UNIT 11 FOG COMPUTING AND EDGE COMPUTING

11.1 INTRODUCTION

Use of emerging technologies like IoT, on-line applications and popularity of social networking are leading to an increasing number of users on the internet. Hence data getting generated on a daily basis is also increasing at an enormous rate leading to increasing workload on Cloud. Also, demand for increased bandwidth and need for real time applications or analytics is also increasing. Fog computing is a technology introduced to collaborate with cloud computing for providing solutions. It attempts to bring cloud-like resources – memory, storage, and compute near end users.

11.2 OBJECTIVES

After going through this unit, you should be able to:

- Know about Fog computing technology
- Know about the differences between fog and cloud computing
- Know about architecture, advantages, applications and challenges associated with fog
- Know about Edge computing
- Differentiate between Cloud, Fog and Edge computing
- Know about Applications of Edge computing

11.3 INTRODUCTION TO FOG COMPUTING

With increasing use of Internet of Things (IoT) devices and internet users, network traffic, storage and processing load is also increasing at an exponential rate. Cisco in 2020 estimated that by the end of 2023, 29.3 billion devices and 5.3 billion internet users will be there.

Cloud computing technology offers computation service over the internet on a pay-per-use basis. Resources offered by this technology like – storage, compute or network can be dynamically provisioned according to user's demand. This technology offers several advantages like – low cost, rapid provisioning, high computation power, flexible, automatic updates, no management or monitoring needed from user's side, etc. Enormous amounts of data generated by IoT devices and users can be stored and processed on cloud servers. But in addition to these benefits, there are several shortcomings associated with this technology – like increased response time due to distant location of servers and centralized architecture, security as resources are remotely stored and provided over insecure internet, demand of higher network bandwidth, increasing load on network due to further increasing users.

Cisco in 2014 introduced a term called 'Fog Computing' to a technology which extends computing to the edge of the network. The fog metaphor is used to represent a cloud close to the ground, similar to as fog concentrates on the edge of the network.

Fog computing is a technology in which resources like - compute, data, storage and applications are located in-between the end user layer (where data is generated) and the cloud. Devices like gateways, routers, base stations can be configured as fog devices. It can bring all the advantages offered by cloud computing closer to the location where data is generated; hence leading to reduced response time, reduced bandwidth requirements, enhanced security and other benefits.

OpenFog Consortium defined fog computing as "a horizontal system level architecture that distributes computing, storage, control and networking functions closer to the users along a cloud-to-thing continuum".

Fog computing is not introduced to replace cloud computing. Resources offered by Fog servers or devices are limited as compared to resources offered by huge cloud infrastructure. Hence the cloud computing model will continue to operate as a centralized computing system (needed for high processing power and storage) with few capabilities shifted towards fog devices which are present in the proximity of users for serving low latency operations.

Three layer logical architecture of fog computing is given in Fig 1. The first layer represents the end devices layer, middle layer represents the fog devices, and the top most layer represents the cloud servers.

