IIoT Use Cases and their Communication Requirements

1st Tarun Devidas Ramani
Technische Universität Ilmenau
tarun-devidas.ramani@tu-ilmenau.de
Matriculation No.: 66160

2nd Majd Ali
Technische Universität Ilmenau
majd.ali@tu-ilmenau.de
Matriculation No.: 71615

***Abstract*—This project explores the IIoT vertical, its architectural components and the communication requirements needed for its implementation. By finding industrial scenarios that benefit from IIoT, we aim to analyse the communication needs from various layers of an IIoT system. The outcomes of this research will provide insights about how IIoT contributes to industrial efficiency.**

***Index Terms*—Industrial Internet of Things (IIoT), Industry 4.0, IIoT Architecture, Fleet Management, Message Queuing Telemetry Transport (MQTT), Low-Power Wide-Area Network (LPWAN), Predictive Maintenance, Ultra-Reliable Low-Latency Communication (URLLC), Massive Machine-Type Communication (mMTC), Enhanced Mobile Broadband (eMBB), Time-Sensitive Networking (TSN), Software-Defined Networking (SDN), Supervisory Control and Data Acquisition (SCADA), Manufacturing Execution System (MES), Digital Twin, Artificial Intelligence (AI), Machine Learning (ML), Wireless Sensor Network (WSN), Application Programming Interface (API)**

I. Introduction

Global industries are undergoing significant changes to meet the demands of the competitive environment. With the emergence of concepts such as Industry 4.0, smart manufacturing, and industrial automation, industries are now using advanced technologies to increase operational efficiency and productivity. The Industrial Internet of Things (IIoT) is an important innovation, enabling industries to integrate interconnected devices and systems for real-time data collection, analysis, and decision-making. IIoT is an advanced concept that connects industrial machines, sensors, devices, etc. to a network enabling the real time data collection and communication. It is a specialised branch of IoT. The Fourth Industrial Revolution is a transformative era of the manufacturing and the industrial processes in which many advancements in manufacturing automations, data-driven decision making, etc. took place. As a part of Industry 4.0, IIoT:

1) Helps to improve productivity and efficiency
2) Converts raw data to actionable information

The key components of IIoT include interconnected devices, cybersecurity, artificial intelligence (AI), machine learning (ML), cloud computing, edge computing, and data mining. [7] [8] These components together enable the functioning and implementation of IIoT.
IIoT offers many applications and benefits. It facilitates real-time decision-making and leverages digital twin technology to replicate physical processes in the digital formats.
The implementation of IIoT also comes with challenges and risks. It has a very high integration cost, and the current skill gap requires expertise in areas such as automation, ML, AI, and analytics. There is a concern for security threats with the use of IIoT.
IIoT has diverse verticals across multiple industries. [1] [2] [3] It is widely utilized in manufacturing, which is the cornerstone of Industry 4.0. IIoT also has various applications in healthcare, logistics, supply chain management, energy and utilities, smart agriculture, retail, oil and gas, mining, transportation, smart cities, food and beverage, and aerospace and defense.

II. IIoT Architecture Components

IIot has a multi-layered infrastructure which facilitates data processing, seamless communication and decision making across thousands of devices in the industrial environment.

Upon reviewing related works [4] [5] [6] [8] we inferred that the IIoT components can be divided into 5 layers.

A. Perception Layer

This is a functional layer which acts as a sensory interface between the real world and the digital infrastructure. This layer is the starting point in the IIoT ecosystem. Without obtaining data from this layer, industrial processes can't be moved to the further layers effectively.
This layer provides real-time monitoring which helps in quality control. For example, cameras and RFID tags on products help in real-time inventory tracking. Sensors collect data and provide information about faults and failures which enables predictive maintenance. Automations can be set up in the industries with the help of data collected in this layer.
There are various types of components in the Perception Layer:

1) Sensors (detect physical parameters)
2) Actuators (valves, motors, switches, etc.)
3) Scanners/Tags (RFID, barcode, etc.)
4) Vision sensors (cameras)
5) Embedded devices (build-in systems in larger machines programmed to do particular jobs)

B. Network Layer

The Network Layer facilitates transmission of data from Layer 1 to the other layers. It enables efficient communication of the industrial environment by connecting sensors, actuators, edge devices to the centralised system like computing units or the cloud. The key functions of this layer include data transmission, device connectivity, protocol management and quality of services. This is because thousands of devices must be linked with a network with minimum latency and maximum reliability for a smooth industrial operation. The components used in this layer are:

