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| RESEARCH ARTICLE

Implementation of a Low Latency Communication Framework for Internet of Things Based Industrial Automation

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| ARTICLE INFORMATION

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| ABSTRACT

The integration of the Internet of Things (IoT) with industrial automation systems has revolutionized manufacturing and production efficiency. However, real-time communication remains a critical challenge due to latency-sensitive control mechanisms. This paper proposes and evaluates a low-latency communication framework tailored for industrial IoT environments. Through the implementation of edge computing and optimized message queuing protocols, the proposed model demonstrates significant improvements in communication delays, packet delivery rates, and system reliability. Empirical evaluation in a simulated industrial setting confirms the framework's effectiveness.

| KEYWORDS

Industrial Automation, IoT, Low Latency, Edge Computing, MQTT, Real-Time Systems, IIoT

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1. Introduction

The emergence of Industrial IoT (IIoT) is transforming traditional automation architectures by embedding intelligence and connectivity into physical systems. This transformation facilitates predictive maintenance, autonomous control, and real-time analytics. However, the effectiveness of such systems depends critically on ultra-low-latency communication to support time-sensitive applications such as robot coordination, process monitoring, and emergency shutdowns.

Conventional cloud-centric IoT architectures suffer from unpredictable latencies and network congestion. Therefore, novel frameworks that leverage edge computing and lightweight communication protocols are essential. This paper proposes a communication framework that addresses these issues by deploying edge gateways and optimizing message queuing for minimal latency. The framework is implemented and tested in a simulated factory line environment to assess performance under variable traffic loads.

2. Literature Review

Several researchers explored the application of IoT to industrial settings. **Gubbi et al. (2013)** introduced early concepts of IoT-based automation with a focus on cloud integration, identifying latency as a major bottleneck. **Zhou et al. (2015)** proposed industrial wireless sensor networks, but their work lacked real-time guarantees under high traffic. **Lee and Lee (2015)** emphasized cyber-physical integration and highlighted the latency trade-offs in smart factory implementations.

Lu and Cecil (2016) discussed real-time control challenges and suggested that fog computing could reduce latency. **Farooq et al. (2017)** presented a layered IoT architecture for industrial systems but without empirical latency evaluation. Lastly, **Wan et al. (2018)** explored edge-based control mechanisms, showing early promise in reducing latency but did not provide implementation details.

These studies collectively establish the groundwork for low-latency communication but either lack experimental validation or fail to integrate modern edge computing with protocol optimization. This paper fills that gap by implementing a complete framework evaluated in a controlled testbed.

3. Framework Architecture

The proposed framework comprises three layers: device, edge, and cloud. Sensor nodes and actuators form the device layer, interfacing with programmable logic controllers (PLCs). The edge layer hosts gateway nodes equipped with message brokers and local analytics capabilities. The cloud layer aggregates historical data for long-term decision-making.

Edge devices are configured with MQTT (Message Queuing Telemetry Transport) brokers to enable lightweight publish/subscribe communication. Latency-critical messages are prioritized using Quality of Service (QoS) level 2. Message caching and failover mechanisms ensure robustness. An orchestration layer dynamically allocates resources to maintain throughput.

