Chapter Seven

Edge Computing Technologies for Internet of Things

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Collected Papers

Mobile Cloud Computing (MCC)

- By growing mobile applications, mobile platforms and end user demands, there are ***some limitations of mobile device 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) aims to overcome these limitations by ***integrating cloud computing into the mobile environment*** **to enable mobile users and mobile application providers to elastically utilize resources in an on-demand fashion.**

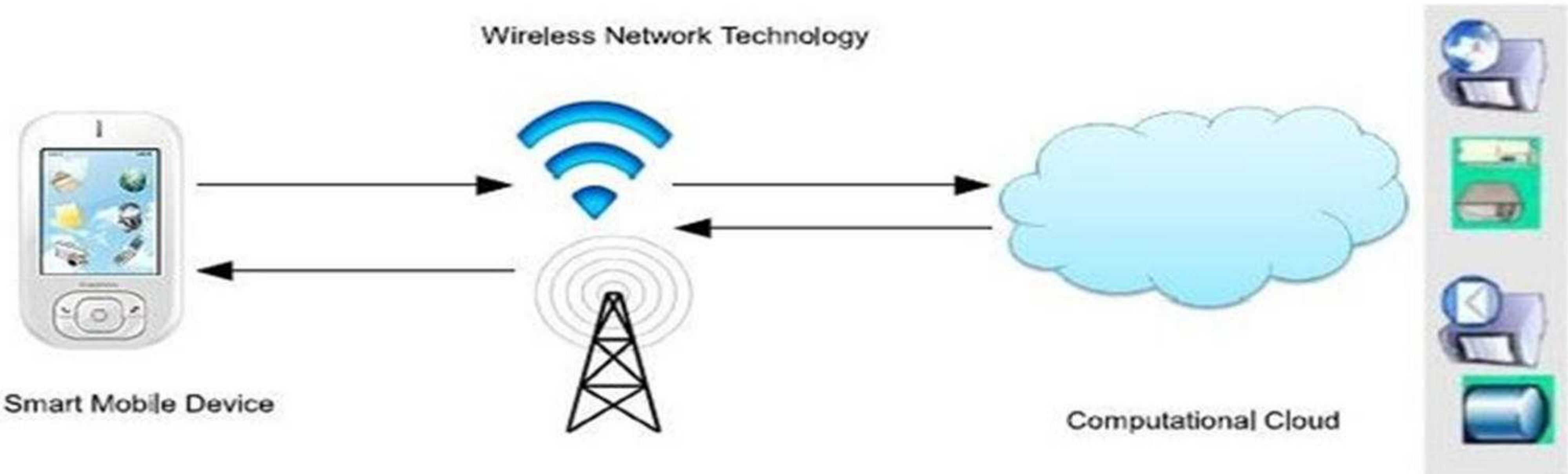
Mobile Cloud Computing- Cont..

- ***Mobile Cloud Computing (MCC)*** is the integration of cloud computing technology with mobile devices to make the mobile devices resource-full in terms of ***computational power***, ***memory***, ***storage***, and ***energy***.

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

Mobile Cloud Computing- Cont..

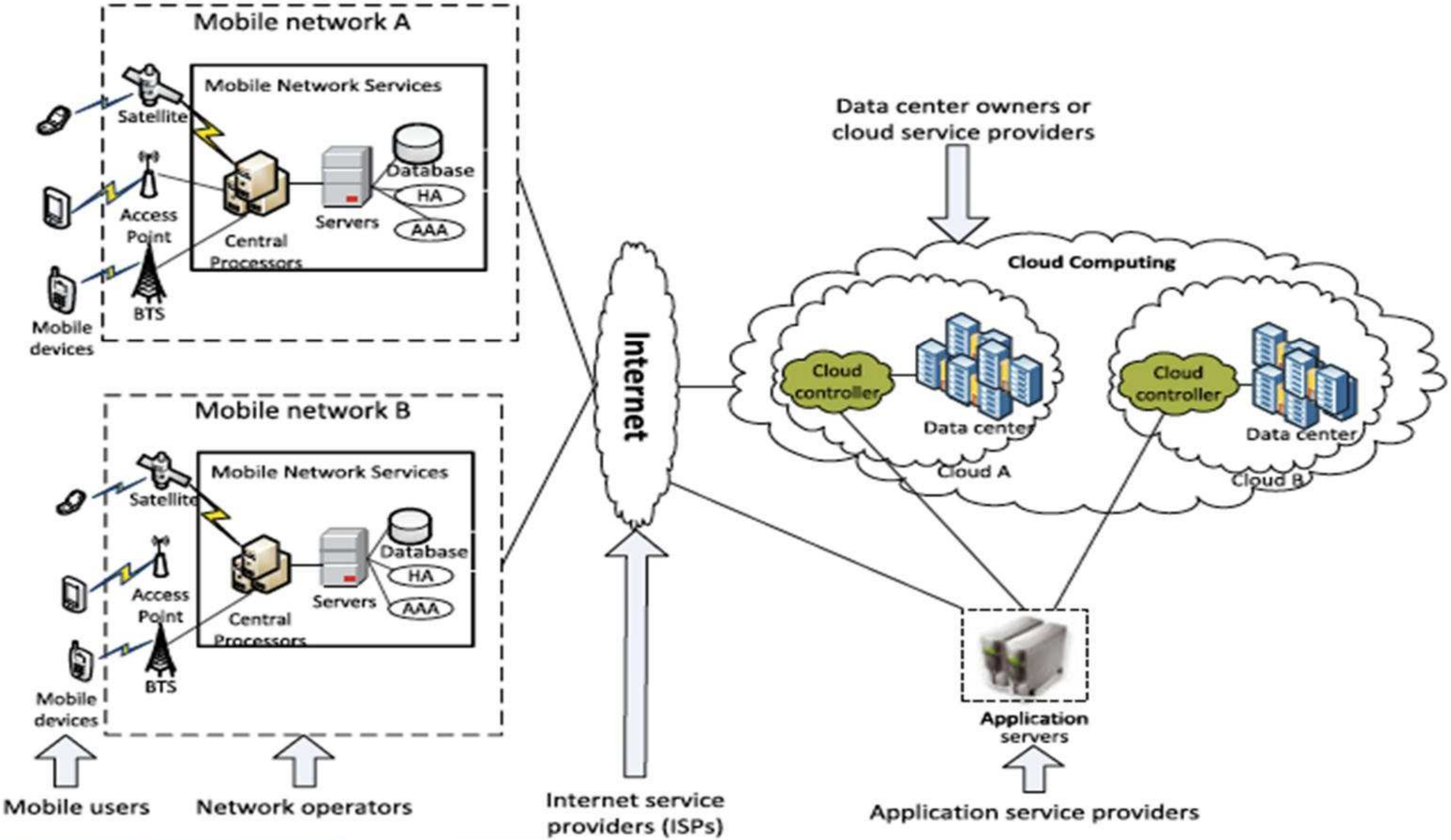
- Mobile cloud applications move the computing power and data storage away from the mobile devices and into ***powerful*** and ***centralized computing platforms*** located in clouds, which are then accessed over the *wireless connection* based on a thin native client.



