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NPTEL ONLINE CERTIFICATION COURSES

Cloud Computing – Fundamentals

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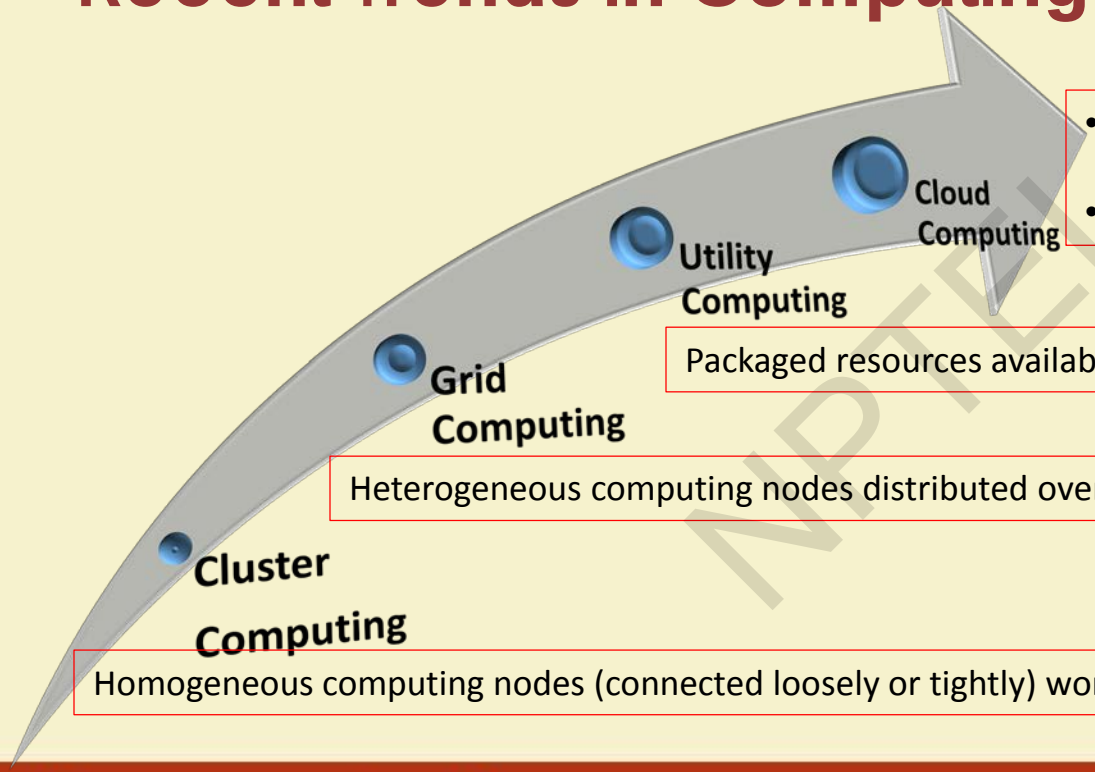
Recent Trends in Computing



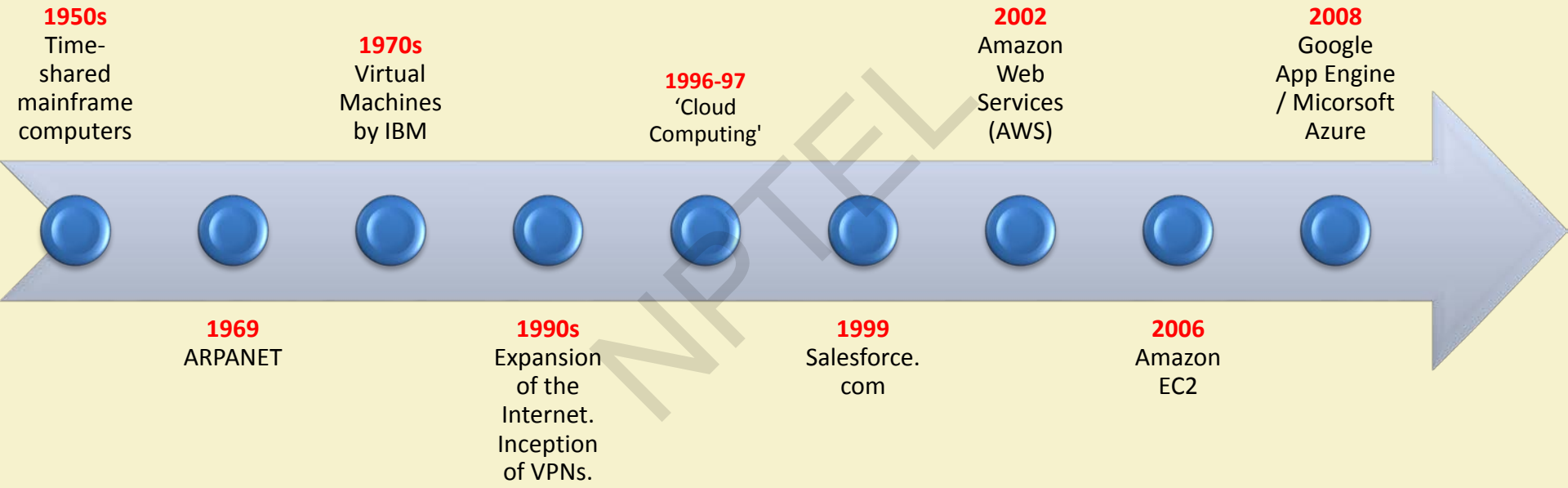
- Shared pool of configurable computing resources
- Ubiquitous, dynamic & on-demand access

Packaged resources available for computing and storage

Heterogeneous computing nodes distributed over a wide area to perform very large tasks

Homogeneous computing nodes (connected loosely or tightly) working together

Evolution of Cloud Computing



Cloud Computing

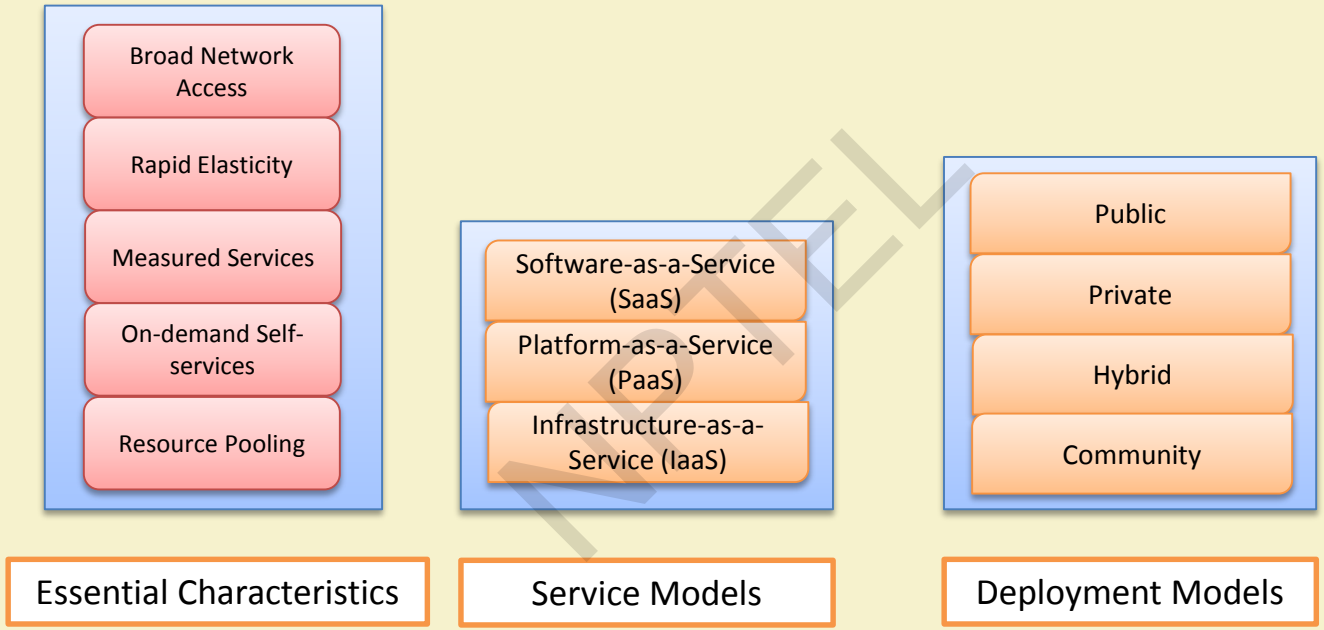
"Cloud computing is a model for enabling convenient, *on-demand network access to a shared* pool of *configurable computing resources* (e.g., network infrastructures, servers, storage, applications, etc.)" – NIST

Source: P Mell & T Grance, "A NIST Notional Definition of Cloud Computing", version 15, 2009.

- It can be envisioned as step on from Utility Computing
- It provides *high level generalization (abstraction)* of computation and storage model
- It can be *rapidly allocated* and *released* with low management effort
- It has some essential **characteristics, service models**, and **deployment models**
- It provides on-demand services, that can be accessed from any place and at anytime

Source: Rajkumar Buyya, "Mastering Cloud Computing: Foundations and Applications Programming", Tata McGraw-Hill Education, 2013

NIST Visual Model of Cloud Computing



Source: NIST

Business Advantages

- ✓ Nearly zero cost for upfront infrastructure investment
- ✓ Real-time Infrastructure availability
- ✓ More efficient resource utilization
- ✓ Usage-based costing
- ✓ Reduced time to market

General Characteristics

- ✓ Improved **agility** in resource provisioning.
- ✓ **Ubiquitous** – independent of device or location
- ✓ **Multitenancy** – sharing of resources and costs across a large pool of users
- ✓ Dynamic load balancing
- ✓ Highly **reliable** and **scalable**
- ✓ Low cost and low maintenance
- ✓ Improved security and access control

Essential Characteristics

- ✓ **Broad network access**
  - Cloud resources should be available over the network
  - Should support standard mechanisms for information retrieval using traditional interfaces
  - Supported clients: heterogeneous thin or thick client platforms (e.g., mobile phones, laptops, and PDAs)

Source: P Mell & T Grance, “A NIST Notional Definition of Cloud Computing”, version 15, 2009.

Essential Characteristics

- ✓ **Rapid elasticity**
  - Cloud resource allocation should be rapid, elastic and automatic
  - Dynamic allocation/release facility for scale-out and scale-in
  - Consumers should feel infinite resources
  - Facility for add/remove of quantity should be there

Source: P Mell & T Grance, “A NIST Notional Definition of Cloud Computing”, version 15, 2009.

Essential Characteristics

- ✓ **Measured service**
  - Resource usage should be recorded and monitored
  - Facility to dynamically control and optimize the resource usage
  - This facility should be transparent between the service provider and consumer.

Source: P Mell & T Grance, “A NIST Notional Definition of Cloud Computing”, version 15, 2009.

Essential Characteristics

- ✓ **On-demand self-service**
  - Provide server time and network storage to users automatically
  - This facility should be available as a self-service

Source: P Mell & T Grance, “A NIST Notional Definition of Cloud Computing”, version 15, 2009.

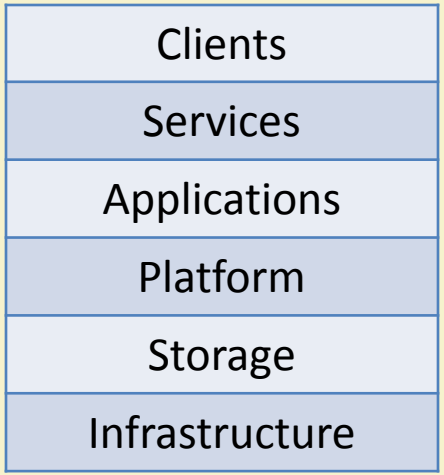
Essential Characteristics

- ✓ **Resource pooling**
  - Automatically pool the whole available resources
  - Serve multiple end-users using a multi-tenant model
  - Resources should be allocated according to user's demand

Source: P Mell & T Grance, "A NIST Notional Definition of Cloud Computing", version 15, 2009.

