

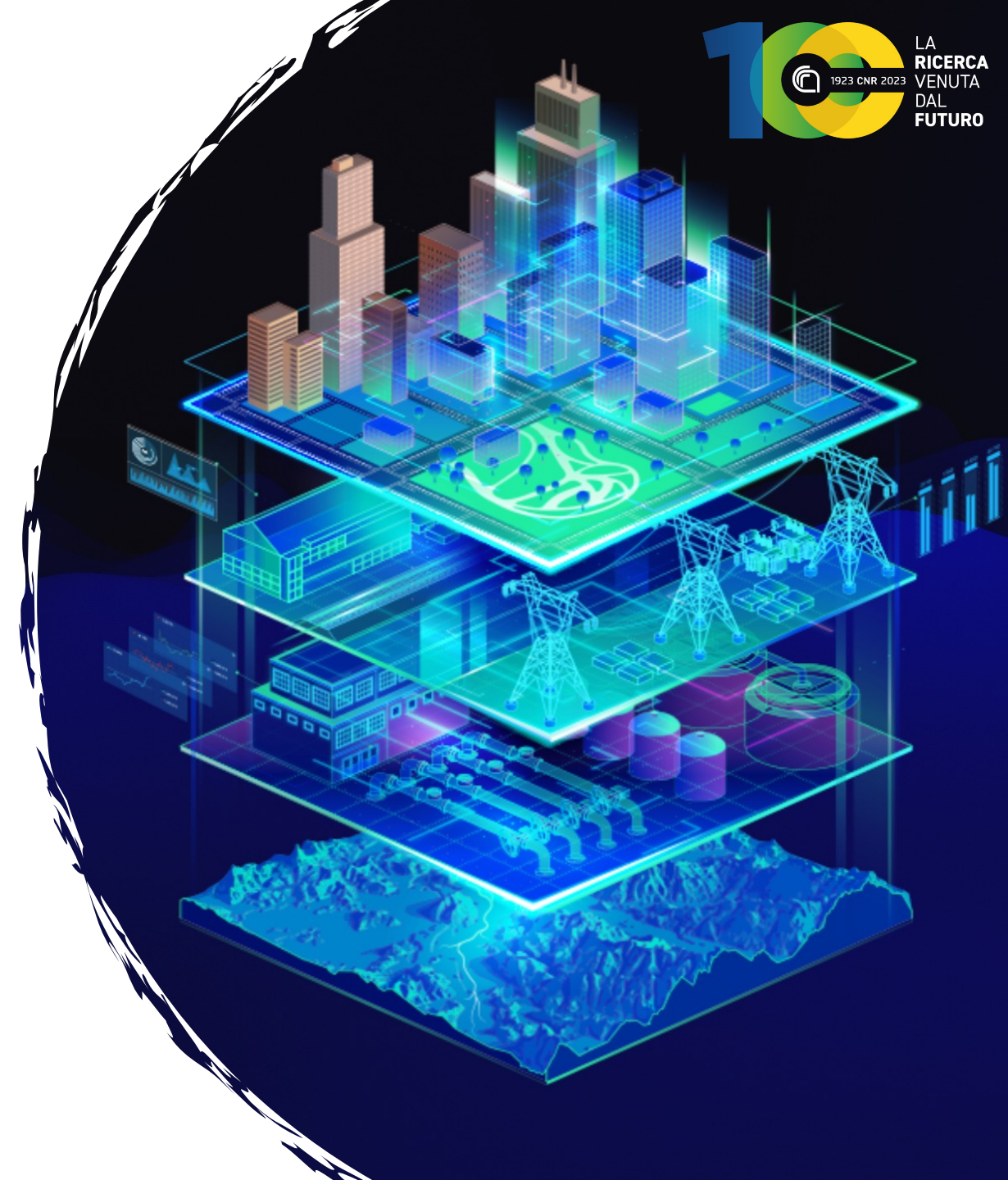
Building an Ecosystem of Interoperable Digital Twins: Challenges & Experiences

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October 19, 2023 - October 20, 2023, Rome, Italy

Digital Twin's Definition & Pillars

A Digital Twin is a comprehensive **software representation** of an individual **physical object**

It includes the **properties, conditions, relationships and behavior(s)** of the real-life object

through **models and data**. A Digital Twin is a set of realistic models that can **digitalize** an

object's behavior in the deployed environment. The digital twin represents and reflects its

physical twin and remains its virtual counterpart across the object's entire **lifecycle**

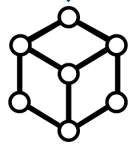
Software



Physical
Communication



Data Processing
& Model



Description
Language



Cyber-Physical
Lifecycle



Digital
Communication



Digital Twin's Pillars (and questions)

- **Software:**

- How can we **design** and structure DT's code ?
- How can we **deploy** DTs ?
- How can we **monitor** DTs ?

- **Physical & Digital Communications:**

- How a DT can **interact** with the **physical** and the **digital** layers ?

- **Data Processing & Model:**

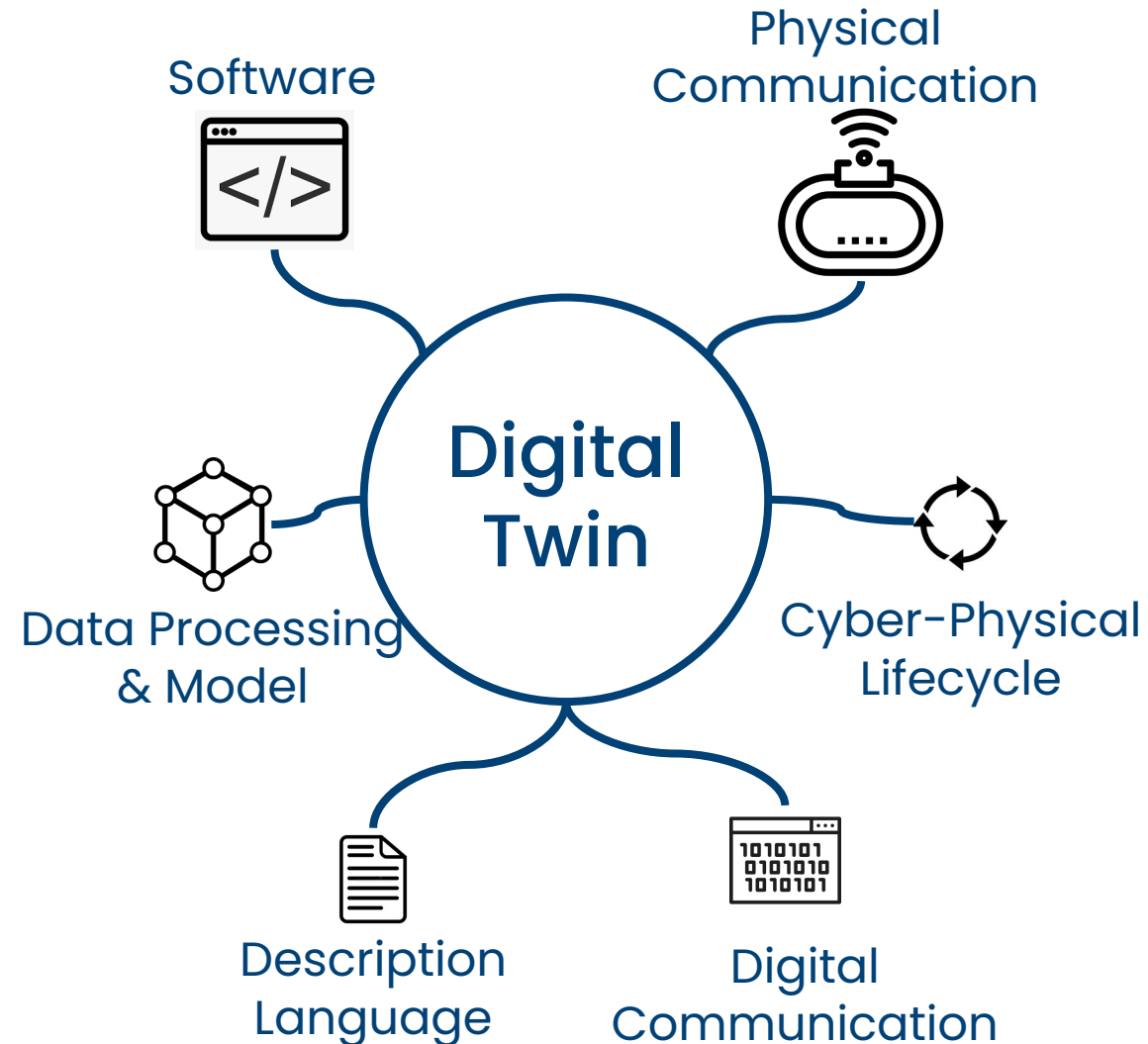
- How can we **define**, **update** and **execute** the DT's **model** ?

