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AquaVision: Scalable IoT-Based Smart Aquaculture Management System with Individual Fish Tracking

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2 - The report is NOT prepared for an engineering audience:
- It is text-based with almost no illustrative figures/diagrams
- The schematic diagram presented in this report does NOT meet the requirements stated in the Project Document.

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4- Executive Summary

AquaVision is a comprehensive **Internet of Things (IoT)** solution designed for commercial-scale smart aquaculture, built on a modular, four-tier hierarchical architecture that allows for **full customization** based on farm size and complexity. While this report details a representative installation featuring **50 sensor nodes** distributed across the farm, the design is inherently scalable to meet varying operational demands. The system's goal is to optimize farm productivity, reduce operational costs, and improve fish health outcomes. At the base, sensor nodes continuously monitor critical environmental parameters (temperature, pH, dissolved oxygen) and employ **Low-Frequency Radio-Frequency Identification (LF-RFID)** to track **7,500 fish** individually for unprecedented behavioral and growth insights.

The Network Layer aggregates this massive dataset via **LoRaWAN** from 5 collector nodes, capitalizing on the protocol's long-range and **ultra-low power consumption**, and ensures reliable, low-latency transmission to the central controller through **wired Ethernet** connections. The **Edge Computing Layer**, built around a **Raspberry Pi 5** central node, provides the system's local intelligence and resilience. This node features a 10.1-inch **touchscreen dashboard** for on-site managers and performs **edge AI inference** for immediate control actions. Bidirectional communication with the remote **AWS IoT Cloud** is established using the secure **MQTT-TLS** protocol over **4G LTE**. Leveraging the Cloud Application Layer, **advanced AI algorithms** analyze historical and real-time data using services like AWS SageMaker and RDS to optimize water quality, predict feeding schedules, and facilitate early **disease outbreak detection**, thereby driving critical, data-driven decisions.

End-users interact with the system through two intuitive interfaces: the local **touchscreen dashboard** for real-time manual control, and a **mobile application** for remote oversight. The mobile app's centerpiece is an **AI-powered chatbot** that supports natural language queries for instant status updates and control commands, complemented by immediate **push notifications** and SMS alerts for critical events. AquaVision represents a **transformative approach** to sustainable aquaculture, positioning fish farms for increased **profitability** and **environmental sustainability** by significantly reducing manual labor and minimizing resource waste through continuous, **AI-driven analytics**.

5- Name of IoT Vertical Application

AquaVision operates squarely within the **Smart Agriculture** vertical, specifically focusing on **Smart Aquaculture** and Precision Fish Farming. The system's primary goal is to transform traditional commercial fish farms into highly efficient, **data-driven** operations by continuously monitoring critical biological and environmental parameters, such as **water quality** and individual **fish welfare**. The deployment aims to optimize resource consumption, maximize yield, and ensure the **environmental sustainability** of modern fish farming practices, positioning it as a key application in the future of food technology [1].

6- Functions Performed by the IOT System

6.1 Individual Fish Tracking via LF-RFID

AquaVision implements a revolutionary fish tracking system using passive Low-Frequency Radio-Frequency Identification (LF-RFID) technology operating at 125 kHz. Each fish in the farm receives a biocompatible glass tube implant (12mm × 2mm dimensions) containing a

Please provide a photo showing a fish implanted with biocompatible glass tube

- What are the tank's dimensions?
- How many RFID Readers are placed on ONE tank?
- How to make sure that ALL fishes inside a tank are continuously monitored?

passive RFID transponder during initial stocking procedures performed by trained veterinarians.

RDM6300 RFID readers integrated into each tank's sensor node continuously scan for tagged fish within a 5-10 cm detection radius. When a fish swims near the reader antenna (typically positioned at feeding zones or circulation areas), the system captures the fish's unique identification number, timestamp, and signal strength (RSSI), creating a comprehensive movement database.

Do you get weight information on fish from RFID detection?
- If YES, explain how.
- If NO, how would you perform growth tracking in an automatic way?

Key Capabilities:

- **Growth Monitoring:** By correlating RFID detections with manual weight measurements during periodic handling, the system tracks individual fish growth rates and identifies slow-growing or potentially diseased individuals requiring intervention.
- **Feeding Behavior Analysis:** Detection frequency at feeding zones indicates appetite levels and feeding competition dynamics, enabling optimization of feeding schedules and quantities to reduce waste while maximizing growth.
- **Mortality Detection:** Fish that show no RFID detections for extended periods (typically 24-48 hours depending on tank size and fish species) trigger mortality alerts, allowing prompt removal of dead fish to prevent water quality degradation.
- **Movement Pattern Analysis:** Unusual movement patterns, such as increased surface activity or lethargic behavior (reduced detection frequency), can indicate environmental stress, disease onset, or water quality issues requiring immediate attention.
- **Inventory Management:** Automated fish counting provides real-time inventory data, eliminating manual counting errors and enabling precise harvest planning and restocking decisions.

This individual tracking capability represents a significant advancement over traditional aquaculture monitoring systems that only measure aggregate environmental parameters without insight into individual fish welfare and behavior.

Should clarify the basis on which these capabilities are stated !!!
(Give a reference that confirms these capabilities
or give detailed clarification of how each feature is realized)

6.2 Multi-Tank Water Quality Monitoring

AquaVision continuously monitors four critical water quality parameters across all 50 tanks simultaneously, ensuring optimal environmental conditions for fish health and growth:

- **Temperature Monitoring:** DS18B20 waterproof digital temperature sensors measure water temperature with ±0.5°C accuracy every 5 minutes. The system maintains species-specific optimal temperature ranges (typically 25-30°C for tilapia, 24-28°C for catfish) and triggers cooling/heating actions when thresholds are exceeded. Temperature data correlates with dissolved oxygen levels and fish metabolic rates, informing feeding and aeration decisions.
- **pH Level Monitoring:** Analog pH sensors track water acidity/alkalinity every 10 minutes with ±0.1 pH unit accuracy. Fish health critically depends on maintaining species-appropriate pH levels (typically 6.5-8.5 for most species). Deviations trigger alerts and guide water treatment interventions such as lime addition (raise pH) or carbon dioxide injection (lower pH).

Give reference

- **Dissolved Oxygen (DO) Monitoring:** Galvanic or optical dissolved oxygen sensors measure oxygen concentration every 5 minutes with ±0.5 mg/L accuracy. DO levels below

Give reference

5 mg/L cause stress; below 3 mg/L causes fish mortality. The system automatically activates aerators when DO drops below 7 mg/L, maintaining a safety margin and ensuring continuous oxygen availability for fish respiration.

- **Water Level Monitoring:** HC-SR04 ultrasonic sensors mounted above each tank measure water depth every 10 minutes with ±1 cm accuracy. Low water levels indicate evaporation or leaks requiring attention; high levels suggest pump malfunctions or overflow risks. Automated pumps maintain target water levels, ensuring proper tank hydraulics and filtration system operation.

The simultaneous monitoring of all 50 tanks enables comparative analysis, identifying systemic issues (affecting multiple tanks) versus localized problems (single tank anomalies), accelerating troubleshooting and reducing response times.

6.3 Hierarchical Data Aggregation (Star Topology)

AquaVision employs a carefully designed hierarchical architecture that balances system scalability, power efficiency, and communication reliability through a star network topology at each hierarchical level.

