Alliance for IoT
and Edge Computing
Innovation

AIOTI AWARD 2024

Enabling edge-driven Dataspace integration through convergence of distributed technologies

Singh, P., Beliatis, M. J., & Presser, M. (2024). Enabling edge-driven dataspace integration through convergence of distributed technologies. Internet of Things, 101087.

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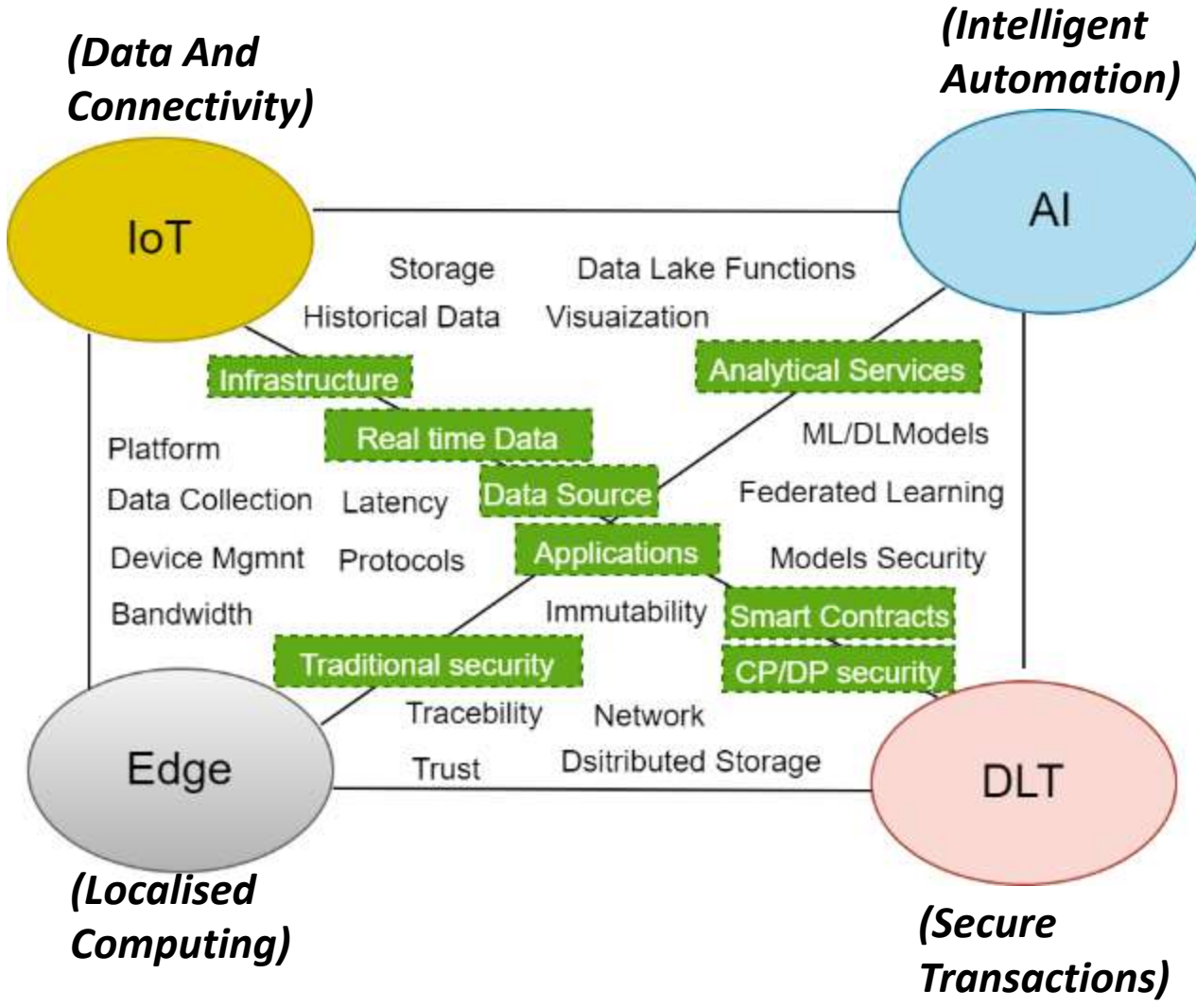
Background and Aims

- Develop value chains using cross-domain data, services, and systems integration.
- Converge **I**oT, **D**LT, **E**dge Computing, and **A**I-driven Machine **L**earning (**IDEAL**) capabilities for combined benefits.
- Enable Dataspace integration for *edge-enabled cross-domain value chain networks.

