

## Simple Architecture Description

```
graph LR
    subgraph Smart_Light_Bulb_System [Smart Light Bulb System]
        A(Smart Light Bulb) <-->|Zigbee| B(Zigbee Gateway)
        B <-->|MQTT| C(Backend Server)
        C -->|MQTT| D(User Applications)
    end
    subgraph Surrounding_Sensors [Surrounding Sensors]
        E(Daylight Sensor) -->|Zigbee| B
        F(Motion Sensor) -->|Zigbee| B
        G(Time Sensor) -->|Zigbee| B
        H(Environment-based Sensors) -->|Zigbee| B
    end
    subgraph Home_IoT_Devices [Home IoT Devices]
        I(Alexa) -->|Skills Kit| C
        J(Google Home) -->|Actions on Google| C
    end
    style A fill:#85C1E9,stroke:#1F618D
    style B fill:#D7BDE2,stroke:#5B2C6F
    style C fill:#82E0AA,stroke:#1E8449
    style D fill:#F9E79F,stroke:#B7950B
    style E fill:#AED6F1,stroke:#2471A3
    style F fill:#F8C471,stroke:#D35400
    style G fill:#D2B4DE,stroke:#7D3C98
    style H fill:#F5B7B1,stroke:#E74C3C
    style I fill:#A9DFBF,stroke:#196F3D
    style J fill:#FADBD8,stroke:#D91E18
```

The proposed architecture for the smart light bulb system with seamless connectivity to home IoT devices like Alexa and Google Home can be described as follows:

### 1. Backend and Synchronization:

- Utilize serverless functions (e.g., AWS Lambda) for handling backend logic and API endpoints.
- Use Firebase Realtime Database to maintain the state of IoT nodes and applications, ensuring real-time synchronization and offline capabilities.
- Employ Apache Kafka or AWS IoT Core for pub/sub messaging, enabling real-time updates and notifications to connected applications and home IoT devices.

### 2. User Access and Authentication:

- Integrate an Identity and Access Management (IAM) system like AWS Cognito or Auth0 for user authentication and authorization.
- Enable sharing functionality by leveraging the IAM system to securely manage user access to light bulbs.

### 3. Hybrid Application Development:

- Utilize a hybrid framework like React Native or Flutter to build applications that work seamlessly on iOS, Android, and Web platforms.

#### 4. Integration with Home IoT Devices:

- Integrate with Alexa using the Alexa Skills Kit (ASK) and AWS Lambda for developing Alexa skills.
- Integrate with Google Home using the Actions on Google platform and Cloud Functions for Firebase to create conversational actions for Google Assistant.

# Comparative Study of IoT Technologies and Protocols

Here's a comparison table for Zigbee, MQTT, Z-Wave, Wi-Fi Direct, AWS IoT, and Cloud Storage based on various factors:

Technology	Maintenance Cost	Setup Cost	Setup Time	Setup Complexity	Scalability	Pricing	
Network Consumption	Interferences	Pros			Cons		
-----	-----	-----	-----	-----	-----	-----	
-----	-----	-----	-----	-----	-----	-----	Zigbee
Medium	Medium	Medium	Medium	High	Moderate	Low	Low
Low power consumption			- Limited range			MQTT	Low
Low	Low	Low	High	Low	Low	Low	- Lightweight and efficient messaging protocol
			- Requires an additional communication layer			Z-Wave	Low
High	Medium	High	High	High	Low	Low	- Secure and reliable wireless communication
			- Limited device compatibility and ecosystem			Wi-Fi Direct	High
Low	Low	High	Low	High	Medium		- Direct connection between devices without a network
			- High power consumption			AWS IoT	High
High	High	High	High	Low	Low		- Integration with AWS services and scalability
			- Higher cost compared to self-hosted solutions			Cloud Storage	Low
Low	Low	High	Variable	High	Low		- Easy access to data from anywhere
			- Relies on a stable internet connection			Bluetooth Classic	Low
Low	Medium	Low	Low	Medium			- Wide device compatibility
							Limited range and data throughput
							Bluetooth Low Energy (BLE)
Low	High	Low	Low	Low			- Low power consumption
							Limited data payload and range
							Bluetooth Mesh
Medium	High	Low	Low	Medium		Medium	Medium
							- Scalable mesh network
							Higher setup complexity and maintenance cost

Choosing the right tech stack for an IoT application depends on several factors, including the specific requirements of the application, the environment in which it will operate, and the available resources. Let's analyze the table to understand the considerations for selecting the appropriate technology stack:

1 Zigbee:

- Pros: Zigbee offers low power consumption and is suitable for battery-operated devices. It provides moderate pricing and low network consumption.
- Cons: However, Zigbee has limited range, which may restrict its usability in larger deployments.