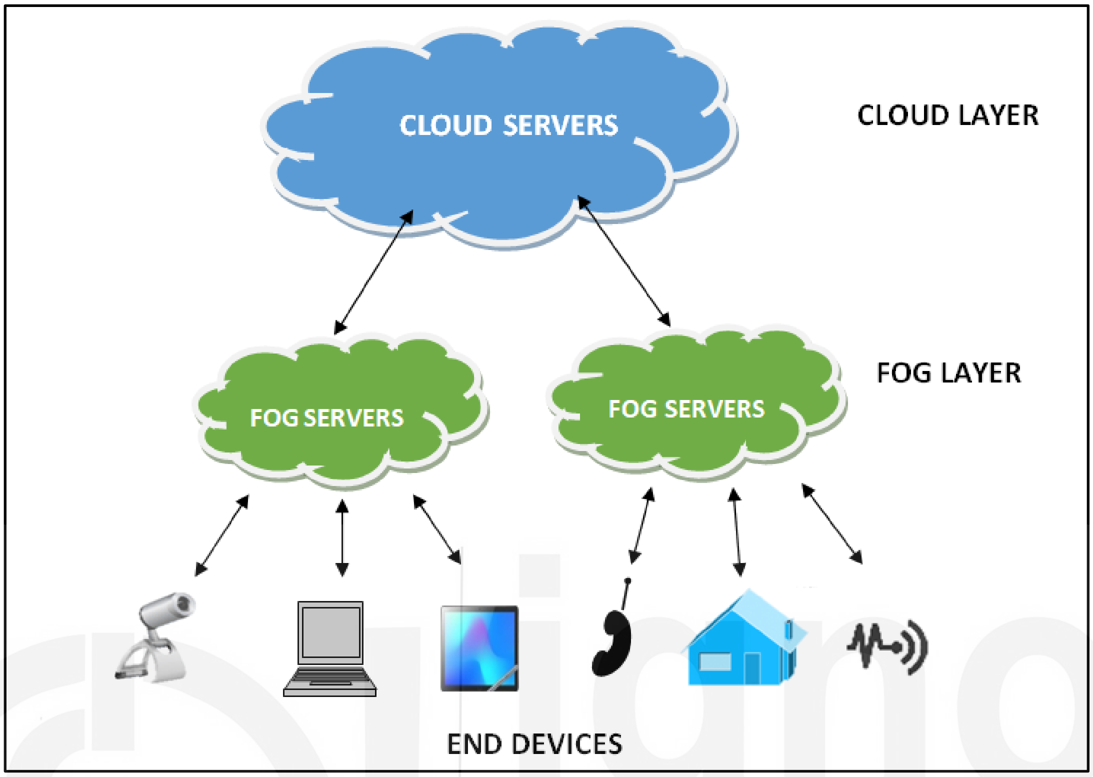

Fig 1. Logical Architecture of Fog computing

11.4 CLOUD COMPUTING Vs FOG COMPUTING

Cloud computing is defined as a model that allows ubiquitous access to shared resources on demand over the internet on a pay-per-use basis. Large pools of resources are maintained at data centers by the cloud service providers. Virtual resources from these pools are dynamically provisioned and allocated to users on demand. High performance can be achieved by using cloud resources but it may not be used for real time applications that demand higher response time due to the distant location of cloud servers.

Fog computing is introduced to fill up the gap between the cloud servers and end devices. Fog servers like cloud servers can offer various resources – compute, storage, or network. Due to its proximity to end users, it allows computations to be done faster or near real time. Hence it is better suited for latency sensitive applications. Since fog computing makes use of devices like- switches, routers, gateways; it is generally limited by resources and hence offers less computation power as compared to cloud.

Some of the differences between cloud computing and fog computing are given in Table 1.

Cloud Computing	Fog Computing

Architecture in centralized	Architecture is distributed
Distant location from the end users	In the proximity of end users
Huge amount of resources	Limited amount of resources
Higher computation capabilities	Lower computation capabilities
More response time	Less response time
Can be accessed over internet	Can be accessed by various protocols and standards
Less security	More security

Table 1: Differences between Cloud Computing and Fog Computing

11.5 FOG ARCHITECTURE

General architecture of fog computing is composed of three layers (as shown in Fig 1.)

1. **End Devices Layer -** Layer 1 is composed of end devices which can be mobile devices, IoT devices, computer systems, camera, etc. Data either captured or generated from these end devices is forwarded to a nearby fog server at Layer 2 for processing.

2. **Fog Layer -** Layer 2 is composed of multiple fog devices or servers. They are placed at the edge of a network, between layer 1 and cloud servers. They can be implemented in devices like – switches, routers, base stations, access points or can be specially configured fog servers.

3. **Cloud Layer -** Layer 3 is composed of Cloud data centers. They consist of huge infrastructure - high performance servers, massive storage devices, etc. They provide all cloud benefits like- high performance, automatic backup, agility.

Check Your Progress 1

1. What is Fog computing?
2. Explain differences between Cloud computing and Fog computing.
3. Explain architecture of Fog computing.

11.6 WORKING OF FOG

Adding fog layer in-between the centralized cloud layer and end devices layer, improves the overall performance of the system. Working of fog computing in collaboration with cloud computing is described below.

