1. Introduction & Problem Context

Ineffective collection schedules are a common problem for urban garbage management systems. Increased operating expenses, traffic congestion, and poor urban cleanliness are the results of some waste containers overflowing before collection and others being emptied too soon.
In order to ensure timely collection with the least amount of resource consumption, this project suggests a Smart IoT-enabled Waste Bin Network that continuously checks bin fill levels and dynamically optimizes garbage truck routes throughout city zones.

2. Suggested System Architecture

2.1 Overview of the System

The system uses a mixed communication architecture and is intended for widespread city deployment (10,000 bins throughout Hyderabad):

NB-IoT for crucial areas and pilot zones

LoRaWAN for extensive, low-cost urban deployment

2.2 Each Trash Bin's Hardware

- Sensor for Fill Level- The Ultrasonic Sensor-Reliable, inexpensive distance measurement
- Microcontroller- STM32/ESP32 as Flexible, low-power peripherals
- Connectivity- LoRa radio or NB-IoT modem- Long-range coverage at the city level
- Strength- Li-ion battery plus a tiny solar panel permits operation for several months
- Outdoor IP-rated casingWeather and tamper resistance

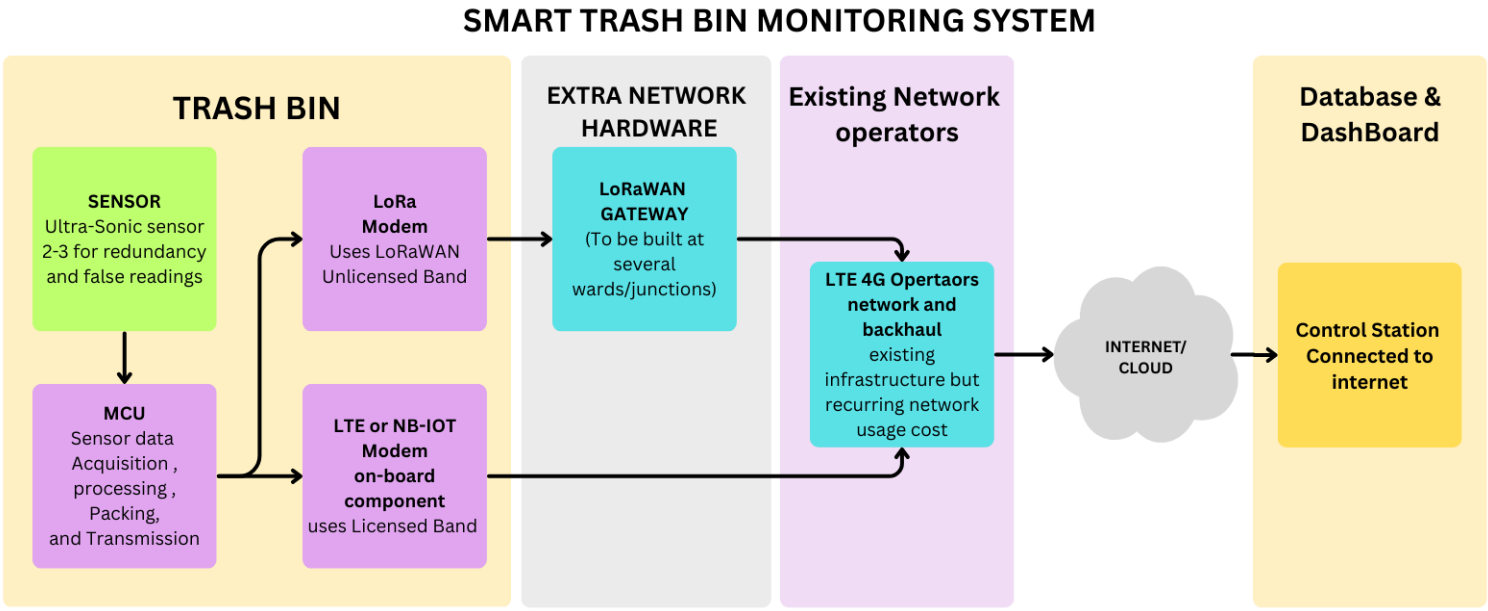
Note: LORAWAN based system requires extra hardware which act as network gateways for several bins to connect and send data to control stations.

