FOG AND EDGE COMPUTING

LEARNING OUTCOMES

- Fog Computing
- Edge Computing
- Fog and Edge Computing Tradeoffs
- Tools and technologies
- Applications
- Challenges and Opportunities

FOG COMPUTING

WHAT IS FOG COMPUTING?

Idea of Fog computing was introduced by Cisco in 2014

Main premise was to bring the cloud services closer to the IoT devices

Term Fog in Fog computing relates to the cloud which is closer to the ground,

- Concentrating the computing power down to earth i.e. closer to the devices generating data

IoT devices generate gigantic amount of diversified data and by the time that data hit the cloud for further processing and analysis, the opportunity to timely act on it might be lost

PURPOSE OF FOG COMPUTING

To assess and send the time critical data at the edge of the network or closer to the source from where it is originated

To timely act on the IoT data so that it may not lose its value

To filter data before it should be sent to cloud to expedite the decision making process rather than blindly sending the entire data stream for long term storage, core analysis and processing

ARCHITECTURE OF FOG COMPUTING

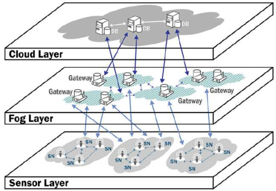


Figure 1: High-level architecture of Fog Computing [8]

Fog acts as a layer between the IoT devices and cloud

Layer consists of Fog node (s) which provide

- Intermediate storage
- Communication
- Processing facilities at a distributed level

Fog is a cloud but it is closer to the end user to minimize latency

HOW DOES FOG NETWORKING WORK?

- Sensors and edge devices are the nodes where the data is produced and composed
- End nodes are not capable of performing intelligent computations and advance data analytics
- Cloud data centers have these capabilities but they are physically at a large distance to timely process and react to data in real time
- Data transmitted directly to cloud by IoT nodes are susceptible to security and privacy implications, particularly when the data is of sensitive nature

HOW DOES FOG NETWORKING WORK? CONTD…

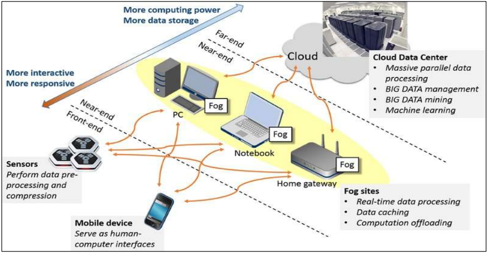
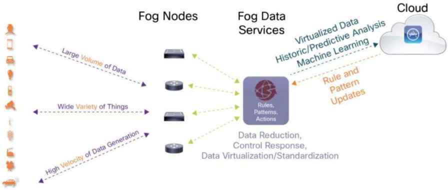


Figure 2: How does Fog works?

HOW DOES FOG NETWORKING WORK? CONTD…



HOW DOES FOG NETWORKING WORK? CONTD…

Extremely time critical Application

- Typically, data is analyzed on the fog node which is adjacent to the data source
- Fog nodes are capable of sending commands to actuators for real time control in case of time sensitive events

In mission critical application,
- Response time is extremely short
- Unnecessary delays might result in serious repercussions

Application Areas
- Surveillance application
- Health care system

HOW DOES FOG NETWORKING WORK? CONTD…

Medium time critical Applications

- Application data can tolerate some latency to receive a decision
- Data can be sent to aggregation node for analysis and action
- Example
  - In the Smart Grid, each substation might have its own aggregation node that reports the operational status of each downstream feeder and lateral

Less time critical Applications

- Application data is less time sensitive
- Data can be sent to cloud for long term storage, temporal analysis and big data analytics
- Example
  - Each of thousands or hundreds of thousands of fog nodes might send periodic summaries of grid data to the cloud for historical analysis and storage

EDGE COMPUTING

WHAT IS EDGE COMPUTING?

Moving processing and data storage closer to the edge of the data source to reduce load on the central server

Any edge device such as switch, router, sensor, or a smart device can perform Edge computing

- Each of these devices are capable of performing data processing intelligently

Unlike Fog nodes, Edge devices may have no association with a cloud or a server

- Edge devices can exist independently as a standalone machine with self-contained functionality

WHAT IS EDGE COMPUTING? CONTD…

Typical functions of Edge Computing include

- Data aggregation
- Filtering
- Anomaly detection and so on

Reduce cost and latency

Control network bandwidth

EXAMPLE

Consider a security system inside a building with many cameras constantly recording and streaming a live feed to a server

Assuming the central server of this system is state-of-art and has a large storage capacity as well as high computing power, it is obvious that at one point in time the server will be saturated and will not be able to handle any further data

Data source, in this case the cameras, are the edge devices

Concept of edge computing is to give these cameras computational power so that they will send selective data to the server

