Cloud/Fog Computing for Smart Grid

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Learning Objectives

Throughout this lecture, it is aimed for the students to be able to

- **Learn the basic concepts and architecture of cloud computing**
- **Learn the basic concepts and architecture of fog computing**
- **Understand why and how cloud computing and fog computing can be applied in smart grid**

Industry Invited Talk Today

Speakers:

- **Ylvisåker Hans Terje,**

  Programsjef

  Smarte Nett, BKK Nett

Title: Robot and Digitalization for Automatic and Real-time Power Grid

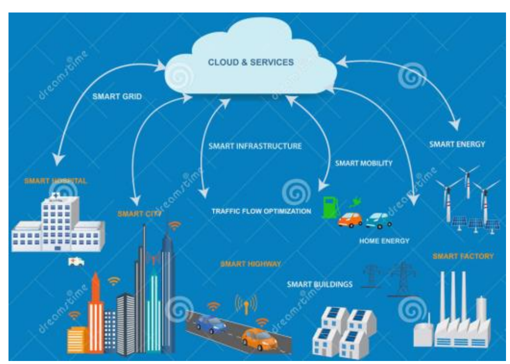
BKK: Founded in 1920; Distribution System Operator; The biggest in Western Norway; Owned by Statkraft

BKK

Outline

Cloud Computing

Fog Computing



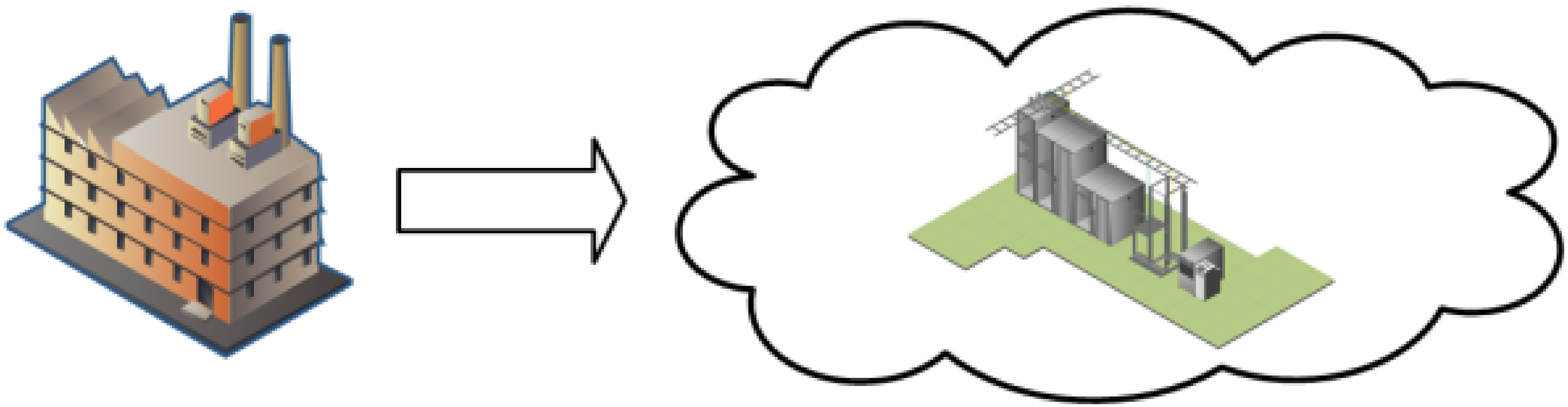
Cloud/Fog Computing for Smart Grid

CLOUD COMPUTING

Evolution of Cloud Computing

- Utility Computing: 1961
- Time Sharing: 1970s
- Large Distributed Data Centers 1980s-1990s
- Internet Computing 2000-Present
- What is new in cloud computing today?
  - Faster data communication
  - Faster and more reliable computing
  - Denser and cheaper storage
  - Newer Programming paradigms
- Comprehensive Computational resource sharing

Why do we need cloud computing?



UiO buildings do not generate their own electricity.

Similarly, IT services can be "generated" remotely by a factory-size bank of powerful computers (servers) and delivered over the Internet to consumers who can take as much, or as little as they need.

Cloud Computing definition

According to NIST (National Institute of Standard and Technology, USA**)**

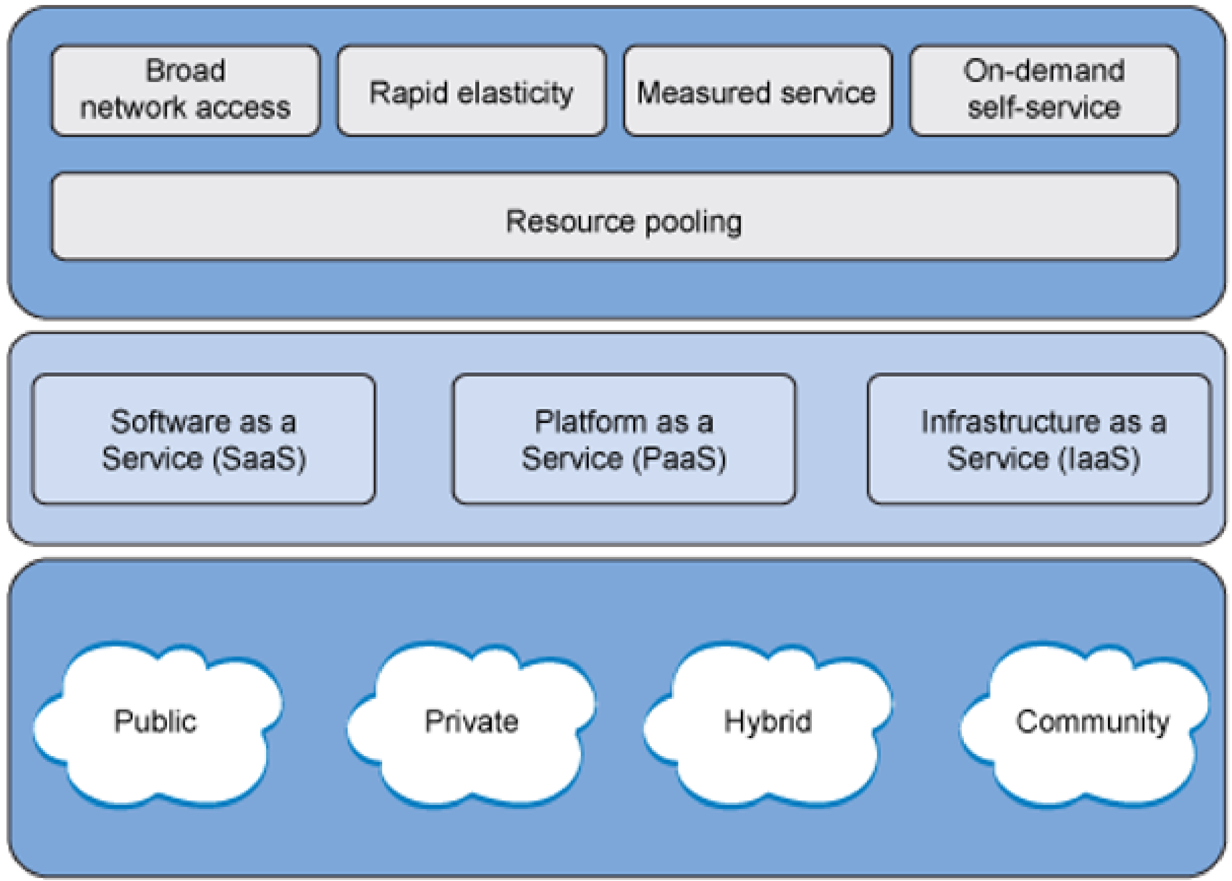
Cloud computing is a model for enabling convenient, on-demand network access to a shared pool of configurable computing resources (e.g., networks, servers, storage, applications, and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction.

NIST’s 5-4-3 Principle for Cloud Computing

Five essential characteristics

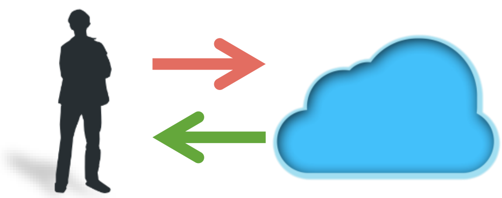
Three service models

Four deployment models



The 5-4-3 principle is a simple, well-structured, and disciplined way of conversing cloud computing. 5 characteristics, 4 deployment models and 3 service models together explain the key aspects of cloud computing.

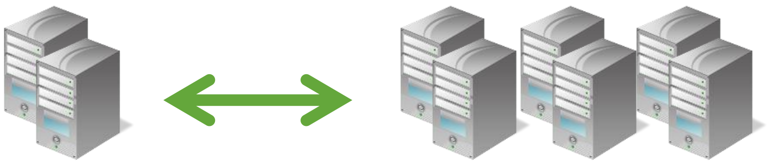
Five Essential Characteristics



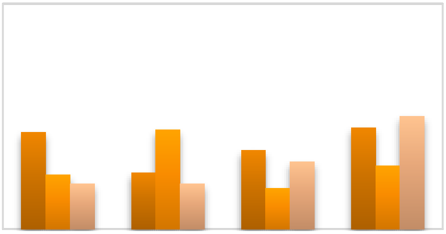
On-demand self-service

Broad network access

Resource pooling

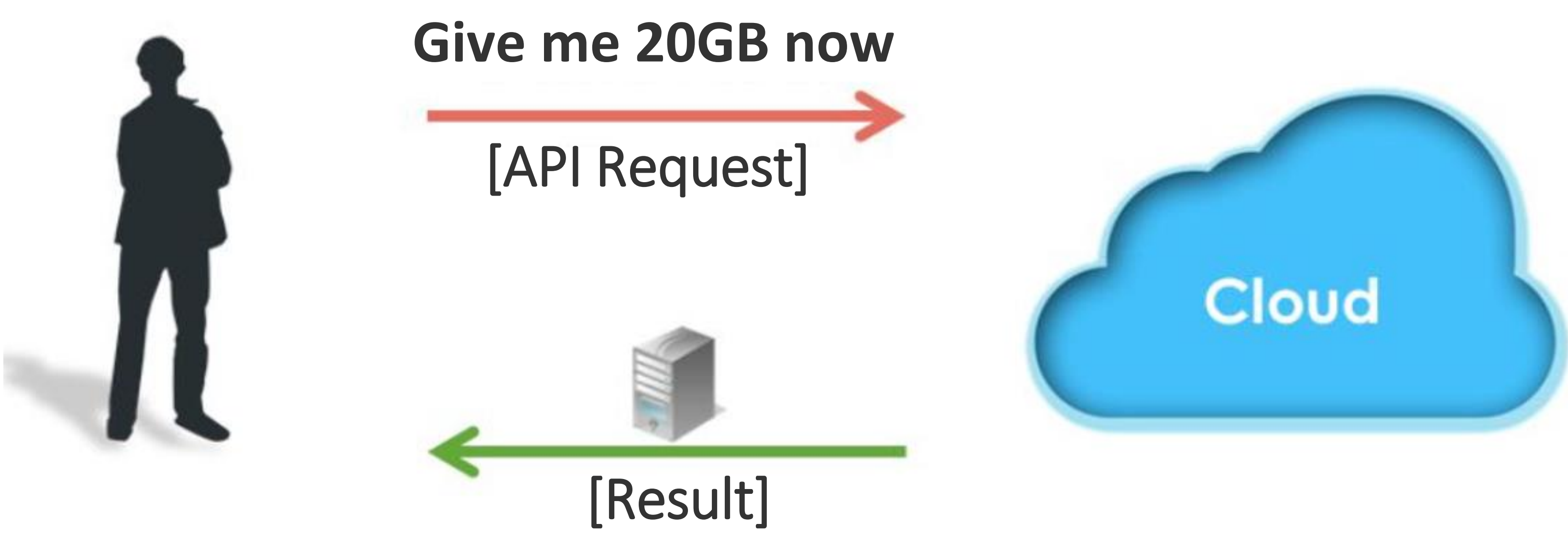


Rapid elasticity



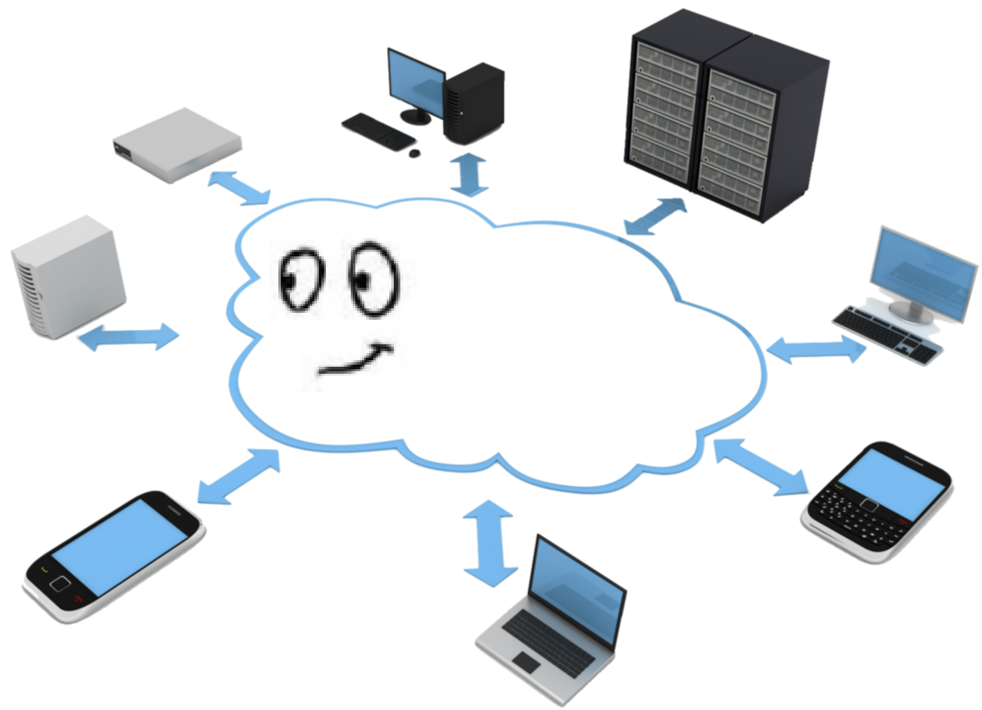
Measured service

Five Essential Characteristics – on-demand self-service



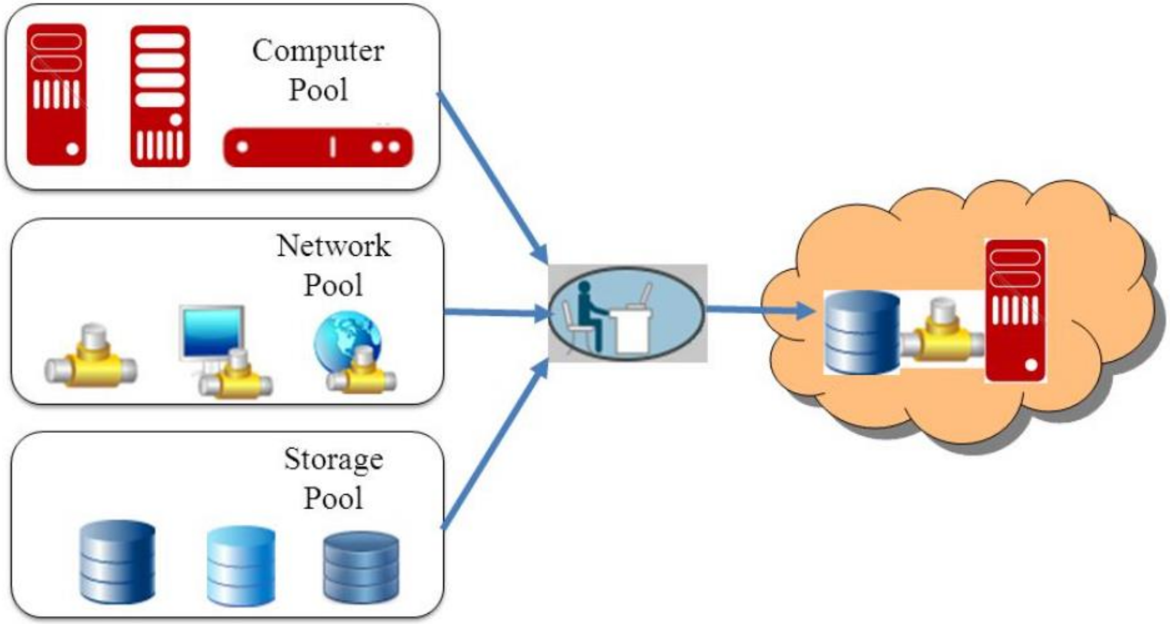
On-demand self-service: **A consumer can provision computing capabilities, such as server time and network storage, as needed, without requiring human interactions with each service provider.**

Five Essential Characteristics – broadband networks access



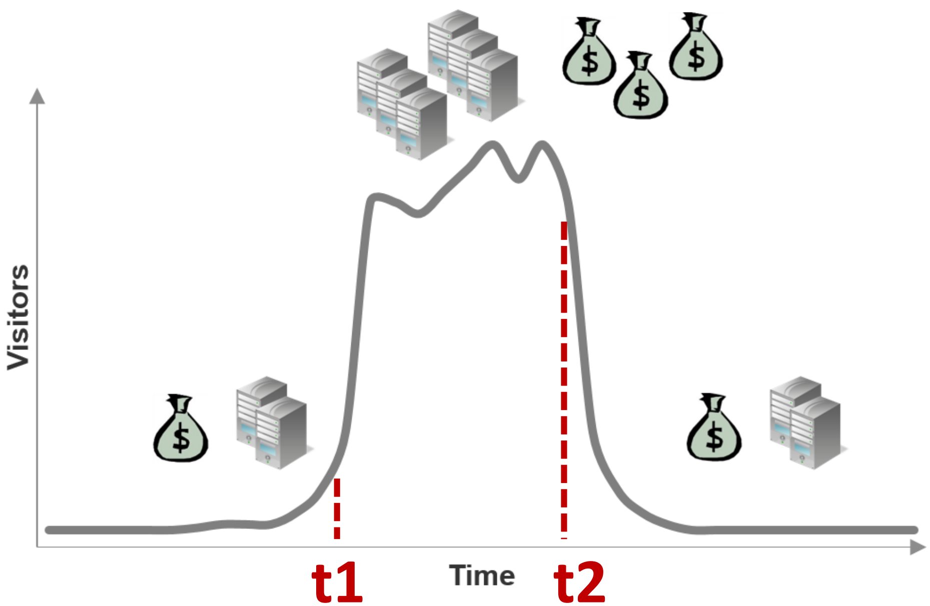
Broad network access: **Capabilities are available over the network and accessed through standard mechanisms that are used by heterogeneous client platforms (mobile phones, tablets, laptops, and workstations) i.e., numerous connectivity options**

Five Essential Characteristics – resource pooling



Resource pooling: The provider's computing resources are pooled to serve multiple consumers with different resources dynamically (re)assigned according to consumer demand. Examples of resources include storage, processing, memory, and network bandwidth.

