The scenario

- Connected devices are creating data at an exponentially growing rate, which will drive performance and network congestion challenges at the edge of infrastructure.

- Performance, security, bandwidth, reliability, and many other concerns that make cloud-only solutions impractical for many use cases.
A possible solution

• Move information processing and intelligence at the logical edge of the networks (“the cloud close to the ground”): many micro data centers located at the network edge

Fog Computing definitions

• “Fog Computing is a highly virtualized platform that provides compute, storage, and networking services between end devices and traditional Cloud Computing Data Centers, typically, but not exclusively located at the edge of network.” (Bonomi et al., 2012)

• “A horizontal, system-level architecture that distributes computing, storage, control and networking functions closer to the users along a cloud-to-thing continuum.” (OpenFog consortium, 2017)
What Fog is

• An extension of the traditional cloud-based computing model where implementations of the architecture can reside in multiple layers of a networks’ topology
• Preserves all the benefits of Cloud computing
  – Including containerization, virtualization, orchestration, manageability, and efficiency
• Allows to meet the latency and scalability requirements of emerging latency-sensitive applications

Fog opportunities

• Fog enables advanced internet of Things (IoT), 5G and artificial intelligence (AI) use cases
The SCALE advantages of Fog

- **Security**: Additional security to ensure safe, trusted transactions
- **Cognition**: awareness of client-centric objectives to enable autonomy
- **Agility**: rapid innovation and affordable scaling under a common infrastructure
- **Latency**: real-time processing and cyber-physical system control
- **Efficiency**: dynamic pooling of local unused resources from participating end-user devices

Example: smart cities
Example: smarts cars and traffic control

- In 2016, the average person creates around 650MB of data every day and more than double by 2020
- Smart autonomous cars will generate multiple terabytes of data every day from the combinations of light detection and ranging, global positioning systems, cameras, …
- A cloud-only model will not work for autonomous transportation!
Other examples

- Wind farm
  - Main requirements: geo-distribution, low/predictable latency, fog-cloud interplay, multi-agency orchestration, consistency

- Visual security and surveillance
  - Main requirements: real-time, low latency, privacy

- Smart buildings
  - Main requirement: time-sensitive (e.g., fire suppression systems) -> processing in close proximity to the infrastructure devices

Fog vs. edge computing

- The distinction between the two is not clear
  - “For us, edge computing is interchangeable with fog computing, but edge computing focus more toward the things side, while fog computing focus more on the infrastructure” (Shi et al. 2016)

- Some differences (according to OpenFog consortium):
  - Fog works with the cloud, whereas edge is defined by the exclusion of cloud
  - Fog is hierarchical, where edge tends to be limited to a small number of layers
  - In addition to computation, fog also addresses networking, storage, control and acceleration
OpenFog consortium

- High-tech industry companies and academic institutions across the world aimed at the standardization and promotion of fog computing
- Founded by Cisco Systems, Intel, Microsoft, Princeton University, Dell, and ARM Holdings in 2015
  - Building the necessary interoperability of fog-enabled applications requires a collaborative approach
- Technology goals of the consortium
  - Develop an open architecture framework for fog computing
  - Solve tough challenges in distributed systems, security, communications, networking
  - Identify, build and share fog computing use cases and requirements
  - Create testbeds to promote and demonstrate interoperability and composability of solutions

Fog computing according to OpenFog
OpenFog Reference Architecture (RA)

- Developed by the OpenFog consortium
  - Released in February 2017
  - [https://www.openfogconsortium.org/RA/](https://www.openfogconsortium.org/RA/)
- A unified vision of the architecture for enabling exciting future applications
- First step in creating new industry standards
- Commitment towards cooperative, open, interactive systems

OpenFog RA pillars
OpenFog RA pillars

• Security

• Scalability
  – Benefits from hierarchical properties of fog and its location at logical edges of networks

• Openness
  – Composability
  – Interoperability
  – Location transparency

• Autonomy
  – Autonomy of discovery
  – Autonomy of orchestration and management
  – Autonomy of operation
  – Cost savings

OpenFog RA pillars

• Programmability
  – Adaptive infrastructure
  – Resource efficient deployments
  – Multi-tenancy
  – Economical operations
  – Enhanced security

• Reliability, Availability, and Serviceability (RAS)
  – Recall the distinction between reliability and availability!
  – Serviceability (or maintainability): ability to install, configure, and monitor a system; to identify exceptions or faults; and to repair the system
OpenFog RA pillars

- Agility
  - Addresses business operational decisions for an OpenFog RA deployment

- Hierarchy

Some Fog computing systems and companies

- Cisco IOx: device management and M2M services in fog environments
- Cisco Data in Motion (DMo): data management and analysis at the network edge
- LocalGrid fog computing platform: embedded software installed on network switches or edge devices
- Cisco ParStream: analytics database to process, analyze, and store data at the edge

- Nebbiolo Technologies

Fog computing and SABD course

- Fog computing: a future reference scenario for Big Data systems and architectures
- We will see that current Big Data frameworks and tools present some limitations to efficiently operate in the Fog environment
• F. Bonomi, R. Milito, P. Natarajan and J. Zhu, 
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