Making the edge devices smarter will allow devices to process data and even store it at the edge for short term before sending it to the server

TYPES OF EDGE DEVICES CONTD…

Edge Sensors/Actuators

- Mainly embedded systems which lack operating system or general purpose processors
- To process, analyze, and store the data collected and transmitted by them
  - Directly harnessed to Edge devices or gateways through inexpensive and low power radio technologies

TYPES OF EDGE DEVICES CONTD…

Edge Devices

- Unlike Edge sensors/actuators, they can run a complete operating system and perform general purpose tasks
- For instance, the devices executing operating systems such as iOS, Linux, or Android are considered as Edge Devices
  - Perform Edge analytics on the incoming data and can also trigger the actuators
  - Battery operated and resource constrained
  - Directly connected to cloud or via an Edge Gateway

TYPES OF EDGE DEVICES CONTD…

Edge Gateway:

- Run operating systems
- Resource sufficient in terms of power supply, computing power and storage
- Provides a communication link between the Cloud and Edge Devices,
- Both Edge Gateways and Devices
  - Forward selected subsets of raw or pre-processed IoT data to the Cloud
  - Regularly receive commands from the Cloud, like configurations, data queries, or machine learning models against which to locally score IoT data

FOG AND EDGE COMPUTING TRADEOFFS

ADVANTAGES

- **Reduce Data Volume**
  - Making edge devices smarter by giving them computational power will mainly decrease the load on a central server or the cloud
  - Edge devices process data and only send selective data
  - Decrease the network traffic
  - Allow to react to data in near real-time
- **Low Latency**
  - Proximity of Edge and Fog computing services allows for low end-to-end latency
  - Edge devices minimize the service delay for end-user IoT applications
  - Applications include: Games, health care, smart cars, aircraft communication

ADVANTAGES CONTD…

- **Scalability**
  - Fog and Edge computing process the data adjacent to the data source
  - Level of data processing reduces on cloud
  - Allow more end devices to be integrated into the IoT system and facilitated by cloud
- **Conservation of Network bandwidth**
  - Fog computing avoids the need for costly bandwidth additions by offloading gigabytes of network traffic from the core network
  - Increased system efficiency

ADVANTAGES CONTD…

- **Security Control**
- Critical or sensitive data can be analyzed locally or inside company walls instead of making it visible on the cloud directly
- For example
  - For a security firm, tracking the latest malware and protecting IoT enabled devices from it requires real time data analysis, insights and visualization

LIMITATIONS

- Fog is a relatively modern trend, so its security and privacy challenges are still are under study
- Security and privacy mechanism available for cloud computing are not suitable for Fog computing
- Fog computing is vulnerable to security threats and attacks which are unlikely to occur in a well-protected cloud environment

LIMITATIONS CONTD…

- Fog computing is particularly suitable for highly dynamic systems
- Static systems would not essentially get benefited if implemented over fog because they
  - don't require real time processing
  - gather only limited quantity of data
  - E.g., if you are observing the displacements of glaciers by capturing a coarse image once per day then sending those images to cloud for processing, analysis and storage would be an optimal approach rather than processing them in a fog environment

TOOLS AND TECHNOLOGIES

TOOLS AND TECHNOLOGIES

- Fog computing typically uses open standard technologies
- Edge computing may run on open or proprietary technologies
  - **CLOUDS Lab at Melbourne University**
    - Mainly focuses on creating Fog environment using IoT devices, Fog devices such as Raspberry pi and enterprise or public clouds
    - Developed a simulator, iFogSim, which facilitates modelling and simulation of Fog computing environments for
      - Assessment of resource management
      - Analyzing the impact on latency, energy ingestion, network traffic, and operating costs
      - Simulates the functions of edge devices, cloud data centers, and network links to evaluate the performance metrics

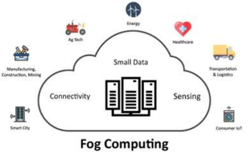
TOOLS AND TECHNOLOGIES CONTD…

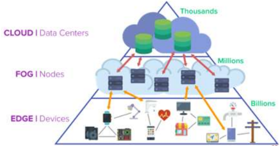
- **OpenFog Consortium**
  - Goal is to develop an open architecture for fog computing, construct operational models and testbeds, promote advance technology through open Fog environment
- **EdgeX Foundry**
  - Open source interoperability platform for Fog and Edge computing
  - Managed by Linux foundation and Dell Technologies
  - Provides tools to rapidly generate IoT edge solutions that are flexible to dynamic enterprise needs

APPLICATIONS

APPLICATIONS

- Popular fog computing applications include smart grid, smart city, smart buildings, health care, vehicle networks and software-defined network



