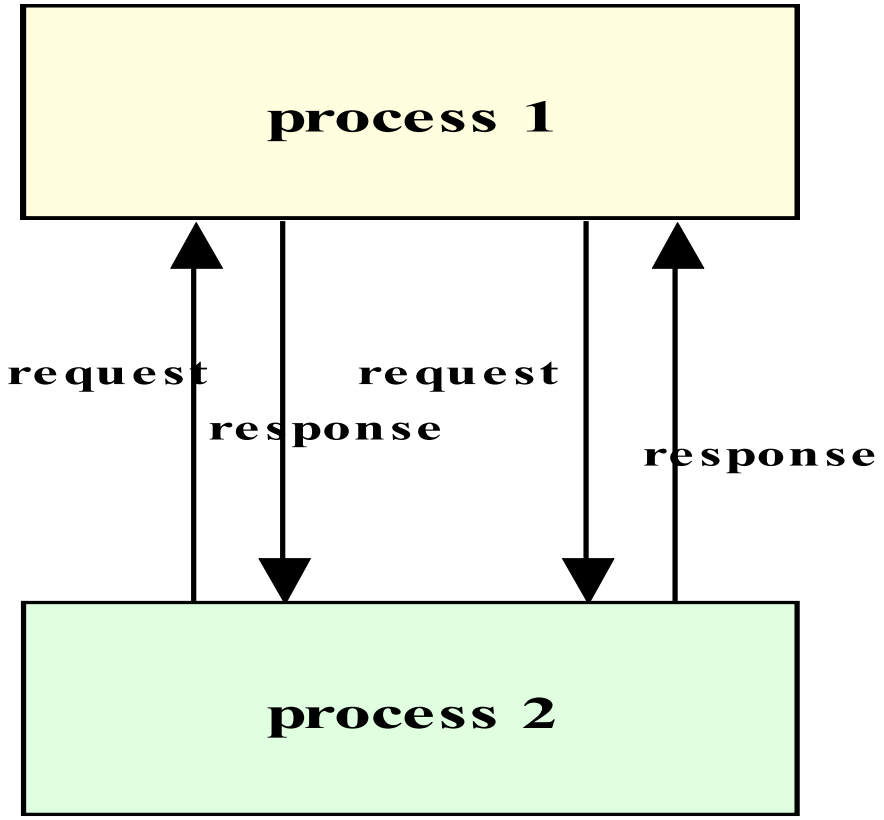
- Easy to set-up
- No need for dedicated server
- Less expensive
- Time saving:  less time in the configuration and implementation of P2P.
- Any computer on the network can function as both a network server and a user workstation

# Disadvantages of P2P

- Network security
- Computers connected on a P2P can be accessed anytime by any member
- No centralized server to manage and control the network.
- Each computer needs to be backed up separately.

# The Peer-to-Peer Distributed Computing

In the peer-to-peer paradigm, the participating processes play equal roles, with equivalent **capabilities** and **responsibilities** (hence the term “peer”). Each participant may **issue** a request to another participant and **receive** a response.