1. Huge amounts of data is generated from end devices and IoT devices like –mobile, camera, laptops, etc. This data is then forwarded to the nearest fog server (in layer 2) for processing.

2. Latency sensitive data or applications that require real time responses, are processed by the fog servers on priority basis. Results of processing or actions to be performed are then reverted back to the end devices. Fog servers also send the summarized results to cloud servers in layer 3 for future analysis. This allows only filtered data to be offloaded to the cloud layer.

3. Fog servers, if not able to serve requests due to unavailability of resources or information, can either interact with neighbouring servers or may forward the request cloud servers at Layer 3 depending upon the offloading strategy. Also, time in-sensitive data is generally forwarded to Cloud servers for processing and storage. After serving the task, response is given to users at layer 1 via. Fog servers.

11.7 ADVANTAGES OF FOG

There are various advantages of using fog computing technology due to its architecture-

1. **Low latency**
   Fog servers provide the benefit of faster response due to its geographical location i.e. they are located nearby from the point of data origination. It is suited for time sensitive or real-time applications.

2. **Reduce bandwidth requirements**
   Fog servers allow lower bandwidth consumption because data gets processed at nearby fog servers, hence avoiding huge amounts of data to be forwarded to distant cloud servers for processing.

3. **Reduced Cost**
   Most of the processing is done locally at the fog layer, leading to conservation of networking resources and hence reducing the overall cost of operations.

4. **Security and Privacy**

It also allows applications to be secure and private because data can be processed locally instead of forwarding to remote centralized cloud infrastructure.

5. **Mobility**
   Fog devices are mobile. They can be easily added or removed from the network and hence offers flexibility.

11.8 APPLICATIONS OF FOG

Fog computing since its introduction, is gaining popularity due to its applications in various industries. Some of the applications are –

Smart Cities

Cities that make use of technology to improve quality of life and services provided to people, can be called smart cities. Fog computing can play a vital role in building smart cities. With the help of smart devices, IoT devices and fog devices, it is possible to do tasks like – creating smart homes and buildings by energy management of buildings, maintaining security, etc; intelligent cities by building smart parking system, infrastructure, traffic management, environment monitoring, etc ; intelligent hospitals, highways, factories, etc.