Why Do We Need MCC?

- Mobile devices face many resource challenges
  - Battery life, storage, Computation Power, bandwidth, etc…
- Cloud Computing offers advantages to users by allowing them to use *infrastructure*, *platforms*, and *software* by Cloud providers at low cost and elastically in an on-demand fashion
- MCC provides mobile users with *data storage* and *processing services* in clouds using powerful devices configuration (e.g., CPU, memory, etc..), and all *intensive computing* can perform in cloud

Mobile Cloud Architecture



Mobile Cloud Architecture- Cont..

- 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

(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).
  - Remote application execution can save energy significantly.
- Many mobile applications take advantages from ***task migration*** and ***remote processing***.

Advantages of MCC- Cont..

(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 applications are not constrained by storage capacity on the devices because their data now is stored on the cloud.

Advantages of MCC- Cont..

(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(almost) available even when the users are moving.

Advantages of MCC- Cont..

(4) Dynamic Provisioning:

- Dynamic on-demand provisioning of resources on a fine-grained, self-service basis
- No need for advanced reservation

(5) 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- Cont..

(6) Multi-Tenancy:

– Service providers can share the resources and costs to support a variety of applications and large number of users.

(7) 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** (Now **4G** and **5G**) 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 by:
  - Enhanced communication quality between students and teachers
  - Help learners access remote learning resources
  - A natural environment for collaborative learning

MCC Applications- Cont..

Mobile Healthcare:

– ***M-healthcare*** is to minimize the limitations of traditional medical treatment (e.g., Small storage, security/privacy, medical errors)

– ***M-healthcare*** provides mobile users with convenient access to medical resources(e.g., 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- Cont..

Mobile Gaming:

- *M-game* is a high potential market generating revenues for service providers.
- Can completely ***offload game*** engine requiring l*arge computing resource* (e.g., graphic rendering) to the server in the 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' demands**

MCC Applications- Cont..

Assistive Technologies:

- *Pedestrian crossing guide* for *blind* and *visually-impaired* (ضعاف السمع)
- *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

1. Mobile Communication Issues:

- ***Low bandwidth:*** One of the biggest issues, because the radio resource for wireless networks is much more rare and weak 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 (***ways-on connectivity***, ***on-demand scalability***, ***energy efficiency***) is a difficult problem

MCC Issues- Cont..

2. Computing Issues:

Computation Offloading:

- It is 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 be offload
- **Two Types:**
  - Computation offloading in a **static environment**
    - A program partitioning based on ***estimation*** of ***energy consumption*** before execution
  - Computation offloading in a **dynamic environment**
    - Changing *connection status* and *bandwidth* in **run time** is harder because: Environment changes cause additional problems and transmitted data may not reach the destination

MCC Issues- Cont..

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).

Open Issues in MCC

4. Network Access Management:

- An efficient network access management not only *improves link performance* but also *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 changes its transmission or reception parameters, in a way where the wireless communications can have spectrum agility in terms of selecting available wireless channels .
- Integrated *CR* with *MCC* for better spectrum utilization

Open Issues in MCC- Cont..

5. Quality of Service (QoS):

- How to ensure QoS is still a big issue, especially on network delay.
- ***CloneCloud;*** 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.
- *CloneCloud* is expected to reduce the network delay.
- *CloneCloud* uses nearby computers or data centers to increase the speed of smart phone applications.

