Fog Computing

Computing for Internet of Things

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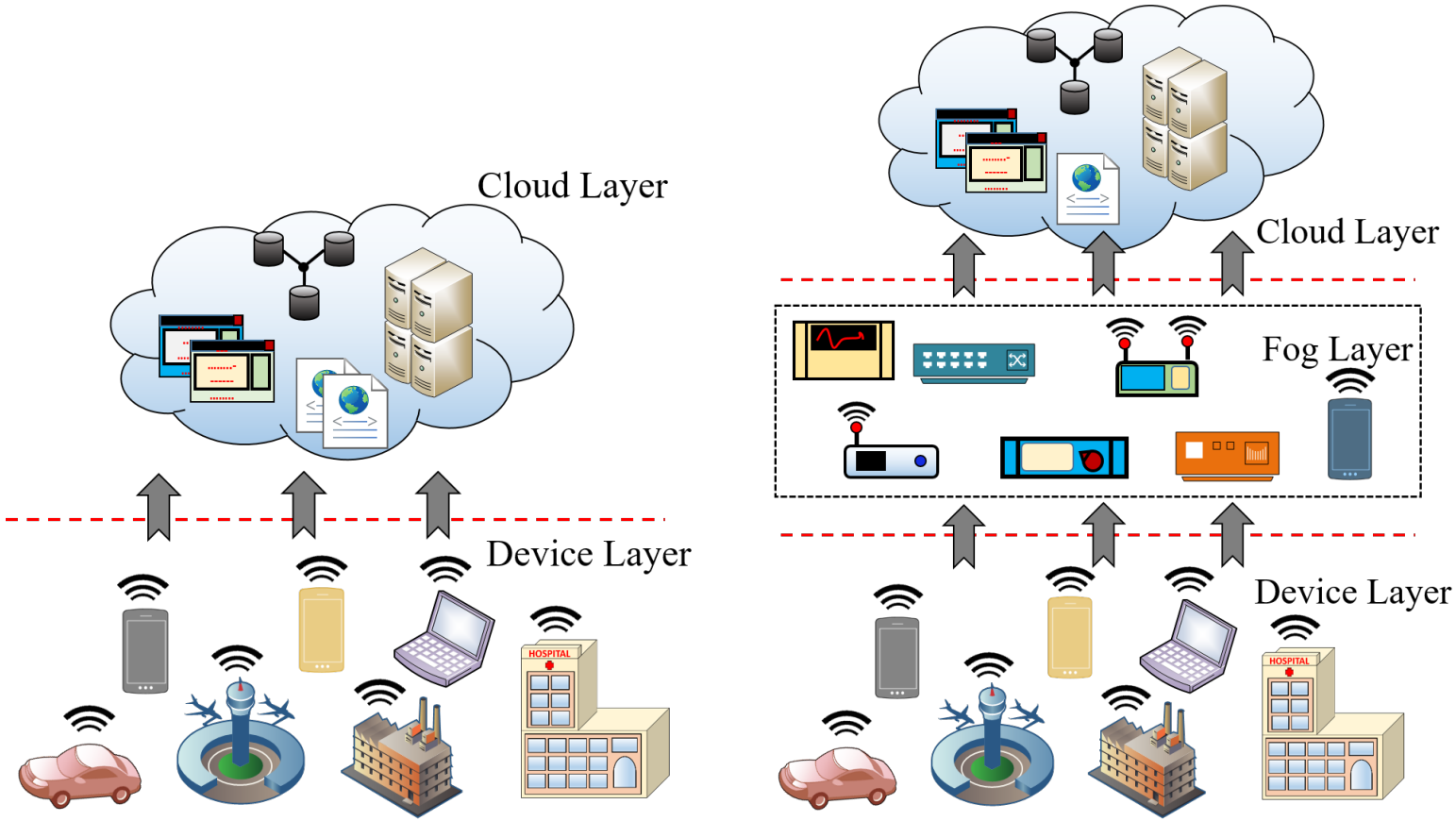
Overview

