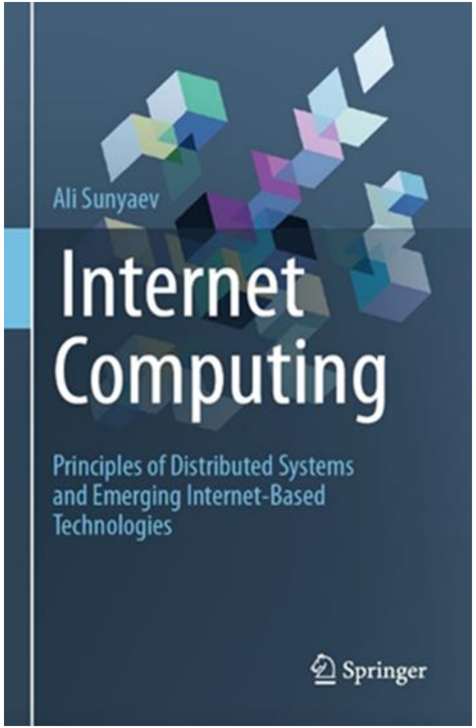
AI: Internet Computing

Lecture 7 and 8 — Cloud, Fog, and Edge Computing

Learning Goals of the Lecture

- Understand the concepts of cloud, fog, and edge computing
- Get to know the most important characteristics, advantages, and challenges of these technologies
- Learn about ‘hot topics’ and use cases
- Understand the differences between these and related technologies

Reference to the Teaching Material Provided



Chapter 7
Cloud Computing

Abstract
Cloud computing is an evolution of information technology and a dominant business model for delivering IT resources. With cloud computing, individuals and organizations can gain on-demand network access to a shared pool of managed and scalable IT resources, such as servers, storage, and applications. Recently, academics as well as practitioners have paid a great deal of attention to cloud computing. We rely heavily on cloud services in our daily lives, e.g., for storing data, writing documents, managing businesses, and playing games online. Cloud computing also provides the infrastructure that has powered key digital trends such as mobile computing, the Internet of Things, big data, and artificial intelligence, thereby accelerating industry dynamics, disrupting existing business models, and fueling the digital transformation. Still, cloud computing not only provides a vast number of benefits and opportunities; it also comes with several challenges and concerns, e.g., regarding protecting customers' data.

Learning Objectives of this Chapter
This chapter provides a brief introduction to the very diverse domain of cloud computing. Besides understanding how cloud computing emerged from technology improvements and innovations in recent decades, students should get to know essential characteristics of cloud computing, as well as of cloud computing service and deployment models. While other chapters in this book have already introduced

Chapter 8
Fog and Edge Computing

Abstract
Thanks to innovations like the Internet of Things and autonomous driving, millions of new devices, sensors, and applications will be going online in the near future. They will generate huge amounts of data, which connected technologies will have to be able to handle. Measuring, monitoring, analyzing, processing, and reacting are just a few examples of tasks involving the vast quantities of data that these devices, sensors, and applications will generate. Existing models like cloud computing are reaching their limits and will struggle to cope with this deluge of data. This chapter introduces fog and edge computing as a model in which computing power moves toward the sources where the data are generated. Following a brief definition and overview of fog and edge computing, eight of their unique characteristics are described, including contextual location awareness and low latency. Differences between this model and the better-known cloud computing model, as well as other related models, are also explained, and the challenges and opportunities of fog and edge computing are discussed. In addition to the definition and characteristics of fog and edge computing, examples of practical implementation are presented.

Learning Objectives of this Chapter
The main learning objective of this chapter is to get an understanding of the concept of fog and edge computing and the opportunities they offer to consumers and organizations. Understanding the differences between cloud computing, edge com-

Literature of the Lecture

Karlsruhe Institute of Technology

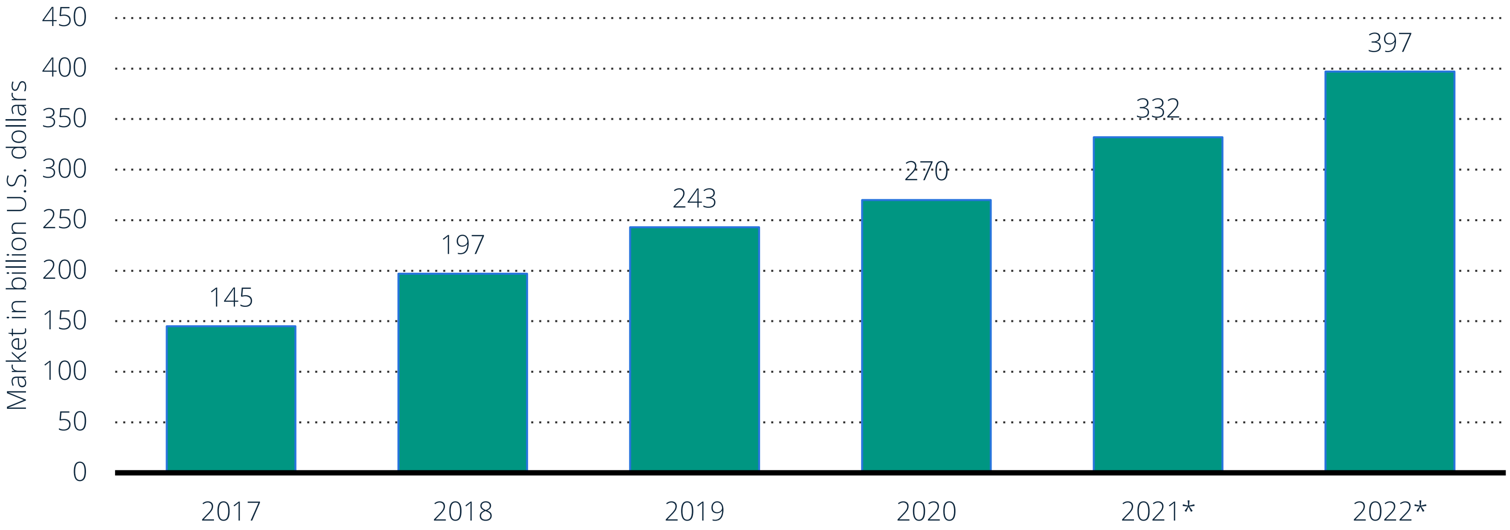
- Marston, S., Li, Z., Bandyopadhyay, S., Zhang, J., and Ghalsasi, A. (2011): Cloud Computing – The Business Perspective. In: Decision Support Systems 51(1), p. 176-189.
- Iorga, M. et al. (2018): Fog Computing Conceptual Model Recommendations of the National Institute of Standards and Technology. NIST Special Publication 500-325. https://doi.org/10.6028/NIST.SP.500-325
- Schneider S, Sunyaev A (2016) Determinant factors of cloud-sourcing decisions: reflecting on the IT outsourcing literature in the era of cloud computing. Journal of Information Technology 31 (1):1-31
- Krcmar, H., Eckert, C., Roßnagel, A., Sunyaev, A., Wiesche, M. (2018): Management sicherer Cloud-Services

Motivation

Cloud Computing?

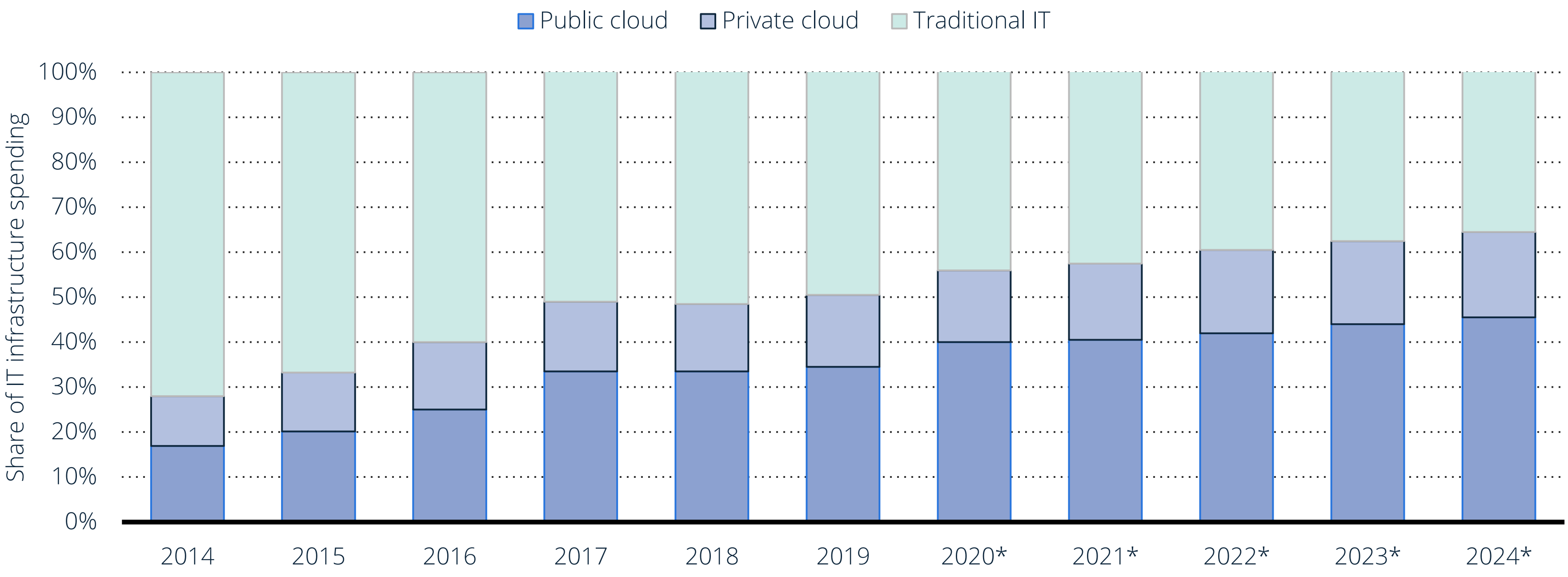
Image source: [Cloud Computing] by Stormotion Team, Oktober 23rd 2017. Licensed under CC BY 2.0.