- **Cyber-Physical Life Cycle:**

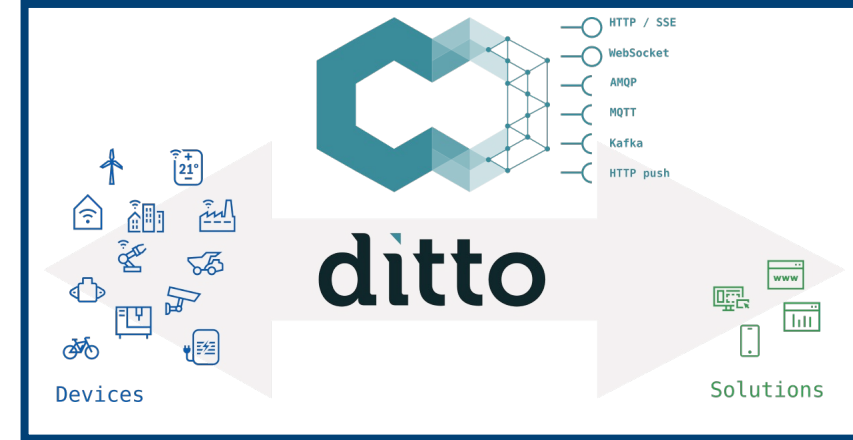
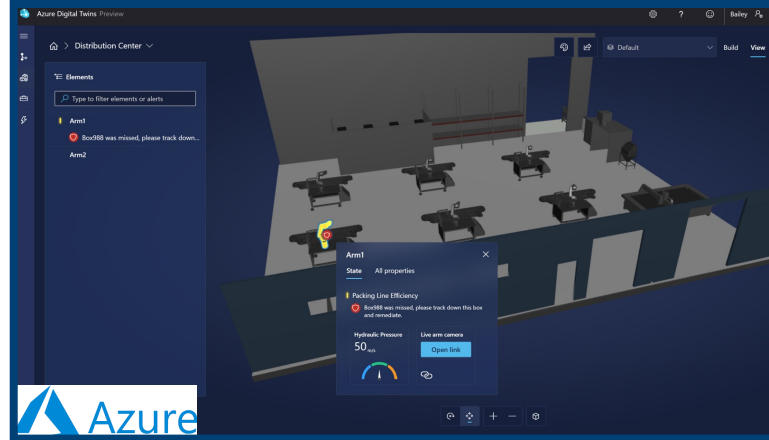
- How the DT **evolve over time** and with respect to the physical and the digital worlds ?

- **Description Language:**

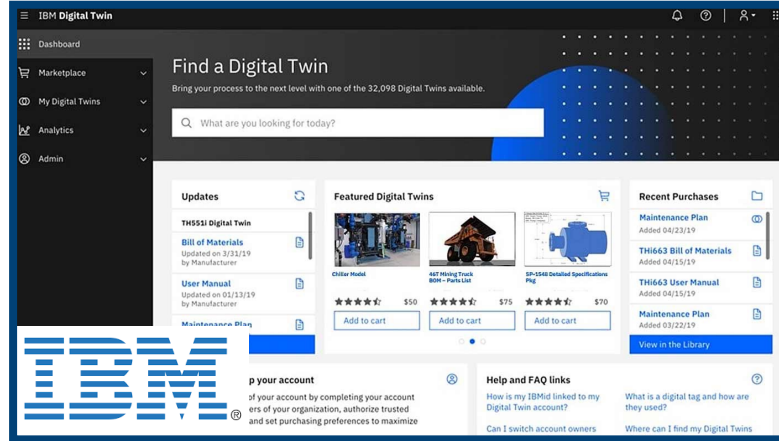
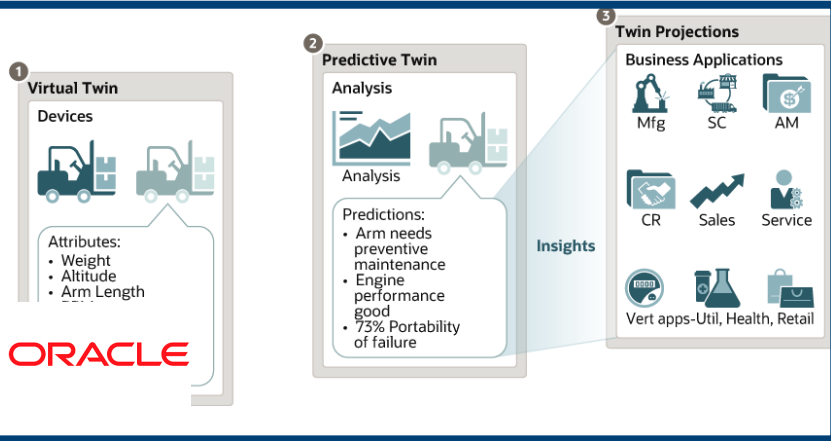
- How can we **describe** a DT through a **uniform**, and **interoperable representation** ?



Digital Twins as a Massive Trending Topic

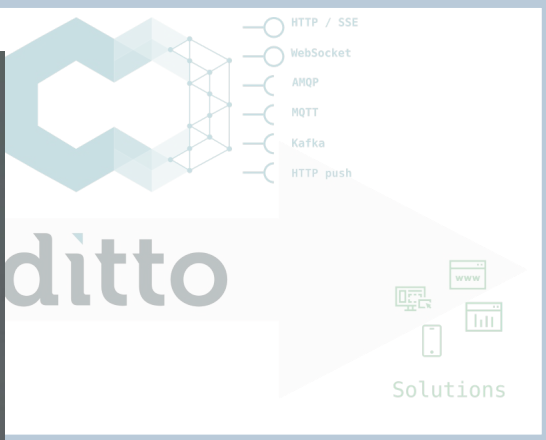


Almost "Everyone" is talking and building Digital Twin in their own way, with independent platforms and fragmented modelling ..



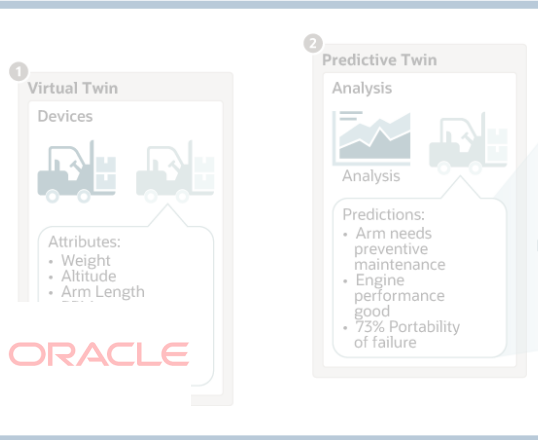
and counting ...

Digital Twin as a Trending Topic



Almost "Everyone" is indexing ...

own way, with ...



1 Virtual Twin
Devices
Attributes:
• Weight
• Altitude
• Arm Length

2 Predictive Twin
Analysis
Predictions:
• Arm needs preventive maintenance
• Engine performance good
• 73% Portability of failure



IBM
p your account
if your account by completing your account
ens of your organization, authorize trusted
and set purchasing preferences to maximize

Help and FAQ links
How is my IBMid linked to my Digital Twin account?
Can I switch account owners?

Maintenance Plan
Add to cart
Add to cart
Add to cart
View in the Library

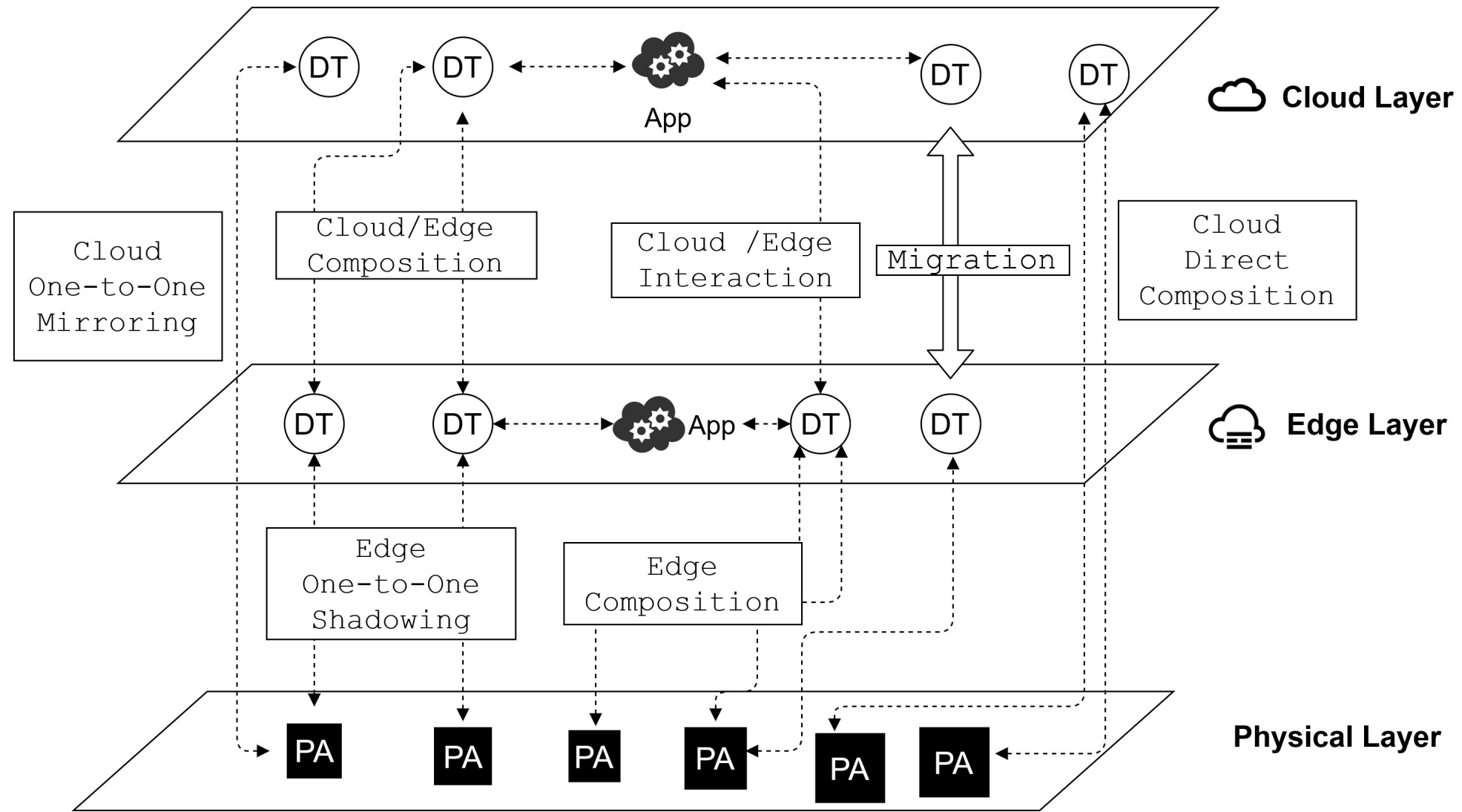
and counting ...

