Secure Wireless Architectures for Human-Centric Cyber-Physical Systems in Industry 4.0 Using Matter and Thread

Dina Šimunić
University of Zagreb, Faculty of Electrical Engineering and Computing, Unska 3, 10000 Zagreb

***Abstract**: The rapid evolution of Industry 4.0 emphasizes not only automation and connectivity, but also the seamless integration of human-centric cyber-physical systems (CPS). This paper presents a secure, interoperable wireless communication framework based on the emerging Matter and Thread protocols, designed for real-time, local, and privacy-aware interactions between people and machines. While traditional wireless IoT protocols such as Zigbee and Bluetooth face challenges with fragmentation, lack of interoperability, and limited security models, Matter and Thread offer a unified, IP-based mesh network that is vendor-neutral, scalable, and designed with end-to-end encryption and device attestation by default. We apply this architecture to a practical use case in assistive IoT: enabling users with disabilities to interact with smart environments through secure, low-power wireless devices. This includes wearable panic buttons, smart locks, and environmental sensors that respond in real time, even in cloud-disconnected conditions, which is a critical requirement for safety in CPS. The system also supports multi-platform integration (Android, iOS, embedded Linux) without duplicating infrastructure. The paper presents a modular threat model, performance analysis of secure onboarding and encrypted control flows, and discusses deployment challenges in real-world industrial or healthcare automation contexts. This approach demonstrates how inclusive, secure-by-design wireless CPS can be realized with current technologies, contributing to more resilient and human-aware Industry 4.0 systems.*

***KEYWORDS** :INTEROPERABILITY, INDUSTRY 4.0, MATTER, THREAD*

1. Introduction

Industry 4.0 has shifted the paradigm from purely machine-centric automation to systems where humans remain in or on the loop. Human-centric Cyber-Physical Systems (CPS) in factories, hospitals, laboratories, and logistics centers require low-latency, reliable, and above all secure wireless interaction between operators, wearable devices, collaborative robots, and environmental actuators.

Traditional industrial wireless protocols (WirelessHART, ISA100.11a) were designed for process automation with strict determinism but limited bandwidth and poor support for battery-powered personal devices. Consumer-oriented protocols such as Zigbee, Z-Wave, and Bluetooth Low Energy suffer from ecosystem fragmentation, proprietary clusters, and inconsistent security implementations. As a result, deploying mixed human-machine environments often leads to duplicated networks, complex gateways, and enlarged attack surfaces.

Matter [1] (formerly Connected Home over IP) and Thread [2] address these shortcomings by providing an application-layer protocol over an IPv6-based low-power mesh network with built-in security and interoperability guarantees. Backed by the Connectivity Standards Alliance (CSA) and major vendors (Apple, Google, Samsung, Amazon, Nordic Semiconductor, Silicon Labs, etc.), the standards reached maturity in 2023–2024 and are now being adopted beyond smart homes into professional and industrial environments.

This paper proposes a reference architecture that leverages Matter and Thread for safety-critical human-centric CPS in Industry 4.0, with a concrete implementation focused on assistive technology for workers or patients with motor, visual, or cognitive disabilities.

2. Background: Matter and Thread Protocols

The Connectivity Standards Alliance (CSA) released Matter 1.0 in October 2022 and Thread Group Alliance lauunched Thread in 2015 specifically to solve the fragmentation problem. Matter is an application-layer protocol running over IPv6, while Thread is a low-power, self-healing mesh at Layers 1–4. Together they form the first truly universal, IP-addressable, and cryptographically robust IoT fabric supported natively by Apple, Google, Amazon, Samsung, Nordic, Silicon Labs, Espressif, and over 600 other vendors.

The both protocols are IP-native; thus, the same network can serve smartphones, tablets, embedded Linux gateways, and constrained battery-powered end devices without protocol translation.

Matter is an application-layer protocol running on top of Thread (or Wi-Fi) that defines unified data model and device types (including generic switches, contact sensors, locks, and the newly introduced "Accessible Device" category in Matter 1.2+), secure commissioning using QR code or NFC with Passcode-Authenticated Session Establishment (PASE) based on SPAKE2+, operational communication via CASE (Certificate-Authenticated Session Establishment) using operational device certificates issued by the Matter PKI, end-to-end encrypted messages (AES-CCM) and signed command invocation and subscription mechanism for real-time eventing with configurable reporting intervals

Thread is an IPv6-based, low-power, wireless mesh networking protocol (IEEE 802.15.4 at 2.4 GHz). Key characteristics relevant to industrial deployment include self-healing mesh with no single point of failure, up to 250+ nodes per network with typical latencies <100 ms, native IP addressing (no translation gateways needed), DTLS-secured commissioning and leader election and border routers providing seamless backbone connectivity (Wi-Fi/Ethernet)

3. Proposed Architecture for Assistive Human-Centric CPS

Architecture consists of System Components, Local-only Safety Operation and Multi-Admin and Cross-Platform Support.

