1.5 IoT Levels & Deployment Templates

In this section we define various levels of IoT systems with increasing completely. An IoT system comprises of the following components:

- **Device:** An IoT device allows identification, remote sensing, actuating and remote monitoring capabilities. You learned about various examples of IoT devices in section 1.2.1.
- **Resource:** Resources are software components on the IoT device for accessing, processing, and storing sensor information, or controlling actuators connected to the device. Resources also include the software components that enable network access for the device.
- **Controller Service:** Controller service is a native service that runs on the device and interacts with the web services. Controller service sends data from the device to the web service and receives commands from the application (via web services) for controlling the device.
- **Database:** Database can be either local or in the cloud and stores the data generated by the IoT device.
- **Web Service:** Web services serve as a link between the IoT device, application, database and analysis components. Web service can be either implemented using HTTP and REST principles (REST service) or using WebSocket protocol (WebSocket service). A comparison of REST and WebSocket is provided below:

- **Stateless/Stateful:** REST services are stateless in nature. Each request contains all the information needed to process it. Requests are independent of each other. WebSocket on the other hand is stateful in nature where the server maintains the state and is aware of all the open connections.
- **Uni-directional/Bi-directional:** REST services operate over HTTP and are uni-directional. Request is always sent by a client and the server responds to the requests. On the other hand, WebSocket is a bi-directional protocol and allows both client and server to send messages to each other.
- **Request-Response/Full Duplex:** REST services follow a request-response communication model where the client sends requests and the server responds to the requests. WebSocket on the other hand allow full-duplex communication between the client and server, i.e., both client and server can send messages to each other independently.
- **TCP Connections:** For REST services, each HTTP request involves setting up a new TCP connection. WebSocket on the other hand involves a single TCP connection over which the client and server communicate in a full-duplex mode.
- **Header Overhead:** REST services operate over HTTP, and each request is independent of others. Thus each request carries HTTP headers which is an overhead. Due the overhead of HTTP headers, REST is not suitable for real-time applications. WebSocket on the other hand does not involve overhead of headers. After the initial handshake (that happens over HTTP), the client and server exchange messages with minimal frame information. Thus WebSocket is suitable for real-time applications.
- **Scalability:** Scalability is easier in the case of REST services as requests are independent and no state information needs to be maintained by the server. Thus both horizontal (scaling-out) and vertical scaling (scaling-up) solutions are possible for REST services. For WebSockets, horizontal scaling can be cumbersome due to the stateful nature of the communication. Since the server maintains the state of a connection, vertical scaling is easier for WebSockets than horizontal scaling.

• **Analysis Component:** The Analysis Component is responsible for analyzing the IoT data and generate results in a form which are easy for the user to understand. Analysis of IoT data can be performed either locally or in the cloud. Analyzed results are stored in the local or cloud databases.

• **Application:** IoT applications provide an interface that the users can use to control and monitor various aspects of the IoT system. Applications also allow users to view the system status and view the processed data.

1.5.1 IoT Level-1

A level-1 IoT system has a single node/device that performs sensing and/or actuation, stores data, performs analysis and hosts the application as shown in Figure 1.14. Level-1 IoT systems are suitable for modeling low-cost and low-complexity solutions where the data involved is not big and the analysis requirements are not computationally intensive.

Let us now consider an example of a level-1 IoT system for home automation. The system consists of a single node that allows controlling the lights and appliances in a home remotely. The device used in this system interfaces with the lights and appliances using electronic relay switches. The status information of each light or appliance is maintained in a local database. REST services deployed locally allow retrieving and updating the state of each light or appliance in the status database. The controller service continuously monitors the state of each light or appliance (by retrieving state from the database) and triggers the relay switches accordingly. The application which is deployed locally has a user interface for controlling the lights or appliances. Since the device is connected to the Internet, the application can be accessed remotely as well.

1.5.2 IoT Level-2

A level-2 IoT system has a single node that performs sensing and/or actuation and local analysis as shown in Figure 1.15. Data is stored in the cloud and application is usually cloud-based. Level-2 IoT systems are suitable for solutions where the data involved is big, however, the primary analysis requirement is not computationally intensive and can be done locally itself.