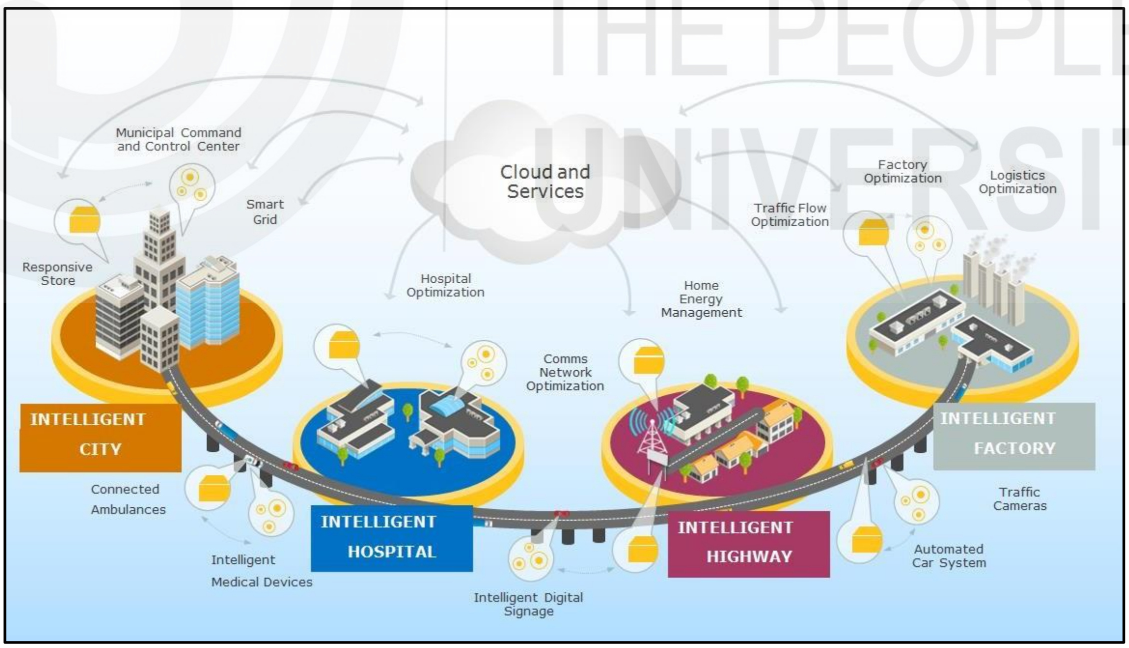

Fig 2: Smart Cities Scenario
Source: www.OpenFogConsortium.org

Smart Car and Traffic Control System

By making use of IoT devices and ubiquitous fog devices, vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communication is possible. Vehicles can communicate with internal, as well as external environments with the help of sensors. Sensors and actuators can also be attached with infrastructure along the roadside like – traffic light, street boards, gates, etc. Sensors can forward the data collected to fog devices, which may be either attached to the vehicle or present at a nearby location. Fog devices after computation can direct the vehicle or infrastructure to take action with the help of various controls (actuators). For example- by detecting vehicles coming from the wrong direction or pedestrians coming, a traffic light may signal red to avoid collisions, or other vehicles may automatically be directed to apply breaks.