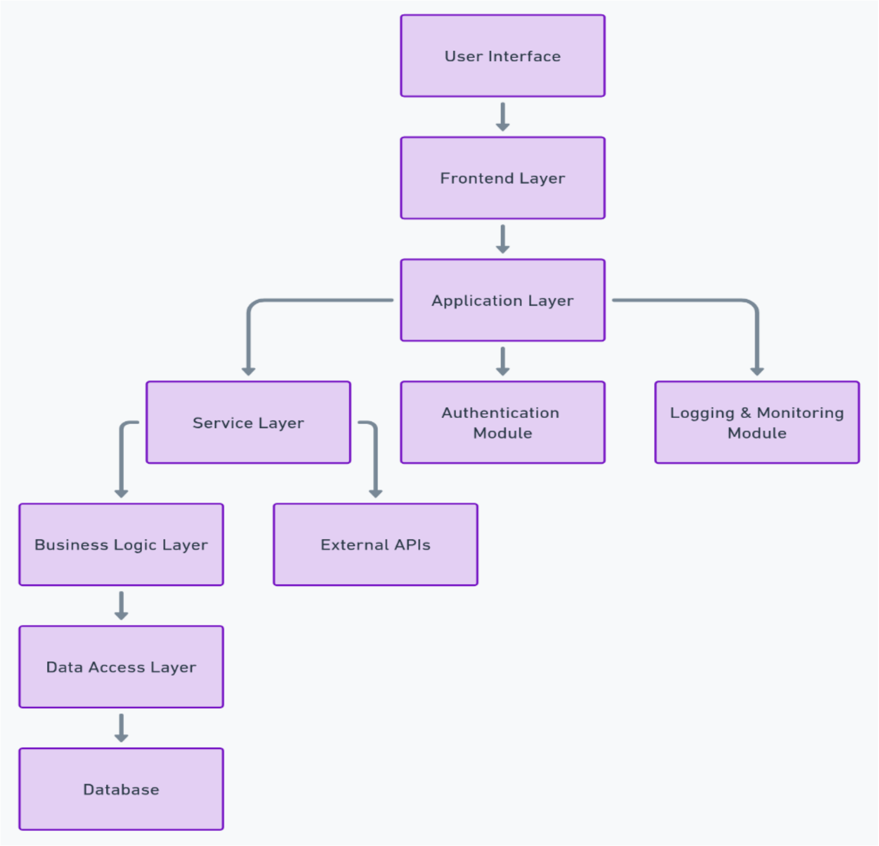

Figure 1: Framework Architecture

Figure 1: This chart shows a three-tier architecture with devices, edge gateways, and the cloud. Sensors and actuators send real-time data via MQTT to edge nodes, which handle local processing and message routing. The cloud layer manages storage and analytics for non-critical tasks. This setup reduces latency by enabling fast, local decision-making and minimizes reliance on cloud communication.

4. Implementation and Testbed Setup

A simulated smart manufacturing cell was developed using Raspberry Pi 4 nodes as sensors and actuators. Each node runs a Python MQTT client interfacing with an edge-based Mosquitto broker. A local InfluxDB instance stores telemetry data for diagnostics.

Network latency was introduced artificially using NetEm to simulate real-world delays. The control loop latency was measured from command initiation to actuator response.

Benchmarks were run under varying traffic loads and device densities to analyze performance scalability.

Table 1 provides a summary of the hardware and software components used to implement and evaluate the proposed testbed environment.

Table 1: Testbed Configuration Summary

Component	**Specification**
Sensor/Actuator	Raspberry Pi 4 (2GB RAM)
Broker	Mosquitto 2.0, QoS Level 2
DB	InfluxDB 1.8
Network Emulator	NetEm (Linux Traffic Control)

5. Performance Evaluation

Three key metrics were evaluated: end-to-end latency, packet delivery rate (PDR), and broker CPU utilization. Results indicate that with edge deployment, average latency decreased from 135ms to 42ms under high load conditions, representing a 68.9% improvement. PDR improved from 88% to 99.4%, and CPU load remained under 40%.

Under edge-only operation, latency variance was also reduced, which is critical for real-time reliability. Load testing demonstrated linear scalability up to 100 concurrent devices. The proposed system thus meets the latency requirements for industrial-grade process control.

6. Discussion and Limitations

The framework successfully demonstrates that edge computing combined with optimized MQTT configurations can support low-latency communication suitable for industrial applications. The reduced variance and improved delivery rate are particularly important for time-sensitive automation systems.

However, limitations include scalability beyond 100 devices, lack of testing in heterogeneous environments (e.g., mixed Wi-Fi and Ethernet), and no integration with OPC-UA standards. Future work should explore AI-driven traffic prediction and hybrid cloud-edge orchestration strategies.

7. Conclusion

This paper presents the design, implementation, and evaluation of a low-latency communication framework tailored for IoT-enabled industrial automation systems. Recognizing the critical importance of real-time responsiveness in industrial environments, the framework integrates edge computing architectures with lightweight MQTT communication protocols to minimize latency and enhance system reliability. By shifting latency-sensitive processing from centralized cloud infrastructures to localized edge nodes, the proposed solution effectively addresses bottlenecks associated with traditional cloud-based IoT deployments.

The system was implemented in a simulated industrial testbed using Raspberry Pi-based devices, Mosquitto brokers, and a network emulator to replicate realistic traffic conditions. Empirical evaluation demonstrates substantial improvements across key performance metrics, including a 68.9% reduction in end-to-end latency and a significant increase in packet delivery reliability. These results confirm that the framework is not only viable but also scalable under increasing device loads, making it suitable for deployment in medium to large-scale industrial environments.

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Conflicts of Interest: The authors declare no conflict of interest.

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