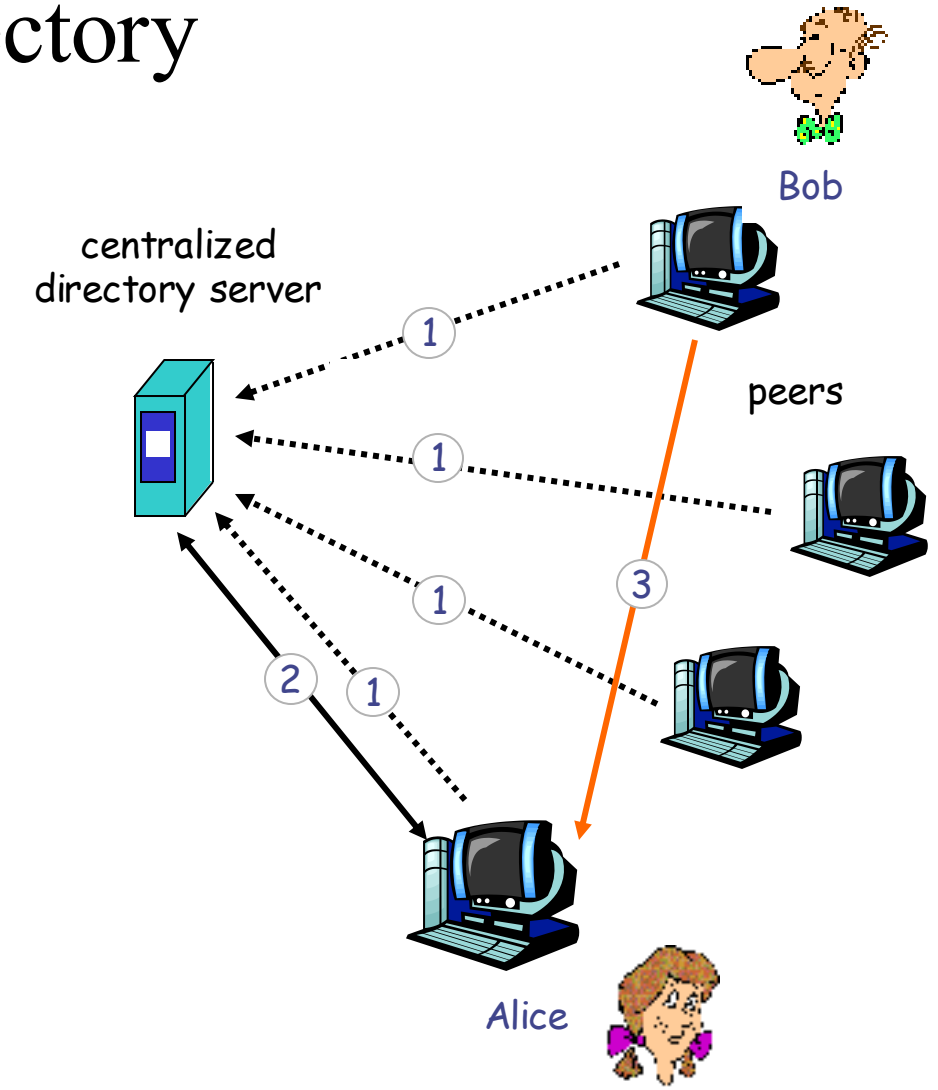
# Peer-to-Peer Distributed Computing

- Whereas the **client-server** paradigm is an ideal model for a centralized network service, the **peer-to-peer** paradigm is more appropriate for applications such as instant messaging, peer-to-peer file transfers, video conferencing, and collaborative work.
- It is possible for an application to be based on **both** the **client-server** model and the **peer-to-peer** model (e.g., Instance Messaging--**sametime**).
- A well-known example of a peer-to-peer file transfer service is ***Napster.com*** or similar sites which allow files (primarily audio files) to be transmitted among computers on the Internet. It makes use of a server for directory in addition to the peer-to-peer computing.

# P2P: centralized directory

original "Napster" design

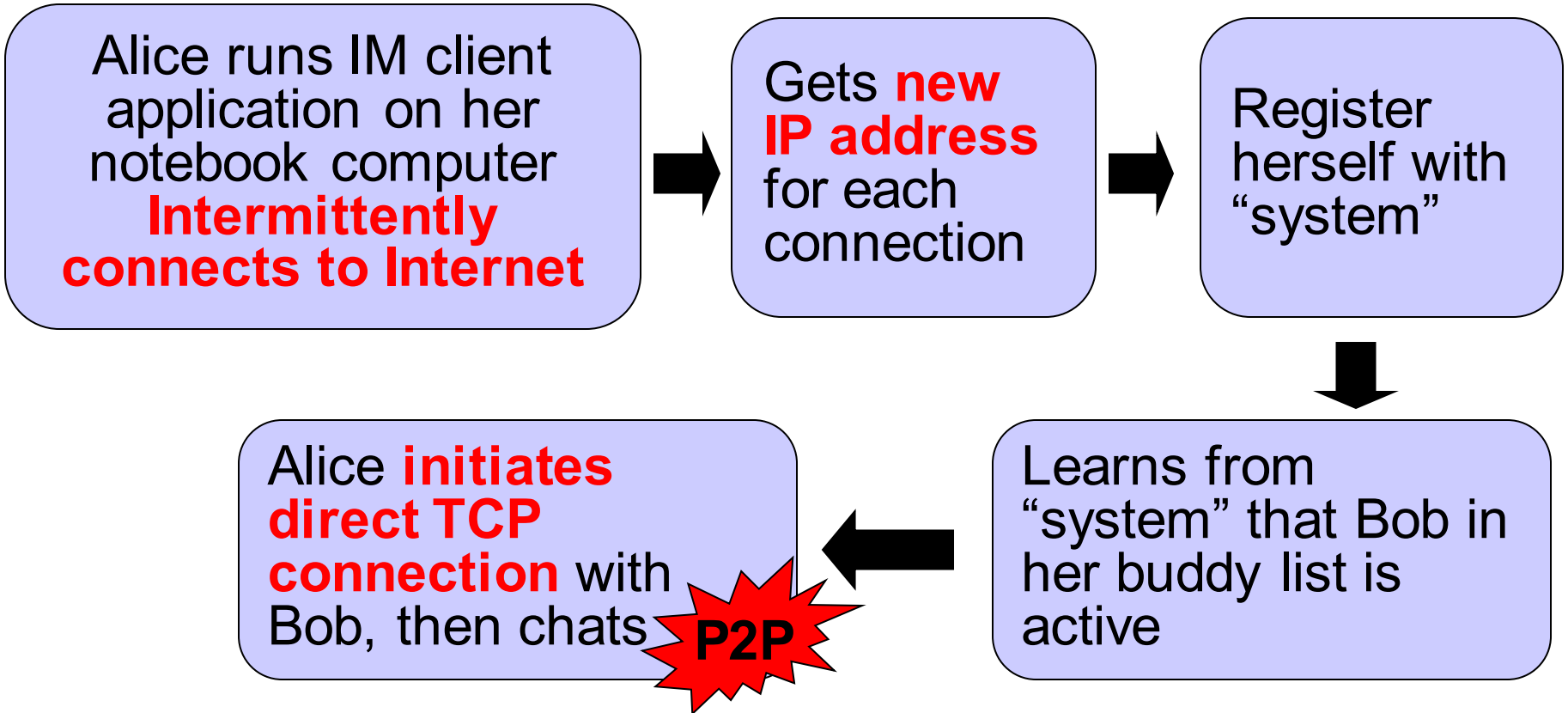
1) when peer connects, it informs central server:
   - IP address
   - contents
2) Alice queries for "Hey Jude"
3) Alice requests file from Bob