Public Cloud Services Market Size 2017–2022 (in Billion U.S. Dollars)



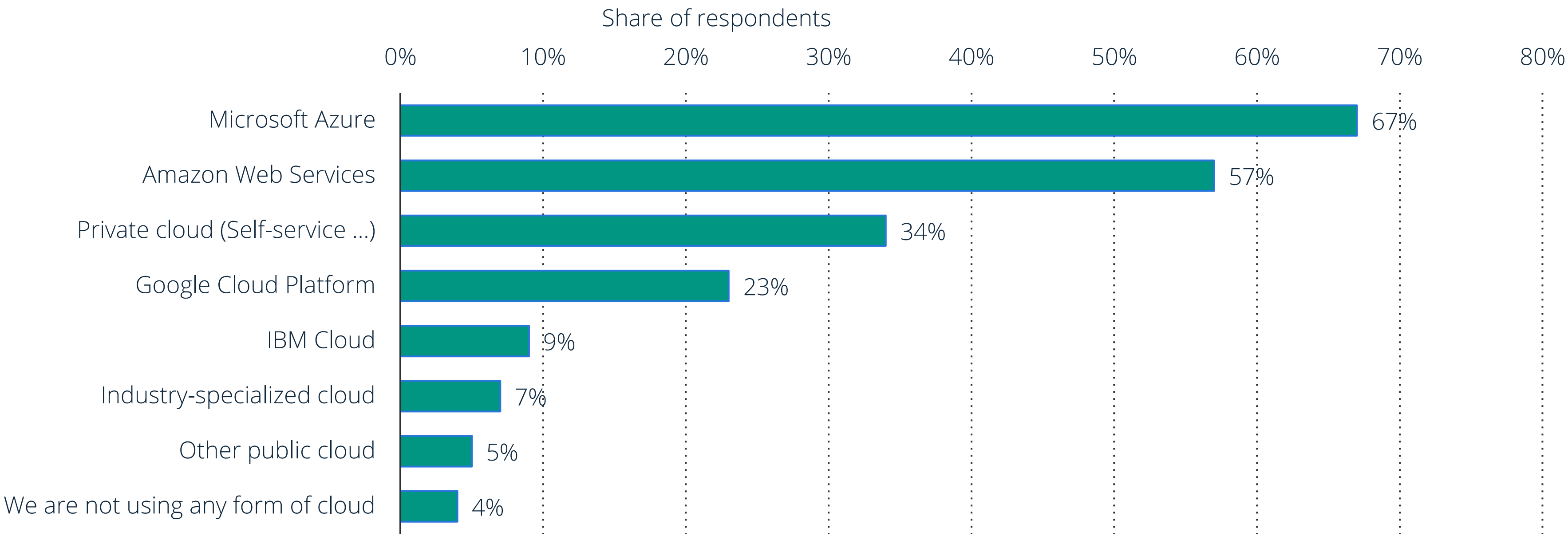
Source: Gartner; ID 273818

Worldwide Information Technology (IT) Infrastructure Spending 2014 to 2024



Source: IDC; Statista estimates; ID 486586

Market Leader 2021, ‘Hyperscaler’



Source: Turbonomic; ID 1224552

The Emergence of Cloud Computing

The Emergence of Cloud Computing

- From examining the history of computing, the arrival of the cloud computing era can be seen as an evolutionary development
- Cloud computing has its roots in the advancements of several technologies:

Cloud Computing			
Hardware (e.g., virtualization, multi-core chips)	Internet Technologies (e.g., web services, service-oriented architectures)	Distributed Computing (e.g., clusters, grids)	Systems Management (e.g., autonomic computing, data center automation)

Source: Voorsluys W, Broberg J, Buyya R (2011) Introduction to cloud computing. In: Buyya R, Broberg J,Goscinski A (eds) Cloud computing. Wiley, Hoboken, NJ, pp 3 – 42
Source: Iyer B, Henderson JC (2010) Preparing for the future: understanding the seven capabilities of cloud computing. MIS Q Exec 9(2):117 – 131.

The Emergence of Cloud Computing

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- The idea of providing computing as a service through networks dates back to the late 1960s and became a driving force behind the early development of the Internet
- Vision became reality with emergence of ‘application service provisioning‘ during the 80s
  - Third-party providers deploy, manage, and remotely host packaged software applications through centrally located servers and deliver them to organizations on a rental or lease arrangement
- However, early application service providers failed due to insufficient bandwidth and computing power
- During the late 1990s: Tremendous investment and entry of new organizations in the telecommunications industry that lead to a large increase in global fiber-optic networking, dramatically reducing network latency and related costs

Source: Venters W, Whitley EA (2012) A critical review of cloud computing: researching desires and realities. J Inf Technol 27(3):179 – 197
Source: Buyya R, Yeo CS, Venugopal S, Broberg J, Brandic I (2009) Cloud computing and emerging IT platforms: vision, hype, and reality for delivering computing as the 5th utility. Futur Gener Comput Syst 25(6):599 – 616
Source: Hogendorn C (2011) Excessive(?) entry of national telecom networks, 1990 – 2001. Telecommun Policy 35(11):920 – 932

The Emergence of Cloud Computing

- The improvement of networking was coupled with the emergence of technologies and techniques to coordinate the large-scale, on-demand provision of computing resources achieved by drawing on innovations around
  - ‘grid computing’
  - ‘utility computing’
  - virtualization of hardware
- At the same time, organizations such as Alphabet (later parent company of Google), Amazon, and Microsoft set up large data centers to transfer computing processes from individual computers and private IT infrastructures to large external and public data centers accessible over the Internet
- Around 2007 became labeled as ‘cloud computing’

Source: Venters W, Whitley EA (2012) A critical review of cloud computing: researching desires and realities. J Inf Technol 27(3):179 – 197

The Emergence of Cloud Computing

- With cloud computing, a product-centric model for IT provisioning is transformed into a global, distributed, service-centric model, leading to a disruptive shift from IT-as-a-product to IT-as-a-service
- Cloud computing has changed the way how IT services are invented, developed, deployed, scaled, updated, maintained, and paid for
- Cloud computing also provides the infrastructure that has powered key digital trends including mobile computing, the Internet of Things, big data, and artificial intelligence, thereby accelerating industry dynamics, disrupting existing business models, and fueling the digital transformation
- Defying initial concerns, cloud computing has become a critical IT infrastructure for almost every aspect of our everyday lives, and it will continue to transform the world we live in on multiple levels and in various ways

Source: Iyer B, Henderson JC (2010) Preparing for the future: understanding the seven capabilities of cloud computing. MIS Q Exec 9(2):117 – 131.

Source: Benlian A, Kettinger WJ, Sunyaev A, Winkler TJ (2018) Special section: The transformative value of cloud computing: a decoupling, platformization, and recombination theoretical framework. J Manag Inf Syst 35(3):719 – 739

Basics of Cloud Computing

NIST’s Cloud Computing Definition

Definition

Cloud Computing is a model which enables

- **flexible and demand-oriented** access to
- a **shared pool** of
- configurable **IT resources**,
- which can be accessed at any time and from anywhere **via the Internet** or a network

Source: Mell P, Grance T (2011) The NIST definition of cloud computing. https://nvlpubs.nist.gov/nistpubs/Legacy/SP/nistspecialpublication800-145.pdf.

Cloud Computing Stack

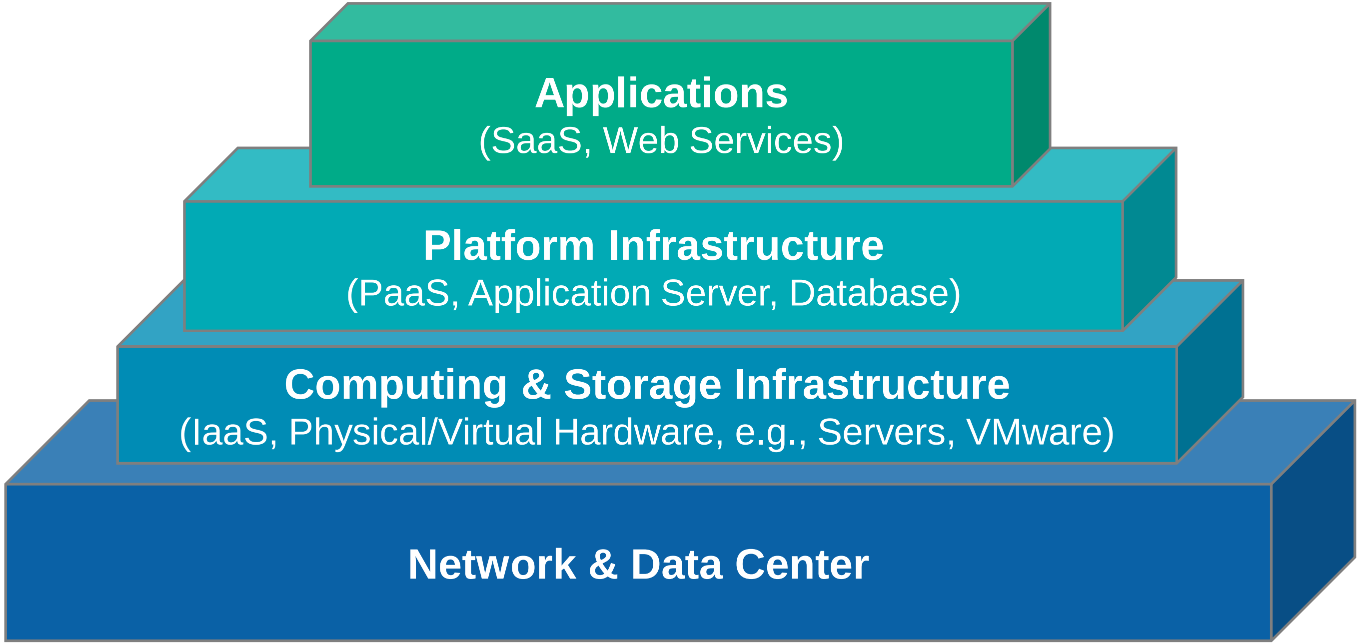

Image source: Adapted from https://searchcloudcomputing.techtarget.com/definition/cloud-infrastructure

Unique Characteristics of Cloud Services

- *Service-based IT-resources*
- *On-demand Self-service*
- *Ubiquitous Access*
- *Multitenancy*
- *Location Independence*
- *Rapid Elasticity*
- *Pay-per-use Billing*

Source: Mell P, Grance T (2011) The NIST definition of cloud computing. https://nvlpubs.nist.gov/nistpubs/Legacy/SP/nistspecialpublication800-145.pdf.