- **Sensor Node Layer:** Each of the 50 sensor nodes operates independently, collecting data from attached sensors and RFID readers. Nodes use ultra-low-power sleep modes between measurements, waking only to read sensors (30 seconds every 5 minutes) and transmit data packets (2-3 seconds per transmission), achieving multi-year battery life from a single 18650 Li-ion cell.
- **Collector Node Layer:** Five collector nodes (Raspberry Pi Zero W with LoRa HAT modules) serve as LoRaWAN gateways, each managing 10 sensor nodes in a star configuration. Collector nodes remain continuously powered via wall adapters, performing several critical functions:
  - **Data Aggregation:** Receiving and buffering data packets from 10 sensor nodes, reducing the number of connections the central node must manage from 50 to 5.
  - **Local Processing:** Basic data validation, outlier detection, and timestamp synchronization to ensure data quality before forwarding to the central node.
  - **Fault Isolation:** If one collector fails, only 10 tanks are affected; the remaining 40 tanks continue normal operation, ensuring system resilience.
- **Central Node Layer:** The Raspberry Pi 5-based central node receives aggregated data from all 5 collectors via wired Ethernet connections (one RJ45 cable per collector). Ethernet provides gigabit bandwidth, sub-millisecond latency, and immunity to wireless interference, ensuring reliable real-time control for critical applications like emergency aerator activation

Star Topology Justification:

The deliberate choice of star topology over mesh networks (common in systems like ZigBee) provides several advantages:

1. **Simplified Routing:** Direct point-to-point communication eliminates complex mesh routing algorithms, reducing software complexity and potential failure modes.
2. **Predictable Latency:** Star topology guarantees single-hop communication with consistent, minimal latency, critical for real-time control applications.

FIVE pages of text without a single drawing !!!
This is NOT an acceptable engineering report !!!

3. **Power Efficiency:** Sensor nodes transmit only to their collector (not relaying for other nodes), minimizing transmission time and power consumption.
4. **Scalability:** Adding new sensor nodes requires only registering them with the nearest collector; no mesh re-optimization needed.
5. **Fault Tolerance:** Collector failures are isolated; nodes do not depend on neighboring nodes for connectivity.

6.4 AI-Powered Water Quality Optimization

Where is the AI Module hosted?

AquaVision's cloud-based AI engine continuously analyzes sensor data alongside external factors (weather forecasts, seasonal patterns, fish growth stage) to dynamically optimize water quality parameters and predict future conditions.

Machine Learning Models:

- **Water Quality Prediction Model:** A time-series forecasting model (LSTM neural network) trained on historical data predicts temperature, pH, and DO levels 6-24 hours ahead based on current readings, time of day, weather forecasts, and seasonal trends. Predictions enable proactive interventions (e.g., pre-cooling water before predicted hot afternoon) rather than reactive responses.
- **Optimal Setpoint Recommendation:** Reinforcement learning algorithms optimize water quality target setpoints dynamically rather than using fixed thresholds. For example, during rapid fish growth phases, the system may recommend slightly elevated DO levels (9-10 mg/L instead of standard 8 mg/L) to support increased metabolic demands, maximizing growth rates while managing energy costs.
- **Anomaly Detection:** Unsupervised learning algorithms (autoencoders) detect unusual patterns in sensor data that may indicate equipment malfunctions (stuck sensor readings), water quality events (sudden pH drops from feed decomposition), or disease outbreaks (temperature spikes from bacterial infections) before they become critical.
- **Energy Optimization:** AI models balance fish welfare requirements against energy costs by optimizing aerator runtime schedules. For example, running aerators at full capacity during cooler nighttime hours (when DO naturally drops) and reducing daytime aeration (when photosynthesis produces oxygen) minimizes electricity costs while maintaining safety margins.
- **Adaptive Control:** Unlike traditional fixed-threshold systems (e.g., "activate aerator if DO < 7 mg/L"), AI-driven control adapts to changing conditions. During feeding periods when fish consume more oxygen, the system preemptively increases aeration; during inactive nighttime periods with low oxygen demand, it conserves energy.

6.5 Predictive Disease Detection and Prevention

Early disease detection is critical in aquaculture; delayed intervention can result in high mortality rates and significant economic losses. AquaVision combines environmental monitoring with fish behavior analysis to predict disease outbreaks before visible clinical signs appear.

Multi-Modal Analysis:

- **Environmental Risk Factors:** Certain water quality patterns correlate with increased disease susceptibility:

- Prolonged elevated temperatures (>32°C) stress fish immune systems
- pH fluctuations indicate ammonia/nitrite issues that harm fish gills
- Low DO levels weaken fish, making them vulnerable to pathogens

The system assigns risk scores based on how long conditions remain suboptimal, triggering preventive alerts when cumulative risk exceeds thresholds.

- **Behavioral Indicators:** RFID tracking reveals behavioral changes that precede visible disease symptoms:
  - **Reduced Activity:** Sick fish show decreased movement (fewer RFID detections per day)
  - **Surface Gathering:** Fish gasping at the surface (increased detections near surface-mounted RFID readers) indicate respiratory distress
  - **Feeding Reluctance:** Reduced detections at feeding zones indicate appetite loss, an early disease symptom
- **Predictive Models:** Historical data from previous disease outbreaks trains classification models to recognize patterns preceding infections. When current data matches these patterns, the system issues early warnings with recommended actions (increase monitoring frequency, prepare medication, reduce feeding to minimize organic load).
- **Preventive Interventions:** Upon detecting elevated disease risk, the system recommends preventive measures:
  - Prophylactic salt treatments to reduce pathogen loads
  - Probiotic supplementation to strengthen fish immunity
  - Water exchange schedules to dilute pathogen concentrations
  - Reduced stocking density in affected tanks to minimize transmission

6.6 Automated Feeding Optimization

Feed represents 50-70% of aquaculture operating costs; optimizing feeding efficiency directly impacts farm profitability. AquaVision's AI-driven feeding system minimizes waste while maximizing fish growth through data-driven feeding schedules.

Dynamic Feed Scheduling:

- **Growth-Stage Adaptation:** Feeding requirements change throughout the fish life cycle. Fingerlings (juvenile fish) require frequent small meals (4-6 times daily) with high-protein content, while market-size fish need less frequent feeding (2-3 times daily). The system adjusts feeding schedules automatically based on average fish age and growth rate data.
- **Environmental Compensation:** Water temperature directly affects fish metabolism and digestion. At optimal temperatures (27-29°C for tilapia), fish digest food efficiently and require normal rations. At lower temperatures (<24°C), metabolism slows; the system reduces feeding quantities to prevent uneaten feed accumulation and water quality degradation.
- **Appetite-Based Adjustment:** RFID detections at feeding zones reveal feeding intensity. High detection frequency during feeding indicates strong appetite; the system may increase next feeding quantity. Low detection frequency suggests satiation or stress; the system reduces feeding to prevent waste.
- **Feed Conversion Ratio (FCR) Optimization:** FCR measures feed efficiency (kg feed ÷ kg fish weight gain). Lower FCR indicates better efficiency. The system tracks FCR per

tank, identifying underperforming tanks requiring investigation (disease, poor water quality, equipment malfunction) and high-performing tanks whose conditions can be replicated elsewhere.

- **Automated Dispenser Control:** Servo-motor-controlled feeders receive commands from the central node, dispensing precise feed quantities at scheduled times. Manual override capabilities allow farm managers to adjust feeding for special circumstances (medication mixing, pre-harvest fasting).

6.7 Dual User Interface System

AquaVision recognizes that different users require different interfaces: on-site farm managers need immediate access to controls and detailed technical data, while remote farm owners need high-level overviews and the ability to check farm status conveniently.

Central Node Touchscreen Dashboard (On-Site Interface):

Raspberry Pi 5 drives a 10.1-inch capacitive touchscreen displaying a real-time dashboard built with React web framework, accessible via localhost web browser.

