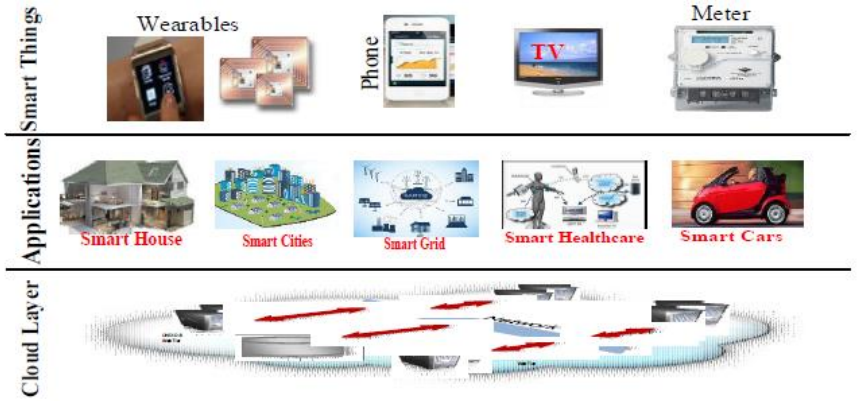
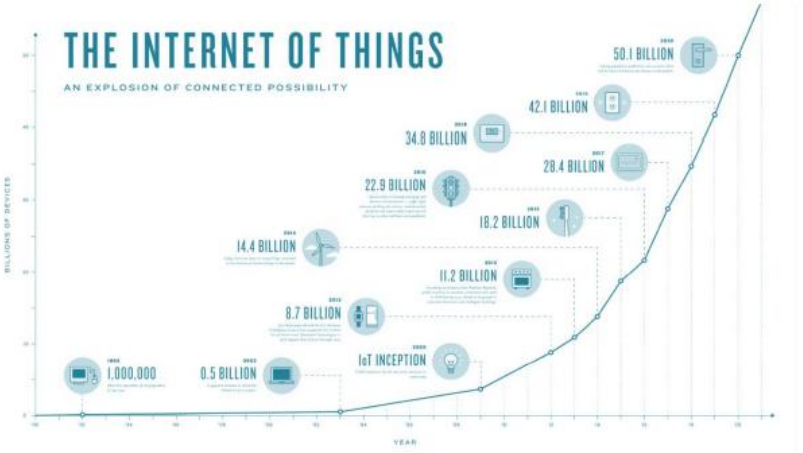
Edge computing
and
Fog computing

Trends

- A plethora of energy limited devices (smartphones, tablets and wearables) are increasingly becoming a mainstream element of our lives.



- Cloud as a centralised server will soon become an untenable computing model.



In 2022:
- 9 billion mobile subscriptions
- 17 billion IoT devices

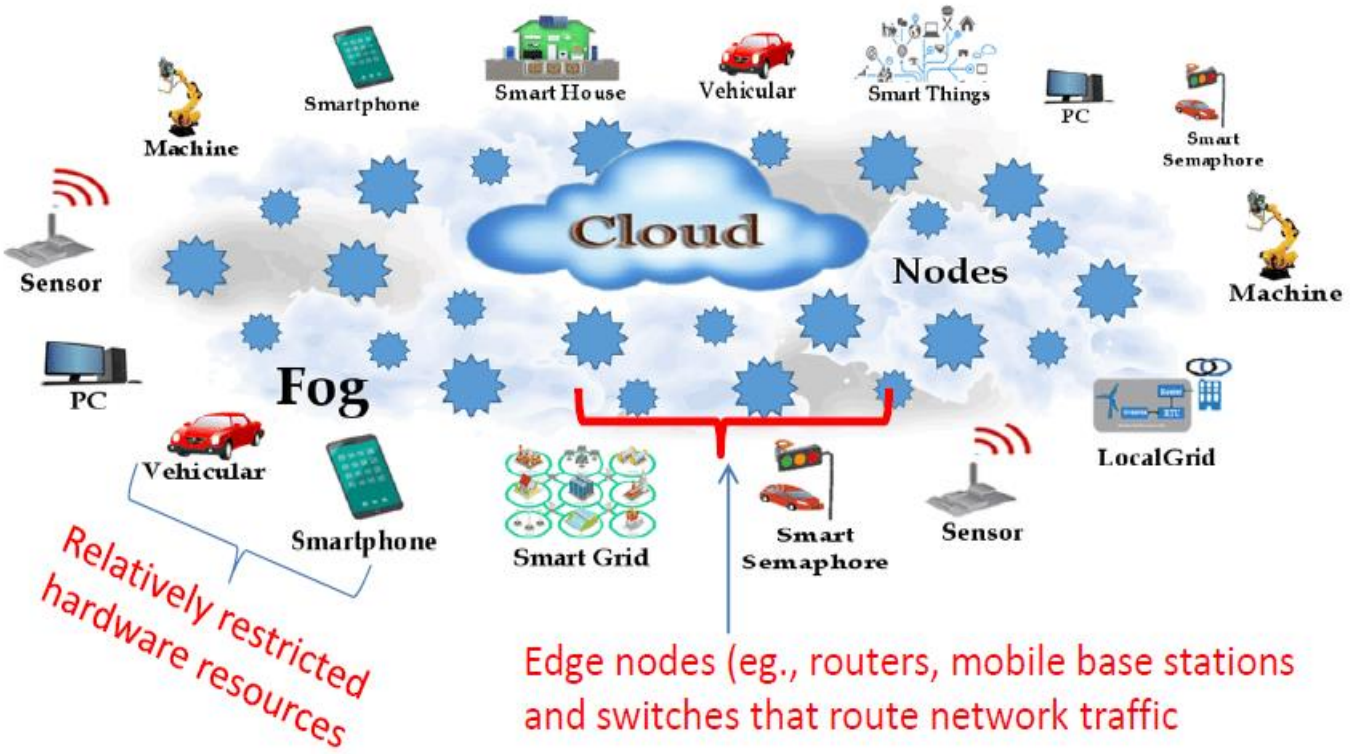
Context

- The emergence of the Internet of Things (IoT) has led to the development of infrastructure that extends beyond centralised data centers
  - from the cloud to the edge, *the so-called cloud-to-thing continuum*
- Forecasts suggest that the number of connected things will continue to explode over the next decade:
  - 42 billion things generating 79.4 zettabytes of data
- The new infrastructures are characterised by:
  - extreme heterogeneity,
  - geographic distribution, and
  - complexity