Introduction

- The concept of Fog computing was introduced considering the high latencies involved in cloud computing.
- Unlike network computing, cloud computing comprises a pool of multiple resources such as servers, storage, and network from single/multiple organizations.
- Fog computing follows a distributed architecture, which enables processes to execute near the edge of the devices to avoid service latency.
- A fog layer is an intermediate layer between the physical IoT devices and the cloud. The term, fog computing, was coined by Cisco.
- In fog computing architecture, time-sensitive data from different devices are transmitted to the fog devices at the fog layer.
- Further, data are processed to serve an end user application.

Introduction



(a) Cloud computing

(b) Fog computing

Figure: Difference between cloud and fog computing

Characteristics of Fog Computing

- **Location Awareness**:
  - The fog nodes operate near the edge of the physical IoT devices.
  - These fog nodes must be aware of their actual locations and how far they are located from the physical devices.
  - A fog node collaborates with its neighboring fog nodes to provide the end user services.
- **Heterogeneity and Interoperability**:
  - The fog nodes have different capabilities of processing, storing, and networking.
  - In fog architecture, it is essential to process the data of a physical device with the most suitable fog nodes.
  - In order to serve applications, a set of fog nodes need to work collaboratively.
  - The fog nodes are manufactured by different vendors.
  - For proper communication among these fog nodes, interoperability is an essential characteristic of fog computing.

Characteristics of Fog Computing

- **Low Latency**:
  - For a time-critical application in a traditional cloud computing architecture, latency affects the quality of service.
  - Fog computing architecture is introduced to process services at the edge itself to avoid latency in time-critical applications.
- **Mobility**:
  - In an IoT scenario, different objects, such as vehicles, are equipped with different sensors; these sensors are used to provide data to an application.
  - The migration of service from one fog node to another, corresponding to the change in position of the object, is essential.
  - Fog computing supports mobility for seamless execution of processes.

Fog Nodes

- The key enabler of the fog computing architecture is the fog node itself.
- These node can be heterogeneous or homogeneous, typically, depending on the application scenario.
- These fog nodes are connected among themselves and follow a distributed computing architecture.
- Examples of fog nodes are routers, gateways, switches, or any processing nodes.

Characteristics of Fog Nodes

- **Autonomous decision making**:
  - Fog computing paradigm follows the distributed computing architecture.
  - In the proximity of a fog node, multiple static and mobile devices may appear.
  - The devices transmit the data to the nearest fog node or the most capable fog node, based on certain predefined optimization algorithms.
  - Within the fog architecture, fog nodes work collaboratively to provide a service.
  - For service migration from one fog node to another, a fog node must select/ switch to another appropriate fog node intelligently and autonomously.

Characteristics of Fog Nodes

- **Programmability**:
  - An essential characteristic of a fog node is programmability.
  - In fog computing architecture, physical devices transmit the data directly to a fog node for providing a service.
  - A fog node must process the data immediately, after receiving it from any physical device.
  - The fog nodes must be programmable so that a pre-defined program can be installed and executed inside the fog device as per requirement.