Unique Characteristics of Cloud Services

Service-based IT-resources

- All cloud offerings can be expressed as a service
- Each service comes with a Service Level Agreement, defining functions and qualities

On-demand Self-service

Ubiquitous Access

Multitenancy

Location Independence

Rapid Elasticity

Pay-per-use Billing

Source: Mell P, Grance T (2011) The NIST definition of cloud computing. https://nvlpubs.nist.gov/nistpubs/Legacy/SP/nistspecialpublication800-145.pdf. Accessed on 22.03.2022.
Image source: [Laptop] by Mohammed Hassan, April 23th 2018. Pixabay License.

Unique Characteristics of Cloud Services

- Service-based IT-resources
- **On-demand Self-service**
- Ubiquitous Access
- Multitenancy
- Location Independence
- Rapid Elasticity
- Pay-per-use Billing

On-demand Self-service:

- A consumer can unilaterally provision computing capabilities as needed automatically
- Without requiring human interaction with each service provider
- Such as server time, network storage and user licenses

Source: Mell P, Grance T (2011) The NIST definition of cloud computing. https://nvlpubs.nist.gov/nistpubs/Legacy/SP/nistspecialpublication800-145.pdf. Accessed on 22.03.2022.
Image source: [Smartphone] by Velázquez Diego, March 20th 2017. Pixabay License.

Unique Characteristics of Cloud Services

- Service-based IT-resources
- On-demand Self-service
- **Ubiquitous Access**
- Multitenancy
- Location Independence
- Rapid Elasticity
- Pay-per-use Billing

Ubiquitous Access:

- Cloud services are provisioned via the Internet or private networks
- Cloud service rely on standardized interfaces to ease interaction
- Use by heterogeneous thin or thick client platforms (e.g., mobile phones, tablets, laptops, and workstations)

Source: Mell P, Grance T (2011) The NIST definition of cloud computing. https://nvlpubs.nist.gov/nistpubs/Legacy/SP/nistspecialpublication800-145.pdf. Accessed on 22.03.2022.
Image source: [Cloud Network] by Linforth Pete, July 20th 2019. Pixabay License.

Unique Characteristics of Cloud Services

- Service-based IT-resources
- On-demand Self-service
- Ubiquitous Access
- **Multitenancy**
- Location Independence
- Rapid Elasticity
- Pay-per-use Billing

- The provider's computing resources are pooled to serve multiple consumers
- Using a multi-tenant model, with different physical and virtual resources dynamically assigned and reassigned according to consumer demand
- Sharing computing resources is part of what could makes cloud computing economically beneficial

Source: Mell P, Grance T (2011) The NIST definition of cloud computing. https://nvlpubs.nist.gov/nistpubs/Legacy/SP/nistspecialpublication800-145.pdf. Accessed on 22.03.2022.
Image source: [A Network of People] by Unknown, n.d. Public Domaín.

Unique Characteristics of Cloud Services

- Service-based IT-resources
- On-demand Self-service
- Ubiquitous Access
- Multitenancy
- **Location Independence**
- Rapid Elasticity
- Pay-per-use Billing

- There is a sense of location independence in that the cloud customer generally has no control over or knowledge of where the provided resources are actually located
- This challenges providers to be compliant with existing data protection requirements, among others

Source: Mell P, Grance T (2011) The NIST definition of cloud computing. https://nvlpubs.nist.gov/nistpubs/Legacy/SP/nistspecialpublication800-145.pdf. Accessed on 22.03.2022.
Image source: [Cloud Services] by Altmann Gerd, November 30th 2018. Pixabay License.

Unique Characteristics of Cloud Services

- Service-based IT-resources
- On-demand Self-service
- Ubiquitous Access
- Multitenancy
- Location Independence
- **Rapid Elasticity**
- Pay-per-use Billing

- Capabilities can be elastically provisioned and released, in some cases automatically, to scale rapidly outward and inward commensurate with demand
- To the consumer, the capabilities available for provisioning often appear to be unlimited and can be appropriated in any quantity at any time

Source: Mell P, Grance T (2011) The NIST definition of cloud computing. https://nvlpubs.nist.gov/nistpubs/Legacy/SP/nistspecialpublication800-145.pdf. Accessed on 22.03.2022.
Image source: [Cloud Services] by Altmann Gerd, Oktober 21th 2020. Pixabay License.

Unique Characteristics of Cloud Services

- Service-based IT-resources
- On-demand Self-service
- Ubiquitous Access
- Multitenancy
- Location Independence
- Rapid Elasticity
- **Pay-per-use Billing**

- Cloud systems automatically control and optimize resource use by leveraging a metering capability at some level of abstraction appropriate to the type of service
- e.g., storage, processing, bandwidth, and active user accounts
- Resource usage can be monitored, controlled, and reported, providing transparency for both the provider and consumer of the utilized service

Source: Mell P, Grance T (2011) The NIST definition of cloud computing. https://nvlpubs.nist.gov/nistpubs/Legacy/SP/nistspecialpublication800-145.pdf. Accessed on 22.03.2022.
Image source: [Fast Computing] by Mohammed Hassan, March 2nd 2019. Pixabay License.

Chances and Challenges of Cloud Computing

Reasons to Move Into the Cloud

- Due to its inherent characteristics (e.g., on-demand self-service, resource pooling, elasticity, and extensibility), cloud computing enables persons and organizations to achieve diverse benefits and opportunities

Low Entry Barriers	Pay-as-you-go	*Access to Leading Edge IT Resources, Skills, and Capabilities*
Quality Improvements	*Cost Savings*	*Focus on Core Capabilities*
Greater Flexibility and Elasticity	*Reduced Time to Market*	*Lower IT Barriers to Innovation*

Source: Sunyaev, A (2020) Internet Computing. Principles of Distributed Systems and Emerging Internet-Based Technologies, Springer

Example Risks and Challenges

Loss of Control

- Cloud customers lose the administrative power, as well as operational and security control over the cloud system
- Hidden actions of the provider might never be detected because the customer cannot continuously monitor providers' actions

Vendor Lock-In

- Customers are confronted with uncertainty about whether they can leave the cloud service without incurring social or economic losses
- In their current form, cloud computing infrastructures and platforms do not employ standard methods of storing user data and applications, and thus data portability is limited

Location Intransparency

- Different countries and regions have different requirements regarding how its citizens' information should be handled
- The customer doesn't know where all the cloud provider's assets reside
- It is difficult to determine with which legislation the customer has to comply

Source: Ahmed M, Litchfield AT (2018) Taxonomy for identification of security issues in cloud computingenvironments. J Comput Inf Syst 58(1):79–88
Source: Bhattacherjee A, Park SC (2014) Why end-users move to the cloud: a migration-theoretic analysis.Eur J Inf Syst 23(3):357–372
Source: Trenz M, Huntgeburth J, Veit D (2018) Uncertainty in cloud service relationships. Inf Manag55(8):971–983

Hot Topics in Cloud Computing

Cloud Gaming

Cloud Gaming

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Definition

Cloud gaming refers to a new way to deliver computer games to users, where computationally complex games are executed on powerful cloud servers, the rendered game scenes are streamed over the Internet to gamers with thin clients on heterogeneous devices, and the control events from their devices are sent back to cloud servers for interactions

Types of cloud gaming services:

- (1) file-based: only a small fragment of the required data is transferred to the users' devices before they start the game.
- (2) command-based: the computer game is executed locally but the game's logic processing is outsourced on cloud servers.
- (3) video-based gaming: entire outsourcing of all relevant gaming components, including the game logic and graphic processing

PlayStation Now

STADIA

Source: Ladewig, S; Lins, S; Sunyaev, A. (2019) Are We Ready to Play in the Cloud? Developing new Quality Certifications to Tackle Challenges of Cloud Gaming Services. Proceedings of the CB
Source: Cai et al. (2016) "A Survey on Cloud Gaming: Future of Computer Games," IEEE Access, vol. 4, pp. 7605–7620.