→ *Wind turbine operational supply chain* demo case for showcasing cross-domain data integration requirements in a multistakeholder environment that uses IDEAL convergence capabilities to give tangible evidence.



IDEAL Capabilities Convergence Model

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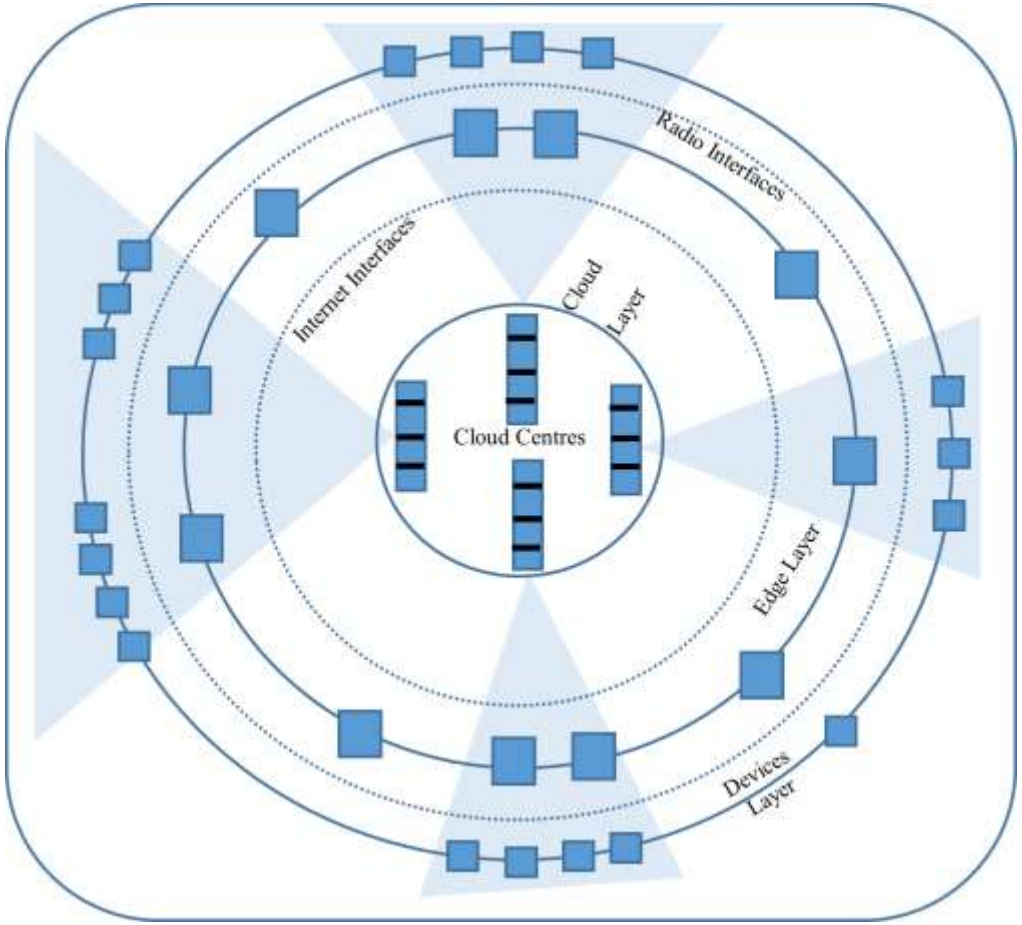
*Edge can be perceived as an organizational unit owning systems, services, data, and associated interfaces.

Challenges

- **Conventional Cloud-Edge-Device continuum** - distributed integration of data and services
  - **Heterogeneity & Interoperability** - Managing diverse systems, services, and data models at different integration levels.
  - **Distributed Operations (Silos), Security & Trust:** Ensuring coordinated, secure and trusted operations and interactions.
  - **Scalability & Resource Management:** Efficient scaling and managing resources.
  - **Modern Day Requirement Limitations:** Inadequate support for dynamic cross-domain data integration and processing needs.

➔ **Need for Paradigm Extension**:

  - **Extend Beyond Traditional Models:** Introduce advanced cross-domain data integration methods.
  - **Address Emerging Challenges:** Focus on overcoming issues related to heterogeneity, security, trust, scalability, and resource management.

