Deakin University

Project Title: Smart Home Lighting System

Project Proposal

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High-Level Problem / Problem Description

In today's rapidly evolving technological landscape, smart home solutions are becoming increasingly prevalent, offering convenience, energy efficiency, and enhanced security.

- However, many existing smart lighting systems suffer from limitations such as complex setup processes, interoperability issues between different manufacturers' devices, and a lack of truly adaptive and scalable control.

I am undertaking this project to address these challenges by developing a robust, user-friendly, and scalable smart home lighting system that prioritizes seamless integration and intelligent automation.

- The ultimate vision is to create an intelligent and adaptive system that integrates with a user's lifestyle, optimizing energy consumption while enhancing comfort and ambiance.

- System that not only allows for remote control but also intelligently adjusts lighting based on environmental factors, occupancy, and user preferences, providing a truly personalized and efficient lighting experience.

The main outcomes of this project will include:

- A functional IoT-enabled smart lighting system prototype capable of controlling multiple lights.

- A scalable architecture demonstrated through AWS deployment.

- A Node-RED flow-based processing system for data aggregation and control.

- An event-based microservice architecture for enhanced flexibility and maintainability.

- A secure deployment of the solution.

- Comprehensive documentation, including a GitHub repository of the code and evidence of scalability experiments.

This project will differentiate itself by focusing heavily on scalability and interoperability from the ground up, utilizing a microservices architecture and cloud-native solutions like AWS.

- While many existing smart lighting systems offer basic control, our solution will emphasize advanced automation based on real-time data, and a flexible architecture that can easily integrate new devices and features without major overhauls.

- The use of Node.js, Node-RED, and AWS as core technologies will provide a robust and extensible foundation for a truly smart and future-proof lighting system.

Solution overview

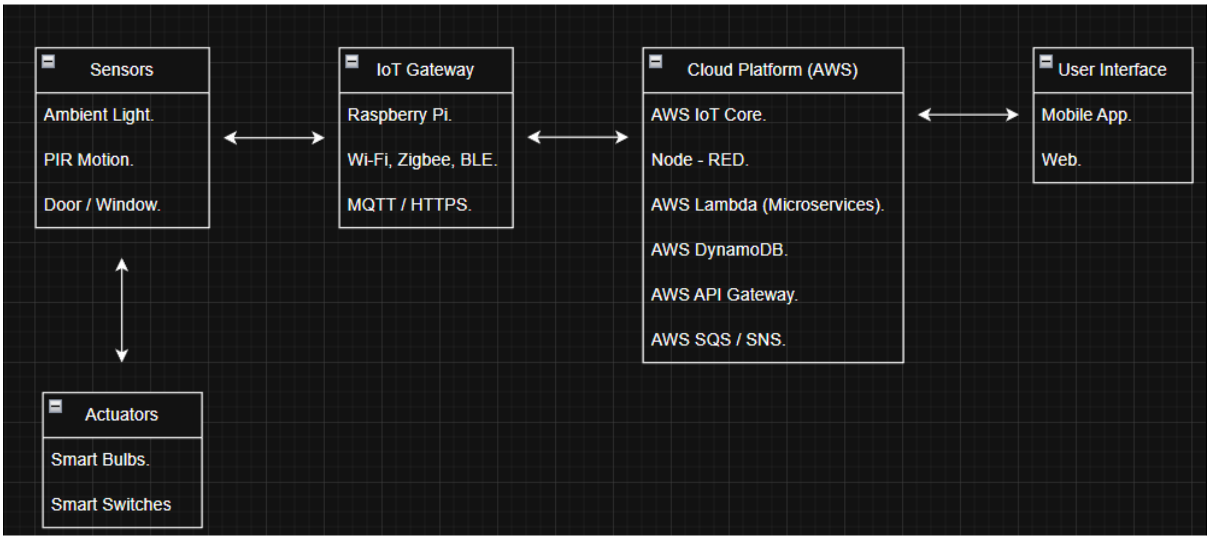
A / Proposed Solution

I am proposing an IoT-enabled smart home lighting system that leverages sensors to gather environmental data (e.g., light intensity, occupancy) and user input to intelligently control lights.

- The system will consist of IoT devices (smart lights, sensors), a gateway for data collection, a cloud-based backend for processing and storage, and a user interface for control and monitoring.

- The core processing logic will be built using Node-RED flows, and the overall architecture will be based on event-driven microservices deployed on Amazon Web Services (AWS).