The Current Digital Twin Ecosystem

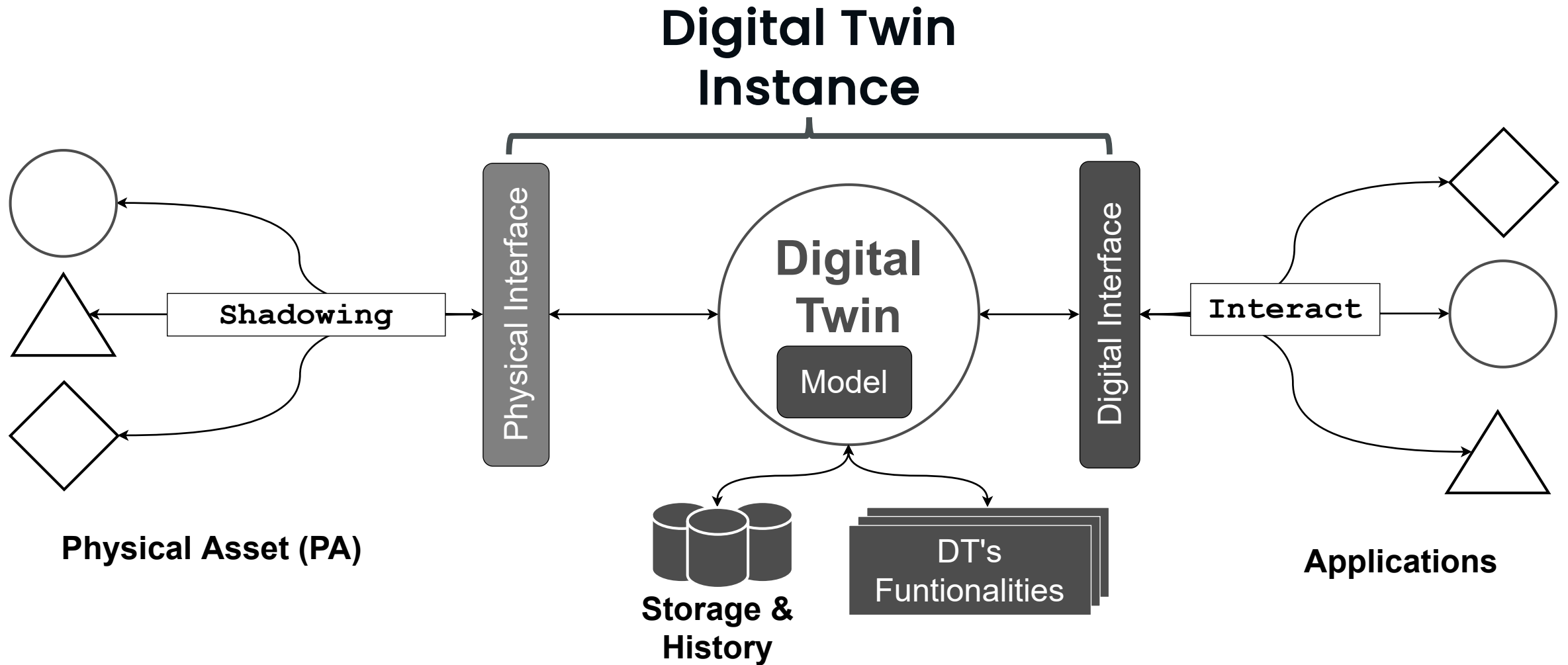
- **IMPORTANT:** Existing Digital Twin platforms and solutions represent amazing contributions to the domain and a tremendous effort toward a widespread experimentation and adoption -> **But they are just the starting point** 😊
- (Some of) Existing Issues:
 - Mainly **centralised/monolithic approaches** where all DTs are aggregated and deployed in the same point (the Cloud)
 - Digital Twins are mainly **passive entities** co-located at the same architectural layer of the platform itself and **subordinated to external modules** to control their properties, data and behaviours
 - Digital Twins are often **“just” data structures** that can be used to represent an application scenario **without a model** and any active behaviour
 - **Platform Specific Digital Twin Description**
 - **Proprietary vertical technology** stacks which are built around a central point of control and which **don't always talk to each other** -> when they do talk to each other it requires **per-vendor integrations** to connect those systems together

Digital Twins represent a **“new”** technology that needs a lot of work to be effective without fragmentation and the definition of a unified conceptual framework

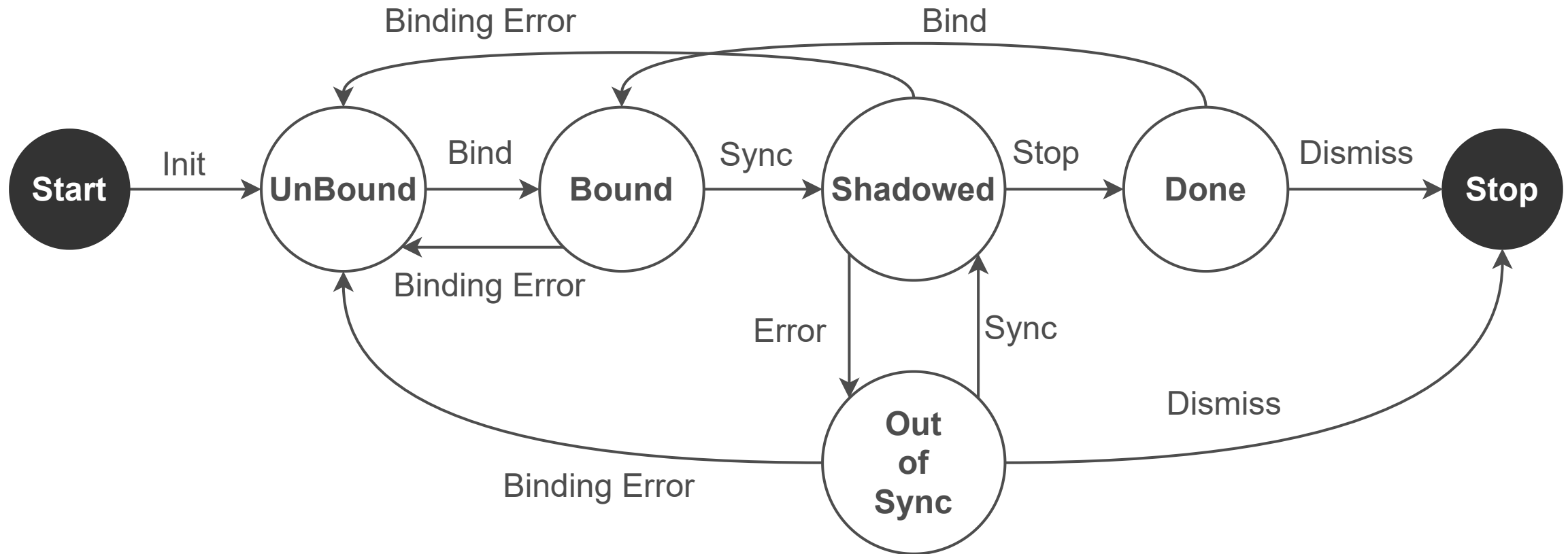
Building an Ecosystem of Interoperable Digital Twins