**Ref**: Computer Networking, Jim F. Kurose and Keith W. Ross

# P2P Communication

- Instant Messaging
- **Skype** is a VoIP P2P system



# Promising properties of P2P

- Massive scalability
- Autonomy : non single point of failure
- Resilience to Denial of Service
- Load distribution
- Resistance to censorship

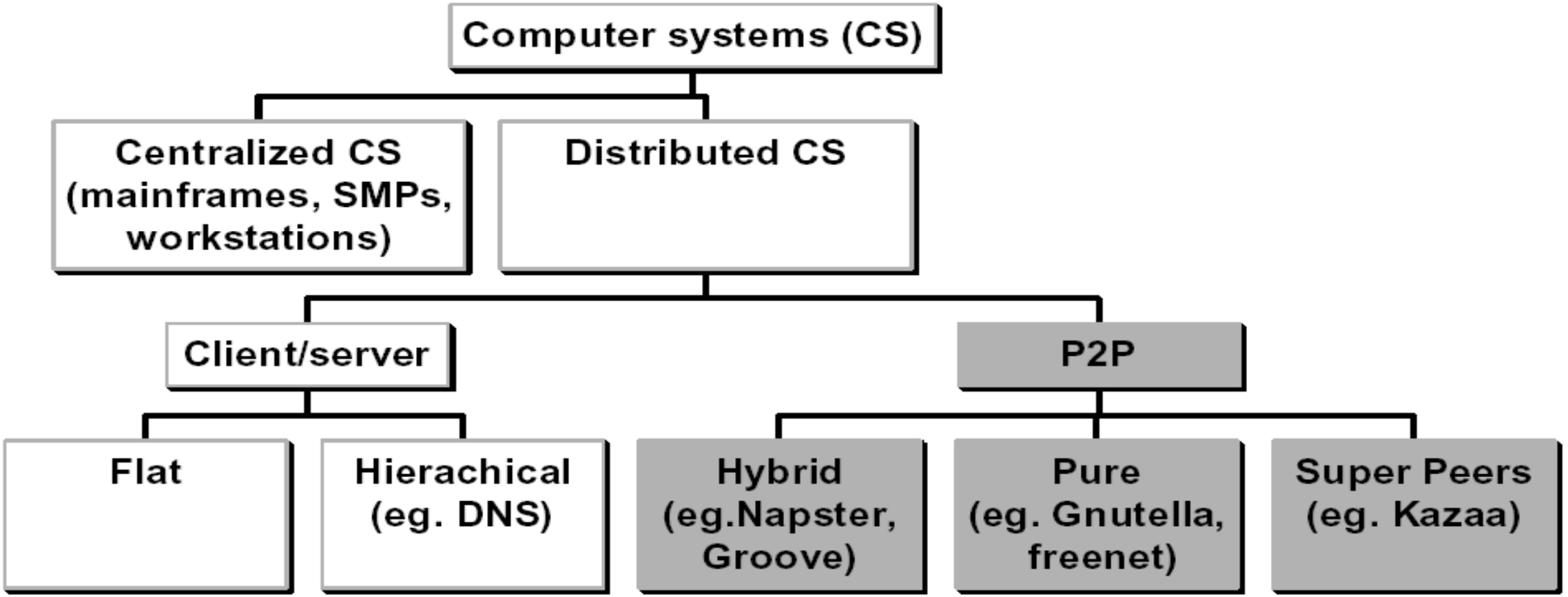
# P2P: problems with centralized directory

- Single point of failure
- Performance bottleneck
- Copyright infringement

File transfer is decentralized, but locating contents is highly centralized

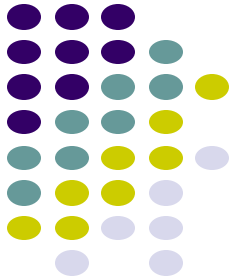
**Ref**: Computer Networking, Jim F. Kurose and Keith W. Ross

# Taxonomy of computer systems

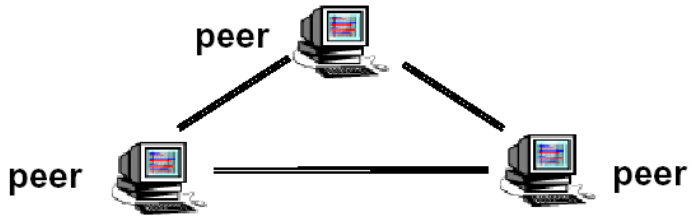


# General Models

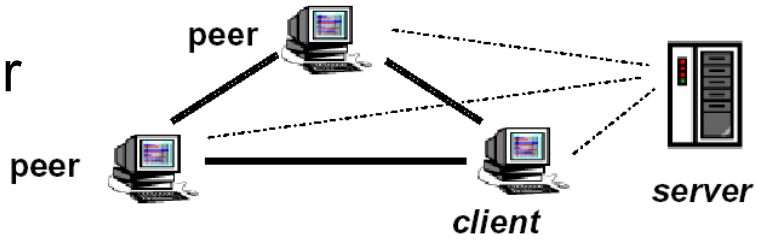
## : pure, hybrid, super-peers



- Pure: peers have same capability and responsibility.
  - symmetric communication. No host superior;
  - all hosts can act as client or server.
  - examples: Gnutella, Freenet