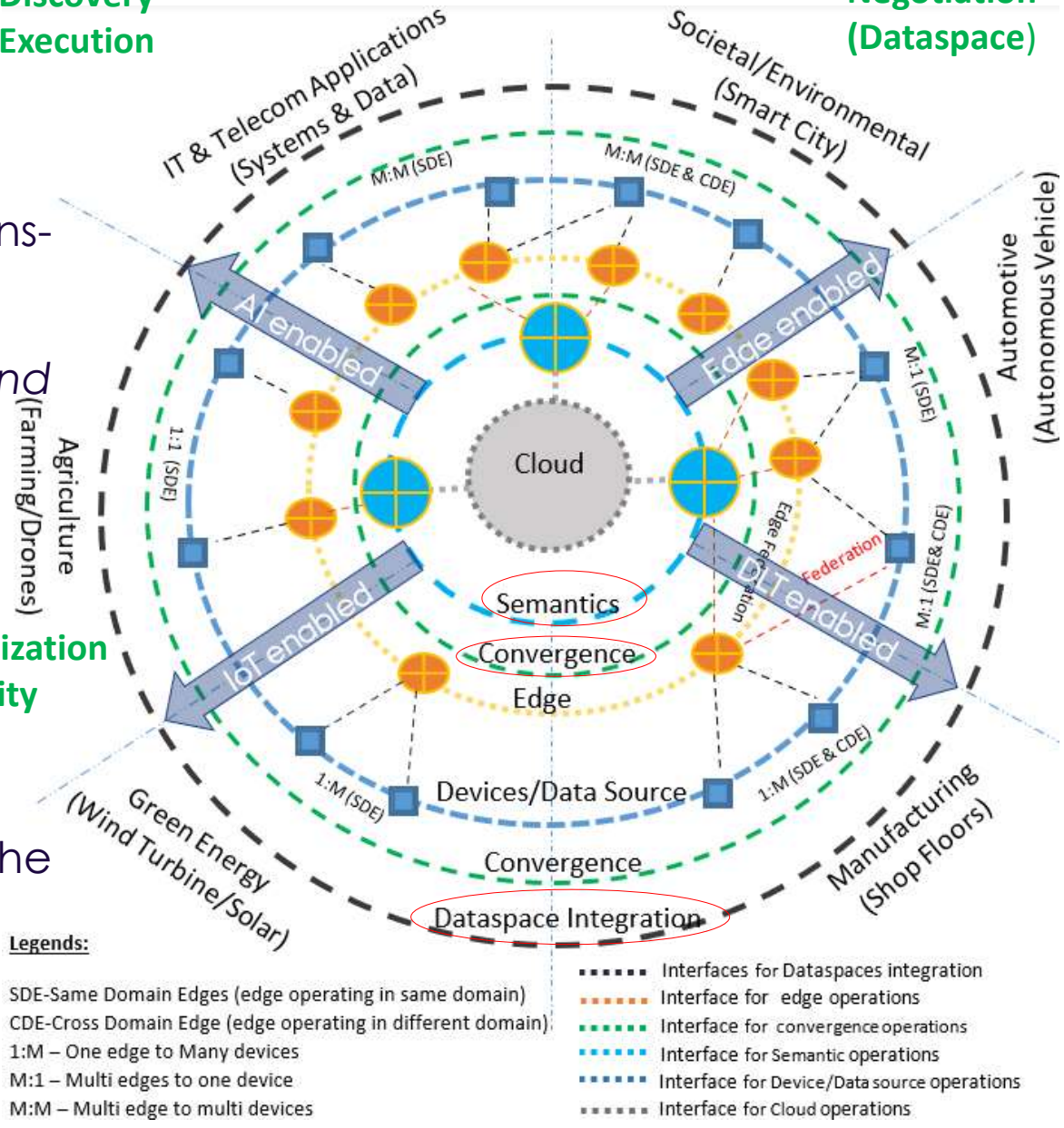


Solution - Architecture

CED extension ➔ Distributed Edge Network Operations-oriented Semantic **(DENOS)** model

- **Three new layers –** *Semantic, Convergence, and Dataspace integration*.
- Leverages the power of **three *semantic **contexts.**
  - **Processing** context (at the **infrastructure** level),
  - **Service** context (at the **interface** level),
  - **Data** context (at the **application** level) contexts
- **Contexts** can be **defined and executed dynamically.**
- Enable the **dynamic implementation context** to suit the **diverse needs** of target use cases