## 2 MQTT:

- Pros: MQTT is a lightweight and efficient messaging protocol, making it ideal for IoT applications. It has low maintenance costs, low setup complexity, and low network consumption.
- Cons: MQTT requires an additional communication layer, which may increase implementation complexity.

### 3 Z-Wave:

- Pros: Z-Wave is known for its secure and reliable wireless communication. It offers

- high scalability and has a low maintenance cost.
  - Cons: Z-Wave has limited device compatibility and ecosystem, which may limit the options for integrating with other devices or systems.
- 4 Wi-Fi Direct:
- Pros: Wi-Fi Direct allows direct device-to-device connection without the need for a network. It offers low setup costs and low complexity.
  - Cons: However, Wi-Fi Direct consumes high network resources and requires higher power consumption, which may not be suitable for battery-powered devices.
- 5 AWS IoT:
- Pros: AWS IoT provides seamless integration with AWS services and offers scalability. It enables easy access to data from anywhere and provides reliable cloud storage.
  - Cons: However, AWS IoT has higher setup costs, high maintenance costs, and higher pricing compared to self-hosted solutions.
- 6 Cloud Storage:
- Pros: Cloud storage enables easy access to data from anywhere and offers high scalability.
  - Cons: It relies on a stable internet connection and may have variable pricing based on usage.

When choosing the right tech stack for an IoT application, consider the following factors:

- 1 Power consumption: If low power consumption is crucial, Zigbee or MQTT may be preferred.
- 2 Range: Consider the coverage area and choose a technology that provides sufficient range, such as Wi-Fi Direct or AWS IoT.
- 3 Security: Evaluate the security features provided by the technology, such as Z-Wave's secure communication.
- 4 Device compatibility: Ensure that the selected technology supports the devices you intend to use in your IoT application.
- 5 Integration requirements: If integration with other services or systems is essential, AWS IoT's seamless integration may be advantageous.
- 6 Cost: Consider the maintenance costs, setup costs, and pricing associated with the technology stack.

Choosing the right tech stack for an IoT application depends on several factors and requirements. Here's a brief discussion based on the comparison table provided:

- 1 Zigbee: Zigbee offers low power consumption and is suitable for applications that require a moderate setup cost, moderate setup time, and scalability. It is commonly used in smart home automation systems. However, its limited range may be a drawback for larger deployments.
- 2 MQTT: MQTT is a lightweight and efficient messaging protocol, making it ideal for resource-constrained devices. It has low maintenance cost, low setup cost, and low setup time. MQTT is commonly used in IoT applications where low overhead and reliable messaging are crucial. However, it requires an additional communication layer to establish the MQTT broker.
- 3 Z-Wave: Z-Wave provides secure and reliable wireless communication. It offers high scalability and is suitable for applications where a high level of interoperability is required. However, Z-Wave devices may have limited compatibility with other ecosystems, and the setup cost can be higher compared to other technologies.
- 4 Wi-Fi Direct: Wi-Fi Direct allows direct device-to-device connection without the need for a network infrastructure. It has low setup cost and low setup time, making it suitable for peer-to-peer IoT applications. However, Wi-Fi Direct consumes higher network resources and may have moderate interferences.

- 5 AWS IoT: AWS IoT offers integration with various AWS services and provides scalability for cloud-based IoT applications. It is suitable for enterprise-level deployments. However, it has higher maintenance cost, setup cost, and setup time compared to other technologies. AWS IoT may be more suitable for projects with specific requirements that align with AWS services.
- 6 Cloud Storage: Cloud storage allows easy access to data from anywhere, making it suitable for applications that require remote data management and analysis. It has low maintenance cost and low setup cost. However, it relies on a stable internet connection, and the network consumption can be high.
- 7 Bluetooth: Bluetooth offers low power consumption and is suitable for battery-operated devices. Bluetooth Classic provides wide device compatibility but has limited range and data throughput. BLE is suitable for low power applications with small data payloads. Bluetooth Mesh offers a scalable mesh network but has higher setup complexity and maintenance cost compared to other Bluetooth technologies.

