Fog Computing: On the Road to an Open Infrastructure for the Internet of Things

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08th of March, 2018
Overview

- Motivation
- Introduction
- Openness and standardization
- Research
- Conclusion and outlook
Takeaways

- You will be able to answer three questions

1. What is fog? *(definition)*
2. What can fog do for me? *(benefits)*
3. What can I do for fog? *(research)*
The Internet of Things (IoT) rapidly evolves
- 100 M IoT-connected cars (2022)
- 800 M smart meters (2020)
- Heavy sensor streams (1 GB/sec in a car)

Data needs to be analyzed and stored
Centralization of computing in data centers

Virtualization allows for elasticity and multitenancy

- Efficient resource usage
- Cutting costs
- Pay-as-you-go
Does Cloud Computing Suit IoT?

Cloud has shortcomings

1. Bandwidth constraints
   ◦ Bandwidth is expensive

2. High latency
   ◦ > 20 ms latency

3. Dependent on Internet Connectivity
   ◦ No Internet – No Cloud!
Use Case 1: Camera Networks

- Municipal security system
- Hundreds of cameras
- Real-time analytics
  - Authentication
  - Crowd behavior
- High bandwidth requirements
Use Case 2: Emergency Response

- Example: Natural disaster
- Supporting services
  - Safety check
  - Maps for rescue team
- Internet connectivity may be disrupted
“Cloud Closer to the Ground”

- Analytics needs to happen close to the data!
- Edge computing (on devices) not enough
  - Some devices are not powerful enough
  - Collaboration between devices must be coordinated

“We need something in between edge and cloud that makes it all work together.”

⇒ This is fog computing.
Fog Computing

- The definition of fog computing:

  “A **horizontal, system-level architecture that distributes computing, storage, control and networking functions closer to the users along a cloud-to-thing continuum.**”  
  (OpenFog Reference Architecture)

- What does this mean in practice?
Fog Architecture

Cloud

Edge Cloud

Fog Tier 1

Fog Tier N

“Things”
How Does Fog Computing Help? In Camera Networks...

- Make use of fog hierarchy
  - Keep computation local
  - Global view on higher level

- Benefits
  - Low latency
  - Less network load
  - Data privacy
How Does Fog Computing Help In Emergency Response...

- Use mobile drones as fog nodes

Benefits
- Local connectivity
- Works when infrastructure unavailable
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“Fog computing is great. Let’s build our own fog infrastructure.”

- Cisco Fog, Bosch Fog, ...
- Smart city fog, traffic fog...

- Redundant developments
- Small businesses cannot develop fog solutions
- Everyone is losing revenues
OpenFog

- Consortium of industry and academia partners
- 57 members
- Goal: Interoperable, open fog infrastructure
- “Fog as a service”
- Standardization (with IEEE)
Open Fog Reference Architecture

The OpenFog Reference Architecture is based on 8 technical pillars

Source: The OpenFog Consortium 2017
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  - FogStore – Data store for fog
  - EmuFog – Fog computing emulator
- Conclusion and outlook
Differences to Cloud

- Administrative domains:
  - Fog is not in one domain
- Locality is first-class citizen in fog
- Fog nodes can be highly heterogeneous

- This challenges existing made-for-cloud systems
Data Stores in Fog

- Data stores move to fog
  - for same reasons as compute moves
- Design challenges
  - Replica placement
  - Consistency guarantees
Cloud Data Stores

- Current data stores are designed for data centers
  - Replica placement → not place in same server rack
  - Consistency management → indifferent of location
  - Apache Cassandra, MongoDB, ...

- Fog is different
  - Might not have server racks
  - Locality of sources and sinks is important (⇒ low latency)
Example: Autonomous Cars

- Cars in red circle need consistent state of traffic light
  - Not both see green at the same time!
- Others can read different states for non-critical tasks
  - E.g., adapt speed to save energy
FogStore: Contributions

- Allows applications to specify a context-of-interest (coi) as per its semantics
  - Coi-aware replica placement for low latency access to replicas
  - Higher tolerance to geo-correlated failures

- Coi-aware per-query consistency mapping
  - Serializability to queries within coi
  - Eventual consistency to queries outside coi (focus on low latency)
FogStore: Architecture

Query API
- `create(key, value, data context)`
- `read(key, client context)`
- `update(key, value, client context, data context)`
- `delete(key, client context)`
- `begin, commit, abort, rollback`

Consistency API

Fog Node

Consistency Mapper

DDS instance

translated query

Wanted: Test Platform for Fog

- **Fog architects:**
  “How to layout the fog architecture for a specific application workload?”

- **Application developers:**
  “How does my application behave in a specific fog architecture?”

- No real fog publicly available
  ➔ Need for a test environment
Three possibilities:
(1) real-world test beds, (2) simulation, (3) (network) emulation

Real-world testbeds not available

Simulation has shortcomings:
- Based on many assumptions that need to be modeled
- Applications need to be adapted/modeled in simulation framework

Network emulation is suitable:
- Run original applications
- Only network is emulated
- Realistic performance measurements of applications
Shortcomings of Existing Emulators

- Existing emulation frameworks lack support for fog
  - Allow to load a network topology and emulate it
  - Missing part (the hard one): placing fog nodes and apps
    ➔ This has to be done “by hand”

- Goal: Provide better support!
EmuFog: Contributions

EmuFog, an emulation platform for fog that supports...

- automatic configuration and emulation of fog infrastructure
- execution of natural fog applications provided as Docker containers
- scaling across a distributed cluster of host machines
- extensibility to user-defined fog node placement strategies
Latest version of EmuFog available on GitHub: https://github.com/emufog/

Paper available:
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Conclusion

1. What is fog?
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Outlook

- Fog matches with recent trends
  - It is all about distribution and decentralization
  - Example: Blockchain
    - Decentralized consensus, cryptocurrencies, ...
    - Can it be used for accounting, provenance, etc.?

- Fog poses challenges on existing made-for-cloud systems
  - Stream processing, machine learning, ...
  - Constrained resources, local processing, ...
Thank you!

Time for Q & A.