Digital Twin's Abstraction

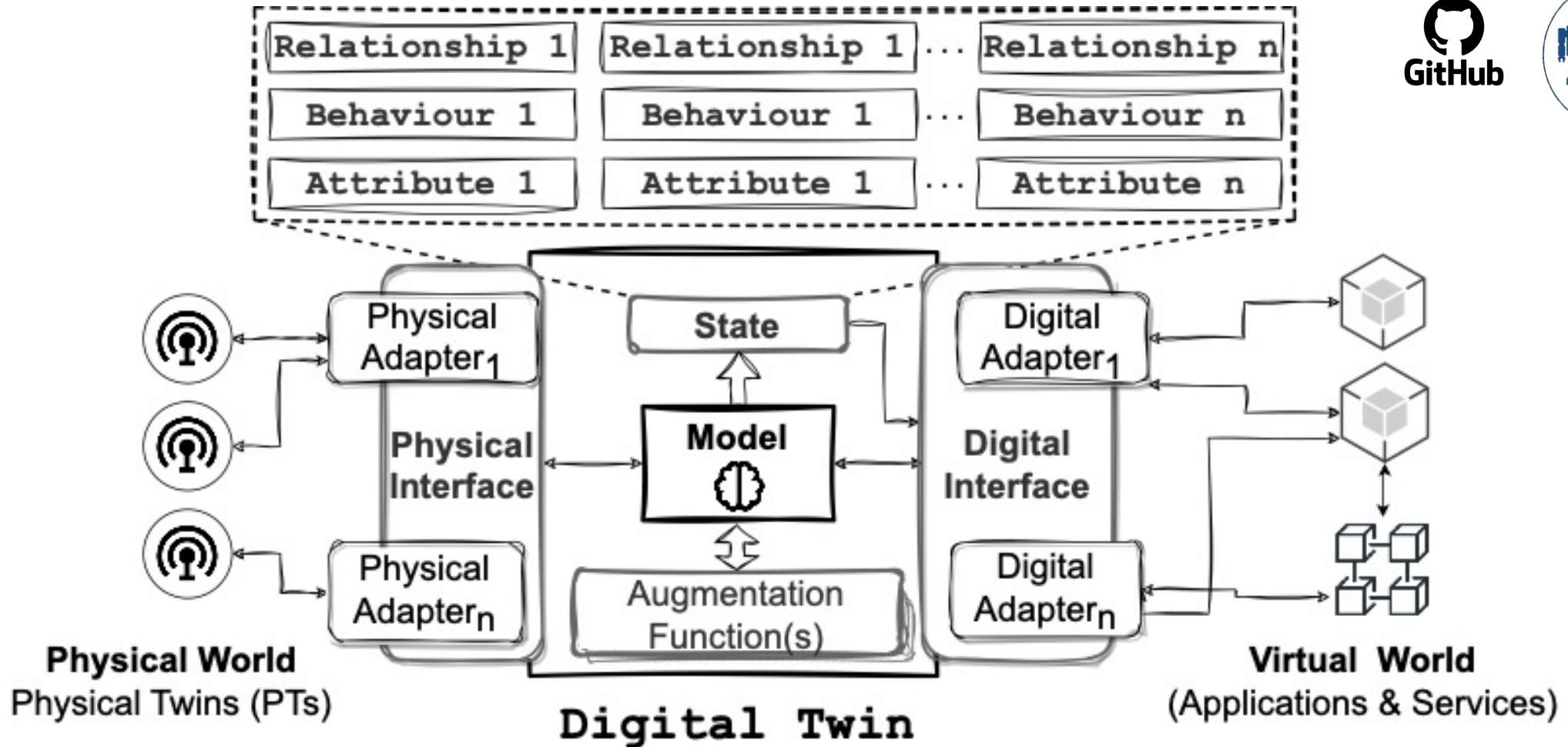
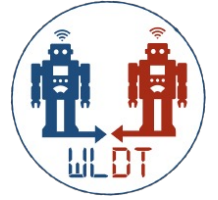


Digital Twin's Life Cycle



Digital Twin Software Architecture

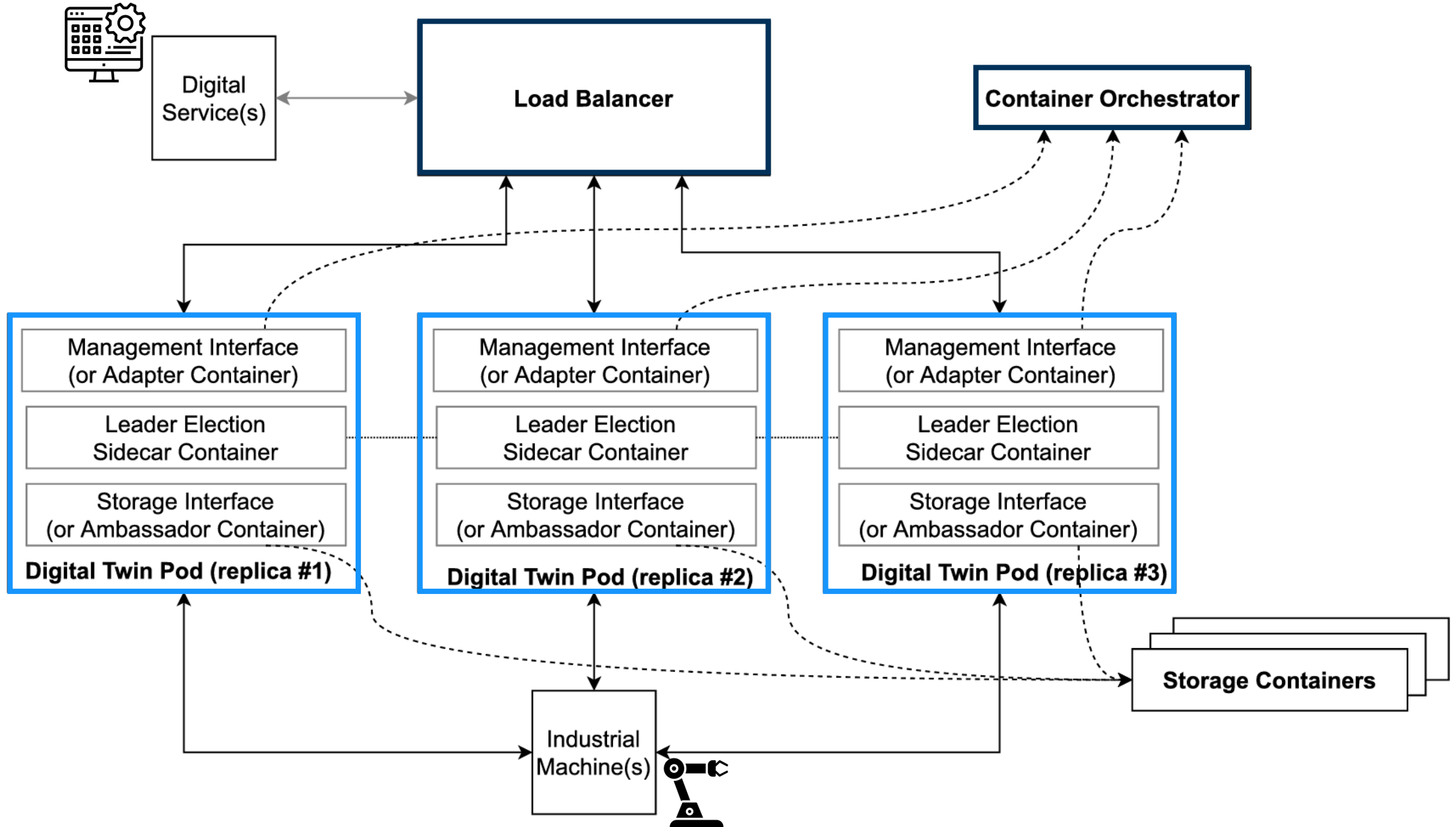
White Label Digital Twin Library
<https://github.com/wldt>



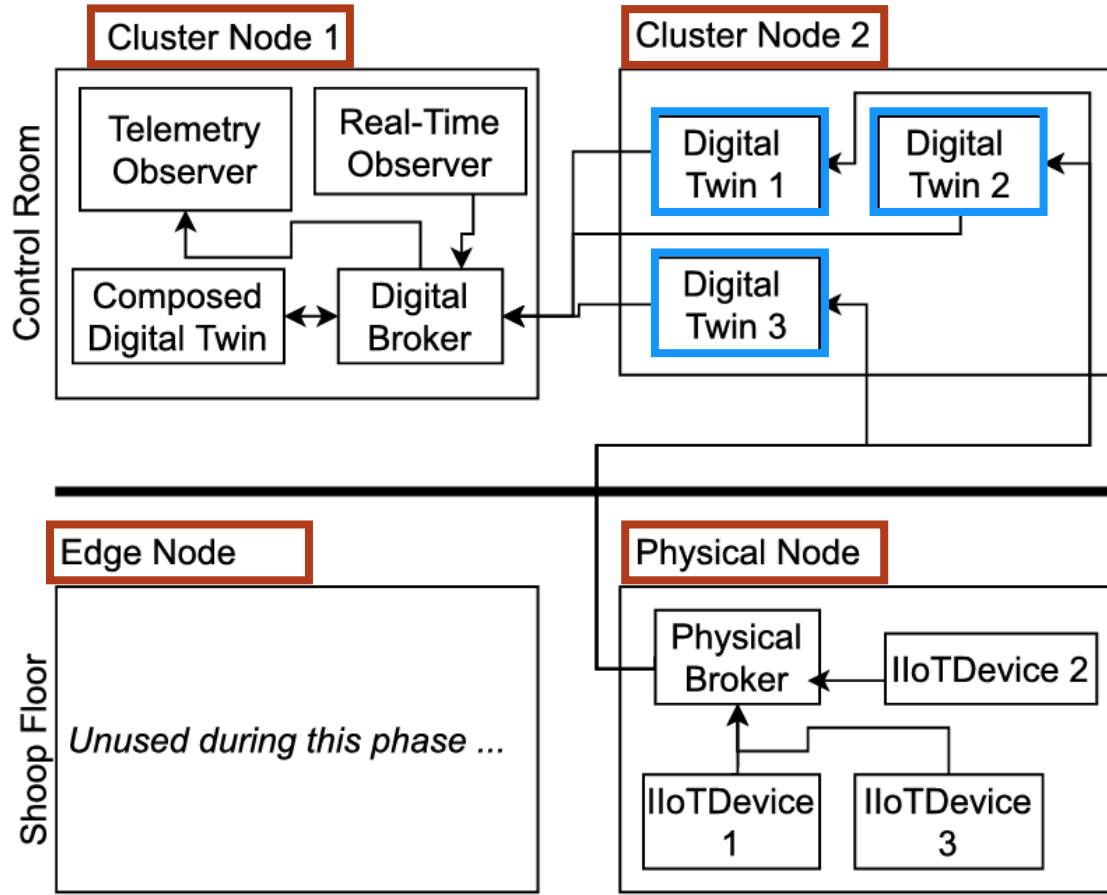
Marco Picone, Marco Mamei, Franco Zambonelli, WLDT: A general purpose library to build IoT digital twins, SoftwareX, Volume 13, 2021, 100661, ISSN 2352-7110, <https://doi.org/10.1016/j.softx.2021.100661>.

