IoT-Based Smart Traffic Control System in Smart Cities

Intelligent Traffic Management

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Abstract

This report presents a comprehensive Smart Traffic Control System designed for IOT-based smart cities. The intelligent system manages the traffic light at intersection by detection vehicules in real-time using multiple sensors (RFID, IR, Ultrasonic), processing the data through the MQTT protocol, and making adaptive decisions in the cloud to optimize traffic flow while prioritizing emergency vehicules. **Keywords:**Zigbee, Mqtt, Wifi, Sensors, Smart Traffic Control, Smart cities.

Contents

Chapter 1

Introduction : Smart Traffic Control Systems

The rapid growth of urban populations has led to significant challenges in traffic management, including congestion, delays, air pollution, and inefficient use of infrastructure. [3]Traditional traffic control systems rely on fixed-timer signal plans and manual monitoring, which are no longer sufficient for dynamic and rapidly changing traffic conditions. According to Zanella et al., the challenges of urban environments (e.g., heterogeneity of devices, data volume, and service diversity) can be addressed by a reference IoT framework specifically designed for smart cities [5]. In their work, they propose an urban IoT architecture that supports a variety of value-added services including traffic management, energy monitoring, and public lighting.

1.1 Definition of Smart Traffic Control

Smart Traffic Control is an intelligent system management that use real-time data collection , advanced analytics ,and automated decision making to dynamically adjust traffic signal timing based on traffic conditions. Unlike the traditional fixed time , smart systems adapt to

- Current vehicle density on each road
- Emergency vehicle

1.2 Benefits of Smart traffic in Lebanon

In Beirut and Greater Beirut Area , 25% of road accidents involving pedestrians , and nearly half occurring at signalized intersections. Traditional traffic signals often fails to protect pedestrians due to unclear signage. Smart traffic control offers effective solutions to enhance pedestrians safety , prevents conflicts between vehicles and pedestrians and reduces congestion. It minimizes the road accidents to 25%[3].

1.2.1 Direct Benefits To Lebanon

- Safety and Emergency Response

- Economics Benefits
- Environmental Benefits (Emission reduction, Fuel Conservation)

1.3 Smart Traffic and Smart grid

Smart grid is integrated system that uses digital communications technology to detect and react to change in usage of Electricity.

1.3.1 Smart traffic as a component of Smart grid

Smart traffic systems are integral to the broader smart city/smart grid ecosystem:

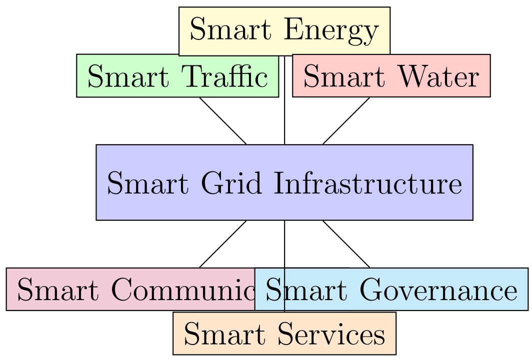

Figure 1.1: Smart Traffic within Smart Grid ecosystem

Chapter 2

IoT Architecture Overview

IoT systems are typically structured into multiple layers that define how data is collected, transmitted, processed, and used to provide intelligent services. The instructor s reference describes IoT within smart grids as a layered model that enables communication and interaction between physical devices, networks, and cloud-based applications [2]. Similarly, Zanella et al. propose a smart city IoT framework where heterogeneous sensors, communication modules, and service platforms cooperate to deliver urban-scale services such as traffic monitoring and environmental sensing [5]. In general, the IoT architecture used in smart traffic applications can be represented through the following layers:

- **Perception Layer:** Responsible for sensing and data acquisition using devices such as IR sensors, ultrasonic sensors, RFID readers, and cameras.
- **Network Layer:** Handles communication technologies including Zigbee, Wi-Fi, LoRa, and MQTT for reliable data transfer.
- **Processing/Application Layer:** Performs data analytics, signal optimization, and service management on cloud platforms.
- **Service/Business Layer:** Provides traffic control decisions, dashboards, and interfaces for city operators and citizens.