- Discovery
- Execution
- Negotiation (Dataspace)
- Optimization
- Security



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*Semantic – "Meaning"
**Context – "Surrounding Information"

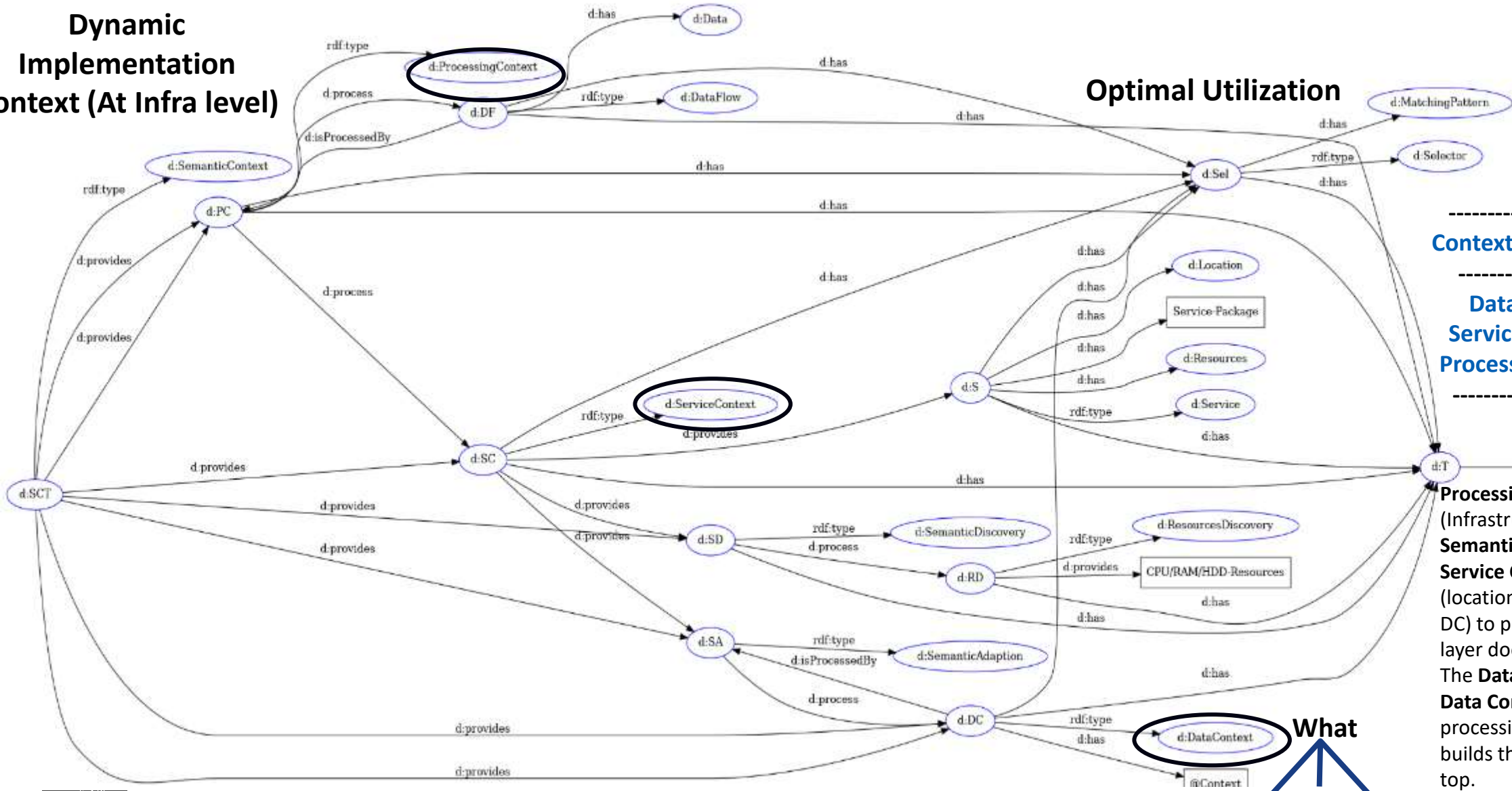
SOLUTION - ARCHITECTURE

Processing/Service/Data Flow Chaining

Semantic Discovery & Adaption

Dynamic Implementation ontext (At Infra level)

Optimal Utilization



Context | Level (CED)

Data | Application
Service | Interface
Processing | Infrastructure

Processing Context (PC) (Infrastructure requirements) at **Semantic l**ayer tells **how** (i.e. **Service Context (SC)**) and **where** (location) and **what** context (e.g. DC) to process. **Convergence** layer does the actual execution. The **Dataspace** layer based on **Data Context (DC)** (supported by processing and service context) builds the data value chain on top.

