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Digital Twins for Large-Scale Multi-Tenant 6G Cyber Security Operations

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6G-PATH Digital Twins for 6G Infrastructures

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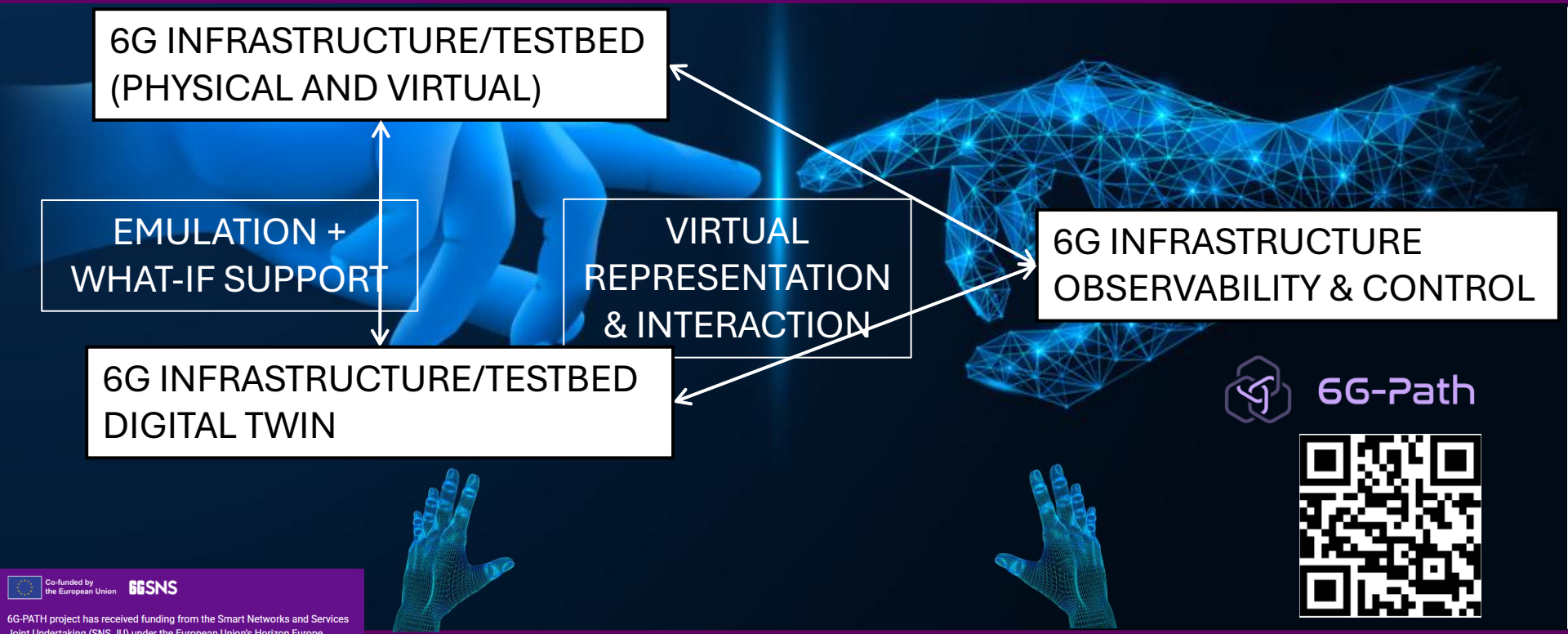

Co-funded by the European Union
6GSNS

6G-PATH project has received funding from the Smart Networks and Services Joint Undertaking (SNS JU) under the European Union's Horizon Europe research and innovation programme under Grant Agreement No 101139172.

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6G-PATH Use Case: Holographic Cyber Education