Dashboard Components:

- **Farm Overview Panel:** Total tanks (50), total fish count (sum of RFID-detected fish across all tanks), active alert count, system health indicators (all collectors online, cloud connectivity status, battery levels for wireless nodes).
- **Tank Status Grid:** 10×5 grid visualization with each cell representing one tank, color-coded by status:
    - Green: All parameters within optimal ranges
    - Yellow: One or more parameters approaching thresholds (warning)
    - Red: Critical condition requiring immediate action
    - Gray: No data received (communication failure or powered off)
- **Detailed Tank View:** Selecting a tank displays real-time gauges (analog-style circular gauges for temperature, pH, DO; linear gauge for water level), 24-hour trend graphs, current fish count, and recent RFID activity timeline.
- **Manual Control Panel:** Farm managers can manually override automated controls:
    - Emergency stop (shuts down all actuators)
    - Per-tank aerator on/off toggle
    - Feeding dispenser manual trigger
    - Water pump start/stop
- **Alert Management:** Prioritized list of active alerts with acknowledge/dismiss buttons, alert history log with timestamps and resolution notes, and alert statistics dashboard showing most frequent issues.

Mobile Application (Remote Owner Interface):

Flutter-based cross-platform mobile app (iOS/Android) connects to AWS cloud backend via HTTPS REST API and WebSocket for real-time updates.

App Features:

- **AI Chatbot:** Natural language interface powered by AWS Lex or OpenAI API, allowing conversational queries:
    - User: "How is my farm doing today?"
    - AI: "Your farm is performing well. All 50 tanks are online. 3 tanks have minor temperature warnings (29-30°C) but within safe limits. Average fish growth rate this week: 45g per fish. No critical alerts."
- **Dashboard View:** Simplified overview showing key metrics (total fish, average temperature/pH/DO, active alerts) and tank grid with same color-coding as central display.
- **Push Notifications:** Critical alerts (DO below 5 mg/L, equipment failures) trigger immediate push notifications even when app is closed. High-priority alerts also send SMS as backup notification channel.
- **Remote Control:** Limited remote control for non-critical functions (acknowledge alerts, adjust automated feeding schedules, view detailed tank data). Critical controls (emergency stop, manual aerator activation) require on-site touchscreen access for safety.
- **Analytics:** Historical reports with graphs showing growth trends, FCR over time, water quality stability metrics, and cost analysis (feed consumption, electricity usage).

6.8 Scalable Commercial Deployment

AquaVision's architecture is designed from the ground up for commercial scalability, supporting farms ranging from 50 tanks (initial deployment) to hundreds or thousands of tanks across multiple farm sites.

Modular Expansion:

- **Adding Sensor Nodes:** New tanks require only:
    1. Install sensor node (ESP32-S3 + sensors + RFID reader + LoRa module) on tank
    2. Power on (node auto-configures and attempts to join nearest collector)
    3. Register node ID in central node configuration (automatic discovery possible) No changes to other nodes or system architecture required.
- **Adding Collectors:** When sensor node density exceeds 10 per collector, add new collector:

  This implies Collector nodes are within 100 meters from the Central node.
  This may NOT be feasible !!!

    1. Deploy Raspberry Pi Zero W with LoRa HAT in new zone
    2. Connect collector to central node via Ethernet
    3. Update central node routing table with new collector ID Sensor nodes automatically associate with strongest-signal collector.
- **Adding Farms:** Multiple farms can share a single AWS cloud infrastructure:
    - Each farm has unique Farm ID in database
    - Central nodes from all farms connect to same AWS IoT Core endpoint
    - Mobile app users select which farm to view from account dashboard
    - Cloud AI models can compare performance across farms, identifying best practices
- **Geographic Distribution:** Farms separated by large distances (different cities/countries) connect to geographically nearest AWS region to minimize latency. AWS global

infrastructure includes regions in Middle East (Bahrain), Europe (Frankfurt, Ireland), and Asia (Mumbai, Singapore), ensuring <200ms latency worldwide.

- **Cost Scaling:** Per-tank hardware costs decrease with volume (economy of scale for bulk component purchases). Cloud costs scale linearly with data volume (AWS charges per GB stored, per million API requests) but remain low ($0.10-0.50 per tank per month for typical data volumes). Energy savings from AI optimization (10-20% reduction in aerator runtime) often exceed cloud service costs.

7- TYPE OF DATA COLLECTED

7.1 Per-Tank Sensor Data

As shown in Table 1, each of the 50 sensor nodes collects environmental data from sensors connected to the ESP32-S3 microcontroller. The following table specifies data format, units, size, and collection frequency for each parameter:

Table 1 Per-Tank Environmental Sensor Data Specifications

Parameter	Data Format	Units	Size (Bytes)	Range	Accuracy	Collection Frequency	Critical Threshold	Purpose
Tank ID	Unsigned Integer (16-bit)	–	2	1–65535	Exact	Every reading	N/A	Tank identification and mapping in database
Timestamp	Unix Epoch (32-bit)	Seconds since 1970	4	0–4.29B	±1 sec	Every reading	N/A	Time reference for correlating measurements
Temperature	Float (32-bit IEEE 754)	°C	4	-55 to +125	±0.5°C	Every 5 min	>32°C (High), <24°C (Low)	Fish metabolic rate control & stress prevention
pH Level	Float (32-bit IEEE 754)	pH units	4	0–14	±0.1 pH	Every 10 min	<6.5 (Low), >8.5 (High)	Maintain ideal alkalinity/acidity balance
Dissolved Oxygen (DO)	Float (32-bit IEEE 754)	mg/L	4	0–20	±0.5 mg/L	Every 5 min	<7 mg/L (Low), <5 mg/L (Critical)	Ensure oxygen availability for respiration
Water Level	Float (32-bit IEEE 754)	cm	4	0–200 cm	±1 cm	Every 10 min	<30 cm (Low), >180 cm (High)	Prevent overflow/underflow & maintain stability
Battery Voltage	Float (32-bit IEEE 754)	Volts	4	0–4.2V	±0.05V	Every reading	<3.3V (Low battery)	Monitor node power health
Signal Strength (RSSI)	Signed Integer (8-bit)	dBm	1	-120 to 0 dBm	±2 dBm	Every reading	< -110 dBm (Weak link)	Evaluate wireless connectivity quality

Total Packet Size per Reading: 2 + 4 + 4 + 4 + 4 + 4 + 4 + 1 = **27 bytes**

Collection Schedule:

- Temperature and DO: Every 5 minutes (critical parameters requiring frequent monitoring)

- pH and Water Level: Every 10 minutes (slower-changing parameters)
- All readings include Tank ID, Timestamp, Battery Voltage, and RSSI metadata

Daily Data Volume per Tank:

- 5-minute readings: (24 hours × 60 min ÷ 5 min) = 288 readings/day
- 10-minute readings: (24 hours × 60 min ÷ 10 min) = 144 readings/day
- Average: ~220 readings/day per tank
- Data volume: 220 readings × 27 bytes = **5.94 KB/tank/day**
- **Total for 50 tanks: 297 KB/day ≈ 0.3 MB/day ≈ 9 MB/month**

Data Encoding: Sensor data is encoded in binary format for transmission efficiency over LoRaWAN (which has strict payload size limits of 51-222 bytes depending on spreading factor). The ESP32-S3 firmware constructs compact binary packets following this structure:

```
[Header: 2 bytes] [Tank ID: 2 bytes] [Timestamp: 4 bytes]
[Temp: 4 bytes] [pH: 4 bytes] [DO: 4 bytes] [Level: 4 bytes]
[Battery: 4 bytes] [RSSI: 1 byte] [Checksum: 2 bytes]
Total: 31 bytes (fits within smallest LoRaWAN payload size)
```

7.2 Fish Tracking Data (LF-RFID)

Provide frame format for the fields shown in Table 2, along with Header & CRC

As seen in Table 2, RFID readers continuously scan for tagged fish. Detection events are logged asynchronously (event-driven rather than periodic sampling) whenever a fish enters the reader's detection zone.