Value Chain

DENOS (Offers) Semantic Context (SC) driven Processing Model

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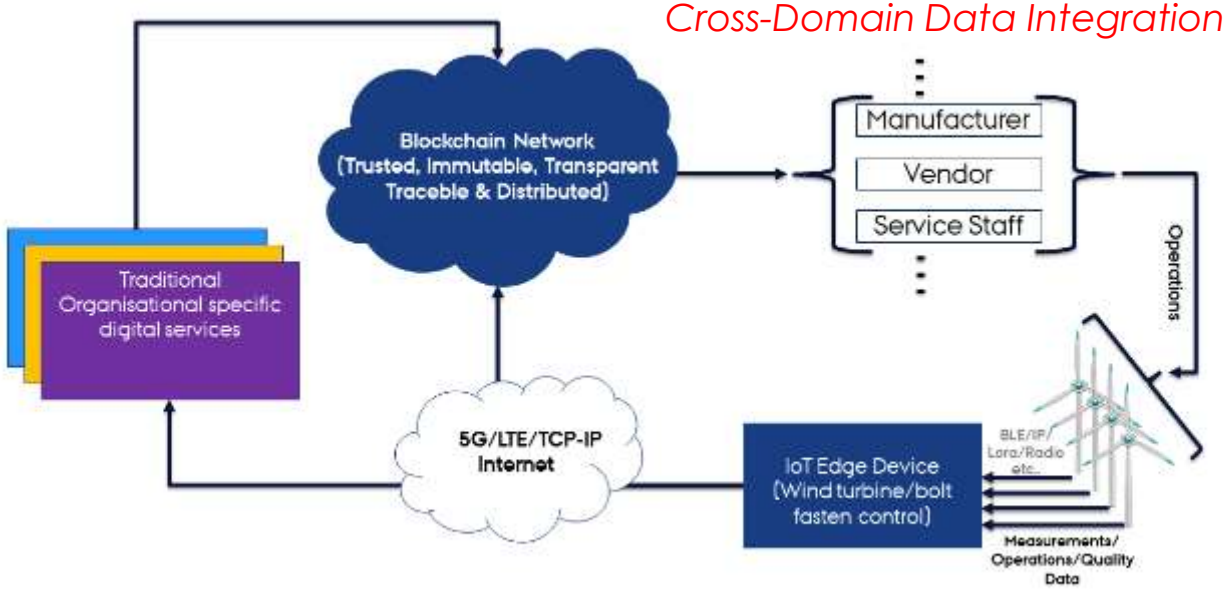
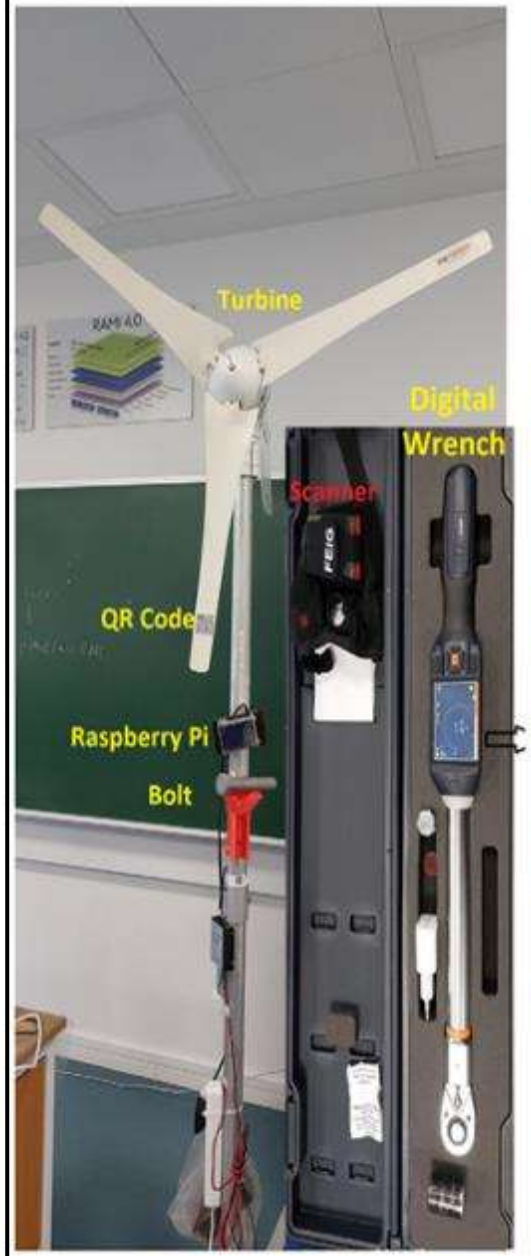
Prototype(Demo Case)