Components of Cloud Computing

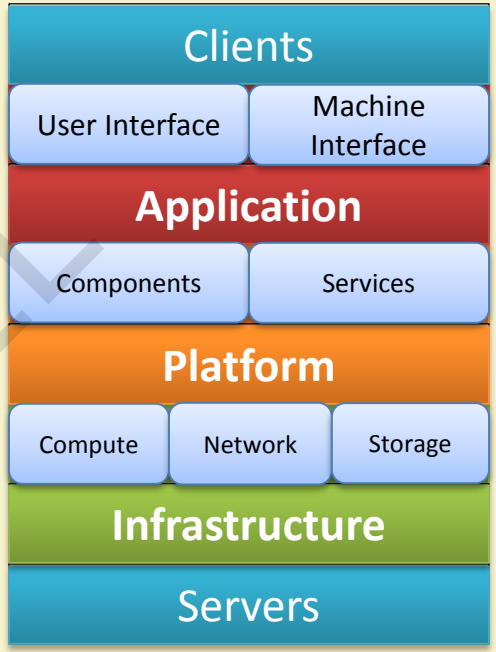
- ✓ **Clients /end-users:** Thick, Thin, Mobile
- ✓ **Services:** Products & solutions (Identity, Mapping, Search, etc.)
- ✓ **Applications:** Web apps, SaaS, etc.
- ✓ **Platform:** Apps/Web hosting using PaaS
- ✓ **Storage:** Database, Data-Storage-as-a-Service (DSaaS)
- ✓ **Infrastructure:** Virtualization, IaaS, EC2



Source: Wikipedia

Service Models

- ✓ Software-as-a-Service (SaaS)
- ✓ Platform-as-a-Service (PaaS)
- ✓ Infrastructure-as-a-Service (IaaS)



Source: Wikipedia

Software-as-a-Service (SaaS)

- ✓ Facility to execute service provider's applications at user's end
- ✓ Applications are available as 'services'
- ✓ Services can be accessed via different types of client devices (e.g. web browser, app)
- ✓ End-users do not posses the control of the cloud infrastructure

Examples: Google Apps, Salesforce, Learn.com.

Source: P Mell & T Grance, "A NIST Notional Definition of Cloud Computing", version 15, 2009.

Platform-as-a-Service (PaaS)

- ✓ Facility for the consumer to execute *consumer-created* or *acquired applications* onto cloud infrastructure
- ✓ Support for deployment of such applications
- ✓ The user does not control the cloud infrastructure
- ✓ User can control the deployed applications using given configurations

Examples: Windows Azure, Google App Engine

Source: P Mell & T Grance, "A NIST Notional Definition of Cloud Computing", version 15, 2009.

Infrastructure-as-a-Service (IaaS)

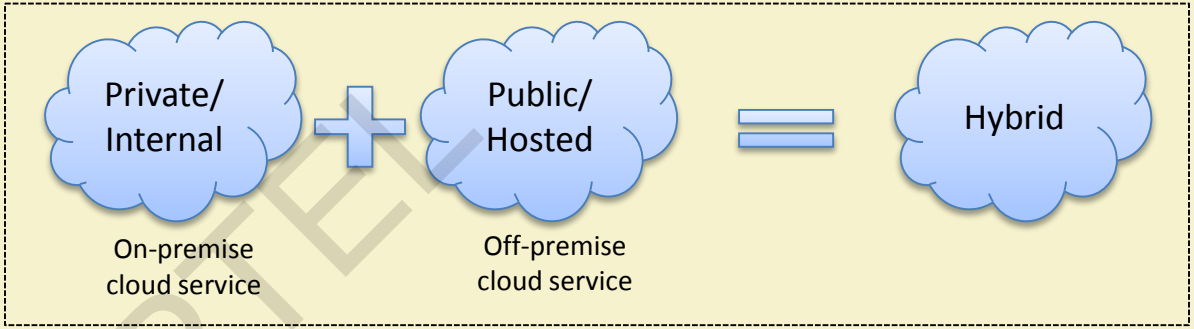
- ✓ Facility to access computing resources such as network, storage, and operating system
- ✓ User can deploy, execute and control any software (O*perating systems* and *other applications*)
- ✓ In some case, the user can control selected networking components (e.g., host firewalls).

Examples: Amazon EC2, GoGrid, iland, Rackspace Cloud Servers.

Source: P Mell & T Grance, "A NIST Notional Definition of Cloud Computing", version 15, 2009.

Deployment Models

- ✓ Public cloud
- ✓ Private cloud
- ✓ Hybrid cloud
- ✓ Others:
  - Community cloud
  - Distributed cloud
  - Multi-cloud
  - Inter-cloud



Source: https://en.wikipedia.org/wiki/Cloud_computing

Public Cloud

- ✓ Cloud set-up for the use of any person or industry
- ✓ Typically owned by an organization who offers the cloud service.
- ✓ Examples: Amazon Web Service (AWS), Google Compute Engine, Microsoft Azure
- ✓ Advantages:
  - Easy to set-up at low cost, as provider covers the hardware, application and bandwidth costs.
  - Scalability to meet needs.
  - Pay-per-use ensures that from user's perspective no resources wasted.

Source: Christian Baun and Marcel Kunze, "A Taxonomy Study on Cloud Computing Systems and Technologies", Cloud Computing - Methodology, Systems, and Applications, L Wang et al. (Eds), CRC Press, 2012

Private Cloud

- ✓ Cloud set-up functioned only for a single organization
- ✓ Typically managed by the organization itself (on-premises) or a third party (off-premises)
- ✓ Advantages:
  - Total control over the system and data
  - Minimum security concerns
- ✓ Disadvantages:
  - Regular maintenance

Source: Christian Baun and Marcel Kunze, "A Taxonomy Study on Cloud Computing Systems and Technologies“, Cloud Computing - Methodology, Systems, and Applications, L Wang et al. (Eds), CRC Press, 2012

Public Cloud vs Private Cloud

	Public Cloud	Private Cloud
Virtualized resources	Publicly shared	Privately shared
Customer types	Multiple	Limited
Connectivity	Over Internet	Over Internet/private network
Security	Low	High

Source: Christian Baun and Marcel Kunze, "A Taxonomy Study on Cloud Computing Systems and Technologies“, Cloud Computing - Methodology, Systems, and Applications, L Wang et al. (Eds), CRC Press, 2012

Hybrid Cloud

- ✓ Cloud set-up constructed by two or more unique cloud set-up (private, community, or public)
- ✓ Pooled together by standardized tools
- ✓ Supports data and application portability (e.g., facility for load-balancing between clouds)
- ✓ Provides multiple deployment models

Source: Christian Baun and Marcel Kunze, "A Taxonomy Study on Cloud Computing Systems and Technologies“, Cloud Computing - Methodology, Systems, and Applications, L Wang et al. (Eds), CRC Press, 2012

Other Types of Cloud

- ✓ **Community cloud**
  - Shared set-up between several organizations having common concerns (security, compliance, jurisdiction, etc.)
  - Managed by internally or by third party
- ✓ **Distributed Cloud**
  - Collection of scattered set of computing devices in different locations, however, connected to a single network
  - Two types – *Public-resource Computing* and *Volunteer Cloud*.

Source: Christian Baun and Marcel Kunze, "A Taxonomy Study on Cloud Computing Systems and Technologies“, Cloud Computing - Methodology, Systems, and Applications, L Wang et al. (Eds), CRC Press, 2012

Other Types of Cloud

- ✓ **Multi-cloud**
  - Multiple cloud computing services offered via single heterogeneous architecture
  - Increases fault-tolerance and flexibility
- ✓ **Inter-cloud**
  - Unified global *'cloud of clouds'* based on the Internet
  - Supports interoperability between cloud service providers

Source: Christian Baun and Marcel Kunze, "A Taxonomy Study on Cloud Computing Systems and Technologies", Cloud Computing - Methodology, Systems, and Applications, L Wang et al. (Eds), CRC Press, 2012

Comparison of Different Deployment Models

	On-premise	Off-premise
Dedicated Access	Private cloud	Hosted private cloud
Shared Access	Community cloud	Public cloud

Source: Christian Baun and Marcel Kunze, "A Taxonomy Study on Cloud Computing Systems and Technologies“, Cloud Computing - Methodology, Systems, and Applications, L Wang et al. (Eds), CRC Press, 2012

Thank You!!

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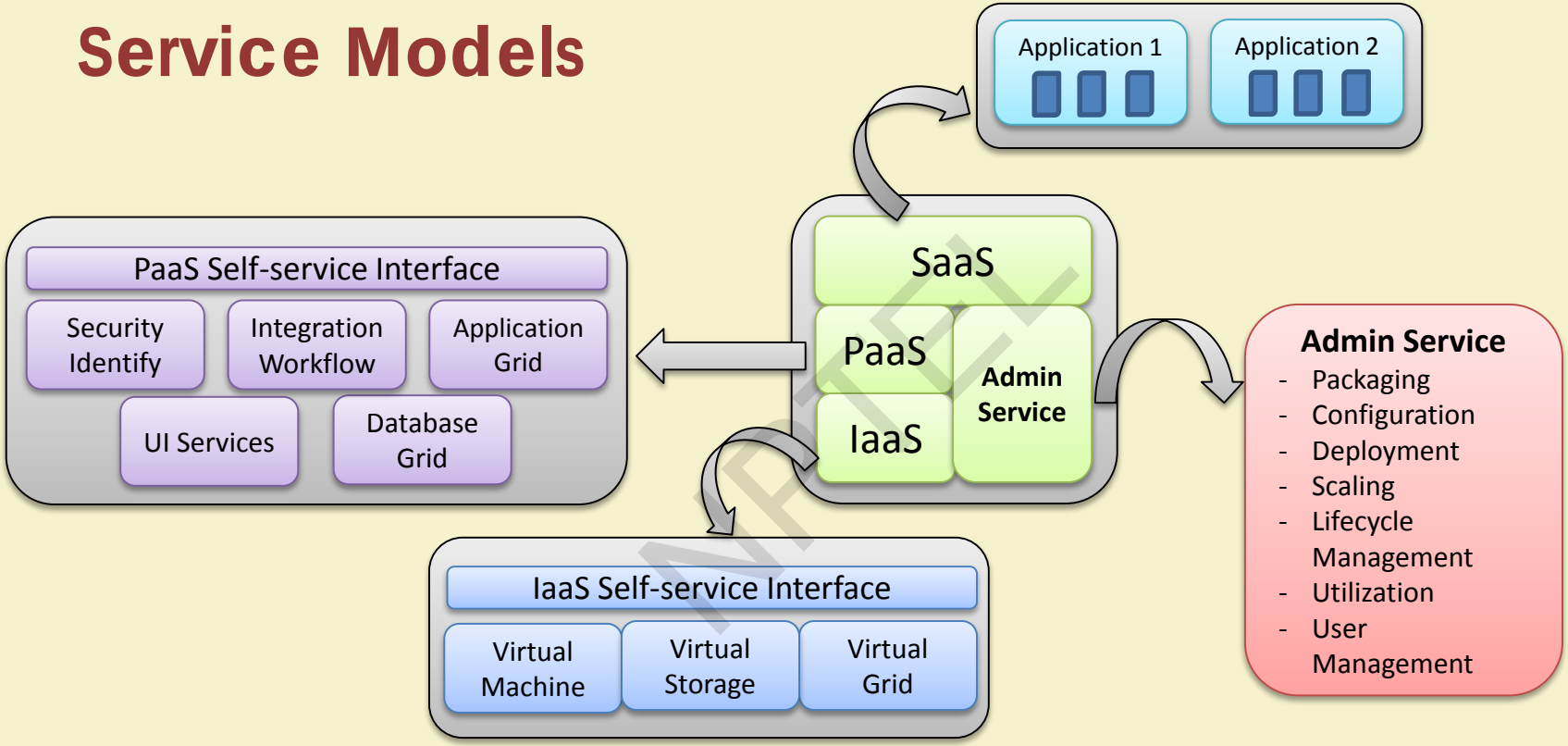
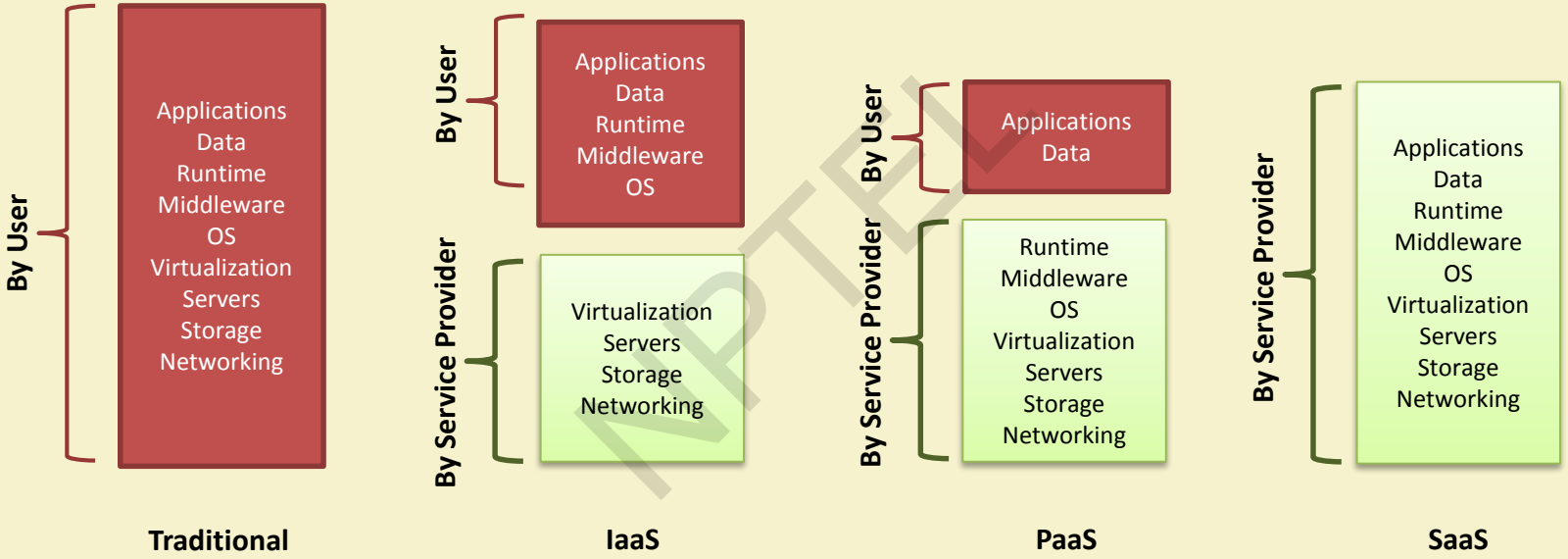
Service Models



