A Reference Architecture for Integrating Time-Sensitive Networking in Industrial Internet of Things

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ABSTRACT

Industrial Internet of Things (IIoT) play an important role in the new round of industrial revolution. However, the isolation of Information Technology (IT) networks and Operational Technology (OT) networks impedes the innovations, developments, and disruptive business models applied in IIoT. With the emergence of time-sensitive networking (TSN), it is feasible to interoperate between IT/OT networks with deterministic data transmission. By integrating TSN in IIoT architecture, the article proposes a reference architecture with *multi-modal interconnection*, *endogenous safety and security*, and *integrated scheduling* as the core elements. We believe the design could give a guidance for IIoT system design and development.

CCS CONCEPTS

• **Networks** → **Network architectures**.

KEYWORDS

Industrial Internet of Things, Time-Sensitive Network, Network Architecture

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1 INTRODUCTION

With the rise of the new round of industrial revolution centered on the Industrial Internet of Things (IIoT), also known as Industrial 4.0, intelligent manufacturing, several countries have already identified the IIoT as an important development strategy. IIoT supports emerging industrial applications such as flexible manufacturing, personalized customization, digital twin by comprehensively connecting people, machines, and things.

At present, factories are connected by diverse networks including Information Technology (IT) networks *e.g.*, Ethernet, Wi-Fi, BlueTooth, and Operational Technology (OT) networks *e.g.*, Profinet, EtherCat, Modbus. IT/OT networks are handled as two seperate domains. As a result, even IT systems can iterate by months, OT systems maintain the status quo for years, which impedes the innovations, developments, and disruptive business models applied in IIoT.

To get out of the dilemma, Association of German Engineers and Industrial IoT Consortium propose new IIoT reference architectures, RAMI 4.0 [2] and IIRA [1], respectively. RAMI 4.0 focuses on manufacturing considering the value chain and the product life cycle while IIRA aims to build, implement and operate IIoT systems from IT to OT. Luo[3] also proposed a IIoT architecture which focuses on the synergy between the cloud and clients. However, all the architectures ignore the isolation of network modalities. Recently, the emerging time-sensitive networking (TSN) [4] provides deterministic mechanisms for the real-time transmission, and makes it possible to interoperate with both IT/OT networks conveniently. Given an insight by TSN, we design a more comprehensive architecture for IIoT to meet the requirement of the convergence of IT/OT networks.

In our context, we summarize the challenges of IIoT and propose a reference architecture with *multi-modal interconnection*, *endogenous safety and security*, and *integrated scheduling* as the core elements. The architecture will provide structural support and key technological recommendations for developing a time-sensitive networking integrated IIoT system.

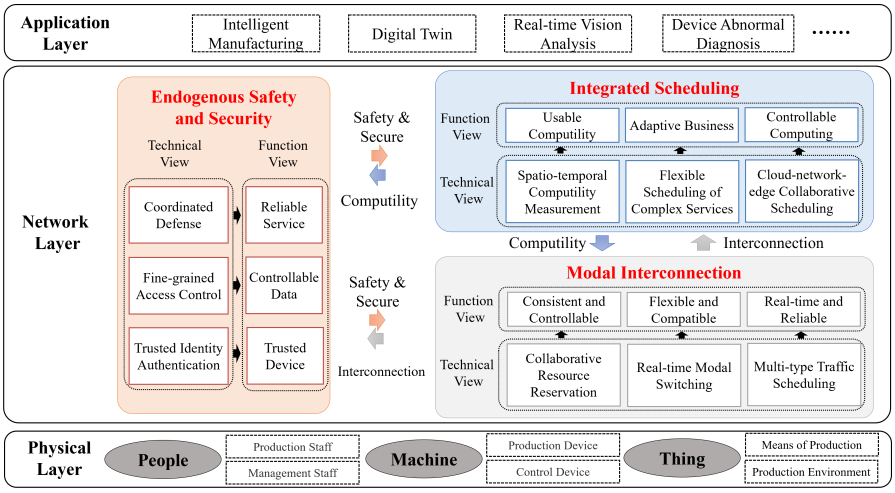

Figure 1: The reference architecture for IIoT

2 CHALLENGES OF IIOT

Challenges to implement IIoT systems can be summarized as the following three aspects:

(i) **Deterministic Transmission**: Different from IT networks, OT networks often require deterministic and reliable networks. Specifically, networks for motion control require low jitters and millisecond or even microsecond latency. However, traditional Ethernet works in *best-effort* mode, therefore only achieves hundred milliseconds latency. Meanwhile, different OT networks adopt diverse real-time guarantee mechanisms, making the deterministic transmission in the converged IT/OT networks more complicated.

(ii) **Industrial Field Security**: The converged IT/OT networks expose industrial vulnerable devices to security threats from the worldwide internet. Traditional patch-based security routes increase the complexity of systems and inevitably introduce new security risks.

(iii) **Joint Scheduling Computing and Networking**: Deterministic tasks are essential to industrial systems. The latency of these tasks is composed of computing latency and network latency. To make sure deterministic latency, it is necessary to joint scheduling computing and networking together. However, joint scheduling computing and networking has been proven NP-hard.

3 DESIGN OF ARCHITECTURE

This work proposes a system architecture of IIoT to solve challenges. The architecture includes the physical layer, the network layer, and the application layer. The physical layer contains people, machines, and things, and is to establish interconnections between them. The network layer use TSN as the critical technology to support scheduling, security, and interconnection of IIoT. Finally, based on computing power and network support, industrial systems and applications provide technology service platforms in the industrial application layer, supporting emerging industrial applications.

The network layer of this system architecture takes "*modal interconnection*, *endogenous safety and security*, and *integrated scheduling*" as the core modules. Specifically:

Modal Interconnection provides device interconnection support. The technical view includes collaborative resource reservation, real-time modal switching and multi-type traffic scheduling, and the functional view is to make the connection consistent, controllable, flexible, compatible, real-time and reliable.

Endogenous Safety and Security (ESS) ensures the security of IIoT systems. The technical view includes coordinated defense , fine-grained access control and trusted identity authentication , and the functional view includes reliable service, controllable data and trusted device.

Integrated Scheduling provides the computility support. The technical view includes spatio-temporal computility measurement , flexible scheduling of complex services and cloud-network-edge collaborative scheduling, and the functional view includes usable computility, adaptive business and controllable computing.

4 CONCLUSION

This article summarizes the challenges of IIoT, and proposes a modal architecture which is based on TSN technology and focuses on "modal interconnection, endogenous safety and security, and integrated scheduling". This architecture is provides structural support for the development of IIoT.

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