B / High-Level Block Diagram



This high-level block diagram illustrates the interconnected components of the smart home lighting system:

- Sensors (Input): Ambient light sensors, PIR motion sensors, and potentially door/window sensors.

- Actuators (Output): Smart light bulbs or smart switches.

- IoT Gateway: A central hub (e.g., Raspberry Pi) that collects data from sensors, translates protocols, and sends commands to actuators.
- Cloud Platform (AWS): The backbone of the system, including AWS IoT Core, Lambda Functions (Microservices), DynamoDB (NoSQL Database), API Gateway, and SQS/SNS (Messaging Services).
- Node-RED: For flow-based programming, automation rules, data aggregation, and integration.
- User Interface: Mobile App/Web Dashboard for monitoring and control.

System Interconnection:

- Sensors like ambient light and PIR gather real-time data and communicate wirelessly (Wi-Fi, Zigbee, BLE) with the IoT Gateway.
- Actuators, primarily smart lights, receive commands from the gateway.

IoT Gateway:

- Acts as a bridge, collecting raw sensor data and forwarding it to the AWS cloud via secure MQTT or HTTPS.
- It also receives commands from the cloud and transmits them to actuators.

Cloud Processing (AWS Lambda, Node-RED):

- Data Ingestion: Sensor data is ingested by AWS IoT Core, which can trigger Lambda functions.
- Node-RED Flows: Used for data aggregation, filtering, simple processing, and defining complex automation rules (e.g., "if motion detected and ambient light is low, turn on lights").
- Microservices (AWS Lambda):
    - Complex business logic, such as predictive lighting, energy optimization, or user management, will be implemented as independent microservices using Node.js and deployed as AWS Lambda functions.
    - These services communicate via AWS messaging services (SQS/SNS).
- Storage (AWS DynamoDB):

- All collected sensor data, device states, user configurations, and automation rules will be stored in AWS DynamoDB due to its scalability and ability to handle high-velocity data from IoT devices.

C / Aggregation, Filtering, and Processing

- ***Aggregation***: Sensor data (e.g., light intensity, occupancy events) will be collected at regular intervals. Aggregation might involve calculating average light levels or counting motion events.

- **Filtering**: Techniques like moving averages or thresholding will be applied to raw sensor data to ensure quality and relevance (e.g., filtering out spurious motion detections).

- ***Processing***:

    - **Rule-based**: Implementing "if-then" rules using Node-RED flows.

    - **Event-driven**: Responding to events like light state changes.

    - **Predictive Analytics (Future)**: Using historical data for proactive lighting adjustments.

    - **User Preference Management**: Processing user input to update lighting scenes and rules.

D / Scalability

Scalability is a core requirement, achieved through:

- Microservices Architecture: Independent, loosely coupled services scaled based on demand.

- Serverless Computing (AWS Lambda): Automatic scaling of code execution.

- Managed Databases (AWS DynamoDB): Seamless scalability for storage and throughput.

- Message Queues (AWS SQS/SNS): Decoupling microservices for asynchronous communication.

- AWS IoT Core: Designed to handle billions of devices and trillions of messages.

- Containerization (Potentially AWS ECS/EKS for Node-RED): Horizontal scaling for Node-RED instances if needed.

E / Testing Plan

The testing plan will cover several phases:

- Unit Testing: Individual components and functions.
- Integration Testing: Communication and interaction between system parts.
- System Testing: End-to-end testing with real-world scenarios.
- Scalability Testing: Assessing performance under load by simulating numerous devices and data streams.
- Security Testing: Verifying secure deployment aspects.
- User Acceptance Testing (UAT): Engaging users to ensure usability and requirements are met (if time permits).

Implementation Plan

A / Hardware/Simulation and Communication

For the initial prototype, I will utilize a combination of simulated components and readily available hardware:

- Simulated Hardware (Initial Phase):
  - Simulated Sensors: Python scripts or Node-RED injection nodes will generate and publish simulated sensor data to AWS IoT Core.
  - Simulated Actuators: Dummy APIs or messages will simulate light bulb state changes.
- Physical Hardware (Later Phase/Ideal Scenario):
  - IoT Gateway: Raspberry Pi 4 Model B running Node-RED.
  - Sensors: BH1750FVI Digital Light Sensor Module and HC-SR501 PIR Motion Sensor Module.
  - Actuators: Smart Light Bulbs (e.g., Philips Hue, Tuya) or ESP32/ESP8266 microcontrollers with relays.
- Communication Technologies:

- Wi-Fi: For Raspberry Pi to internet, and Wi-Fi enabled smart bulbs.
- MQTT: Primary protocol for IoT Gateway and AWS IoT Core communication.
- Zigbee/Bluetooth Low Energy (BLE): For local communication with specific smart home devices if needed.