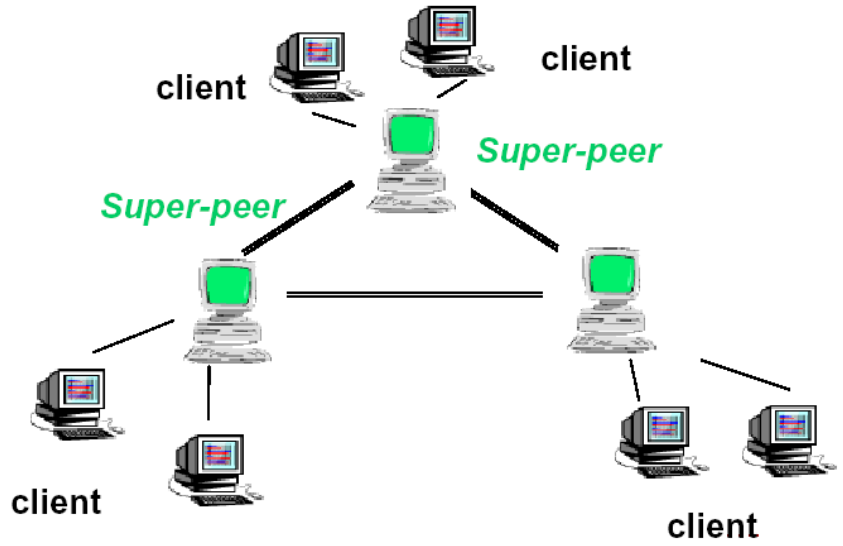

- Hybrid: servers facilitate the interaction between peers
  - addressing bypasses the DNS, but a central server as directory
  - examples: Napster, ICQ, Jabber



# P2P Models

## : pure, hybrid, super-peers

- Super-peers
  - A super-peer is a node in a peer-to-peer network that operates both as a server to a set of clients, and as an equal in a network of super-peers.
  - Super-peer networks try to balance the efficiency of centralized search, and the autonomy, load balancing and robustness to attacks provided by distributed search.
  - example: Kazaa



# The future of peer-to-peer

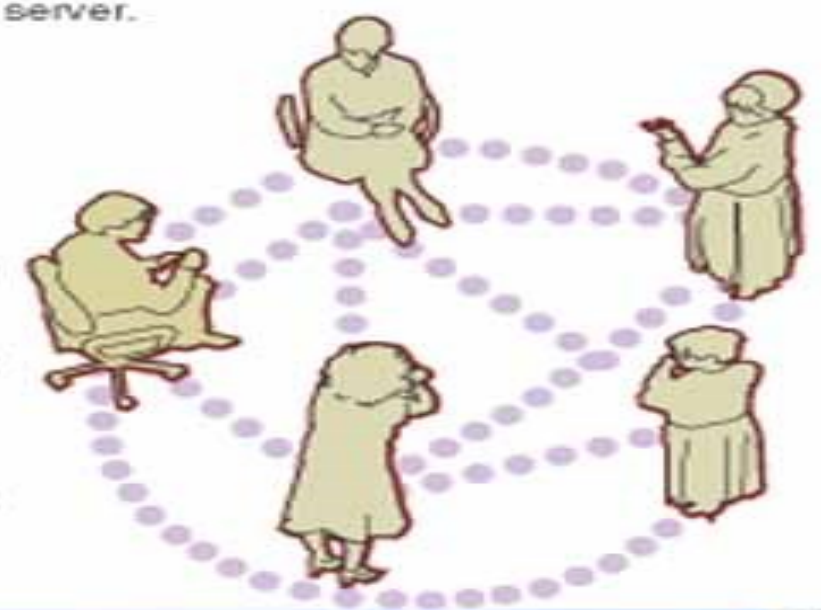
The file-swapping technology popularized by Napster, known as peer-to-peer networking, is about to change how people and corporations use the Internet. Instead of relying on central servers to process and relay information, new applications being developed will allow users to turn any computing device into a server.

## A virtual meeting room

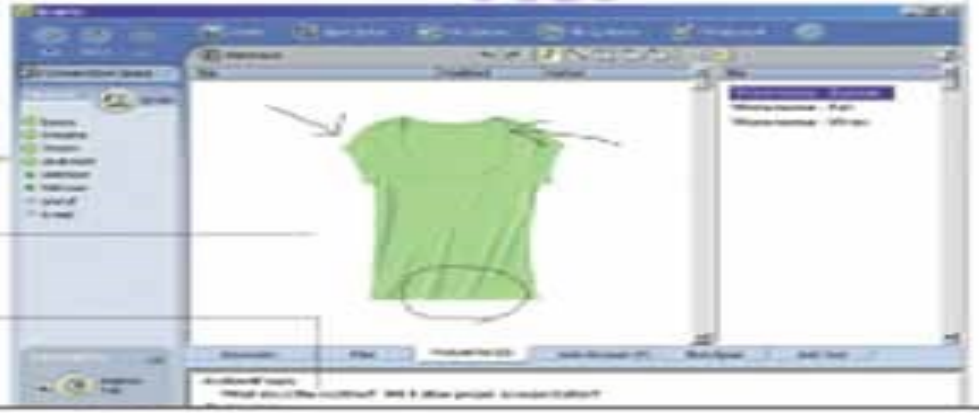
Users logon to the Internet using a program that looks like an online chat room.