Let us consider an example of a level-2 IoT system for smart irrigation. The system consists of a single node that monitors the soil moisture level and controls the irrigation system. The device used in this system collects soil moisture data from sensors. The controller service continuously monitors the moisture levels. If the moisture level drops below a threshold, the irrigation system is turned on. For controlling the irrigation system actuators such as solenoid valves can be used. The controller also sends the moisture data to the computing cloud. A cloud-based REST web service is used for storing and retrieving moisture data which is stored in the cloud database. A cloud-based application is used for visualizing the moisture levels over a period of time, which can help in making decisions about irrigation schedules.

1.5.3 IoT Level-3

A level-3 IoT system has a single node. Data is stored and analyzed in the cloud and application is cloud-based as shown in Figure 1.16. Level-3 IoT systems are suitable for

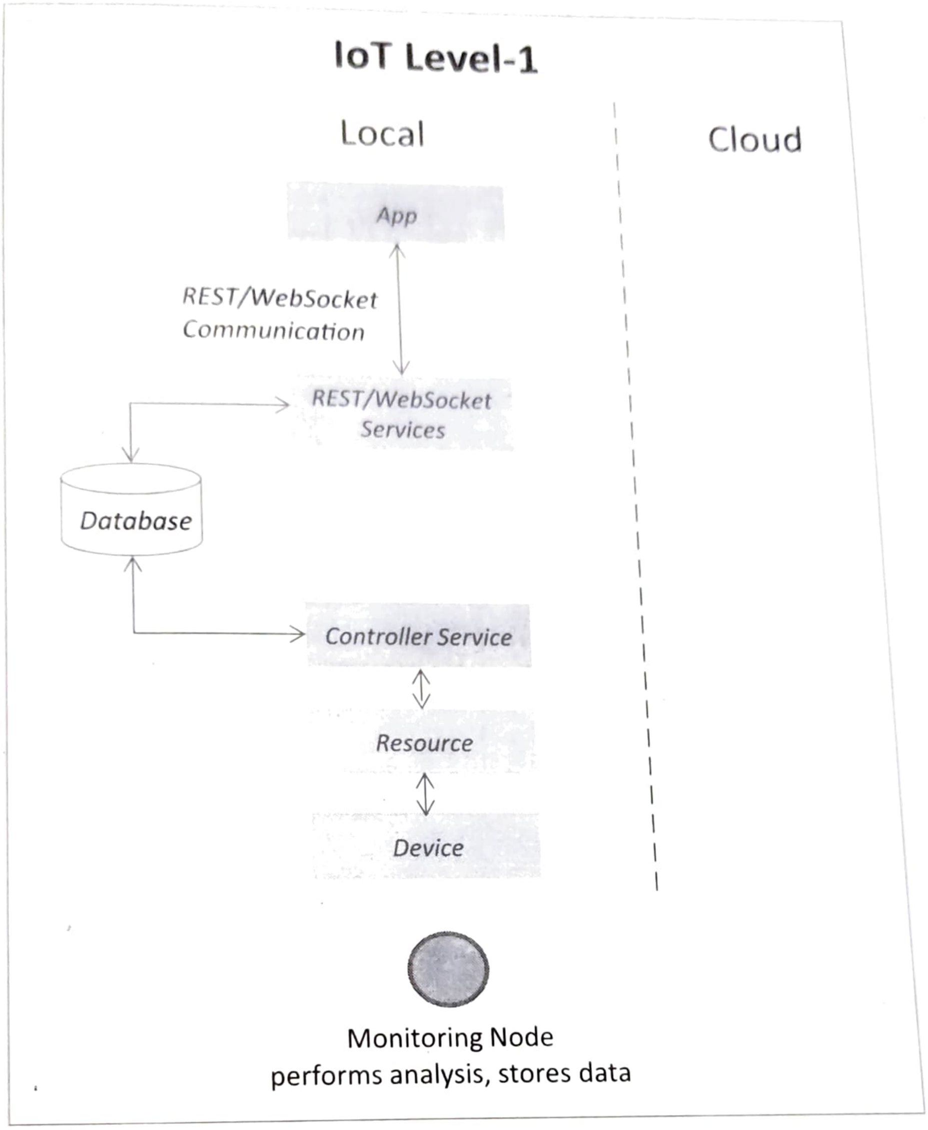

Figure 1.14: IoT Level-1

solutions where the data involved is big and the analysis requirements are computationally intensive.