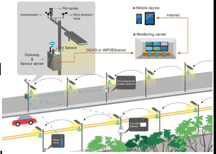


APPLICATIONS CONTD…

- **Aircraft Communication**
  - A Boeing 787 generates 40 TB of data per hour of flight, but just half a TB of this data is ultimately transmitted to a data center for analysis and storage
  - It is not sensible, nor possible to install a full data center on a plane
  - Therefore, edge or fog computing steps in to validate and pre-process this data either within a local network (fog) or a gateway device (edge)

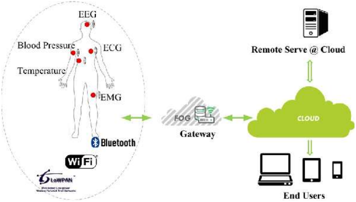
APPLICATIONS CONTD…

- **Smart lighting system**
  - A smart lighting system which operates based on movement
  - When there is movement detected, the lights are turned on
  - When no movement has been detected for a period of time, the lights should be turned off
  - Data and resulting decisions are best processed at the edge
  - However, the “bigger picture” of how the smart lighting is being used would require data to be collated and processed by a reporting system running in the cloud



APPLICATIONS CONTD…

- Many medical actuator devices need to respond immediately to sensor data in milliseconds
- Cannot wait for minutes for sensor data to be sent



SUMMARY

SUMMARY

- Fog and Edge computing are closely linked architectures to manage the data inundation by
  - Offloading data from the cloud
  - Process it by bringing it to the network edge, closest to the data generating source
- Add a layer of computing between the device and the cloud
  - Not only minimizes the latency cost but also provides rich user experience
- Deliver real-time value to end users by
  - Instantaneous consumption of data where immediate actions are required within milliseconds of data acquisition

SUMMARY CONTD…

- Unlike traditional cloud solution, the data preprocessing or validation logic is placed at the network edge
- Fog and Edge computing differs in the context of where the computing power is located
  - Fog computing delegates the data processing and communication capabilities to local area network comprising of fog nodes
  - Edge computing pushes these functionalities directly into a data acquisition device

SUMMARY CONTD…

- Unlike Edge computing, Fog computing has an association with cloud services
  - Fog devices implement all functions of an Edge computing device and are also flexible in distributing workloads between the fog nodes and cloud data centers
- Fog computing also offers the benefits of well-defined software frameworks, making the fog and cloud transparent to the user and developer
- Fog and Edge Computing are synergistic, not exclusive
- Equally valuable computing solutions as IoT expands

CASE STUDIES

CASE STUDY 1: REAL-TIME DATA PROCESSING IN SMART CITIES

Scenario/Background

A metropolitan city is deploying a **smart traffic management system** with 5,000 IoT-enabled cameras and sensors. Each sensor generates **200 KB of data every second**, resulting in **1 GB of data every second citywide**. If all this data were sent to the cloud for analysis, it would cause massive bandwidth congestion and delay in traffic signal adjustments. The city planners must choose between **Fog Computing** and **Edge Computing** to handle data efficiently.

CASE STUDY 1: REAL-TIME DATA PROCESSING IN SMART CITIES

Question

Which approach (Fog or Edge) should the city adopt for real-time traffic management? Justify your answer with quantitative reasoning based on **latency, bandwidth usage, and scalability**.

CASE STUDY 1: REAL-TIME DATA PROCESSING IN SMART CITIES

Answer

The city should implement **Fog Computing** for traffic management.

1. **Quantitative Data Analysis**

- Each sensor = 200 KB/s → 1 GB/s for all 5,000 sensors.
- Over an hour = **3.6 TB of raw data**. Sending this to the cloud would overwhelm networks. With Fog Computing, intermediate fog nodes (local servers) process data regionally, reducing transmission load by **up to 80%**, since only processed insights (alerts, trends) are forwarded to the cloud.

CASE STUDY 1: REAL-TIME DATA PROCESSING IN SMART CITIES

Answer

2. **Latency**

- Real-time traffic light adjustments require response times <100 ms.
- Cloud-only processing can take >1,000 ms (1 second) due to long routing.
- Edge devices offer <50 ms latency but only work at individual intersections. Fog nodes aggregate data from multiple intersections, achieving **low latency (50–100 ms)** while also coordinating between districts.

CASE STUDY 1: REAL-TIME DATA PROCESSING IN SMART CITIES

Answer

3. **Scalability**

- Fog Computing allows new intersections to simply add local fog nodes without stressing a central cloud.
- Cloud scaling would require continuous bandwidth expansion.

CASE STUDY 1: REAL-TIME DATA PROCESSING IN SMART CITIES

Answer

4. **Comparative Justification**

- Edge-only would localize each intersection but fail to coordinate across districts (e.g., highway traffic redirection).
- Cloud-only would cause bandwidth congestion and slow responses.
- **Fog Computing balances both by combining local responsiveness and regional coordination.**

CASE STUDY 1: REAL-TIME DATA PROCESSING IN SMART CITIES

Answer

Conclusion:

Fog Computing provides the only feasible solution for smart traffic by balancing **latency, bandwidth efficiency, and scalability**, making it superior to Edge-only or Cloud-only models.

