Chi XU, Haibin YU, Xi JIN, Changqing XIA, Dong LI, Peng ZENG, 2024. Industrial Internet for intelligent manufacturing: past, present, and future. *Frontiers of Information Technology & Electronic Engineering*, 25(9):1173-1192. https://doi.org/10.1631/FITEE.2300806

Industrial Internet for intelligent manufacturing: past, present, and future

Key words: Intelligent manufacturing; Industrial Internet; Thin waist; Transparent service; Manufacturing as a service

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Introduction

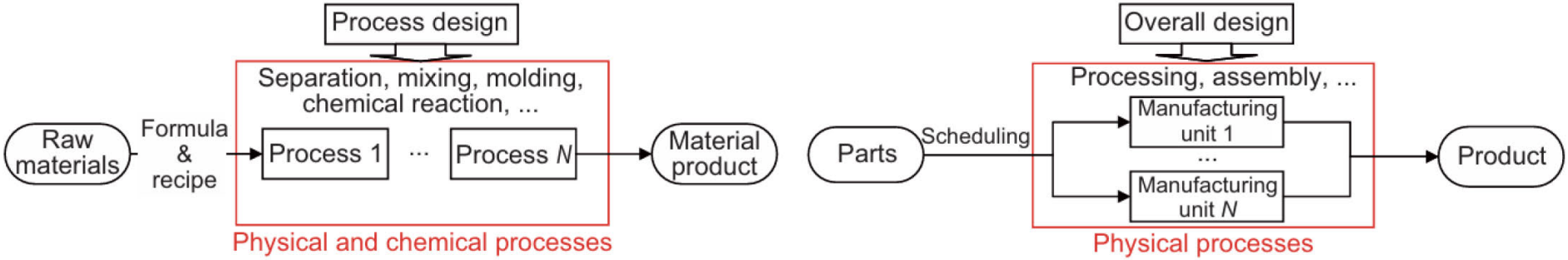
- **Manufacturing revolution:** The manufacturing industry is undergoing a major transformation from quantity and scale expansion to quality and efficiency improvement. This evolution is characterized by the shift from a plain “manufacturing” mode to a “manufacturing + service” comprehensive mode.
- **Need of MaaS:** The top priority now is to fully open up the production, value, and industry chains and establish transparent channels for manufacturing and services to realize manufacturing as a service (MaaS).
- **Industrial Internet:** Through the deep integration of next-generation information and communication technology (ICT) and industrial operational technology (OT), the industrial Internet is regarded as the core technology to realize intelligent manufacturing.

Contributions

- We analyze the basic characteristics and requirements of typical intelligent manufacturing scenarios, i.e., process manufacturing and discrete manufacturing, and highlight the importance and urgency of using industrial Internet to achieve MaaS.
- We provide an overview on the integrating process of ICT and OT, and systematically analyze and compare the networking capabilities and problems of the current industrial Internet.
- We establish a novel industrial Internet's "thin waist" (IITW), which integrates sensing, communication, computing, and control, to establish a transparent channel between manufacturing and services.
- We introduce the key technologies and the challenges in establishing IITW and discuss future research directions.