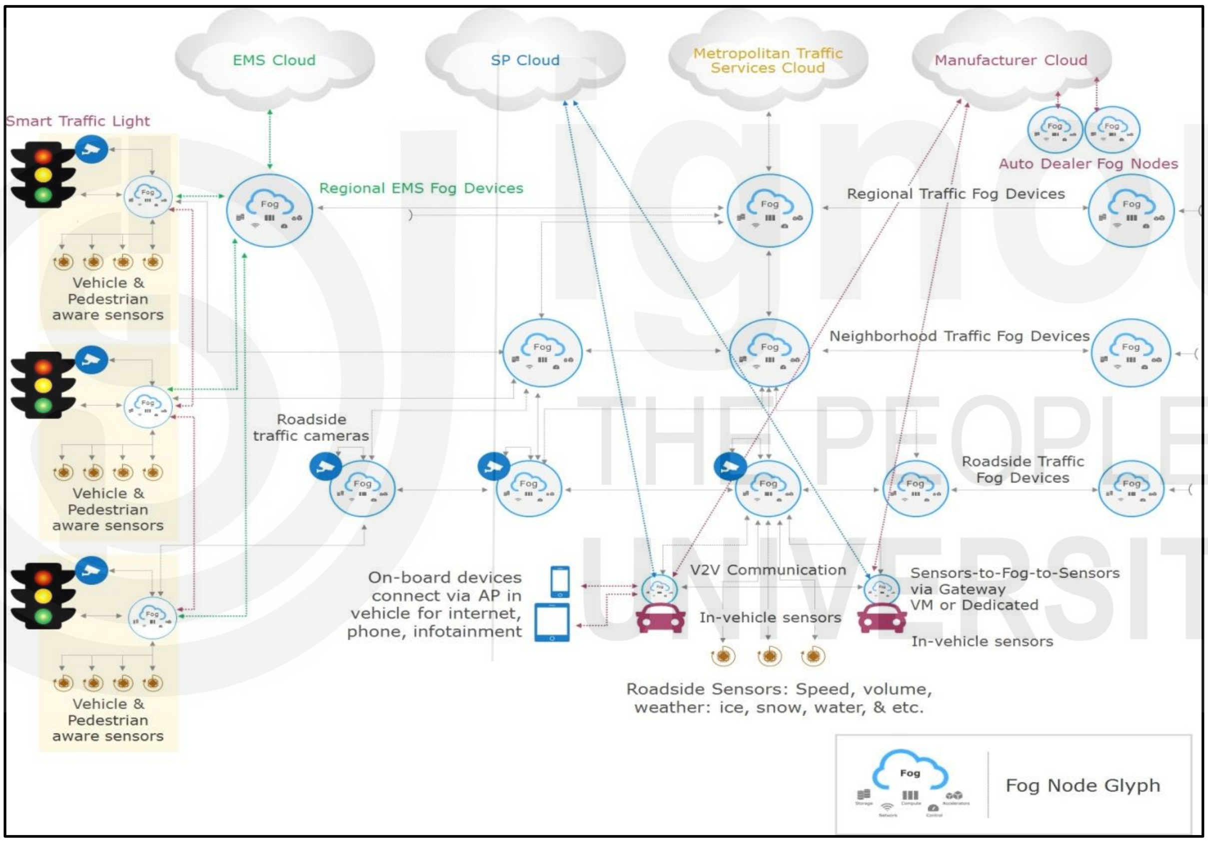

Fig 3: Smart car and Traffic control system scenario
Source: www.OpenFogConsortium.org

Smart Grids

Electrical grid is a network which delivers energy generated from various sources to consumers. The process of efficient distribution of energy is possible by making use of fog computing. IoT sensors can monitor energy generated from various sources – like wind energy farms, thermal plants, hydraulic plants, etc. This data is then passed on to the nearby fog server to identify the optimal source of energy to be used and can also identify problems like equipment malfunctions. Depending upon the problems it may also identify alternative sources of energy to be used in order to maintain efficiency.

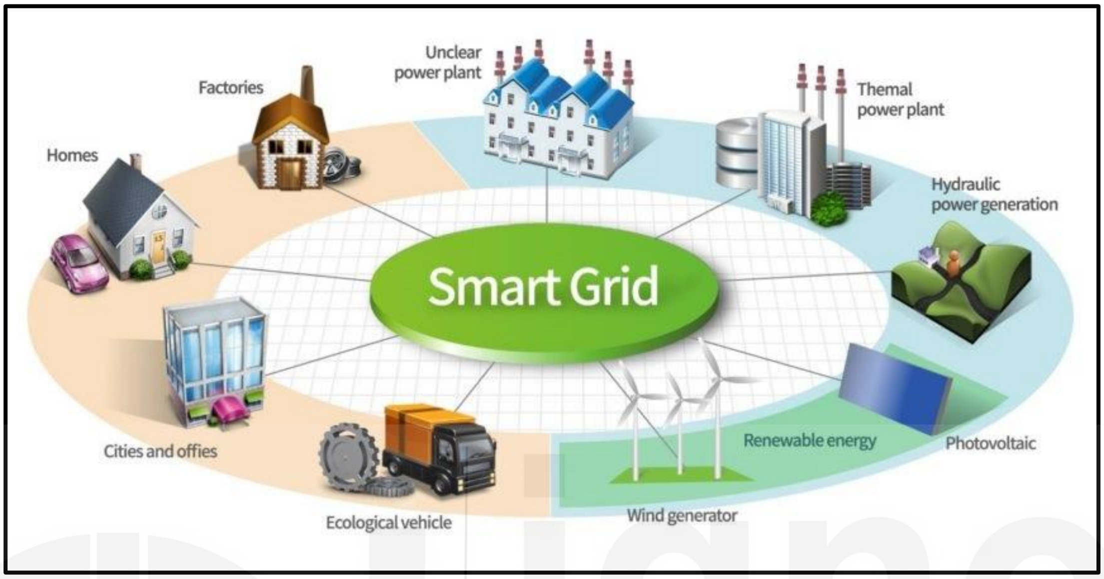

Fig 4: Smart Grid

Smart Healthcare Systems

Fog computing has applications in the healthcare system also. Health reports of patients can be recorded using different types of sensors and forwarded to fog devices. Fog devices after performing analysis examples - diagnose cardiac diseases, etc can take necessary actions.

Surveillance

Security and Surveillance cameras are deployed in many areas. It is difficult to send massive amounts of data collected by these cameras to cloud servers due to bandwidth constraints. Hence data collected from these can be forwarded to nearby fog servers. Fog servers in turn can perform video processing to find out problems like theft, kidnapping, murders, finding missing people. Necessary action can then be taken by generating alerts or reporting to police stations.