Needs

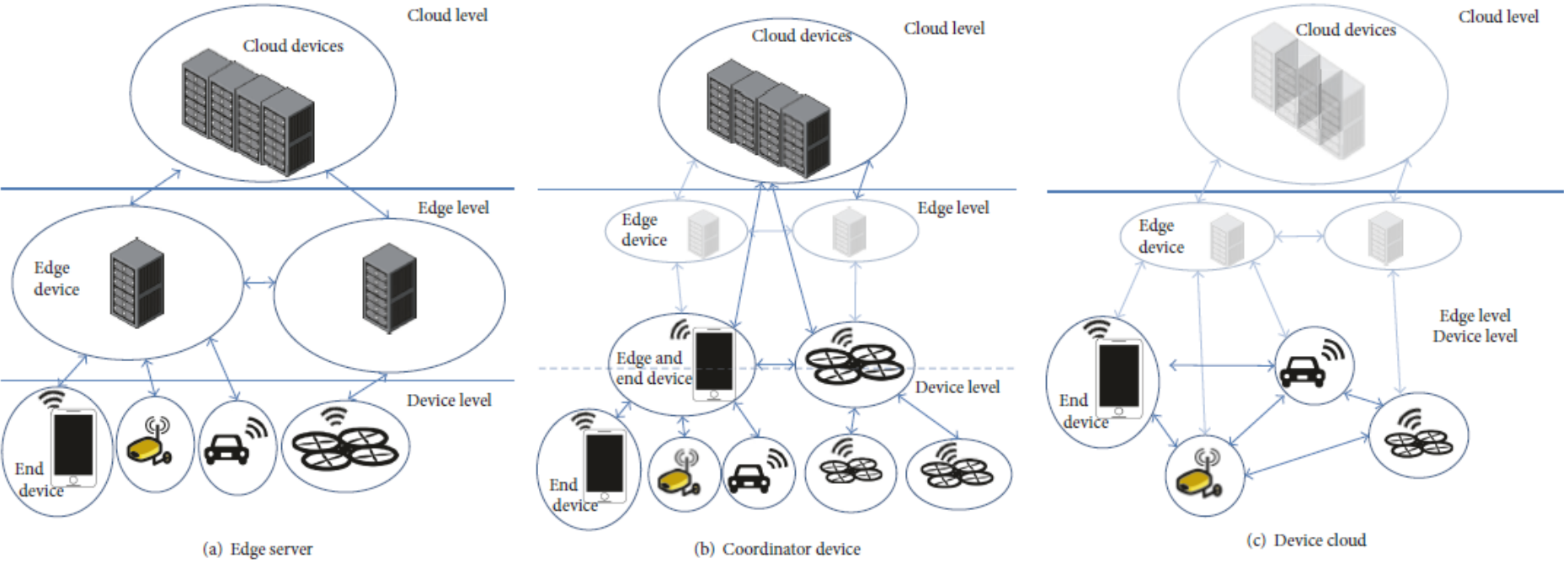
- **Novel services, applications and communication paradigms based on Internet technologies**
  - Internet of Things (IoT)- including industry and agriculture, Smart cities, M2M, Vehicular communications, Content/media oriented communications, Social networks, Big data applications, etc**.**
    - "Internet of Everything" (IoE)
- **Requirements:** Low latency/response time, high bandwidth, location and context awareness, reduction in amount of data transferred to Cloud and back
- **Supporting technologies (**used in cooperative mode!)
  - *Cloud Computing (CC)*
  - *Edge Computing (EC)*
  - *Multi-access/Mobile Edge Computing (MEC)*
  - *Fog Computing (FC)*
  - *Cloudlets*

Cloud/Fog/Edge – an example



Paola G. V. Naranjo, Zahra Pooranian, Shahaboddin Shamshirband, **Jemal H. Abawajy** and Mauro Conti, Fog over Virtualized IoT: New Opportunity for Context-Aware Networked Applications and a Case Study, *Appl. Sci.* **2017**, *7*(12), 1325; doi:10.3390/app7121325

Edge Computing: architecture categories



Example of simple descriptions of Edge Computing

- Consists in having network nodes with computational and storage resources close to the devices (mobile phones, sensors) at the edge of the current network
- Refers to a broad set of techniques designed to move computing and storage out of the remote cloud (public or private) and closer to the source of data

Terminology

- **End devices:** those objects located at the user end of the network which produce data or need cloud/edge resources
- **Edge devices:** the devices that are connecting the end devices to the rest of the network, for example, home routers, gateways, access points, or base station
- **Cloud devices:** physical components of the cloud

Timeline

- 2012: Fog Computing (CISCO)
- 2013: Cloudlets (Carnegie Mellon University)
- 2014: Mobile Edge Computing - MEC (ETSI)
- 2015: Micro data center (Microsoft)
- 2015: Open Fog Consortium – standards to enable interoperability
- 2016: Edge Computing Consortium
- 2017: Multi-access Edge Computing – MEC redefined (ETSI)