Cross-Domain Data Integration



- ***Requirement:*** *End-to-end digitized bolt operation (latency sensitive to apply precise torque on the bolt) on a wind turbine to ensure quality, error avoidance, and proactive maintenance. In addition, the data during the assembly and maintenance phase should be able to be used during insurance claims of bolt damages within the life cycle of the turbine.*
  - ***Hardware Components:*** *Wind Turbine, Digital Wrench, QR code Scanner, Bolt, Edge device (Raspberry Pi4.0), and Edge/Cloud Server (Ubuntu20.04, 8 GB RAM, 2 VCPU, 60 GB HDD).*
  - ***Software Components****: DLT service (HyperLedgerFabric/Ethereum test net for private DLT neworks), Odoo-based ERP to replicate traditional cloud-enabled centralized systems, Node-Red, NodeJS, JavaScript, Python.*

Stakeholders Involved*: Bolt Vendor, Turbine Operator, Service Engineer (SvcEng.), Insurance official.*



Register Id
- QR Codes for Turbine and Bolt Identification
- Ethereum based Application APIs provides QR code generation

Digital Tagging
- Tag Turbine and Bolt with QR codes
- Physical asset mapping to digital traceability in Blockchain

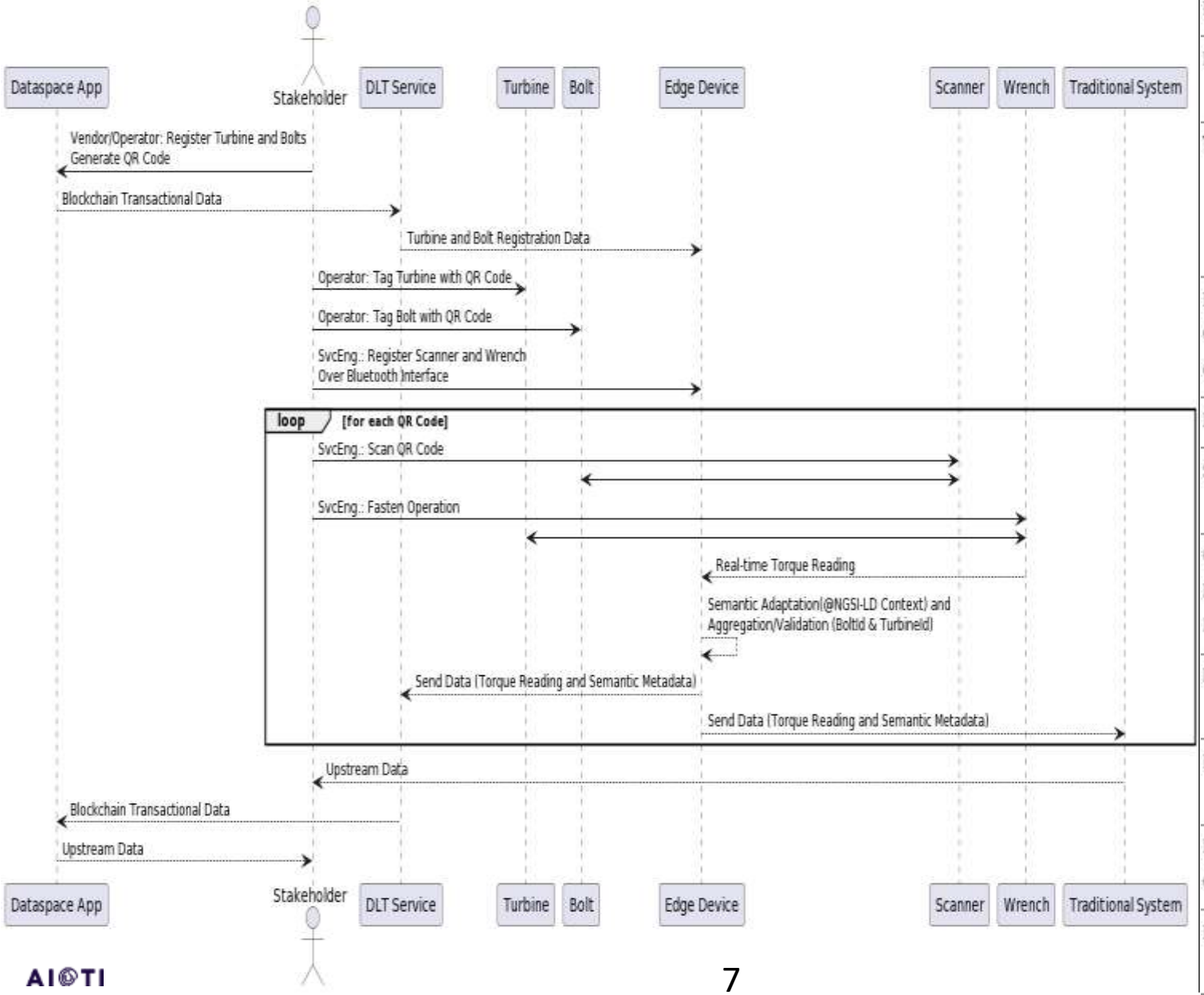
Device Register
- Turbine, Batch of Bolts (using QR Code)
- Scanner & Digital Wrench Device