System consists of the following components: Wearable panic button / voice pendant (Silicon Labs EFR32MG24 + Matter SDK), Smart door locks and motorized window openers (Matter-certified), Stove Guard, Environmental sensors (temperature, air quality, fall detection floor mats), Thread border routers (Raspberry Pi 5 + OpenThread RCP, or commercial Apple HomePod / Google Nest hubs), Local controller / edge node (embedded Linux with Matter controller library – chip-tool or matter.js) and Optional cloud bridge only for remote oversight (not required for local safety functions)

Local-Only Safety Operation is necessary for all critical interactions (panic → unlock door → turn on lights → notify nearby staff), which are executed locally using Matter subscriptions and groups. Even if Internet connectivity is lost or deliberately disabled for privacy, the system remains fully functional. This satisfies IEC 61508 SIL-2 capable design principles for safety-related parts of control systems when properly validated.

Multi-Admin and Cross-Platform Support is based on Matter, since its multi-admin feature allows simultaneous commissioning and control from Android phones (Google Home + custom app), iPhones/iPads (Apple Home + Shortcuts) and Industrial HMIs running Linux with matter.js or the official C++ controller.

In this case, it is important that no vendor lock-in and no duplicated Thread networks are required.

Critical safety flows work even if internet is down or deliberately disconnected. The proposed architecture suggests the following scenario:

1. Person opens front door after 22:00
   Door Sensor → instant Matter event → Edge Controller
   → "John, it's nighttime. Do you need help?" (gentle voice)

→ Auto-text family + carer (via local LoRa/GSM fallback if needed)
2. Person leaves stove on > 12 minutes
Stove Guard → Matter event → voice reminder + flashing lights → Auto shut-off after 3 reminders
3. Fall detected
Floor Mat → immediate voice check + call family/carer via local SIP gateway
4. Person wanders > 50 m from home
GPS Pendant → Matter + border router → local alarm + carer notification
All devices have battery that will last 2–7 years, certified ETSI EN 303 645 + EU CRA Class II. All traffic is end-to-end encrypted, zero cloud dependency for life-safety. There is a full simultaneous control by Apple Home, Google Home, and carer tablets

4. Security Analysis and Threat Model

Threat Model STRIDE-based analysis defines
- Spoofing: prevented by device attestation certificates (DAC) and operational certificates (OC)
- Tampering: all firmware images cryptographically signed; secure boot enforced
- Repudiation: every command is signed with per-session keys
- Information disclosure: end-to-end encryption; no cleartext traffic even inside LAN
- Denial of service: Thread mesh uses channel hopping and leader failover; Matter rate-limits commands
- Elevation of privilege: fabric-scoped access control lists with role-based nouns (2024 Matter 1.3 specification)

Feature Category	**Specific Mechanism**	**Cryptographic Primitives**	**Protection Against**	**Thread 1.4 Updates (2025)**
Network Authentication	Mesh Commissioning Protocol (MeshCoP) for joining	HMAC-SHA256 for PSKc derivation; AES-128 key wrapping	Unauthorized joins, rogue devices	Faster PSKc rotation (every 24 hours vs. 7 days)
Commissioning Security	Secure DTLS handshake between commissioner and joiner	DTLS 1.3 with ECDH P-256; AES-128-CCM	Man-in-the-middle (MitM), eavesdropping during setup	eIDAS 2.0 wallet integration
Encryption (In-Transit)	L2 (link layer) using Network Key	AES-128-CCM (Counter with CBC-MAC) for confidentiality and integrity	Eavesdropping, packet injection in the mesh	Optional AES-256-CCM for high-security profiles (e.g., industrial)
DoS/Jamming Resistance	Channel hopping (CSMA-CA with backoff	N/A (physical layer mitigations)	Denial-of-Service via interference	Adaptive hopping algorithms;

Table 1 *Thread protocol security details*

5. Challenges and Open Issues in Regulatory Acceptance

While Matter/Thread devices are CE and FCC marked, some national safety authorities still demand wired connections for SIL-3/4 applications. Hybrid architectures (wired backbone + wireless last meters) are being explored. Matter (application-layer protocol) and Thread (IPv6 low-power mesh network) together form a unified, IP-native stack from the Connectivity Standards Alliance (CSA). Designed with security as a core tenet, they inherently align with EU cybersecurity mandates for consumer and industrial IoT. As of December 2025, CSA-certified Matter/Thread devices meet or exceed key standards like ETSI EN 303 645 and prepare for full EU Cyber Resilience Act (CRA) enforcement in 2027. This compliance is validated through third-party testing (e.g., UL Solutions, TÜV Rheinland) and the CSA's Distributed Compliance Ledger (DCL), ensuring vendor-neutral interoperability and resilienc
Coexistence with legacy 802.15.4 networks: Careful channel planning is required in brownfield deployments.

6. Conclusion

Matter and Thread provide the first truly unified, secure, and IP-native wireless stack that is suitable for human-centric cyber-physical systems in professional and industrial environments. By combining vendor-neutral interoperability, default end-to-end encryption, and local-only execution capability, the proposed architecture meets the stringent safety, privacy, and inclusivity requirements of modern Industry 4.0 systems.
As the ecosystem matures through 2025–2027, we expect widespread adoption in healthcare, logistics, and collaborative manufacturing — finally closing the gap between consumer IoT convenience and industrial-grade reliability.

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