Five Essential Characteristics – rapid elasticity



- **At time t1**, there are many new visitors and more resources are provisioned
- **At time t2**, there are low visitors and much less resources are provisioned

Rapid elasticity. **Capabilities can be elastically provisioned and released to scale rapidly with dynamic demand.**

Five Essential Characteristics – measured service

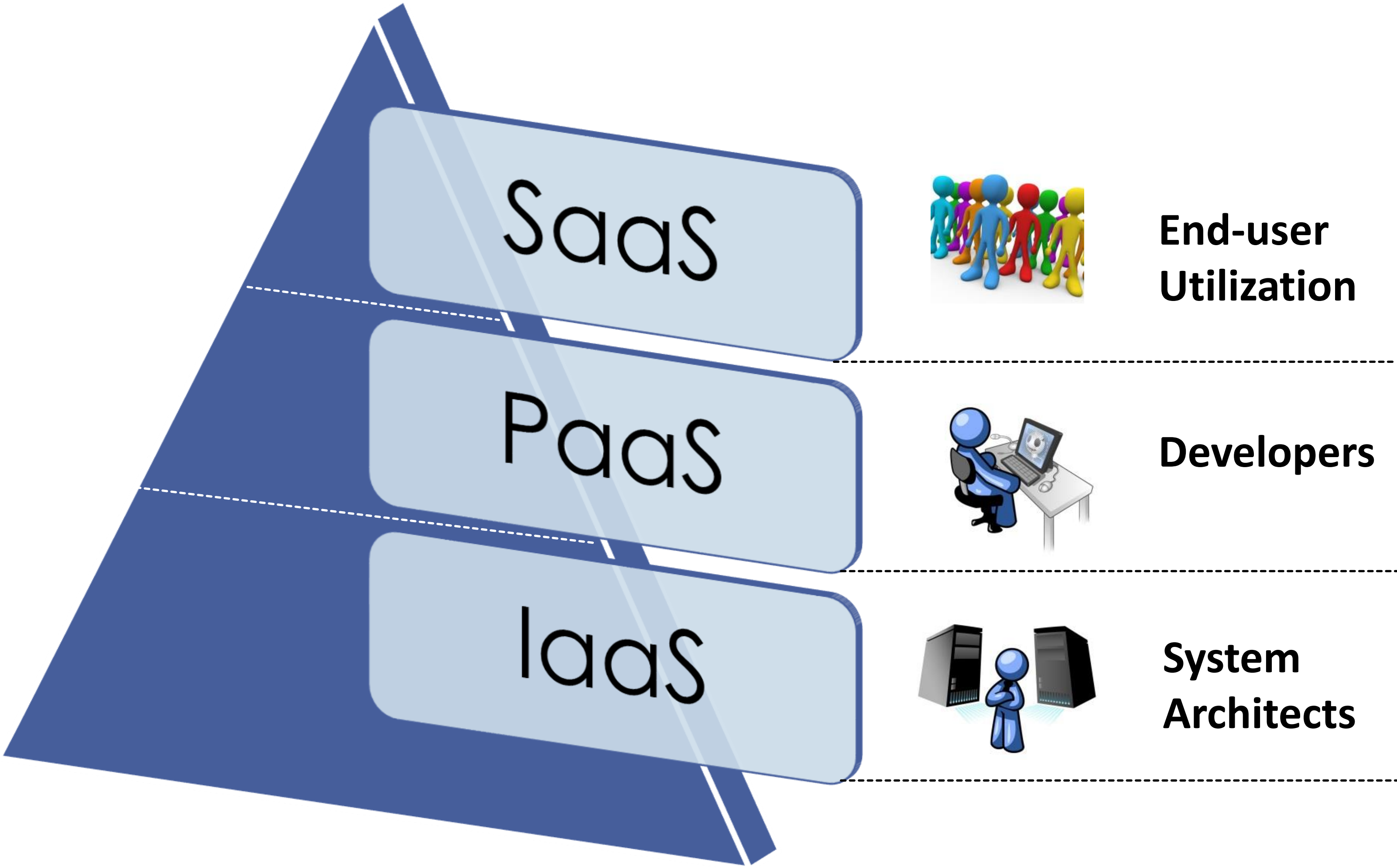
Details

Expand All Services | Collapse All Services — Printer Friendly Version

AWS Service Charges		**$9.28**
Amazon Elastic Compute Cloud Download Usage Report »		**$8.27**
US East (Northern Virginia) Region		
Amazon EC2 running Linux/UNIX		
$0.020 per Micro Instance (t1.micro) instance-hour (or partial hour)	275 Hrs	5.50
Amazon EC2 EBS		
$0.10 per GB-month of provisioned storage	8.100 GB-Mo	0.81
$0.10 per 1 million I/O requests	38,962 IOs	0.01
$0.125 per GB-Month of snapshot data stored	0.069 GB-Mo	0.01
Elastic IP Addresses		
$0.00 per Elastic IP address not attached to a running instance for the first hour	1 Hr	0.00

Measured service: Cloud systems automatically control and optimize resource use by leveraging a metering capability appropriate to the type of service (e.g., storage, processing, bandwidth, active user accounts). Resource usage can be monitored, controlled, audited, and reported, providing transparency for both the provider and consumer.

Three Service Models



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

IaaS, Paas, SaaS Provide Different Hardware/Software

SaaS

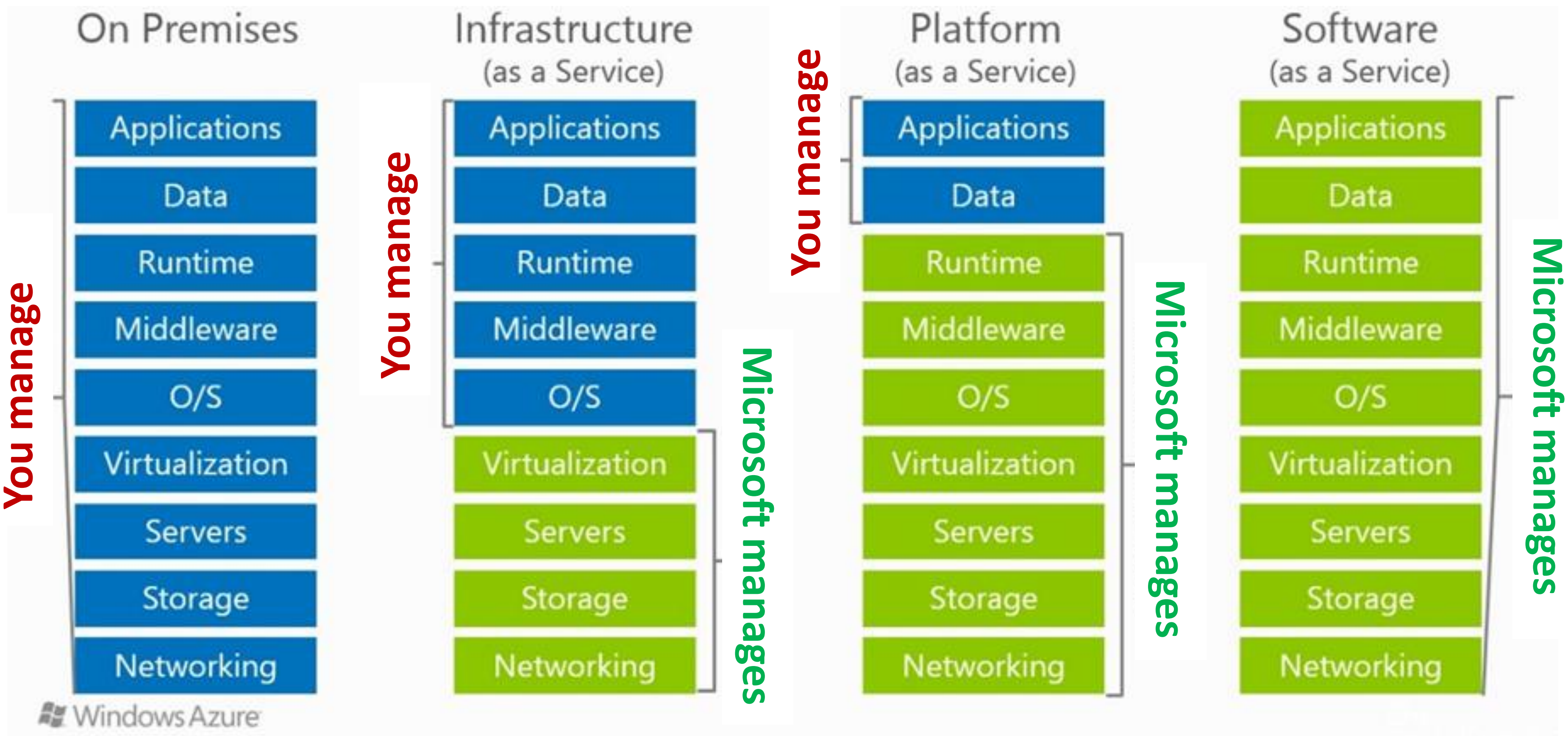
PaaS

IaaS

Hosted applications	Development tools, database management, business analytics	Operation systems	Servers and storage	Networking firewalls, security	Data center physical building

IaaS, PaaS, SaaS provide different level of hardware and software services

IaaS, Paas, SaaS have Different Software Stack Control

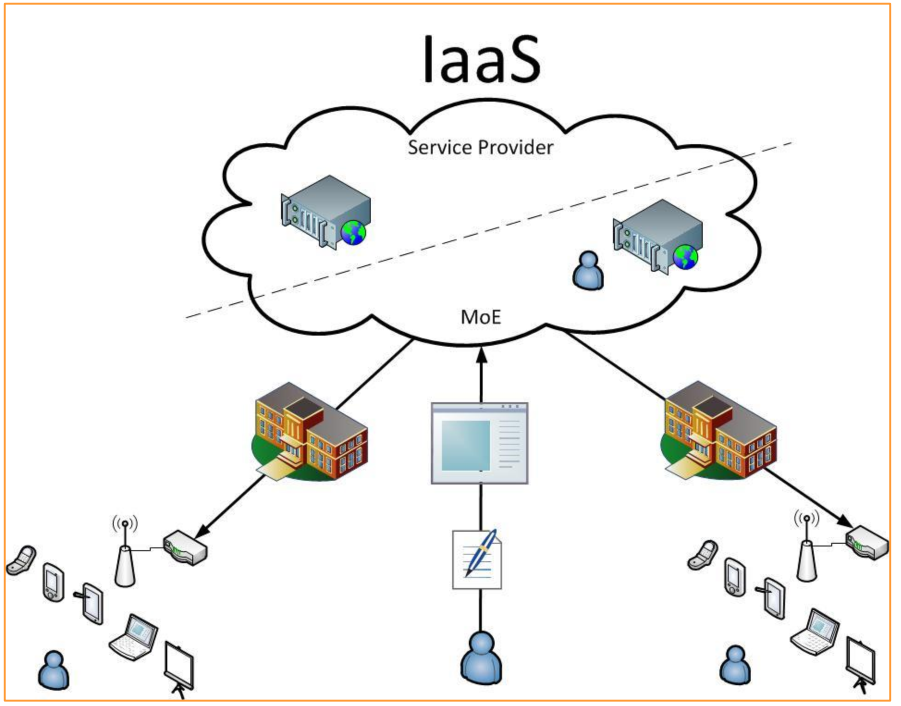


Microsoft Azure Cloud Services as an example to show IaaS, PaaS and SaaS software stack control, by Microsoft and by customers

Three Service Models - IaaS

IaaS: provide the consumer processing, storage, networks, and computing resources. The consumer is able to deploy and run arbitrary software, e.g., operating systems and applications.

The consumer does not manage or control the underlying cloud infrastructure but has control over operating systems, storage, and deployed applications



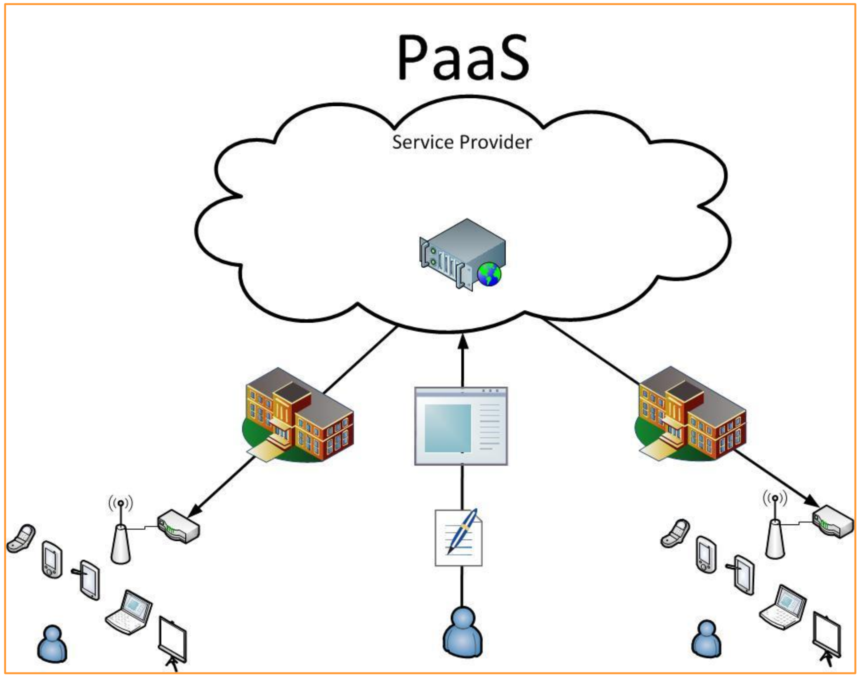
Plain language: provision storage, CPU, network and other computing resources. Deploy and run your own OS and software

Example: Amazon Web Service (AWS)

Three Service Models - PaaS

PaaS: provide the consumer to deploy onto the cloud infrastructure. Then, the consumer can create applications using programming languages, libraries, services, and tools supported by the provider.

The consumer does not manage or control the underlying cloud infrastructure including network, servers, operating systems, or storage, but has control over the deployed applications.