Table 2 Fish Tracking RFID Data Specifications

Parameter	Data Format	Units	Size (Bytes)	Range/Description	Collection Trigger	Purpose
Fish ID	String (12 chars ASCII)	-	12	Unique RFID tag UID (e.g., "3A4B5C6D7E8F")	When fish detected	Individual fish identification
Tank ID	Unsigned Integer (16-bit)	-	2	1-50	When fish detected	Current fish location
Detection Timestamp	Unix Epoch (32-bit)	Seconds	4	Current time	When fish detected	Movement timeline
Reader ID	Unsigned Integer (8-bit)	-	1	1-255	When fish detected	Which reader in tank (if multiple readers)
RSSI	Signed Integer (8-bit)	dBm	1	-60 to -20 dBm	When fish detected	Fish proximity estimation (closer = stronger signal)
Detection Duration	Unsigned Integer (16-bit)	Milliseconds	2	10-5000 ms	When fish detected	How long fish remained in detection zone

Total Packet Size per Detection: 12 + 2 + 4 + 1 + 1 + 2 = **22 bytes**

Detection Frequency: RFID detection frequency depends on fish activity patterns:

- **High Activity Periods (Feeding Time):** 10-20 detections per fish per hour (fish congregate near feeders where RFID readers are often positioned)

- **Normal Activity:** 2-5 detections per fish per hour (fish swim throughout tank, occasionally passing near reader)
- **Low Activity (Night):** 0.5-2 detections per fish per hour (fish rest on tank bottom or corners)

Estimated Daily Data Volume (Fish Tracking):

- Average detections per fish: ~100 detections/day (varies by species behavior)
- Fish per tank: 150
- Detections per tank per day: 150 fish × 100 = 15,000 detections
- Data per tank: 15,000 × 22 bytes = **330 KB/tank/day**
- **Total for 50 tanks: 16.5 MB/day ≈ 495 MB/month**

Storage Optimization: Raw RFID detection logs generate significant data volume. The system employs two-tier storage:

1. **Real-Time Edge Storage (Last 7 Days):** Full-resolution detection logs stored in Central Node local SQLite database for immediate analysis
2. **Cloud Long-Term Storage (Historical):** Aggregated summaries stored in AWS S3:
   - Per-fish daily summaries (total detections, average RSSI, time distribution)
   - Tank-level hourly summaries (total unique fish detected, movement heatmaps)
   - Reduces storage by ~95% while preserving analytical value

7.3 Collector Aggregated Data

Provide frame format for the fields shown in Table 3, along with Header & CRC

As seen in Table 3, collector nodes receive data from 10 sensor nodes, perform local aggregation, and forward consolidated packets to the central node via Ethernet.

Table 3 Collector Node Aggregated Data Structure

Parameter	Data Format	Units	Size (Bytes)	Frequency	Description
Collector ID	Unsigned Integer (8-bit)	-	1	Every transmission	Collector identification (1-5)
Timestamp	Unix Epoch (32-bit)	Seconds	4	Every transmission	Data collection timestamp
Number of Active Nodes	Unsigned Integer (8-bit)	Count	1	Every transmission	How many of 10 nodes successfully transmitted
Sensor Data Payload	Nested Array	Mixed	Variable (270-310 bytes)	Every 5 minutes	Contains all 10 sensor node readings
RFID Data Payload	Nested Array	Mixed	Variable (0-2000 bytes)	Batch every 10 minutes	Contains RFID detections since last transmission
Alert Flags	Bitfield (16-bit)	Flags	2	Every transmission	Per-tank critical alert status (1 bit per tank)
Collector Health	Struct	Mixed	8 bytes	Every transmission	CPU load, memory usage, uplink status

Transmission Frequency:

- **Environmental Data:** Every 5 minutes (synchronized with sensor node transmission schedule)
- **RFID Data:** Every 10 minutes (batched to reduce Ethernet traffic)
- **Alerts:** Immediate (out-of-band transmission if critical condition detected)

Daily Data Volume per Collector:

- Environmental data: 288 transmissions × 280 bytes avg = 80.6 KB/day
- RFID data: 144 batches × 500 bytes avg = 72 KB/day
- Total per collector: **~153 KB/day**
- **Total for 5 collectors: 765 KB/day ≈ 23 MB/month**

Ethernet Communication: Collectors connect to central node via CAT6 Ethernet cables (up to 100m length). TCP/IP protocol ensures reliable delivery with automatic retransmission of lost packets. Each collector is assigned a static IP address (192.168.10.11 through 192.168.10.15) on a dedicated IoT subnet isolated from farm office network for security.

Provide frame format for the fields shown in table 4, along with Header & CRC

7.4 Central Node to Cloud Data

As seen in Table 4, the central node aggregates data from all 5 collectors, performs edge AI processing, and forwards consolidated datasets to AWS IoT Cloud.

Table 4 Central Node to Cloud Data Transmission Structure

Parameter	Data Format	Units	Size (Bytes)	Frequency	Description
Farm ID	UUID (128-bit)	–	16	Every transmission	Unique farm identifier enabling multi-farm scalability
Transmission Timestamp	Unix Epoch (64-bit)	ms	8	Every transmission	High-precision timestamp for synchronization & ordering
Full Sensor Snapshot	JSON Object	–	5–10 KB	Every 15 min	Includes temperature, pH, DO, level for all tanks
Fish Tracking Batch	JSON Object	–	2–5 KB	Every 10 min	Aggregated LF-RFID movement logs & fish presence events
Alert Events	JSON Array	–	0–2 KB	On-trigger	Emergency conditions (low DO, high temp, abnormal pH)
System Health Report	JSON Object	–	1–2 KB	Hourly	Collector uptime, CPU %, RAM %, packet loss, storage usage
AI Inference Results	JSON Object	–	500–1000 B	Every 15 min	Predictive outputs (DO forecast, disease index, feed plan)

7.5 Data Format – JSON Sensor Snapshot

The central node periodically transmits a consolidated JSON payload to the cloud containing all active tank measurements. This structure ensures lightweight data transfer, efficient parsing, and seamless integration with AI pipelines.

Example JSON Packet – Real-Time Sensor Snapshot

```
{
  "farmId": "f47ac10b-58cc-4372-a567-0e02b2c3d479",
  "timestamp": 1701456789123,
  "tanks": [
    {
      "tankId": 1,
      "temp": 28.5,
      "ph": 7.2,
      "do": 9.1,
      "level": 145,
      "battery": 3.8,
      "rssi": -75
    }
    // ... 49 additional tank entries
  ]
}
```


7.6 Transmission Protocol

As shown in Table 5, all data is transferred using **MQTT-TLS over 4G LTE**, ensuring integrity, security, and guaranteed delivery even in rural network conditions

Table 5 MQTT Advantages for IoT Communication

Feature	Benefit
Publish/Subscribe Model	Efficient bidirectional messaging
QoS 1 Delivery	Guaranteed arrival with acknowledgement
Lightweight Header	~2 bytes → ideal for constrained networks
Persistent Sessions	Messages auto-buffer if connection drops

Daily Data Volume – Central → Cloud is seen in Table 6

Table 6 Daily Data Volume

Data Type	Size per Push	Frequency	Daily Total
Sensor Snapshot	~8 KB	every 15 min (96/day)	**~768 KB/day**
RFID Batch Upload	~3.5 KB	every 10 min (144/day)	**~504 KB/day**
Alerts	Variable	event-based	**10–50 KB/day**
Health Reports	~1.5 KB	hourly (24/day)	**36 KB/day**

Cloud → Central Node Download is seen in Table 7

Table 7 Cloud Download

Payload	Avg Size	Frequency	Daily Total
AI Setpoints & Corrections	5 KB	hourly	**120 KB/day**
Remote Commands	<10 KB	rare	negligible
Firmware Updates	50–100 MB	quarterly	infrequent burst

Cellular Data Plan Recommendation is seen in Table 8

Direction	Monthly Average
Upload	~40 MB
Download	~4.5 MB
Total	**~45–50 MB/month**