Paolo Bellavista, Nicola Bilocchi, Mattia Fogli, Carlo Giannelli, Marco Mamei, Marco Picone, Requirements and design patterns for adaptive, autonomous, and context-aware digital twins in industry 4.0 digital factories, Computers in Industry, Volume 149, 2023, 103918, ISSN 0166-3615

Digital Twin & Distributed Software Environment

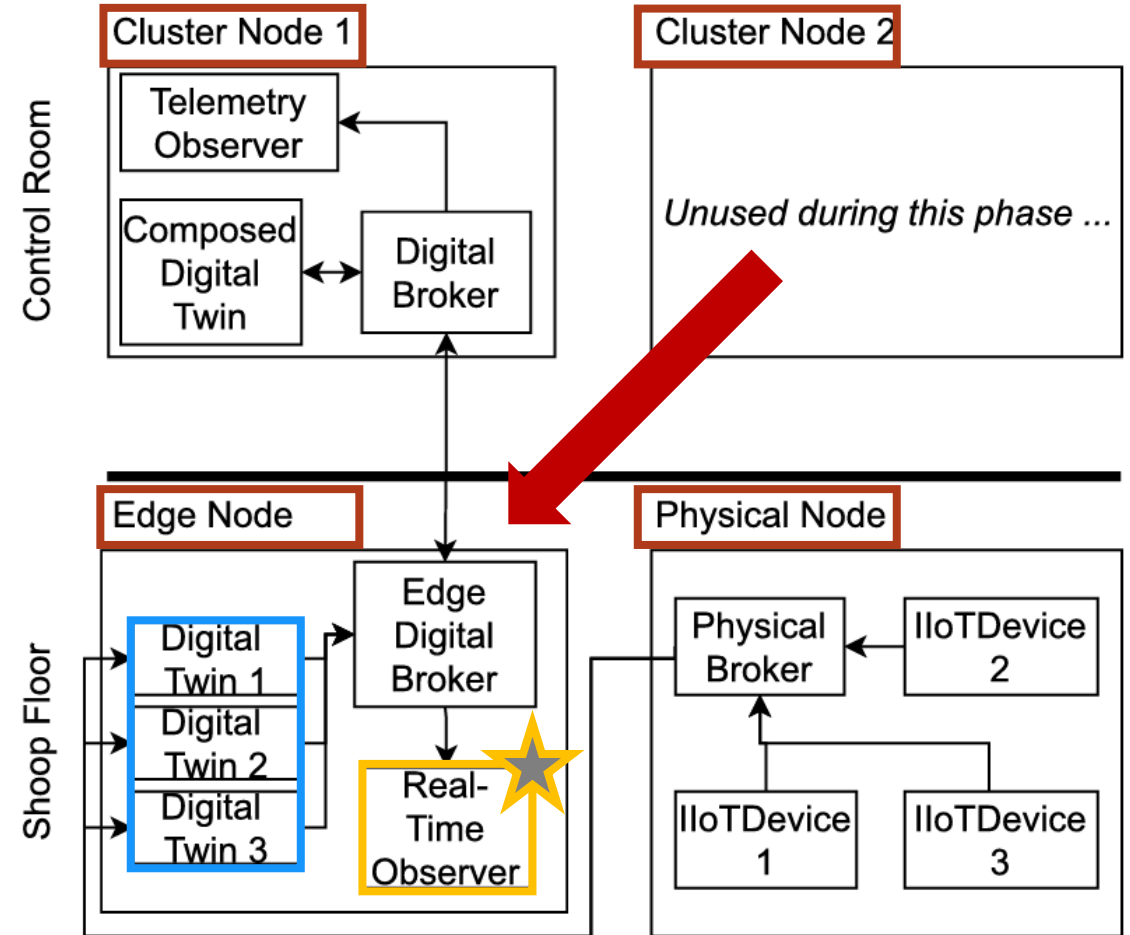


Digital Twin & Distributed Software Environment



(a) Initial deployment.

1

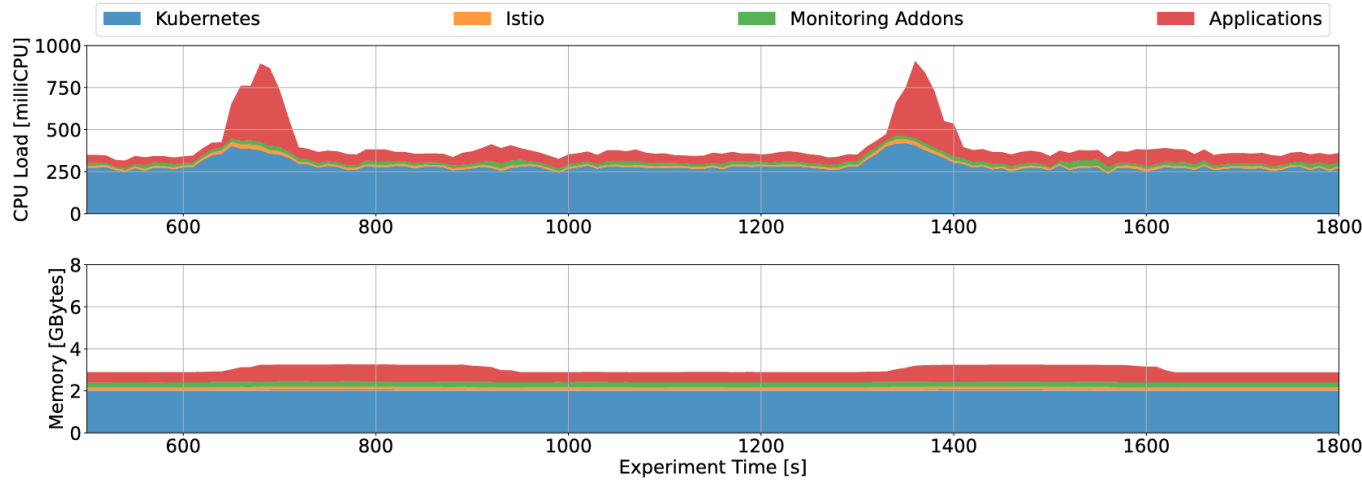


(b) Adaptive deployment.