## Technical stack combinations for the development

- 1 LoRaWAN + MQTT + AWS IoT + Cloud Storage:
  - LoRaWAN for long-range, low-power wireless communication.
  - MQTT as the messaging protocol for lightweight communication.
  - AWS IoT for device management, data processing, and analytics.
  - Cloud storage for storing and retrieving IoT data.
- 2 Bluetooth Low Energy (BLE) + MQTT + Azure IoT + Edge Computing:
  - BLE for short-range communication with low power consumption.
  - MQTT for efficient and reliable messaging.
  - Azure IoT for device management, data processing, and edge computing capabilities.
  - Edge computing to perform real-time analytics and decision-making at the network edge.
- 3 Thread + CoAP + Google Cloud IoT + Cloud Functions:
  - Thread as a low-power, mesh networking protocol for IoT devices.
  - CoAP (Constrained Application Protocol) for resource-constrained devices and efficient communication.
  - Google Cloud IoT for device registration, management, and integration with Google Cloud services.
  - Cloud Functions to trigger serverless functions and perform actions based on IoT data.
- 4 NB-IoT + MQTT + IBM Watson IoT Platform + Blockchain ( not low cost ):
  - NB-IoT (Narrowband IoT) for wide-area coverage and low-power communication.
  - MQTT for lightweight messaging between devices and the cloud.
  - IBM Watson IoT Platform for device management, data visualization, and analytics.
  - Blockchain for secure and transparent transaction recording and smart contract execution.

## Comparative analysis of technical stacks:

Technical Stack Combination	Communication Protocol	Cloud Platform	Edge
Computing   Data Storage	Key Features and Benefits		

||

----- | ----- | ----- | ----- |  
 ----- |

LoRaWAN + MQTT + AWS IoT + Cloud Storage	LoRaWAN, MQTT	AWS IoT	Not applicable   Cloud
Bluetooth Low Energy (BLE) + MQTT + Azure IoT + Edge Computing	BLE, MQTT	Azure IoT	Edge computing
Thread + CoAP + Google Cloud IoT + Cloud Functions	Thread, CoAP	Google Cloud IoT	Not applicable   Cloud
NB-IoT + MQTT + IBM Watson IoT Platform + Blockchain	NB-IoT, MQTT	IBM Watson IoT Platform	Not applicable

## Why suggest Zigbee + MQTT ?

Zigbee, being a low-power wireless communication protocol, is well-suited for connecting and controlling devices in a local area network. It enables efficient communication between devices, consuming minimal network resources. Zigbee devices can operate in a mesh network, allowing them to relay messages and form a robust and scalable network infrastructure.

On the other hand, MQTT is a lightweight messaging protocol designed for efficient data exchange in IoT applications. It follows a publish-subscribe pattern, where devices (publishers) publish messages to a central broker, and other devices (subscribers) receive those messages based on their subscription topics. MQTT is highly efficient in terms of network consumption, minimizing the amount of data sent over the network.

By combining Zigbee and MQTT, the sync operations can be performed in the following way:

- 1 Devices (such as smart light bulbs) connected through Zigbee protocol can have their configurations synchronized using MQTT messages.
- 2 When a user updates the configuration parameters in the user application, the application sends an MQTT message to the backend server indicating the desired changes.
- 3 The backend server receives the MQTT message and updates the respective device's configuration information in its database.
- 4 The backend server then forwards the configuration update to the Zigbee gateway using MQTT, which acts as a bridge between the Zigbee devices and the server.
- 5 The Zigbee gateway translates the MQTT message to Zigbee protocol and communicates with the corresponding Zigbee devices to apply the configuration changes.

This approach offloads the heavy lifting of device synchronization from the server by utilizing the efficient Zigbee protocol for local device communication. MQTT is used as a lightweight and scalable messaging protocol for transmitting configuration updates between the server, gateway, and devices. This helps in minimizing the load on the server and network during sync operations.