Nowadays: cooperation OFC, ETSI, ECC etc

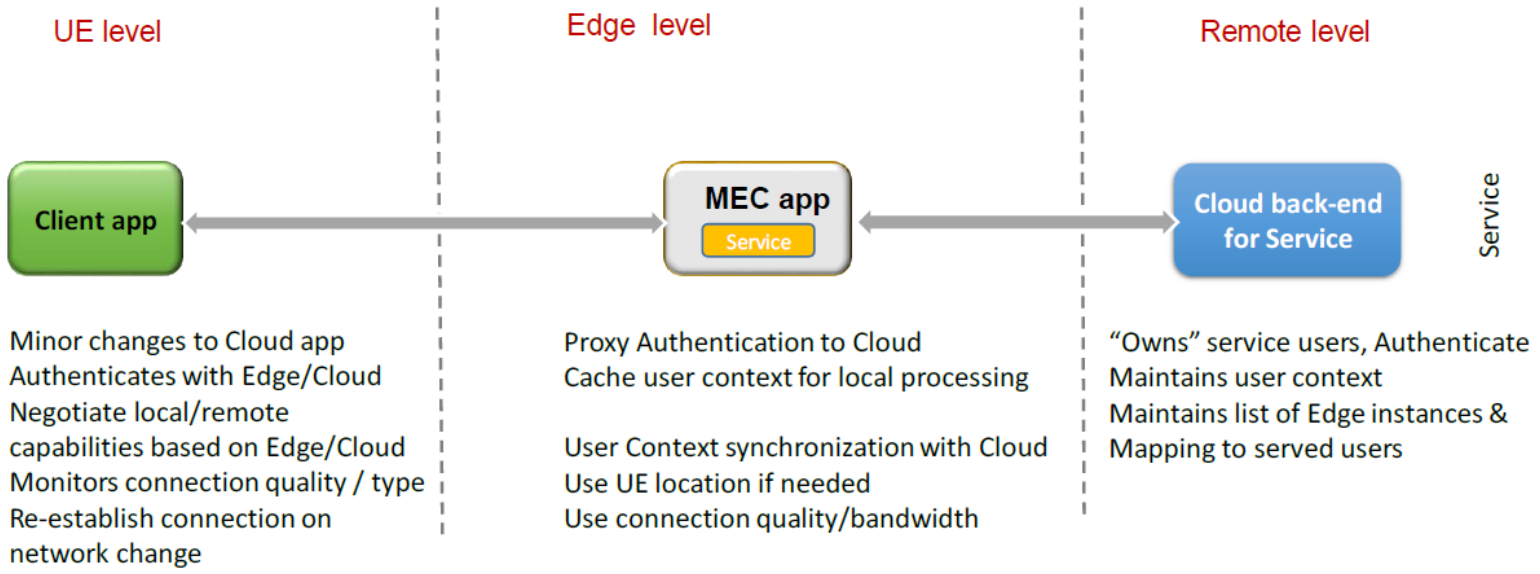
Cloud, Edge and Fog

- **Cloud Computing (CC)**
- **Edge computing (EC) –**
  - Part of CC capabilities and operations are offloaded from centralised CC Data Center (CCDC) to the *network, edge and/or terminal devices*
  - *Generic definition:* Provides context aware storage and distributed computing at the network edge
- **Fog computing (FC)**
  - *Initial definition* (Bonomi, CISCO): “highly virtualized platform providing compute, storage and networking services between end devices and traditional CCDC typically, but not exclusively located at the edge of the network” [complementary to CC, do not replace]
  - *Extended:* continuum of devices from CCDC down to the edge of networks, for secure management and control of domain specific HW/SW and standard compute, storage and network functions within the domain
  - FC nodes are typically located away from the main cloud data centers

MEC and Cloudlet

- **Mobile Edge Computing (MEC):**
  - CC platform within the Radio Access Network (RAN) close to mobile subscribers to serve delay sensitive, context aware applications
  - Multi-access Edge Computing - multi-access…to include non-cellular actors
- **Cloudlet:**
  - A cloudlet is middle tier of a 3-tier hierarchy: ‘mobile device – cloudlet – cloud’
  - Cloudlet ~ "data center in a box" whose goal is to "bring the cloud closer"’
  - Cloudlets are mobility-enhanced *micro data centers* located at the edge of a network and serve the mobile or smart device portion of the network
  - designed to handle resource-intensive mobile apps. and take the load off both the network and the CCDC and keep computing close to the point of origin of information

Example of splitting an app into 3 components in MEC vision



Different views of the relationships!

- OpenFogConsortium view
- NIST view
- ETSI view
- Industry view

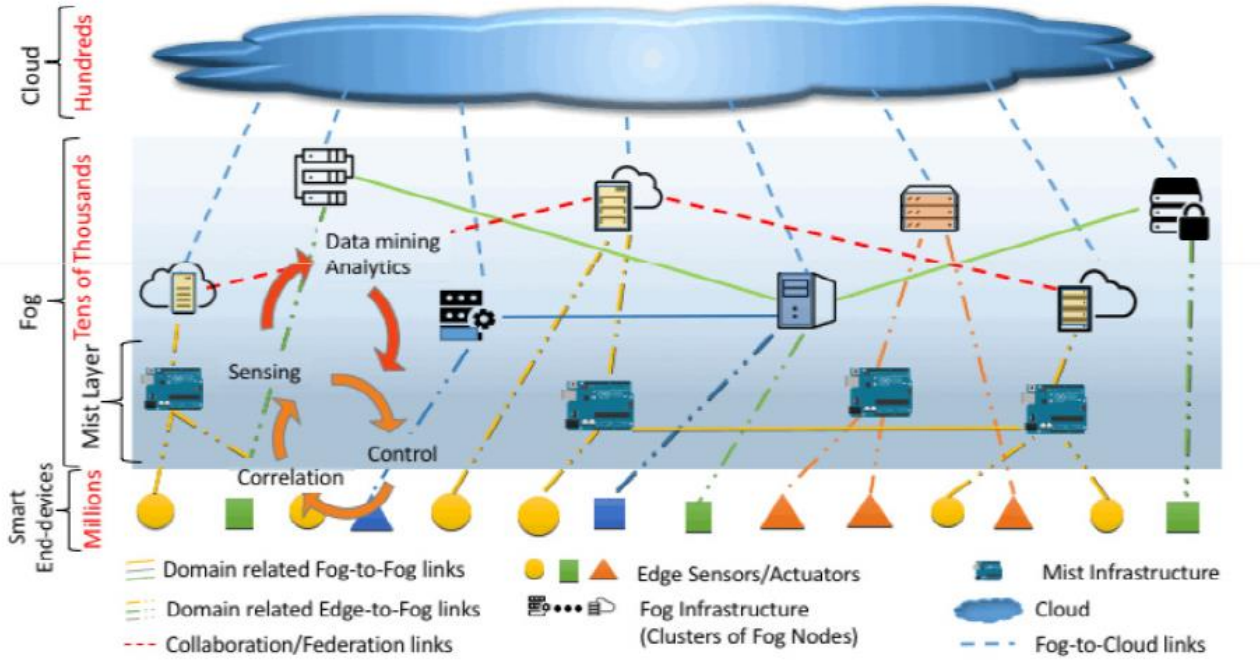
...