Let us consider an example of a level-2 IoT system for tracking package handling. The system consists of a single node (for a package) that monitors the vibration levels for a package being shipped. The device in this system uses accelerometer and gyroscope sensors for monitoring vibration levels. The controller service sends the sensor data to the cloud in real-time using a WebSocket service. The data is stored in the cloud and also visualized using a cloud-based application. The analysis components in the cloud can trigger alerts if

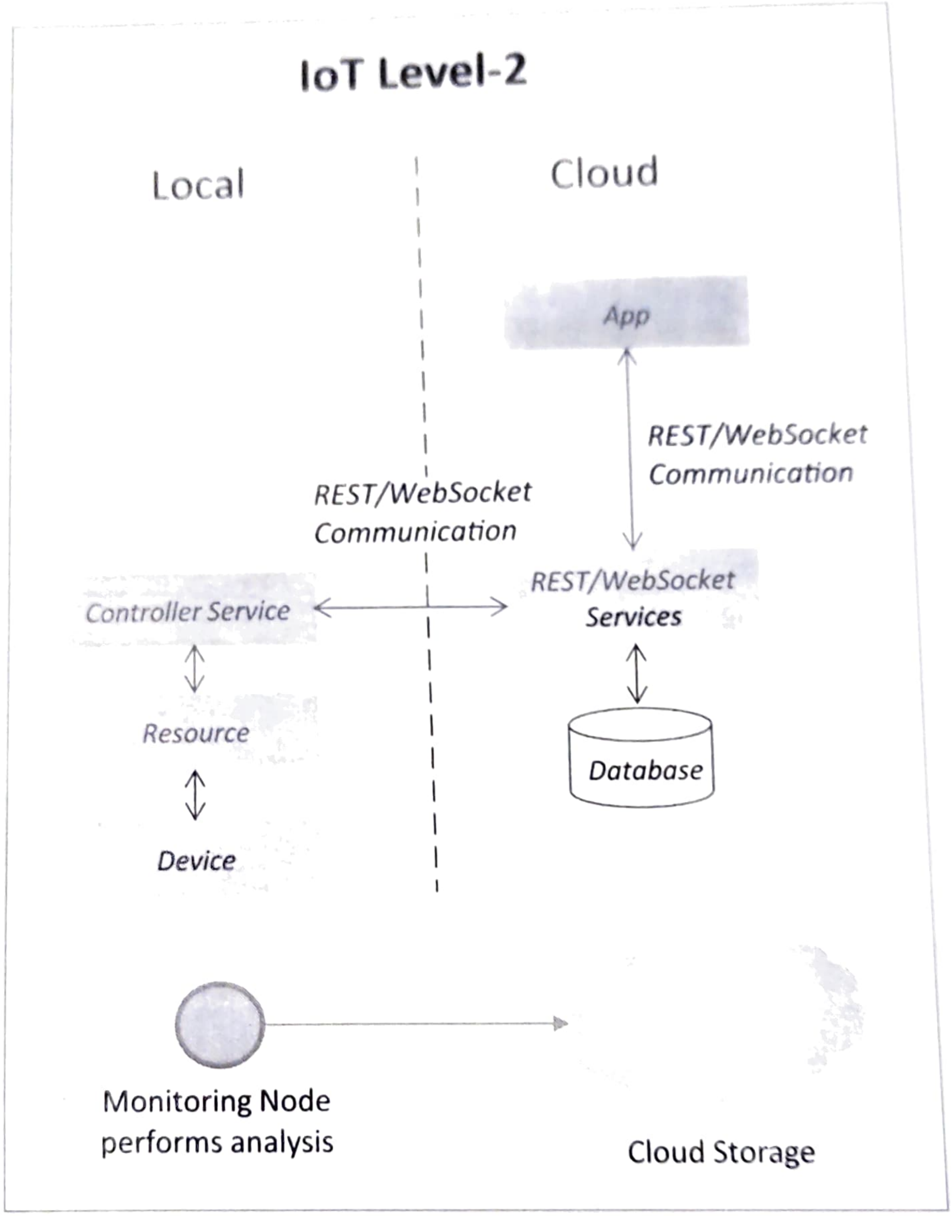

Figure 1.15: IoT Level-2

the vibration levels become greater than a threshold. The benefit of using WebSocket service instead of REST service in this example is that, the sensor data can be sent in real time to the cloud. Moreover, cloud based applications can subscribe to the sensor data feeds for viewing the real-time data.