Cloud Gaming Benefits

- Customers can provision various computer games on demand without downloads, installations, or hardware upgrades
- Game manufacturers do not have to worry about how to physically deliver the computer game to the customer
- It is no longer possible to make illegal copies of the software because only a video stream of a live game is transferred

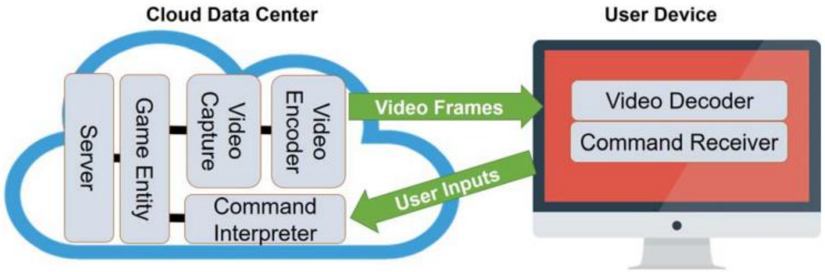

Image source: Ladewig, S; Lins, S; Sunyaev, A. (2019) Are We Ready to Play in the Cloud? Developing new Quality Certifications to Tackle Challenges of Cloud Gaming Services. Proceedings of the CBI

AI as a Service (AIaaS)

The Trouble with Using AI

- Artificial Intelligence (AI) is undoubtedly one of the most actively debated technologies, providing glaring opportunities to contribute to individuals' well-being, the success and innovativeness of organizations, and societies' prosperity and advancement
- One major challenge for organizations is the complex and demanding process of adopting and integrating AI, which is rather considered "*a journey and not a destination*"

Scarcity of AI experts	Challenge to collect and process data appropriately
Lack of organizations' abilities and budgets to set up and maintain the extensive IT resources	Limited knowledge on how to deploy and configure the AI-based systems

…

Source: Lins et al. (2021) Artificial Intelligence as a Service – Classification and Research Directions. In: Business & Information Systems Engineering (forthcoming)

The Emergence of Artificial Intelligence Services

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Definition

AIaaS refers to cloud-based systems providing on-demand services to organizations and individuals to deploy, develop, train, and manage AI models

Benefits

- optimizing users' core business with the support of cloud-based AI services
- achieving short time-to-market
- no need to rely on AI engineers
- achieving higher performance and resilience
- …

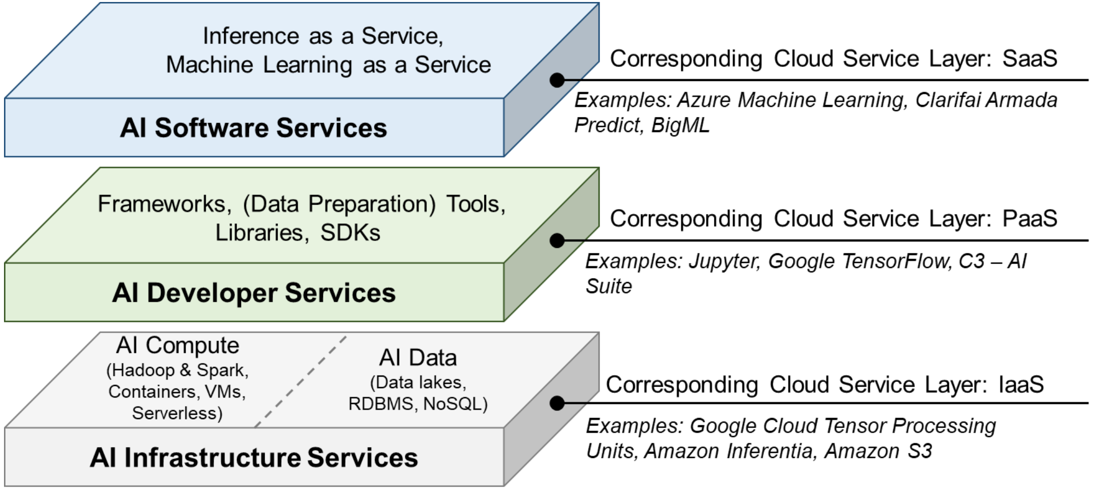
Challenges

- trade-off between user control and ease of use
- technical robustness and interoperability of services
- data governance and protection mechanisms
- trade-off between accuracy and fairness vs. generalizability
- …

Source: Lins et al. (2021) Artificial Intelligence as a Service – Classification and Research Directions. In: Business & Information Systems Engineering (forthcoming)

AIaaS — Service Stack

- **AI software services** that are ready-to-use AI applications and building blocks
- **AI developer services** that are tools for assisting developers in implementing code to bring out AI capabilities
- **AI infrastructure services** that comprise raw computational power for building and training AI algorithms, and network and storage capacities to store and share data



Source: Lins et al. (2021) Artificial Intelligence as a Service – Classification and Research Directions. In: Business & Information Systems Engineering (forthcoming)

GAIA-X

GAIA-X: A Federated Data Infrastructure for Europe

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- Developing the foundations for a federated, open data infrastructure based on European values
- Connecting centralized and decentralized infrastructures in order to turn them into a homogeneous, user-friendly system
- The resulting federated form of data infrastructure strengthens the ability to both access and share data securely and confidently

GAIA-X

The GAIA-X Ecosystem Idea

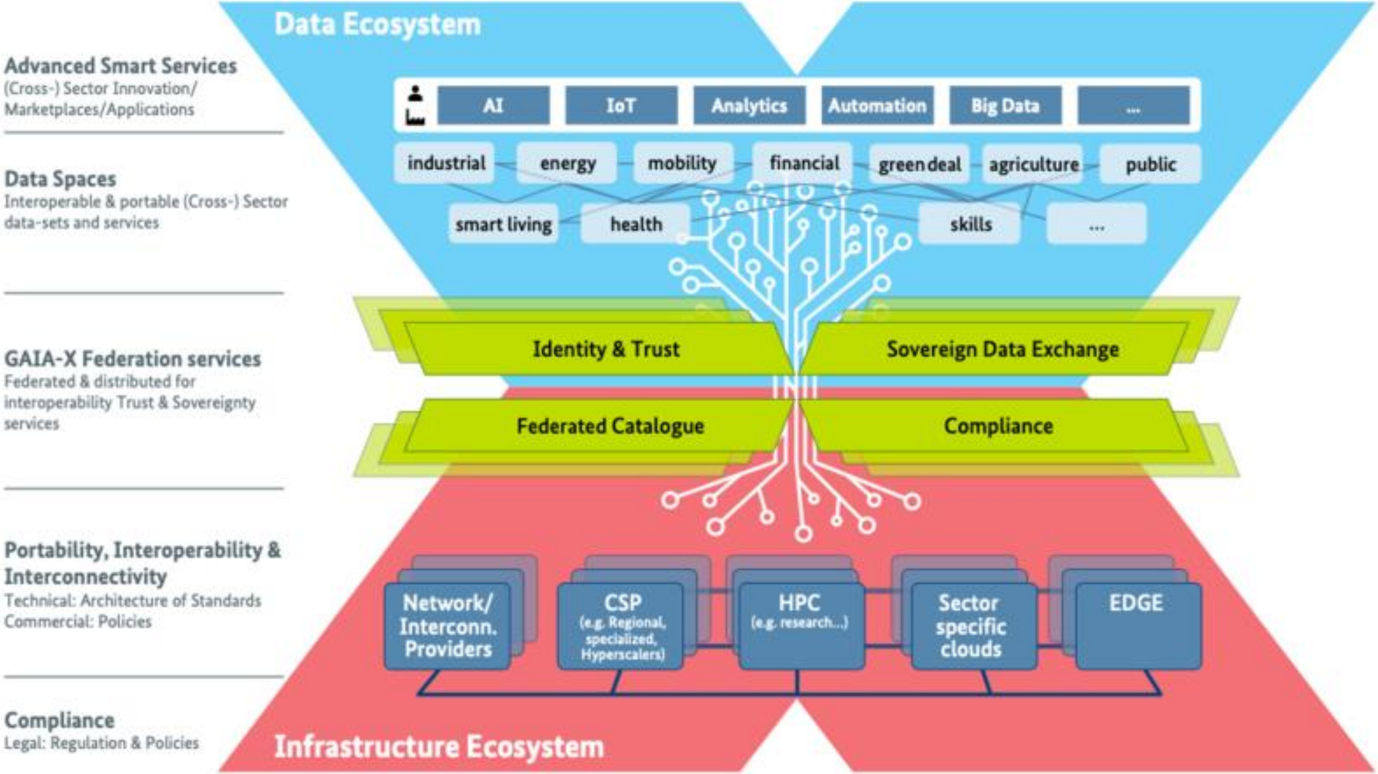


Image source: [GAIA-X Ecosystem] by BMWI n.d. Public Domain.