OpenFogConsortium view

- **EC:**
  - also referred to as Mesh Computing,
  - it places applications, data and processing at the logical extremes of a network
- **FC:**
  - A horizontal, system-level arch. that distributes computing, storage, control and networking functions closer to the users along a cloud-to-thing continuum
  - FC - extends the traditional CC model; implementations of the architecture can reside in multiple layers of a network's topology
  - the CC benefits are extended to FC (containerisation, virtualisation, orchestration, manageability, and efficiency)
  - FC can cooperate with CC
- **Differences:**
  - FC works with the cloud, whereas EC is defined by the exclusion of cloud.
  - FC is hierarchical, where edge tends to be limited to a small number of layers
  - In addition to computation, FC also addresses networking, storage, control and acceleration.

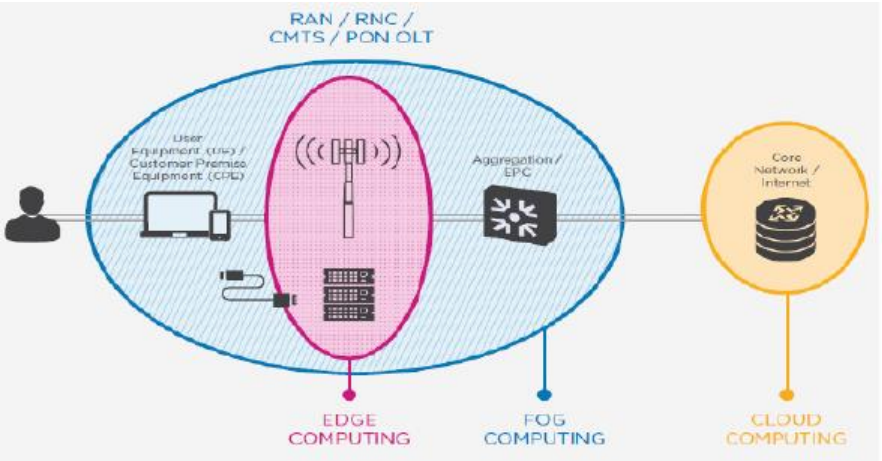
NIST view of FC

- **FC :** horizontal, physical or virtual resource paradigm that resides between smart end-devices and traditional cloud or data centers.
- **FC** supports vertically-isolated, latency-sensitive applications by providing ubiquitous, scalable, layered, federated, and distributed computing, storage, and network connectivity



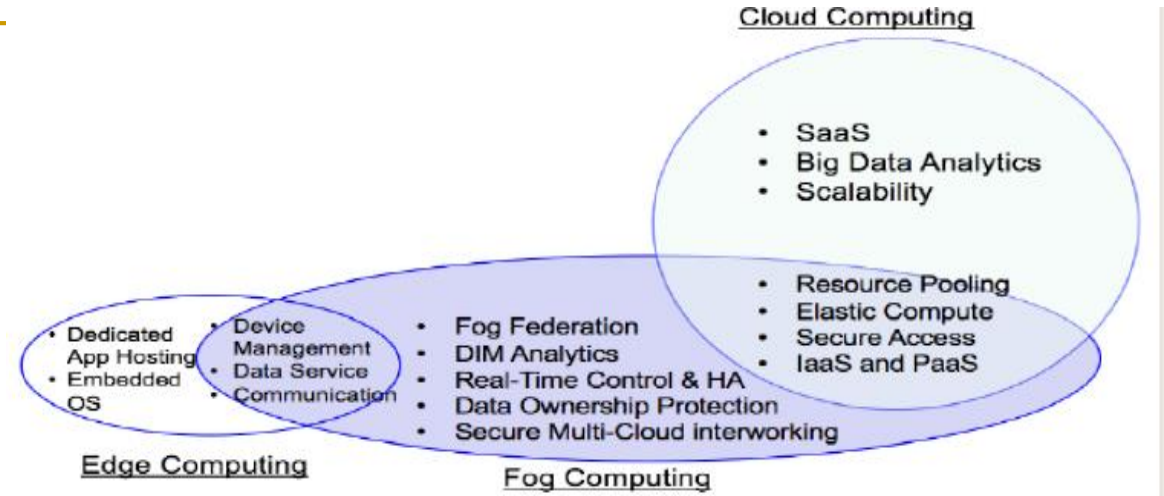
ETSI view of EC

- MEC servers - are usually hosted typically at access points, *one hop away from the user.*
- Fog computing is seen here as a superset of edge computing
- FC - essentially *including everything that is not a central cloud*