Open Issues in MCC- Cont..

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.
- ❑ 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- Cont..

7. 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 mobile devices for web interface could be an issue.
- ***Standard protocol***, ***signaling***, and ***interface*** for interacting between ***mobile users*** and ***cloud*** would be required. (eg, HTML5 & CSS3)

Open Issues in MCC- Cont..

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.
- 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. Multi-Cloud ??
- ***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.***

References

1) Le Guan, Xu Ke, Meina Song, and Junde Song, "A Survey of Research on Mobile Cloud Computing", IEEE/ACIS 10th International Conference on Computer and Information Science (ICIS), 2010, pp. 387-392.
2) Xiaopeng Fan, Jiannong Cao, and Haixia Mao. "A Survey of Mobile Cloud Computing," ZTE Communications, 9(1):4-8, Mar 2011.
3) Hoang T. Dinh, Chonho Lee, Dusit Niyato, and Ping Wang. "A survey of Mobile Cloud Computing: Architecture, Applications, and Approaches", Wireless Communication and Mobile Computing.
4) http://www.csie.ndhu.edu.tw/~showyang/MCloud2012/04 MobileCloudSurvey.pdf
5) Chetan S., Gautam Kumar, K. Dinesh, Mathew K. and Abhimanyu M.A., "Cloud Computing for Mobile World," 2010. (http://chetan.ueuo.com/projects/CCMW.pdf)

Internet of Things (IOT)

- IOT refers to the ***interaction and communication between billions of devices that produce and exchange data related to real-world objects*** (i.e. things).
- Cisco estimates that the number of devices connected to the IoT will be added to **50 billion** by 2020.
- 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 +Cloud Computing Technology

- IoT applications generate enormous amounts of data (**Big Data**) by ***IoT 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 ***IoT 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 is encountering ***severe challenges***:
  - High latency,
  - Low Spectral Efficiency (SE), and
  - Non-adaptive machine type of communication
- Edge devices of the network solve these challenges
- Three typical Edge Computing technologies:
  - Cloudlets,
  - Mobile Edge Computing (MEC), and
  - Fog Computing.

IOT + Edge Computing Technology

- Edge Computing is more suitable to be integrated with IoT to provide ***efficient***, ***fast***, and ***secure*** services for a large number of end-users
- So, Edge computing-based architecture can be considered for the ***future IoT infrastructure***
- Software Defined Networking (**SDN**) and the associated concept of Network Function Virtualization (**NFV**) 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 identified as one of the major requirements of the fifth generation (5G) Radio Access Networks (RANs)

IOT + Edge Computing Technology

- Although the computing capabilities of ***wearable watches***, ***smart phones***, and other ***IoT devices*** have been significantly improved, they are still constrained by the fundamental challenges, such as:
  - ***Memory size***, ***battery life***, ***heat consumption***, etc.
- **Mobile devices** need to extend **battery lifetime** by ***offloading*** energy consuming computation of the applications to the Edge of the network

Edge Computing

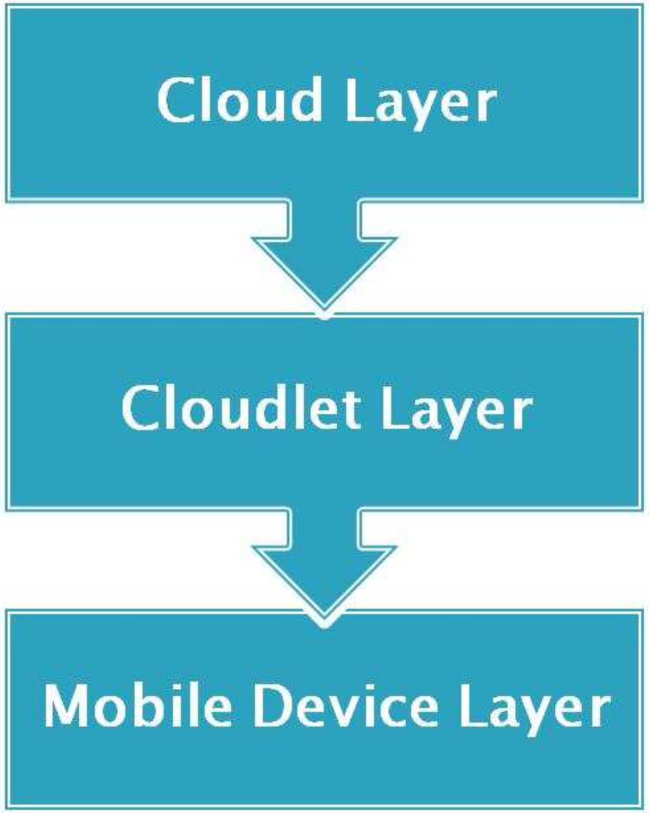
- Edge computing systems should integrate with cloud environments, to create a ***Hybrid Edge-Cloud infrastructure***.
- **Applications**, **data**, **logs** generated at the edge should be linked back to the cloud, whether private or public.
- Likewise, **resources** that exist primarily in the cloud should be **tied back** to the edge, to ensure production continues even if the cloud disappears for a time.