The network architecture to be chosen is **stars of star** topology where each bin is not constrained to one gateway node but to several gateways present in its range and differentiated based on the Bin ID.
Each LoRaWAN gateway

Would be connected back to the internet using 4G LTE or 5G network to the internet using the standard modems available in the market.

The following proposed system involves two methods for network connectivity-

1. NB-IOT network
2. LoRaWAN network



3. Design and Protocols for Data Flow

3.1 Data Flow:

Sensor → MCU → Communication Module → Network → Cloud → Database → Dashboard → Optimization Engine

3.2 Protocols for Communication:

MQTT Scalable, low-power, and lightweight → Cloud
Cloud → Dashboard REST/HTTP Simple alerts for integration Webhooks and Push Real-time alerts

3.2 Data Packing:

Use Ward number for bin identification, city block number and assign ID for areas like Indranagar(eg. ID- 21), 4th block, 3rd ward, 1st main, bin number 2- data packet format- **2104030102** : **Area code, block, ward, main, bin id.**
Gateways will not have explicit addressing for identification as they would be unnecessary.

4. Strategy for Route Optimization

4.1 Rules for Making Decisions

- Bin full ≥ 80% is a high priority.
- 60–80% is the medium priority.
- Low Priority: less than 60%

4.2 Algorithm for Optimization

- Sort high-priority containers.
- Zone-based clustering.
- Create truck routes that are optimum and assign tasks to trucks based on density of bins to be collected.

5. Power Management Strategy MethodAn explanation

- MCU takes deep naps in between measurements.
- The number of measurements and transmission will be 2-3 times per day.
- Transmission Driven by EventsOnly threshold or daily report data is sent using data analytics for prediction based frequency of operation from control station.
- Radio Modes with Low Power LoRa sleep modes and NB-IoT PSM.
- Battery life is extended via solar charging.
- Including MOSFET for cutting off and powering on the transmitter modem only when needed.

6. Reliability & Fault Handling

Issue	Solution
False readings	Median filtering & multi-sample validation
Blocked sensor	Timeout detection → maintenance alert
Node failure	Heartbeat monitoring
Calibration	Monthly auto-calibration cycle

7. Network Design Topology and Scalability

- NB-IoT star topology- Need for designing the network topology and maintenance is negligible as it is maintained by mobile network services.
- LoRaWAN star-of-stars topology, high networking cost and complexity of building and maintaining.
- By dispersing entrances and zoning the city, the design accommodates more than 1,000 bins.

8. Cost & Feasibility Analysis

Estimated Per-Bin Cost

Item	Cost (INR)
MCU + Connectivity	1,500 – 3,500
Sensor + Power + Enclosure	1,000 – 1,500
Total	**approx. 2,500 – 5,000 per bin**

- The upfront cost of both systems is high but the recurring cost of NB-IOT cannot ignored- the cost of network paid to the network provider.
- NB-IOT Network- Yearly network plans can be helpful as they provide cheaper plans for low data consumption and zero talk-time.
- LoRaWAN will have initial hardware cost for network gateways at each ward and again connecting to the internet would be coming to the same cost. But LoRa systems can have longer battery life.

9. Conclusion

Feature	LoRaWAN	NB-IoT
Network ownership	Private network (own gateways)	Operator-managed cellular network
Topology	Star-of-stars	Star
Recurring cost	Low (Internet at gateways)	Moderate (SIM + data plan)
Infrastructure cost	Higher initial (gateways)	Lower (no gateways)
Power consumption	**Very low**	Low
Battery life	Longer	Slightly shorter
Scalability	Very high (10k+ nodes)	Very high (10k+ nodes)
Deployment complexity	Medium–High	**Low**