1.5.4 IoT Level-4

A level-4 IoT system has multiple nodes that perform local analysis. Data is stored in the cloud and application is cloud-based as shown in Figure 1.17. Level-4 contains local and

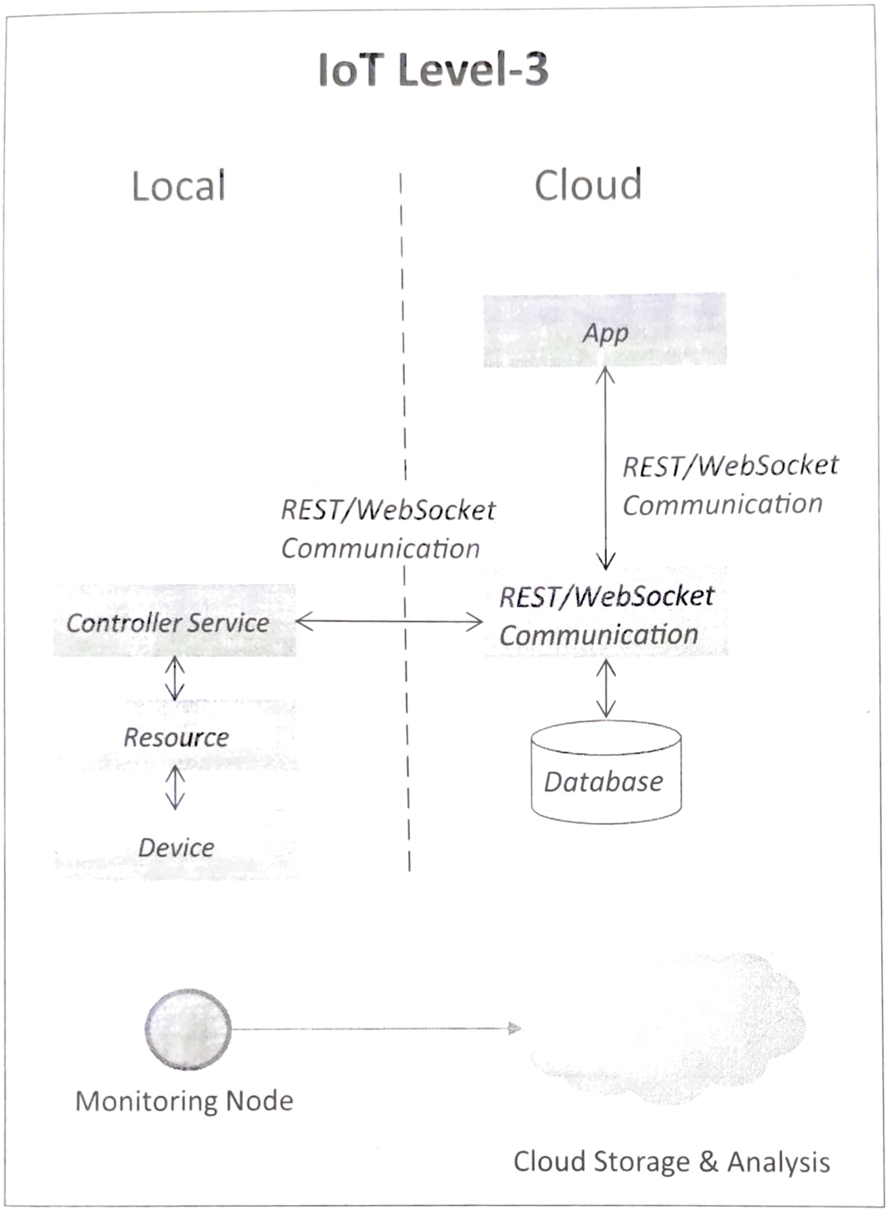

Figure 1.16: IoT Level-3

cloud-based observer nodes which can subscribe to and receive information collected in the cloud from IoT devices. Observer nodes can process information and use it for various applications, however, observer nodes do not perform any control functions. Level-4 IoT systems are suitable for solutions where multiple nodes are required, the data involved is big and the analysis requirements are computationally intensive.