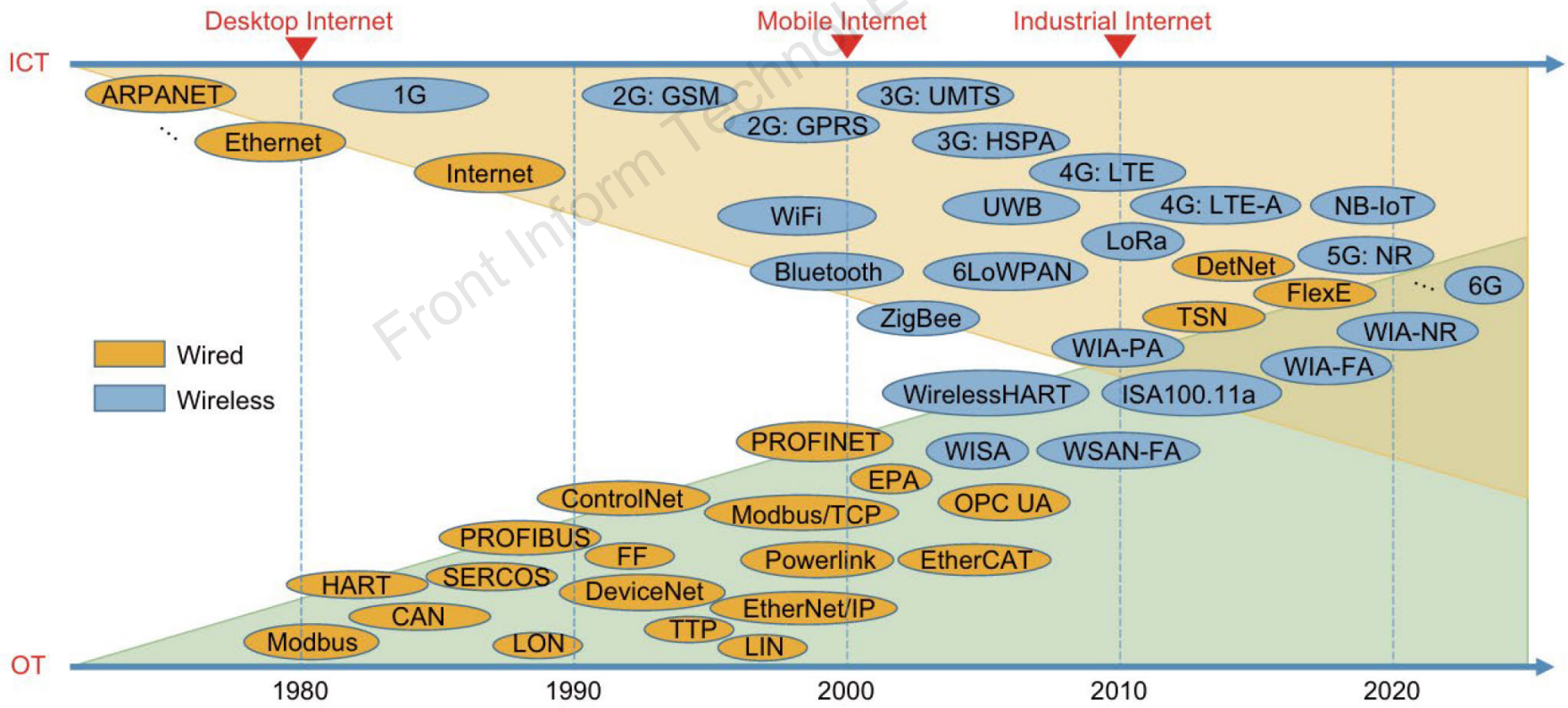
1) Basic requirements of intelligent manufacturing

- **Process manufacturing:** related to the elementary raw material industries such as petroleum, chemical, metallurgy, and other industries, emphasizing ubiquitous sensing and precision control for the entire manufacturing process.
- **Discrete manufacturing:** related to industries such as aviation, aerospace, shipping , automobiles, and home appliances, emphasizing modular organization and dynamic reconstruction, supporting high-precision processing and assembly.