Edge Computing Technologies:

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

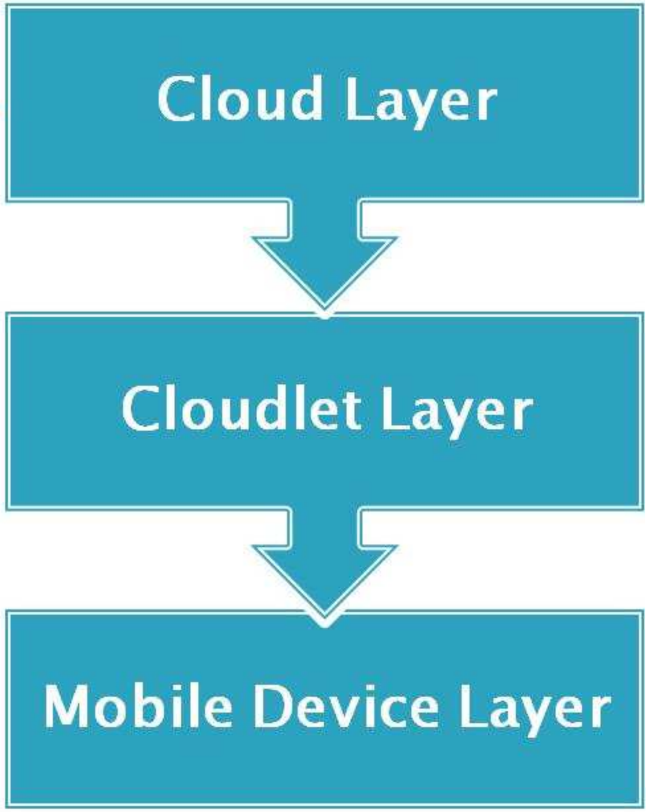
[I]Cloudlets Technology

- 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*.



[I]Cloudlets Technology-Cot..

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



- *Cloudlets* represent the middle tier of the 3-tier hierarchy architecture:
  - Mobile device layer, Cloudlet layer, and Cloud layer to achieve ***fast response time***.

Cloud and Cloudlets

- Important differentiators between cloud data center and Cloudlet:

1. Cloudlet needs to be more agile in their provisioning because 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 on 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 has to **discover**, **select**, and **associate** with the appropriate ***cloudlet*** among multiple candidates before it starts provisioning.

VM handoff is 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 end-to-end 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 applications***.

Applications of Cloudlet

- Carnegie Mellon University implemented an **open source platform** called OpenStack++ as a derivative of the **OpenStack platform** for cloud computing by extending the functionality of OpenStack to support cloudlets by open source key technology such as :
  - ***Cloudlet discovery***,
  - ***just-in-time provisioning***, and
  - ***VM hand-off***

[II] MOBILE EDGE COMPUTING (MEC)

- Current cloud computing paradigm is unable to meet the requirements of ***low latency***, ***location awareness***, and ***mobility support***.
- MEC a 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 in close proximity to mobile subscribers"
- Mobile Cloud Computing (MCC) turns into a problem for ***communication-intensive applications,*** which need to meet the **delay requirements**, specially, in ***smart cities*** or ***Internet of Things***.

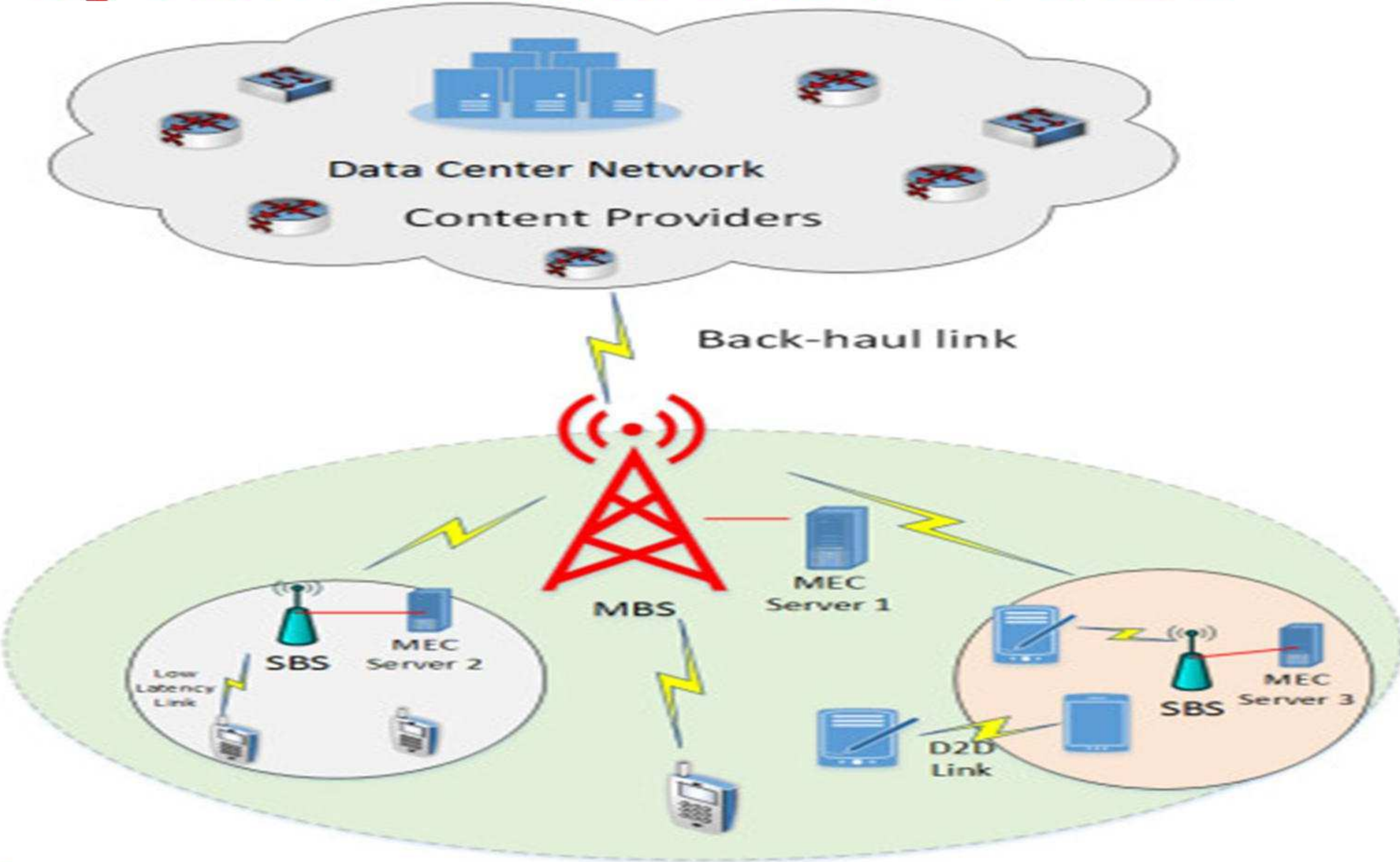
[II] MOBILE EDGE COMPUTING (MEC)