Source: NIST (2011)

Comparison of Different Service Models



Source: NIST (2011)

Infrastructure-as-a-Service (IaaS)

"Infrastructure-as-a-Service, abbreviated as IaaS, contains the basic building blocks for cloud IT and typically provide access to networking features, computers (virtual or dedicated hardware), and data storage space." – Amazon

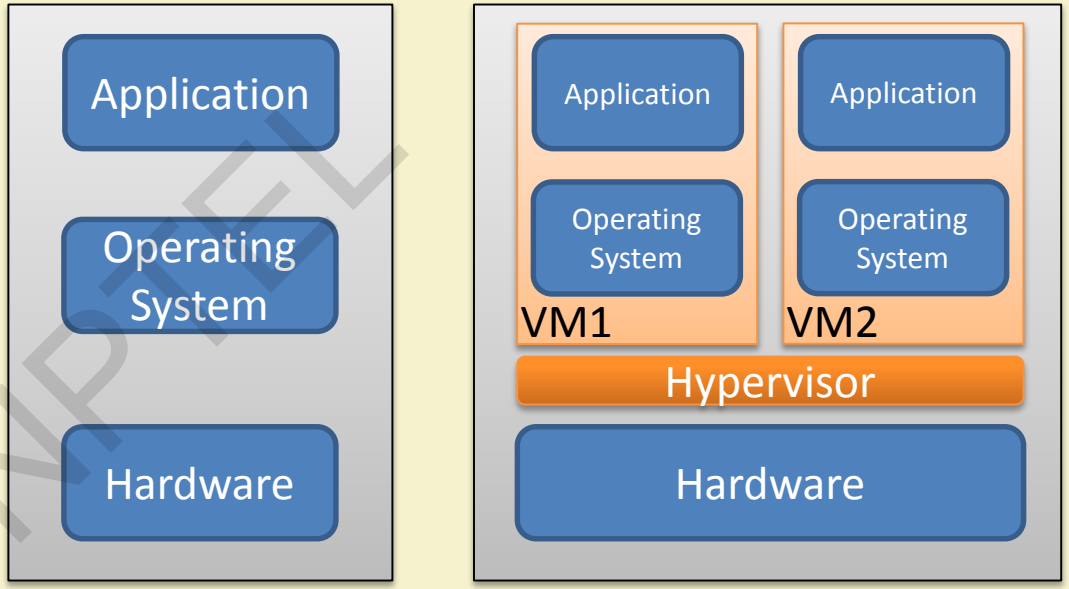
Source: https://aws.amazon.com/types-of-cloud-computing/

- ✓ On-demand delivery of **computing infrastructure**
- ✓ IaaS provides the following:
  - Servers- Compute, machines
  - Storage
  - Network
  - Operating system

Source: Rajkumar Buyya, "Mastering Cloud Computing: Foundations and Applications Programming", Tata McGraw-Hill Education, 2013

Working Methodology

- The user rents servers, software, **data center space** or network equipment
- Cloud service provider offers resource management
- Outsourced service on-demand model



Source: Wikipedia, Hardware Virtualization

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Sensor-Cloud-Part I

Sensor-as-a-Service

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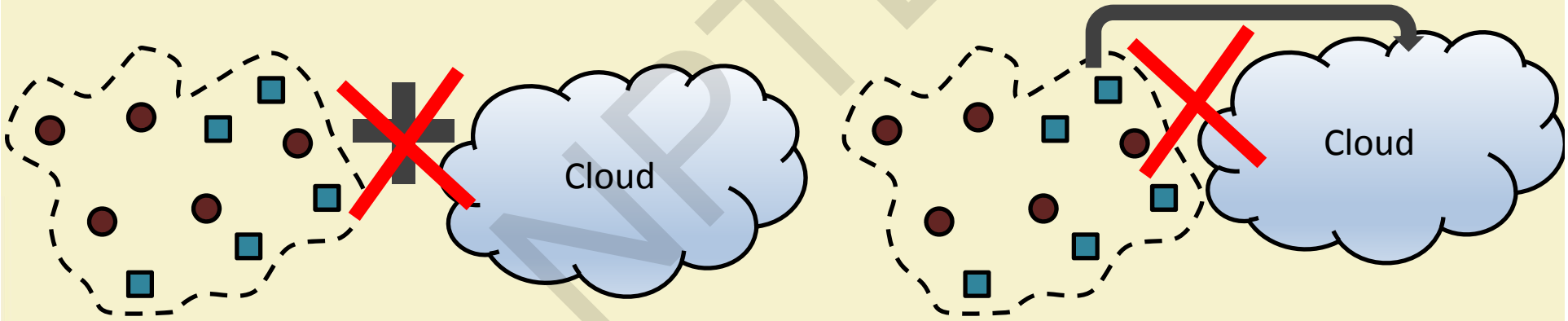
Introduction

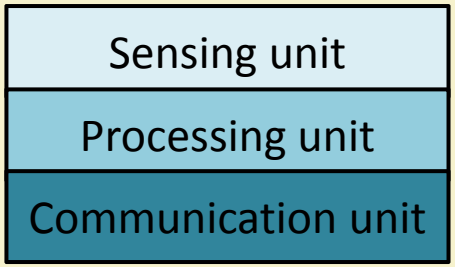
- ✓ It is not mere integration of sensors and cloud computing
- ✓ It is not only “dumping the sensor data into cloud”



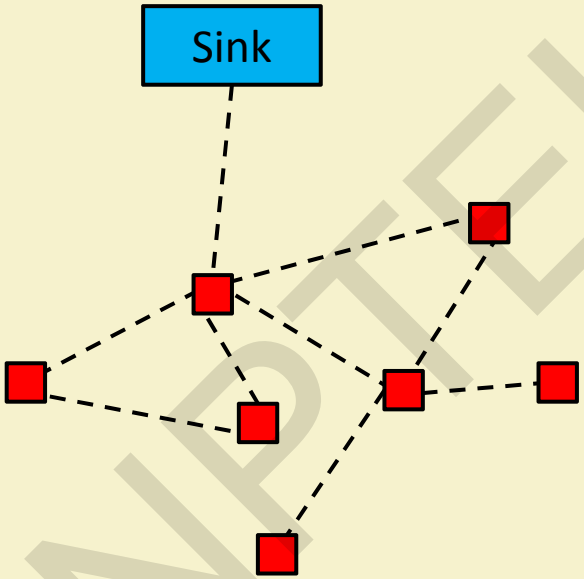
Wireless Sensor Networks (WSNs): Recap

- ✓ Contain sensor nodes which sense some physical phenomena from the environment
- ✓ Transmit the sensed data (through wireless communication) to a centralized unit, commonly known as Sink node
- ✓ The communication between Sink node and other sensor nodes in the network may be single/multi-hop
- ✓ Sink node further process data

Wireless Sensor Networks (WSNs): Recap



Major Components of a Sensor Node



Wireless Sensor Networks

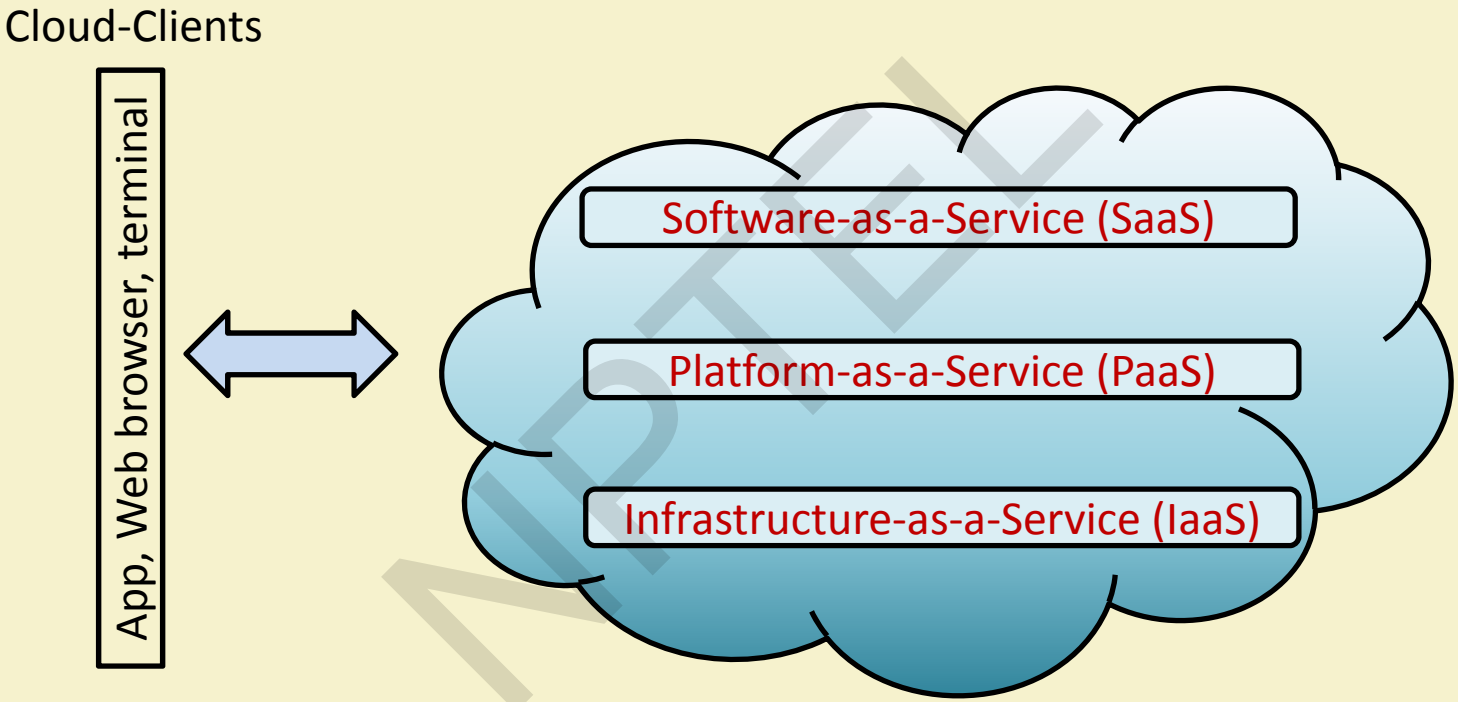
Applications

- ✓ Target Tracking
- ✓ Wildlife Monitoring
- ✓ Healthcare
- ✓ Industrial Applications
- ✓ Smart Home
- ✓ Smart City
- ✓ Agriculture
- ✓ …

Cloud Computing: Recap

- ✓ An architecture which provides on-demand computing resources
- ✓ Advantages
  - ✓ Elasticity: Scaling up/down
  - ✓ Pay-per-use: Payment for the resource as per requirement
  - ✓ Self Service: Resource can be accessed by self

