

IoT Enabling Technologies and their Applications

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Abstract: The IoT represents a continuously developing technological ecosystem in which physical devices, sensors, and systems are connected to the Internet for intelligent data exchange and decision-making automation. The IoT is enabled by wireless communication protocols of several types, including Wi-Fi, Bluetooth, Zigbee, and LoRaWAN, as well as sensor networks, cloud computing, edge and fog computing, embedded systems, and data analytics. These integrated technologies collect, process, and transmit real-time information that comes from distributed environments. Such advanced technologies as AI, machine learning, RFID, and cybersecurity frameworks further fortify IoT in terms of improving automation, increasing accuracy, and ensuring secure device-device communication. IoT applications span across many domains related to smart homes, healthcare monitoring, agriculture automation, industrial IoT, transportation systems, and environmental monitoring. It presents intelligent traffic management, waste monitoring, and energy-efficient infrastructure facilities for smart cities. Remote patient monitoring and real-time diagnostics are prominent aspects of IoT in the field of health care, while for agriculture, it enhances irrigation, tracking of crops, and livestock management. Similarly, industrial domains use this technology to predict maintenance, optimize processes, and increase operational efficiencies. In summary, IoT enabling technologies are revolutionizing conventional systems into intelligent and connected environments. Their various applications pave the way for smarter, more efficient, and sustainable solutions, thereby raising innovation across industries and ultimately improving the quality of life.



INTRODUCTION

The IoT has emerged as one of the most transformer technologies in the modern digital era, enabling the smooth integration and connectivity of physical devices and computing systems with the internet. IoT combines smart sensors and actuators, communication protocols, and intelligent software for data collection and transmission, thereby permitting the operation of machines and environments autonomously and more efficiently. As billions of devices become interconnected, the foundation of IoT provides for the creation of intelligent systems offering real-time monitoring, control, and decision-making. The enabling technologies for the growth of IoT include advanced wireless networks, embedded systems, cloud and edge computing, RFID, and data analytic.

These ensure reliable communication, efficient data processing, and secure device management. Supported by artificial intelligence and machine learning, IoT systems can analyze patterns, predict events, and optimize performance across different domains. IoT applications are starting to span different sectors, such as healthcare, agriculture, smart homes, transportation, and industrial automation. In addition, IoT is making its mark: from wearable in health applications to smart irrigation and predictive maintenance in industries. IoT will continue to grow and will become imperative for construction of smarter, safer, more sustainable environments for the future.

IoT ARCHITECTURAL LAYER

Architecture-wise, the IoT follows a 4-layer architecture that structures how devices sense, communicate, process, and deliver intelligent services. Each of these layers has specific technologies, functions, and responsibilities which, in coordination, create smart IoT systems.



1. Perception Layer (Sensing Layer)



It is the foundational layer in IoT responsible for interacting with the physical world.

Key Functions:

- Detects physical or environmental changes such as temperature, pressure, sound, light, and gas.
- Converts analog signals into digital data.
- Performs basic filtering, local storage, and low-level processing.
- Controls actuators for actions; for example, switching on/off devices.

Technologies & Components:

Sensors: temperature, humidity, IR, ultrasonic, gas sensors.

Actuators: motors, relays, valves.

RFID tags & readers.

Smart embedded boards: Arduino, ESP32, Raspberry Pi.

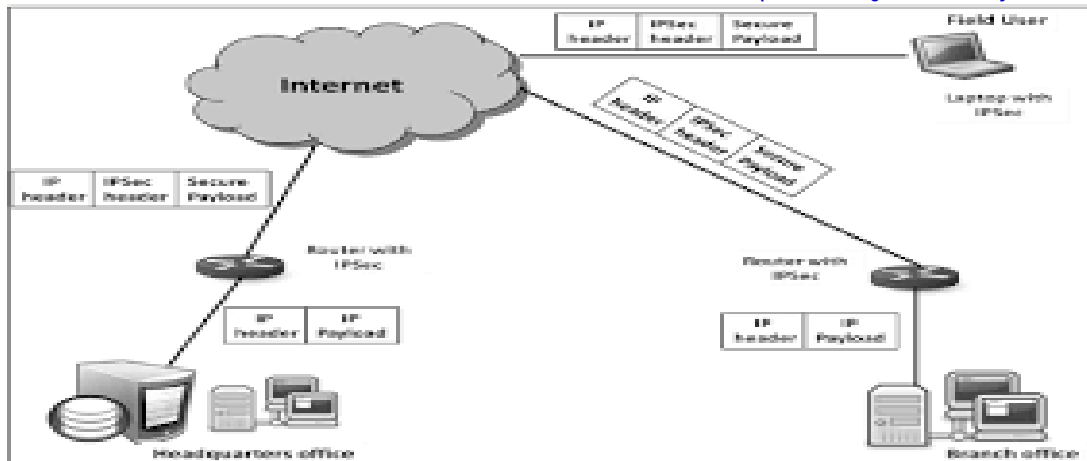
Examples:

Heart rate sensors in wearables.

Soil moisture sensor in agriculture.

Motion sensor in home security.