2

Digital Twin & Distributed Software Environment

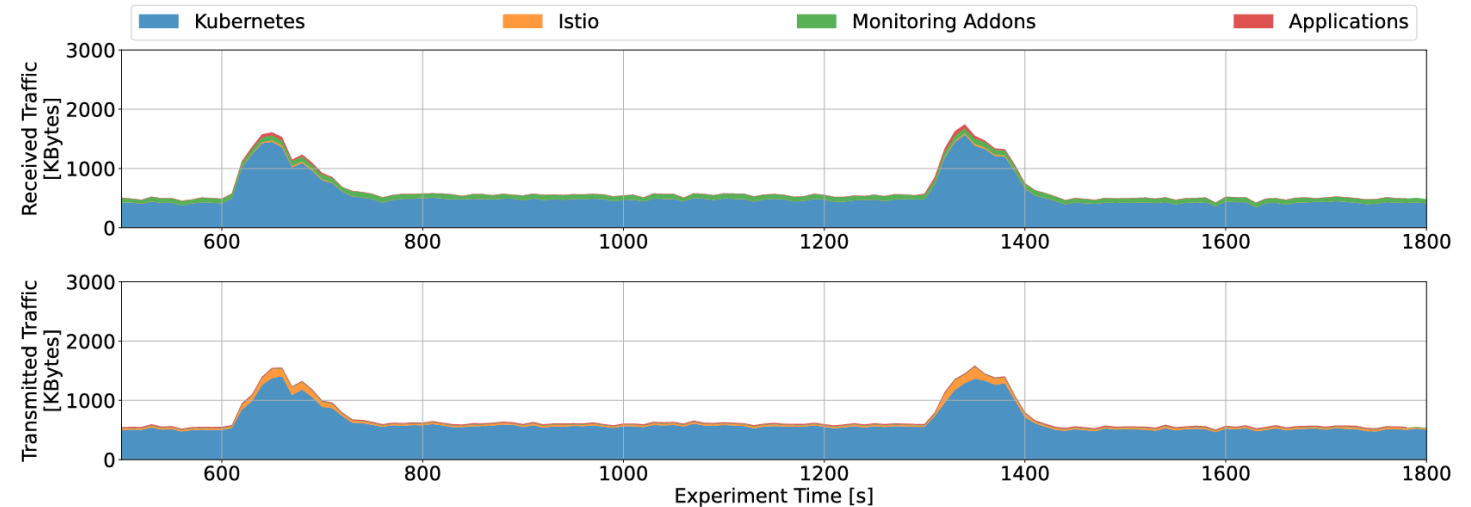
System Resource Consumption



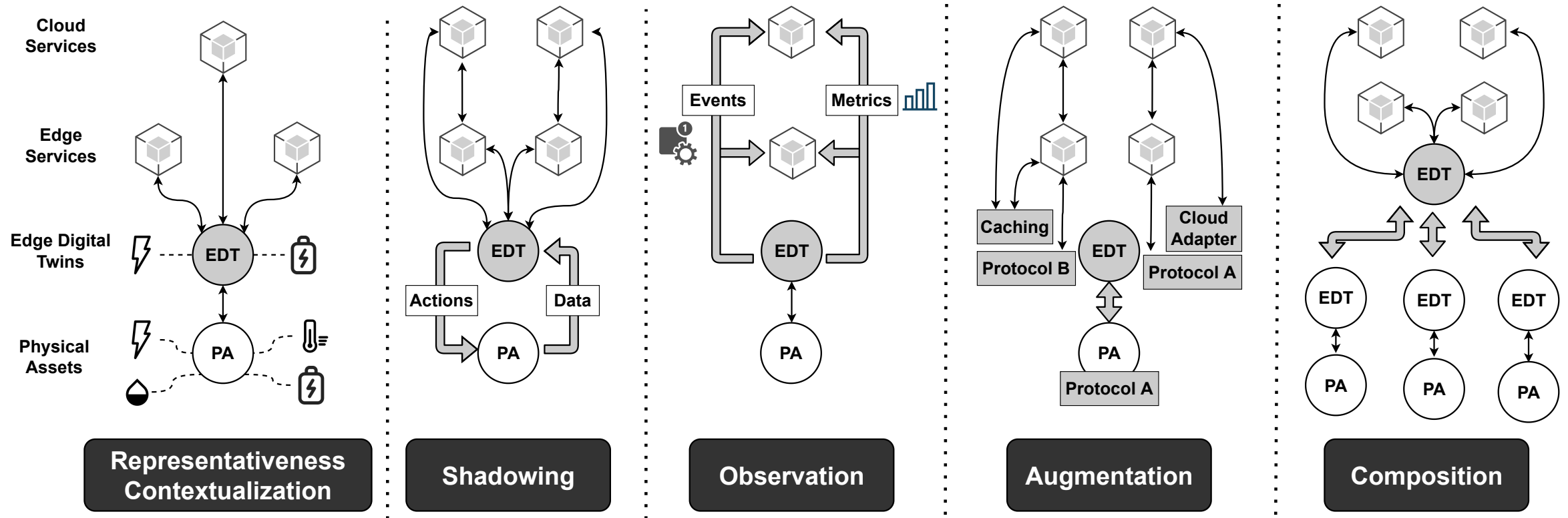
Introduced overhead in terms of CPU and Memory consumption with respect to a basic Kubernetes deployment during the phases of migration and rollback.

Received and transmitted KB by Kubernetes, Istio, Monitoring addons and DT applications during the phases of migration and rollback.

System Network Consumption



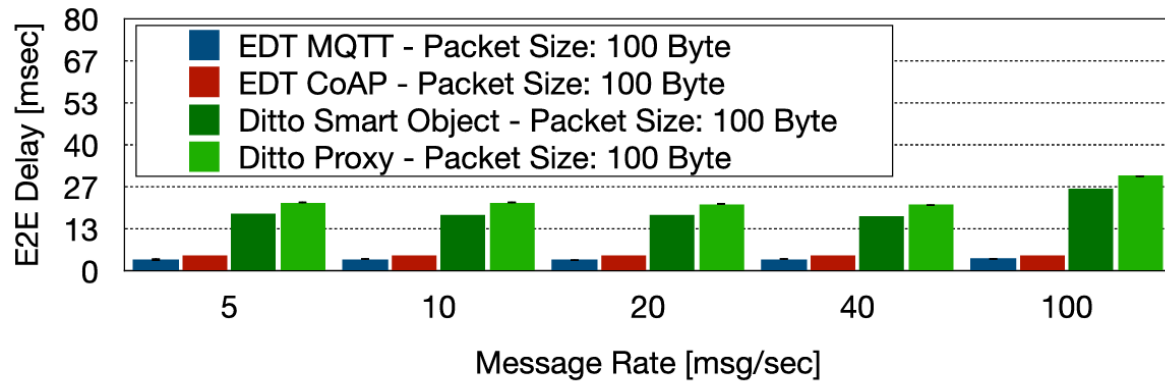
Digital Twins on the Edge ?



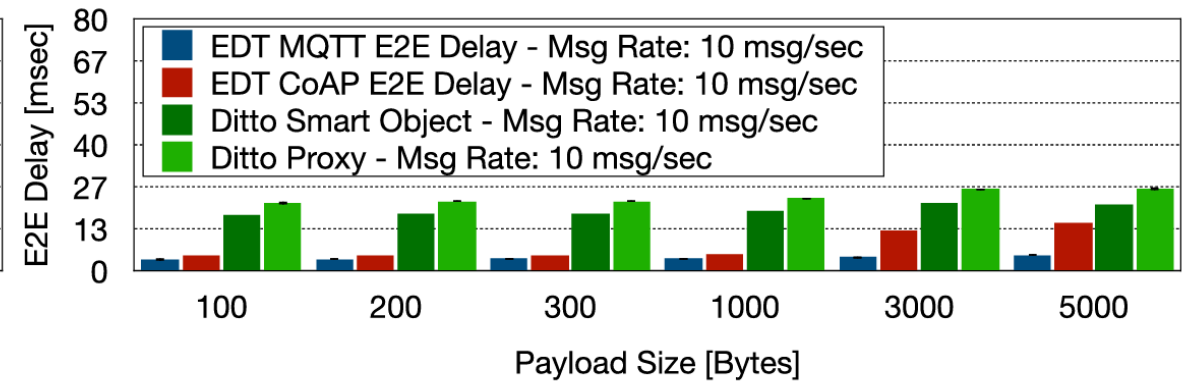
Marco Picone, Marco Mamei, and Franco Zambonelli. 2023. **A Flexible and Modular Architecture for Edge Digital Twin: Implementation and Evaluation.** ACM Transaction of Internet of Things 4, 1, Article 8 (February 2023), 32 pages. <https://doi.org/10.1145/3573206>

Digital Twins on the Edge ?

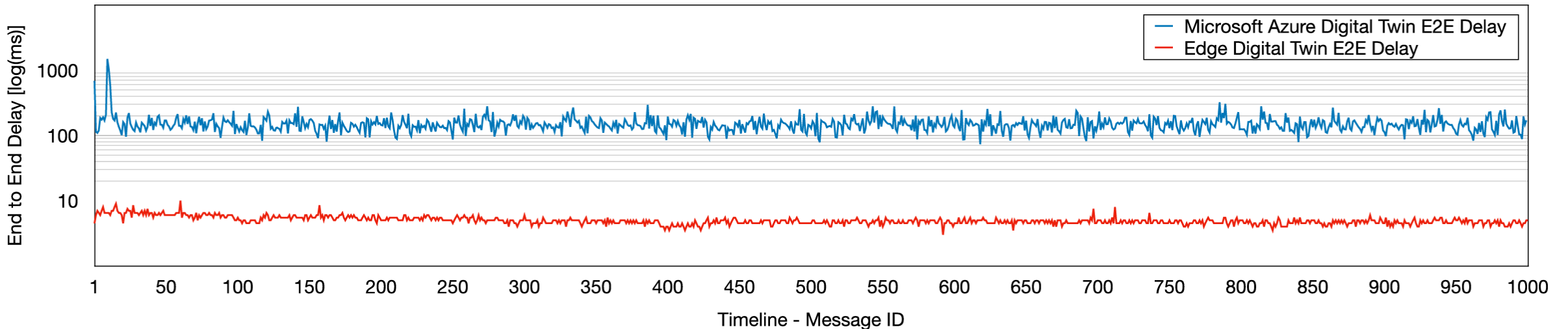
Average Eclipse Ditto - E2E Delay - Message Rate



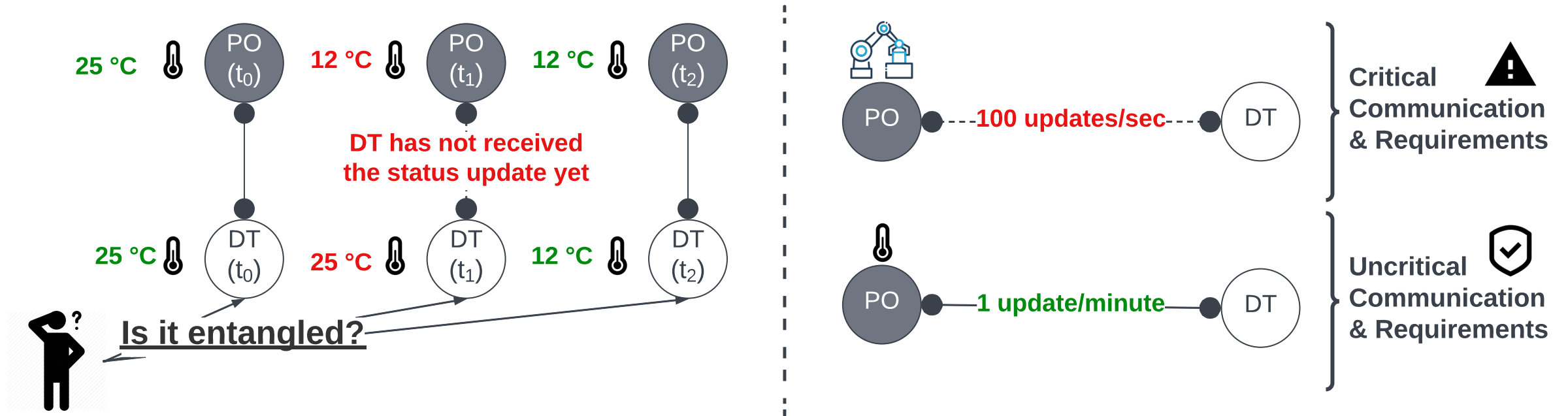
Average Eclipse Ditto - E2E Delay - Payload Size



Timeline End to End Delay Analysis - Azure Cloud Digital Twin vs Edge Digital Twin - 10 msg/sec - Payload 200 Bytes



Can we rely on Digital Twins ?