Cloud Computing: Services



Cloud Computing: Services

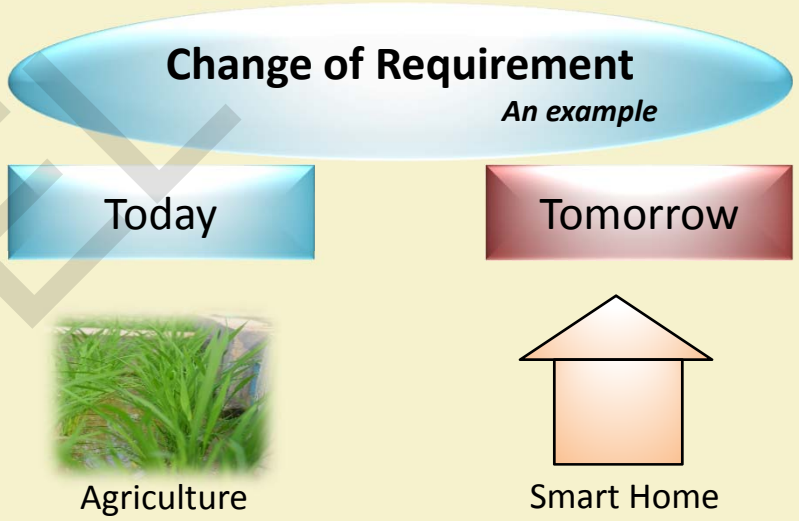
- ✓ Software-as-a-Service (SaaS)
  - ✓ A third party provides a host application over internet
  - ✓ Example: Microsoft Office 365
- ✓ Platform-as-a-Service (PaaS)
  - ✓ Provide a platform to develop and run applications
  - ✓ Example: Windows Azure
- ✓ Infrastructure-as-a-Service (IaaS)
  - ✓ Provide computing resources
  - ✓ Example: Storage space

Virtualization Concept

- ✓ One computer host appears as many computers-concept of Virtual Machine (VM)
- ✓ Improve IT throughput and costs by using physical resources as a pool from which virtual resources can be allocated.
- ✓ Benefit
  - ✓ Sharing of resources: Same resource can be shared, in turn cost reduction
  - ✓ Encapsulation: A complete computing environment
  - ✓ Independence: Runs independently of underlying hardware
  - ✓ Portability: VM Migration

Limitations of WSNs

- ✓ Procurement
  - ✓ Price
  - ✓ Right vendor
  - ✓ Types of sensor integrated with it
- ✓ Deployment
  - ✓ Right way of deployment
  - ✓ Right place of deployment
- ✓ Maintenance
  - ✓ Post deployment maintenance
  - ✓ Battery lifetime

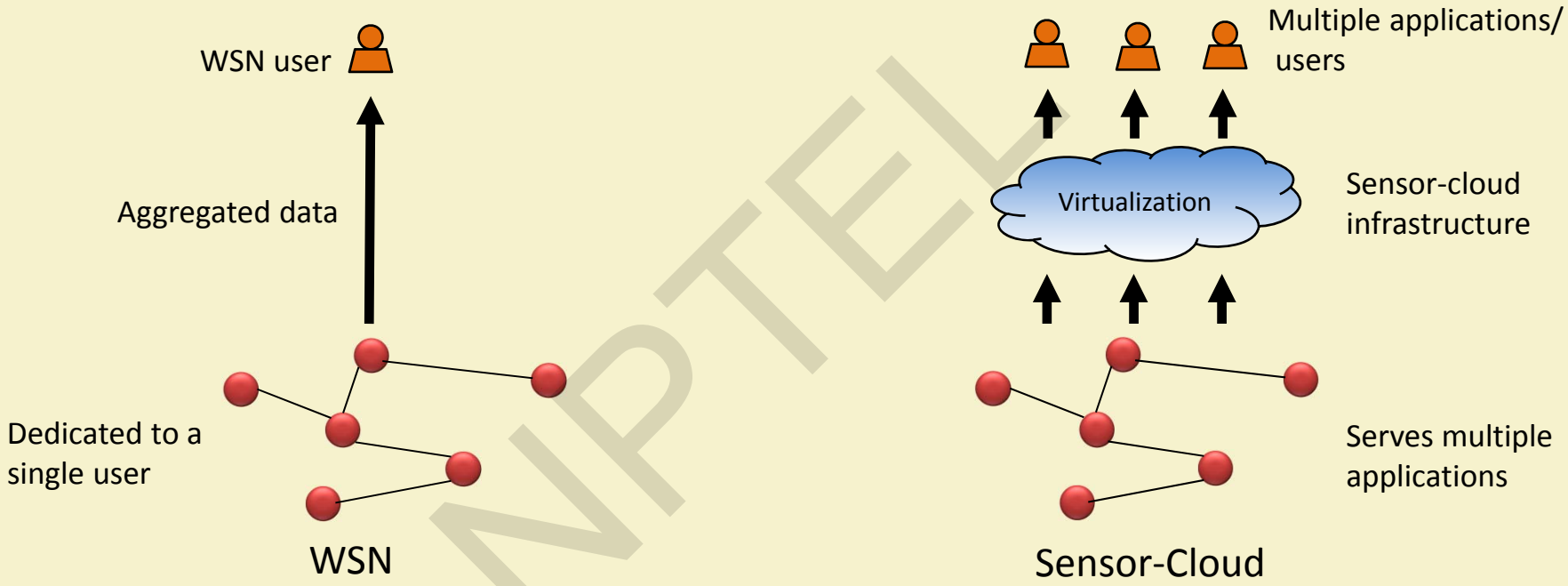


Result: Change in Sensor type, deployment area, topology design, and many more….

Sensor-Cloud: Introduction

- ✓ Not only the mere integration of cloud computing and sensor networks, but sensor-cloud is more than that
- ✓ Concept of virtualization of sensor node
- ✓ Pay-per-use
- ✓ One sensor node/network appears as many
- ✓ A stratum between sensor nodes and end-users

Difference with WSN



Source: S. Misra; S. Chatterjee; M. S. Obaidat, "On Theoretical Modeling of Sensor Cloud: A Paradigm Shift From Wireless Sensor Network," in *IEEE Systems Journal* , vol.PP, no.99, pp.1-10

Difference with WSN (Contd.)

Actors and Roles		
Attributes	**WSN**	**Sensor Cloud**
Ownership	WSN-user	Sensor-owner
Deployment	WSN-user	Sensor-owner
Redeployment	WSN-user	SCSP
Maintenances	WSN-user	SCSP
Overhead	WSN-user	SCSP
Usage	WSN-user	End-user

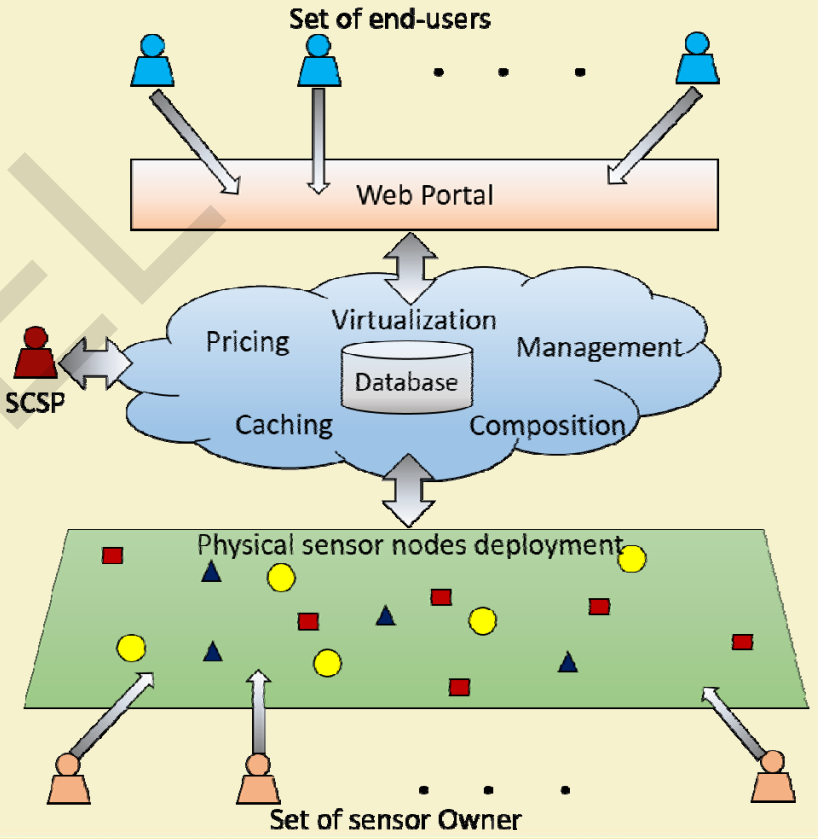
Source: S. Misra; S. Chatterjee; M. S. Obaidat, "On Theoretical Modeling of Sensor Cloud: A Paradigm Shift From Wireless Sensor Network," in *IEEE Systems Journal* , vol.PP, no.99, pp.1-10

Actors in Sensor-cloud

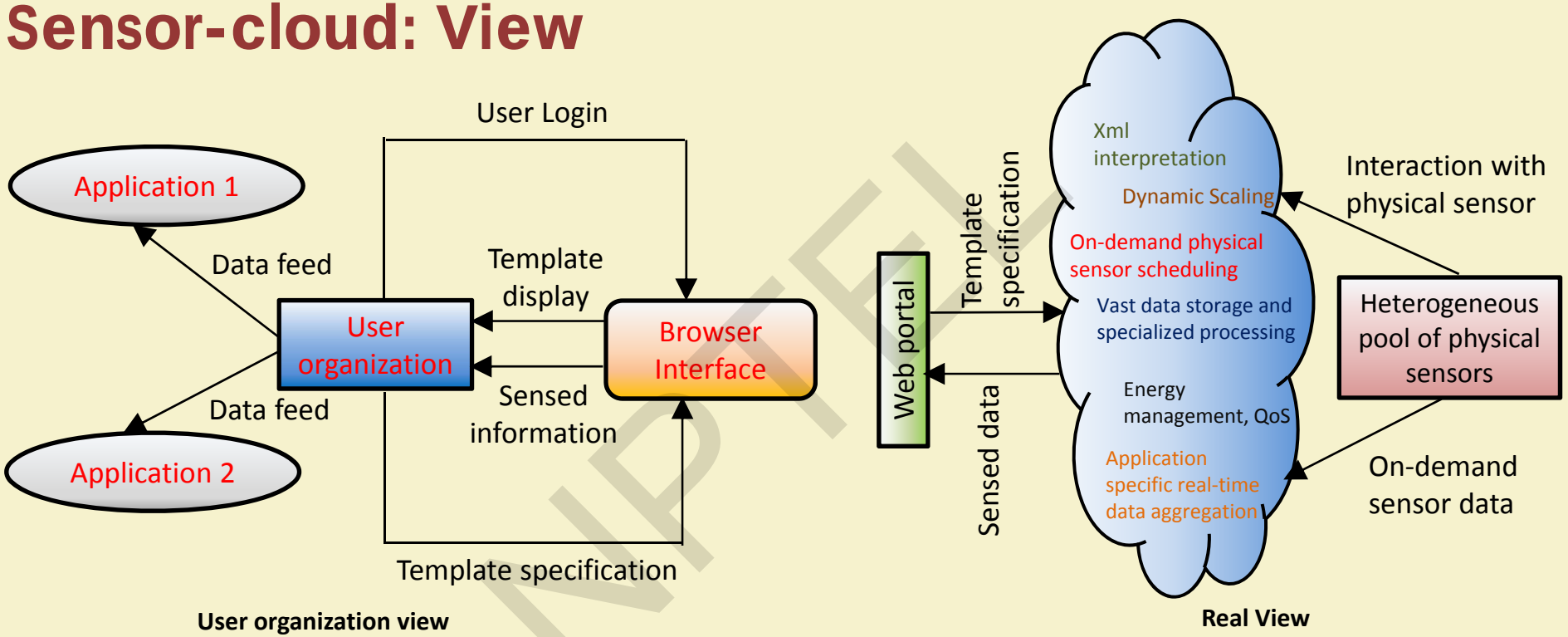
- ✓ End-users
  - ✓ Enjoy Se-aaS through applications as per the requirements.
  - ✓ Unknown about what and which physical sensor is/are allocated to serve the application
- ✓ Sensor-owner
  - ✓ Plays a role from business perspective.
  - ✓ They purchase physical sensor devices, deployed over different geographical locations, and lend these devices to the sensor-cloud
- ✓ Sensor-Cloud Service Provider (SCSP)
  - ✓ A business actor.
  - ✓ SCSP charges price from the end-users as per their usage of Se-aaS.

