**CH 7: Edge Computing & IoT**

**Mobile Cloud Computing (MCC)**

As mobile applications, mobile platforms and end user demands grow, there are some limitations on mobile resources such as: Computation, storage capacity, energy, and shared wireless medium.

**Mobile devices challenges:** Need further improvements of application quality of service (QoS), guarantee service reliability/availability and information privacy.

﻿**Mobile Cloud Computing (MCC):** is the integration of cloud computing with mobile devices to make mobile devices resource-full in terms of computational power, memory, storage, and energy. an infrastructure where both the data storage and data processing happen outside of the mobile.

■ 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.

■ Cloud controllers process the requests to provide users with the corresponding cloud services.

﻿**Advantages of MCC**

1. **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).

■ Many mobile applications take advantages from task migration and remote processing.

﻿**2. 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 apps are not constrained by storage on the devices as their data is stored on the cloud.

﻿**3. 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, they are always available even when the users are moving.

**4. Dynamic Provisioning:**

■ Dynamic on-demand provisioning of resources on a fine-grained, self-service basis.

**5. Scalability:**

■ Mobile applications can be performed and scaled to meet the unpredictable user demands

Service providers can easily add and expand a service.

﻿**6. Multi-Tenancy:**

■ Service providers can share resources and costs to support a variety of apps and many users.

**7. Ease of Integration:**

■ Services from different providers can be integrated through cloud and the Internet as demanded.

﻿**Mobile Commerce:**

■ M-commerce allows business models for commerce using mobile devices.

■ Examples: Mobile financial, mobile advertising, mobile shopping...

■ M-commerce apps face various challenges(low bandwidth, high complexity of devices, security..)

■ Integrated with cloud can help address these issues

■ Example: Combining 3G (Now 4G, 5G) and cloud to increase data processing speed and security.

**Mobile Learning:**

■ M-learning combines e-learning and mobility.

■ limitations: High cost of devices/network, Low transmission rate, Limited educational resources

■ Cloud-based M-learning can solve these limitations by: Enhanced communication quality between students and teachers, help learners access remote learning resources, A natural environment for collaborative learning.

**﻿Mobile Healthcare:**

**M-healthcare:** to minimize the limitations of traditional medical treatment (e.g., small storage, security/privacy, medical errors), provides mobile users with convenient access to medical resources, offers 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).

**Mobile Gaming:**

■ M-game is a high potential market generating revenues for service providers.

■ Can completely offload game engine requiring large computing resource to the server in cloud.

■ Computation offloading can also save energy and increase game playing time

■ Rendering adaptation technique can dynamically adjust the game parameters based on

communication constraints and gamers' demand.

﻿**Assistive Technologies:**

■ Pedestrian crossing guide for blind and visually impaired

■ Mobile currency reader for blind and visually impaired, Lecture transcription for hearing impaired.

**Other Applications:**

■ Sharing photos/videos, Keyword-based, voice-based, tag-based searching

■ Monitoring a house, smart home systems

﻿**MCC Issues**

**1. Mobile Communication Issues:**

■ Low bandwidth: as radio resource for wireless networks is much rarer and weaker than wired.

■ 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 (ways-on connectivity, on-demand scalability, energy efficiency) is difficult.

﻿**2. 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 the computation and which portions of the service codes to offload.

■Offloading in static env: partitioning based on estimation of energy use before execution.

■Offloading in dynamic env: Changing connection status and bandwidth in run time is harder as: Environment changes cause additional problems and transmitted data may not reach destination.

**3. 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).

**4. Network Access Management:**

■Efficient network access management improves link performance, optimizes bandwidth usage.

■Cognitive Radio (CR) can be expected as a solution to achieve the wireless access management.

•CR is a form of wireless communication in which a transceiver can intelligently detect which communication channels are in use and which ones are not.

•CR can automatically change its transmission or reception parameters, such that the wireless communications can have spectrum agility in terms of selecting available wireless channels.

•Integrated CR with MCC for better spectrum utilization.