A file is placed into a "shared space" within the virtual meeting room, which allows users to work on data files at the same time.

Users work in real time and can instant message each other. In the future, this might be done through devices such handhelds and cell phones.



## What is on the screen




SOURCES: Groove Networks; compiled from AP wire reports

AP

# Peer-to-Peer Distributed Computing

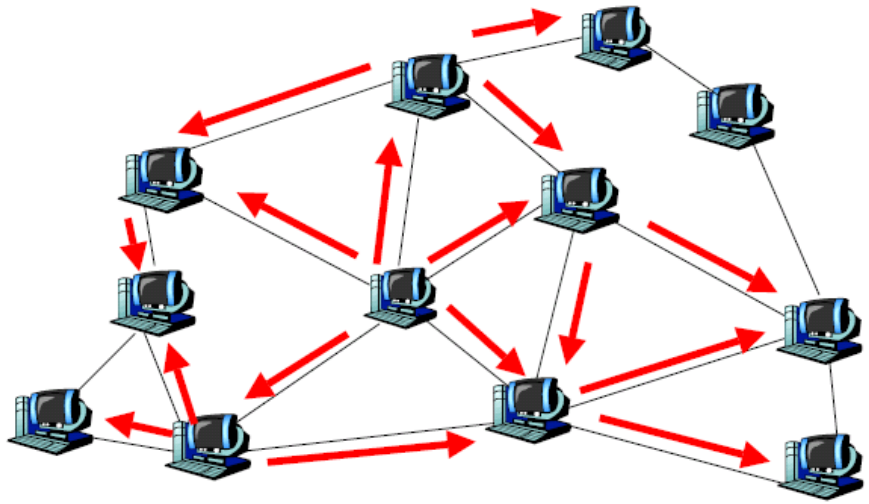
The peer-to-peer paradigm can be implemented with facilities using any tool that provide message-passing, or with a higher-level tool such as one that supports the point-to-point model of the Message System paradigm.

For web applications, the ***web agent*** is a protocol promoted by the XNSORG (the XNS Public Trust Organization) for peer-to-peer interprocess communication

"Project JXTA is a set of open, generalized peer-to-peer protocols that allow **any connected device** (cell phone, to PDA, PC to server) on the network to communicate and collaborate--**interoperability and platform independence**. JXTA is short for Juxtapose, as in side by side. It is a recognition that peer to peer is juxtapose to client-server or Web based computing -- what is considered today's traditional computing model. "

# Gnutella

- **Fully decentralized lookup** for files
  - **Unstructured** P2P
  - Flooding based lookup
  - Obviously **inefficient** lookup in terms of scalability and bandwidth



# Gnutella Scenario

***Step 0: Join the network***

***Step 1: Determining who is on the network***

- **"Ping"** packet is used to announce your presence on the network.
- Other peers respond with a **"Pong"** packet.
- Also forwards your Ping to other connected peers
- A Pong packet also contains:
  - an IP address
  - port number
  - amount of data that peer is sharing
  - Pong packets come back via same route

***Step 2: Searching***

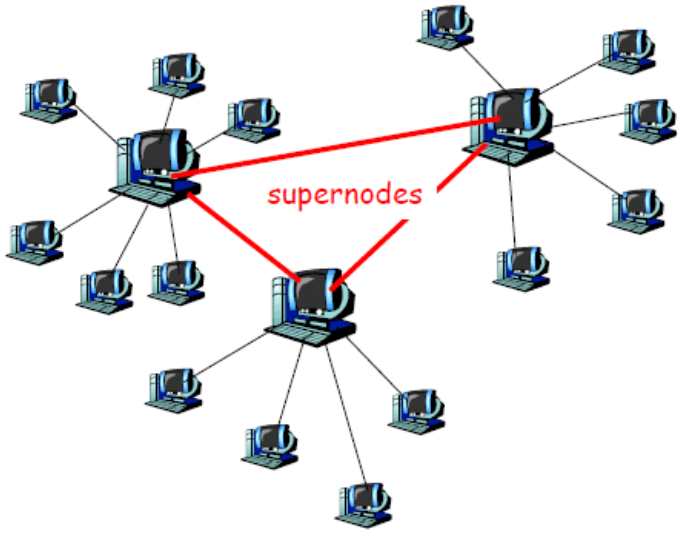
- Gnutella "Query" ask other peers if they have the file you desire A Query packet might ask, ***"Do you have any content that matches the string 'Hey Jude"?***
- Peers check to see if they have matches & respond (if they have any matches) & send packet to connected peers
- Continues for TTL (how many hops a packet can go before it dies )

***Step 3: Downloading***

- Peers respond with a "QueryHit" (contains contact info)
- File transfers use direct connection using HTTP protocol's GET method