Sensor-cloud: Architecture

- ✓ End-users: Registered themselves, selects templates, and request for application(s)
- ✓ Sensor-owner: Deploy heterogeneous/ homogeneous physical sensor nodes over different geographical location
- ✓ SCSP: Plays managerial role



Sensor-cloud: View



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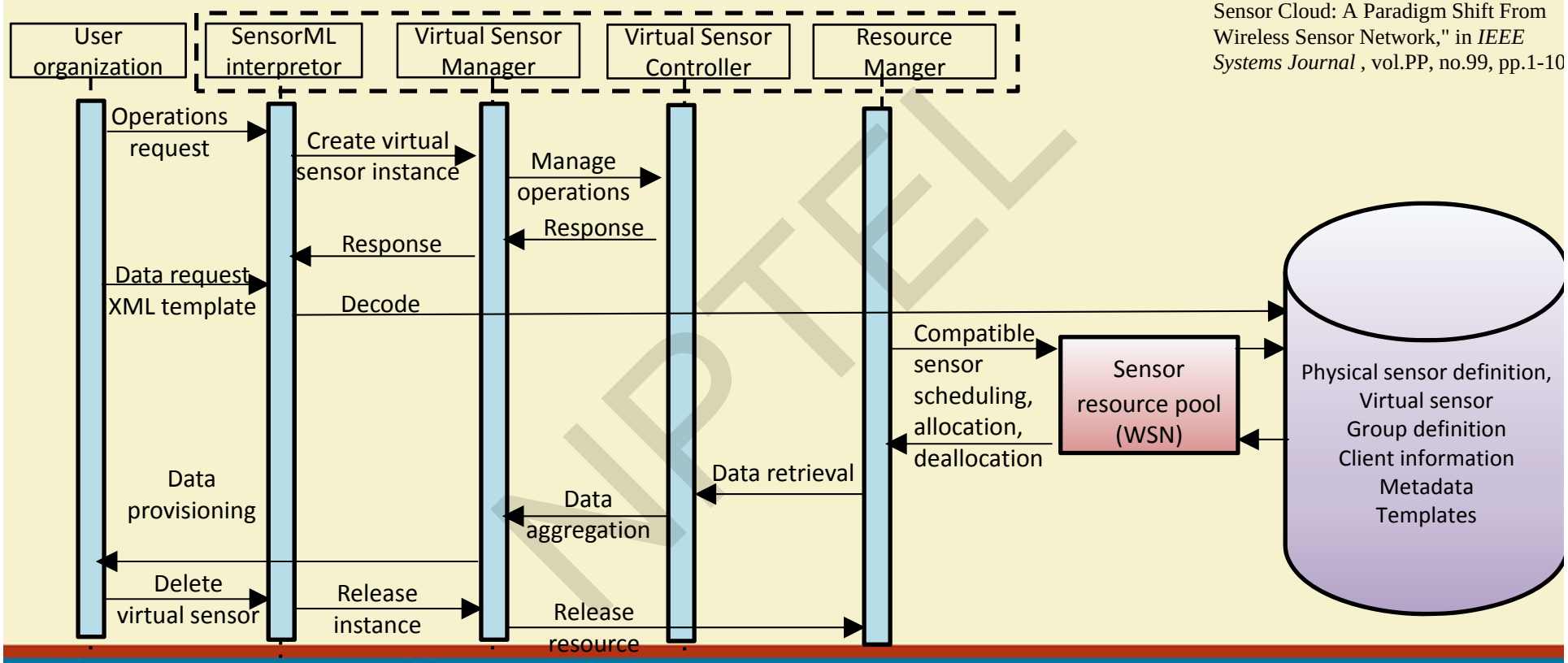
Work Flow of Sensor-Cloud



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Case Study: Target Tracking

"We consider a WSN-based target tracking application, in which a WSN owner refuses to share the sensed information with an external body, even in exchange of money. Consequently, any organization that wishes to detect intrusion within a particular zone has to deploy its own WSN. This leads to a long-term investment due to costly network setup and maintenance overheads. However, in a sensor-cloud environment, the same organization can use the same tracking application and still get the service without actually owning the WSN"

Source: S. Misra; S. Chatterjee; M. S. Obaidat, "On Theoretical Modeling of Sensor Cloud: A Paradigm Shift From Wireless Sensor Network," in *IEEE Systems Journal* , vol.PP, no.99, pp.1-10

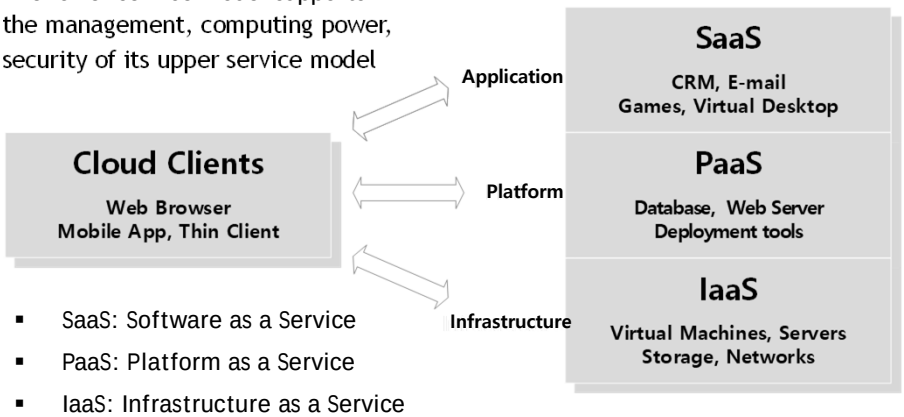
Cloud Technology

IaaS, PaaS, SaaS

IaaS, PaaS, SaaS

❖ Cloud Service Models

The lower service model supports the management, computing power, security of its upper service model



- SaaS: Software as a Service
- PaaS: Platform as a Service
- IaaS: Infrastructure as a Service

IaaS, PaaS, SaaS

❖ IaaS (Infrastructure as a Service)

- Infrastructure support over the Internet
- Cloud's Computing & Storage Resources
  - Computing Power
  - Storage Services
  - Software Packages & Bundles
  - VLAN (Virtual Local Area Network)
  - VM (Virtual Machine) Features

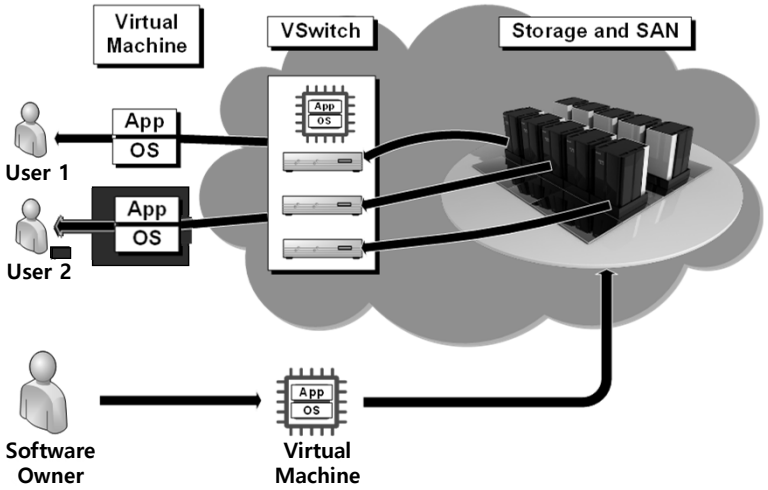
IaaS, PaaS, SaaS

❖ VM (Virtual Machine) Administration

- IaaS enables control of computing resources through Administrative Access to VMs
  ➔ Server Virtualization features
- Access to computing resources are enabled by Administrative Access to VMs
- VM Administrative Command examples
  - Save data on cloud server
  - Start web server
  - Install new application

IaaS, PaaS, SaaS

❖ IaaS Procedures



IaaS, PaaS, SaaS

❖ IaaS Benefits

- Flexible and Efficient Renting of Computer & Server Hardware
  - Virtual Desktops
  - Rentable Resources
    - VM, Storage, Bandwidth, Firewalls, IP Addresses, Monitoring Services, etc.
  - Rent Payment Basis
    - Resource type
    - Usage time
    - Service packages

IaaS, PaaS, SaaS

❖ IaaS Benefits

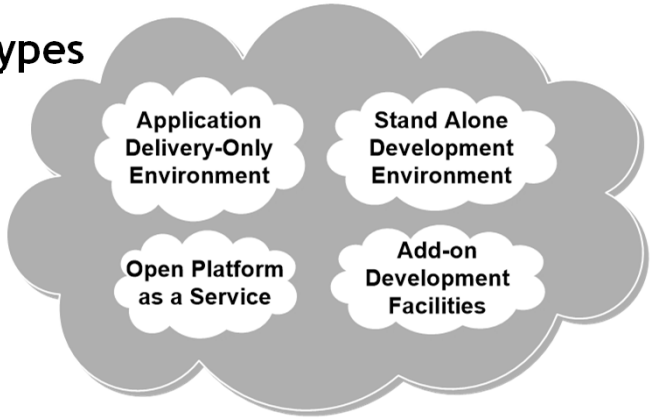
- Portability & Interoperability with Legacy Applications
- Enables portability based on infrastructure resources that are used through Internet connections
- Enables a method to maintain interoperability with legacy applications and workloads between IaaS clouds

IaaS, PaaS, SaaS

❖ PaaS (Platform as a Service)

- Provides development & deployment tools for application development

❖ PaaS Types



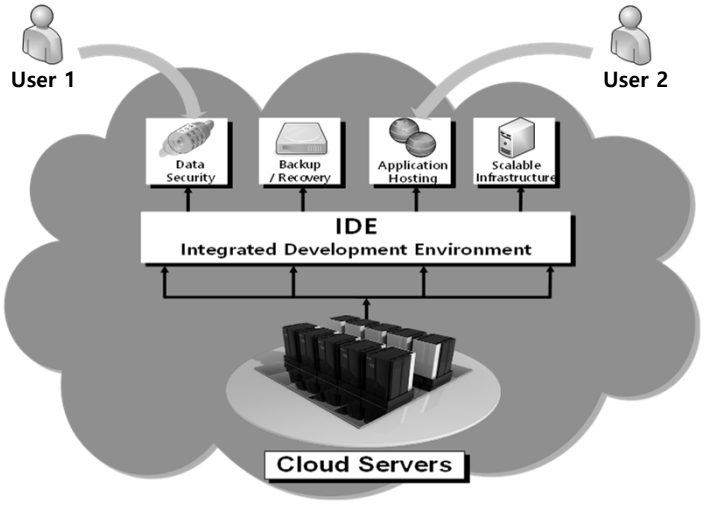
IaaS, PaaS, SaaS

❖ PaaS Types

- Application Delivery-Only Environment
  - Provides on-demand scaling & application security
- Stand-Alone Development Environment
  - Provides an independent platform for a specific function
- Open Platform as a Service
  - Provides open source software to run applications for PaaS providers
- Add-On Development Facilities
  - Enables customization to the existing SaaS platforms

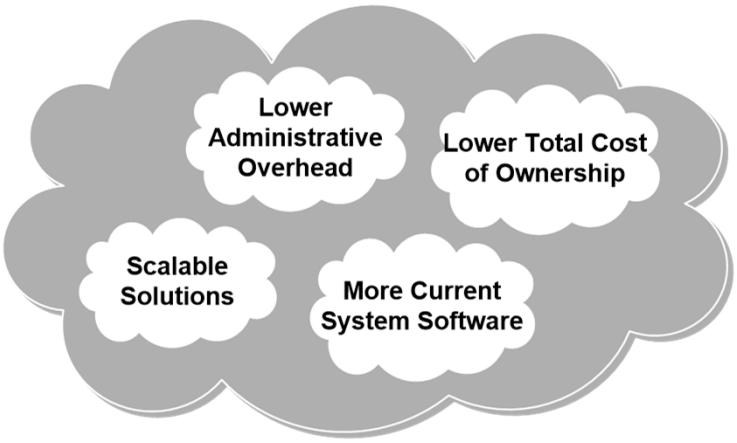
IaaS, PaaS, SaaS

❖ PaaS Runtime Environment for Apps



IaaS, PaaS, SaaS

❖ PaaS Benefits



IaaS, PaaS, SaaS

❖ PaaS Benefits

- Lower Administrative Overhead
  - User does not need to be involved in any administration of the platform
- Lower Total Cost of Ownership
  - User does not need to purchase any hardware, memory, or server

IaaS, PaaS, SaaS

❖ PaaS Benefits

- Scalable Solutions
  - Application resource demand based automatic resource scale control
- More Current System Software
  - Cloud provider needs to maintain software upgrades & patch installations

IaaS, PaaS, SaaS

❖ SaaS (Software as a Service)

- Provides software applications as a service to the user
- Software that is deployed on a cloud server which is accessible through the Internet

IaaS, PaaS, SaaS

❖ SaaS Characteristics

- On Demand Availability
  - Cloud software is available anywhere that the cloud is reachable via Internet
- Easy Maintenance
  - No user software upgrade or maintenance needed
    - ➔ All supported by the cloud
- Flexible Scale Up or Scale Down
  - Centralized Management & Data