- 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 application 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***
- MEC is the ***near-real-time processing*** of large amounts of data produced by edge devices and applications ***closest*** to where it's captured.

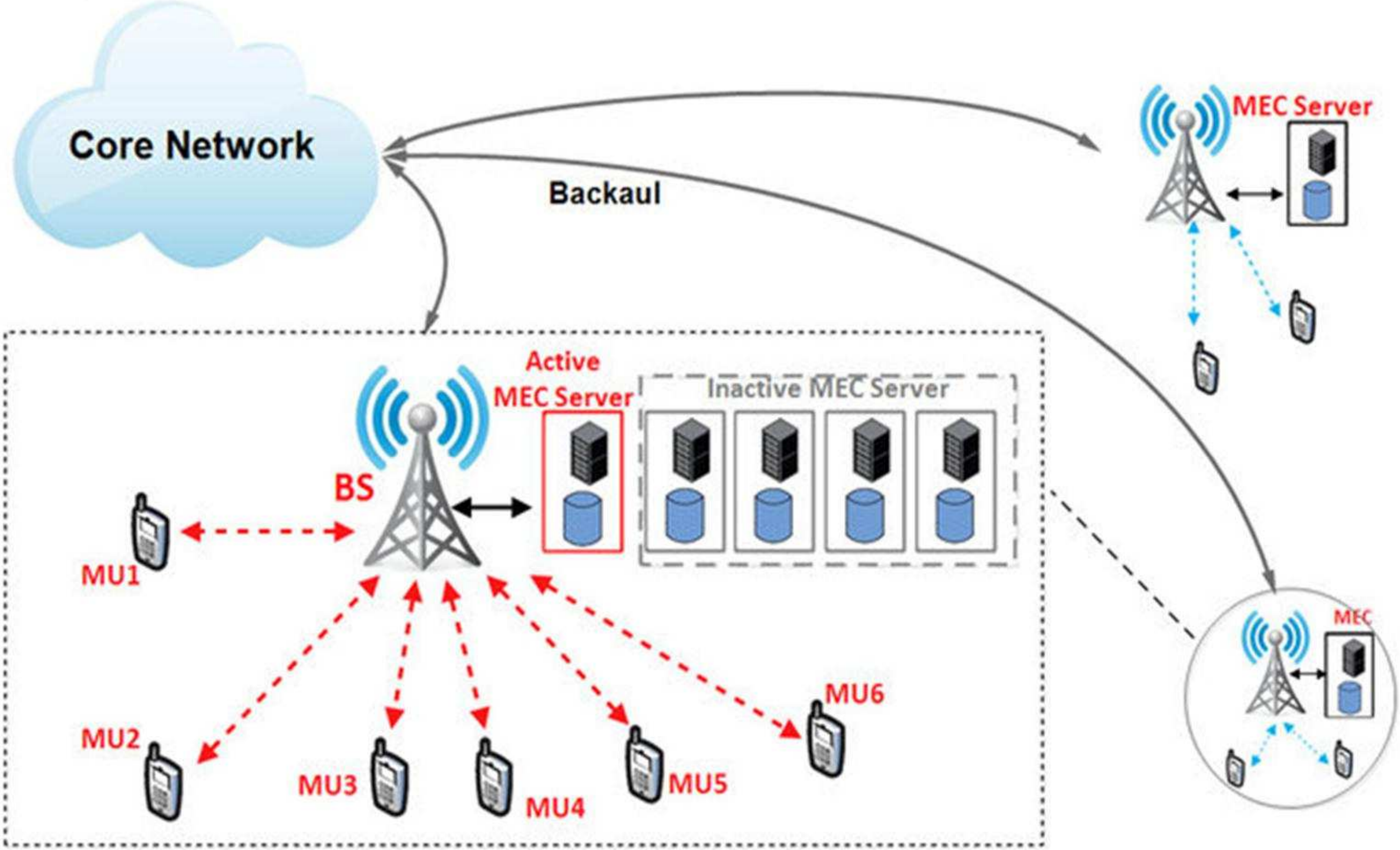
[II] MOBILE EDGE COMPUTING (MEC)