7.7 Bandwidth & Storage Evaluation

The system bandwidth is shown in Table 8

Table 8 System-Wide Data Volume Summary

Source	Daily Volume	Monthly Volume	Annual Volume	Storage Location
Environmental Sensor Data	0.3 MB	9 MB	108 MB	Local cache + RDS
RFID Raw Logs	16.5 MB	495 MB	5.9 GB	Local short-term (7d), S3
RFID Aggregated	0.8 MB	24 MB	288 MB	S3 permanent archive
Collector Batches	0.8 MB	23 MB	276 MB	Transit only
Cloud Upload	1.3 MB	40 MB	480 MB	AWS IoT → DB
Cloud Download	0.15 MB	4.5 MB	54 MB	Temporary
Total Network Traffic	**19.85 MB/day**	**596 MB/month**	**7.1 GB/year**	Distributed
Cloud Stored (Long-Term)	**2.1 MB/day**	**64 MB/month**	**768 MB/year**	S3 + RDS

As shown in Table 9. cloud Storage Cost Projection:

Table 9 Cloud Cost [2] [3]

Storage Type	Cost
AWS S3 Standard	$0.023/GB/month
Estimated long-term storage (768 MB/year)	**≈ $0.25/year**
RDS instance (500 GB capacity)	$60–100/month → supports **hundreds of farms**

As shown in Table 10, Bandwidth Optimization Strategies

Table 10 Bandwidth Optimization

Technique	Effect
Edge aggregation	reduces cloud RFID traffic by ~95%
Delta data transmission	send only changed values → less redundancy
gzip JSON compression	60–70% average size reduction
Scheduled bulk uploads	moves non-critical data to off-peak hours
Local 30-day cache	ensures zero data loss during outages

8- Information Presentation to End-User

AquaVision provides multi-layer access to farm data through a **local touchscreen dashboard**, a **remote mobile application**, and an **AI conversational interface** supported by intelligent alerting and decision-support logic. This ensures both on-site operators and remote owners receive continuous visibility, alerts, control capability, and predictive analytics.

8.1 Central Node Touchscreen Dashboard (On-Site Interface)

As shown in Table 11 and 12, the touchscreen dashboard acts as the primary Human-Machine Interface (HMI) inside the farm. It enables operational monitoring, manual override control, alert acknowledgement, and real-time visualization of all tank conditions.

Table 11 Hardware Configuration

Component	Specification
Controller	Raspberry Pi 5
CPU	Cortex-A76 Quad-core @ 2.4 GHz
RAM	4 GB
Display	10.1" Capacitive Touch (1280×800)
Protection	IP65 Waterproof enclosure
Mounting	Adjustable stand for eye-level operation

Table 12 Software Architecture

Layer	Technology
OS	Raspberry Pi OS (Debian)
Backend	Python 3.11 + Flask REST server
Frontend	React.js Web UI
Local Storage	SQLite (rolling 30-day buffer)
Access Mode	Chromium kiosk full-screen UI

Dashboard Structure Overview is seen in Figure 1

1) Status Bar — Always Visible

- Farm Name + ID
- Network Status (LTE/Wi-Fi/Ethernet)
- Cloud Sync Timer
- System Resource Usage (CPU / RAM / Disk)
- Active Alert Counter (Color Severity Indicator)

2) Farm Overview Panel

A high-level summary displayed in large overview tiles:

Metric	Example Display
Total Tanks	50 Tanks (50 online)
Fish Count	7,458 fish detected
Avg Temperature	28.2°C
Avg DO Level	8.7 mg/L
Active Alerts	2 Warnings — 0 Critical
Collector Status	5/5 operational

3) Tank Status Grid (10×5 Interactive Map)

Each square represents a single tank block as it appears visually:

Tank 1	Tank 2	Tank 3	Tank 4	Tank 5
Optimal	Warning	Critical	Offline	Optimal

Color Indicators:

- Optimal
- Warning
- Critical
- Offline

Tap any tile → Opens full analytics screen.

4) Detailed Tank View Panel

Displayed when a tank tile is selected.

Live Sensor Gauges

Parameter	Display Method
Temperature	Dial 0–40°C (cold/optimal/high/critical zones)
pH	Bar 4–10 with optimal band 6.5–8.0 highlighted
DO Oxygen	Speedometer 0–15 mg/L w/ threshold
Water Level	Vertical tank UI meter + percentage

Historical Graphs

- 24-hour line charts — Temperature / DO / pH / Water Level
- Markers: aeration, feeding, threshold breaches
- Zoom Levels: 1h / 6h / 24h / 7d

Fish Tracking Insights

- Fish Count trend (24 hr)
- Feeding activity detection curve
- Behavior health score
- Predicted growth (AI forecast)

Manual Overrides

Control	Mode
Aerator	On / Off / Auto
Feeder	Pulse-feed / Scheduled
Pump	Circulation enable / disable
Emergency Drain	**Double-confirm failsafe**

Back → Tank Grid

5) Alert Management System

Severity	Trigger	UI Response
Critical	DO <5 mg/L	Flashing red + Alarm
High	Temp >32°C or pH out-of-range	Yellow banner + Prompt
Medium	Low battery or weak signal	Log + Daily report
Low	Maintenance reminder	Weekly digest

Alert Panel Displays:

- Timestamp
- Root parameter cause
- Automated action taken
- Acknowledge / Dismiss / Open Tank View

7-day alert history is preserved.

6) Manual Global Control Panel

Control	Action
Emergency Stop All	Instant actuator shutdown
Pause AI Automation	Temporary manual override
Resume AI	Restore full autopilot
Bulk Feed / Aeration	Farm-wide command broadcast

Per-tank control remains accessible individually.

Figure 1 Dashboard Overview

8.2 Mobile Application Interface (Owner Remote Access)

As seen in figure 2, the mobile application replicates dashboard functionality with long-range access plus AI conversational control powered by cloud inference.

Figure 2 Mobile Dashboard Overview

s

8.3 AI Conversational Assistant

As shown in Table 13, the assistant allows natural language control and insight extraction.

Table 13 AI Capabilities

Query Type	Examples
Status	"How is the farm?"
Tank-specific	"Show me Tank 12 oxygen level"
Predictive	"Will I face DO problems tomorrow?"

Control	"Feed tanks now"
Analytics	"Growth trend for last month"

Supports follow-up context and Arabic/English bilingual usage.

8.4 Alert Notification & Escalation System

As seen in Table 14 and 15, AquaVision ensures no critical event goes unnoticed using **multichannel redundant alerting**.

Table 14 Alert Channels

Notification	Trigger Scope
UI Banner	All alerts
Push Notification	High + Critical
SMS Failover	Critical unacknowledged
Email Digest	Warnings + summaries

Table 15 Automated Intervention Examples

Condition	Action
Low DO detected	Aerator auto-enabled
High temp spike	Shading + circulation boost
Tank unresponsive	Reconnect attempts + alert
Mortality suspicion	Inspection request

9- Detailed Schematic Diagram for the Overall System

9.1 Physical Deployment Layout

As shown in Figure 3, the AquaVision deployment covers an **80m × 40m farm layout** (total area ≈ **3,200 m²**). The facility contains **50 circular grow-out tanks**, each 4m in diameter and 2m deep. Tanks are arranged in **5 rows × 10 columns**, with **2m spacing** between units to allow walkways and maintenance access.