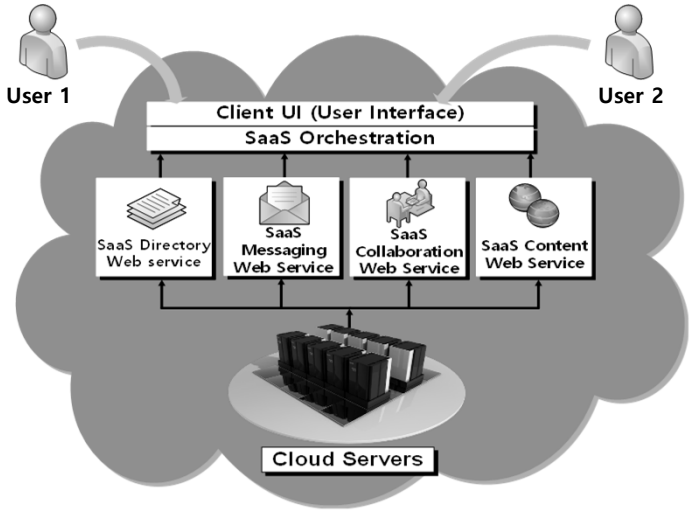
IaaS, PaaS, SaaS

❖ SaaS Characteristics

- Enables a Shared Data Model
  - Multiple users can share a single data model and database
- Cost Effectiveness
  - Pay based on usage
  - No risk in buying the wrong software
- Multitenant Programming Solutions
  - Multiple programmers are ensured to use the same software version
    - ➔ No version mismatch problems

IaaS, PaaS, SaaS

❖ **Open SaaS Applications**



Cloud Technology

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  - MobileMe Logo, By Apple Inc. [Public domain], via Wikimedia Commons

Course Title

IoT Wireless & Cloud Emerging Technologies

❖ **Modules**

- 1. IoT Business & Products
- 2. IoT Architecture & Technologies
- 3. IoT Networks
- 4. Wi-Fi & Bluetooth
- **5. Cloud Technology**
- 6. IoT Bluetooth & Wi-Fi and EC2 Cloud Projects

Cloud Technology

Cloud Market Analysis

Cloud Market Analysis

❖ 2017 Cloud Infrastructure Services

From mainframe to cloud
Article ResearchGate· January 2014
B. Radenlovic, Pertar Kocovic

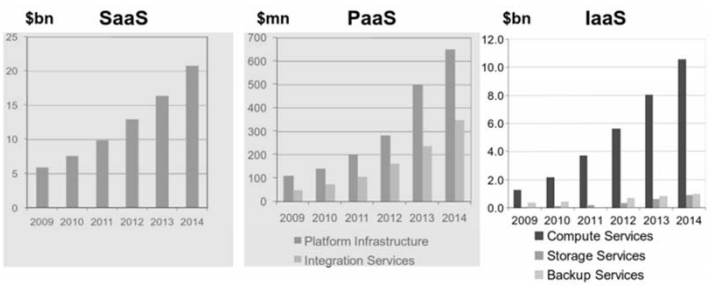

Figure 5. Cloud market per segment: SaaS, PaaS, IaaS

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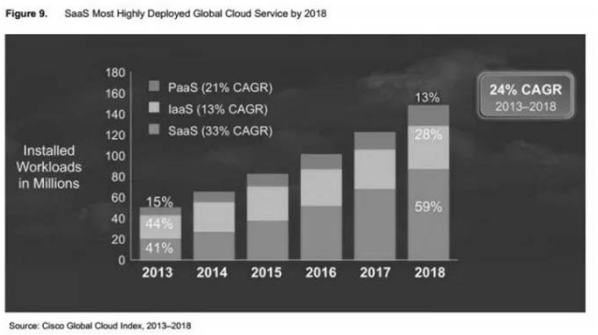
Cloud Market Analysis

❖ 2017 Cloud Infrastructure Services

Top Ten Reasons to Leverage SaaS for Your Business
Posted on August 19, 2016 by Nathaniel Lewis in Best Practices, Cloud Best Practices

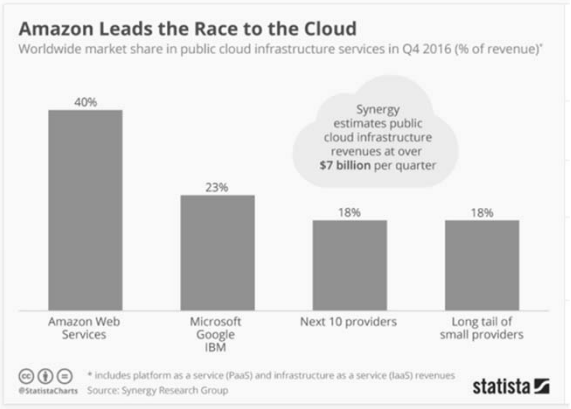


Reference :https://solutionsreview.com/devops/2016/08/19/top-ten-reasons-leverage-saas-business/

Cloud Market Analysis

❖ 2017 Cloud Infrastructure Services

Amazon Leads the Race to the Cloud
by Felix Richter, Feb 8, 2017



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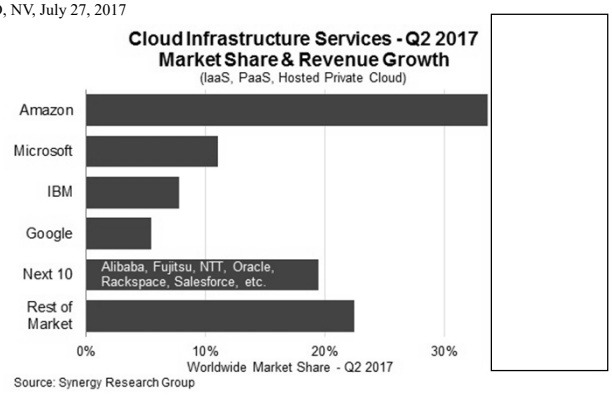
Cloud Market Analysis

❖ 2017 Cloud Infrastructure Services

The Leading Cloud Providers Continue to Run Away with the Market
RENO, NV, July 27, 2017



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Cloud Market Analysis

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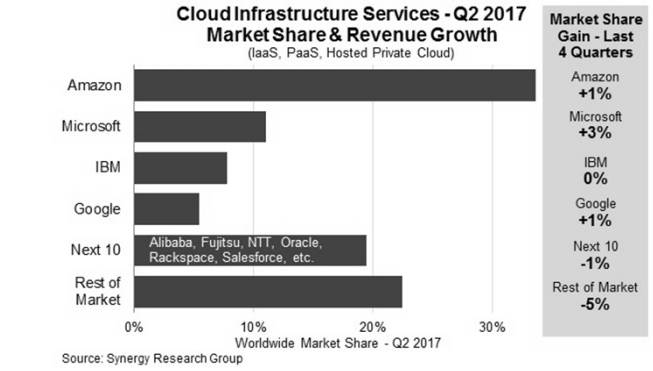

Reference :https://www.srgresearch.com/articles/leading-cloud-providers-continue-run-away-market

Cloud Technology

Top Cloud Companies & Services

Top Cloud Companies & Services

❖ **Top Cloud Provider Companies**

- Amazon Web Service 

- Microsoft 

- IBM 

- Google 

Cloud Technology

AWS

Top Cloud Companies & Services

❖ **AWS**

- AWS (Amazon Web Service)
- The #1 Cloud Corporation (1^{st} > 2^{nd}+3^{rd}+4^{th})
- Launched in 2006
- AWS global cloud-based products
  - Computing, Storage, Databases, Analytics
  - Networking, Mobile, IoT, Management, Security
  - Developer & Management tools, Enterprise Apps.

Top Cloud Companies & Services

❖ **AWS**

- Amazon EC2 (Amazon Elastic Compute Cloud)
  - Web services that provides Cloud computations
  - Secure
  - Resizable
  - Developer tools are provided
    - Supports failure resilient application development
    - Helps to eliminate common failure scenarios

Top Cloud Companies & Services

❖ AWS

- Amazon S3 (Simple Storage Service)
  - Security and Access Management
    - Includes several mechanisms to control and monitor who can access your data
    - Can easily control how, when, and where your data is accessible
    - Secure connections using VPC (Virtual Private Cloud) endpoints
      - Does not need a gateway or NAT instances

Top Cloud Companies & Services

❖ Amazon S3

- Public web service original releases
  - United States in March 2006
  - Europe in November 2007
- Provides storage through web service interfaces
  - REST
  - SOAP
  - BitTorrent

Top Cloud Companies & Services

❖ Amazon Cloud Drive

- Amazon Cloud Drive was released in March 2011
- Web storage application from Amazon
- Storage Space Characteristics
  - Allowed access from up to 8 devices
    - Multiple mobile devices & different computers
    - Access permitted using different browsers on the same computer

Top Cloud Companies & Services

❖ Amazon Cloud Drive

- Cloud Player (Originally bundled)
  - Users can play music in their Cloud Drive from any computer or Android device
  - Music browsing based on song titles, albums, artists, genres (website only), and playlists

Top Cloud Companies & Services

- **Amazon Cloud Drive Options**
  - Unlimited Photos
    - Unlimited storage for photos & raw data files
    - Multi-gigabyte video storage capacity
  - Unlimited Everything
    - Unlimited storage for photos, videos, documents, and various files types

Cloud Technology

Microsoft

Top Cloud Companies & Services

❖ Microsoft

- The #2 Cloud Corporation
- Launched in 1975
- Microsoft develops, manufactures, licenses, supports, and sells computer software, consumer electronics, personal computers, and services
- In 2014, the company started to scale back on hardware development and started to focus more on Cloud technology

Top Cloud Companies & Services

❖ Microsoft

- Microsoft Office 365
  - Cloud-based subscription service
  - Combines apps (like Excel and Outlook) with cloud services (like OneDrive and Microsoft Teams)
  - Enables users to create and share anywhere on any device

Top Cloud Companies & Services

❖ Microsoft

- Microsoft Azure
  - Compute, Networking, Storage, Web, Mobile, Database, Data analysis, etc.
  - Users can access, build, and deploy cloud technology wherever needed
  - Hybrid cloud technology
  - Helps to develop data-driven intelligent apps
  - Advantages in Microsoft security, privacy, transparency, and computer compliances

Cloud Technology

IBM

Top Cloud Companies & Services

❖ **IBM**

- IBM (International Business Machines) Corporation
- The #3 Cloud Corporation
- Supports public, private, and hybrid clouds
- Offers more than 130 unique services
  - IaaS (Infrastructure as a Service)
  - PaaS (Platform as a Service)
  - SaaS (Software as a Service)

Top Cloud Companies & Services

❖ **IBM's Main Service**

- IBM Cloud Object Storage
  - Supports data storage, management, and controlled access
  - Direct application connection to Object Storage and integration to IBM Cloud services
  - Supports Self-Service Portals & REST APIs
    - REST: Representational State Transfer
    - API: Application Programming Interface

Top Cloud Companies & Services

❖ IBM's Main Service

- IBM Cloud Private
  - Transformative platform used in building (or modernizing) cloud applications
  - Pre-packaged enterprise-class solution
  - Provides enhanced security, speed, and control
- IBM Cloud Streaming Video
  - Provides solutions that simplify workflow management and video streaming
  - B2B (Business to Business) based video services support

Cloud Technology

Google

Top Cloud Companies & Services

❖ **Google**

- The #4 Cloud Corporation
- Launched in 1998
  - Google Search is the most dominant search engine in the United States market, with a market share of 65.6%
- In 2011, Google started the Google Cloud Platform

Top Cloud Companies & Services

❖ **Google**

- Google Compute Engine
  - Provides IaaS based VMs (Virtual Machines)
    - VMs run in Google's data centers
  - Provides cloud tools and workflow support
  - Enables scalable global services based on advanced load-balancing cloud technology

Top Cloud Companies & Services

❖ Google Cloud

- Google App Engine
  - Released as a preview in April 2008
  - PaaS (Platform as a Service) for web applications
  - Provides automatic scaling based on resource demands and server load
- Google Cloud Storage
  - Launched in May 2010
  - Online file storage service

Top Cloud Companies & Services

❖ Google Cloud

- Google BigQuery
  - Released in April 2012
  - Data analysis tool that uses SQL-like queries to process big datasets in seconds
- Google Compute Engine
  - Released in June 2012
  - IaaS (Infrastructure as a Service) support to enable on demand launching of VMs (Virtual Machines)

Top Cloud Companies & Services

❖ Google Cloud

- Google Cloud Endpoints
  - Released in November 2013
  - Tool to create services inside App Engine
  - Easily connects from Android, iOS, and JavaScript clients
- Google Cloud DNS (Domain Name System)
  - DNS service supported by the Google Cloud

Top Cloud Companies & Services

❖ Google Cloud

- Google Cloud Datastore
  - NoSQL (No Structured Query Language) data storage
- Google Cloud SQL (Structured Query Language)
  - Released in February 2014 as GA (General Availability)
  - Fully managed MySQL database

Top Cloud Companies & Services

❖ Apple's iCloud

- Developed by Apple, Inc.
- Public release in October 2011
- Cloud Storage & Cloud Computing
- OS (Operating System)
  - OS X (10.7 Lion or later)
  - Microsoft Windows 7 or later
  - iOS 5 or later