- MCE helps ***performance enhancements***, including higher bandwidth, lower latency, and faster response times and decision-making.
- MEC also allows different applications and smart mobile devices to ***respond***, ***process data*** and ***make informed decisions*** in a ***near real-time*** manner as soon as data is generated / created to eliminate the lag delay.
  - This is of the essential assets for many emerging technologies such as ***self-driving*** cars and ***real-time navigation*** systems
- Furthermore, MEC offers ***local storage with the ability to process data without putting it in a remote public cloud.***
  - This feature adds an extra layer of security that is useful for sensitive and private data.

System Architecture of MEC



System Architecture of MEC



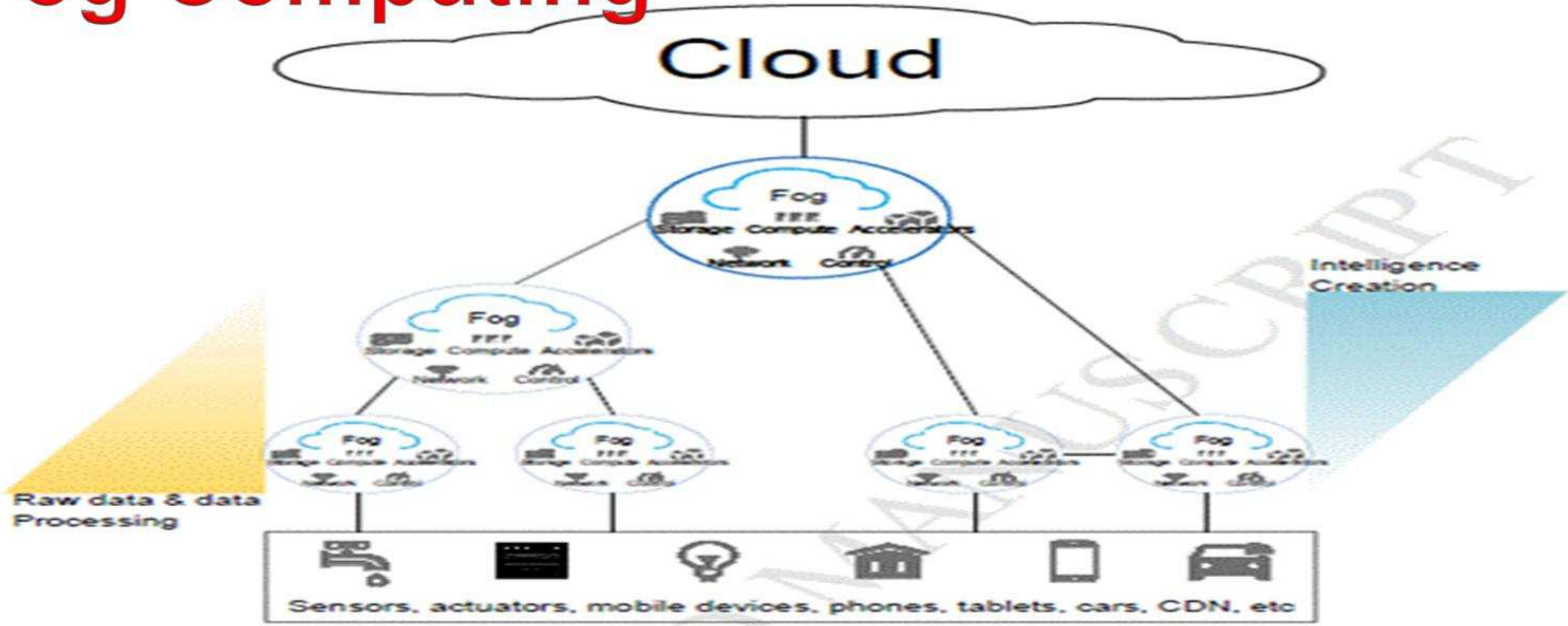
MEC Applications

- Due to the MEC characteristics, such as *low latency*, ***proximity***, ***high bandwidth***, and ***real-time insight into radio network information*** and ***location awareness***, MEC enables a large number of applications and services for multiple sectors, such as consumer, enterprise, health, etc…
- MEC is a promising solution for handing ***video streaming services*** in the context of smart cities by locally processing and analyzing the Video streams receiving form the monitoring devices to extract meaning 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 IoT data streams**