This layered architecture enables interoperability, scalability, and real-time responsiveness, which are essential for smart traffic control systems. =

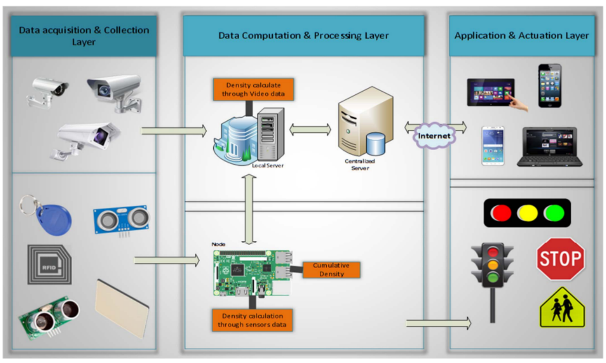

Figure 2.1: The System model[1]

2.1 Perception Layer (Sensors)

This layer is responsible for detecting vehicles and emergencies at the intersection using multiple types of sensors deployed across the roadway. [1].

2.1.1 Components

Ultrasonic Sensors:

These sensors measure the distance of vehicles by emitting sound waves and detecting their reflection, which allows accurate estimation of traffic density. [1]. Functions:

- Count number of vehicles
- Range : Approximately 3- 5 meters.

IR Sensors (Infrared)

- **Function:** Detect vehicle presence (binary 0 or 1 (presence or absent))
- **Range:** Approximately 1-2 meters. **Reliability:** 95%+ accuracy

RFID Readers - Radio Frequency Identification

- **Functions:** Detect emergency vehicles(ambulance)
- **Outputs:** 0 or 1
- **Range:** 100-200 meters