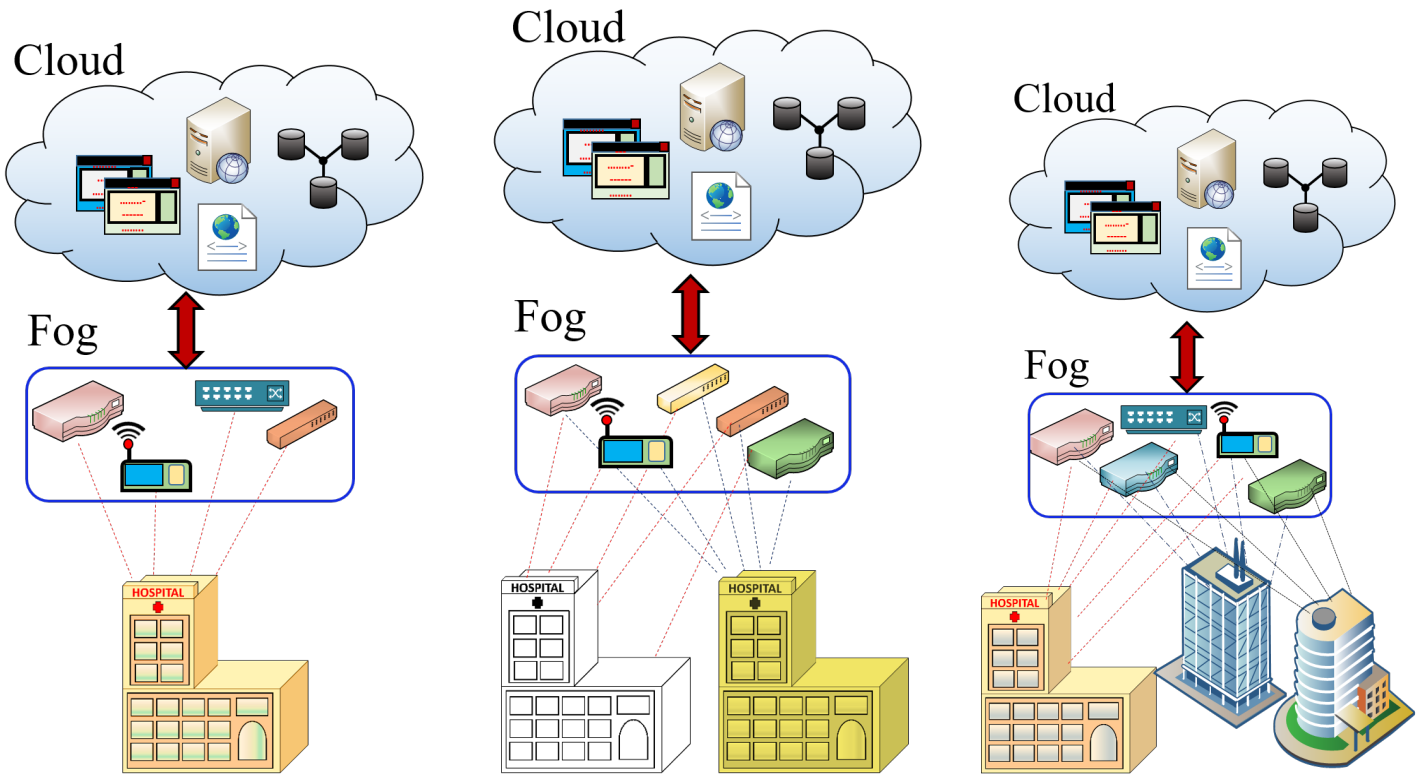
Characteristics of Fog Nodes

- **Heterogeneity**:
  - Heterogeneity is introduced as different vendors manufacture the various constituents of fog devices.
  - The devices at the fog layer may be of different types and include components such as routers, switches, gateways, and other processing devices.
  - Based on the accessibility and requirements, these devices are used for provisioning different services.
- **Network-enabled**:
  - For a particular application, a set of fog nodes work together.
  - These fog nodes may be located at different physical locations.
  - For establishing communication among these fog nodes, the network becomes an essential component.
  - Therefore, fog devices need to be network-enabled.

Fog Node Deployment Model

- **Private fog node**: These fog nodes are allocated dedicatedly for a single user organization.
- **Community fog node**: These fog nodes are used for a set of functionally similar organizations or a community.
- **Public fog node**: The fog nodes that are accessible and used by multiple functionally different organizations are known as public fog nodes.
- **Hybrid fog node**: A hybrid fog node consists of single or multiple public, community, or public fog nodes, which are logically combined to provide services to multiple organizations.