[III] FOG COMPUTING

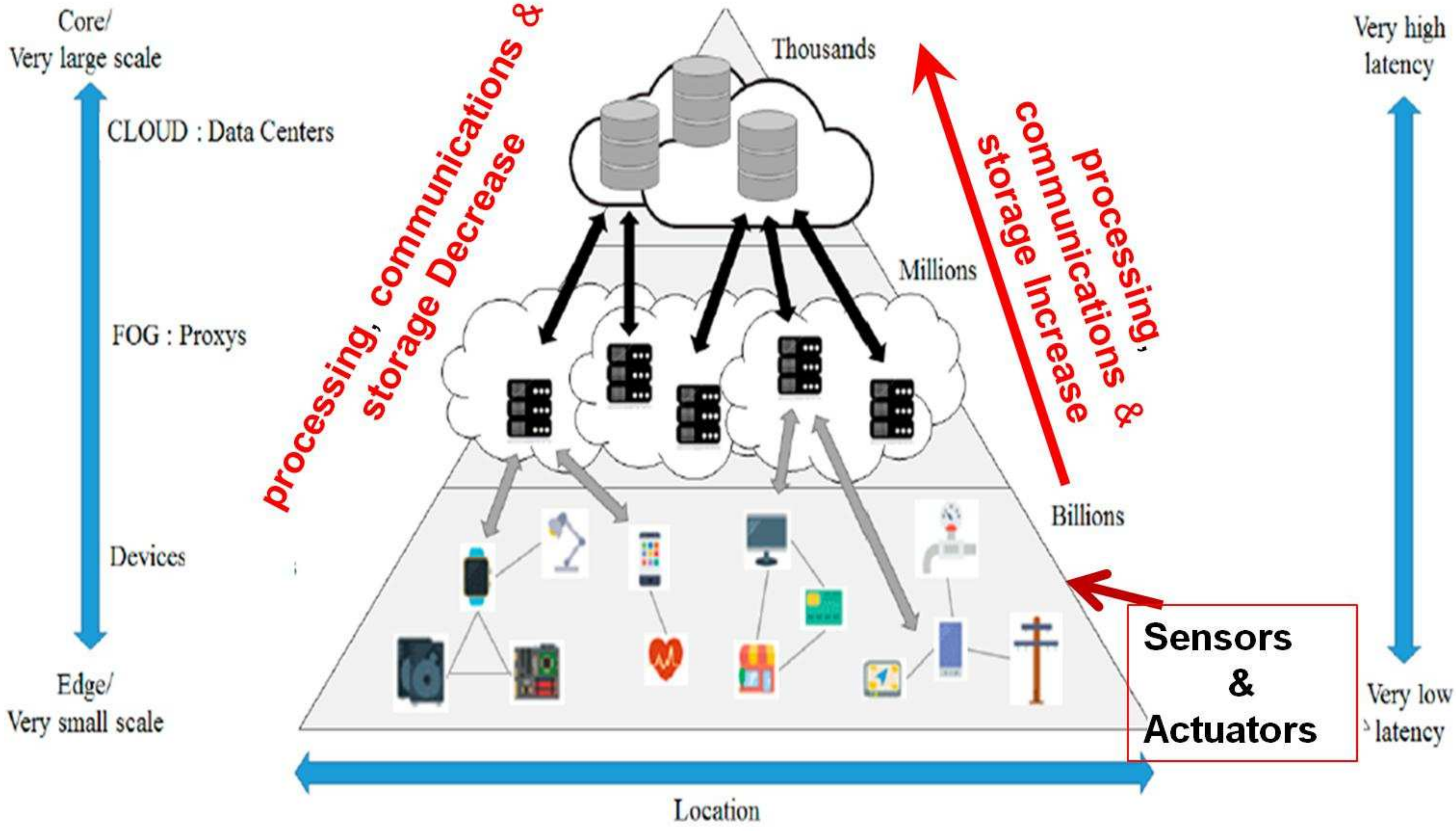
- "**Fog computing** is a **system-level horizontal architecture** that distributes resources and services of computing, storage, control and networking anywhere along ***the continuum from Cloud to Things (Sensor, and Actuators)***"
- **Fog computing** is a ***decentralized computing infrastructure*** 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.

Hierarchical Architecture Based on Fog Computing



A typical hierarchical architecture based on fog computing

Generally, there is a rich set of **sensors** and **actuators** at the edge of the network in an application scenario. These sensors and actuators are connected to the Fog nodes via a multitude of interfaces, such as PCIe, USB, Ethernet, etc.