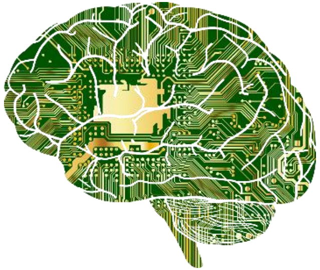
Fog & Edge Computing

Motivation

One of the biggest challenges for future trends and digital innovations like the Internet of Things (IoT), embedded artificial intelligent, or ubiquitous computing is the **management, storage and processing of huge amounts of data**

- Millions of new devices, sensors and applications will be going online in the next decade
- Measuring, monitoring, analyzing, processing and reacting are just a few examples of tasks that have to be done with the data flood that will be generated by them
- Current infrastructure will struggle to cope with the data flood

[1]

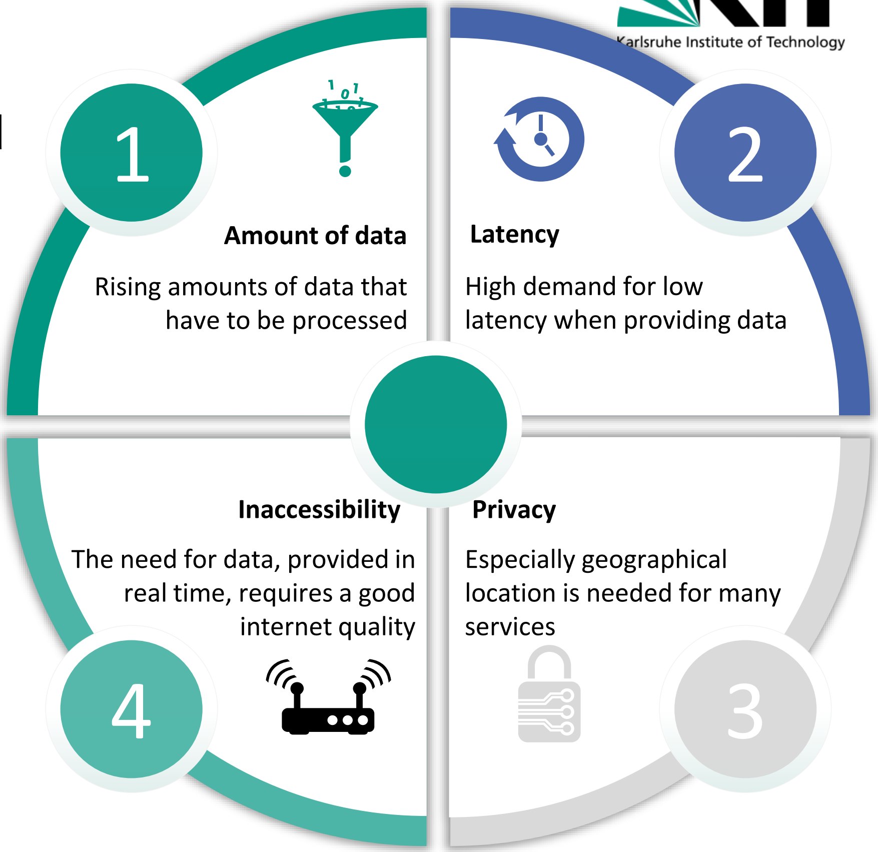


[2]

Image source [1]: [Internet of things] by jeferrb, May 25th 2015. Pixabay License.
Image source [2]: [Artificial intelligence] by Gordon Johnson, October 20th 2016. Pixabay License.
Source: Brogi A, Forti S (2017) QoS-aware deployment of IoT applications through the fog. IEEE Internet Things J 4(5):1185–1192
Source: Madsen H, Burtschy B, Albeanu G, Popentiu-Vladicescu F (2013) Reliability in the utility computing era: towards reliable fog computing. Proc. international conference on systems, signals and image processing (IWSSIP)
Source: Bittencourt LF, Lopes MM, Petri I, Rana OF (2015) Towards virtual machine migration in fogcomputing. Paper presented at the 10th international conference on P2P, parallel, grid, cloud andinternet computing (3PGCIC)

Example Data Challenges

- How to handle the up-coming data flood of consuming and producing large data amounts?
- How to deal with the high demand for a low latency for providing the data?
- How to deal with rising costs and sensitive data concerns?
- How to address the inaccessibility of data? (IoT devices need the data up on time and would have significant problems when the connection is bad)



Motivation — Example: Connected Car

[1]

[2]

- ➢ **It is essential to provide data in real-time**
- ➢ **Demanding for innovative ways to ensure low latency**

Fundamentals of Fog and Edge Computing

Fog, Edge, and Cloud Computing

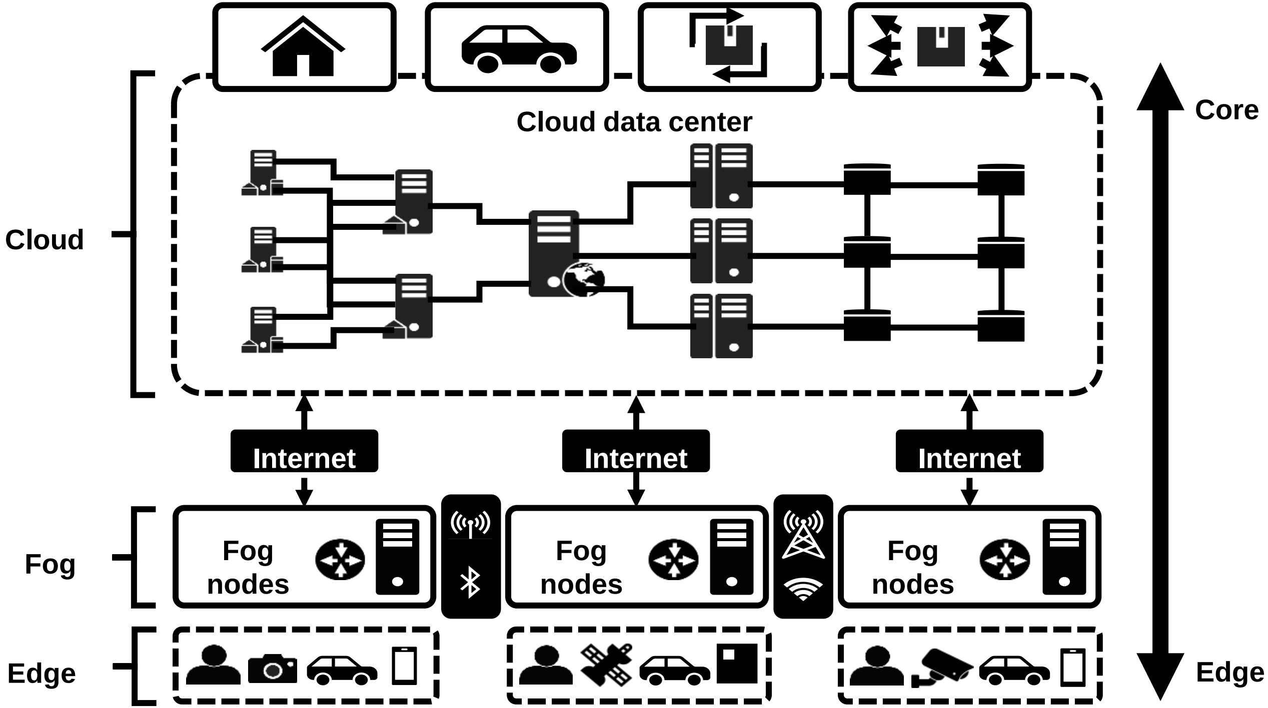


Image source: Sunyaev, A (2020) Internet Computing. Principles of Distributed Systems and Emerging Internet-Based Technologies, Springer
adapted from Hu P, Dhelim S, Ning H, Qiu T (2017) Survey on fog computing: architecture, key technologies,applications and open issues. J Netw Comput Appl 98:27 – 42

NIST’s Fog Computing Definition

- To cope with these challenges, fog computing presents a new distributed architecture that helps to reduce latency and supports the storage, management and processing of huge data amounts

Definition

Fog computing is a layered model for enabling ubiquitous access to a shared continuum of scalable computing resources. The model facilitates the deployment of **distributed, latency-aware applications and services**, and consists of **fog nodes (physical or virtual)**, residing between smart end-devices and centralized (cloud) services.

Source: Iorga M, Feldman L, Barton R, Martin MJ, Goren N, Mahmoudi C (2018) Fog computing conceptual model (NIST SP 500-325). https://nvlpubs.nist.gov/nistpubs/SpecialPublications/NIST.SP.500-325.pdf. Accessed 17 Sept 2019

Fog Nodes

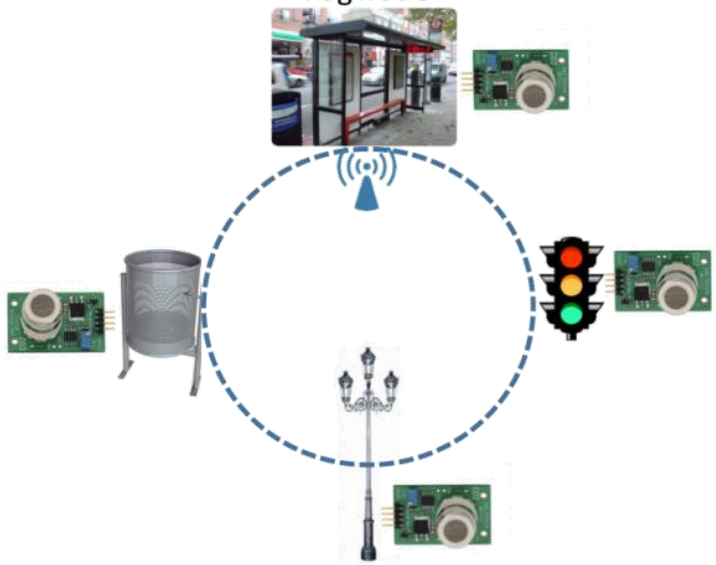
Definition

Fog nodes are either physical components or virtual components that are tightly coupled with the smart end-devices or access networks and provide computing resources to these devices.

- A fog node typically…
  - provides some form of data management (i.e., computing or storage)
  - enables communication services between network's edge layer and the fog computing service or the centralized (cloud) computing resources
  - is aware of its geographical distribution and logical location
  - can be deployed in a centralized or decentralized manner
- Fog nodes are either…
  - Physical: gateways, switches, routers, servers, …
  - Virtual: virtualized switches, virtual machines, cloudlets, …

Source: Iorga M, Feldman L, Barton R, Martin MJ, Goren N, Mahmoudi C (2018) Fog computing conceptual model (NIST SP 500-325). https://nvlpubs.nist.gov/nistpubs/SpecialPublications/NIST.SP.500-325.pdf. Accessed 17 Sept 2019

Fog Nodes — Examples



Fog node processing sensor’s data

Cloud&Heat: Data Center in the ‚Box‘

Source: https://www.cloudandheat.com/wp-content/uploads/2018/06/cebitCloudHeat-9511.jpg

Image source: Tordera et al. (2016): What is a Fog Node? A Tutorial on Current Concepts towards a Common Definition. https://arxiv.org/ftp/arxiv/papers/1611/1611.09193.pdf.