Let us consider an example of a level-4 IoT system for noise monitoring. The system consists of multiple nodes placed in different locations for monitoring noise levels in an area.

The nodes in this example are equipped with sound sensors. Nodes are independent of each other. Each node runs its own controller service that sends the data to the cloud. The data is stored in a cloud database. The analysis of data collected from a number of nodes is done in the cloud. A cloud-based application is used for visualizing the aggregated data.

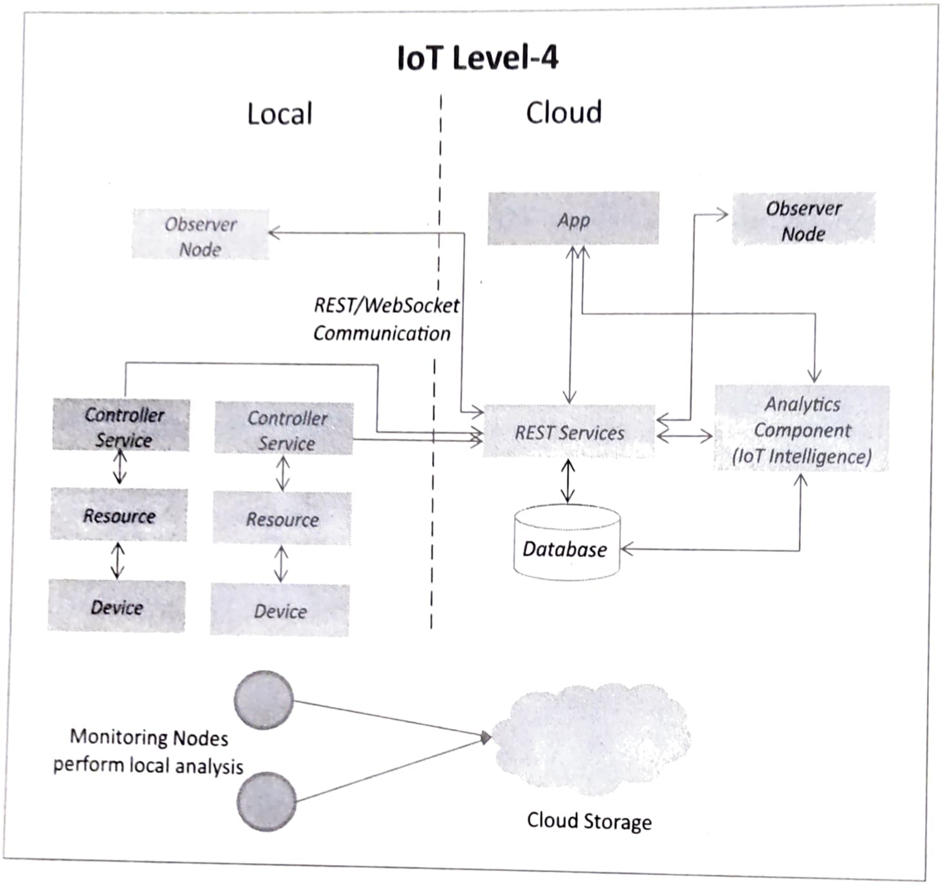

Figure 1.17: IoT Level-4

1.5.5 IoT Level-5

A level-5 IoT system has multiple end nodes and one coordinator node as shown in Figure 1.18. The end nodes that perform sensing and/or actuation, Coordinator node collects data from the end nodes and sends to the cloud. Data is stored and analyzed in the cloud and application is cloud-based. Level-5 IoT systems are suitable for solutions based on wireless sensor networks, in which the data involved is big and the analysis requirements are computationally intensive.

Let us consider an example of a level-5 IoT system for forest fire detection. The system consists of multiple nodes placed in different locations for monitoring temperature, humidity and carbon dioxide (CO_2) levels in a forest. The end nodes in this example are equipped with various sensors (such as temperature, humidity and CO_2). The coordinator node collects the data from the end nodes and acts as a gateway that provides Internet connectivity to the IoT system. The controller service on the coordinator device sends the collected data to the cloud. The data is stored in a cloud database. The analysis of data is done in the computing cloud to aggregate the data and make predictions. A cloud-based application is used for visualizing the data.