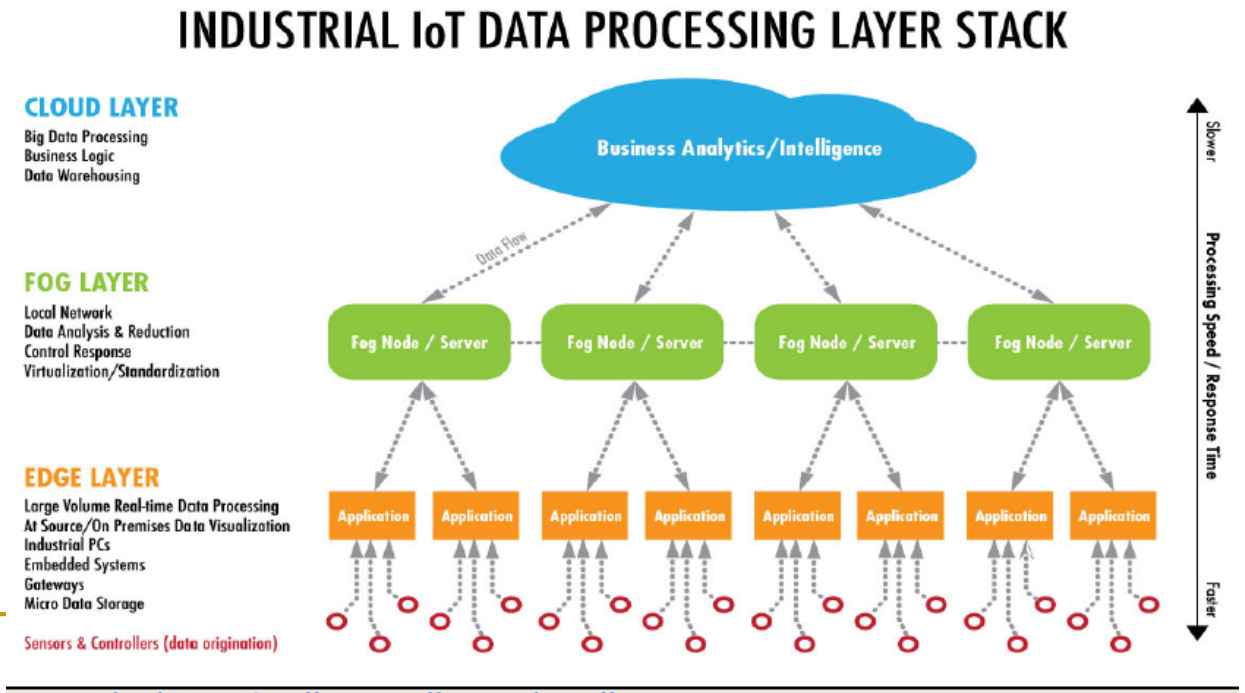


- **RAN** - Radio Area Network for LTE/5G
- **RNC**- Radio Network Controller for WiFi
- **CMTS-** Cable Modem Termination System
- **PON OLT** for fiber
- **EPC** – evolved Packet Core

Industry views

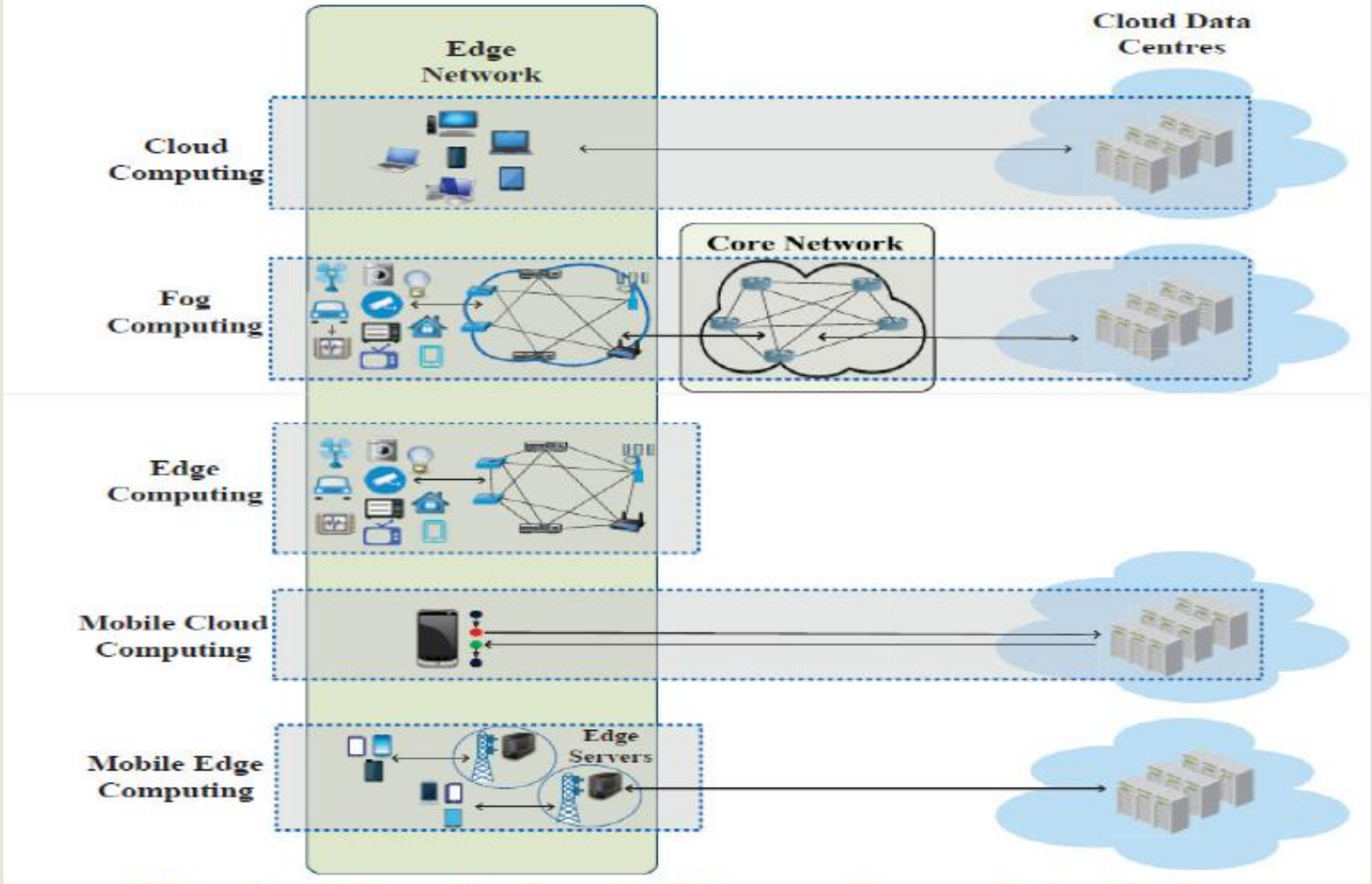


Fog vs Edge Computing, https://www.nebbiolo.tech/wp-content/uploads/whitepaper-fog-vs-edge