Here's a small diagram illustrating the sync operations using Zigbee + MQTT:

```
graph LR
  subgraph User_Applications
    UA((User Application))
  end
  subgraph Backend_Server
    BS((Backend Server))
  end
  subgraph Zigbee_Gateway
    ZG((Zigbee Gateway))
  end
  subgraph Smart_Light_Bulbs
    LB1((Light Bulb 1))
    LB2((Light Bulb 2))
  end
  UA -->|MQTT Config| BS
```

```

BS -->|MQTT Config| ZG
ZG -->|Zigbee Config| LB1
ZG -->|Zigbee Config| LB2

```

In the diagram, the user application (UA) sends an MQTT configuration message to the backend server (BS). The backend server then forwards the configuration update to the Zigbee gateway (ZG) using MQTT. The Zigbee gateway translates the MQTT message to Zigbee protocol and communicates with the respective smart light bulbs (LB1, LB2) to apply the configuration changes.

This architecture ensures minimal load on the server and network as the synchronization is performed efficiently through the Zigbee protocol for local communication and MQTT for lightweight messaging between the server and gateway.

## Communication Flow

```

flowchart LR
    subgraph User Applications
        UA1((User Application 1))
        UA2((User Application 2))
    end
    subgraph Zigbee Gateway
        ZG((Zigbee Gateway))
    end
    subgraph Backend Server
        BS((Backend Server))
        subgraph Database
            DB
        end
        subgraph Message Queue
            MQ
        end
        subgraph Identity and Access Management
            IAM
        end
    end
    subgraph Smart Light Bulbs
        LB1((Light Bulb 1))
        LB2((Light Bulb 2))
    end
    subgraph Invited Users
        IU1((Invited User 1))
        IU2((Invited User 2))
    end
    LB1 -->|Zigbee State Change| ZG
    LB2 -->|Zigbee State Change| ZG
    ZG -->|Zigbee Config| LB1
    ZG -->|Zigbee Config| LB2
    ZG <-->|MQTT State Change| BS
    UA1 -->|MQTT Config| BS
    UA1 -->|MQTT Access| BS
    UA1 -->|MQTT Notifications| IU1
    UA1 -->|MQTT Notifications| IU2
    UA2 -->|MQTT Config| BS
    UA2 -->|MQTT Access| BS

```

```

UA2 -->|MQTT Notifications| IU1
UA2 -->|MQTT Notifications| IU2
BS -->|MQTT Config| ZG
BS -->|MQTT Access| UA1
BS -->|MQTT Access| UA2
BS -->|MQTT Access| IU1
BS -->|MQTT Access| IU2
BS -->|MQTT Control| LB1
BS -->|MQTT Control| LB2
BS -->|MQTT State Change| UA1
BS -->|MQTT State Change| UA2
IU1 -->|MQTT Access| BS
IU1 -->|MQTT Config| BS
IU1 -->|MQTT Control| BS
IU1 -->|MQTT State Change| LB1
IU1 -->|MQTT State Change| LB2
IU2 -->|MQTT Access| BS
IU2 -->|MQTT Config| BS
IU2 -->|MQTT Control| BS
IU2 -->|MQTT State Change| LB1
IU2 -->|MQTT State Change| LB2

```

The above diagram illustrates the communication flow for the given points - ( other smart devices are not included in the diagram )

The diagram includes the following components and flows:

- 1 User Applications (UA1, UA2): User applications through which users configure parameters and send MQTT messages to the backend server.
- 2 Backend Server (BS): Manages configuration updates, state changes, and access permissions.
- 3 Zigbee Gateway (ZG): Acts as a bridge between the backend server and the smart light bulbs, translating messages between MQTT and Zigbee protocols.
- 4 Smart Light Bulbs (LB1, LB2): Light bulbs that receive configuration changes and state change notifications via Zigbee messages.
- 5 IAM System (IAM): Manages user authentication and authorization.
- 6 Invited Users (IU1, IU2): Users who have been granted access to specific light bulbs by the backend server.