1) Wired Communication Technology (Ethernet, Fieldbus Systems, Machine-to-Machine Communication)
2) Wireless Communication Technology (Wifi, Bluetooth, Zigbee, LPWAN, 5G)
3) Networking Devices (routers, switches, gateways)
4) Protocols
   a) IP-based Protocols (IPv6)
   b) Industrial Protocols (OPC-UA, MQTT, CoAP)

The Network Layer is the communication backbone of the IIoT ecosystem. It uses technologies like: [1] [2]

1) URLLC (Ultra-Reliable Low-Latency Communication): designed for applications which need high reliability and minimum industrial automation, remote surgeries, and autonomous vehicles
2) mMTC (Massive Machine Type Communication): supports many low-power and low-data-rate devices in IoT networks
3) eMBB (Enhanced Mobile Broadband): helps in providing high-speed internet access and improved mobile broadband experiences for users in applications like video streaming
4) TSN (Time-Sensitive Networking): set of Ethernet standards used to provide ensure low latency and high reliability in data transmission for applications like industrial control systems and automotive networks
5) SDN (Software-Defined Networking): uses software applications to configure network resources in data centers and cloud computing
6) Edge-to-Cloud Communication: network architecture that enables seamless data flow between edge devices (like sensors) and the cloud allowing real-time data processing

C. Fog/Edge Computing Layer

The Edge Computing Layer brings data processing and decision making closer to the data source and hence reduces dependency on centralised systems. This layer ensures real-time decision making, latency minimisation and helps in decreasing the network load.

Fog computing nodes are distributed computing resources between edge devices and cloud which provide higher computing power than edge devices.

This layer brings advantages like improved performance, cost savings, data privacy and localised decision making.

Components that make the Edge Computing Layer include:

1) Edge Devices: located near data source that perform preliminary processing (industrial PCs, smart gateways)
2) Local Storage: temporarily store data in case of failure
3) AI/ML Models at the Edge: continuously learn from real data and predict information to perform actions

Few use case of the Edge Computing Layer are:

1) Autonomous robots
2) Video analytics
3) Predictive maintenance

D. Application Layer

Application Layer provides the end-users with tools, applications and platforms to monitor and control the systems. This layer directly interacts with the industrial operations and provides data insights which are then transformed into actionable decisions by the users. Supply-chain visibility and remote monitoring can be achieved using this layer with the help of technologies like Big Data Analytics, AI, ML, AR, VR and Integration protocols (APIs, middleware).

The Application Layer provides:

1) Dashboards
2) Analytics Platforms
3) Industrial Applications: tailored software solutions designed specifically for unique requirements of an industry (SCADA, MES)
4) Degital Twins: virtual replicas of the entire systems used for experiments, training, simulations, etc.
5) Cloud Platforms: used for data storage, application hosting, data processing, etc.

E. Management Layer

The Management Layer is responsible for orchestration, monitoring and security of all the components in the IIoT system. It makes sure that all the components work seamlessly and efficiently throughout their life cycles.

Management Layer provides components which have the following functionalities:

1) Device Management
2) Network Management
3) Security Management
4) Data Management
5) Automation and Orchestration

The key functions of the Management Layer are:

1) Handling software availability, installation and updates
2) Performance tracking of networks, devices, applications
3) Identification of issues and bottlenecks
4) Authentication, Encryption and detection of cyber threats
5) Overseeing life cycles of IIoT components from deployment to decommissioning
6) Enforcement of operation rules, policies and regulations
7) Storage, backup and retrieval of operational data

III. Industrial Scenarios that may benefit from IoT

In this research, we discussed the role of IIoT in fleet management. In fleet management, IIOT refers to a network of linked objects that communicate with one another via the internet without requiring human contact.
Using sensors, communication entities, and communication networks, IIoT in fleet management collects, analyzes, and assesses data from various resources (drivers, assets, vehicles, etc.). Fleet managers might use this information to make data-driven decisions, improve operations, enhance safety, and cut expenses.