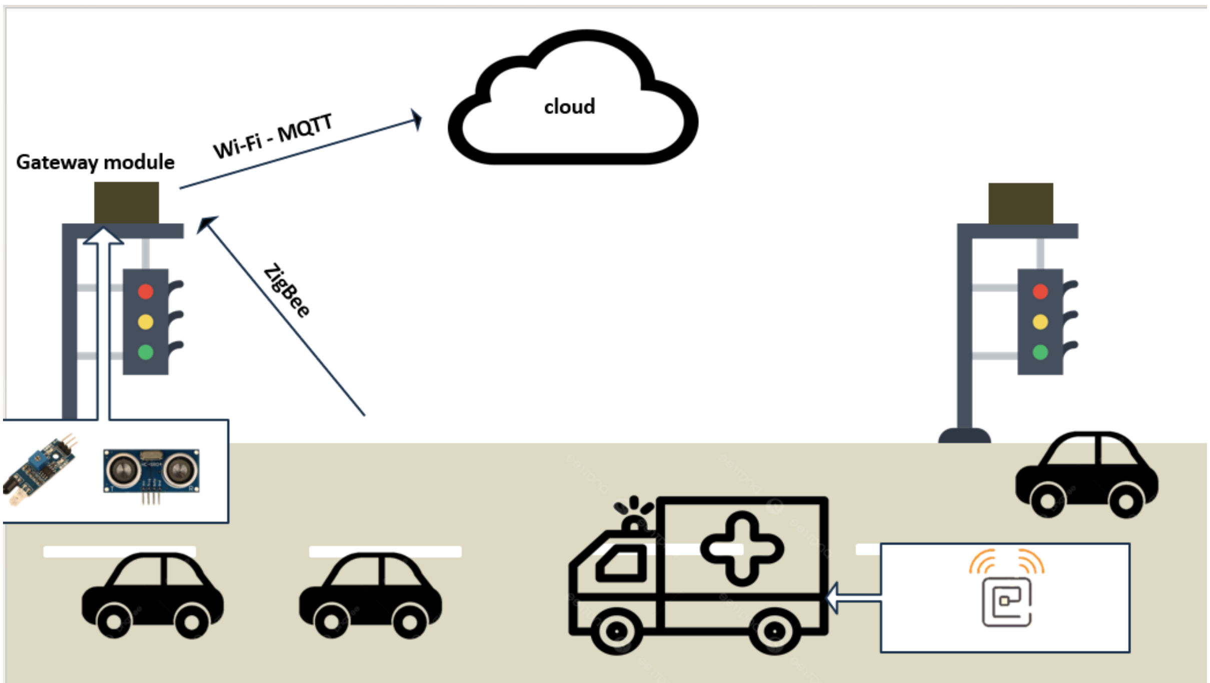

Figure 2.2: Sensors Network

2.2 Network Layer (Communication Technologies)

The network layer is responsible for the robust and reliable transmission of data from sensor nodes to the centralized cloud or server, and for relaying control commands back to the sensors. This layer is crucial for maintaining the real-time performance of the smart traffic control system.

2.2.1 Local Gateways:

Edge devices such as Raspberry Pi or similar microprocessors are deployed at intersections to aggregate data from local sensors. These gateways act as intermediaries between the perception layer and the processing layer, ensuring that sensor readings are collected and transmitted efficiently.

2.2.2 Communication Protocols:

Communication in smart traffic systems can be categorized into short-range and long-range transmissions:

- **Short-Range (Sensor to Gateway):** Zigbee is chosen for sensor-to-gateway communication due to its low power consumption and suitability for short-range, low-data-rate sensing devices. It enables reliable transmission of small packets—such as vehicle detection signals, ultrasonic measurements, or RFID triggers—from roadside sensors to the gateway. Zigbee's mesh networking capability ensures stable communication even in environments with multiple deployed sensors.

  NB: Zigbee is specifically optimized for lightweight sensing tasks and supports a maximum data rate of **250 kbps**, which is ideal for transmitting small, frequent packets while maintaining very low energy consumption.

- **Long-Range (Gateway to Cloud):** Gateways transmit collected data to the cloud using lightweight protocols such as **Wifi** , **LoRaWAN** or **NB-IOT** this enables real timemonitoring and data analysis for traffic control systems.

Why Zigbee and Wifi for Smart Traffic Control?

Zigbee enables energy-efficient, short-range communication for low-power sensors at intersections, while Wifi supports real-time monitoring and easy integration . This combination is well-suited for real-time monitoring and control of traffic conditions where sensors transmit small but frequent data packets.

2.3 Processing Layer (Data Analytics and Traffic Management)

The processing layer is responsible for analyzing the data collected from sensors via the network layer and generating actionable information for traffic control. Processing can occur at the local gateway (edge processing) or in the cloud, depending on the computational requirements and latency constraints.

2.4 Application Layer (Service and User Interface)

The application layer delivers the processed data to end users and system operators. It provides interfaces such as dashboards, traffic monitoring platforms, and automated control systems. For smart traffic control, this layer can:

- Display real-time traffic density and congestion maps for city operators.
- Automatically adjust traffic signal timings to minimize delays.
- Generate alerts for unusual traffic conditions or incidents.
- Support integration with other smart city services, such as emergency response systems or environmental monitoring.

By combining real-time data analytics with actionable interfaces, the application layer ensures that the benefits of IoT—efficiency, reduced congestion, and improved safety—are realized throughout the city [5].

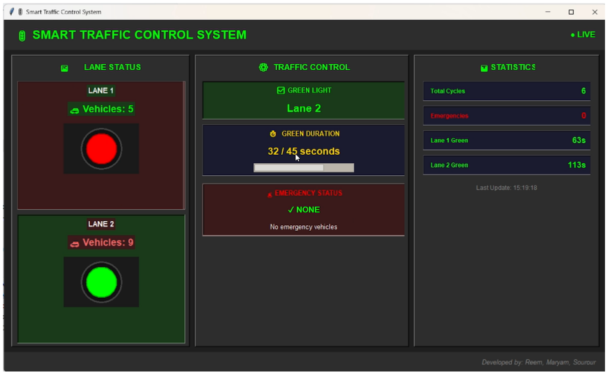

Figure 2.3: Dashboard of Smart traffic control system

2.5 Case Study:Adaptive Signal Timing

The most critical functionality of the smart traffic system is its ability to dynamically adjust green light duration based on observed demand, unlike traditional fixed-time models. The flowchart illustrates the traffic management algorithm used in the proposed system. It shows how signal timing is dynamically adjusted based on traffic density, rush intervals, and the presence of emergency vehicles. Normal traffic is managed through density and interval checks, while emergency vehicles are given priority to ensure smooth passage.