Action Mapping
- Perform bolt fasten operation using digital wrench on bolt.
- Real time Torque measurements monitoring started.

Tracing
- Data/Metadata is collected and processed in IoT application.
- Application sends data to blockchain network accessible to all stakeholders in transparent, secure and trustable manner.

Combined use of Technologies - IoT, Edge, AI, and DLT

Prototype – Cross-Domain Data Flow (Multi-stakeholder)



Functional block	Technology used	Use case usage context
Data Sources	IoT	Wrench, Scanner, QR code (Bolt and Turbine)
Transport Protocols	HTTPS, Bluetooth (BLE)	Torque reading, QR code scanning data stream used BLE between turbine and edge device. HTTPS is used between Edge device and other services interacting with it
Distributed Service Chaining (Service Context)	Node-Red	Realization of service context (BLE, DLT, Dataspace handlers)
Data Ingestion	Node-Red, REST and BLE	Ingest data for onsite turbine operations
Semantic Context	JSON, NGSI-LD (Node-Red based)	For Semantic Adaptation
Custom Programming Interface	Node-Red, NodeJS	For implementing Service Context at the edge
Persistence	HyperledgerFabric/Ethereum, Postgres	Store DLT transactions and traditional system data
Distributed Security	HyperledgerFabric/Ethereum, OAUTH2	For CP operations and User Identity Management
Edge Service Orchestration	Kubernetes/Docker	For implementing predefined Processing context
Data Visualization	Node-Red-Dashboard	For Dataspace App (frontend part), displaying Turbine, Bolt and Torque Data

Benefits or results

- **Theoretical foundation** on Distributed Edge Architectures
- **CED extension** via Semantic, Convergence, and Dataspace integration layers.
- An **architectural framework** for dynamic implementation context
- **Convergence** of IDEAL (IoT+ DLT+Edge+AI) technological capabilities
  - **IoT= Data** Generation & Collection, **Edge= Localised** Computing;
  - **DLT=** Distributed **Security; AI=** Data & Operations **Intelligence**
- Capable of **addressing** relevant **challenges**
- **Validation** through wind farm operations use case
  - Real-time **Event Monitoring** & **Quality Optimization**
  - **Efficient** energy production
  - **Reduced** maintenance **costs**
  - **Cross-Domain** Data **Integration** for multiple stakeholders
  - Enhanced, **trusted**, and **transparent** bolt-turbine **value chain** management

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Conclusions

- **CED paradigm extension** by adding new layers and semantic contexts**.**
- **Convergence of technologies** IoT, AI, and DLT to reap combined benefits & solve relevant challenges.
- **Dynamic implementation** context.
- **Prototyped validation** via a Wind-Turbine Use Case.
- **Dataspace enabled cross-domain data integration** for value chain enablement using distributed edge architectural framework i.e. DENOS.

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Thank you