The flows in the diagram are as follows:

### Configuration and Control:

- User applications send MQTT configuration messages to the backend server.
- The backend server forwards the configuration updates to the Zigbee gateway in MQTT format.
- The gateway translates the MQTT messages to Zigbee protocol and communicates with the corresponding light bulbs to apply the configuration changes.

### Physical Button Interaction:

- When a physical button on a light bulb is pressed, the bulb sends a Zigbee message to the Zigbee gateway indicating the state change.
- The gateway converts the Zigbee message to MQTT format and forwards it to the backend server.
- The server updates the state of the respective light bulb and sends notifications to the user applications via MQTT, indicating the state change.

## User Access and Sharing:

- The backend server manages user authentication and authorization using an IAM system.
- Users can share access to specific light bulbs with others through the applications.
- The server updates the access permissions, and notifications are sent to the invited users via MQTT.
- Invited users can control and configure the shared light bulbs through their authorized user applications.

## Simple Functionality interaction diagrams

### Time-based Modes

```
flowchart LR
    subgraph User_Applications
        UA((User Application))
    end
    subgraph Backend_Server
        BS((Backend Server))
    end
    subgraph Smart_Light_Bulb
        LB((Light Bulb))
    end
    UA -->|MQTT Mode Change| BS
    BS -->|MQTT Mode Change| LB
```

### Motion Sensor Mode

```
flowchart LR
    subgraph Motion_Sensor
        MS((Motion Sensor))
    end
    subgraph Smart_Light_Bulb
        LB((Light Bulb))
    end
    subgraph Backend_Server
        BS((Backend Server))
    end
    MS -->|Motion Detection| LB
    LB -->|MQTT State Change| BS
```

### Light Sensor Mode

```
flowchart LR
    subgraph Light_Sensor
        LS((Light Sensor))
    end
    subgraph Smart_Light_Bulb
        LB((Light Bulb))
    end
    subgraph Backend_Server
        BS((Backend Server))
    end
```



```

    BS((Backend Server))
end
LS -->|Light Level| LB
LS -->|Light Level| BS

```

## Environment-based Sensors

```

flowchart LR
    subgraph Environment Sensors
        ES((Environment Sensors))
    end
    subgraph Smart Light Bulb
        LB((Light Bulb))
    end
    subgraph Backend Server
        BS((Backend Server))
    end
    ES -->|Sensor Data| LB
    ES -->|Sensor Data| BS

```

## Mood-based Modes

```

flowchart LR
    subgraph User Applications
        UA((User Application))
    end
    subgraph Backend Server
        BS((Backend Server))
    end
    subgraph Smart Light Bulb
        LB((Light Bulb))
    end
    UA -->|MQTT Mode Change| BS
    BS -->|MQTT Mode Change| LB

```

## Full System Interaction with Features

The functionalities described below pertain to the smart light bulb system, which incorporates various modes and sensor-based controls to enhance user experience and energy efficiency. Here is a summary of each functionality:

### 1 Time-based Modes:

- The smart light bulb adjusts its lighting configuration based on different time periods such as Morning, Daytime, Evening, and Night.
- Mode changes are scheduled by the backend server, and the bulb receives commands via MQTT to adjust its color, brightness, and other parameters accordingly.
- This feature ensures appropriate lighting for different times of the day, creating a comfortable and suitable environment.

### 2 Motion Sensor Mode:

- When the motion sensor detects activity, the smart light bulb automatically turns on.
- The motion sensor sends a signal to the bulb or backend server upon detecting

- motion, and the bulb adjusts its state accordingly.
- This functionality ensures that the light is activated only when someone is present in the area, improving energy efficiency and convenience.

### 3 Light Sensor Mode:

- The smart light bulb adjusts its brightness based on the ambient light level.
- The light sensor continuously measures the surrounding light, and the bulb or backend server receives the sensor data.
- The bulb then adjusts its brightness or turns off based on the received light sensor data.
- This feature optimizes lighting based on the available natural light, enhancing comfort and energy savings.

### 4 Environment-based Sensors:

- Additional sensors like temperature, humidity, or air quality sensors can be integrated with the smart light bulb.
- These sensors provide data about the surrounding environment, allowing the bulb to respond accordingly.
- The collected sensor data is analyzed by the bulb or backend server, triggering appropriate actions or changes in the bulb's behavior.
- This functionality enables the bulb to indicate warnings or adjust its lighting based on environmental conditions, promoting safety and comfort.