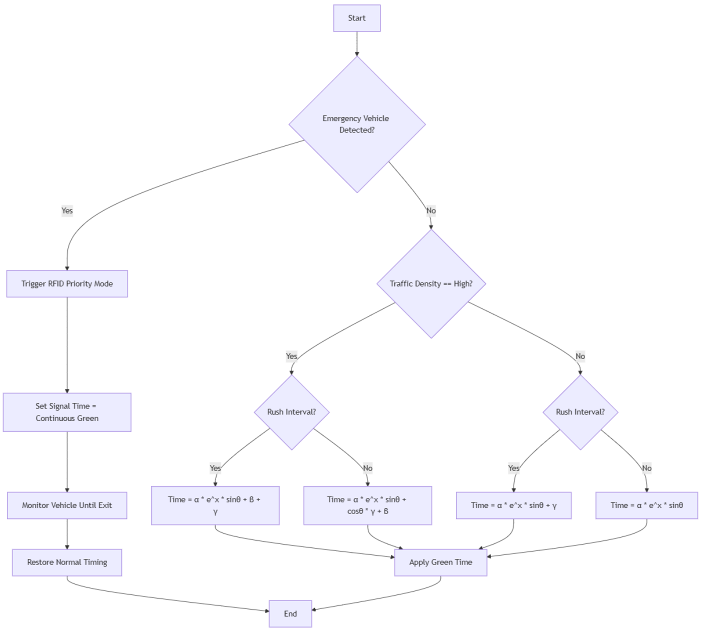

Figure 2.4: Traffic Management Algorithm

Chapter 3

MQTT Communication Protocol

3.1 What's MQTT?

MQTT stands for **Message Queuing Telemetry Transport** . It is a lightweight, open standard published subscriber protocol designed specifically for IOT applications[4].

3.1.1 MQTT Characteristics

- **Lightweight:**Minimale bandwidth(2-3 bytes)
- **Publish - Subscriber:** Decouples producers from consumers.
- **Reliability:** Qos (Quality of service) ensures 3 levels of Qos.
- **Scalabilty:** Can handles a thousands of devices.

3.1.2 Why MQtt for smart traffic?

Requirement	**Traditional API**	**MQTT Solution**
Multiple sensors	Direct connections	Publish to single topic
Real-time data	High latency	Sub-second latency
Bandwidth	High overhead	Minimal bandwidth
Scalability	Complex	Easy to add devices
Reliability	No guarantee	QoS levels
Device coupling	Tight coupling	Loose coupling

Table 3.1: MQTT advantages over traditional APIs

3.2 MQTT Architecture

As we can see in , it has a 3 components.

3.2.1 Components:

MQtt Broker:

We have a nultiple types of Broker , HiveMQ is the best for this application for several reasons:

- **Service:** HiveMQ Cloud (Free tier)
- **Address:** broker.hivemq.com
- **Port:** 1883 (non-secure)
- **SLA:** 99.9% uptime
- **Capacity:** Handles 1000s of devices and topics

Publisher:

Devices that send data to MQTT Broker In smart traffic , the publishers are the sensors.

Subscriber:

A device or software that receives messages from the MQTT broker.

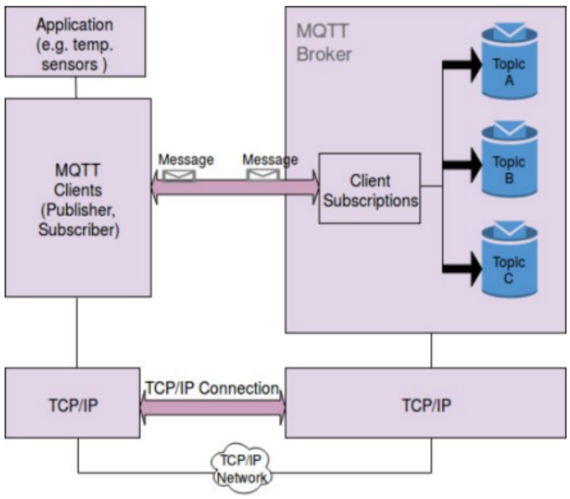

Figure 3.1: MQTT Architecture[4]