2. Network Layer (Communication & Transport Layer)



It acts as a bridge between sensors and processing systems.

Key Functions:

Data is transferred securely from devices to cloud/server.
Manages communication protocols, addressing and routing.
Ensures low latency, reliability, and interoperability.

Technologies:

Short range: Wi-Fi, Bluetooth, Z-wave, RFID, and NFC.
Long-range: LoRaWAN, Sigfox, NB-IoT, LTE, 5G.
Transport protocols: MQTT, CoAP, HTTP, TCP/IP.

Examples:

Bluetooth communication from fitness bands to smartphones.
LoRa for long-distance farm monitoring
5G IoT in smart vehicles.

3. Middleware Layer (Processing / Service Layer)



This is the intelligence layer, where all major processing happens.

Key Functions:

Data storage, database management. SQL/No-SQL.
Data analytics, machine learning, and predictive modeling.
Real-time data processing with cloud or edge computing.
Device authentication, access control and security services.
Provides API for application development.

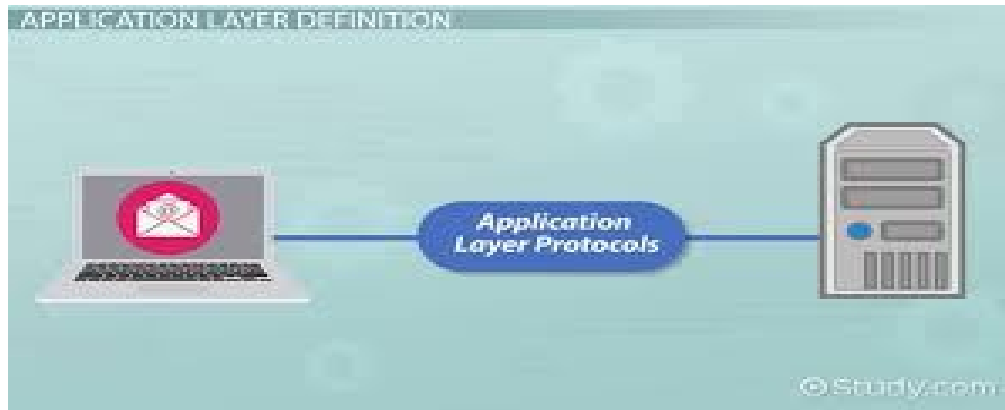
Technologies:

Cloud platforms include AWS IoT, Microsoft Azure IoT, and Google Cloud IoT.
Edge/Fog computing: Cisco Fog Node, Edge gateways.
Big data tools: Hadoop, Spark, Kafka.
AI/ML frameworks: TensorFlow, PyTorch.

Examples:

Cloud-analyzing health data for abnormal patterns.
Edge devices processing camera feeds for object detection.
Predictive maintenance in industrial IoT.

4. APPLICATION LAYER



This is the topmost layer that delivers the IoT services to users.

Key Functions:

Provides the user-facing interfaces, including dashboards, applications, and notifications.
Transforms processed data into meaningful actions.
Offers customized applications for different domains.

Domains & Examples:

Smart Homes: smart lighting, security systems.
Healthcare: Remote Patient Monitoring, Emergency Alerts.
Agriculture: smart irrigation, crop health monitoring
Transportation: smart parking, traffic monitoring.
Industry: automation, predictive maintenance, robotics.

Output Examples:

Mobile notifications for health abnormalities.
Graphical Dashboards in Smart Factories. Automatic adjustment of irrigation with respect to soil moisture.

IoT ENABLING TECHNOLOGIES



IoT enabling technologies are the basic building blocks that support the development, functioning, and expansion of IoT systems. These technologies enable devices to sense, communicate, process, store, and analyze data in real time. Sensors and actuators, which constitute the base of IoT, gather physical data from the environment and act accordingly. Wireless communication technologies including Wi-Fi, Bluetooth, Zambesi, Lora-wan, NB-IoT, and 5G facilitate seamless connectivity among devices, gateways, and cloud platforms. Cloud computing offers large-scale storage, data processing, remote access, and device management, whereas edge and fog computing bring computation closer to the physical devices, reducing latency and enhancing real-time decision-making. Big data analytic and artificial intelligence further enhance IoT systems by identifying patterns, predicting outcomes, and enabling intelligent automation. Embedded systems such as Arduino, ESP32, and Raspberry Pi are basically hardware controllers that integrate sensors, communication modules, and software logic. Besides, light-weight IoT communication protocols like MQTT and CoAP ensure efficient and secure data transmission. Cybersquatting technologies, such as encryption and authentication, protect IoT networks against threats and unauthorized access. All these put together provide an enabling ecosystem that makes IoT applications efficient, intelligent, calculable, and widely applicable across various domains.

1. Sensors and Actuators

These sensors pick real-time environmental data on temperature, humidity, motion, light, pressure, or gas levels. Actuators are supposed to run commands such as switching devices ON/OFF, opening valves, or controlling motors. These are very critical parts of IoT because they enable the device to interact with the physical world and provide the raw input necessary for processing and automation.