B / Data Design and Storage

The data design will primarily focus on using AWS DynamoDB, a NoSQL document database, for its scalability, low latency, and flexibility.

1. Data Collected:

- Sensor Data: deviceId, timestamp, dataType, value, location.
- Actuator/Light State Data: lightId, timestamp, state, commandSource, location.
- User Preferences/Automation Rules: userId, ruleId, ruleName, conditions, actions, schedule.

2. How it is Stored (DynamoDB Tables):

- SensorData Table: Primary Key: deviceId (Partition Key), timestamp (Sort Key).
- LightStates Table: Primary Key: lightId (Partition Key), timestamp (Sort Key).
- UserRules Table: Primary Key: userId (Partition Key), ruleId (Sort Key).

This schema allows for efficient querying of time-series data and flexible storage of user-defined rules.

C / Cloud Computing Deployment (AWS)

Amazon Web Services (AWS) will be central to deploying our scalable IoT solution:

- IoT Core: Secure and scalable messaging broker for all IoT devices.
- Lambda: Serverless computing for all business logic, data processing, and microservices (Node.js).
- DynamoDB: Persistent storage for all sensor readings, device states, and user configurations.
- Node-RED Deployment: Can be on an EC2 instance or containerized using AWS ECS/EKS.

- API Gateway: Exposing RESTful APIs for the user interface.
- CloudWatch: Monitoring performance, logging, and setting alarms.
- IAM: Managing permissions and securing access to AWS resources.
- Optional Services: SQS for message queuing, SNS for notifications, S3 for larger files/backups.

Project Plan

<table>
<tr><th>Week</th><th>Planned</th><th>Outcomes</th></tr>
<tr><td>1</td><td>Project Scoping and Initial Setup:
Define problem.
Gather requirements.
Confirm tech stack.
Set up AWS and Git.</td><td>Clear problem statement.
Initial project structure.
Configured AWS account.</td></tr>
<tr><td>2</td><td>Solution Design and High-Level Architecture:
Develop block diagram, data model, scalability design, security plan.</td><td>Detailed high-level design, data schema, Node-RED plan.</td></tr>
<tr><td>3</td><td>Data Collection (Simulation) and Node-RED Basic Flows:
Develop simulated sensors.
Configure AWS IoT Core.
Create basic Node-RED ingestion flows.
Set up DynamoDB tables.</td><td>Simulated sensor data flowing to AWS IoT Core.
Initial Node-RED flows.
DynamoDB tables created.</td></tr>
<tr><td>4</td><td>Microservice Architecture (Core Logic) & Data Storage:
Develop "Sensor Data Processor" and "Light Control" Lambda functions.
Integrate with DynamoDB, unit test.</td><td>Core Lambda functions developed and integrated with DynamoDB.</td></tr>
<tr><td>5</td><td>Node-RED Automation and Actuator Integration (Simulation):
Develop advanced Node-RED automation flows.
Integrate with simulated actuators.
Implement error handling.</td><td>Functional Node-RED automation.
Simulated light control.</td></tr>
<tr><td>6</td><td>Deployment & Scalability Experiments:
Deploy all components to AWS.
Conduct initial scalability tests.
Optimize services.</td><td>Initial deployed solution.
Preliminary scalability test results.</td></tr>
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<tr><td>7</td><td>Secure Deployment & Monitoring:
Implement security best practices.
Set up CloudWatch alarms and dashboards, troubleshoot.</td><td>Secure AWS deployment, comprehensive monitoring in CloudWatch.</td></tr>
<tr><td>8</td><td>Final Review, Refinement, and Documentation:
Code review, refactor, final scalability experiments, report writing, GitHub README.</td><td>Optimized code.
Comprehensive project report.
Updated GitHub repository.</td></tr>
<tr><td>9</td><td>Final Submission Preparation:
Compile report.
Finalize GitHub.
Collect evidence.
Review all submission requirements.</td><td>Complete submission package.
All evidence prepared.</td></tr>
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