11.9 CHALLENGES IN FOG

Fog computing offers several advantages, but there are several challenges associated with it. Some of them are –

1. **Complexity**

   Fog devices can be diverse in architecture and located at different locations. Fog devices further store and analyse their own data hence add more complexity to the network.

2. **Power Consumption**

Fog devices require high power consumption for proper functioning. Adding more fog devices increases energy consumption, which results in an increase of cost.

3. **Data Management**

   Data is distributed across multiple fog devices hence data management and maintaining consistency is challenging.

4. **Authentication**

   Establishing trust and authentication may raise issues.

5. **Security**

   Since there are many fog devices, each with a different IP. Getting access to personal data by spoofing, taping, and hacking can be a challenge.

Check Your Progress 2

1. Explain advantages and challenges associated with fog computing.
2. What are the various application areas of fog computing.

11.10 EDGE COMPUTING

Edge computing is a technology which offers data processing on the same layer where data is generated by making use of edge devices having computation capabilities. This allows data to be processed even faster than processing at fog devices at no or a very low cost. This also increases utilization of edge devices.

Edge or end devices found today are smarter with various advanced features like artificial intelligence enabled in them. Edge computing takes advantage of this intelligence to reduce load on network or cloud servers. Also edge devices when used for computation offers hardware security along with low power consumption. It can improve security by encrypting data closer to the network core.

Edge computing is often seen as similar to fog computing but there are several differences. Edge computing devices are limited in their resource capabilities and therefore cannot replace existing Cloud or Fog computing technology. But edge computing when added with these technologies can offer numerous advantages and applications. Fig 5 shows the Cloud-Fog-Edge collaboration scenario.