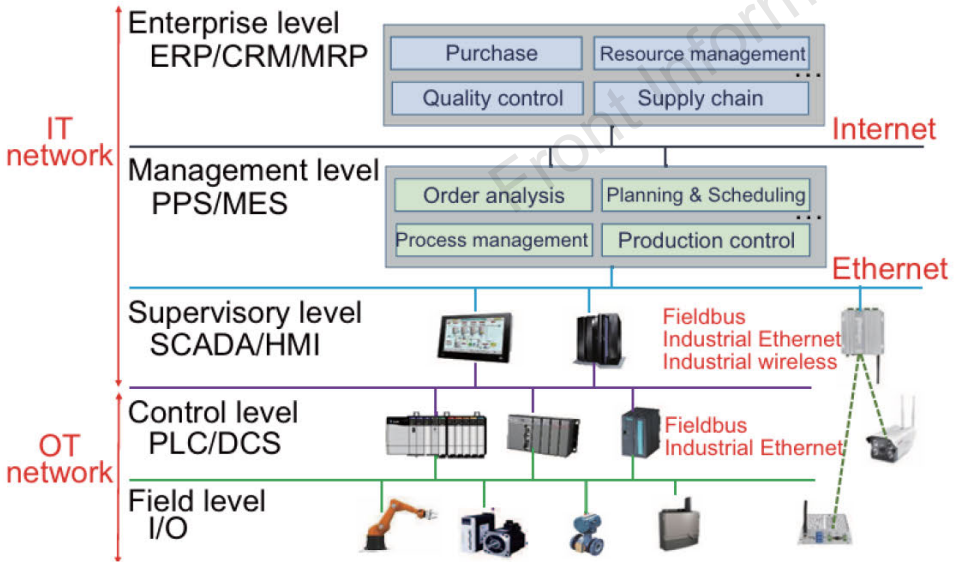
2) Development of industrial Internet

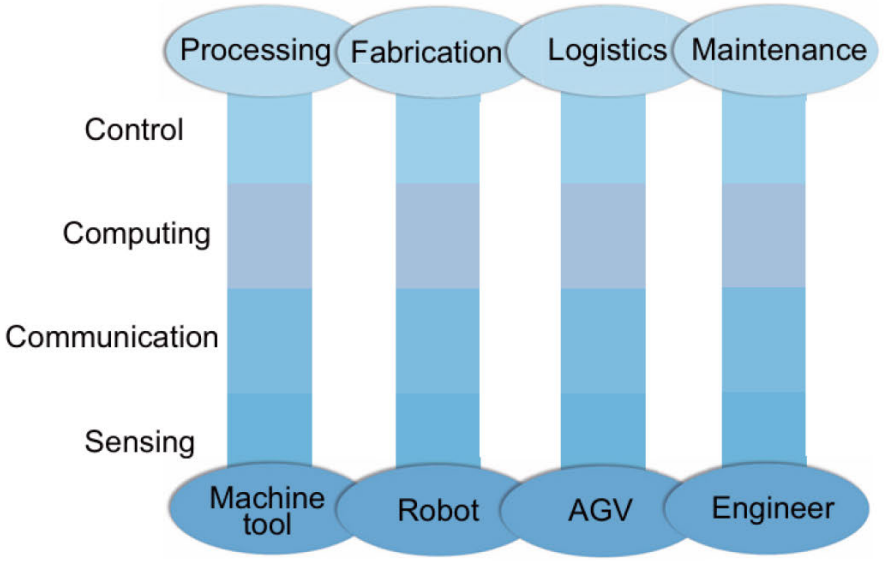
- ICT and OT continuously collide and integrate to satisfy the escalating service requirements of both process manufacturing and discrete manufacturing, during which numerous networking technologies have been developed for industrial Internet.