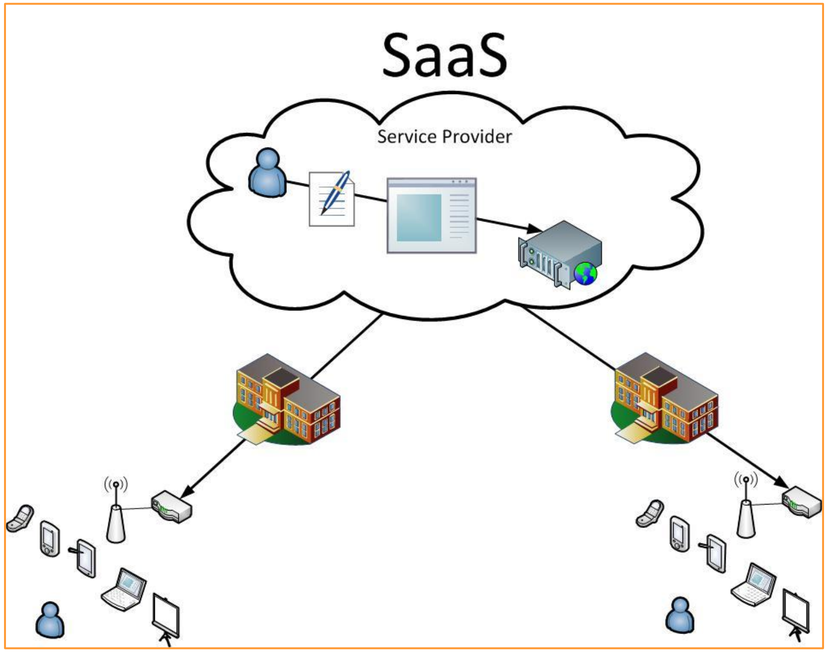


Plain language: use the languages, libraries, services and tools supported by the provider to deploy customers-created applications on the provider's network (e.g., "Heroku" which operates on top of the Amazon Web Services IaaS system)

Three Service Models - SaaS

SaaS: provide the consumer to use the provider's applications running on a cloud infrastructure. The applications are accessible from various client devices, e.g., a thin client, or web browser.

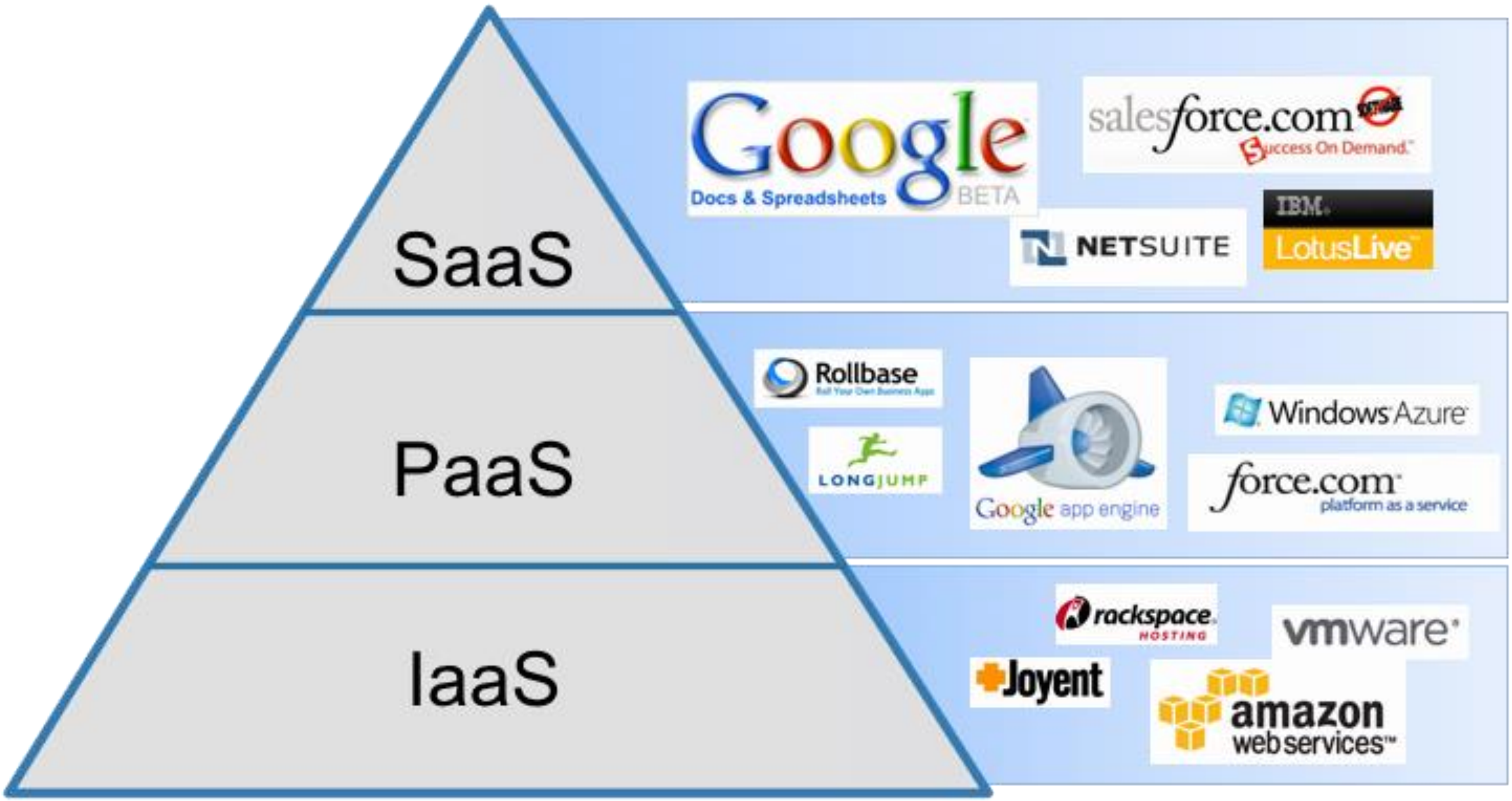
The consumer does not manage or control the underlying cloud infrastructure, or even individual application capabilities.



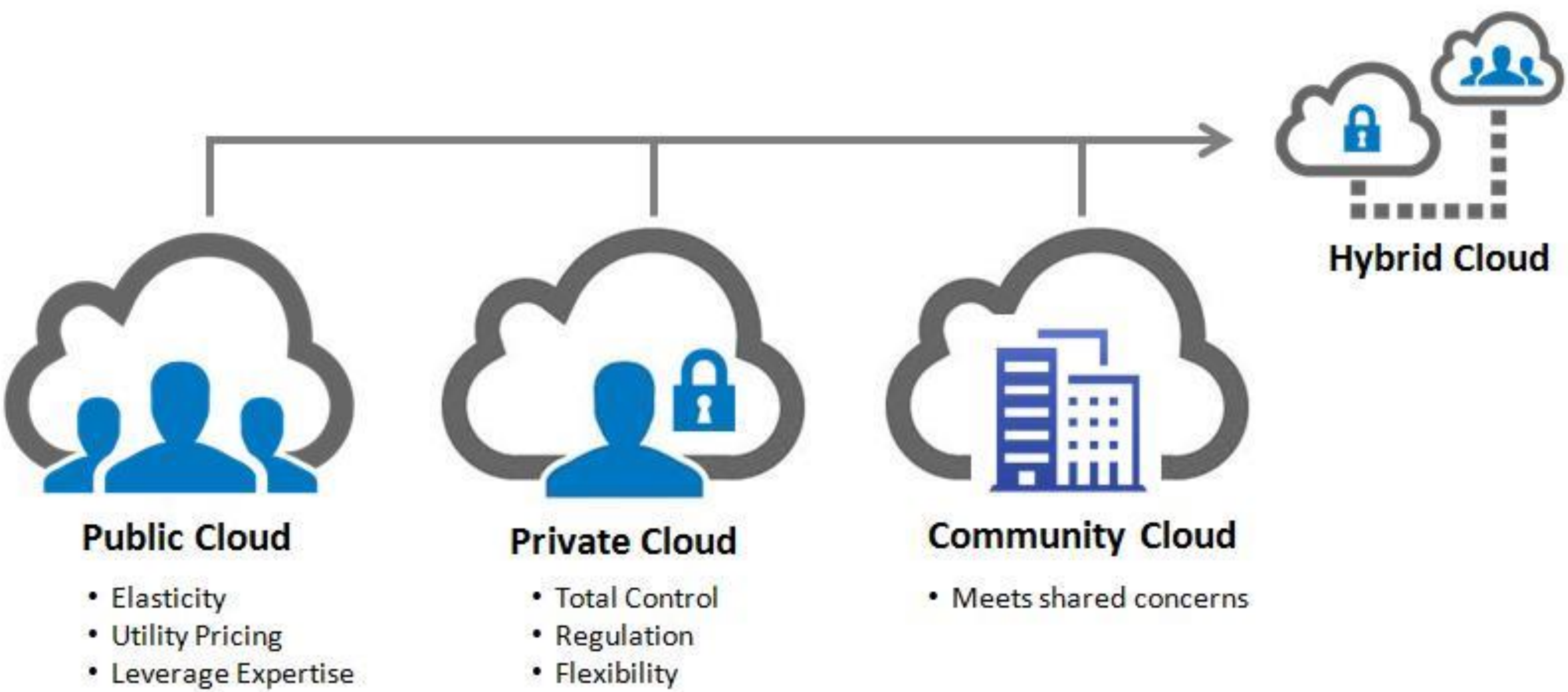
Plain language: the service is typically offered by third party software and web app developers and are hosted on IaaS and PaaS platforms.

Example: "Google Apps"

Example Vendors

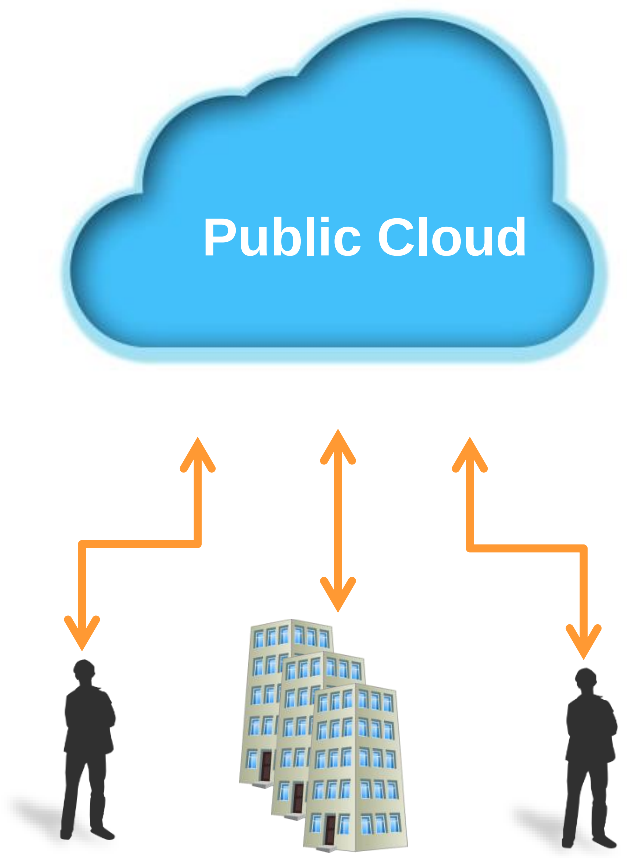


Four Deployment Models



Four Deployment Models – public cloud

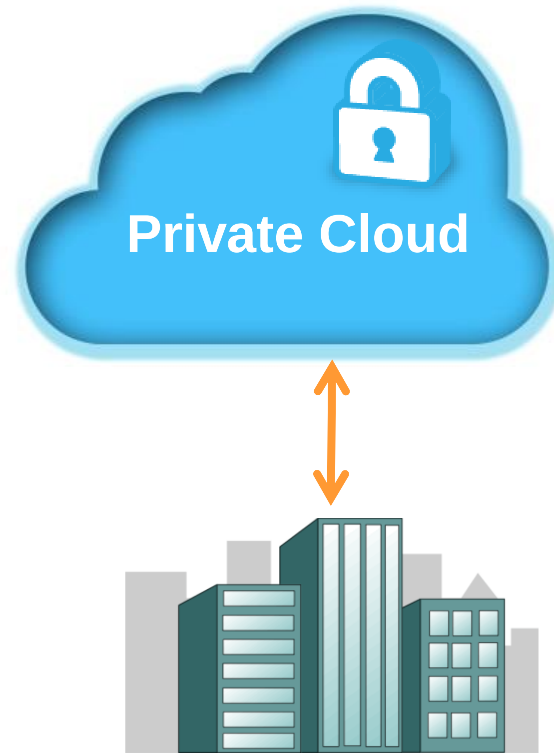
Public cloud: The cloud infrastructure is provisioned for open use by the general public. It may be owned, managed, and operated by a business, academic, or government organization.



Example: public cloud service providers like Amazon Web Service (AWS)

Four Deployment Models – private cloud

Private cloud: The cloud infrastructure is provisioned for exclusive use by a single organization comprising multiple consumers (e.g., business units). It may be owned, managed, and operated by an organization, a third party, or a combination of them



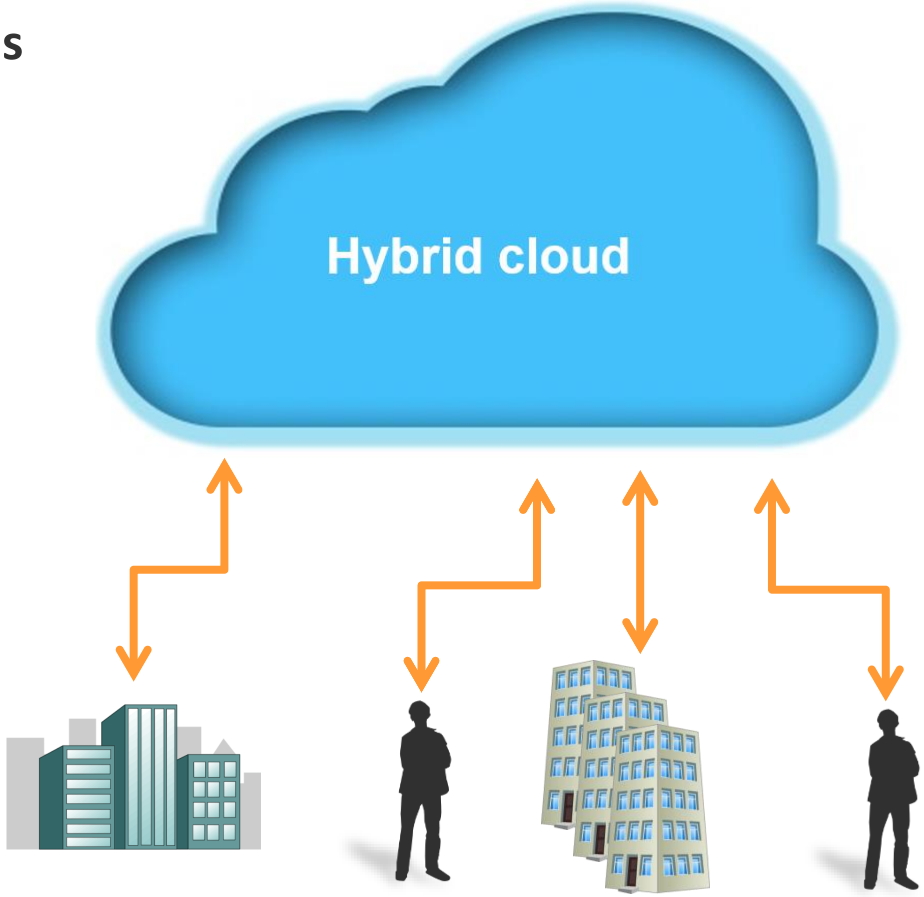
Example: Amazon AWS GovCloud

Four Deployment Models – hybrid cloud

Hybrid cloud: The cloud infrastructure is a composition of two or more distinct cloud infrastructures (private, community, or public) that remain unique entities.

They are bound together by standardized technology that enables data and application portability.