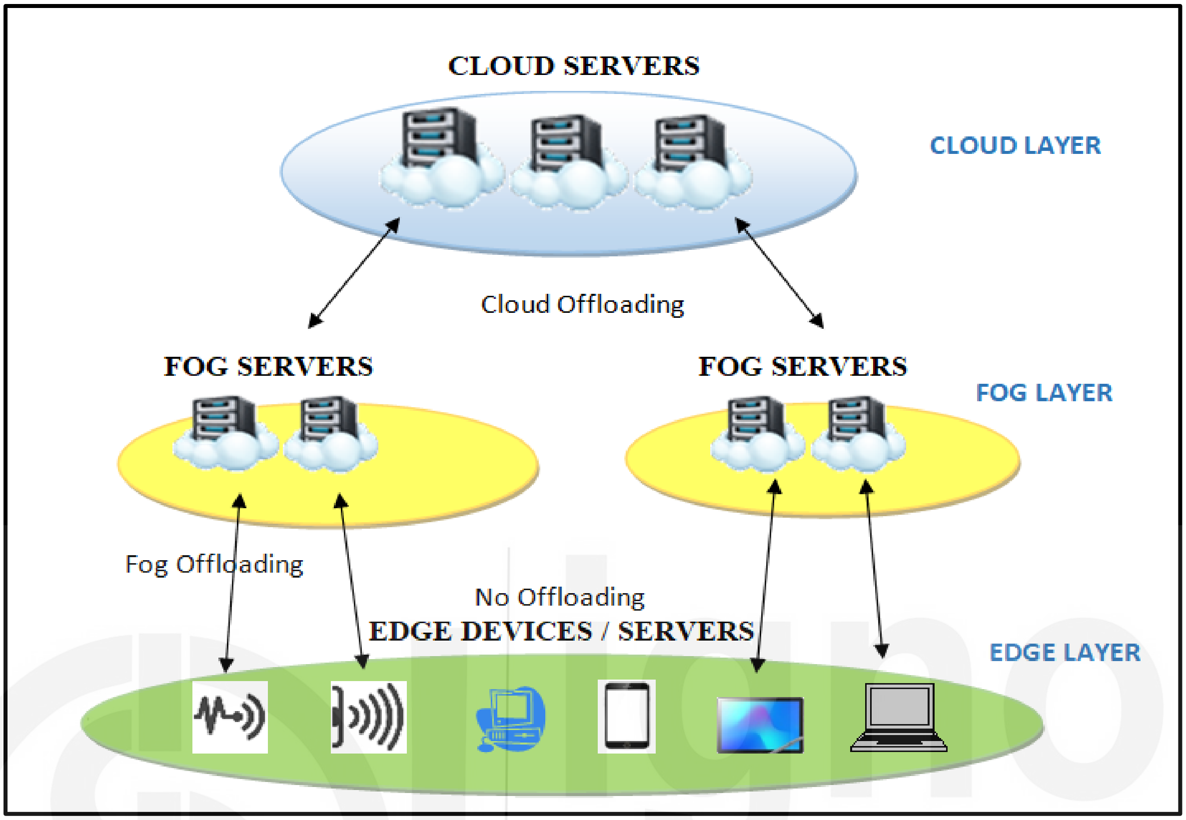

Fig 5: Cloud – Fog – Edge Computing architecture

11.11 WORKING OF EDGE COMPUTING

Edge computing allows data processing to be done at the network edge. This can offer several advantages like – decreases latency, reduces data to be offloaded to cloud or fog, reduces cost of bandwidth, reduces energy consumption, etc.

Edge computing can work in collaboration with cloud computing only or can be either implemented with Cloud –Fog collaboration environment.

Instead of sending all the data directly to the cloud or fog layer from the edge devices, data is first processed at the edge layer. Processing data at the edge layer gives near real time response due to physical proximity of edge devices. As data generated at the edge layer is huge, it cannot be handled entirely at the edge layer. Hence it is offloaded to the Cloud or Fog layer. In Cloud-Fog-Edge collaboration scenario, data from edge layer is first offloaded to fog servers over a localized network, which in turn can offload it to cloud servers for updates or further processing needs. In Cloud-Edge scenarios, data after processing on the edge layer, can be offloaded to the cloud layer as resources available at the edge layer are insufficient to handle large amounts of data. Here the edge layer can decide what is relevant and what is not before sending to further layers, hence reducing load on cloud and fog servers.

11.12 CLOUD Vs FOG Vs EDGE COMPUTING

Cloud, fog and edge computing all are concepts of distributed computing. All of them perform computation but at different proximity levels and with different resource capacities. Adding Edge and fog layer to the cloud reduces the amount of storage needed at cloud. It allows data to be transferred at a faster data rate because of transferring relevant data. Also the cloud would store and process only relevant data resulting in cost reduction.

Edge computing devices are located at the closest proximity to users. Fog computing devices are located at intermediate proximity. Cloud computing devices are at distant and remote locations from users. Fog computing generally makes use of a centralized system which interacts with gateways and computer systems on LAN. Edge computing makes use of embedded systems directly interfacing with sensors and controllers. But this distinction does not always exist. Some of the common differences between Cloud, Fog and Edge computing are shown in Table 2.

Cloud Computing	Fog Computing	Edge Computing
Centralized approach	Distributed approach	Distributed approach
Large amount of resources	Intermediate amount of resources	Limited resources
High latency	Medium latency	Low latency
Low data rate	Medium data rate	High data rate
Globally distributed	Regionally distributed	Locally distributed
Non-real time response	Near real time response	Real time response
Can be accessed with internet	Can be accessed with internet or without internet	Can be accessed without internet

Table 2: Differences between Cloud, Fog and Edge Computing

11.13 APPLICATION OF EDGE COMPUTING

Edge computing has applications similar to fog computing due to its close proximity. Some of the applications are listed below.

1. Gaming

Gamings which require live streaming feed of the game depends upon latency. In this, edge servers are placed closed to the gamers to reduce latency.

2. Content Delivery
   It allows caching of data like- web pages, videos near users in order to improve performance by delivering content fastly.

3. Smart Homes
   IoT devices can collect data from around the house and process it. Response generated is secure and in real time as round-trip time is reduced. For example –response generated by Amazon's Alexa.

4. Patient monitoring
   Edge devices present on the hospital site can process data generated from various monitoring devices like- temperature sensors, glucose monitors etc. Notifications can be generated to depict unusual trends and behaviours.