3.3 Quality of Service (QoS)

MQTT provides three QoS levels:

3.3.1 QoS Level 0: At Most Once

- **Guarantee:** Message delivered 0 or 1 times
- **Overhead:** Minimal

- **Use case:** Non-critical sensor readings (IR, Ultrasonic)
- **Behavior:** Fire and forget

3.3.2 QoS Level 1: At Least Once

- **Guarantee:** Message delivered 1 or more times
- **Overhead:** Moderate (acknowledgment required)
- **Use case:** Important data (emergency alerts, decisions)
- **Behavior:** Broker resends until acknowledged

3.3.3 QoS Level 2: Exactly Once

- **Guarantee:** Message delivered exactly once
- **Overhead:** High (complex handshake)
- **Use case:** Financial transactions (not used in traffic)
- **Behavior:** Four-way handshake for delivery

3.3.4 QoS Selection in Our System

Topic	**QoS**	**Reason**
traffic/lane1	0	Non-critical sensor data
traffic/lane2	0	Non-critical sensor data
traffic/emergency	1	Critical - must detect emergency
traffic/summary	1	Important operational data

Table 3.2: QoS level selection for each topic

Chapter 4

Simulation & Testing

4.1 Methodology

4.1.1 Purpose od Simulation

The purpose of this simulation is to demonstrate how smart traffic control systems can optimize traffic flow and enhance road safety using real-time sensor data.

4.1.2 Simulation Architecture

The simulation replaces real sensors with software that generates realistic data:

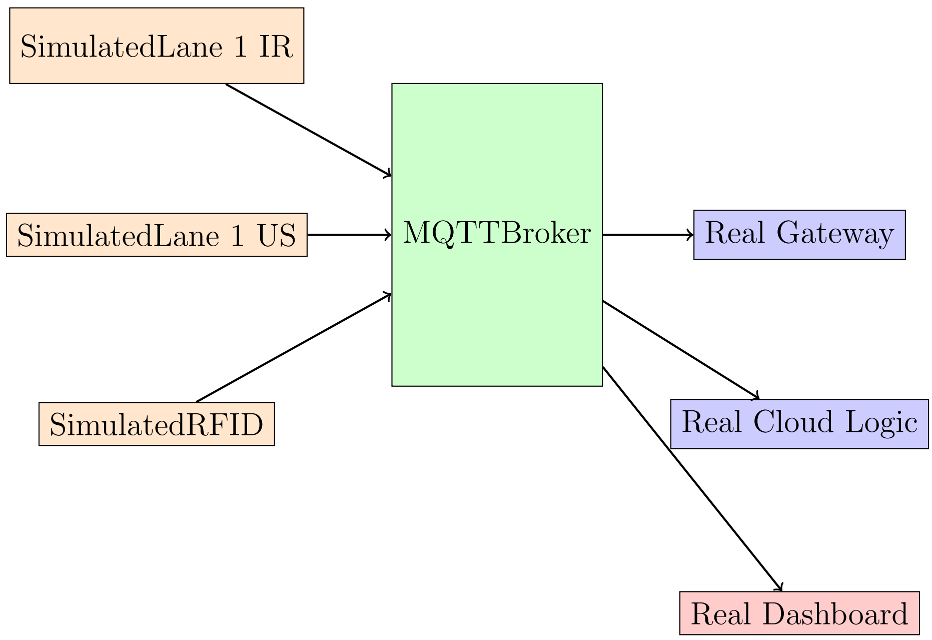

Figure 4.1: Simulation architecture: Real components with simulated sensors

4.2 Sensor Simualtion Details

4.2.1 MQTT Topics and Messages

Topic: traffic/lane1

Purpose

Transmit sensor data from Lane 1

Publishers

- Lane 1 IR sensor - Lane 1 Ultrasonic sensor

Subscribers

- Gateway

Message Format

```
# IR Sensor Message
{
    "lane": "Lane␣1",
    "sensor": "IR",
    "vehicle_detected": 0 or 1
}

# Ultrasonic Sensor Message
{
    "lane": "Lane␣1",
    "sensor": "Ultrasonic",
    "vehicle_count": 15"
}
```