Example: An enterprise can deploy a private cloud to host sensitive workloads, but use a third-party public cloud provider, e.g., Google Compute Engine, to host less-critical resources

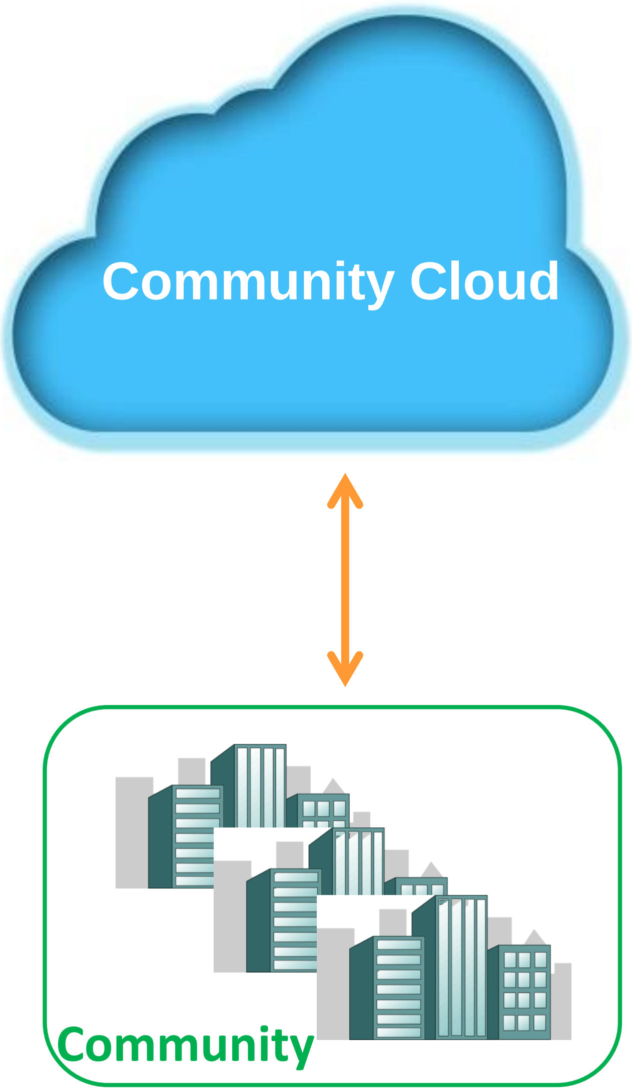


Four Deployment Models – community cloud

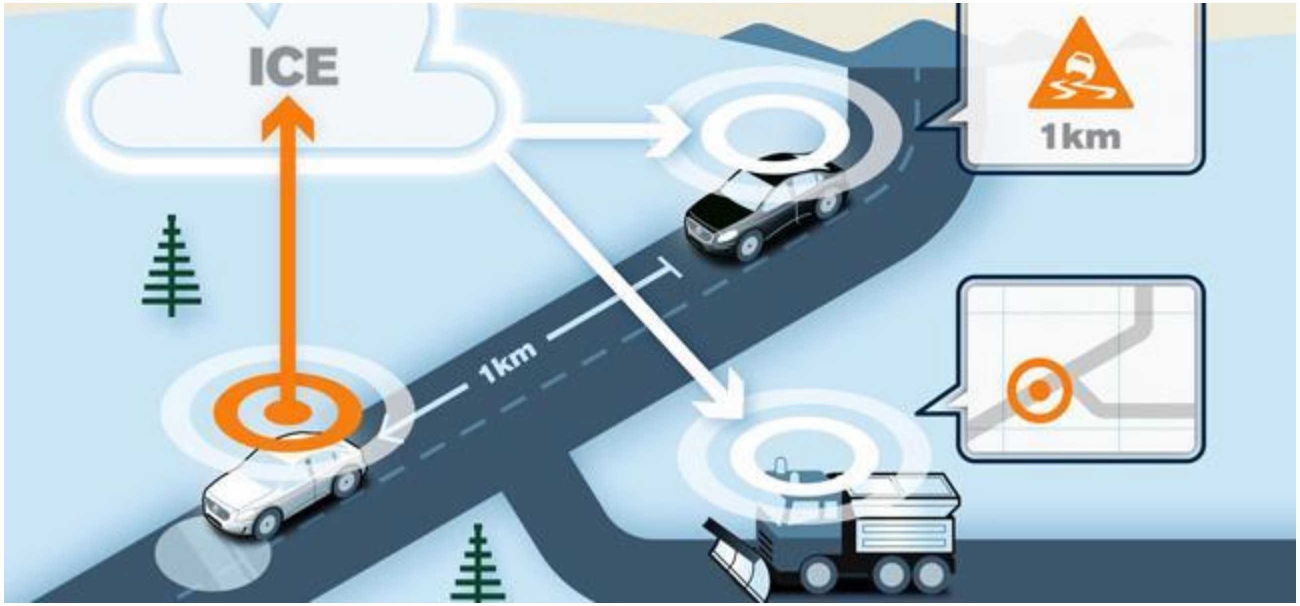
Community cloud: The cloud infrastructure is provisioned for exclusive use by a specific community of consumers from organizations that have shared concerns (e.g., mission, security requirements, policy, and compliance considerations). It may be owned, managed, and operated by one or more of the organizations in the community, a third party, or a combination of them.

Q: Is community cloud a public or a private cloud?

A community cloud is a private cloud of an associated community.



Cloud Computing for Transport in Norway

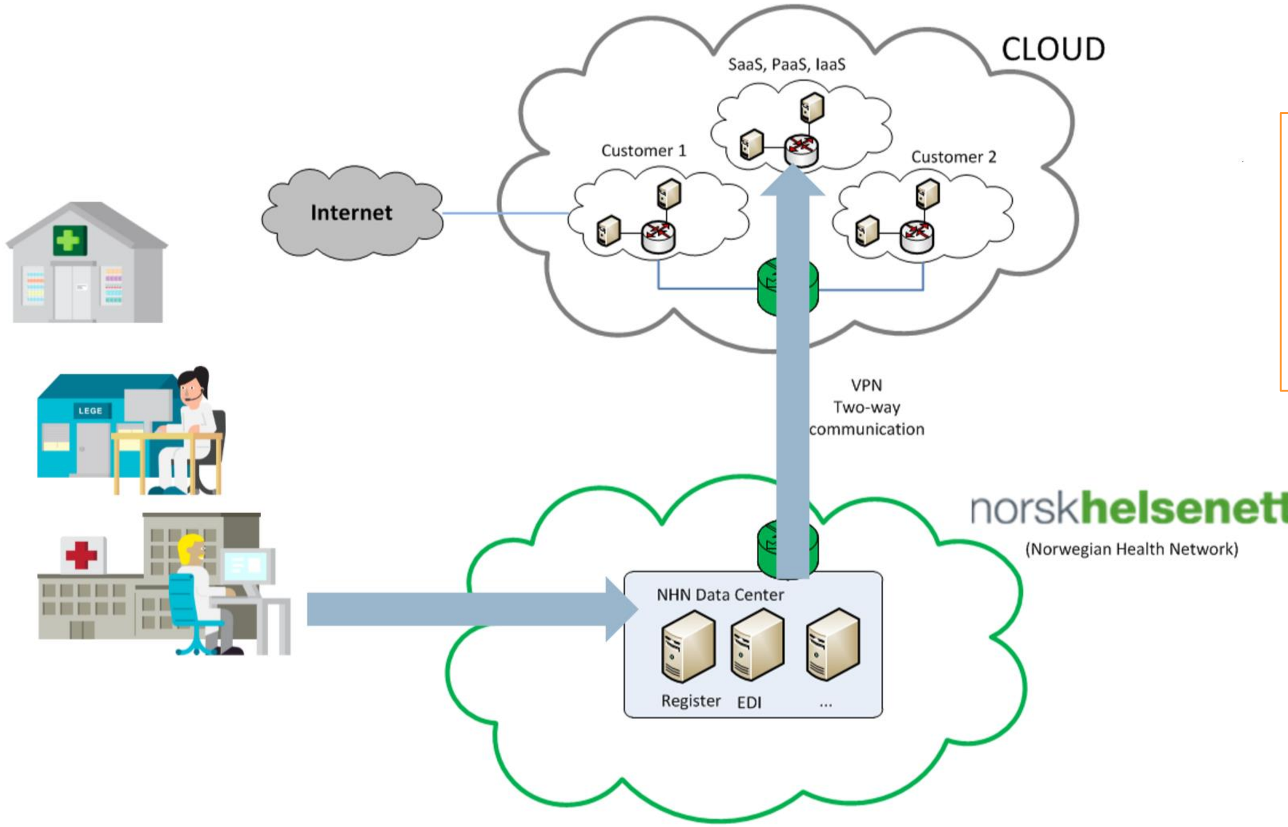


Background: Driving in slippery condition could be very dangerous. It will be easy to maneuver if you already know where to look out for on the road.

Volvo works with Norwegian Public Roads Administration to launch cloud-based system to share road friction information provided by individual cars

Approach: 50 test cars on the roads. The Volvo test car detects an icy road, the information is transmitted to Volvo's database via the network ICE and then transmitted to other vehicles that are approaching the slippery area

Cloud Computing for Healthcare - work in progress by Norwegian Health Network



Use case study: **Consuming cloud services from the Health Network**

Nearly all health care providers in Norway are connected to the Norwegian Health Network, and approx. 150 third-party service providers

Main focus: information security and control. Norwegian laws on public archives do not allow storage of archive material outside of Norway

We are recently seeing new challenges for cloud computing…

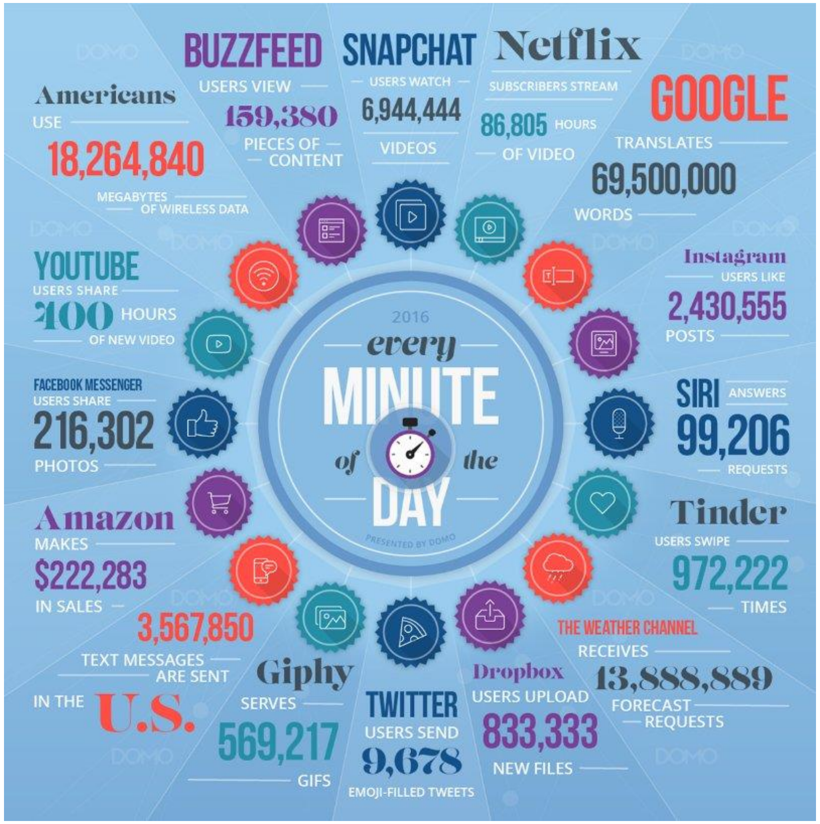
New Observation 1: people as end-users are changing…

An end-user is changing from a pure data consumer to both data consumer and data producer. This change requires more new functions at the end-user side.

Data Consumer: an end-user watches a YouTube video on a smart phone.

Data Producer: people are producing data from their mobile devices.

For example, every single minute, YouTube users upload 100hours of new video content; Instagram users post nearly 2430000 new photos



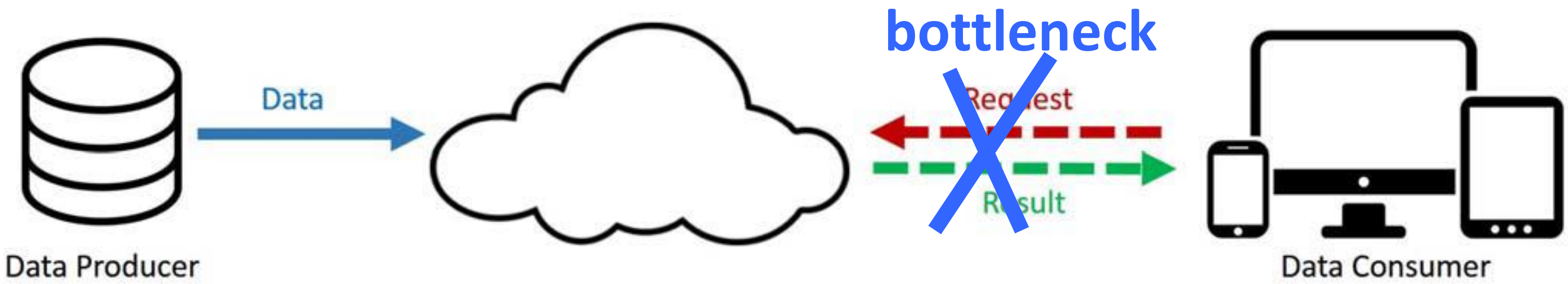
New Observation 2: things as end-terminals are changing …

50 billion things
(devices/terminals/sensors/vehicles) will be connected to the Internet by 2020 – CISCO

Data produced by such massive number of things will reach 500 zettabytes (10^27 bytes). Comparatively, the global data center IP traffic will reach 10.4 zettabytes by that time - estimated by Cisco Global Cloud Index

Q: what are new challenges for cloud computing when end-users and end-terminals are changing?

1st New Challenge for Cloud Computing – Data Transmission



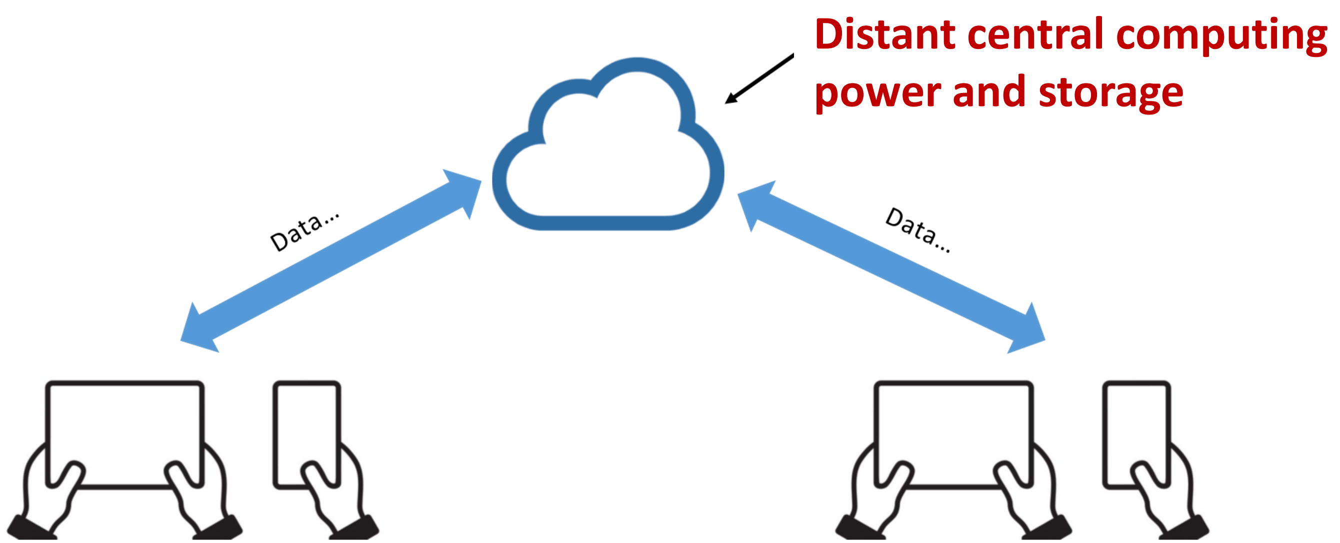
Cloud Computing Principle

With the growing data generation at the end, speed of data transmission is becoming the bottleneck for the cloud-based computing paradigm

For example: about 5 GB data is generated by a Boeing 787 every second(*), but the bandwidth between the airplane and satellite or base station on the ground is not large enough for data transmission

* Boeing 787s to Create Half a Terabyte of Data Per Flight, Says Virgin Atlantic. Accessed on Dec. 7, 2016. [Online]. Available: https://datafloq.com/read/self-driving-carscreate-2-petabytes-data-annually/172

2nd New Challenge for Cloud Computing –Latency



Cloud may have high latency which does not fit certain applications

An autonomous vehicle generates 1 GB data every second and it requires real-time processing to make correct decisions. If all the data needs to be sent to the cloud for processing, the response time would be too long.

3rd New Challenge for Cloud Computing – Privacy

Storing data and important files on external service providers in cloud always opens up risks

CHANGING FACE OF SECURITY

LinkedIn Lost 167 Million Account Credentials in Data Breach

Robert Hackett
May 18, 2016

Remember LinkedIn's 2012 data breach?