Introduction



(a) Private (b) Community (c) Public

Figure: Different fog node deployment models [2]

Node View

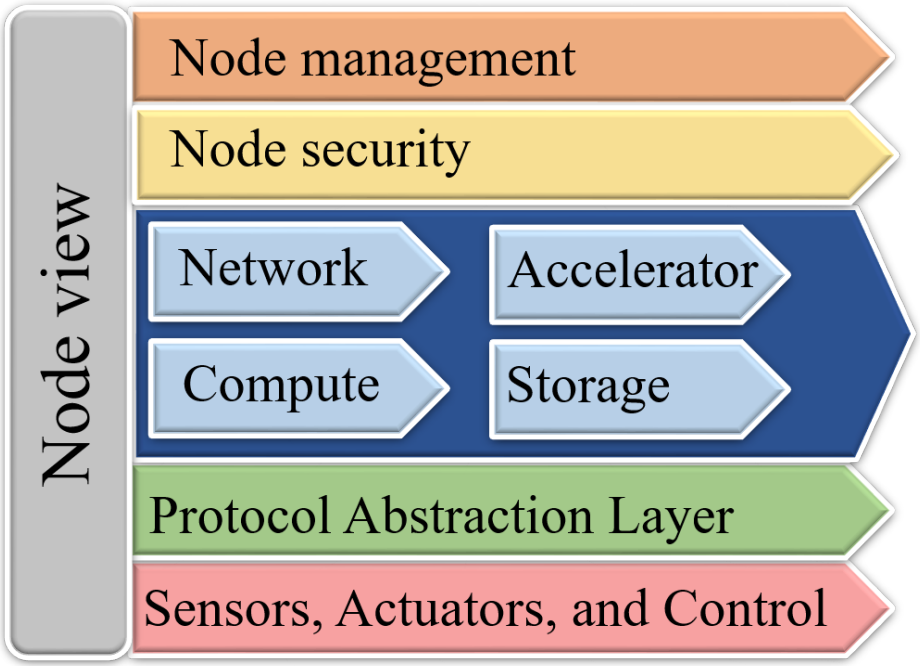


Figure: Node view [1]

Node View

- **Node management**: Before bringing a node in a fog architecture, it should support the existing interface by which the node will be managed.
- **Node security**:
  - Security is an essential aspect that needs to be considered in the fog computing architecture.
  - There are certain scenarios where a fog node acts as a gateway node; the data from the smart IoT sensors are transmitted to the higher level through this gateway.
  - The security in fog node is a major concern, which needs to be addressed.
- **Network**:
  - Fog computing is used for reducing the service delay of an application.
  - A fog node must communicate with other nodes and smart IoT devices efficiently with the least possible delay.
  - This will also enable the fog computing network to support time-sensitive networking (TSN).

Node View

- **Accelerators**: In order to increase the speed of service accessibility, fog applications use accelerators.
- **Computation**: The fog nodes must have the computational capabilities for taking instant and quick decisions for certain applications.
- **Storage**: The fog node should have adequate storage facilities associated with it and this storage must be reliable and meet the performance requirements of the applications.
- **Protocol abstraction layer**:
  - available smart IoT devices may not be able to communicate with the fog devices directly.
  - a protocol abstraction layer logically connects smart IoT devices with fog components at the fog layer
- **Sensors, Actuators, and Control**:
  - These smart devices lie at the bottom of the fog architecture and one or multiple fog nodes can connect to multiple smart IoT devices.
  - Typically, these devices have less processing capabilities and limited connectivity capabilities, such as Wi-Fi, Zigbee, and Ethernet.