5. Manufacturing
   Data collected in manufacturing industries through sensors can be processed in edge devices. Edge devices here can apply real time analytics and machine learning techniques for reporting production errors to improve quality.

Check Your Progress 3

1. What is Edge computing.
2. Explain differences between cloud, fog and edge computing.
3. State some of the applications of edge computing.

11.14 SUMMARY

In this unit two emerging technologies – Fog computing and Edge computing are discussed. Cisco introduced Fog Computing as a technology which extends computing to the edge of the network. In this technology, resources like - compute, data, storage and applications are located in-between the end user layer and the cloud. It reduces response time, reduces bandwidth requirements and enhances security. Edge computing is a technology which offers data processing on the same layer where data is generated by making use of edge devices having computation capabilities. These technologies cannot replace cloud computing but can work in collaboration with cloud computing in order to improve performance.

Solutions to Check your progress 1

1. Cisco in 2014 introduced a term called 'Fog Computing' to a technology which extends computing to the edge of the network. Fog computing is a technology in which resources like -

compute, data, storage and applications are located in-between the end user layer (where data is generated) and the cloud. Devices like gateways, routers, base stations can be configured as fog devices. It can bring all the advantages offered by cloud computing closer to the location where data is generated; hence leading to reduced response time, reduced bandwidth requirements, enhanced security and other benefits.

2. Some of the differences between cloud computing and fog computing are :-

Cloud Computing	Fog Computing
Architecture in centralized	Architecture is distributed
Distant location from the end users	In the proximity of end users
Huge amount of resources	Limited amount of resources
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More response time	Less response time
Less security	More security

3. Architecture of fog computing is composed of three layers :-

   1. End Devices Layer – It is composed of end devices which can be mobile devices, IoT devices, computer systems, camera, etc. Data either captured or generated from these end devices is forwarded to a nearby fog server at Layer 2 for processing.

   2. Fog Layer – It is composed of multiple fog devices or servers. They are placed at the edge of a network, between layer 1 and cloud servers. They can be implemented in devices like – switches, routers, base stations, access points or can be specially configured fog servers.

   3. Cloud Layer – It is composed of Cloud data centers. They consist of huge infrastructure - high performance servers, massive storage devices, etc. They provide all cloud benefits like- high performance, automatic backup, agility.

Solutions to Check your progress 2

1. Various advantages associated with fog computing are –
   a) Low latency
   b) Reduced bandwidth
   c) Reduced cost
   d) Mobility

Various challenges associated with fog are –

a) Complexity
b) Maintaining security
c) Authenticating
d) Additional power consumption

2. Various application areas of fog computing are –

   a) Smart Cities
   Fog computing can play a vital role in building smart cities. With the help of smart devices, IoT devices and fog devices, it is possible to do tasks like – creating smart homes and buildings by energy management of buildings, maintaining security, etc.

   b) Smart Car and Traffic Control System
   By making use of IoT devices and ubiquitous fog devices, vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communication is possible. Fog devices after computation can direct the vehicle or infrastructure to take action with the help of various controls (actuators).

   c) Surveillance
   Security and Surveillance cameras are deployed in many areas. Data collected from these can be forwarded to nearby fog servers. Fog servers in turn can perform video processing to find out problems like theft, kidnapping, murders, etc.

Solutions to Check your progress 3

1. Edge computing is a technology which offers data processing on the same layer where data is generated by making use of edge devices having computation capabilities. This allows data to be processed even faster than processing at fog devices at no or a very low cost. This also increases utilization of edge devices.

2. Various differences between cloud, fog and edge computing are –

Cloud Computing	Fog Computing	Edge Computing
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3. Some applications of edge computing are -

   a) Gaming
      Gamings which require live streaming feed of the game depends upon latency. In this, edge servers are placed closed to the gamers to reduce latency.
   b) Content Delivery
      It allows caching of data like- web pages, videos near users in order to improve performance by delivering content fastly.
   c) Smart Homes
      IoT devices can collect data from around the house and process it. Response generated is secure and in real time as round-trip time is reduced. For example –response generated by Amazon's Alexa.