Can we rely on traditional network metrics ?

Do we need something more related to the cyber-physical relationship between the DT and the PO ?

Example

Context: Network Delay = 1 Sec

Question: Is it a problem for an application observing and interacting with the DT ?

How can we measure the Entanglement ?

Timeliness

How fresh the collected data are

$$T(100 \text{ ms}, \text{now} - 5 \text{ m}, O) = 0.99$$

Reliability

The ratio of the received status updates
to the expected ones

$$R(\text{now} - 5 \text{ m}, O) = 0.8$$

Availability

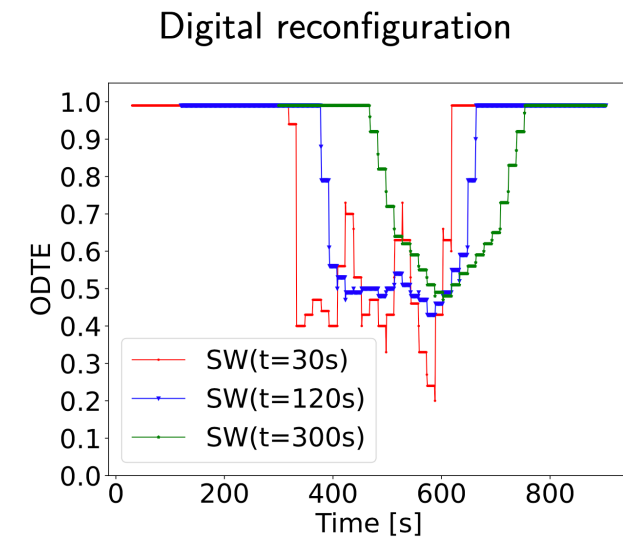
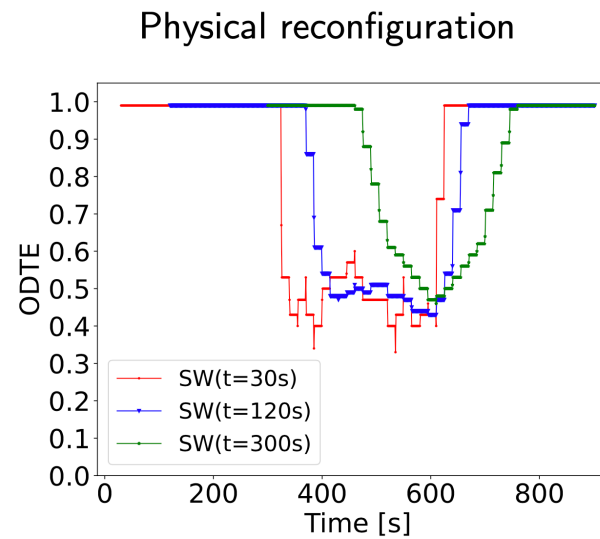
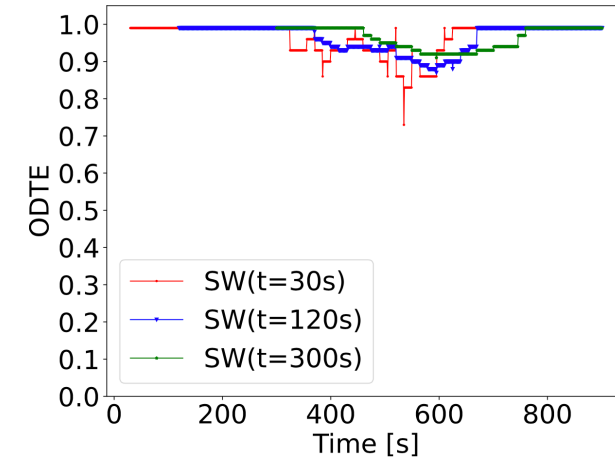
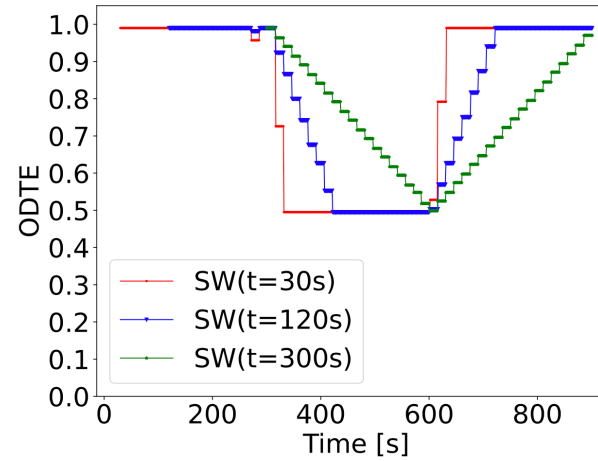
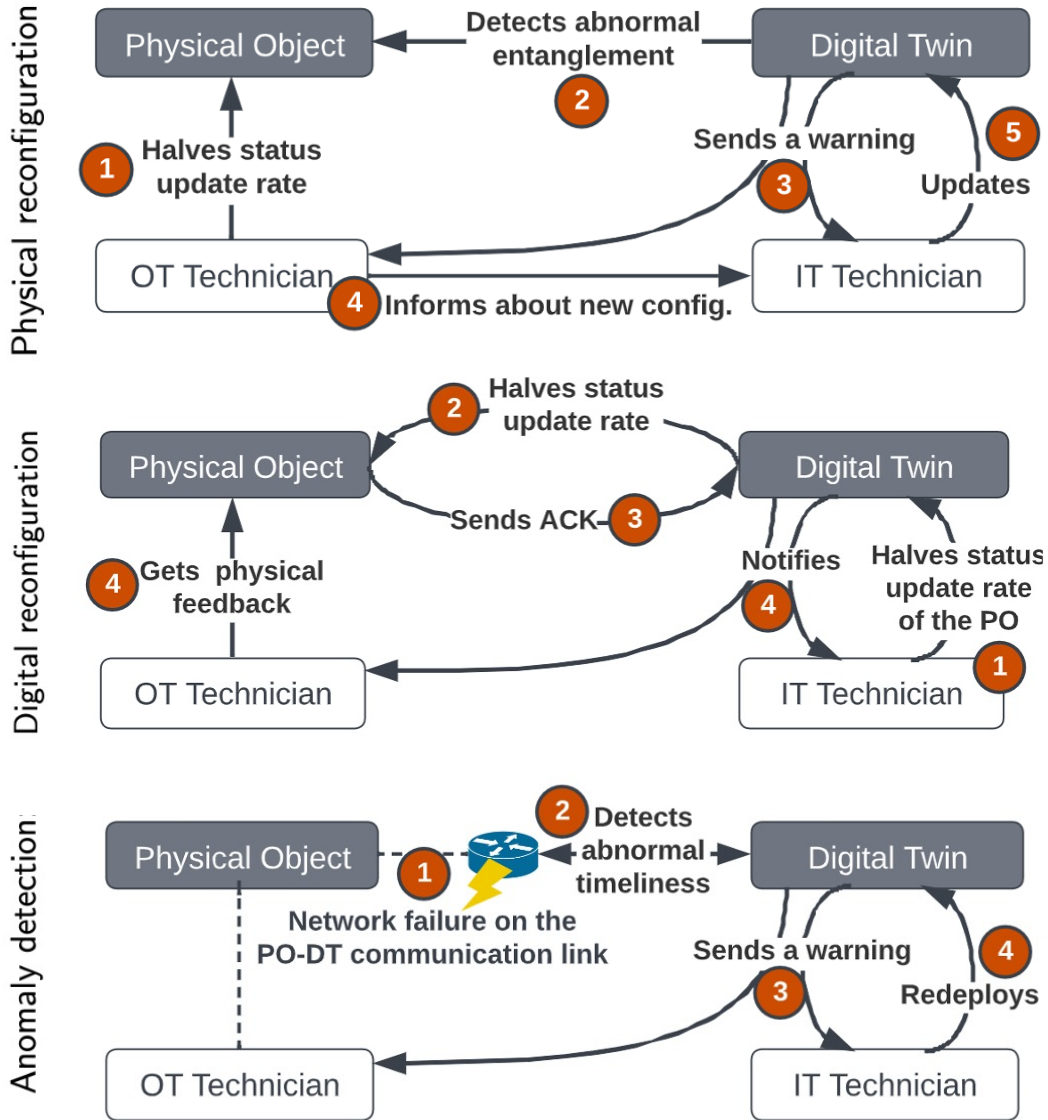
The expected up-time of the PO from
the perspective of the DT

$$A(\text{now} - 5 \text{ m}) = 0.5$$

Putting it all together: **Overall Digital Twin Entanglement (ODTE)**

$$ODTE = \textit{Timeliness} \times \textit{Reliability} \times \textit{Availability}$$

Entanglement Measurement & Target Scenarios



Anomaly detection: Latency

Anomaly detection: Latency & loss

Standardization Trend

ETSI Projects Portal

SAREF Digital Twins
Ref. Body: SmartM2M - Project No: 641
From 2022-12-01 to 2024-09-30

Technical Description (Part B)

ISO Standards About us News Taking part Store

← ISO/IEC JTC 1

ISO/IEC JTC 1/SC 41

Internet of things and digital twin

About
Secretariat: **KATS**
Committee Manager: **Ms Jooran Lee**
Chairperson (until end 2025): **Dr François Coallier**

ISO Technical Programme Manager [TPM]: **Mr Stephen Duttall**
ISO Editorial Manager [EM]: **Mme Christine Lacroix**

Creation date: 2017

Scope
ISO/IEC JTC 1/SC 41 is being supported administratively by IEC. All information related to ISO/IEC JTC 1/SC 41 is available on the **IEC web site** Standardization in the area of Internet of Things and related technologies.