# KaZaA

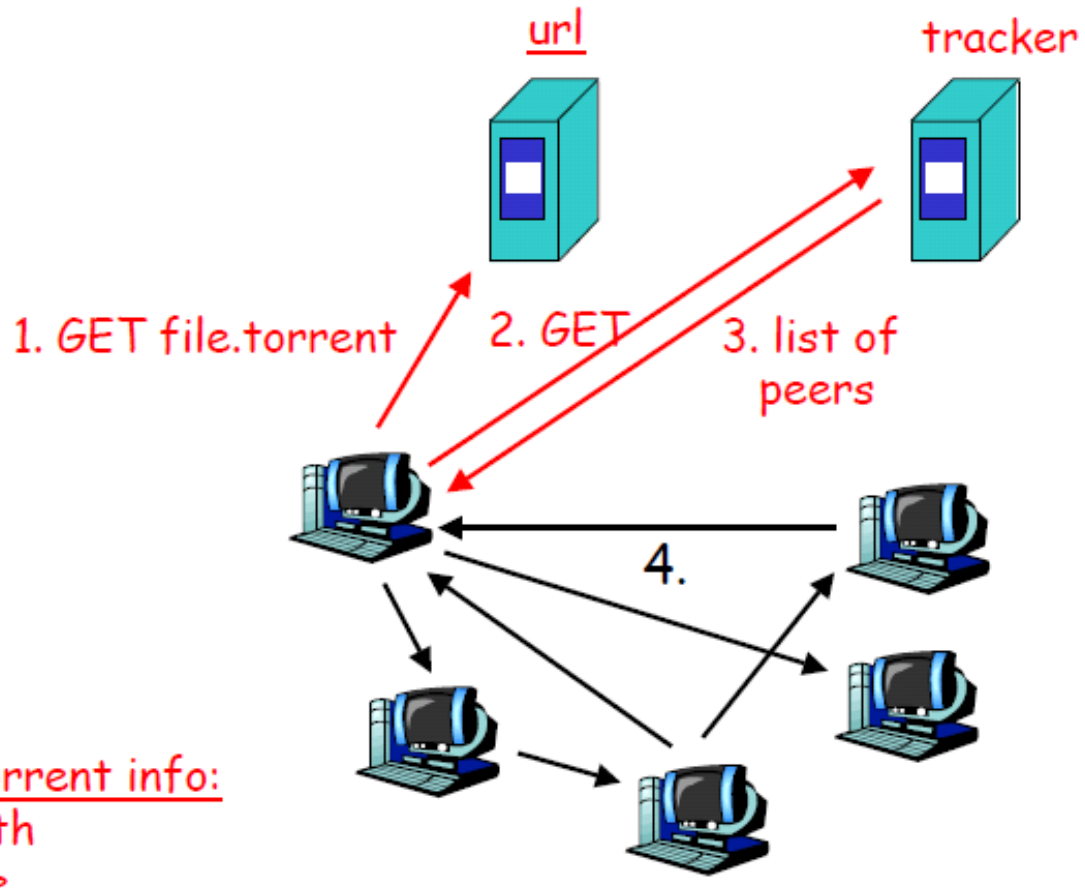
- **Hierarchical approach between Gnutella and Napster**
  - Powerful nodes (supernodes) act as local index servers, and client queries are propagated to other supernodes. Two-layered architecture.
  - Each supernode manages around 30-50 nodes
  - More efficient lookup than Gnutella and more scalable than Napster



