Resource Scheduling for Reliable Wireless Communication in Industrial Environments

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I. Background and Motivation

In industrial manufacturing, achieving low latency is often more critical than maximizing bandwidth. Even a few milliseconds of delay can interrupt safety loops, affect robotic synchronization, or destabilize process control [1]. This is because communication must satisfy tight real-time and reliability requirements to avoid physical damage or loss of time [1]. As industries move from wired fieldbus systems such as Modbus and Profibus to wireless machine to machine (M2M) networks, new challenges arise from interference, congestion, and unpredictable transmission delays. Standard IEEE 802.11 networks use contention based access (CSMA/CA), which introduces variability in latency and packet delivery [2]. Although Time Sensitive Networking (TSN) and Fifth Generation (5G) Ultra Reliable Low Latency Communication (URLLC) offer deterministic performance, the challenge remains in integrating these guarantees into low power, cost effective platforms such as STM32 and ESP32, which are commonly used in embedded control and Internet of Things (IoT) applications.

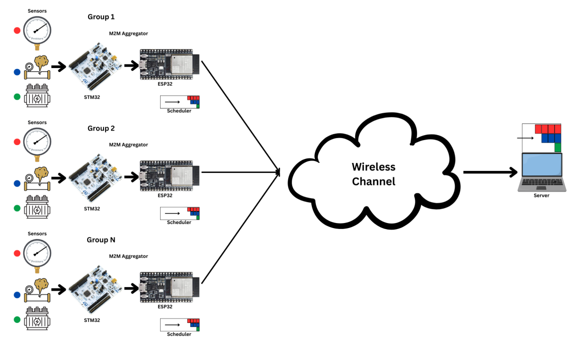

Fig. 1. Proposed wireless industrial testbed. Each STM32 and ESP32 pair represents an M2M node transmitting prioritized sensor data over a shared Wi Fi channel to a central server.

II. Related Work and Research Gap

Industrial wireless reliability has typically relied on hardware level synchronization or proprietary communication protocols. Wi Fi Quality of Service (QoS) extensions such as IEEE 802.11e Enhanced Distributed Channel Access (EDCA) allow traffic differentiation, but this mechanism does not provide deterministic performance [2]. Crucially, IEEE 802.11-based WLANs are often deemed ineligible for control-centric industrial applications owing to insufficient reliability and non-deterministic latency [2]. There remains a gap in lightweight scheduling and prioritization techniques that improve reliability without changing the physical or medium access control (MAC) layer. By leveraging embedded microcontrollers already common in industrial IoT, this project will demonstrate that real time scheduling and prioritization can be implemented directly at the node level. We will explore high-efficiency schemes like Earliest Deadline First (EDF) scheduling, which is critical for resource-limited real-time task management in IoT applications [3].

III. Proposed System and Objectives

The project will design and prototype a small scale wireless industrial testbed using STM32 and ESP32 devices (Fig. 1). Each STM32 microcontroller will simulate multiple industrial sensors categorized by timing sensitivity as *critical*, *control*, or *monitoring*, and communicate with an ESP32 gateway through Universal Asynchronous Receiver Transmitter (UART). The ESP32 will transmit data over Wi Fi to a central server for logging and analysis. Each STM32 and ESP32 pair acts as a local M2M node that sends prioritized sensor data across a shared wireless channel, emulating an industrial environment with several nodes competing for network access.

The system will explore methods to:

- Classify and schedule sensor data by priority (e.g., using EDF),
- Test different queue and transmission strategies under varying load,
- Measure latency, jitter, and packet delivery rate,
- Demonstrate improved predictability through software layer scheduling.

The project will show that with appropriate scheduling and data management logic, reliable timing performance can be achieved using existing embedded hardware. Verification will include latency, jitter, and packet delivery measurements under different traffic conditions.

References

[1] A. Willig, "Recent and emerging topics in wireless industrial communications: A selection," *IEEE Transactions on Industrial Informatics*, vol. 4, no. 2, pp. 102–124, 2008.

[2] A. Aijaz, M. M. Hassan, F. Alouini, and S. Halder, "High-Performance Industrial Wireless: Achieving Reliable and Deterministic Connectivity Over IEEE 802.11 WLANs," *IEEE Open Journal of the Industrial Electronics Society*, vol. 1, pp. 28–37, 2020.

[3] S. Abolhassani Khajeh, M. Saberikamarposhti, and A. M. Rahmani, "Real-Time Scheduling in IoT Applications: A Systematic Review," *Sensors*, vol. 23, no. 1, p. 232, 2023.