System View

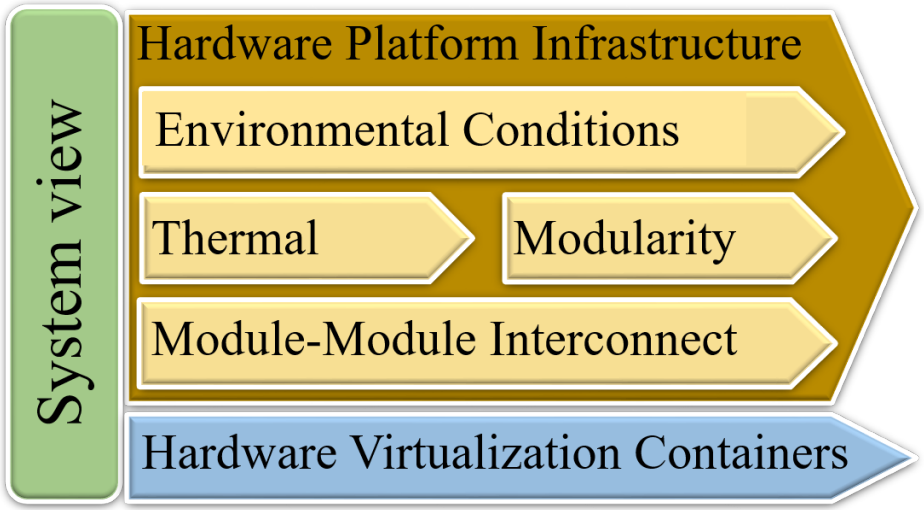


Figure: System view [1]

System View

Hardware Platform Infrastructure:

- **Environmental conditions**:
  - Internationally, there are different environmental safety and responsibility standards to which a fog architecture must comply.
  - Many applications, such as industrial, military, and commercial, have a higher range of operating temperatures.
  - With the increasing range of temperature, the fog nodes may fail to work properly.
  - It must be ensured that fog computing architectures operate well under such harsh operating conditions.
  - The fog nodes must work under any environmental condition.
- **Deployment**:
  - A fog node may be required for deployment over certain areas with high thermal effects.
  - In such high-temperature conditions, the fog nodes should not require any additional cooling systems, such as a fan.
  - During the deployment of a fog-based solution, the issue of thermal effects and other such possibilities must also be taken into account.

System View

Hardware Platform Infrastructure:

- **Modularity**: The fog architecture should be modular in such a way that the other required components can be, robustly and easily, configured with it.
- **Module–Module Interconnection**:
  - The interconnectivity among different modules is necessary for a fog computing architecture.
  - These interconnecting medium between any two modules can be wired.
  - This connecting medium is also referred to as its fabric.

Hardware Virtualization and Containers:

- Hardware virtualization is an essential component of a fog computing architecture.
- The concept of hardware virtualization enables physical hardware to be shared among multiple entities.
- The concept of containers enables isolation in fog computing architecture.

Software View

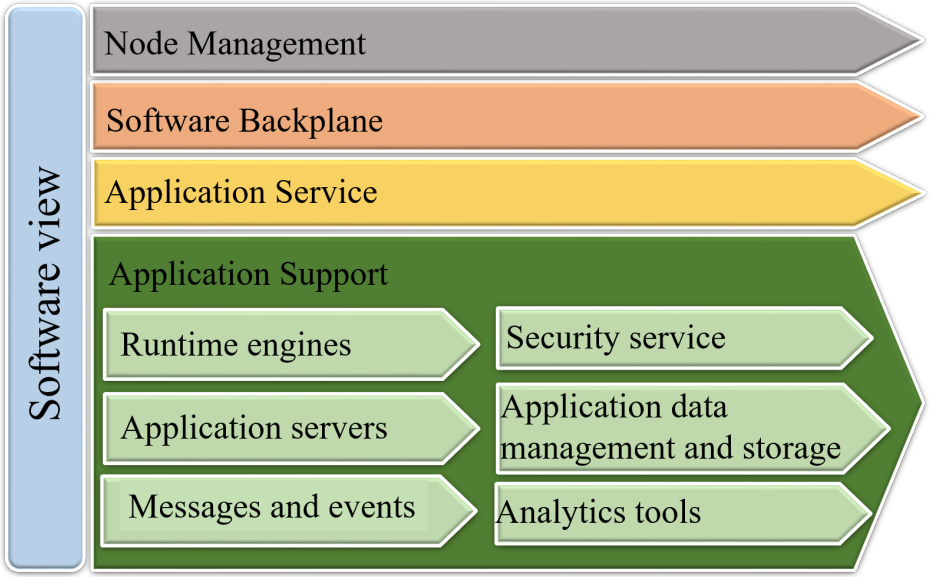


Figure: Software view [1]