The benefits of IIoT in fleet management include:

1) Improved Decision-Making: Fleet managers can monitor their vehicle status and take actions in advance in case of any possible issue.
2) Real-time Vehicle Tracking: fleet managers can respond quickly to delays or unexpected issues, by having real-time location of their vehicles.
3) Cost Saving:
    a) Optimise fuel usage: and save operating expenses by using real-time traffic data
    b) Predictive maintenance: reduce downtime, avoid expensive repair and maintenance
4) Improved Operations: preventing accidents involves keeping an eye on driver behavior and vehicle circumstances, such as speeding or aggressive driving.
5) Theft Prevention: alerting users to unlawful vehicle movements

IV. Communication Requirements for Identified Industrial Scenarios

A. Key Factors of Effectiveness

IIoT in fleet management depends on different factors of communication protocols and network technologies according to the applications used.

1) Delay: Delay refers to the time required for transmitting data from the sender to the receiver. In IIOT, this delay is crucial in real-time applications, which require instant data communication.
Fleet managers must make quick decisions regarding route optimization and monitor vehicle condition and safety, and this is done by providing them with real-time location data with low latency.
To avoid accidents and increase safety, instant alerts should be sent with minimal delay.
To avoid costly repairs and minimize downtime, predictive maintenance sensors should monitor the condition of the vehicle's components.

2) Bandwidth: Each application has different bandwidth needs.

1) Low Bandwidth: Telemetry data consists of small data packets which do not require high bandwidth. Therefore, Low-BW is enough for this type of communication. This data includes speed, fuel level, temperature, engine status, location, etc.
2) High bandwidth: Videos from cameras require higher Bandwidth to deal with large packets with minimal delay and high quality. For this purpose, 4G and 5G networks are normally used according to the 3GPP standards.

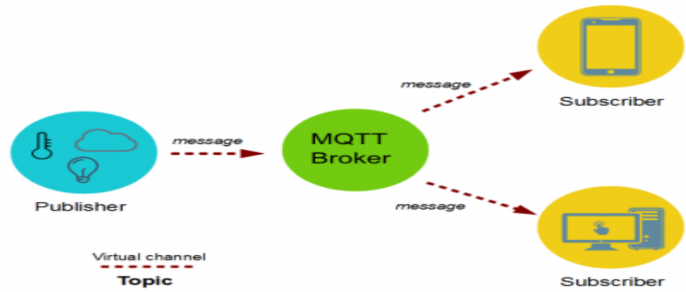

Fig. 1. MQTT Workflow

3) 24/7 Availability: Any breakdown or failure can lead to delays and potential safety risks. Therefore, continuous and smooth communication must be ensured to monitor the condition of the vehicles.

4) Security: Ensuring integrity and confidentiality are crucial factors to avoid unauthorised access:

1) Data Encryption: helps ensure that even if data is intercepted during transmission, it remains unreadable to unauthorised users
2) Secure Communication Protocols: using HTTPS, MQTT with SSL/TLS encryption, ensures secure communication and prevents data manipulation or interception during transmission

Choosing the network in fleet management depends on several factors, including the amount of transmitted data and the geographic range.

1) Cellular Network: for real-time data transmission, 4G/5G are the most common choice as they provide the required bandwidth to support continuous tracking.
2) LPWAN: Low Power Wide Area Networks are developed for low data transfer, low current consumption, low cost and enhanced coverage for IoT applications. IoT devices operate in challenging environments in remote locations, where changing batteries is difficult and expensive. Hence, a low power consumption is a very important requirement.
3) Wi-Fi and Bluetooth: used for connecting devices in a small range
4) Satellite: useful where the coverage is poor, especially in rural and remote areas where cellular networks might be expensive to use.

B. Message Queuing Telemetry Transport (MQTT)

In fleet management, data such as location, fuel levels , speed are sent periodically to a central system. Therefore,

TABLE I
COMMUNICATION REQUIREMENTS BASED ON FLEET MANAGEMENT USE CASES

Perception Layer	Provides connectivity between sensors, actuators and cameras with the digital world.	1) Minimal delay. 2) Low bandwidth and high frequency of data exchange.
Network Layer	Ensures that the data is transmitted by providing a connection between the physical devices and the cloud.	1) High-speed and reliable communication. 2) Low latency and high bandwidth. 3) Communication protocols (e.g., Ethernet, Wi-Fi, 5G, MQTT, CoAP)
Edge Computing Layer	Data is processed near the source, decisions can be made quickly.	1) Low-latency communication. 2) High computing power and local storage
Application Layer	Monitor and control the system	Real-Time Monitoring Predictive Maintenance Compliance
Management Layer	Responsible for monitoring and the security of IIOT system.	1) High-reliability and secure communication 2) Low latency 3) encryption and authentication

MQTT uses a message broker that sends small packets between devices and the fleet management platform, which leads to reducing bandwidth usage and power consumption.
MQTT is used for M2M (Machine-to-Machine) and loT connectivity. It is a publish-subscribe-based messaging protocol. It is very lightweight and thus suited for M2M, WSN (Wireless Sensor Network) and loT sensors, where communication nodes communicate with applications through the MQTT message broker.
MQTT is designed for limited devices, high latency, and low bandwidth communication.
TABLE 1 explains the communication requirements for each layer of the IIoT architecture in fleet management.