A hacker stole 6.5 million encrypted passwords from the site and posted them to a Russian crime forum. Now it appears that data theft was just the tip of the

For example: for wearable health devices, since the physical data collected by the things is usually private, uploading raw data to cloud has the risk of privacy issues

Three New Challenges Motivate Fog Computing Paradigm

Data transmission

Low latency

Privacy & security

New challenges motivate to put computation, storages, services close to the end-users to significantly reduce latency and protect private data.

Expectation: by 2019, 45% of data will be stored, processed, analyzed, and acted upon close to, or at the edge of the network

FOG COMPUTING

Fog Computing definition

According to CISCO

Fog Computing extends the cloud computing paradigm that provides computation, storage, and networking services between end devices and traditional cloud servers. Fog Computing nodes are typically located at the edge of network located away from the main cloud data centers.

Edge computing vs. fog computing

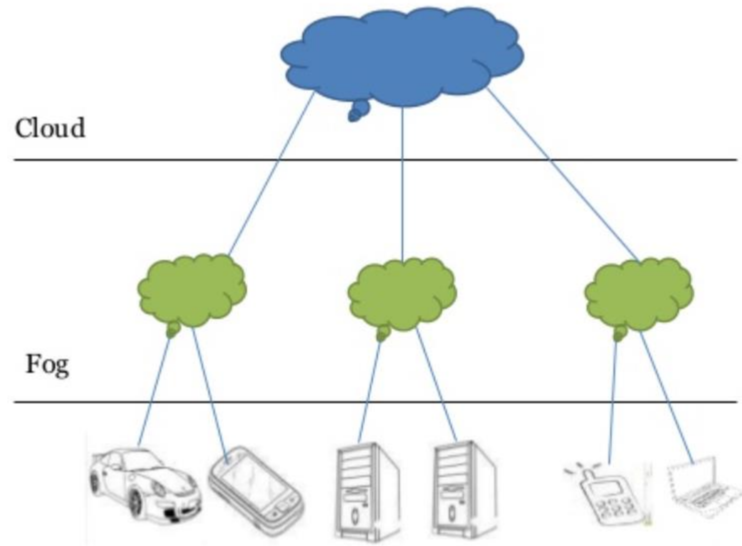
We define "edge" as any computing and network resources between data sources and cloud data centers.

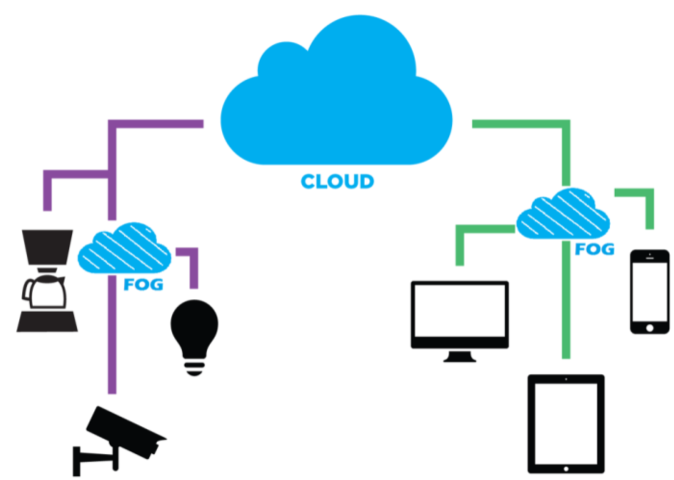
Fog Computing Architecture

The initial definition of fog computing has been expanded. Fog computing now is not a mere extension of cloud computing, but a paradigm of its own.

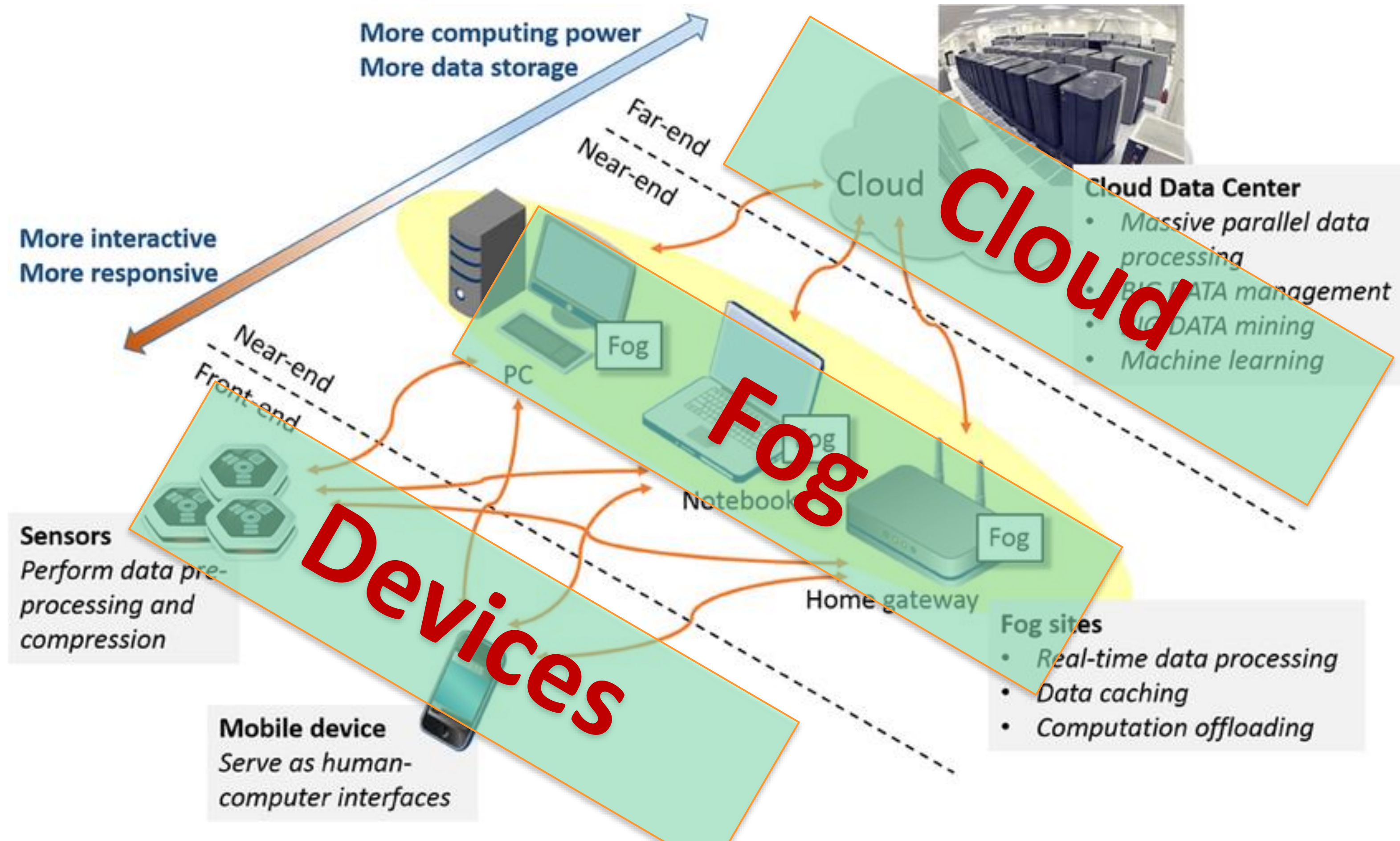
Fog computing now refers to a three-tier architecture (Clients ⇔ Fog nodes ⇔ Central Servers)

- Centralized cloud servers coexist with fog nodes but are not essential for the execution of fog services
- Fog nodes can range from resource-poor devices (e.g. end devices) to more powerful cloud servers (e.g. Internet routers, 5G base stations).





Where is Fog or Edge? – an example



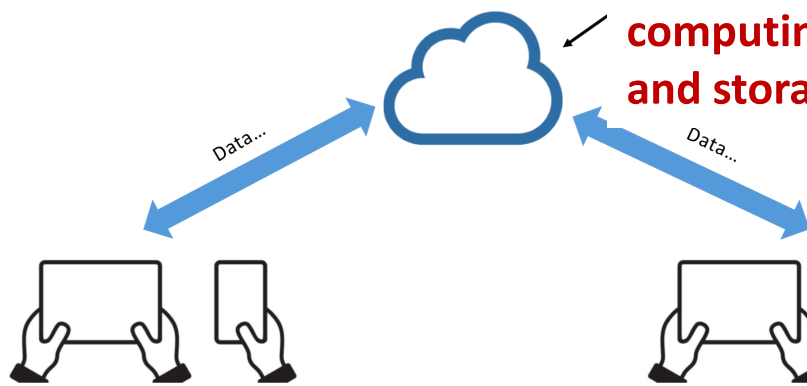
Source: "Pervasive Brain Monitoring and Data Sharing based on Multi-tier Distributed Computing and Linked Data Technology", Frontiers in Human Neuroscience, June 2014

Three-layer architecture: End-devices ➔ Fog layer ➔ Cloud layer.
We also call this Fog-to-Cloud (F2C) architecture

Main Difference between Cloud Computing and Fog Computing

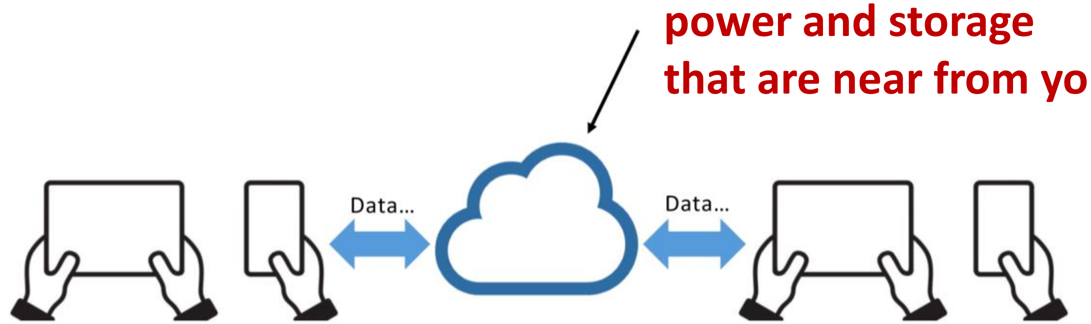
Cloud computing

Servers, computing power, storage are centralized. The specific location of the resources are not known to end users; and they have no or limited control of the cloud infrastructure.

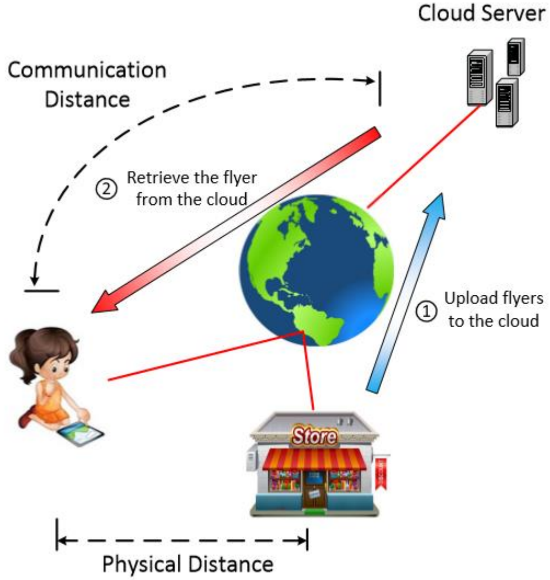


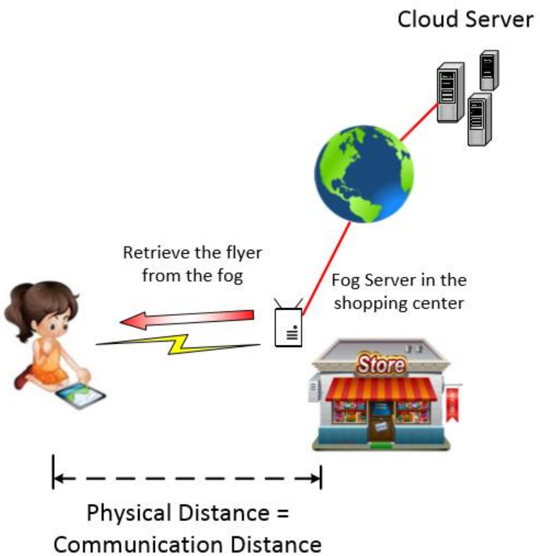
Fog computing

Servers, computing power and storage are close to end users. The specific location of the resources may be known; end users may be able to manage partially.



Fog Computing Advantage – an example





Face recognition (*): a user uses an app in a smart phone to capture a face photo of herself or any other people, and the app will transmit the face photo to a server, either in a fog or in Amazon EC2 cloud. The server will recognize the face by matching it in the local face photo database.

Response time: reduced from 900 to 169 ms by moving computation from cloud to the edge. The time duration from when the smartphone begins to upload the face photo to when the smartphone receives the result.

*** S. Yi, et al. "Fog computing: Platform and applications," HotWeb 2015**

Comparison of Fog Computing and Cloud Computing

	Cloud Computing	Fog Computing
Target Users	General Internet users.	Mobile users
Service Type	Global information collected from worldwide	Limited localized information services related to specific deployment locations
Hardware	Ample and scalable storage space and compute power	Limited storage, compute power and wireless interface
Distance to Users	Faraway from users and communicate through IP networks	In the physical proximity and communicate through single-hop wireless connection
Working Environment	Warehouse-size building with air conditioning systems	Outdoor (streets, parklands, etc.) or indoor (restaurants, shopping malls, etc.)
Deployment	Centralized and maintained by Amazon, Google, etc.	Centralized or distributed in regional areas by local business (local telecommunication vendor, shopping mall retailer, etc.)

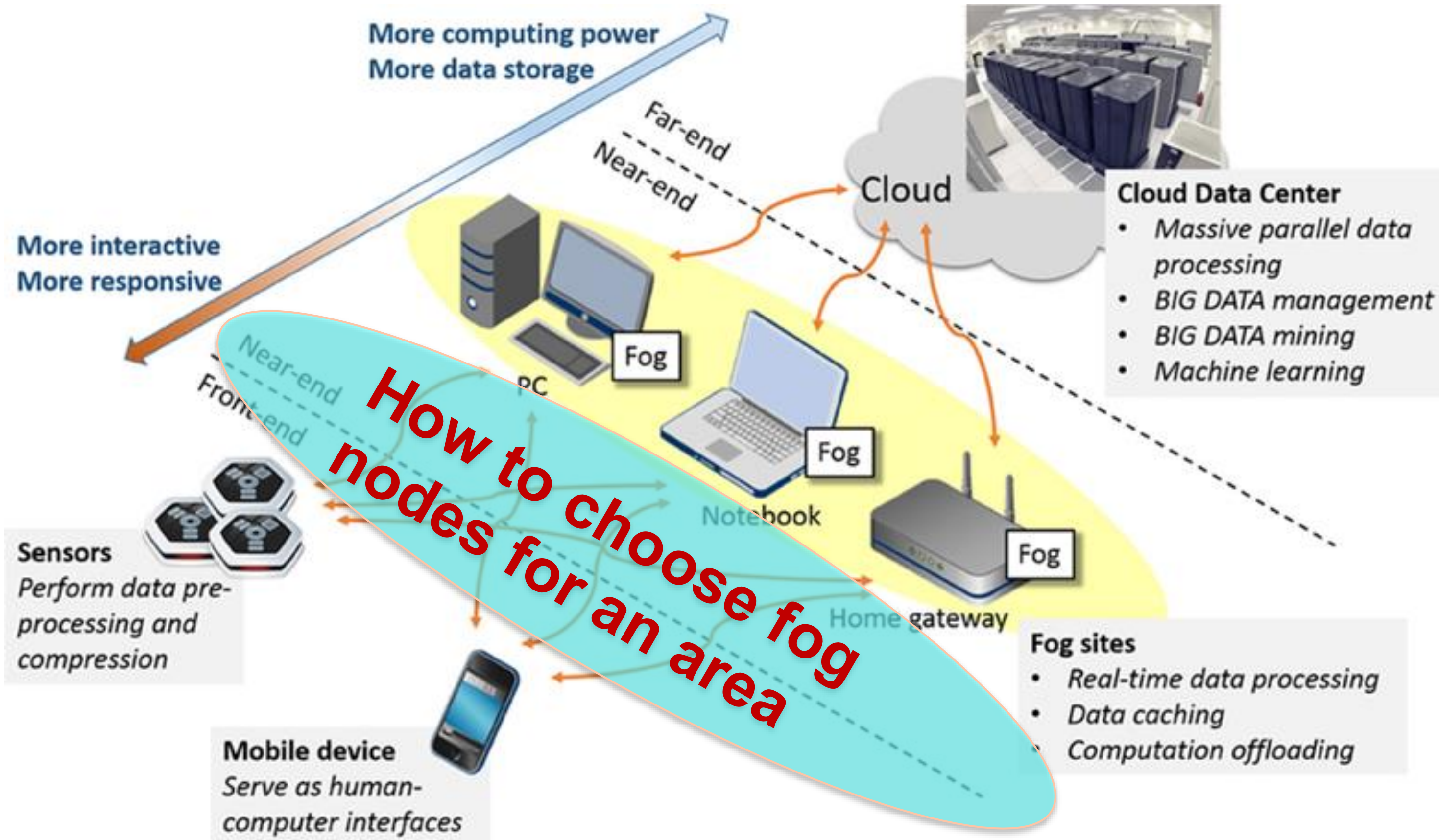
T H. Luan et.; al. , "Fog Computing: Focusing on Mobile Users at the Edge" arXiv:1502.01815v3 [cs.NI] 30 Mar 2016