Fog Computing's Key Characteristics

Contextual location awareness and low latency
Devices are aware of their location which enables Location based Services (LBS)

Geographical distribution
Distributed in environment, so that low latency is guaranteed. Keeping the data locally also avoids security issues

Autonomy & Heterogeneity
Virtual and physical devices with widely varying functions can be fog nodes.

Interoperability and Federation
Cooperation between different fog service providers is required, and fog nodes must be compatible with each other

Real-time Interactions
Real-time decision making without interruptions (e.g. autonomous car)

Scalability and Agility of Federated Fog Clusters
Scalability is reached through the clustered architecture

+ Predominance of Wireless Access

Support for Mobility

Source: Iorga M, Feldman L, Barton R, Martin MJ, Goren N, Mahmoudi C (2018) Fog computing conceptual model (NIST SP 500-325).
Source: Yi S, Qin Z, Li Q (2015) Security and privacy issues of fog computing: a survey. Paper presented at the international conference on wireless algorithms, systems, and applications
Source: Bonomi F, Milito R, Zhu J, Addepalli S (2012) Fog computing and its role in the internet of things. Paper presented at the first edition of the MCC workshop on mobile cloud computing

Key characteristics:

Contextual Location Awareness and Low Latency

Contextual location awareness and low latency

- Fog nodes are aware of…
  - their logical location in the context of the entire system
  - the latency costs for communicating with other nodes
- Because fog nodes are often co-located with the smart end-devices, analysis and response to data generated by these devices is much quicker than from a centralized cloud service

→ Fog computing offers the lowest-possible latency

Source: Refer to previous slide and reference list for further sources

Key characteristics:

Geographical Distribution

Geographical distribution

- Fog computing consists of many fog nodes that are distributed in the environment
- Based on this distribution, fog nodes can track the location of the end-devices
- Demanded by applications and services that…
  - need low latency for real-time decision making,
  - are location-based or
  - have special security requirements
- Distributed endpoints and fog nodes ensure context awareness

Source: Refer to previous slide and reference list for further sources

Key characteristics:

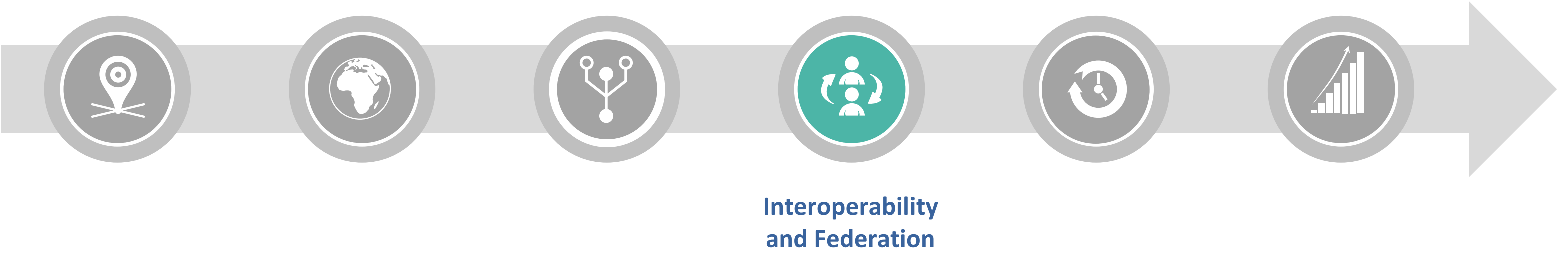
Autonomy and Heterogenity

- Autonomy: fog nodes can operate independently and make own decisions local
- Fog computing has many heterogeneous fog nodes:
    - They can be virtual or physical
    - Their functions range from collecting data up to analyzing or processing huge amounts of data and can change immediately
    - The variety of distributed environments, where fog computing is used (office environment vs. outdoor environment)

Source: Refer to previous slide and reference list for further sources

Key characteristics:

Interoperability and Federation



- Fog nodes must be able to interoperate and services must be federated across different domains
- Fog computing supports hierarchical structures. Nodes can be configured to deliver the service as stand-alone fog node (organized vertically) or as federated node to form clusters that provide horizontal scalability over disperse geolocations (organized horizontally)
- Interoperability refers to that each fog node is able to provide and receive services from other actors in the fog infrastructure and to use these services to operate effectively together

Source: Refer to previous slide and reference list for further sources

Key characteristics:
Real-time Interactions

Real-time Interactions

- Fog computing applications involve real-time interactions rather than batch processing
- Fog computing supports for example real-time decision making for speedy services without any interruptions
- In the context of connected cars, the real-time interactions of fog computing between vehicles, access points and traffic lights makes it much safer and more effective

Source: Refer to previous slide and reference list for further sources
Image Source: [Google Self-Driving car] by Smoothgroover22, May 28th 2014. Licensed under CC BY-SA 2.0.

Key characteristics:

Scalability and Agility of Federated Fog Clusters

- Fog computing is designed to cover millions of end-devices → can handle large scales and elastic scalability
- Each fog node merely takes care of a small part of the demand → total pressure on cloud computing is reduced
- Fog computing is scalable because of its different clusters of fog nodes or even clusters of clusters
- Supporting elastic compute, resource pooling, data-load changes, and network condition variations

Source: Refer to previous slide and reference list for further sources

Additional Characteristics of Fog Computing

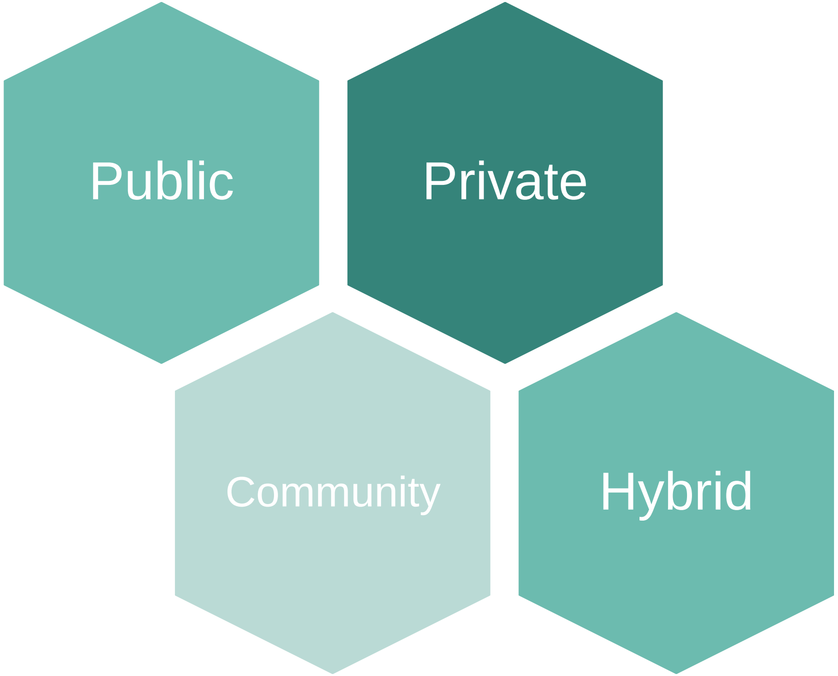
- In addition to these six key characteristics, the following characteristics are often associated with fog computing:
  - Predominance of wireless access: The large scale of wireless sensors in IoT implementations demand distributed computing power
  - Support for mobility: Fog nodes can communicate directly with mobile devices → enables mobile data analytics (opportunity for IoT, smart city or smart vehicles). Mobility is a key distinction between fog computing and cloud computing.

Source: Refer to previous slide and reference list for further sources

Fog Computing Service & Deployment Models

Similar to cloud computing:

- Software-as-a-Service (SaaS)
  - Offers fog applications
- Platform-as-a-Service (PaaS)
  - Offers the opportunity to run and deploy applications on a fog platform
- Infrastructure-as-a-Service (IaaS)
  - Offers computing and storage power on a fog infrastructure



Source: Yi S, Qin Z, Li Q (2015) Security and privacy issues of fog computing: a survey. Paper presented at the international conference on wireless algorithms, systems, and applications
Source: Iorga M, Feldman L, Barton R, Martin MJ, Goren N, Mahmoudi C (2018) Fog computing conceptual model (NIST SP 500-325)
Source: Mahmood Z (2018) Fog computing: concepts, frameworks and technologies, 1st edn. Springer,Cham

Edge Computing

Karlsruhe Institute of Technology

Definition

Edge computing refers to the enabling technologies allowing computation to be performed at the edge of the network, on downstream data on behalf of cloud services and upstream data on behalf of IoT services.

- Describes end-device layer, which are used for local computations or sensing
- Sensors, actuators, or other smart devices
- Main difference to fog computing: proximity of computation to the sensing
- Example: Smartphone connected to sensors on the body (heart rate etc.)

Source: Shi W, Cao J, Zhang Q, Li Y, Xu L (2016) Edge computing: vision and challenges. IEEE Internet Things J 3(5):637 – 646
Source: Iorga M, Feldman L, Barton R, Martin MJ, Goren N, Mahmoudi C (2018) Fog computing conceptual model (NIST SP 500-325).

Enabling Technologies — Overview

Tagging Technologies

Identification

Image source: [Access control] by Plank Susanne, July 3rd 2019. Pixabay License.