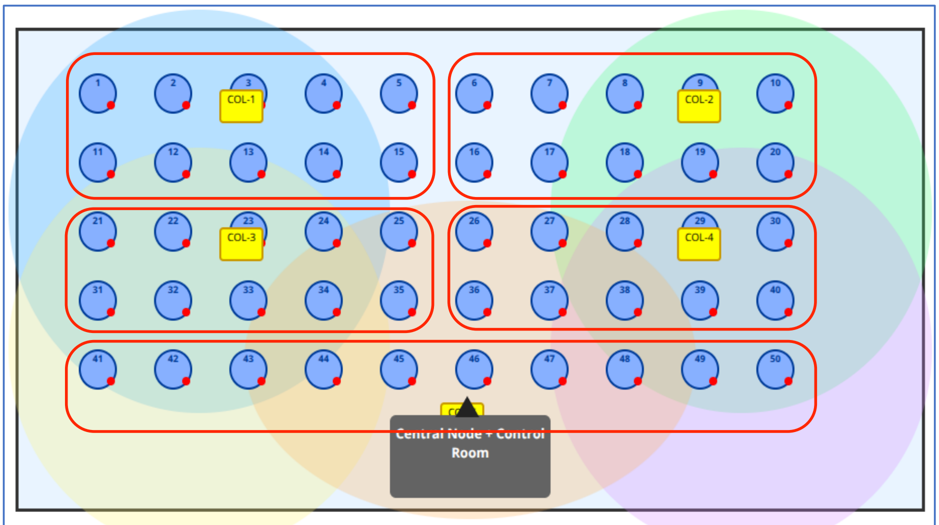


Figure 3 AQUAVISION FARM PHYSICAL LAYOUT (TOP VIEW)

The farm is logically subdivided into **five operating zones**, each containing **10 tanks**, distributed as seen in Table 16

This diagram needs to be revised and redrawn to show - for one representative tank - location of ALL SENSORS, ALL RFID Reader(s), ESP32-S3 µcontroller, as well as the pump, the feed and the aerator. Also show - for one representative zone - location of Collector node and the HW/SW used for its implementation. Further, show for the Central node, the links between it and the 5 Collector nodes, as well as the HW/SW used for Central node implementation. Furthermore, depict on your schematic diagram: the connectivity between the Central node and the Internet, the connectivity between the Internet and the Cloud, the HW/SW resources used in the Cloud and the interface to the End-User. Protocols used for data transfer over various links are to be shown, as well as the location of any SW modules deployed to enable protocol implementation.

Table 16 Zone Description

Zone	Tank Range	Approx. Physical Position
Zone 1	Tanks 1–10	Upper-Left quadrant
Zone 2	Tanks 11–20	Upper-Right quadrant
Zone 3	Tanks 21–30	Middle-Left region
Zone 4	Tanks 31–40	Middle-Right region
Zone 5	Tanks 41–50	Lower-Central region

Each zone is equipped with **one collector node placed centrally**. These collectors act as the uplink gateways for LoRa-based tank sensors. They are illustrated in the figure as **yellow blocks labeled COL-1 to COL-5**, each drawn with antenna markers to denote wireless capability. Every collector manages exactly **ten sensor nodes**, corresponding to its assigned tanks, and communication is strictly one-hop — **sensor → zone collector → central controller**. No peer-to-peer mesh paths exist, which reduces routing complexity and conserves power

9.2 Sensor Placement and Radio Coverage

Every tank hosts a **single embedded sensor node**, positioned physically at the tank rim. These are shown in Figure 3 as **small red dots** (SN-01 to SN-50). The deployment ensures that:

- All nodes are within the coverage radius of a nearby collector.
- Communication distance never exceeds **180m**, staying well within LoRa operational limits.
- Each collector's reception footprint is represented by colored circular zones (150–200m radius) as seen in Table 17:

Table 17 Zone Coverage

Zone	Coverage Color
Zone 1	Light Blue
Zone 2	Light Green
Zone 3	Light Yellow
Zone 4	Light Purple
Zone 5	Light Orange

These coverage rings overlap intentionally to provide redundancy against antenna misalignment, radio reflections, or environmental interference.

9.3 Central Node & Backhaul Connectivity

At the bottom of the layout appears the **Central Control Room**, drawn as a grey building. This is the processing hub of the system. All collectors connect to it via **CAT6 Ethernet cabling**, represented by converging blue lines. The longest physical run remains below **120m**, keeping signal attenuation minimal without requiring repeaters.

A roof-mounted **4G LTE antenna** is depicted above the control room to indicate cloud connectivity for telemetry, analytical processing, and remote supervision.

Finally, spatial annotations in Figure 4.1 document real-world deployment density:

- **Tank spacing:** ~2m aisle gaps allow maintenance access.
- **Maximum node-to-collector distance:** ≤180m.
- **Collector-to-central cable length:** ≤120m.

There is NO Fig. 4.1 !!!

- This structured arrangement ensures scalability, predictable RF behavior, and high-availability data acquisition across all 50 tanks

9.4 System Architecture

Figure 4 illustrates the overall network-to-cloud architecture of AquaVision using a four-tier hierarchy, where each layer performs a distinct role in sensing, collection, inference, storage, and human interaction.

Tier 1 — Perception Layer (Tank Nodes)

The bottom layer contains **50 embedded sensor nodes**, one assigned to each tank. They perform direct physical measurement — water temperature, pH, dissolved oxygen, water level, and RFID-based fish presence. This layer is the biological interface of the system. Energy is conserved through deep sleep cycles, ensuring months of untethered battery operation.

Why do you use batteries to energize your sensors/µ-controller? Is it NOT possible to provide electricity to each tank?

Tier 2 — Network Aggregation (Collectors)

Sensor telemetry is forwarded wirelessly to **five distributed collector gateways**, where packets are validated, time-stamped, optionally buffered, and routed to the next tier. Each collector is responsible for its own zone and handles no more than ten sensor endpoints, providing clear fault boundaries. This layer eliminates raw traffic flooding and significantly reduces cloud bandwidth costs.

Tier 3 — Edge Computing & Supervisory Control (Central Node)

At the farm control room resides the **edge intelligence layer**. This unit aggregates traffic from all collectors via Ethernet and performs:

- Local AI inference with sub-second latency
- Real-time dashboard rendering on the touchscreen
- Device control (aeration, feeding, pumps)
- On-site alert evaluation and risk prediction
- 30-day rolling data retention

The central node also manages cloud synchronization through an encrypted 4G connection.

Tier 4 — Cloud Platform and AI Services

The topmost tier comprises the AWS environment where long-term analytics, storage, user access, and AI modeling occur. Data from the farm is processed using pipeline services (IoT Core → Lambda → RDS/S3). Predictive models such as LSTM for water stability, Random Forest for disease risk, and RL-based feeding optimization execute here. Users access results through mobile/Web dashboards or via natural-language chatbot assistants

These facilities/resources are to be shown on the schematic diagram

Figure 4 AquaVision Four-Tier Architecture

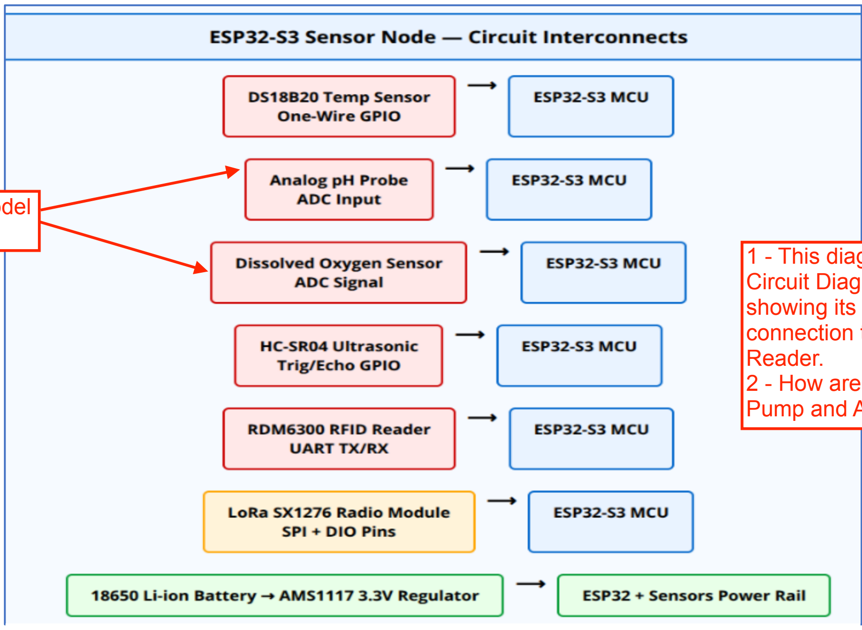
Enlarge font to make it legible.and use “Black” color for text.