2. Wireless Communication Technologies

IoT relies on communication technologies to connect devices. The local connectivity is enabled by the short-range technologies of Wi-Fi, Bluetooth, Zigbee, and RFID. The long-range networks, such as LoRaWAN, Sigfox, NB-IoT, LTE-M, and 5G, give it wide-area communication capability. These technologies have ensured that data is transmitted reliably over gateways, cloud servers, or other devices for real-time monitoring and control.

3. Cloud Computing

These cloud platforms provide large-scale storage, remote processing, analytics, and device management; they support millions of connected devices, enabling access to data from anywhere. AWS IoT, Azure IoT Hub, and Google Cloud IoT are some services employed in storing big IoT data, running dashboards, automating workflows, and managing devices securely.

4. Edge and Fog Computing

Edge computing handles the data nearer to the device, thus reducing the delay and increasing speed. Fog computing works as an intermediary layer between cloud and edge, providing storage and computation at a localized level. These enable real-time applications such as autonomous vehicles, healthcare monitoring, and industrial automation, among others, which require decision-making in less than a second.

5. Big Data Analytics

IoT produces massive volumes of data that should be analyzed to find trends and patterns. Big data technologies like Hadoop, Spark, and Kafka process this large amount of data efficiently. Analytics come in handy with regards to predictive maintenance, anomaly detection, performance optimization, and decision-making to enable smarter and more accurate IoT systems.

6. Artificial Intelligence and Machine Learning

AI/ML algorithms bring intelligence into IoT systems. They help devices learn from data, predict events that will happen, detect anomalies, and classify objects and conduct several complex tasks on their own. Examples include health prediction, smart city traffic control, industrial fault detection, etc. AI delivers more adaptive, efficient, and autonomous IoT.

7. Embedded Systems and Micro controllers

These micro controllers include Arduino, ESP32, STM32, and single-board computers such as Raspberry Pi, acting as the "brain" of any IoT device. A microcontroller controls sensors, processes signals, runs programs, and manages communication modules. Embedded systems ensure low-power operation and seamless integration of hardware and software.

8. IoT Communication Protocols

The protocols define the way in which IoT devices communicate. Lightweight protocols such as MQTT, CoAP, and AMQP provide fast, efficient, and low-power data transfer. Other protocols like HTTP/HTTPS and TCP/IP are used to provide secure and reliable communication. In summary, they ensure interoperability among devices and cloud platforms.

9. Cybersquatting Technologies

Security is essential because IoT devices are widely distributed and vulnerable. Encryption, authentication, secure boot, firewalls, and block-chain are some of the technologies that ensure data integrity with protection for devices from attacks. Strong cybersquatting safeguards user privacy and prevents unauthorized access to IoT systems.

10. RFID (Radio Frequency Identification)

RFID technology is employed for identifying or locating questions using radio waves. The whole system entails tags and readers, which communicate wirelessly. It has widespread applications in inventory, logistics management, access control, toll systems, and asset tracking.

CHALLENGES IN IoT

1. Security Issues

IoT devices generally have poor security features and, hence, are highly susceptible to hacking, malware, and data theft.

2. Privacy Concerns

IoT systems collect sensitive personal data, creating risks of unauthorized access and misuse.

3. Interoperability Issues

Devices from different manufacturers use different protocols and standards for communications, which make them very difficult to coordinate.

4. Scaling Issues

With increasing IoT networks, managing millions of devices, data streams, and connections becomes complex.

5. Limitations in Connectivity

IoT performance is affected by low network coverage, poor bandwidth, and unstable internet connections.

6. High Power Consumption

Many of the IoT devices are battery-driven and require energy-efficient designs for longtime operation.

7. Data Management Issues

Large volumes of data must be stored, processed, and analyzed, calling for powerful cloud and edge infrastructure.

8. Reliability and Accuracy of Sensors

Sensor data can be inaccurate or inconsistent due to environmental conditions, noise, or hardware faults.

9. High Cost of Deployment and Maintenance

High initial investment and technical expertise are needed for installing sensors, gateways, and networks.

10. Lack of Standardization

There is no universal standard for IoT, causing problems in both compatibility and security.

11. Challenges in Upgrading

Many IoT devices are difficult or impossible to update and patch, creating long-lasting security vulnerabilities.

12. Limited Technical Skills

Organizations require professional training in designing, managing, and maintaining IoT systems.

CONCLUSION

The IoT has emerged as a powerful technology that revolutionizes industries by enhancing efficiency and providing more intelligent decision-making. IoT, enabled by sensors, wireless communication, cloud and edge computing, big data analytic, and artificial intelligence along with strong security systems, can capture, process, and analyze information from the physical world in real-time. While IoT has enormous benefits, challenges about security risks, issues related to interoperability, and management of large volumes of data have arisen. These limitations are continuously improving because of the upgrades being made in networking, embedded systems, and intelligent analytic. On the whole, IoT remains a key driver of digital innovation, where smart homes, healthcare, agriculture, transportation, and industrial automation use powerful solutions. With continuous enhancement in technological fields, IoT is geared towards creating environments of the future that will be more connected, efficient, and sustainable.

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