**5. Quality of Service (QoS):**

■CloneCloud; clone entire set of data and apps from the phone onto the cloud and to selectively execute some operations on the clones, reintegrating the results back into the smartphone.

■CloneCloud is expected to reduce the network delay, uses nearby computers or data centers to increase the speed of smart phone applications.

**6. 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.

■The business model including pricing and revenue sharing must be carefully developed for MCC.

**7. Standard Interface:**

■Interoperability becomes an important issue when mobile users need to interact with the cloud.

■Web interfaces are not the best option, not designed for mobile, may have more overhead.

■Compatibility among mobile devices for web interface could be an issue, Standard protocol, signaling, and interface for interacting between mobile and cloud is required. (e.g., HTML5 & CSS3).

**8. Service Integration:**

■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. A new scheme is needed in which the mobile users can utilize multiple clouds in a unified fashion. The scheme should be able to automatically discover and compose services for the user.

■Sky Computing is a model where resources from multiple clouds providers are leveraged to create a large-scale distributed infrastructure.

■Mobile Sky Computing (Multi-Cloud) 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.

**Internet of Things (IOT)**

■IOT: interaction and communication between billions of devices that produce, and exchange data related to real-world objects.

■ IOT introduces new challenges that cannot be adequately addressed by centralized cloud compute architecture, such as:

•Stringent latency, •Capacity constraints, •Resource-constrained devices,

•Uninterrupted services with occurring at irregular intervals connectivity, and •Enhanced security

■IoT apps generate enormous amounts of data (Big Data) by loT sensors which needs to analyze to determine reactions to events or to extract analytics or statistics. Sending all data to the Cloud will require high network bandwidth.

■In Edge computing, massive data generated by different kinds of loT devices can be processed at the network edge instead of transmitting it to centralized Cloud to solve bandwidth, latency and energy consumption concerns, so; Services could be provided with faster response and greater quality comparing to cloud computing.

**Edge Computing**

■The traditional centralized cloud computing challenges:

•High latency, •Low Spectral Efficiency (SE), and• Non-adaptive machine type of communication.

■Edge Computing technologies:

• Cloudlets, • Mobile Edge Computing (MEC), and • Fog Computing.

■Edge Computing is more suitable to be integrated with loT to provide efficient, fast, and secure services So, Edge computing-based architecture can be considered for the future loT infrastructure

■ Software Defined Networking (SDN) and Network Function Virtualization (NFV) concept are proposed as emerging solutions for the future network. NFV enables Edge devices to provide computing services and operate network functions by creating multiple virtual machines (VMs).

■ Ultra-low latency is one of the major requirements of the (5G) Radio Access Networks (RANS)

﻿■ computing capabilities of wearable watches, smart phones, and other loT devices have been significantly improved. but still constrained by the fundamental challenges, such as: Memory size, battery life, heat consumption.

■ Edge computing systems should integrate with cloud environments, to create a Hybrid Edge-Cloud infrastructure.

■ Apps, data, logs generated at the edge should be linked back to the cloud, if private or public.

■ Likewise, resources that exist primarily in the cloud should be tied back to the edge, to ensure

production continues even if the cloud disappears for a time.

**1.Cloudlets Technology**

A diagram of cloud layers

Description automatically generated■ 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.

■ Cloudlet is a mobility-enhanced small-scale cloud data center located at the edge of the internet. Support low-latency requirements for resource-intensive and interactive mobile applications.

**Cloud data center and Cloudlet:**

1. Cloudlet needs to be more agile in their provisioning because of the association with highly dynamic mobile devices due to user mobility.

2. To support user mobility, VM handoff technology needs to be used to seamlessly migrate offloaded services from the first cloudlet to the second cloudlet as a user moves away from the currently associated cloudlet.

3. Since cloudlets are small data centers distributed geographically, a mobile device first must discover, select, and associate with the appropriate cloudlet among multiple before provisioning.

**VM handoff**: a technique for seamlessly transferring VM encapsulated execution to a more optimal offload site as users move.