Top Cloud Companies & Services

❖ iCloud replaces MobileMe

- Subscription-based collection of Apple's online services and software
- MobileMe was replaced by iCloud
  - MobileMe ceased services in June 2012
  - MobileMe users were allowed transfers to iCloud until July 2012

Top Cloud Companies & Services

❖ iCloud Features

- Email, Contacts, and Calendars
- Find My Friends
- Backup & Restore
  - Back up feature for device settings & data
  - iOS 5 or later required
- Find My iPhone
  - Enables a user to track the location of an iOS device or Mac
  - Formerly a feature of MobileMe

Top Cloud Companies & Services

❖ iCloud Features

- Can manage lost or stolen Apple devices
- Back to My Mac
  - Enables remote log in to other computers that have Back to My Mac installed (using the same Apple ID)
- iWork for iCloud
  - Apple's iWork suite (Pages, Numbers, and Keynote) made available on a web interface

Top Cloud Companies & Services

❖ iCloud Features

- Photo Stream
  - Can store (most recent) photos
  - Free storage (with day limit)
- iCloud Photo Library
  - Stores all photos at original resolution
  - Stores photo metadata
- Storage
  - First introduced in 2011
  - Free storage per account

Top Cloud Companies & Services

❖ iCloud Features

- iCloud Drive
  - Can save photos, videos, documents, and apps
- iCloud Keychain
  - Secure database for Website and Wi-Fi password
  - Secure Credit card & Debit card management for quick access and auto-fill

Top Cloud Companies & Services

❖ iCloud Features

- iTunes Match
  - iTunes music library scan and match tracks function
  - Serves tracks copied from CDs or other sources

Cloud Technology

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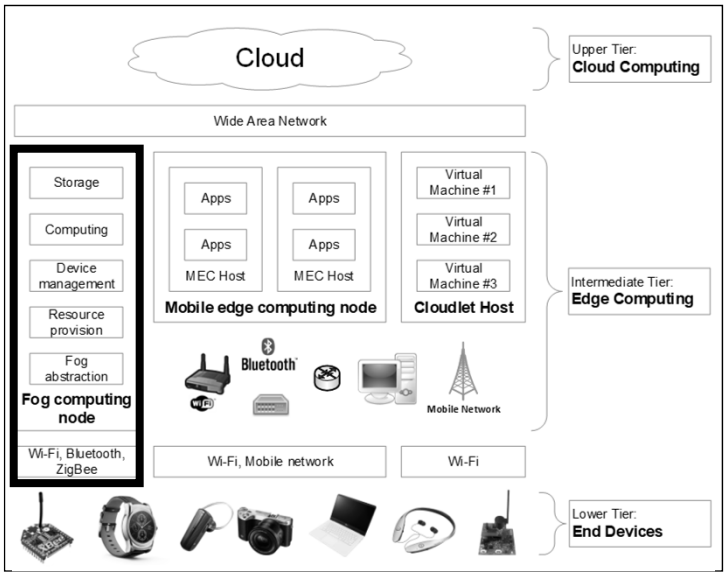
Cloud Technology

Fog Computing

IoT & Mobile Cloud Technology



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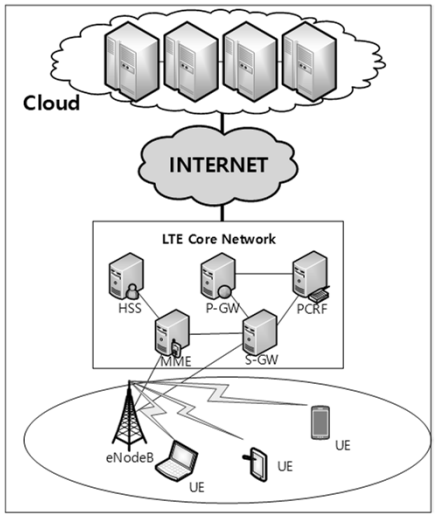
❖ Fog Computing



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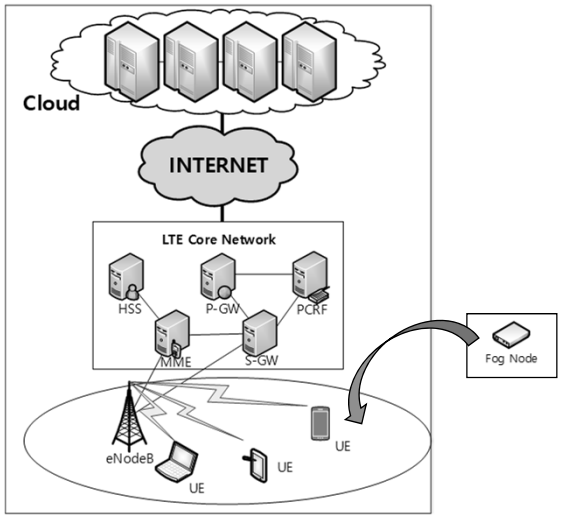
❖ Fog Computing



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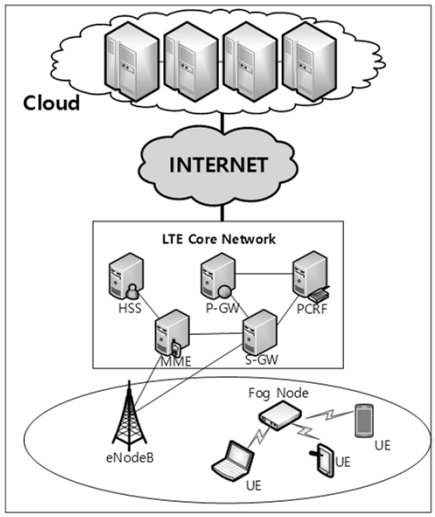
❖ Fog Computing



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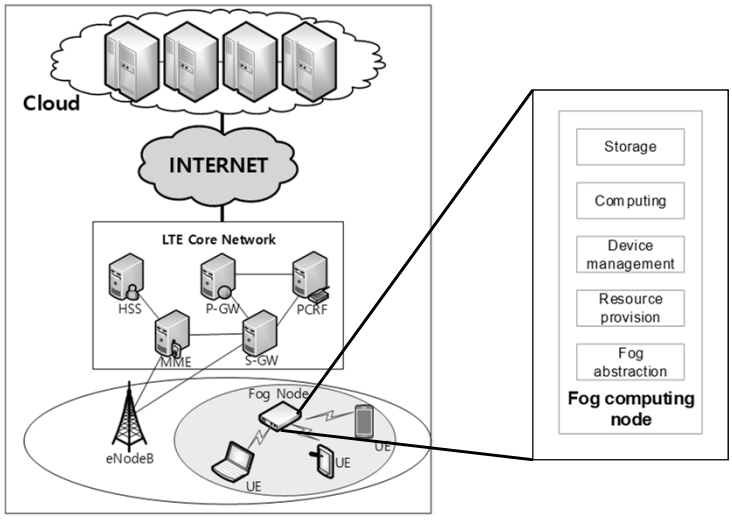


IoT & Mobile Cloud Technology

❖ Fog Computing Definition

- Fog Computing or Fog Networking
- Uses one or more collaborative end-user Clients or near-user Edge devices
- Fog support services
  - Substantial amount of storage
    - Instead of storing in a cloud data center
  - Communications
    - Instead of routing over the Internet backbone

IoT & Mobile Cloud Technology

❖ Fog Computing Definition

- Fog Computing or Fog Networking
- Uses one or more collaborative end-user Clients or near-user Edge devices
- Fog support services
  - Control, configuration, measurement and management
    - Instead of being controlled by Internet gateways or LTE S-GWs or the P-GW

IoT & Mobile Cloud Technology

❖ Fog Computing Characteristic

- Decentralized Computing infrastructure is based on FCNs (Fog Computing Nodes)
- FCNs can be placed anywhere between the end devices and cloud
- FCNs are heterogeneous in nature, and can include various functional elements
  - Routers, switches, AP (Access Point), IoT gateways, set-top box, etc.

IoT & Mobile Cloud Technology

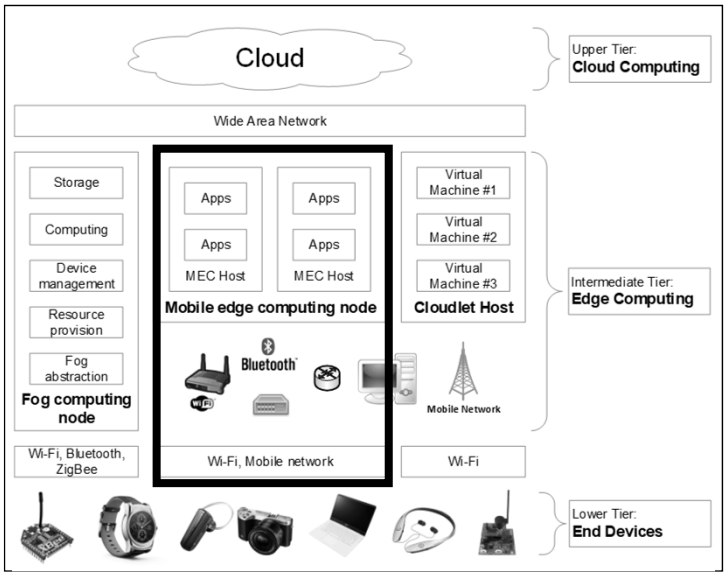
❖ Fog Computing Characteristic

- FCN heterogeneity enables support for different protocols as well as IP and non-IP based access to Cloud services
- Uniform Fog abstraction layer has functions to support resource allocation, monitoring, security, device management, storage, and compute services for various types of end devices

Cloud Technology

MEC (Mobile Edge Computing)

IoT & Mobile Cloud Technology



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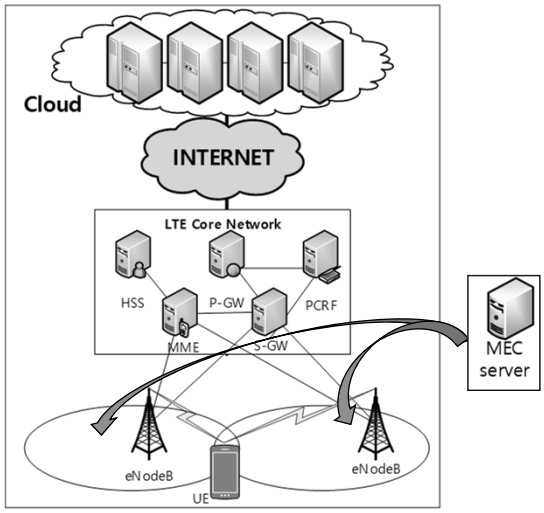

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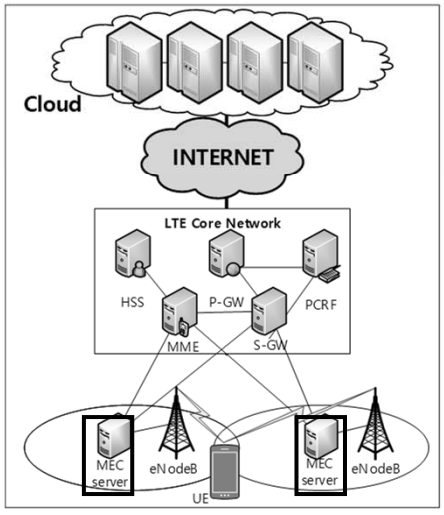

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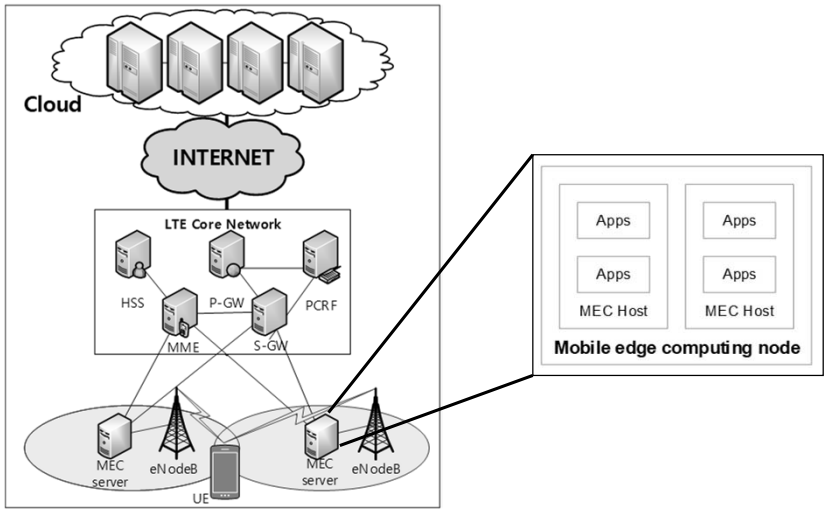


IoT & Mobile Cloud Technology

❖ MEC (Mobile Edge Computing) Definition

- MECs enable cloud computing and IT services at the edge of the mobile cellular network
- Why use MECs?
  - Faster cloud services to mobile UEs
  - Reduces network congestion
  - More reliable application support

IoT & Mobile Cloud Technology

❖ MEC Characteristics

- MECs enable cellular operators to open their RAN (Radio Access Network) to authorized third-parties (e.g., application developers, content providers, etc.)
- MEC servers offer real-time information
  - Network information (e.g., network load and capacity)
  - Information on the end devices connected to the servers (e.g., location information, etc.)