Tagging technologies allow to **track and count** virtually **any physical object**.

Sensor Technologies

Perception

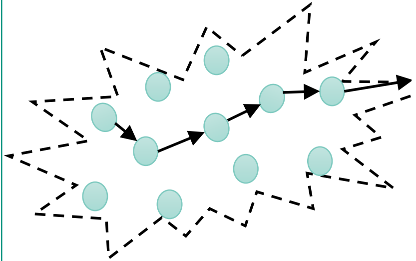


Image source: Adapted from [Wireless Sensor Network] by Mohammed Mehdi Saleh, April 16th 2019.

Sensors **collect data about the real world**. They can augment and complement human senses.

Smart Technologies

Intelligence

Image source: [Künstliche Intelligenz] by Altmann Gerd, May 11th 2018. Pixabay License.

“Things become smart” they are being equipped with **data processing capabilities**.

Miniaturization Technologies

Size

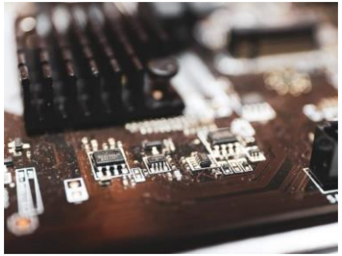


Image source: [Chip] by Altmann Gerd, June 3th 2020. Pixabay License.

To embed intelligence in all kinds of physical objects, computer chips and sensors **need to become ever so smaller**.

Source: Sunyaev, A (2020) Internet Computing. Principles of Distributed Systems and Emerging Internet-Based Technologies, Springer

Source: Swan M (2012) Sensor mania! The internet of things, wearable computing, objective metrics, and the quantified self 2.0. J Sens Actuator Netw 1(3):217 – 253

‘Things‘ in the Edge Layer

Image source: [Smart Objects] by Altmann Gerd, May 13th 2018. Pixabay License.

Smart Objects are physical objects augmented with sensing, processing, and network capabilities that act autonomous, make sense of their situation, and interact with humans and other objects.

Smart Devices

Smart Objects

Smart Environ-ments

Smart devices tend to be multi-purpose ICT devices, operating as a single portal to access sets of popular multiple application services that may reside locally on the device or remotely on servers.

Image source: [Smart Devices] by Altmann Gerd, August 1th 2018. Pixabay License.

A ***Smart Environment*** is a physical world that is richly and invisibly interwoven with sensors, actuators, displays, and computational elements, embedded seamlessly in the everyday objects of our lives, and connected through a continuous network.

Source: Sunyaev, A (2020) Internet Computing. Principles of Distributed Systems and Emerging Internet-Based Technologies, Springer
Source: S. Poslad, Ubiquitous Computing: Smart Devices, Environments, and Interactions, 2009. G. Kortuem et al., Smart Objects as Building Blocks for the Internet of Things, 2010

Image source: [Smart Enviroment] by Moondance, April 6th 2021. Pixabay License.

Key Differences to Cloud Computing

	Cloud Computing	Fog and Edge Computing
Architecture	Centralized (data centres)	Distributed in nodes
Location of server nodes	On the Internet (global)	At the Edge of the network (local)
Location awareness	No	Yes
Latency	Medium	Low
Amount of nodes	Few (large servers)	Millions (fog/edge nodes)
Support for mobility	Limited	Supported
Computing capabilities	Higher	Lower
Analysis	Long-term/deep analysis	Short-term
Connection	Internet	Various protocols and standards
Risk of failure	Medium (depending on the Internet)	Low (based on different connections)
Security	Medium	High (due to distributed architecture)

Layered Model of Cloud, Fog, and Edge Computing

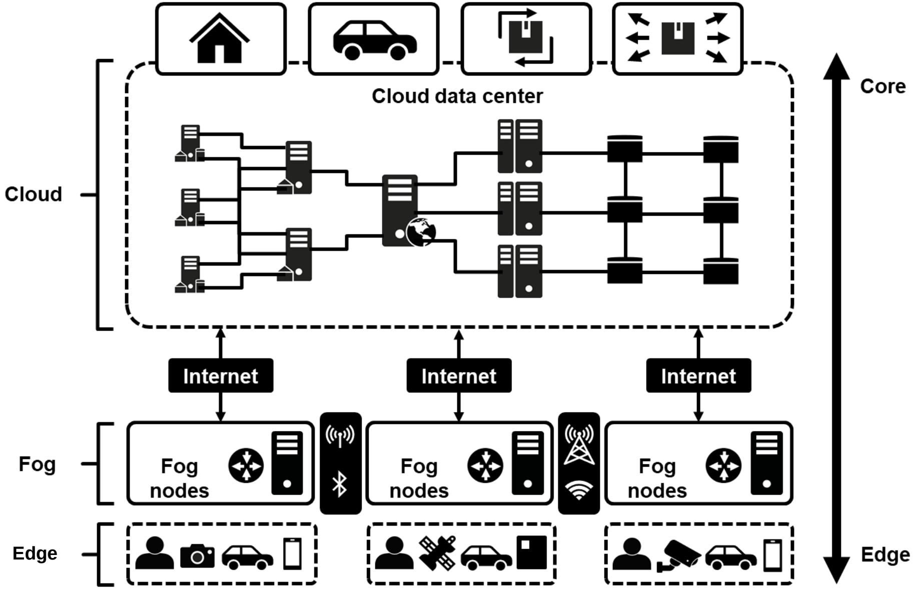


Image source: Sunyaev, A (2020) Internet Computing. Principles of Distributed Systems and Emerging Internet-Based Technologies, Springer
adapted from Hu P, Dhelim S, Ning H, Qiu T (2017) Survey on fog computing: architecture, key technologies,applications and open issues. J Netw Comput Appl 98:27 – 42

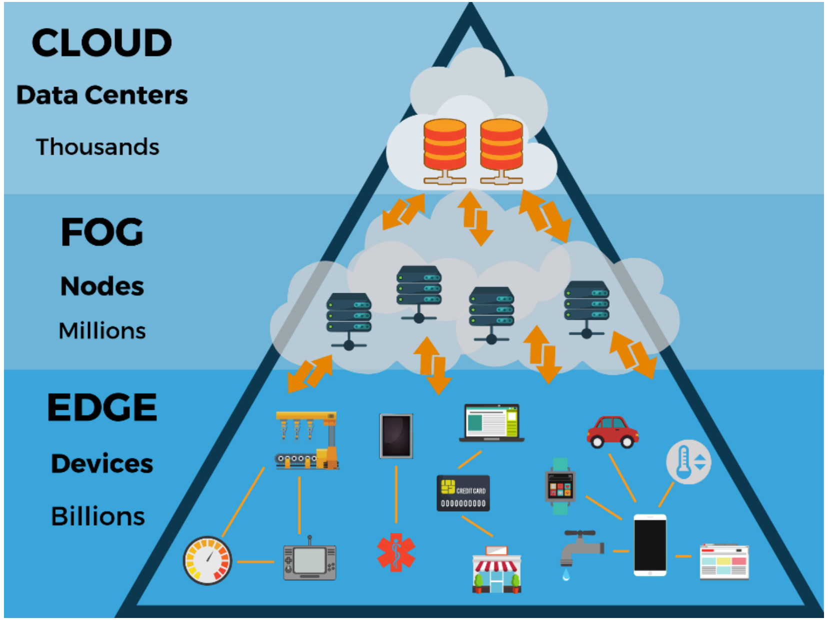


Image source: Apapted from Recent advances in mobile edge computing and content cac
By Sunitha Safavat, Naveen Naik Sapavath, Danda B.Rawat.
https://www.sciencedirect.com/science/article/pii/S2352864819300227.
Accessed on 22.03.2022.

Challenges of Fog and Edge Computing (1/4)

1 Security

2 Heterogeneity

3 Programming platform

4 Energy management

- The distributed architecture is not optimal to deploy fog and edge nodes outside safe data centres
- The heterogeneous nature of fog and edge nodes makes the pursuit of trust more difficult
- Authentication at different levels of fog nodes is the primary security issue of fog computing
- The massive number of objects and widely distributed data pose challenges in the access control
- Network security is the most common issue is the intrusion detection
- There are three critical categories of privacy issues (data privacy, usage privacy, and location privacy)

Source: Sunyaev, A (2020) Internet Computing. Principles of Distributed Systems and Emerging Internet-Based Technologies, Springer
Source: Hu P, Dhelim S, Ning H, Qiu T (2017) Survey on fog computing: architecture, key technologies, applications and open issues. J Netw Comput Appl 98:27 – 42
Source: Yi S, Qin Z, Li Q (2015) Security and privacy issues of fog computing: a survey. Paper presented at the international conference on wireless algorithms, systems, and applications

Challenges of Fog and Edge Computing (2/4)

1 Security

2 Heterogeneity

3 Programming platform

4 Energy management

- Computational and storage capabilities of fog, edge, and cloud computing differ significantly from each other
- Variation between and within different fog and edge domains
- Data is generated from different end devices, with various processors, having to interact with each other
- Network infrastructure of fog and edge computing includes not only high-speed links, but also wireless access technologies

Source: Sunyaev, A (2020) Internet Computing. Principles of Distributed Systems and Emerging Internet-Based Technologies, Springer
Source: Mahmud R, Kotagiri R, Buyya R (2018) Fog computing: a taxonomy, survey and future directions. In: Di Martino B, Li K-C, Yang LT, Esposito A (eds) Internet of everything: algorithms, methodologies, technologies and perspectives. Springer, Singapore, pp 103 – 130
Source: Mouradian C, Naboulsi D, Yangui S, Glitho RH, Morrow MJ, Polakos PA (2018) A comprehensive survey on fog computing: state-of-the-art and research challenges. IEEE Commun Surv Tutorials 20(1):416 – 464