Can ONE RFID Reader track 150 fishes in a tank of 4 meters diameter? I don't think so.

9.5 Type and Location of Sensors

Each of the 50 fish tanks in the AquaVision system is equipped with a multi-sensor IoT node designed to continuously monitor critical environmental parameters required for healthy and high-yield aquaculture. Every node integrates five sensing units — Temperature, pH, Dissolved Oxygen (DO), Water Level, and Fish RFID tracking — giving a system-wide total of **250 analog/digital sensors** and **50 RFID tracking arrays**.

What is the sensor brand/model for these measurements?



1 - This diagram should be replaced by a Circuit Diagram for ESP32-S3 MCU, showing its various ports and their connection to the various sensors/RFID Reader.
2 - How are control signals for Feed, Pump and Areator provided?

Figure 5 Sensors Connections

Need to show the information of this table usinng a drawing

All sensors are physically mounted directly at the tank location to ensure the highest accuracy and fastest feedback response. Placement and purpose are summarized in Table 18

Table 18 Sensor Location

Sensor Type	Mounting Location	Purpose
DS18B20 Waterproof Temperature Probe	Suspended 30 cm underwater	Monitors thermal conditions affecting metabolism and growth
Analog pH Sensor + Glass Electrode	Mid-depth, continuously submerged	Tracks acidity/alkalinity balance to prevent stress and mortality
Galvanic Dissolved Oxygen Probe	Near water inlet circulation	Measures oxygen availability for respiration and feeding patterns
HC-SR04 Ultrasonic Water-Level Sensor	1.5m above water surface	Prevents overflow/underfill; monitors evaporation and pumping state
Low-Frequency RFID Coil + RDM6300 Reader	Flat inside feeding/feeding-zone	Detects presence & movement of tagged fish (behavior mapping)

Each sensor module is contained inside an **IP67-rated polycarbonate enclosure**, positioned on the tank rim using a stainless-steel L-bracket. Cable glands protect all probes and maintain waterproof integrity. Antennas extend vertically to optimize LoRa reach toward the nearest zone collector.

This contradict with requiremennts that temperature sensor be placed inside water !!!

Since tank height is 2 meters, this means fish has less than 50 cm for its motion. This is TOO SHALOW !!!

The physical installation avoids direct sunlight (mounted north-side), minimizes condensation, and withstands humidity and splashing. Probes are fully submersed where necessary to ensure real biological exposure rather than surface-level measurement

9.6 Power Budget and Energy Model

Since each sensor node operates on a 3.7V 18650 lithium battery, long-life and low-power behavior are mandatory. The node's energy profile is optimized through deep-sleep cycling, duty-timing of sensors, and short-burst LoRa transmissions.

Table 19 Baseline Power Characteristics [4] [5]

Subsystem	Active Current	Avg. Duty Time	Avg Consumption
ESP32-S3 MCU	80 mA	30s/5min	~0.40 mA
LoRa TX Burst	120 mA	2s/5min	~0.08 mA
RFID Reader (duty cycled)	50 mA	10s/5min	~0.17 mA
DO Sensor	30 mA	5s/5min	~0.05 mA
pH Module	20 mA	5s/5min	~0.03 mA
HC-SR04 Ultrasonic	15 mA	2s/10min	~0.005 mA

As shown in Table 19, Average node draw ≈ 0.73 mA

With a 3000mAh cell:

= 4109 hours
= 171 days
= 5.7 months

$$Lifetime = \boxed{\frac{3000mAh}{0.73mA}} \approx \mathbf{8\text{–}10\ months}$$

With **solar trickle charging**, lifetime extends **beyond 18 months**, converting nodes into maintenance-light infrastructur

9.7 Type & Location of Actuators

Actuators are installed directly at each of the 50 aquaculture tanks and interface with the IoT control system through relay drivers.

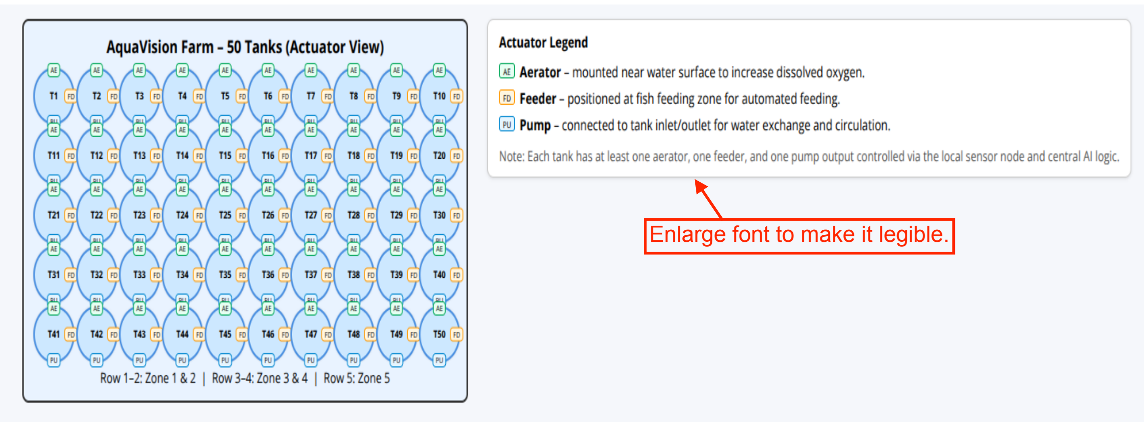


Figure 6 Actuator Layout on Physical Farm

Need to show the information of this table usinng a drawing

As seen in Figure 6, they appear on the schematic as actuator blocks surrounding each tank, with electrical routing linked to the nearest controller node.

Need to clarify this statement, and depict it on your drawing.

Table 20 Acuator Location

Actuator Type	Function	Physical Placement	Trigger Mechanism
Aerators	Increase dissolved oxygen through surface diffusion	One aerator mounted on upper tank rim	Auto-activated when DO <7 mg/L (critical <5 mg/L)
Auto-Feeders	Dispense feed pellets periodically	Mounted above tank feeding zone	AI-optimized feeding schedule based on growth + behavior trends
Water Pumps	Drain/renew water & increase circulation	Connected to outlet plumbing line	Used automatically for cooling, water exchange, emergency flush

Deployment Summary

- **Total Actuators Installed:**
  50 aerators + 50 feeders + 50 pumps = 150 active control nodes
- Controls operate **individually or globally** (per-tank or whole-farm).
- Commands originate from the **Central Edge Node**, routed via collector → node → actuator relays.

  Should be depicted on a drawing.
- This enables closed-loop automation driven by DO/pH status & AI feeding recommendations.

This mapping allows AquaVision to administer **oxygenation, feeding and circulation dynamically**, keeping water quality stable while optimizing energy + feed cost.