Software View

- **Node Management**:
  - This layer is associated with the management of nodes and the connections among them.
  - The software and hardware are required to be managed properly so that they can provide the expected services.
  - The operating system and support configuration are managed with certain software.
  - For monitoring different components of a fog architecture, operational management, such as generating alarm, is crucial.
  - Node management also includes security related issues, such as key and identity management. Availability management is an essential component of node management.
  - Upon failure of a working piece of hardware, alternate hardware needs to be arranged.
  - Upon encountering major disruptions in software, the VMs must be regenerated.

Software View

- **Software backplane**:
  - This layer coordinates the communications among all the levels, such as between smart IoT devices to fog architecture, one fog architecture to another, and between fog and cloud architecture.
  - All the security-related aspects (such as confidentiality, integrity, and non-repudiation) should be taken care of by the software backplane.
  - Sometimes, multiple fog architectures are required for serving certain applications.
  - In such a situation, service discovery is essential to work cooperatively within the fog architecture.
  - A new fog node should broadcast its presence to the existing fog architecture so that the new fog node can participate in serving an application.
  - node discovery is a vital component of the software backplane.

Software View

- **Application services**:
  - The application services include fog connector service, core service, supporting service, analytics service, integration service, and user interface service.
  - In this layer, the fog connector service works above the protocol abstraction layer.
  - The key role of a fog connector is to convert the data received from smart devices into a common data structure and to transmit those to the core services.
  - Further, core services provide suitable data to the services.
  - The responsibilities of the supporting layer are data logging, scheduling, and service registration.
  - In fog computing, reactive and predictive capabilities are essential features. The analytics service is responsible for performing both reactive and predictive operations close to the edge.

Software View

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  - In fog computing, reactive and predictive capabilities are essential features. The analytics service is responsible for performing both reactive and predictive operations close to the edge.
  - The intergeneration services enable a fog node to retrieve data from another fog node with the correct format, place, and time.
  - The user interface (UI) is mostly useful for displaying the collected and merged data at the fog node.
  - Additionally, it displays the results, analytics, status, and operation in a fog node.

Software View

- **Application support**:
  - **Runtime engines**: These engines provide the execution environment for the services, which includes VMs, containers, platform, and program language libraries.
  - **Application servers**: These servers are responsible mainly for hosting the microservices.
  - **Messages and events**: These primarily support the messages and event-based applications.
  - **Security service**: This service looks after the security – intrusion detection and prevention, and packet inspection – of the applications.
  - **Application data management and storage**: This layer handles the data management and storage issues, including database and cache.
  - **Analytics tools and frameworks**: These layers take care of different analytical tools such as Hadoop.

Importance of fog computing

- Data generated from the smart IoT device are analyzed in the cloud.
- During the transmission of data from the smart IoT devices to the cloud, an additional delay is incurred in serving an application.
- In such a situation, the use of fog computing is pertinent.
- In a fog computing architecture, a large geographical application area can be divided logically into multiple subareas.
- A set of fog devices are responsible for serving these sub-areas.
- Therefore, in fog computing architecture, the data from the smart IoT devices are analyzed and processed in one of the fog devices in a particular sub-area, which may also be restricted geographically.
- As in this architecture, the data is analyzed near the edge, the latency of data transmission reduces as compared to the traditional cloud computing architecture.