# BitTorrent

Sharing large volume of files faster and more efficiently

Maximizing the utilization of bandwidth




file.torrent info:
- length
- name
- hash
- url of tracker

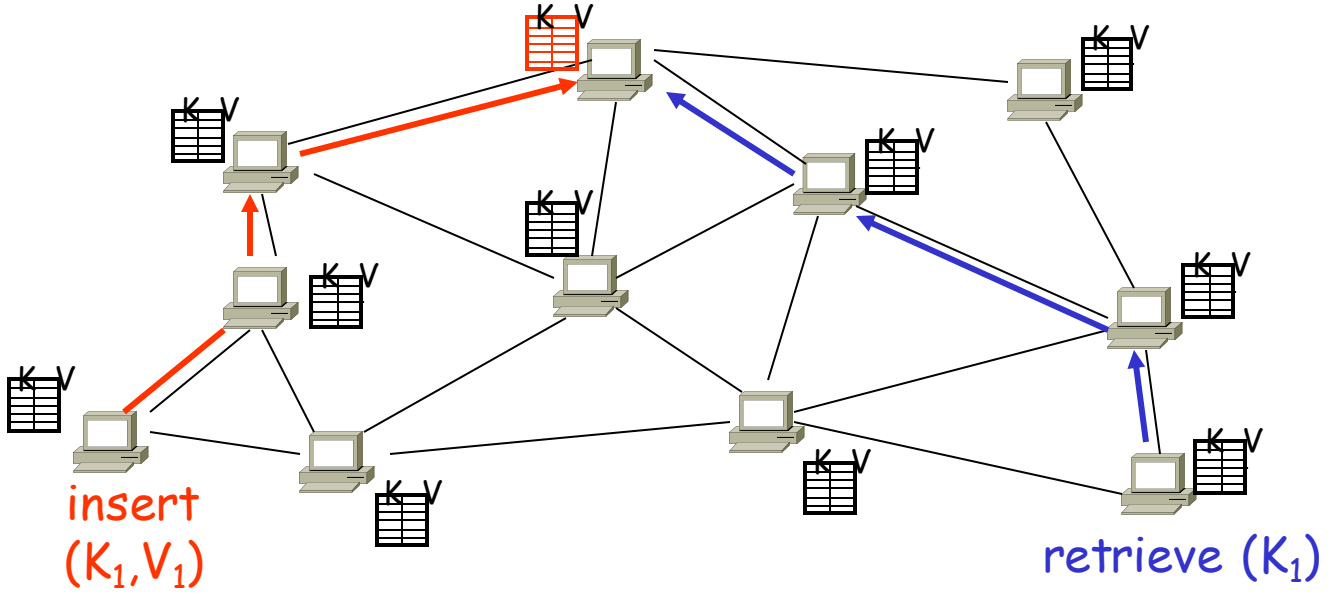
# BitTorrent : Pieces

- File is broken into pieces
  - Typically piece is 256 KBytes
  - Upload pieces while downloading pieces
- Piece selection
  - Select **rarest piece**
  - Except at beginning, select random pieces
- **Tit-for-tat**
  - Bit-torrent uploads to at most four peers
  - Among the uploaders, upload to the four that are downloading to you at the highest rates
  - A little randomness too, for probing
  - MORE DETAIL…..EXAMPLES….

# Structured P2P

- Peer-to-peer hash lookup:
  - Node ID(Key) , Object ID(Key)
  - Lookup(key) → IP address
- How does these route lookups?
- How does these maintain routing tables?

Chord,
Pastry,
Tepastry,
Can,
Kademlia,
etc

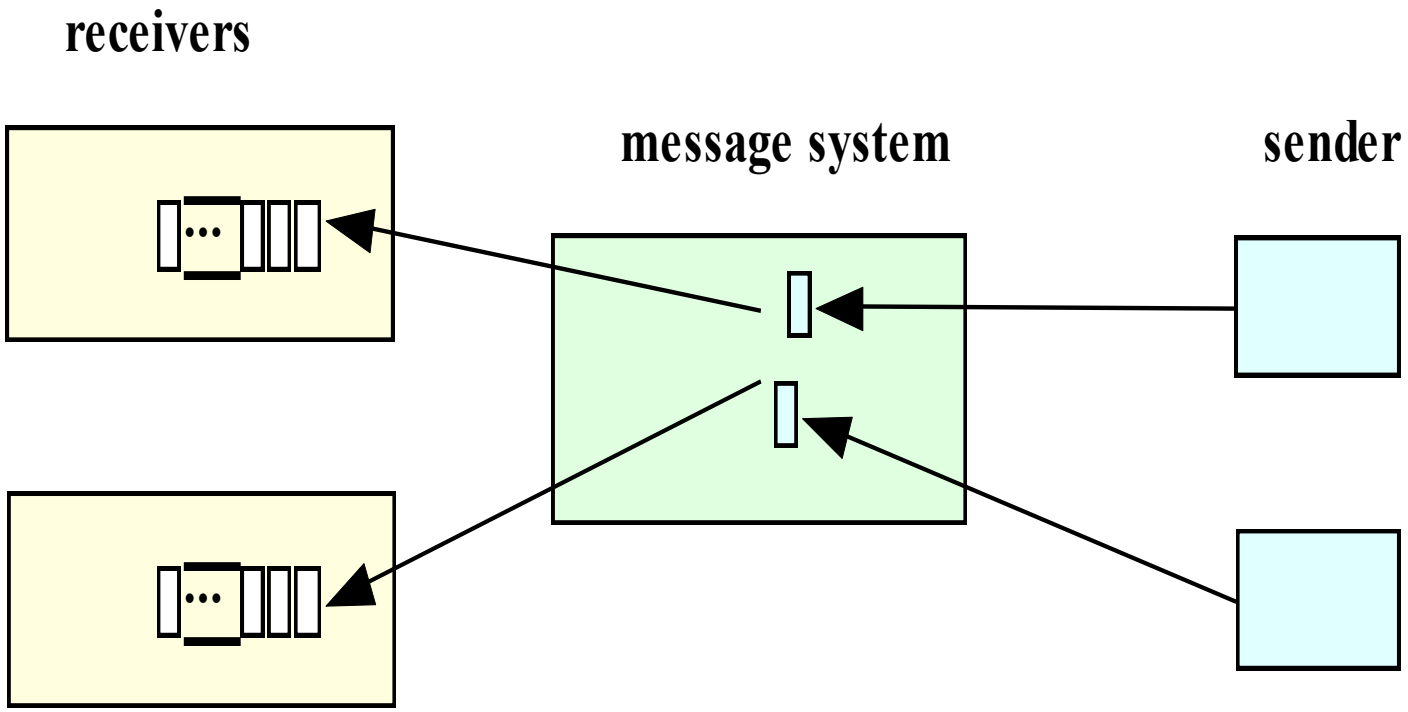


# The Message System Paradigm

- The Message System or **Message-Oriented Middleware** (**MOM**) paradigm is an elaboration of the basic message-passing paradigm (e.g., socket).
- In this paradigm, a **message system** serves as an intermediary among separate, independent processes.
- The message system acts as a **switch** for messages, through which processes exchange messages **asynchronously**, in a **decoupled** manner.
- A sender **deposits** a message with the message system, which forwards it to a message queue associated with each receiver. Once a message is sent, the sender is **free** to move on to other tasks.