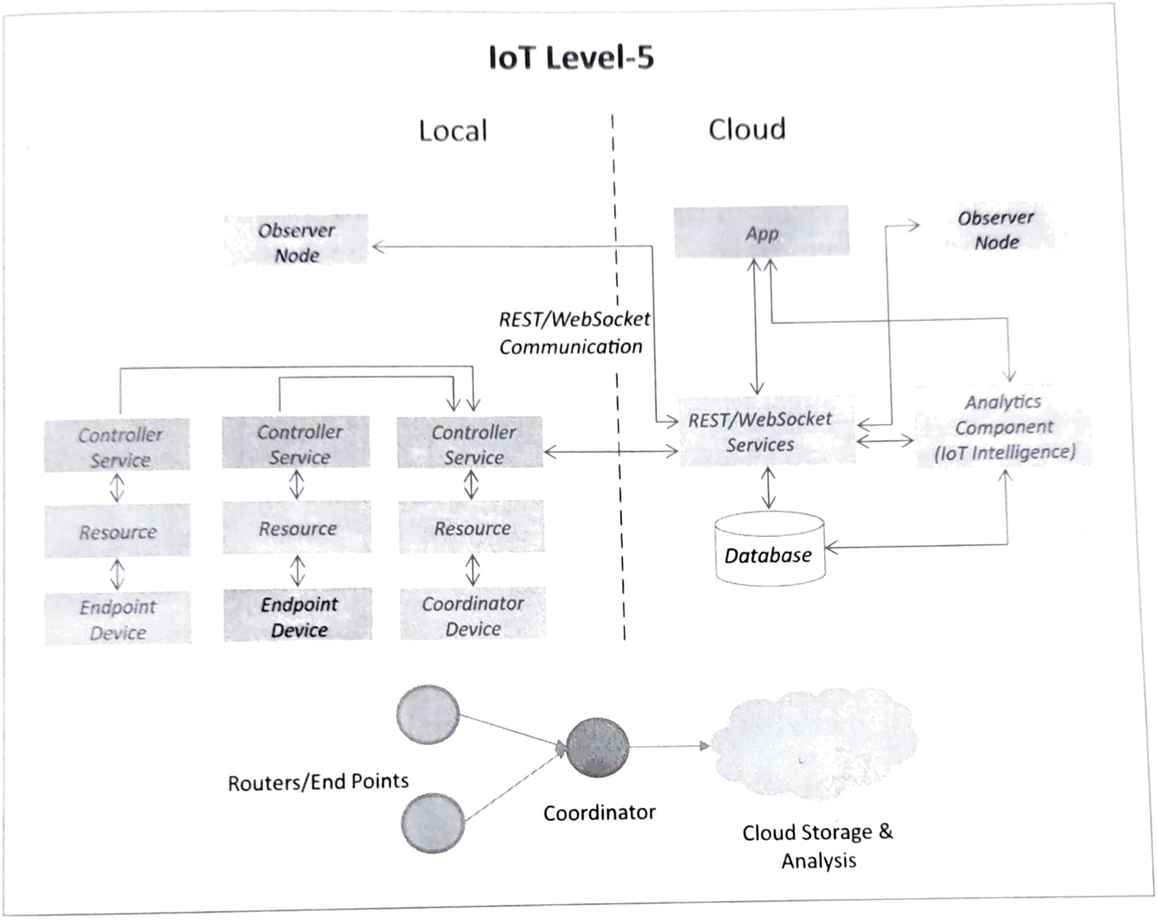

Figure 1.18: IoT Level-5

1.5.6 IoT Level-6

A level-6 IoT system has multiple independent end nodes that perform sensing and/or actuation and send data to the cloud. Data is stored in the cloud and application is cloud-based as shown in Figure 1.19. The analytics component analyzes the data and stores the results in the cloud database. The results are visualized with the cloud-based application. The centralized controller is aware of the status of all the end nodes and sends control commands to the nodes.

Let us consider an example of a level-6 IoT system for weather monitoring. The system consists of multiple nodes placed in different locations for monitoring temperature, humidity and pressure in an area. The end nodes are equipped with various sensors (such as temperature, pressure and humidity). The end nodes send the data to the cloud in real-time using a WebSocket service. The data is stored in a cloud database. The analysis of data is done in the cloud to aggregate the data and make predictions. A cloud-based application is used for visualizing the data.