Time sensitiveness in fog computing

- **Extremely time-sensitive data**:
  - These data are required to be analyzed within a fraction of a second, and the decision has to be made immediately in an application.
  - The nearest best possible fog nodes handle these data and after analyzing the data, the summary is transferred to the cloud.
- **Moderately time-sensitive data**:
  - These data are comparatively less time-sensitive than extremely time-sensitive data; they may need to be analyzed within a minute.
  - The aggregate fog analyze the moderately time-sensitive data through the nearest fog node of the smart IoT device.
  - A fog aggregate node takes the decision and acts on the smart IoT devices.
  - The summary of the data analysis, decisions, and actions are sent to the cloud for future reference.
- **Non-time-sensitive data**:
  - These data are not time-sensitive, and can wait for analysis for hours, weeks, and months.
  - The non-time-sensitive data are analyzed in the cloud itself.

Time sensitiveness in fog computing

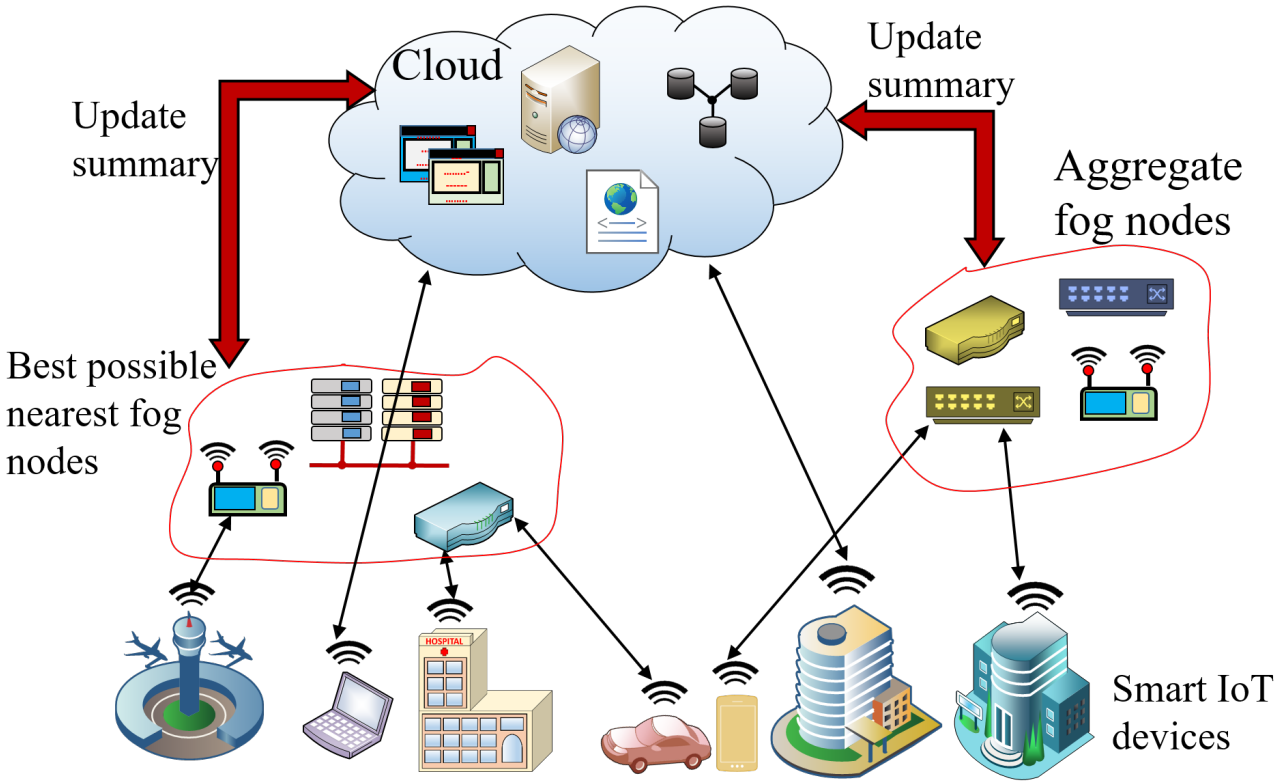

Figure: Time sensitiveness

Applications of fog computing

- Smart road transportation system (SRTS)
- Healthcare
- Mining industries
- Product advertisement

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