3) Problems of current industrial Internet

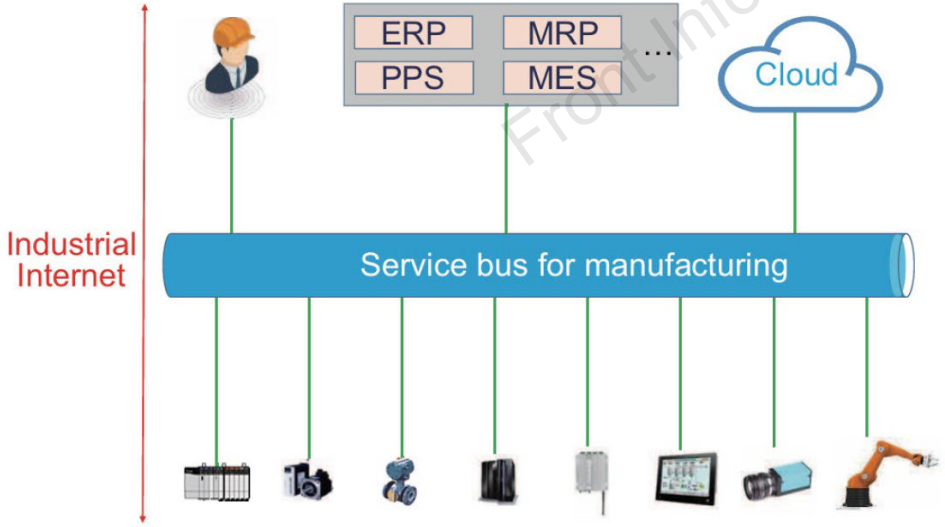
- **Heterogeneous network architecture:** The existing hierarchical heterogeneous “pyramid” architecture leads to information silos, making it difficult to achieve transparent connections between manufacturing and services.
- **Numerous network protocols:** Different ICN protocols lead to difficulties in interconnection and interoperability, affecting productivity and quality.

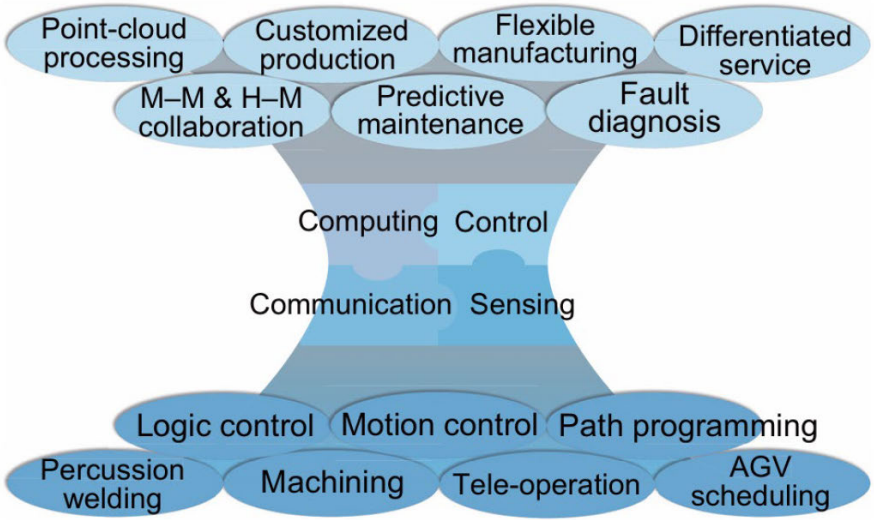




4) “Thin waist” for future industrial Internet

- **Flat network architecture:** establish a flat network architecture similar to a service bus to break the existing chimney-like service model and achieve transparent connections between manufacturing and services.
- **A novel “thin waist” for industrial Internet (IITW):** IITW fully considers the coupling characteristics among sensing, communication, computing, and control in industrial Internet.





5) Key technologies and future research directions

- **Multi-dimensional collaborative sensing of task–resource**: discussing the need of sensing manufacturing tasks and network protocols, modeling task classification and mapping resource requirements
- **End-to-end deterministic communication of heterogeneous networks:** emphasizing the need for multi-protocol fusion communication and high-precision time synchronization to support real-time, high-reliability manufacturing tasks.
- **Virtual computing and operation control of industrial Internet:** discussing the need for conducting a digital twin model to provide dynamic re-configurability and on-demand customized services for flexible manufacturing tasks.

Conclusions

- We first analyzed in detail the basic networking capability requirements of process manufacturing and discrete manufacturing.
- We made a systematic comparison of the current networking capabilities of industrial Internet.
- For future industrial Internet, we proposed IITW by integrating sensing, communication, computing, and control to establish a flat network.
- We summarized the key technologies in three areas requiring urgent breakthroughs, including the multi-dimensional collaborative sensing of task–resource, the end-to-end deterministic communication of heterogeneous networks, and the virtual computing and operation control of industrial Internet.

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