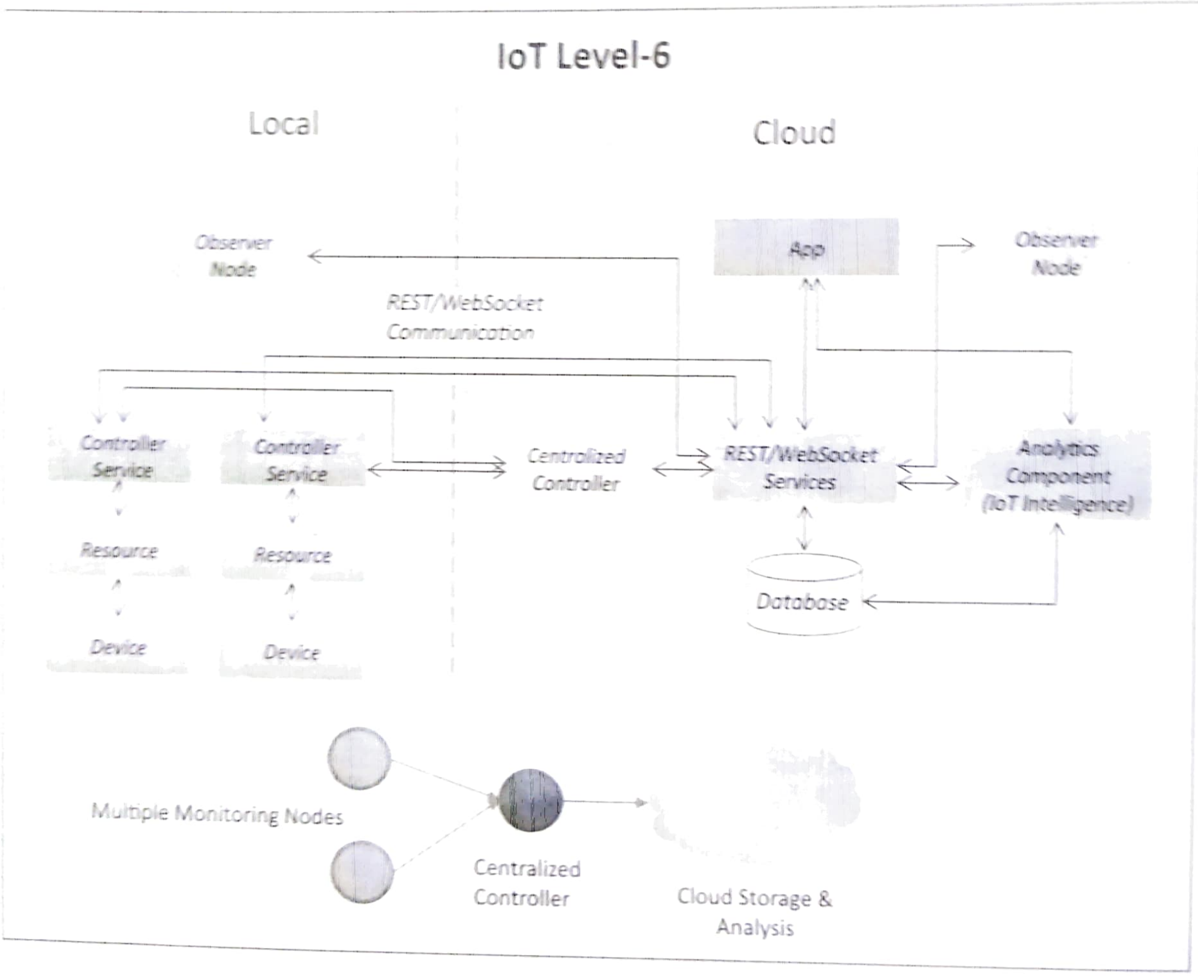

Figure 1.19: IoT Level-6

Summary

Internet of Things (IoT) refers to physical and virtual objects that have unique identities and are connected to the Internet. This allows the development of intelligent applications that make energy, logistics, industrial control, retail, agriculture and many other domains of