V. CONCLUSION

In conclusion, this study highlights the role of IIoT in enhancing industrial operations through real-time data collection, predictive maintenance, and operational optimisation. By analyzing IIoT's layered architecture, we identified components such as perception, network, edge computing, application, and management layers, each playing an important part in the seamless communication and decision-making processes.
The study of Fleet Management as a use case showed how IIoT enables improved efficiency, cost savings, and enhanced security. Technologies like MQTT, 4G/5G, LPWAN, and edge computing are essential in meeting communication requirements, ensuring reliability and scalability.
While IIoT presents many advantages, challenges like cybersecurity threats, integration complexities, and skill gaps must be addressed.
Future research can explore advancements in edge computing, AI-driven analytics, and secure communication protocols to further enhance IIoT applications.

REFERENCES

[1] M. Alabadi, A. Habbal and X. Wei, "Industrial Internet of Things: Requirements, Architecture, Challenges, and Future Research Direcyions," in IEEE Access, vol. 10, pp. 66374-66400, 2022, doi: 10.1109/ACCESS.2022.3185049.
[2] F. Zezulka, P. Marcon, Z. Bradac, J. Arm, T. Benesl, I. Vesely, Communica on Systems for Industry 4.0 and the IIoT, IFAC-PapersOnLine, Volume 51, Issue 6, 2018, Pages 150-155, ISSN 2405-8963, https://doi.org/10.1016/j.ifacol.2018.07.145.
[3] A. Zafeiropoulos et al., "Benchmarking and Profiling 5G Ver cals' Applica ons: An Industrial IoT Use Case," 2020 6th IEEE Conference on Network So wariza on (NetSo), Ghent, Belgium, 2020, pp. 310-318, doi: 10.1109/NetSo 48620.2020.9165393.
[4] Ioan Ungurean, Nicoleta Cristina Gaitan, "A Software Architecture for the Industrial Internet of Things—A Conceptual Model", 2020.
[5] Liliana Antão, Rui Pinto, João Reis, Gil Gonçalves, "Requirements for Testing and Validating the Industrial Internet of Things", 2018.
[6] Deepika Navani, Sanjeev Jain, Maninder Singh Nehra, "The Internet of Things (IoT): A Study of Architectural Elements", 2017.
[7] "Industrial Internet of Things (IIoT): Key Components and Game-Changing Impact for Manufacturing Organizations", https://secomea.com/iiot/industrial-internet-of-things-iiot/.
[8] "Components of the Industrial Internet of Things", https://control.com/technical-articles/components-of-the-industrial-internet-of-things
[9] Comprehensive IoT-Driven Fleet Management System for Industrial Vehicles.
[10] IoT Fleet Management: Benefits, Challenges and Use Cases IoT Fleet Management: Benefits, Challenges and Use Cases
[11] "What is MQTT and How MQTT Works?", https://microcontrollerslab.com/what-is-mqtt-and-how-it-works/
[12] 3GPP Technical Specifications (TS 22.261, TS 23.501) This study explores the architecture, components, and communication requirements of Industrial Internet of Things (IIoT) systems. By understanding the Automation Pyramid and dividing the IIoT ecosystem into a layered structure we understand how IIoT operates to make industrial processes efficient.
[13] By studying fleet management, we understand how IIoT solutions make real-time data collection, predictive maintenance and operational optimisation possible and also overcome communication problems. We understand that MQTT, 4G/5G, LPWAN, and edge computing play an important role in meeting requirements of industrial scenarios, ensuring efficiency, reliability, and scalability.
[14] Future research under this topic can be focused on addressing the barriers and understanding edge computing, AI, and secure communication protocols to make the best use of IIoT.
[15] In conclusion, this study highlights the critical role of IIoT in innovation and efficiency of industrial operations.
[16] https://www.3gpp.org/specifications