CASE STUDY 2: HEALTHCARE – REMOTE PATIENT MONITORING

Scenario/Background

A hospital monitors **1,000 patients** using IoT wearable devices (heart rate, oxygen levels, glucose monitoring). Each device generates **50 KB every 2 seconds**, totaling about **25 MB/minute** of raw data. Critical alerts (e.g., arrhythmia detection) must be identified **within 200 ms**. The hospital is deciding whether to use **Edge Computing** (on-device processing) or **Fog Computing** (local server near hospital).

CASE STUDY 2: HEALTHCARE – REMOTE PATIENT MONITORING

Question

Which solution is better for remote patient monitoring, Edge or Fog Computing? Justify with quantitative reasoning on **speed of response, data handling efficiency, and privacy**.

CASE STUDY 2: HEALTHCARE – REMOTE PATIENT MONITORING

Answer

The hospital should adopt **Edge Computing** for real-time monitoring, with cloud support for long-term storage.

1. **Quantitative Data Analysis**

- 1,000 patients × 50 KB/2s = **25 MB/minute = 36 GB/day**.
- Sending all raw data to the cloud increases cost and latency. Edge devices filter abnormalities locally and send summaries, reducing bandwidth by **>70%**.

CASE STUDY 2: HEALTHCARE – REMOTE PATIENT MONITORING

Answer

2. **Speed of Response**

- Life-threatening conditions require **alerts in <200 ms**.
- Edge devices process data instantly (<50 ms), ensuring immediate response. Fog adds another layer (100–150 ms) but may delay urgent reactions.

CASE STUDY 2: HEALTHCARE – REMOTE PATIENT MONITORING

Answer

3. **Privacy and Security**

- Edge ensures that most sensitive data stays within devices, reducing exposure.
- Fog nodes are still vulnerable, requiring additional security measures.

CASE STUDY 2: HEALTHCARE – REMOTE PATIENT MONITORING

Answer

4. **Comparative Justification**

- Fog is better for aggregating data across multiple patients and running analytics for hospital-wide trends.
- Edge is best for **individual, real-time, life-critical decisions.**

CASE STUDY 2: HEALTHCARE – REMOTE PATIENT MONITORING

Answer

Conclusion:

For patient safety, **Edge Computing is the only correct choice**, as it provides **ultra-low latency (50 ms)**, efficient data filtering, and strong privacy for life-critical monitoring. Fog can be layered later for hospital-level insights.

CASE STUDY 3: AVIATION – BOEING 787 DATA MANAGEMENT

Scenario/Background

A Boeing 787 generates **40 TB of data per hour of flight**, but only **500 GB/hour** is transmitted to ground data centers. Engineers must decide whether to rely more on **Fog Computing (in-flight local servers)** or **Edge Computing (smart sensors within aircraft subsystems)** for efficient handling of this data.

CASE STUDY 3: AVIATION – BOEING 787 DATA MANAGEMENT

Question

Should aircraft primarily rely on Fog or Edge Computing to manage such large-scale in-flight data? Support your answer with **quantitative justification**.

CASE STUDY 3: AVIATION – BOEING 787 DATA MANAGEMENT

Answer

Aircraft should rely primarily on **Fog Computing** with limited Edge integration.

1. **Quantitative Analysis**

- 40 TB/hour raw data vs 500 GB/hour transmission → only **1.25% of total data is transmitted**.
- Sending all 40 TB is impossible due to satellite bandwidth constraints. Fog Computing preprocesses and aggregates data in-flight, cutting unnecessary transmissions by **>95%**.

CASE STUDY 3: AVIATION – BOEING 787 DATA MANAGEMENT

Answer

2. **Edge vs Fog**

- Edge sensors (e.g., engine vibration monitors) detect local anomalies but cannot coordinate across the entire aircraft system.
- Fog nodes within the aircraft integrate multiple subsystems (engine, navigation, communications), enabling **real-time cross-analysis** critical for safety.

CASE STUDY 3: AVIATION – BOEING 787 DATA MANAGEMENT

Answer

3. Latency and Reliability

- Edge processing is fast (<10 ms), but scope is limited.
- Fog processing is slightly slower (<100 ms) but enables **aircraft-wide situational awareness**, which is vital for avoiding failures mid-flight.

CASE STUDY 3: AVIATION – BOEING 787 DATA MANAGEMENT

Answer

Conclusion:

While Edge sensors handle micro-level monitoring, only **Fog Computing can preprocess terabytes of data, integrate subsystems, and reduce transmission load**. Thus, **Fog is the correct answer** for large-scale aviation systems.

Thank You!