IoT & Mobile Cloud Technology

❖ MEC Characteristics

- MEC nodes (or servers) are usually co-located with a RNC (Radio Network Controller) or macro BS (Base Station)
  - eNB BS in LTE and LTE-A 4G networks
  - gNB BS in 5G networks
- Servers may run multiple MEC Hosts
- MEC Hosts can perform computation and storage through virtualized interfaces

IoT & Mobile Cloud Technology

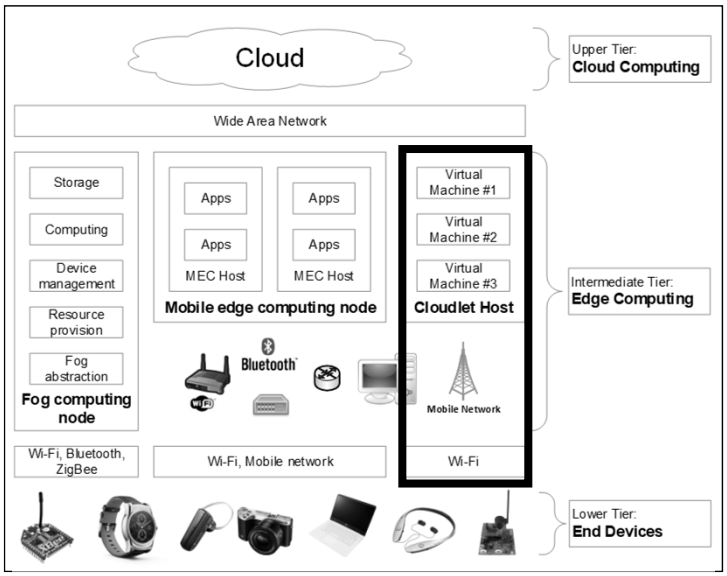
❖ MEC Controller

- MEO (Mobile Edge Orchestrator)
  - Manages MEC hosts
  - Controls information flow for services offered by each MEC host
  - Controls resources and network topology
  - Manages the Mobile Edge applications

Cloud Technology

Cloudlet

IoT & Mobile Cloud Technology



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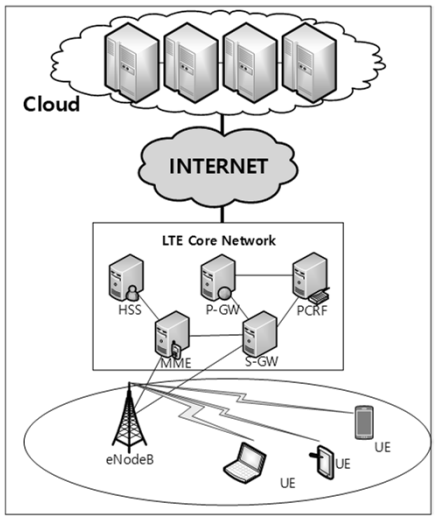

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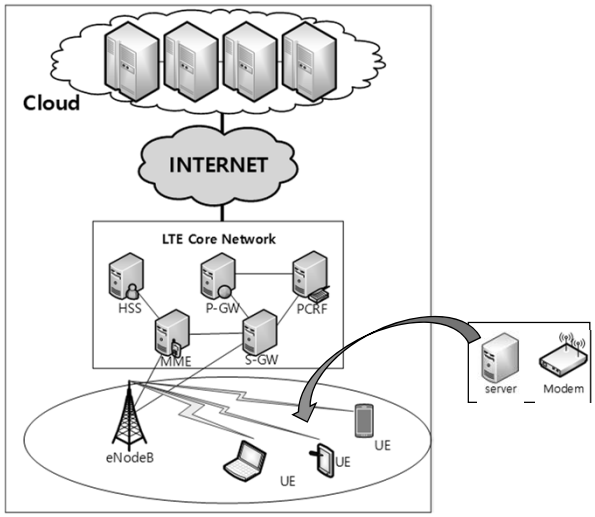

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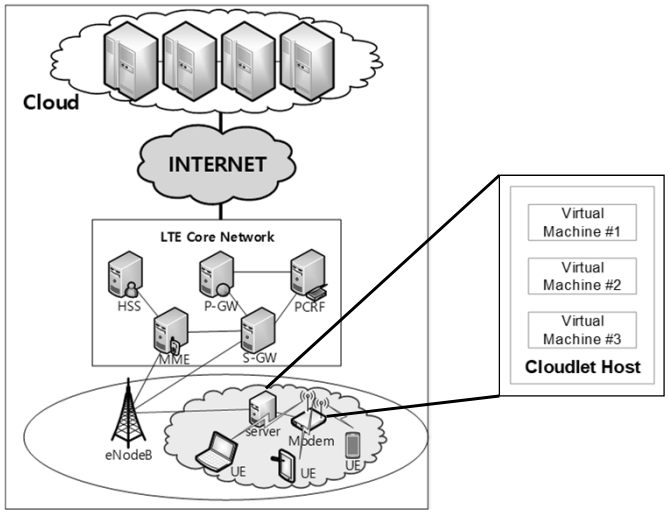

IoT & Mobile Cloud Technology

❖ Cloudlet Definition

- Mobility-enhanced small-scale cloud data center
- Located at the edge of the Internet nearby the mobile devices
- Supporting resource-intensive and interactive mobile applications
- Provides powerful computing resources to mobile devices with low latency

IoT & Mobile Cloud Technology

❖ Cloudlet Definition

- Used between UE ↔ Cloudlet ↔ Cloud
- Cloudlet is a data center in a box that brings the cloud closer to the UE
- Cloudlets use a VM (Virtual Machine) to provision resources for UEs in real-time over Wi-Fi networks
  - Direct one-hop Cloud access ➔ Low latency

IoT & Mobile Cloud Technology

❖ Cloudlet Architecture: 3 Layers

- Cloudlet layer
  - Group of co-located nodes
  - Managed by a Cloudlet Agent
- Node layer
  - Multiple Execution Environment(s) running on top of the OS (Operating System)
  - Managed by a Node Agent
- Component layer
  - Includes a set of services that interface to the (higher layer) execution environment

IoT & Mobile Cloud Technology

❖ Compare of Fog Computing, MEC, Cloudlet

	Fog Computing	Mobile Edge Comp.	Cloudlet Computing
Node Device	Routers, Switches, Access points, Gateways	Servers running in base stations	Data center in a box
Node location	Varying between end devices & cloud	Radio network controller/ Macro base station	Local/outdoor installation
Software Architecture	Fog abstraction layer	Mobile orchestrator	Cloudlet agent
Context Awareness	Medium	High	Low
Proximity	One or multiple hops	One hop	One hop
Access Mechanisms	Bluetooth, Wi-Fi, Mobile networks	Mobile networks	Wi-Fi
Internode Comm.	Supported	Partial	Partial

IoT & Mobile Cloud Technology

❖ Compare of Fog Computing, MEC, Cloudlet

Physical proximity	High	Fog computing, Cloudlet computing
	Low	Mobile edge computing
Power consumed	High	Mobile edge computing
	Low	Fog computing, Cloudlet computing
Computation time	High	Fog computing
	Low	Mobile edge computing, Cloudlet computing
Context awareness	High	Mobile edge computing
	Low	Fog computing, Cloudlet computing
Logical proximity	Ensured	Cloudlet computing
	Maybe	Fog computing, Mobile edge computing
Non-IP support	Yes	Fog computing
	No	Mobile edge computing, Cloudlet computing

Cloud Technology

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Cloud Technology

IoT & Mobile Cloud Technology

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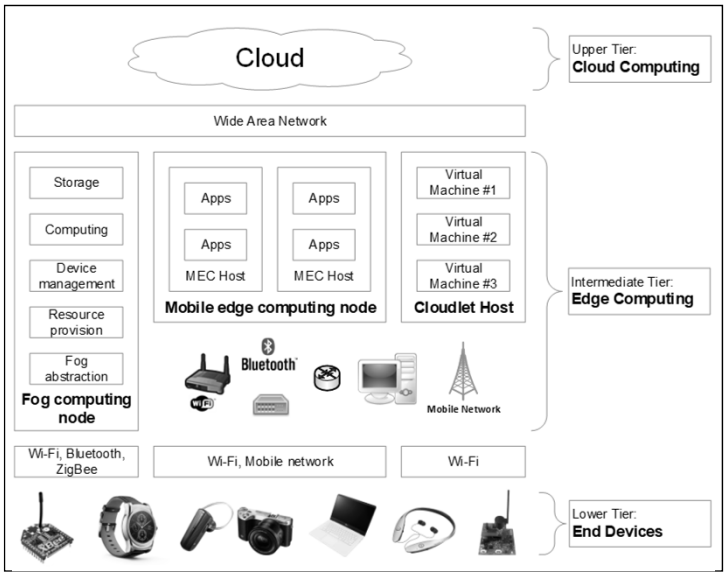

Cloud Technology

MCC (Mobile Cloud Computing)

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❖ **Trends in Cloud Computing**

- User requirements for high data rates and QoS (Quality of Service) are exponentially increasing
- Technological evolutions in smartphones, IoT devices, sensors, and actuators enable new highly advanced services and apps
- New IoT and mobile devices have more powerful CPUs (Central Processing Units)

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❖ **Issues in Cloud Computing**

- However, CPUs are not sufficient to process all data and provide results in time
- Optimal decisions based on comprehensive SA (Situational Awareness) are needed
- Not all data is available at a node
- Collected data size is too big to compute at one node
- Limited battery energy restricts fast & large amounts of computing

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❖ **MCC (Mobile Cloud Computing)**

- MCC (Mobile Cloud Computing) allows cloud computing to mobile and IoT users
- UE (User Equipment) and IoT systems can use power computing and storage resources of a distant CC (Centralized Cloud) through a CN (Core Network) of a mobile operator and the Internet

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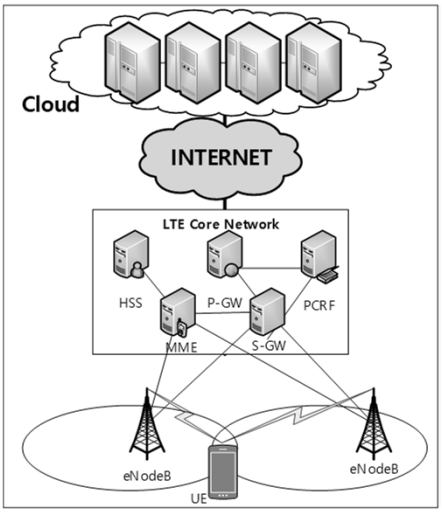
❖ MCC over LTE Networks



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❖ MCC (Mobile Cloud Computing)

- MCC Major Advantages
  1. Extends battery lifetime by Offloading energy consuming computations to the cloud
  2. Enables faster sophisticated application support (i.e., IaaS, PaaS, SaaS) to mobile users and IoT systems
  3. Provides massive data storage to mobile users and IoT systems

Cloud Technology

Edge Computing

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❖ Comparing MCC & Edge Computing

- Conventional MCC
  - Cloud services to the mobile device are accessed via the Internet connection
  - Conventional MCC Characteristics
    - Long delay time & QoS performance
    - High usage of the network resources
    - High battery usage of IoT & Smart Devices
    - Significant packet interarrival time jitter
      - Large DBV (Delay Bound Violation) for real-time multimedia services

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❖ Comparing MCC & Edge Computing

- Edge Computing
  - Computing & storage resources are moved closer to the edge (i.e., near the BS (Base Station) or AP (Access Point)) of the network closer to the UE
  - Edge Computing Characteristics
    - Very short delay time with high QoS support
    - Low usage of the network resources
    - Low battery usage of IoT & Smart Devices
    - More Complex: Prediction and pre-fetching of contents and control functions needed

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❖ Comparing MCC & Edge Computing

Technical Aspect	MCC	Edge Computing
Deployment	Centralized	Distributed
Distance to the UE	Far	Close
Latency	Long	Short
Jitter	High	Low
Computational Power	Abundant	Limited
Storage Capacity	Abundant	Limited

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