# The Message System Paradigm

- The Point-To-Point Message Model
- The Publish/Subscribe Message Model



# The Point-To-Point Message Model

- A message system forwards a message from the **sender** to the **receiver's message queue**. Unlike the basic message passing model (using a socket), the middleware provides a message **depository**, and allows the **sending** and the **receiving** to be **decoupled**. Via the middleware, a sender deposits a message in the message queue of the receiving process. A receiving process extracts the messages from its message queue, and handles each one accordingly.
- Compared to the basic message-passing model, this paradigm provides the additional abstraction for asynchronous operations. To achieve the same effect with basic message-passing, a developer will have to make use of **threads** or **child processes**.

# The Publish/Subscribe Message Model

- Each message is **associated** with a specific topic, **task**, or **event**. Applications interested in the occurrence of a specific event may ***subscribe*** to messages for that event. When the awaited event occurs, the process publishes a message announcing the event or topic. The middleware message system **distributes** the message to **all** its ***subscribers***. (e.g., **Rendezvous** from TIBCO)
- The **publish/subscribe message** model offers a powerful abstraction for multicasting or group communication. The ***publish*** operation allows a process to multicast to a group of processes, and the ***subscribe*** operation allows a process to listen for such multicast.

# Early Models of Cloud Computing

- Basic reasoning: information and data processing can be done more efficiently on large farms of computing and storage systems accessible via the Internet.
- Two early models:

1. **Grid computing** – initiated by the National Labs in the early 1990s; targeted primarily at scientific computing.
   - *"Grid computing is the collection of computer resources from multiple locations to reach a common goal. The grid can be thought of as a distributed system with non-interactive workloads that involve a large number of files."* from Wikipedia
2. **Utility computing** – initiated in 2005-2006 by IT companies and targeted at enterprise computing.
   - *"Utility computing is a service provisioning model in which a service provider makes computing resources and infrastructure management available to the customer as needed, and charges them for specific usage rather than a flat rate."* from Wikipedia

# Cloud computing - Characteristics

"*Cloud Computing offers on-demand, scalable and elastic computing (and storage services). The resources used for these services can be metered and users are charged only for the resources used.* " from the Book

**Shared Resources and Resource Management:**

1. Cloud uses a shared pool of resources
2. Uses Internet techn. to offer **scalable** and **elastic** services.
3. The term "**elastic computing**" refers to the ability of **dynamically** and **on-demand** acquiring computing resources and supporting a variable workload.
4. Resources are metered and users are charged accordingly.
5. It is more cost-effective due to **resource-multiplexing.** Lower costs for the cloud service provider are past to the cloud users.

# Cloud computing (cont' d)

**Data Storage:**

6. Data is stored:
   - in the "cloud", in certain cases closer to the site where it is used.
   - appears to the users as if stored in a location-independent manner.
7. The data storage strategy can increase reliability, as well as security, and can lower communication costs.

**Management:**

8. The maintenance and security are operated by service providers.
9. The service providers can operate more efficiently due to specialisation and centralisation.

# Cloud Computing Advantages

1. Resources, such as CPU cycles, storage, network bandwidth, are **shared.**

2. When multiple applications share a system, their peak demands for resources are not synchronised thus, **multiplexing** leads to a higher resource utilization.

3. Resources can be **aggregated** to support data-intensive applications.

4. Data sharing facilitates **collaborative** activities. Many applications require multiple types of analysis of shared data sets and multiple decisions carried out by groups scattered around the globe.

# Cloud Computing Advantages

5. Eliminates the **initial investment costs** for a private computing infrastructure and the maintenance and operation costs.

6. **Cost reduction**: concentration of resources creates the opportunity to pay as you go for computing.

7. **Elasticity**: the ability to accommodate workloads with very large peak-to-average ratios.

8. **User convenience**: virtualization allows users to operate in familiar environments rather than in idiosyncratic ones.

# Cluster Computing

Cluster Computing: Network of Independent standalone computers that works as single integrated resource.

Cluster computing refers that many of the computers connected on a network and they perform like a single entity. Each computer that is connected to the network is called a node.

# Cluster Computing

Cluster computing offers solutions to solve complicated problems by providing faster computational speed, and enhanced data integrity

## Features of Cluster computing

- All the connected computers are the same kind of machines
- They are tightly connected through dedicated network connections
- All the computers share a common home directory.

# Types of Cluster Computing

- Cluster Load Balancing: These clusters are built to handle large volume of client requests using multi-tasking and multi-users environments. Load balancing can either be software-based or hardware-based. Software-based load balancing uses special software on servers to manage the load based on different algorithms. Whereas, hardware-based load balancing uses specialized switches or routers to balance the load.

# Types of Cluster Computing

- High-availability clusters: They are meant to support server applications and are maintained with a minimum down-time. Redundant computers are harnessed in a cluster to maintain high level of reliability and to maintain the down time.
- High performance computing clusters: This networking approach utilizes supercomputers to resolve complex computational problems. The jobs are submitted to clusters for execution and cluster will manage the resources required for the job.

# Advantages of Cluster Computing

- **Cost efficacy**
- **Processing speed**
- **Extended resource availability**: When one node gets failed, the other nodes will be active and will function as a proxy for the failed node. This makes sure for enhanced availability.
- **Expandability**
- **Flexibility**: Cluster computing can be upgraded to the superior specification or extended through the addition of additional nodes (computer systems).