9.8 Type & Location of Gateways — Network Layer Distribution

Gateways form the **Tier-2 LoRaWAN aggregation layer**, receiving uplink data from tank nodes and transmitting it to the farm's core server

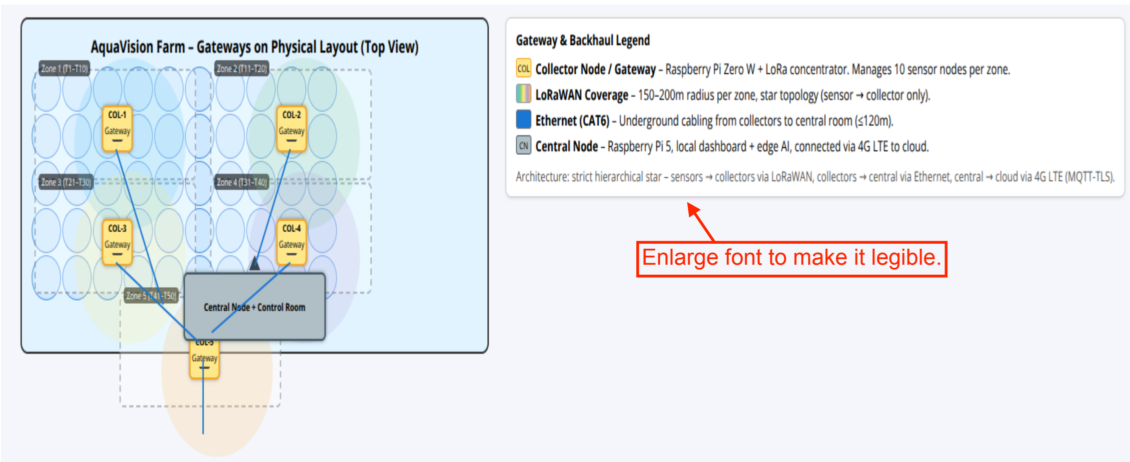


Figure 7 Gateway Placement

As seen in Figure 7, five gateways — marked **COL-1 through COL-5** — are placed **centrally inside each zone of ten tanks**, ensuring balanced RF coverage.

Gateway Responsibilities is shown in Table 21

Table 21 Gateway unction

Gateway Count	Coverage	Handled Devices	Connectivity
5 gateways	10 tanks per gateway	50 sensor units total	LoRaWAN uplink + Ethernet backhaul

Placement Justification

- Maximum **sensor-to-collector distance ≤180m**, well within LoRa link budget.
- Ethernet cabling from all 5 collectors converges into the **Central Control Room**, guaranteeing low-latency forwarding with no RF interference.
- Gateway fault isolation improves resiliency — failure disables only 10 tanks, not the entire farm.

This arrangement establishes a **hierarchical, star-based communication network** with predictable performance, minimal collisions and strong scalability.

9.9 Communication Technique — Sensor Nodes → Gateway

Communication Link: LoRaWAN 868 MHz
Topology: Star (not mesh)

Reason for Selection is shown in Table 22

Table 22 LoRaWAN Advantages [5] [6]

Advantage	Impact
Long range (up to 2-3 km open-field)	Easily covers farm radius with margin
Ultra-low power TX	Maximizes battery life of nodes
High penetration through humidity	Stable in wet aquaculture environment
Simple star routing	No re-routing, no mesh overhead

LoRaWAN offers the best trade-off between power, coverage, cost, and simplicity.

9.10 Communication Technique — Gateways → Central Node

Communication Link: CAT6 Ethernet (TCP/IP)

Justification:

- Guaranteed throughput even during high sensor traffic
- Electromagnetic immunity (important near motors & pumps)
- Zero packet-loss vs wireless mesh alternatives
- Supports PoE upgrades in future

Cable length constraints (≤120m) are satisfied in physical layout

9.11 Communication Technique — Internet Link (Central → Cloud)

Method: 4G LTE uplink with fallback to Wi-Fi when available

Reason for it is seen in Table 23

Table 23 4G LTE Benefits [7]

Benefit	Value
Works in remote farms with no wired internet	100% deployment flexibility
Cloud connectivity independent of local failures	High resiliency
Sufficient bandwidth for telemetry + firmware + analytics packets	Scales with farm size

Cloud sync rate ≈ **45–50 MB/month**, far below LTE capacity.

9.12 Software Protocol for Data Transfer (Cloud + Edge)

Protocol Selected: MQTT over TLS 1.2 encryption

You propose MQTT to send data from Central node to Cloud.
However, you did NOT explain how data is sent from Sensor node to Collector node, and from Collector node to Central node

Justification is detailed in Table 24

Table 24 MQTT Features [8]

Feature	Why it is appropriate
Lightweight & low overhead	Ideal for periodic sensor telemetry
Pub/Sub architecture	Supports scalable multi-client access
QoS delivery guarantees	Prevents data loss during signal drop
Persistent broker retention	Messages are saved if gateway offline

MQTT broker runs inside AWS IoT Core, cloud-side, and **MQTT client runs inside the Central Node**.

9.13 Backend Servers for Storage & Processing

Table 25 Backend Services [9]

Backend Service	Function
Amazon RDS (PostgreSQL)	Stores structured sensor data + RFID detections
Amazon S3	Long-term archive, AI model storage
DynamoDB	User sessions, chatbot memory, farm state cache
AWS Lambda	Event processing + real-time alerts
AWS SageMaker	AI inference for feeding, disease prediction, DO forecast

As seen in Table 25, these services execute analytics, forecasting, reinforcement optimization, and historical record storage.

9.14 Human Interface Layer (Man–Machine Interaction)

Two primary user interfaces exist:

Interface	Platform	Role
Central Touchscreen Dashboard	Raspberry Pi 5	On-site real-time monitoring & actuator control
Mobile Application + Cloud Portal	iOS / Android	Remote control, analytics, alert notification, AI chatbot

The combination ensures visibility **anywhere on site, anywhere off site**

Data for your references is incomplete !!!
Important details include:
Title of reference
Author(s) of reference
Date of reference
Name of Publication Authority or Publication Journal

10- References:

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[8] Banks, A., Briggs, E. *MQTT Version 3.1.1 Specification*. OASIS Standard, 2014.

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10.1 Appendix A: Acronyms and Abbreviations

Table 26 summarizes all acronyms used throughout this report for quick reference.

Table 26 Acronyms and Abbreviations[1]

Acronym	Full Meaning / Definition
AI	Artificial Intelligence
API	Application Programming Interface
AWS	Amazon Web Services
BNC	Bayonet Neill–Concelman Connector (for pH probe)
CPU	Central Processing Unit
CSS	Cascading Style Sheets
DO	Dissolved Oxygen
ESP32-S3	Espressif Systems Dual-Core MCU Series
FCR	Feed Conversion Ratio
GB	Gigabyte
GPIO	General Purpose Input/Output
GSM / LTE	Long-Term Evolution Cellular Network
HTML	HyperText Markup Language
HTTP/HTTPS	Hypertext Transfer Protocol / Secure TLS Version
IoT	Internet of Things
IP67	Ingress Protection Rating (Dust-tight + Immersion Protected)
JSON	JavaScript Object Notation
LCD	Liquid Crystal Display
LF RFID	Low-Frequency Radio-Frequency Identification (125 kHz)
LMIC	LoRaWAN MAC Implementation in C
LoRa	Long Range Radio Modulation
LoRaWAN	Long Range Wide Area Network

LSTM	Long Short-Term Memory Neural Model
MQTT	Message Queuing Telemetry Transport Protocol
NFC (if used later)	Near-Field Communication
NTP	Network Time Protocol
PCB	Printed Circuit Board
pH	Potential of Hydrogen (acidity measure)
QoS	Quality of Service Level
RAM	Random Access Memory
RDS	Relational Database Service (AWS PostgreSQL)
RFID	Radio-Frequency Identification
RFM95W	LoRa Radio Module (SX1276 chipset)
RPM	Revolutions Per Minute (motor/pump units)
S3	Simple Storage Service (AWS)
SD Card / microSD	Secure Digital Memory Storage
SDK	Software Development Kit
SLA	Service Level Agreement
SMBus/I2C	Inter-Integrated Circuit Serial Bus
SMS	Short Message Service
SPI	Serial Peripheral Interface
SQL	Structured Query Language
TLS	Transport Layer Security
UART	Universal Asynchronous Receiver Transmitter
UI	User Interface
UPS	Uninterruptible Power Supply
UUID	Universally Unique Identifier
VPN (if added later)	Virtual Private Network
Wi-Fi	Wireless Fidelity (local wireless standard)