Topic: traffic/lane2

Same structure as `traffic/lane1` but for Lane 2

Topic: traffic/emergency

Purpose

Transmit emergency vehicle detection

Publisher

- RFID emergency reader

Subscriber

- Gateway

Message Format

```
{
    "sensor": "RFID",
    "emergency": 0 or 1,
    "emergency_lane": "Lane 1" or "Lane 2" or null
}
```

4.3 Test Scenarios

4.3.1 Scenario 1: Normal Traffic

Parameter	Lane 1	Lane 2	Expected Result
Vehicle count	12	8	Green to Lane 1
Emergency	0	0	No priority
Calculated duration	-	-	10 + (12/20)*35 = 31s

Table 4.1: Scenario 1: Normal traffic

4.3.2 Scenario 2: Emergency Vehicle

Parameter	Lane 1	Lane 2	Expected Result
Vehicle count	8	8	Equal
Emergency	0	1	Green to Lane 2
Duration	-	-	45s (maximum)

Table 4.2: Scenario 2: Emergency vehicle detected

4.3.3 Scenario 3: High Congestion

Parameter	Lane 1	Lane 2	Expected Result
Vehicle count	18	20	Lane 2 has more
Emergency	0	0	No priority
Duration for Lane 2	-	-	10 + (20/38)*35 = 28s

Table 4.3: Scenario 3: High congestion on both lanes

4.3.4 Scenario 4: Low Traffic

Parameter	Lane 1	Lane 2	Expected Result
Vehicle count	2	1	Lane 1 has more
Emergency	0	0	No priority
Duration for Lane 1	-	-	10 + (2/3)*35 = 33s

Table 4.4: Scenario 4: Low traffic

4.4 Running the Simulation

4.4.1 Prerequisites

```
# Install Python 3.7+
# Install required library
pip install paho-mqtt
```

4.4.2 Execution Steps

```
# In separate terminals, run in order:
python lane1_ir.py
python lane1_ultrasonic.py
python lane2_ir.py
python lane2_ultrasonic.py
python rfid.py
python gateway_publsiher.py
python traffic_logic.py
python dashboard.py
```

Chapter 5

Conclusion

The four-layer IoT architecture provides a simple and effective way to build smart traffic control systems. By separating sensing (Perception), data transmission (Network), analysis (Processing), and control (Application), the system can adapt to changing traffic conditions. This approach allows dynamic signal timing, reduces congestion, and improves overall urban mobility, showing the real benefits of IoT in smart cities.

Bibliography

[1] Sabeen Javaid, Ali Sufian, Saima Pervaiz, and Mehak Tanveer. Smart traffic management system using internet of things. In *2018 20th international conference on advanced communication technology (ICACT)*, pages 393–398. IEEE, 2018.

[2] Hossein Shahinzadeh, Jalal Moradi, Gevork B Gharehpetian, Hamed Nafisi, and Mehrdad Abedi. Iot architecture for smart grids. In *2019 International Conference on Protection and Automation of Power System (IPAPS)*, pages 22–30. IEEE, 2019.

[3] Abida Sharif, Jianping Li, Mudassir Khalil, Rajesh Kumar, Muhammad Sharif, Atiqa Sharif, and Raja Kumar. Internet of things — smart traffic management system for smart cities using big data analytics. 11 2018.

[4] Dipa Soni and Ashwin Makwana. A survey on mqtt: a protocol of internet of things (iot). In *International conference on telecommunication, power analysis and computing techniques (ICTPACT-2017)*, volume 20, 2017.

[5] Andrea Zanella, Nicola Bui, Angelo Castellani, Lorenzo Vangelista, and Michele Zorzi. Internet of things for smart cities. *IEEE Internet of Things journal*, 1(1):22–32, 2014.