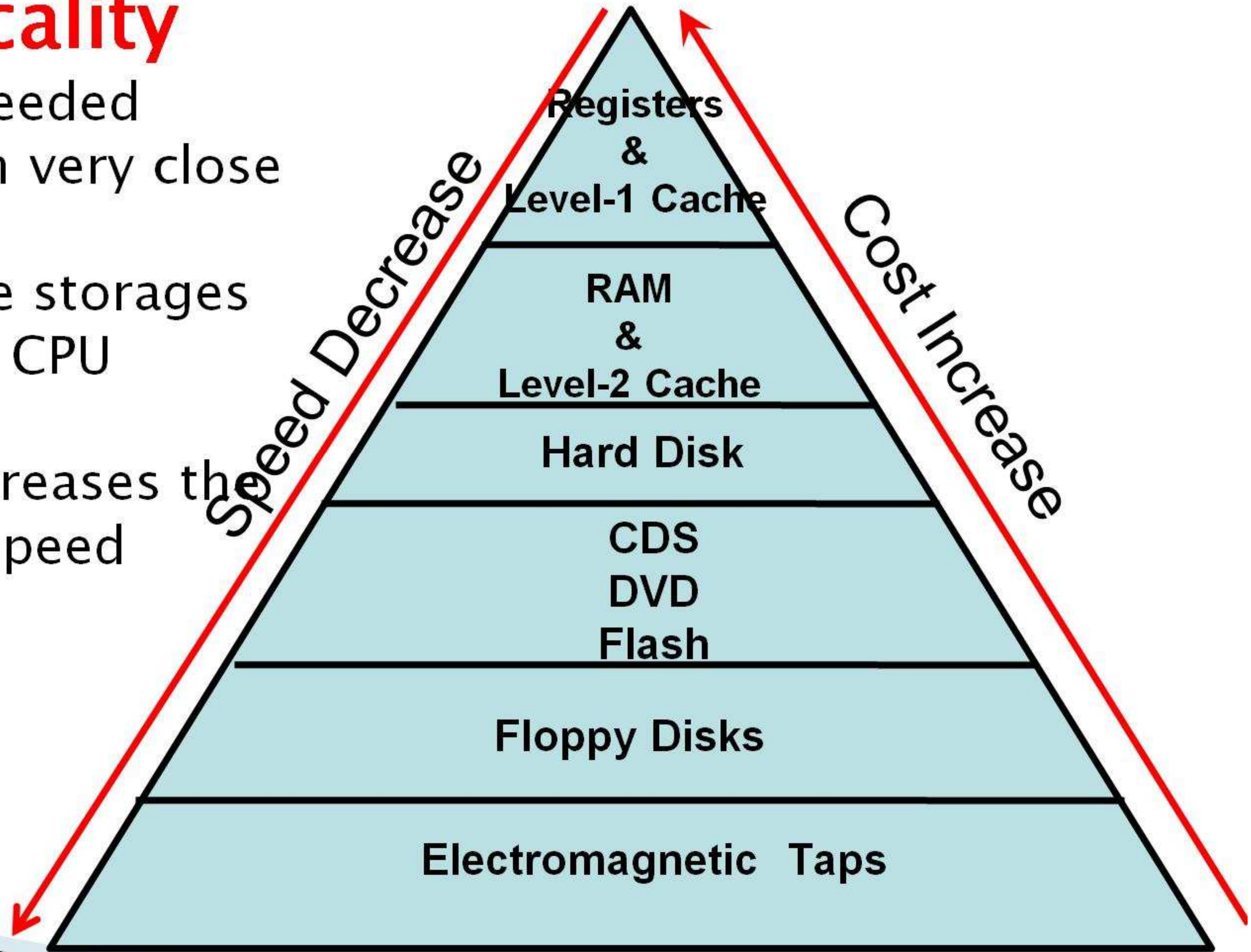
The Structure of Fog Computing.

This looks like Memory Hierarchical of traditional Computer

Computer Memory Hierarchical

Data Locality

- Keep the needed Information very close to CPU
- Arrange the storages to increase CPU Locality
- Locality increases the computer speed



Hierarchical Architecture Based on Fog Computing

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*.
- At the next higher tier, Fog nodes are focused on *data filtering, compression, and transformation*.
- At the higher tiers or nearest the backend cloud, Fog nodes are focused on *aggregating data and turning the data into knowledge*.
- Architecturally, Fog nodes at the edge may be less processing, communications, and storage than nodes at high levels.

Fog Computing & Cloud Computing

- 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.
- Once an end device connects to a Fog node, the Fog node can serve it either ***directly*** or with ***assistance*** from the cloud. Thus, there is an essential interaction between **Fog nodes** and **cloud**, and many applications require both ***Fog localization*** and ***cloud globalization***.

Edge Computing & Cloud Computing

- 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 IoT **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 IoT applications that are energy-efficient in Fog computing architecture should be identified.

References

1. SK Alamgir Hossain, Md. Anisur Rahman, M. Anwar Hossain, “Edge computing framework for enabling situation awareness in IoT based smart city,” Journal of Parallel Distributed Computing, Vol. (122), PP. 226-237, 2018
2. Wazir Zada Khana , Ejaz Ahmedb , Saqib Hakakb , Ibrar Yaqoobc , Arif Ahmed, “Edge Computing: A Survey,” Future Generation Computer Systems, 2019
3. Kewei ShaT. Andrew YangWei WeiSadegh Davari, “A survey of edge computing based designs for IoT security,” Digital Communications and Networks journal , 2020
4. Dario Sabella, Alessandro Vaillant, Pekka Kuure, Uwe Rauschenbach, Fabio Giust, “Mobile Edge Computing Architecture -The role of MEC in the Internet of Things,” https://www.researchgate.net/publication/308767796_Mobile-Edge_Computing_Architecture_T

References

5. Pengfei Hu, Sahraoui Dhelim, Hong Liu, "Survey on Fog Computing: Architecture, Key Technologies, Applications and Open Issues," Journal of Network and Computer Applications, Vol. 98,, PP. 27-42, 2017

6. Kiryong Ha, Yoshihisa Abe, Zhuo Chen, Wenlu Hu, Brandon Amos, Padmanabhan Pillai†, "Adaptive VM Handoff Across Cloudlets," https://www.cs.cmu.edu/~satya/docdir/CMU-CS-15-113.pdf,