Challenges of Fog and Edge Computing (3/4)

1. Security
2. Heterogeneity
3. Programming platform
4. Energy management

- The computation is done in user end-devices that most likely run on heterogeneous platforms
- Programming in such heterogeneous platforms is a huge challenge
- The need for a unified development framework has become indispensable

Source: Sunyaev, A (2020) Internet Computing. Principles of Distributed Systems and Emerging Internet-Based Technologies, Springer

Challenges of Fog and Edge Computing (4/4)

1 Security

2 Heterogeneity

3 Programming platform

4 Energy management

- Many distributed nodes raise expected energy consumption
- Therefore, the need for new and effective energy-saving protocols and architectures rises

Source: Sunyaev, A (2020) Internet Computing. Principles of Distributed Systems and Emerging Internet-Based Technologies, Springer
Source: Shi W, Cao J, Zhang Q, Li Y, Xu L (2016) Edge computing: vision and challenges. IEEE Internet Things J 3(5):637 – 646

Fog and Edge Computing Use Cases

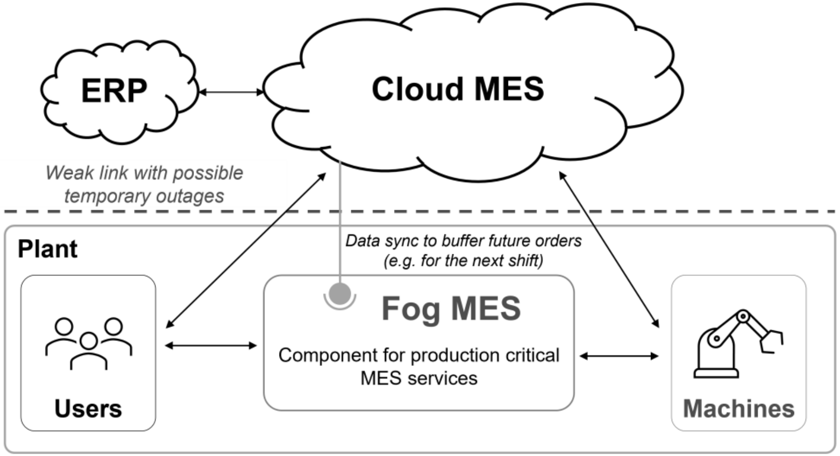
Fog Computing in Health Care

- A wide variety of research about monitoring, detection, diagnosis and visualization of health maladies have been proposed in recent years
- Cao et al. (2015) proposed FAST: A fog computing assisted distributed analytics system to monitor fall for stroke mitigation
- They implemented fall detection algorithms and incorporated them into fog-based distributed fall detection system, which distribute the analytics throughout the network by splitting the detection task between the edge devices (smart phones attached to the users) and the server (servers in the cloud)

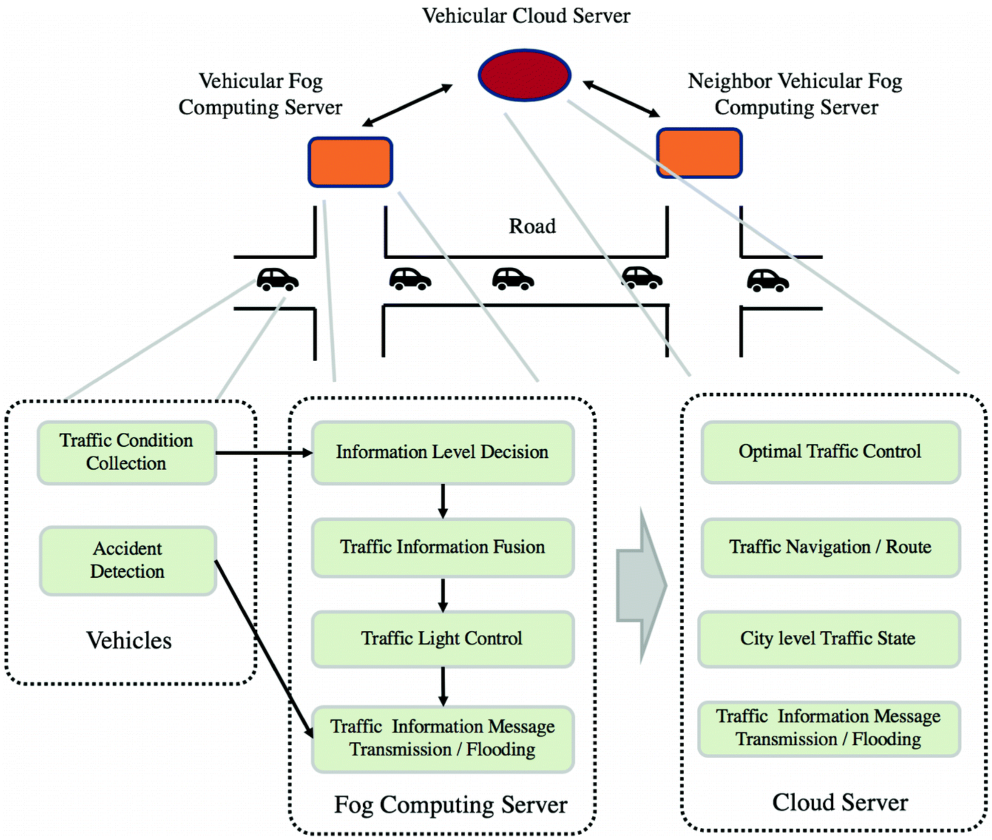
Source: Shi W, Cao J, Zhang Q, Li Y, Xu L (2016) Edge Computing: Vision and Challenges. IEEE Internet of Things Journal 3 (5):637-646. doi:10.1109/JIOT.2016.2579198
Image source: [First Aid] by Gordon Johnson, September 27th 2017. Pixabay License.

Manufacturing Execution Systems

- Manufacturing execution systems (MES) are central tools to control the factory operation
- Fog-based MES may supervise the process control systems, collects data on the process and handles non-conformances
- Low-latency and high fault-tolerance ensure 100% productivity of machines in each factory



Vehicular Fog Computing Based Traffic Information Delivery System to Support Connected Self-Driving Vehicles in Intersection Environment



Source: Youn J. (2020) Vehicular Fog Computing Based Traffic Information Delivery System to Support Connected Self-driving Vehicles in Intersection Environment. In: Park J., Park DS., Jeong YS., Pan Y. (eds) Advances in Computer Science and Ubiquitous Computing. CUTE 2018, CSA 2018. Lecture Notes in Electrical Engineering, vol 536. Springer, Singapore

Public Fogs in Buses

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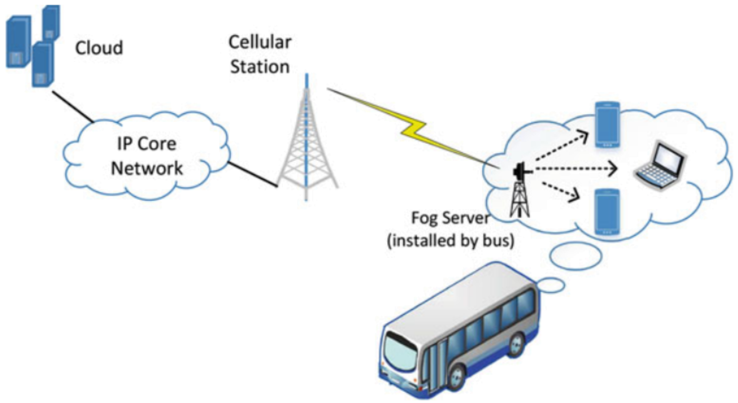
- Inter-State Bus Greyhound has launched “BLUE”, an on-board Fog computing system over inter-state buses for entertainment services
- Fog server can be deployed inside the bus
- Fog provides on-board video streaming, gaming and social networking services to travellers using WiFi
- The on-board Fog server connects to the Cloud through cellular networks to refresh the pre-catched contents and update application services
- Using its computing facility, the Fog server can also collect and process user’s data, such as number of travellers and their feedbacks, and report to cloud



Source: Gao L., Luan T.H., Liu B., Zhou W., Yu S. (2017) Fog Computing and Its Applications in 5G. In: Xiang W., Zheng K., Shen X. (eds) 5G Mobile Communications. Springer, Cham.

Transportation — Decentralizing maintenance

- Transport companies are under constant pressure not just to make deliveries on time but to maintain their vehicles as well
- Companies using edge devices onboard of trucks monitoring the condition of brake pads and how much mileage a vehicle has
- This produces valuable data but there is the problem of poor connectivity in areas where there is no cellular coverage during transit
- No cellular coverage means that data can’t be transmitted to the cloud
- The fog computing solution is to send that data to a fog node and notify the driver if action needs to be taken

→ Decentralizing maintenance in this way helps to ensure that vehicles stay updated and on the road.

Source: What is Fog Computing by Keary Tim. https://www.itprc.com/fog-computing/
Image source: [Self driving transport vehicle] by Linneakornehed, July 3th 2018. Licensed under CC BY-SA 4.0.

Questions

Questions

1. What are the main characteristics of cloud services?
2. What are the major reasons for organizations moving into the cloud?
3. Which risks that cloud service customers face, have been addressed by cloud providers?
4. What are the key characteristics of fog and edge computing?
5. What is the role of a fog node in the fog computing environment?
6. Why is fog computing an add-on for the traditional cloud computing model?
7. What are the differences between edge computing and fog computing?
8. What are the challenges of fog and edge computing?

Further Readings and References

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Karlsruhe Institute of Technology

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