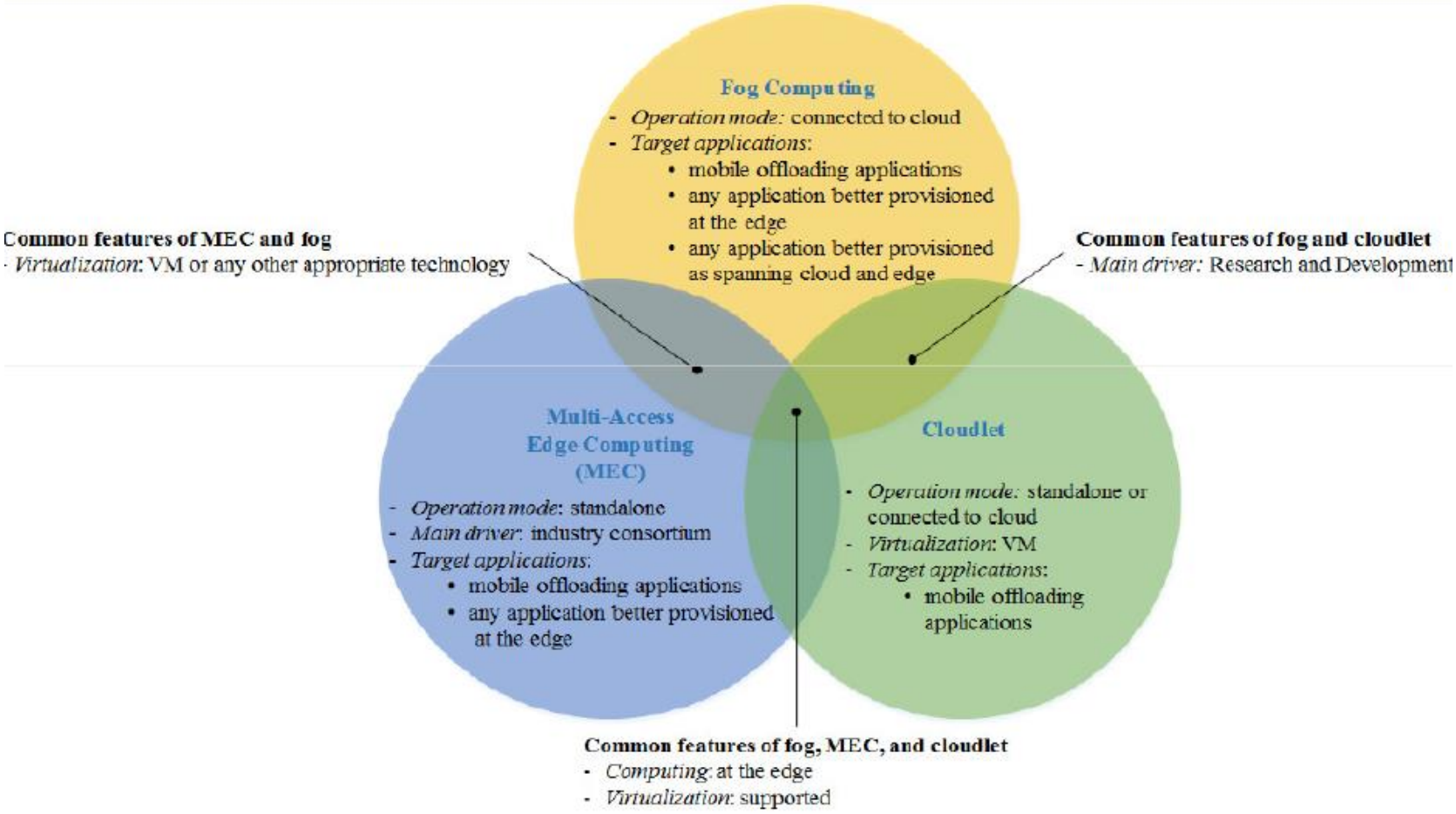
https://www.winsystems.com/cloud-fog-and-edge-computing-whats-the-difference/

Compromise 1::