More Comprehensive Comparison between Cloud Computing and Fog Computing

Parameters	Cloud Computing	Fog Computing
Server nodes location	Within the Internet	At the edge of the local network
Client and server distance	Multiple hops	Single/multiple hop
Latency	High	Low
Delay Jitter	High	Low
Security	Non-locally controllable	Locally controllable
Location awareness	No	Yes
Vulnerability	Higher probability	Lower probability
Geographical distribution	Centralized	Dense and Distributed
Number of server nodes	Few	Very large
Real time interactions	Not fully supported	Supported
Usual last mile connectivity	Leased line /wireless	Mainly wireless
Mobility	Limited support	Supported

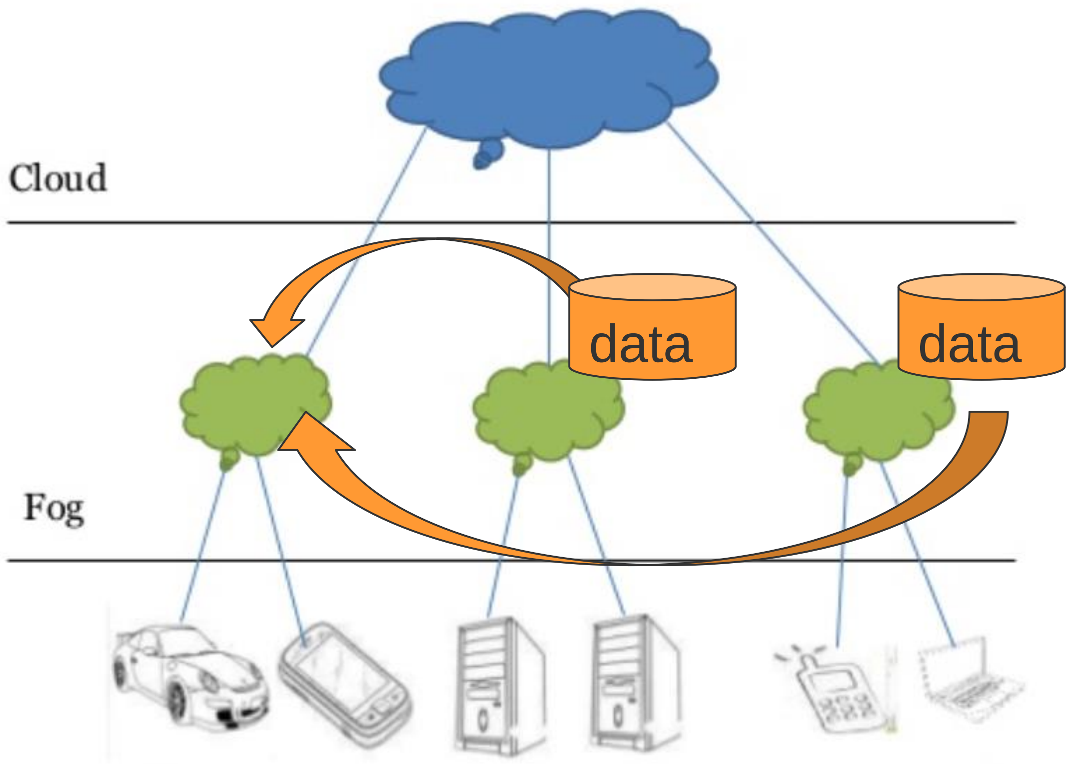
K.P.Saharan and A.Kumar" Fog in Comparison to Cloud: A Survey", Int'l. Journal of Computer Applications, vol. 122, no.3, July 2015

Fog Computing Challenges – Quality-of-Service (I)



Connectivity: fog nodes provide new opportunities for reducing cost and expanding connectivity. The selection of fog node from end users will heavily impact the performance. We can dynamically select a subset of fog nodes to increase the availability of fog services for a certain area.

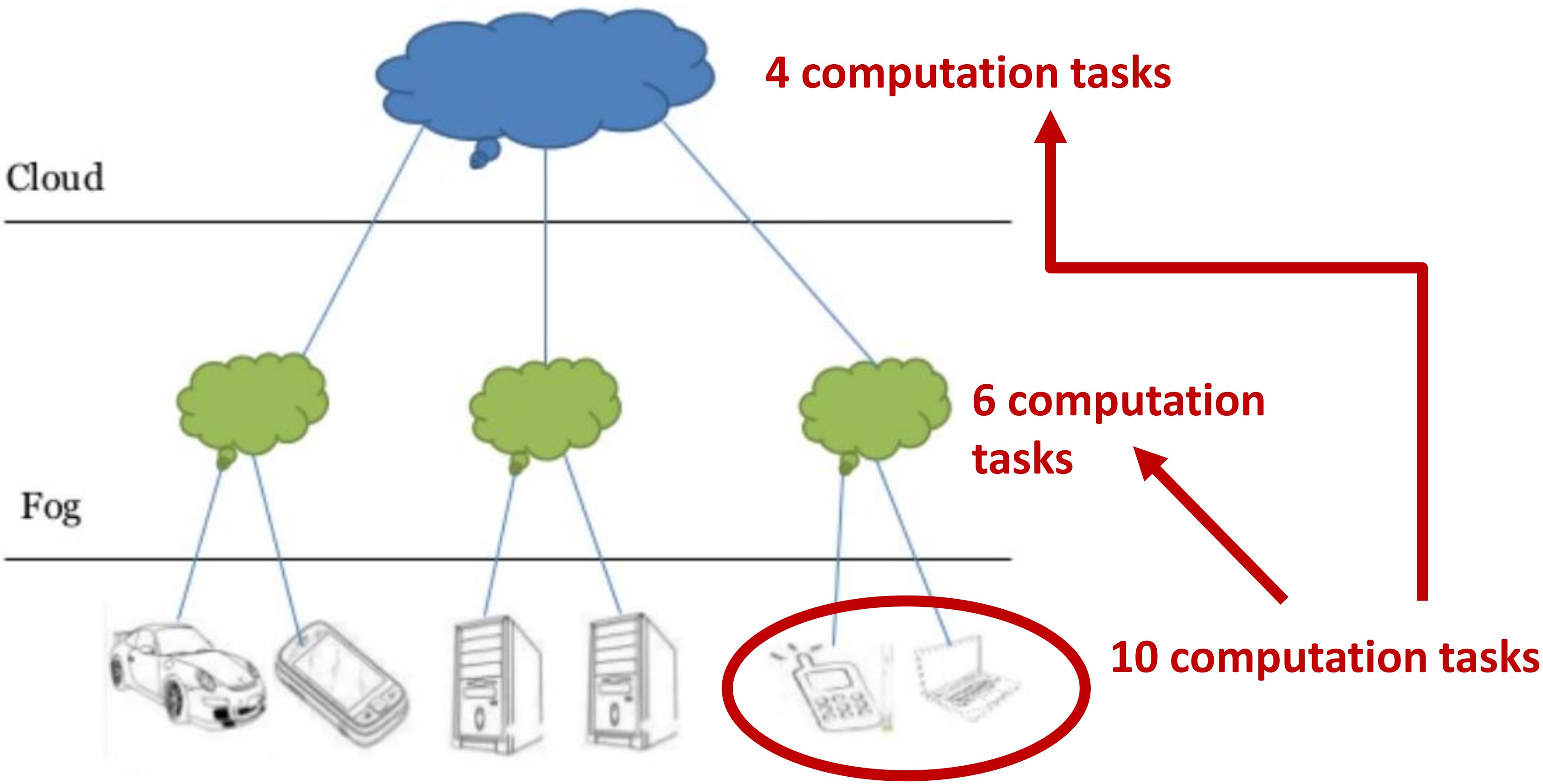
Fog Computing Challenges – Quality-of-Service (II)



Capacity: It is important to investigate how data is placed in fog network since data locality for computation is very important. Need to consider two aspects: 1) network bandwidth, 2) storage capacity.

For example, a fog node may need to compute on data that is distributed in several nearby nodes. The computation cannot start before the completion of data aggregation, which adds delay to services.

Computation Offloading



Computation offloading: heavy computation tasks can be done in fog or cloud instead of mobile devices. This saves storage and battery lifetime.

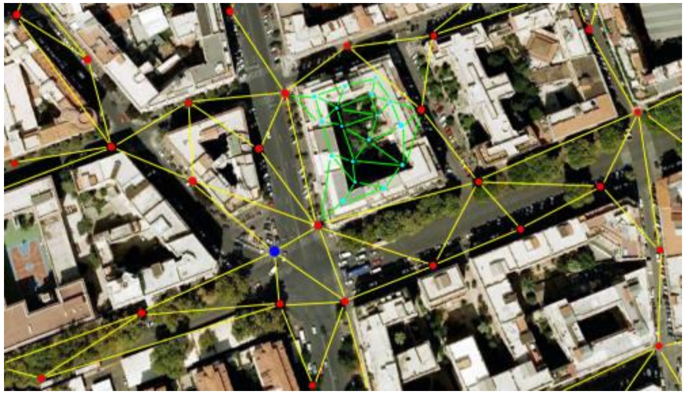
The main challenges in offloading in fog computing are how to deal with the dynamics. In three-layered architecture: device-fog-cloud. A typical question: how to partition tasks to offload on fog and cloud.

Fog Computing Applications (I)

Fog/Edge computing is able to deal with new applications that suffer from the limitations and poor scalability of the centralized cloud paradigm. The applications can be:

Applications susceptible to latency: Typical examples are manufacturing, urban transport and smart energy, where actuation has to be driven in real-time.

Geo-distributed applications: Typical examples include environmental monitoring, which are based on the collection and processing of streams from thousands or even millions of sensors.



Fog Computing Applications (II)

Mobile applications: typical applications involving fast moving objects, e.g., autonomous cars. They require moving objects to access local resources (computing, storage) residing at their vicinity.

Distributed multi-user applications with privacy implications and need for fine-grained privacy control. These applications can benefit from a decentralization of the storage and management of private data to the various edge servers, thus alleviating the risk of transferring, aggregating and processing all private datasets at the centralized cloud.

Fog Computing in Industry (I)

The OpenFog Reference Architecture, to be released in 1Q 2017, is based on eight pillars.

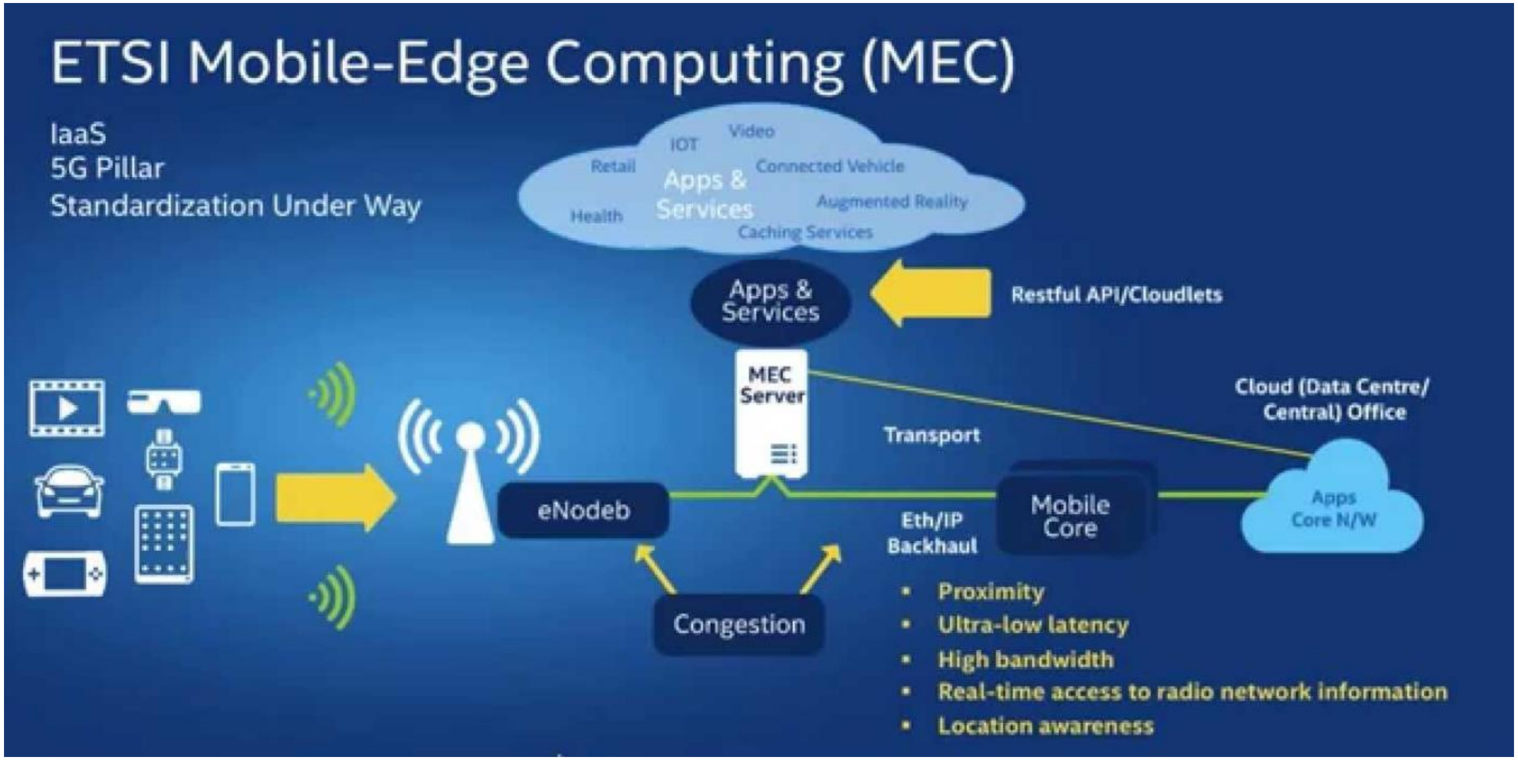
IT industry leaders (e.g., ARM, Cisco, Dell, Intel, Microsoft, and the Princeton University Edge Laboratory) formed a coalition and have joined forces to create the OpenFog Consortium

Goal: acceleration of Fog computing technology deployment for the good of the industry https://www.openfogconsortium.org/

Fog Computing in Industry (II)

Mobile Edge Computing (MEC) is developed by ETSI Specification. MEC pushes the cloud computing capabilities close to the Radio Access Networks in 4G. MEC server can be a mini-data center