1. Serve as the focus and proponent for JTC 1's standardization programme on the Internet of Things and Digital Twin, including their related technologies.

digital twin CONSORTIUM

Our Working Groups collaborate to

chnology and
pecific vertical
markets.

VIEW ALL WORKING GROUPS

Internet Research Task Force
Internet-Draft
Intended status: Informational
Expires: 6 September 2022

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Telefonica I+D
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Huawei
M. Boucadair
C. Jacquenet
Orange
5 March 2022

Digital Twin Network: Concepts and Reference Architecture
draft-zhou-nmrg-digitaltwin-network-concepts-07

Abstract
Digital Twin technology has been seen as a rapid adoption technology in Industry 4.0. The application of Digital Twin technology in the networking field is meant to develop various rich network applications and realize efficient and cost effective data driven network management and accelerate network innovation.

This document presents an overview of the concepts of Digital Twin Network, provides the basic definitions and a reference architecture, lists a set of application scenarios, and discusses the benefits and key challenges of such technology.

Status of This Memo
This Internet-Draft is submitted in full conformance with the provisions of BCP 78 and BCP 79.
Internet-Drafts are working documents of the Internet Engineering Task Force (IETF). Note that other groups may also distribute

2023-06-23 **Work Programme** Version 2.3.3

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Details of 'DGR/CIM-0017' Work Item

ETSI	Work Item Reference	ETSI Doc. Number	STF	Technical Body in Charge	Download Standard
	DGR/CIM-0017	GR CIM 017		CIM	
	Current Status (Click to View Full Schedule)	Latest Version	Cover Date	Standstill	Creation Date
	Publication (2022-12-21)	1.1.1	2022-12-21	View Standstill Information	2020-05-07
	Rapporteur	Technical Officer	Harmonised Standard		
	Franck Le Gall	Patrick Guillemin	No		
Title	Context Information Management (CIM); Feasibility of NGSi-LD for Digital Twins NGSi-LD for Digital Twins				
Scope and Field of Application	This document identifies the various (historical) definitions and types and characteristics of Digital Twins (e.g. in areas of representing human actions, in health/biological areas, for smart manufacturing, etc) and considers the usage of the NGSi-LD information model and API for realising such systems. Special concern should be given to issues of privacy and leakage of data, depending on the use case and including the area of monitoring for handling pandemics. The purpose of the document is to show to what extent various Digital Twin types can be realized or facilitated by NGSi-LD and to identify new features for NGSi-LD which would make it more useful for such areas of usage. The document will identify from the SDO and research landscape a number of groups to contact for exchange of views. Contact with relevant ETSI groups such as SmartM2M, 3GPP, oneM2M, etc is expected.				
Supporting Organizations	Orange, NEC Europe Ltd, CNIT, University of Murcia, Fiware Foundation, EGM, Ubiwhere Lda (UW)				

The need for interoperability and standardization of Digital Twins through cross-domain applications is becoming a fundamental enabler

Specialist Task Force Proposal – STF 628 (Ref. Body TC SmartM2M) DIGITAL TWINS

ETSI Members Support

#	ETSI Member	Supporting delegate
1	TELECOM ITALIA S.p.A.	Enrico Scarrone
2	HUAWEI Technologies Sweden AB	Francisco da Silva
3	Facultad de Informatica	Raul Garcia Castro (UPM)
4	Futurewei	John Strassner
5	FBK	Mauro Dragoni (Fondazione Bruno Kessler)
6	SBS aisbl	Massimo Vanetti
7	INRIA	Luigi Liquori
8	Deutsche Telekom AG	Thomas Kessler
9	CNRS	Samir Medjah
10	JK Consulting and Projects	Joachim Koss (ETSI Applicant member)
11	FBCConsulting S.A.R.L.	Michelle Wetterwald

Experts Team

AI4 People

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University of Modena and Reggio
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Massimo Vanetti (Expert)

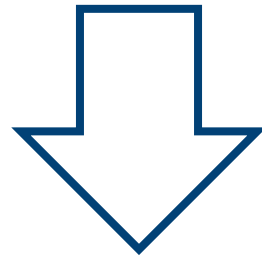
Mauro Dragoni (Expert)

William R. Flynn, IV (Expert)

<https://portal.etsi.org/XTFs/#/xTF/628>

Build (Together) a Digital Twin Ecosystem

Envision a **pervasive softwarisation of the physical world** in terms of highly dynamic ecosystems of **connected** and **interoperable DTs**, across **different** application **domains** and different **network levels** (from cloud to edge).



To make DTs a real opportunity we need a structured **cross-field fertilization and collaboration** (e.g., Software Engineering, Networking, Standardization Bodies, Companies, Universities ...)

Are you interested to collaborate on Digital Twins ?



References (Some ...)

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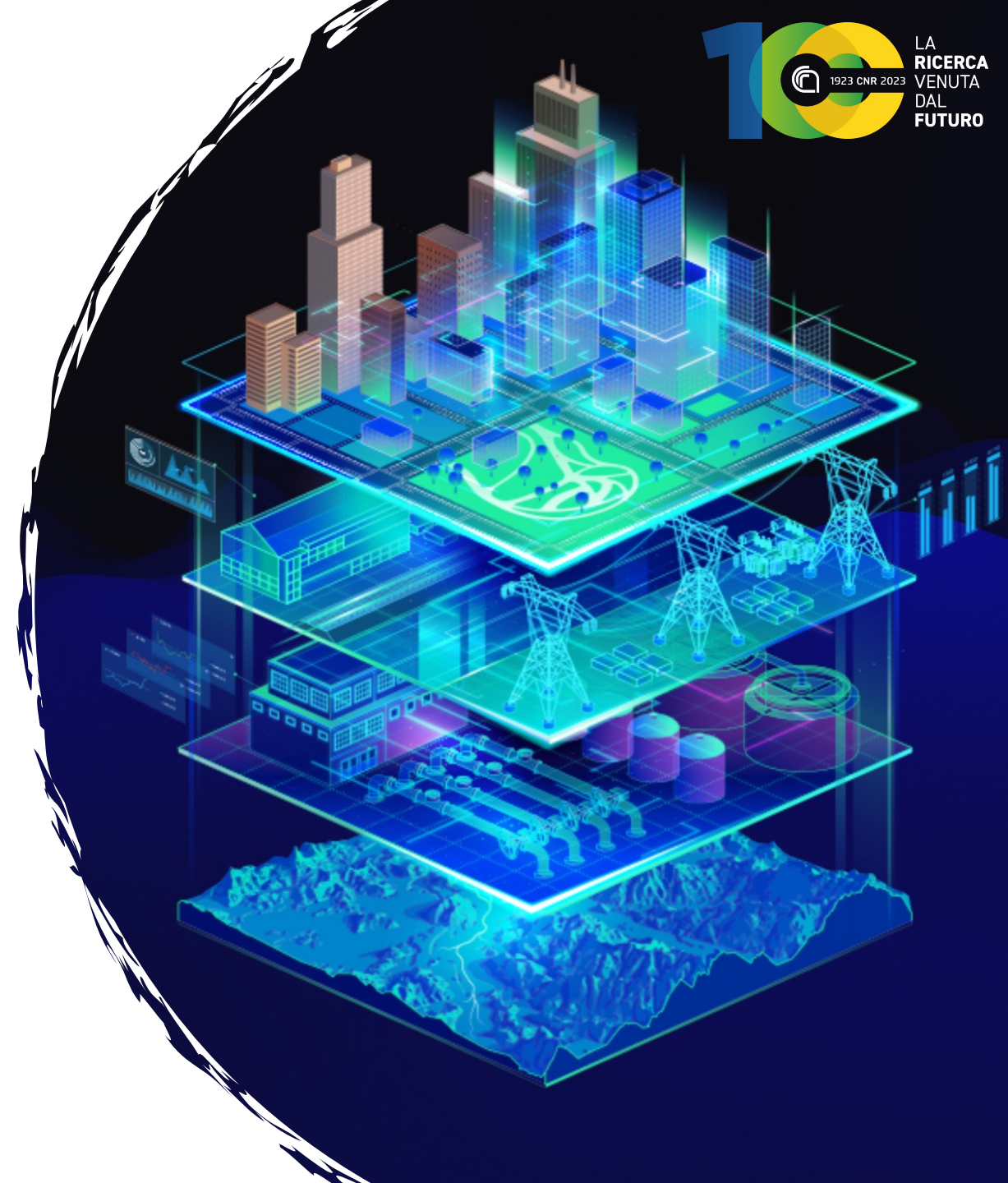
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