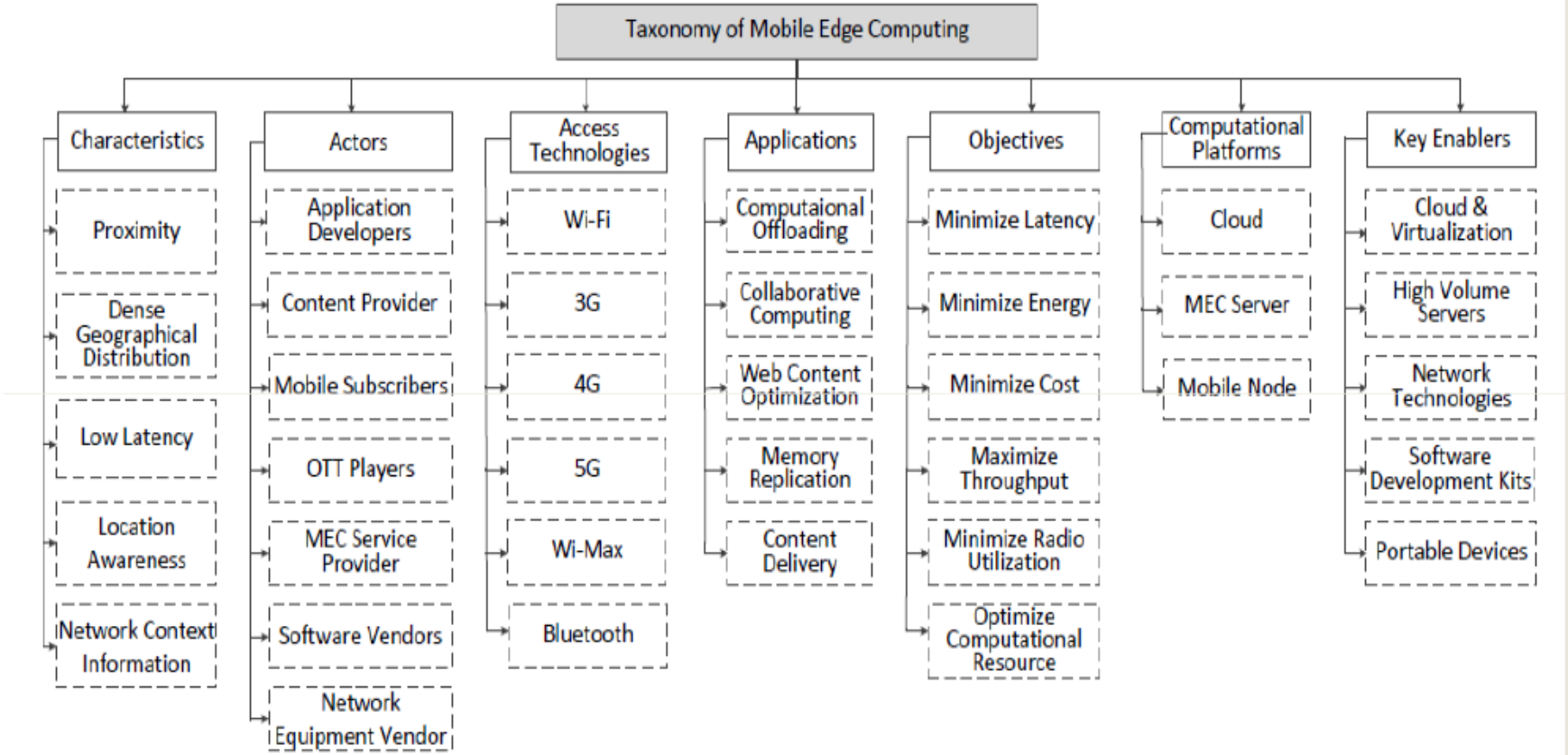
Source R.Mahmud and R.Buyya, Fog Computing: A Taxonomy, Survey and Future Directions, arXiv:1611.05539v3 [cs.DC] 24 Nov 2016

FC vs MEC vs Cloudlet



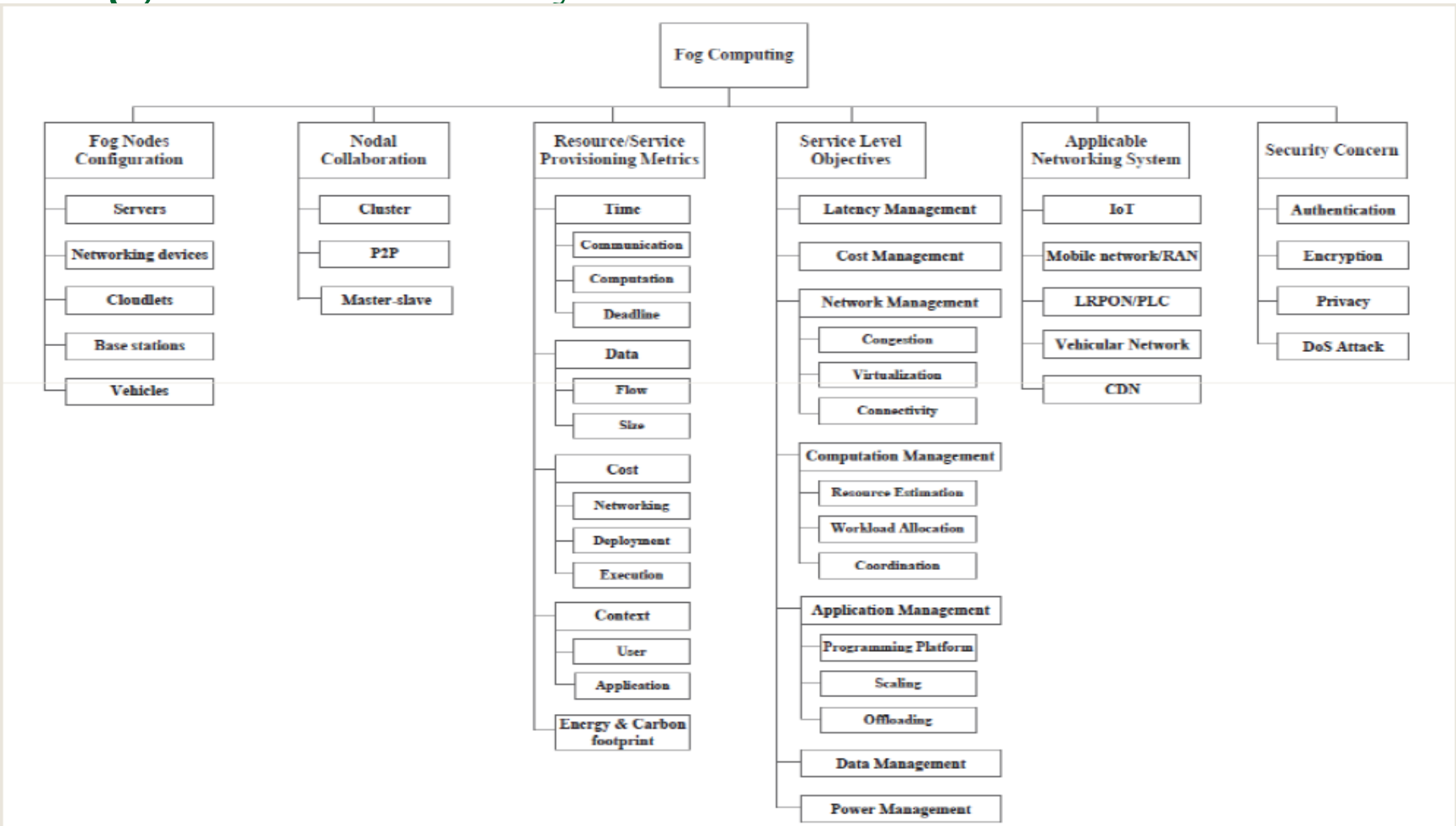
Source: C. Mouradian, et.al., A Comprehensive Survey on Fog Computing: State-of-the-art and Research Challenges, IEEE Communications Surveys & Tutorials, 2017