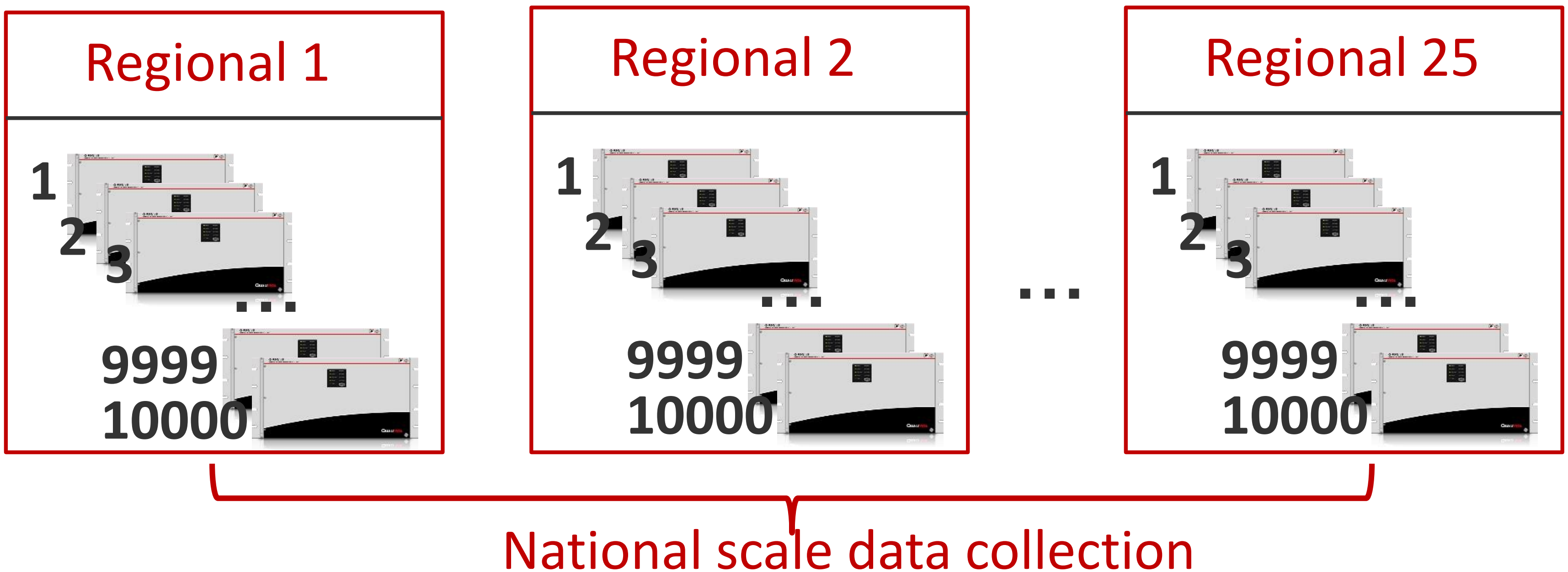
- **located in either the base station**
- **storage close to the radio access networks**



CLOUD/FOG COMPUTING FOR SMART GRID

National Scale Phasor Data Collection – an example

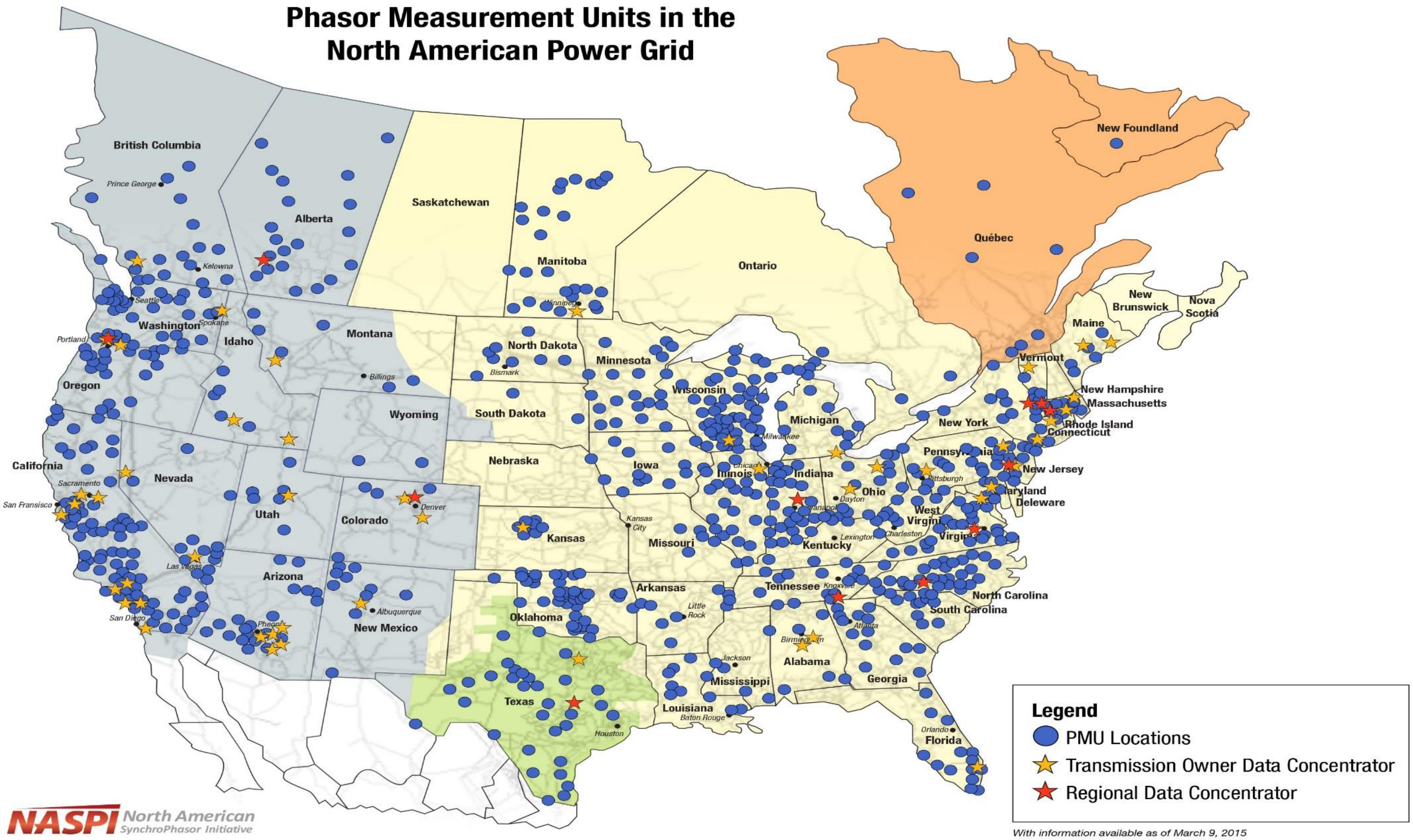
Phasor Measurement Unit (PMU) is a device which measures the electrical waves on an electricity grid. Using a PMU, it is simple to detect abnormal waveform shapes and hence very important for power grid stability.



A nation has 25 regions. Each region has 10000 PMU. Each PMU has 30measurement/sec and each measurement has 256 bytes.

Generated data: 256*30*10000*25=15Gbit/sec!

NASPI PMU Map (as of Mar 9, 2015)



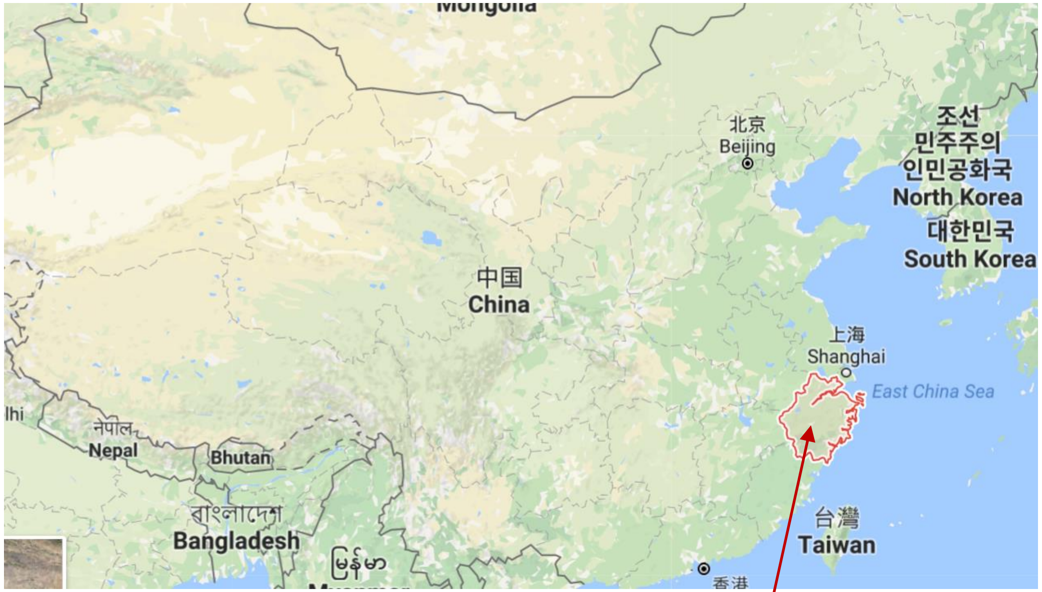
Source : https://www.naspi.org/File.aspx?fileID=1514

Tremendous Smart Meters Data in Smart Grid

The amount of data in smart grid may be tremendous since: i) there are a huge number of smart meters/sensors; ii) each meter shall transmit data periodically to the control center.

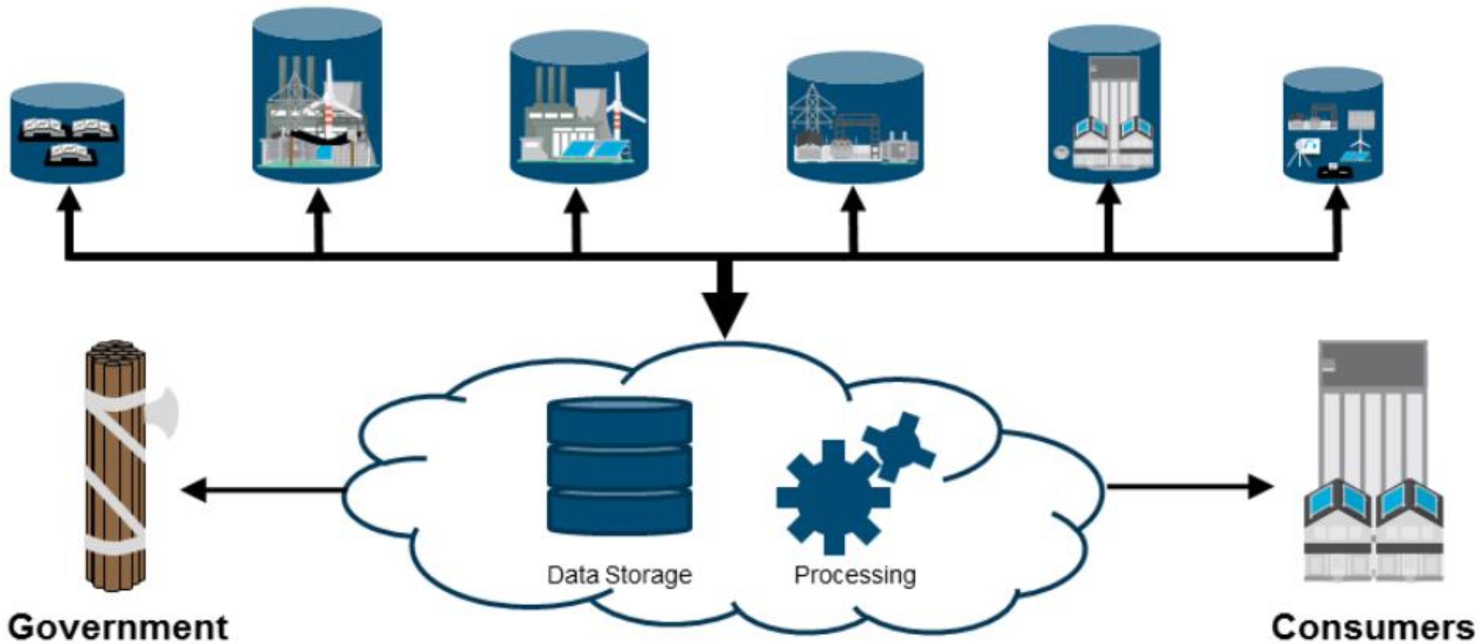
22million smart meters in Zhejiang Province, China, as required by China State Grid.

A smart meter should be 96 measures/day, which leads to 2.1billion records per day.



Zhejiang province

Cloud computing is important for smart grid



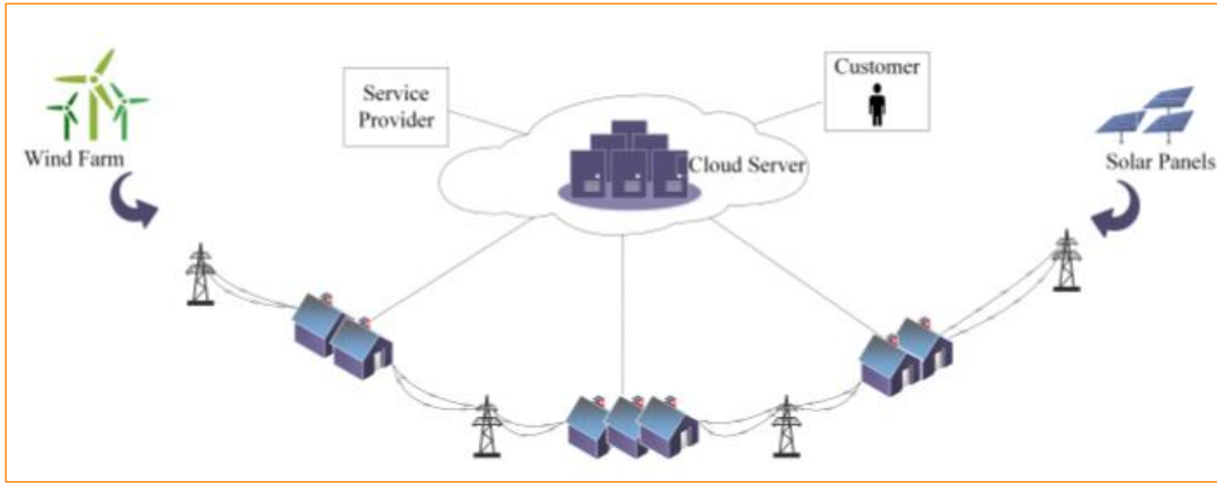
Dynamic: cloud platform opens up analytics and data to wide groups of users, inside and potentially outside of the utilities, on a dynamic basis

Reliable: access to cloud data streams and ease of data duplication is allowing utilities to provide wide set of reliable data across the enterprise

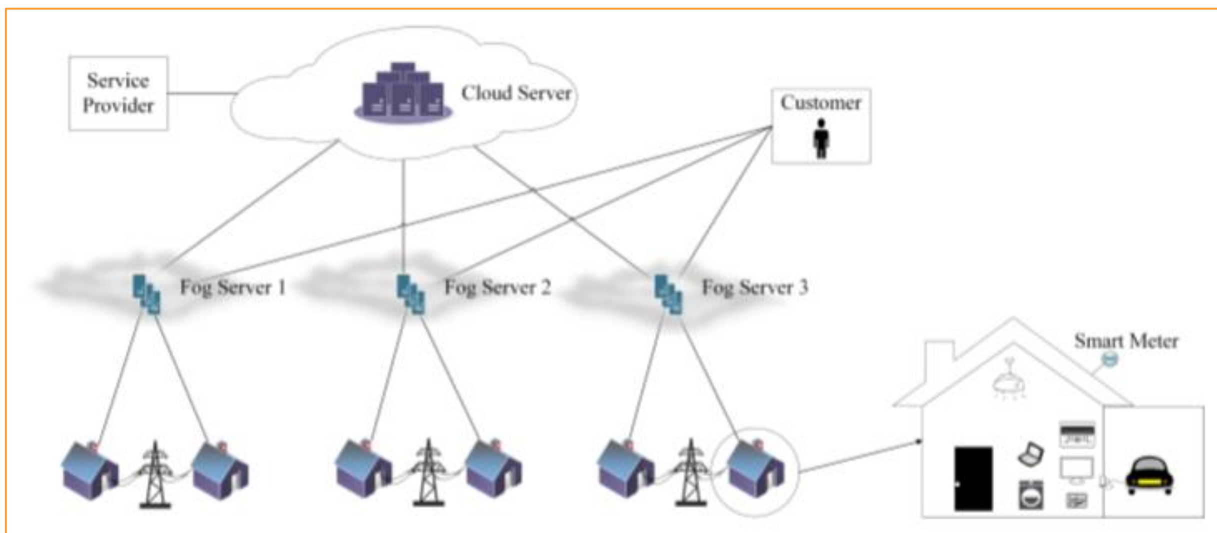
Deregulated: value of data access varies widely in deregulated territories where utilities are requested to provide usage data to customers

Cloud/Fog Architecture for Smart Grid

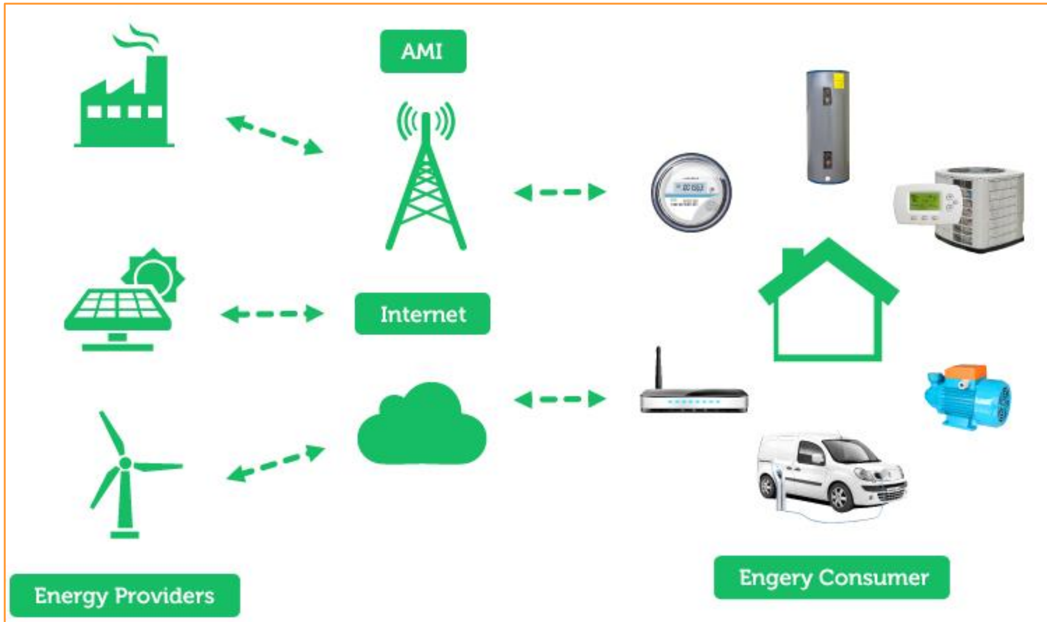
Cloud computing: all smart meter data is stored and processed in the cloud.