### 5 Mood-based Modes:

- The smart light bulb offers pre-defined or customizable modes to create different moods or atmospheres.
- Users can select desired modes, such as Relaxing, Energizing, or Romantic, from the application.
- The backend server sends the mode configuration to the bulb via MQTT, adjusting its color, brightness, and effects accordingly.
- This feature allows users to personalize their lighting experience and create desired ambiances for different occasions.

Overall, these functionalities provide users with flexibility and automation in controlling their smart light bulbs. The integration of sensors, MQTT communication, and coordination with the backend server enable dynamic adjustments, energy efficiency, and a tailored lighting experience.

## Complete System Diagram

```

flowchart LR
    subgraph User_Applications
        UA1((User Application 1))
        UA2((User Application 2))
    end
    subgraph Backend_Server
        BS((Backend Server))
        subgraph Database
            DB
        end
        subgraph Message_Queue
            MQ
        end
    end
    subgraph IAM[Identity and Access Management]
    end

```

```

    IAM
  end
end
subgraph Smart Devices
  subgraph Zigbee Gateway
    ZG((Zigbee Gateway))
  end
  subgraph Smart Light Bulbs
    LB((Smart Light Bulb))
  end
  subgraph Motion Sensors
    MS((Motion Sensor))
  end
  subgraph Light Sensors
    LS((Light Sensor))
  end
  subgraph Environment Sensors
    ES((Environment Sensors))
  end
  MM((Mood-based Modes))
end
subgraph Invited Users
  IU1((Invited User 1))
  IU2((Invited User 2))
end
UA1 -->|MQTT Config| BS
UA2 -->|MQTT Config| BS
BS -->|MQTT Config| ZG
ZG -->|Zigbee Config| LB
LB -->|Time-based Mode Command| MM
LB -->|Motion Sensor Command| MS
LB -->|Light Sensor Command| LS
LB -->|Environment Sensor Data| ES
LB -->|Mood-based Mode Command| MM
LB -->|State Change Notification| BS
LB -->|Sensor Data| BS
LB -->|Mode Change Notification| BS
LB -->|State Change Notification| UA1
LB -->|State Change Notification| UA2
UA1 -->|MQTT Notifications| IU1
UA1 -->|MQTT Notifications| IU2
UA2 -->|MQTT Notifications| IU1
UA2 -->|MQTT Notifications| IU2
IU1 -->|MQTT Control| BS
IU2 -->|MQTT Control| BS
BS -->|MQTT Control| LB
LB -->|Motion Sensor Command| MS
LB -->|Light Sensor Command| LS
LB -->|Environment Sensor Data| ES
LB -->|Mood-based Mode Command| MM
IU1 -->|MQTT Config| BS
IU2 -->|MQTT Config| BS
BS -->|MQTT Config| ZG
ZG -->|Zigbee Config| LB

```

```

IU1 -->|MQTT State Change| LB
IU2 -->|MQTT State Change| LB
LB -->|Motion Detection Command| MS
LB -->|Light Sensor Data| LS
LB -->|Environment Sensor Data| ES
LB -->|Mode Configuration| MM
IU1 -->|MQTT Access| BS
IU2 -->|MQTT Access| BS
BS -->|MQTT Access| IU1
BS -->|MQTT Access| IU2
subgraph Backend Server
    BS
end
subgraph Identity and Access Management
    IAM
end
subgraph User Applications
    UA1
    UA2
end
subgraph Smart Devices
    ZG
    LB
    MS
    LS
    ES
    MM
end
subgraph Sensors
    MS
    LS
    ES
end
BS -->|MQTT Config| UA1
BS -->|MQTT Config| UA2
BS -->|MQTT State Change| LB
BS -->|MQTT Access| IU1
BS -->|MQTT Access| IU2
BS -->|MQTT Control| LB
BS -->|MQTT Notifications| UA1
BS -->|MQTT Notifications| UA2
LB -->|Sensor Data| BS
LS -->|Light Sensor Data| LB
MS -->|Motion Detection Command| LB
ES -->|Environment Sensor Data| LB
MM -->|Mode Configuration| LB

```