MEC Taxonomy



Source *A. Ahmed, E. Ahmed, "A Survey on Mobile Edge Computing"*
IEEE, Int'l Conf. on Intelligent System and Control ISCO 2016
https://www.researchgate.net/publication/285765997

Fog Taxonomy



Source : Redowan Mahmud and Rajkumar Buyya, Fog Computing: A Taxonomy, Survey and Future Directions. arXiv:1611.05539v3 [cs.DC] 24 Nov 2016

Edge computing applications (ETSI)

- Video content delivery optimization
- Video stream analytics and video surveillance
- Augmented Reality and Virtual Reality (AR/VR)
- Enterprise applications enablement and local breakout
- Applications with critical communication needs such as traffic safety and control, autonomous cars, Industrial IOT and Healthcare
- Connected Cars
- IoT applications and Gateway
- Location and Context aware Services
- Smart City applications

Fog computing applications

- IoT:
  - Industrial IoT, automation
  - Smart Agriculture
  - Sustainable Smart Cities:
    - Transportation (safety, traffic mgmt., information and entertaining)
    - Health and Well-Being
    - Waste Management
    - Water Management
    - Greenhouse Gases Control
    - Power Grid
    - Retail Store Automation
    - Smart buildings, home
    - Safety and emergency applications
- Mobile Network / Radio Access Network
- Long-Reach Passive Optical Network / Power Line Communication
- Internet of vehicles (all applications), Vehicle to Grid systems
- Content Distribution Network

MEC applications

- **Consumer-oriented services (offloading)**
  - Augmented/assisted/virtual reality
  - Face recognition
  - Web accelerated browsing
  - Image/video editing
  - Gaming, Remote desktop
  - RAN-aware Content Optimization and delivery
  - Distributed Content and DNS Caching
- **Network performance and QoE improvement services**
  - Traffic monitoring/shaping
  - Content caching
  - Radio/backhaul optimization
  - Application-aware cell performance optimization
- **Operator and third party services**
  - Internet of Things (IoT)
  - Vehicular communications
  - Big Data
  - Video Analytics

Cloudlets

- Carnegie Mellon University (CMU) has developed ***Cloudlets*** and also implemented various mechanisms as open source code
- A cloudlet
  - represents **the middle tier of a 3-tier hierarchy**: “mobile device – cloudlet – cloud”
  - can be viewed as **a "data center in a box“,** with no hard state, whose goal is to
  - "bring the cloud closer to the user„
  - architectural element realizing convergence between CC and mobile computing, middle tier of the hierarchy
- Related proposal- Microsoft Research:
  - concept of micro datacentre as an extension of today’s hyperscale cloud data centres (as Microsoft Azure)
  - to meet new application demands like lower latency and new demands related to devices (e.g. lower battery consumption)
- Cloudlet is included in Fog technologies by some authors

Cloudlets characteristics

- **Technology:**
  - based on standard cloud technology
  - encapsulates offload code from mobile devices in virtual machines (VMs)
  - may have specific role and functionality
  - similar infrastructure to clouds based on Openstack
- **Soft state only**
  - no hard state, but may contain cached states from the cloud
  - may buffer data originating from a mobile device and going to the cloud
  - after installation it is entirely self-managing
- **Location**
  - “Logical proximity" of the mobile devices, i.e., capable to have low E2E latency and high bandwidth (e.g., one-hop Wi-Fi)
- **Resources and connectivity**
  - sufficient CPU, RAM, etc. to offload resource-intensive computations from several mobile devices
  - good connectivity (bandwidth) to the cloud
  - not limited by electric power supply

Open- Stack++

- derivative of the widely used OpenStack platform for cloud computing
- The “++” refers to the unique extensions necessary for use of OpenStack in cloudlet environments.
- Some key components of OpenStack++ such as cloudlet discovery and just-in-time provisioning have been developed and are available as open source

Adapt in Edge and Fog computing

- mobile devices or IoT devices are resource-constrained devices, whereas the cloud has almost unlimited but far away resources.
- self-adaptive resource scheduling is one of the key issues in resource management of fog computing
- keeping data close to where it was generated enables better control, especially for privacy-related issues

Adapt in Edge computing

- Providing and/or managing the resources at the edge will enable the end device to spare resources (e.g., stored energy in batteries) and speed up computation and allows using resources it does not possess.
- Being located close to the user, edge computing makes it possible to increase the quality of provided services through the use of profiling within a local context, without compromising the privacy or having to handle a large number of users.
- This is known as ***context adaptation***.

Context adaptation in Edge computing

- Providing tailored service depending on the user's physical location of course has to be taken care of at the application level.
- However, it also impacts resource management as those applications will require resources to provide those services, in particular considering data (about supply mobility and abundance) as a resource.