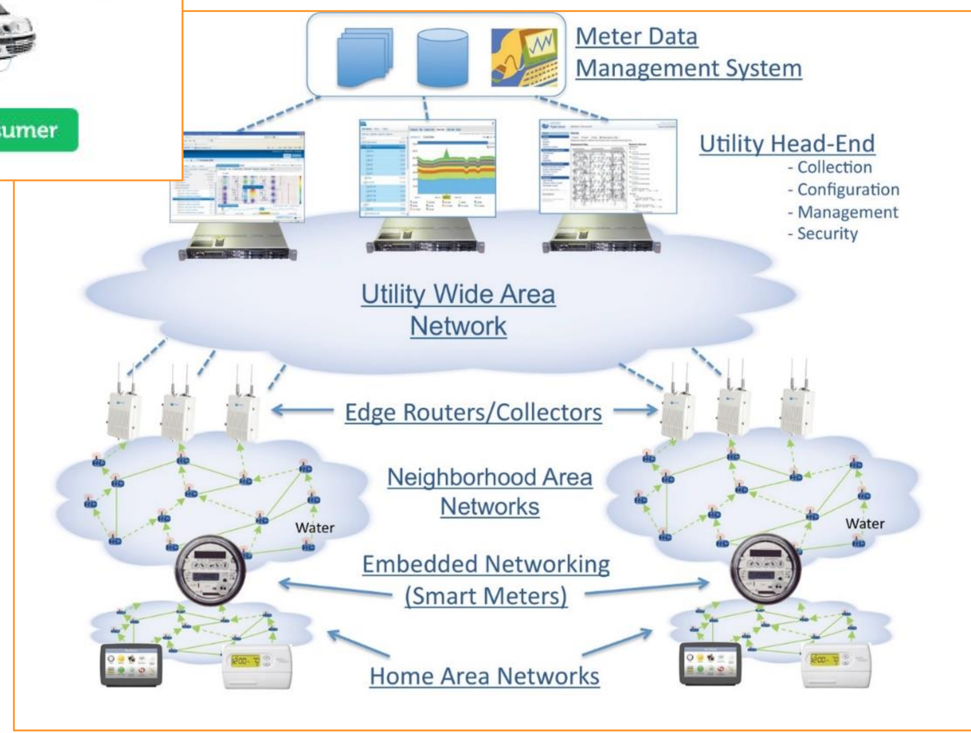
Cloud/Fog Architecture: Various communication and computations need very low latency and improved privacy, which can easily be addressed by fog computing.



Advanced Metering Infrastructure (AMI)



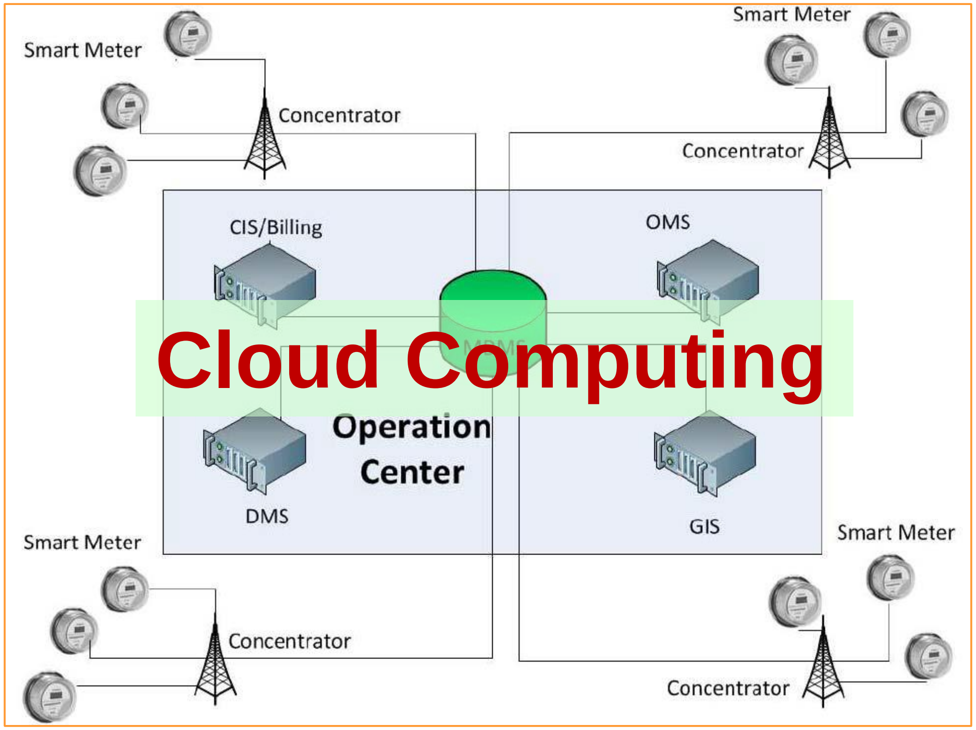
AMI is an integrated system of smart meters, communications networks, and data management systems



Central Cloud Computing for Data Management

MDMS (Meter Data Management Systems) uses cloud computing to perform long-term data storage and management for the vast quantities of usage data and events

MDMS enables the interaction with operation and management systems that: (i) manages the billing and customer information, (ii) provides power quality report and load forecasting based on meter data

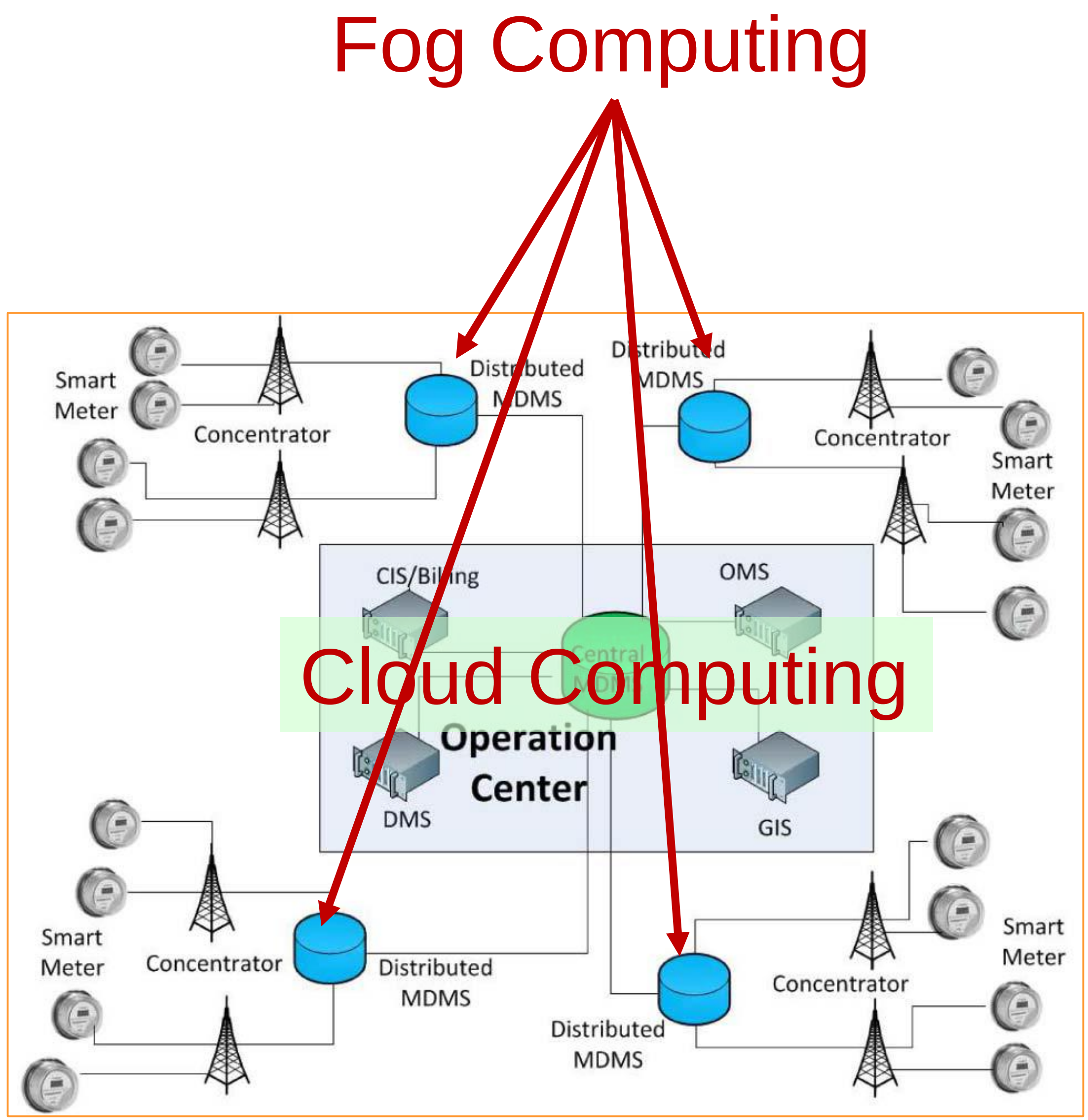


Q: all data from the smart meters need to go through the centralized cloud, it makes the system non-scalable. Why?

One approach: Cloud/fog computing for data management

Several distributed MDMSs using fog computing are close to smart meters. Each MDMS is responsible for the specific area.

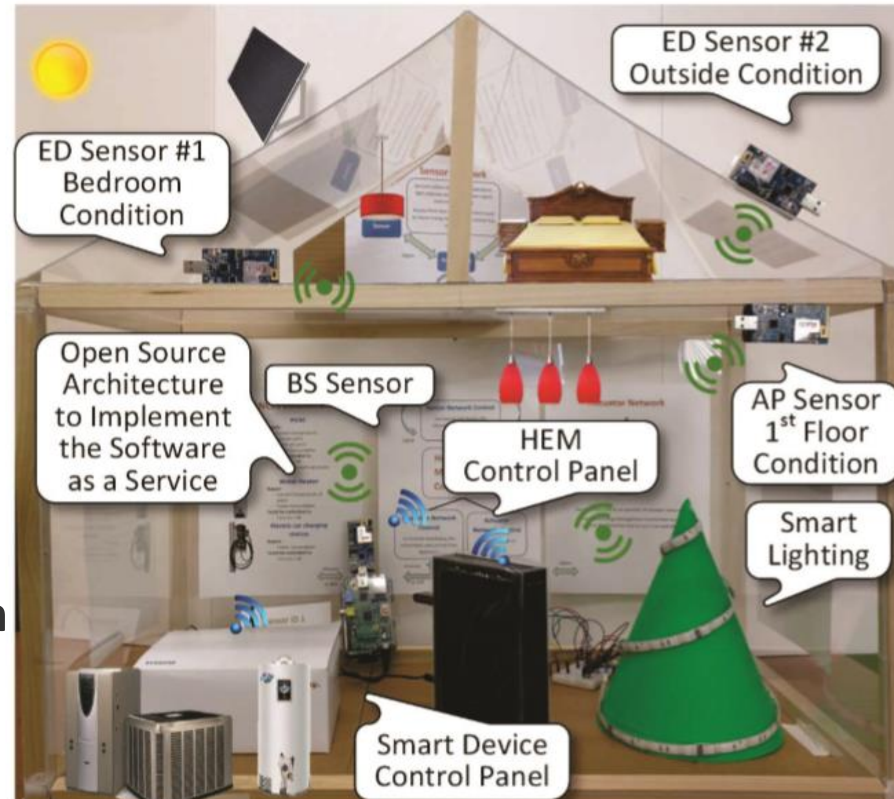
Communication distance for data collection is largely reduced, and the corresponding resources needed are also less.



Fog Computing for Smart House

In smart house, the home of the future might be equipped with a variety of power use meters and monitoring devices, adapting behavior to match cost of power, load on the grid, and activities of the residents.

A fog node/server at home can collect, process, analyze, aggregate and transmit a large amount of data. The fog server can also manage the smart house for decision making, e.g., demand response, temperature control.



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Fog Computing for Wind Farm

A large wind farm may consist of hundreds of individual wind turbines, and cover an area of hundreds of square miles. Modern wind turbines are very large control structures aimed at improving wind power capture and power quality.

Wide geographical deployment of a large system consists of a number of autonomous yet coordinated turbines. A turbine is supposed to quickly respond to external weather and environment, which gives rise to the need of a fog computing platform.

Wind Farm System Needs Fog Infrastructure

Cloud infrastructure

Global controller: gathering data, building the global state, determining the policy.

Network Infrastructure: An efficient communication network between sub-systems, system and the internet (cloud)

Fog infrastructure

The continuous supervisory role of the global controller requires low latency locally in the edge type deployment

Data analytics: This system generates huge amounts of data. Much of this information is actionable in real time. The data can be also used to run analytics over longer periods (months, years). The cloud-fog infrastructure is the natural approach to run to support both long-term and short-term tasks.

Fog Computing for Wind Farm - example

ParStream software is used by Envision, a power generation company that manages a 13 GW fleet of wind and solar panels.

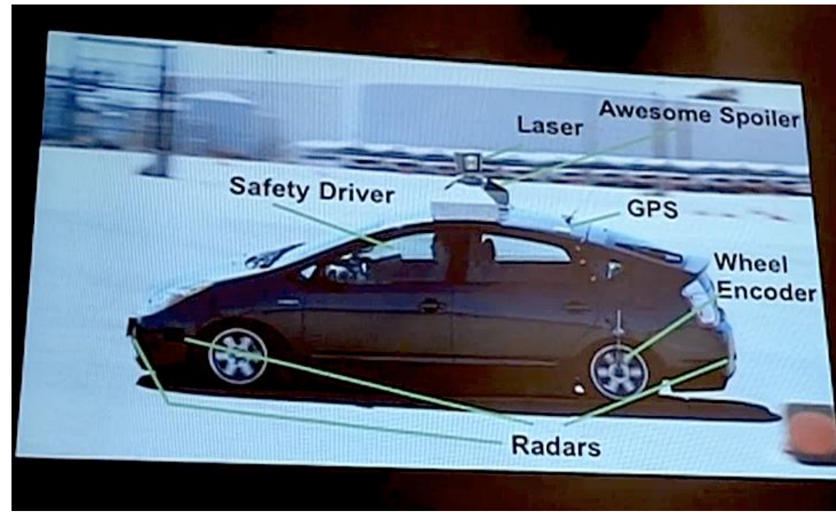
The real-time output of wind turbines increased by 15 percent by analyzing data at the edge of a network with response times of less than a second

MORE CONSIDERATIONS…

Self-driving Car: use cloud computing or fog computing?

A self-driving car is a complex robotic system equipped with sensors, actuators and ICT capabilities.

Requirement: approximately 1 GB of data will need to be processed each second. This data will need to be analyzed quickly enough so that the vehicle can react to changes in its surroundings in less than a second.



Shall we use cloud computing or fog computing for self-driving car?

The requirement mean a self-driving vehicle would require a lot of computing power to minimize application latencies, as well as very low network latencies.

Cloud Computing Future: Anything as a Service (XaaS)

Recent advances: Drones as a Service, Robot as a Service, Blockchain as a Service

Drones as a Service: For example: Amazon delivers packages to your home with their drone delivery system

Drones are used as data mule to deliver data from wind farms to edge server or control center

Too far to send massive data directly to control center

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