**Principle of Cloudlet: VM overlay (VM Synthesis)**

■ During VM migration from Cloudlet to another, If the base VM exists on the cloudlet, only its difference relative to the desired custom VM, needs to be transferred.

■ The VM overlay approach is used to provisioning cloudlets and VM handoff.

**Applications of Cloudlet**

■ by leveraging a low latency, the real-time interaction can be implemented on wearable cognitive assistance.

■ By real-time data analysis at the edge of internet, cloudlets can reduce ingress bandwidth into the Cloud

■ By serving as physically proximate representatives of the cloud that are unavailable due to failures or cyber-attacks, cloudlets can improve robustness and availability in hostile environment.

■ cloudlets can enable mobile access to the huge legacy world of Windows-based desktop apps.

**2. MOBILE EDGE COMPUTING (MEC)**

■ Current cloud computing is unable to meet the requirements of low latency, location awareness, and mobility support.

■ MEC: new technology that provides an IT service environment and cloud-computing capabilities at the edge of the mobile network, within the Radio Access Network (RAN) and near mobile subscribers, MCC turns into a problem for communication-intensive applications.

■ Therefore, by deploying a service on a MEC platform the following metrics are improved:

Latency, energy efficiency, network throughput, system resource footprint and quality.

■ MEC is a decentralized computing concept in which computing resources and app services distribute along the communication path from the point storing data to Base Stations (BSS) in wireless networks.

• MEC is known as multi-access computing

■ MCE enhance performance, higher bandwidth, lower latency, and faster response times and decision-making, allows different apps and mobile devices to respond, process data and make informed decisions in a near real-time manner as soon as data is created to eliminate the lag delay.

■ MEC offers local storage that process data without putting it in a remote public cloud (security).

■ MEC enables many apps and services for multiple sectors, such as consumer, enterprise, health.

■ MEC is a one solution for handing video streaming services in context of smart cities by locally processing and analyzing the Video streams receiving form the monitoring devices to extract data.

■ MEC can be used to support Augmented Reality (AR) mobile application by processing the collected data on a local MEC server instead of a centralized server.

■ MEC can be used to collect, classify, and analyze loT data streams.

**3. FOG COMPUTING**

Fog computing: a decentralized computing infrastructure in which data, compute, storage and applications are located somewhere between the data source (Things) and the cloud.

■ Like Edge computing, Fog computing brings the advantages and power of the cloud closer to where data is created and acted upon.

■ A set of sensors and actuators at the edge of the network in an app scenario are connected to the Fog nodes via a multitude of interfaces, such as PCIe, USB, Ethernet, etc.

﻿**Data Locality**

•Keep the needed Information very close to CPU, •Arrange the storages to increase CPU Locality •Locality increases computer speed.

■ There are often three tiers in a Fog computing system, but more tiers can be allowed for the special application scenario:

• At the edge of the network, Fog nodes are typically focused on sensor data acquisition/collection, data normalization, and command/control of sensors and actuators, and focused less on processing, communications, and storage.

• At the next higher tier, Fog nodes are focused on data filtering, compression, and transformation.

• At the higher tiers near the backend cloud, Fog nodes are focused on aggregating data and turning data into knowledge.

■ Fog nodes provide localized services deployed in different locations, while cloud provides global services and acts as a central controller for those distributed Fog nodes.

■ In addition, the cloud is like a central information repository from which the Fog nodes get the requested information for their own caches to serve subsequent requests locally.

■ Thus, there is an essential interaction between Fog nodes and cloud, and many applications require both Fog localization and cloud globalization.

■ Cloud and Edge computing complement each other to form a mutually beneficial and inter-dependent service continuum.

■ Some functions are naturally more advantageous to carry out in centralized cloud, while others are better suited to the Edge.

■ Fog computing as an improved, eco-friendly computing platform that can support loT better compared to the existing cloud computing paradigm because IOT applications need real-time and low Latency services.

■ To take advantage of Edge computing and to complement centralized cloud computing, a portion of loT applications that are energy-efficient in Fog computing architecture should be identified.