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6G-Path

https://6gpath.eu/

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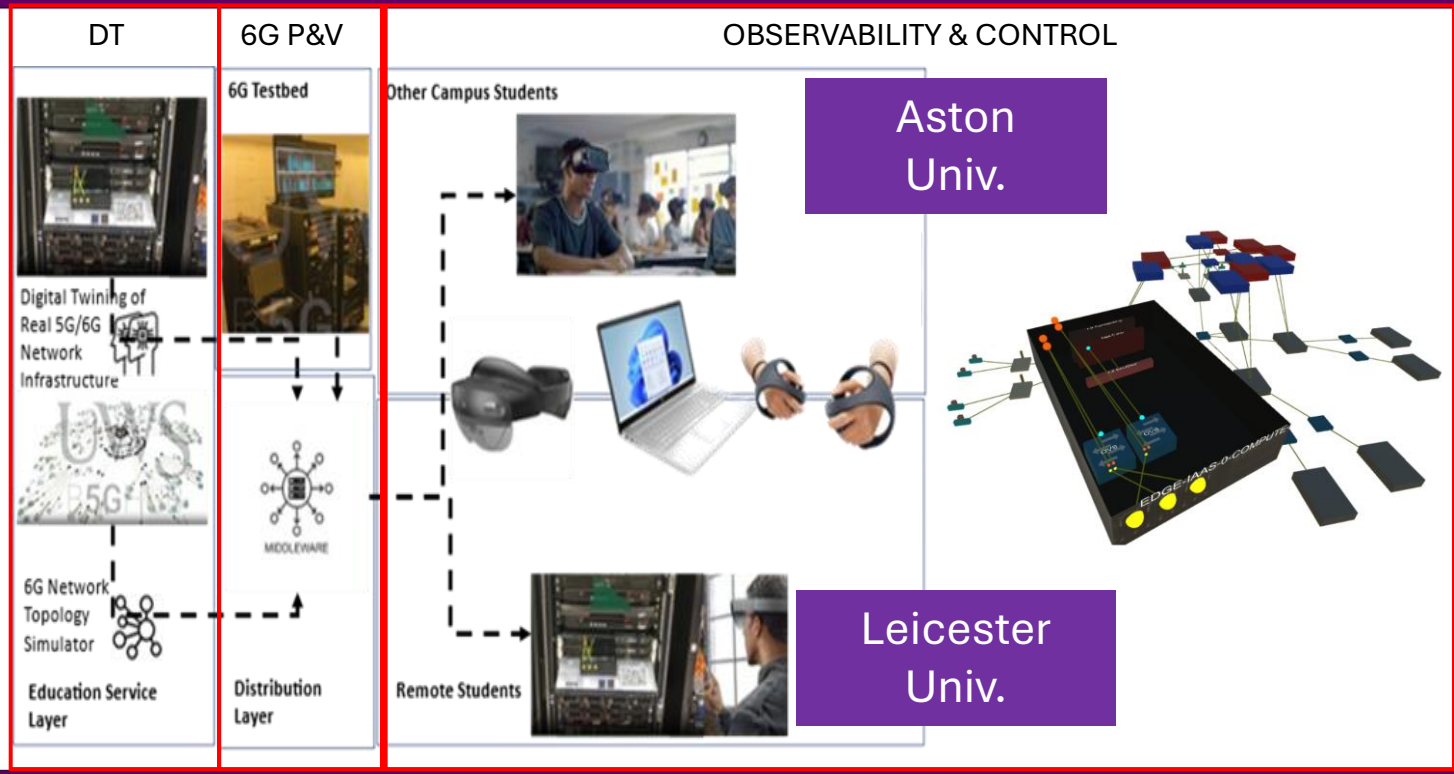
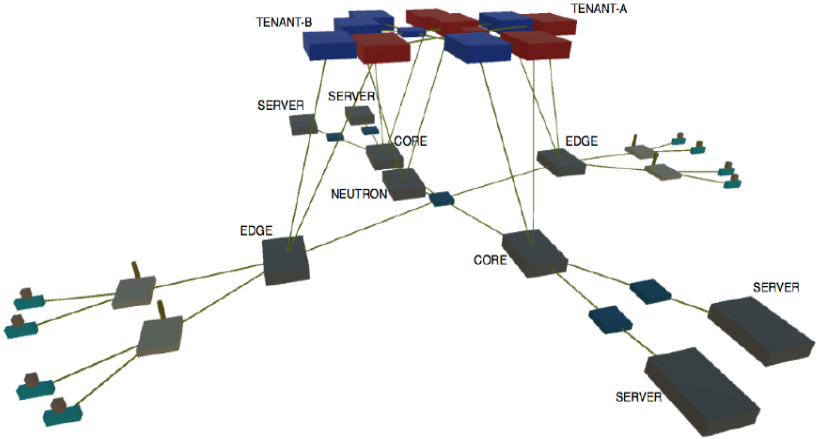
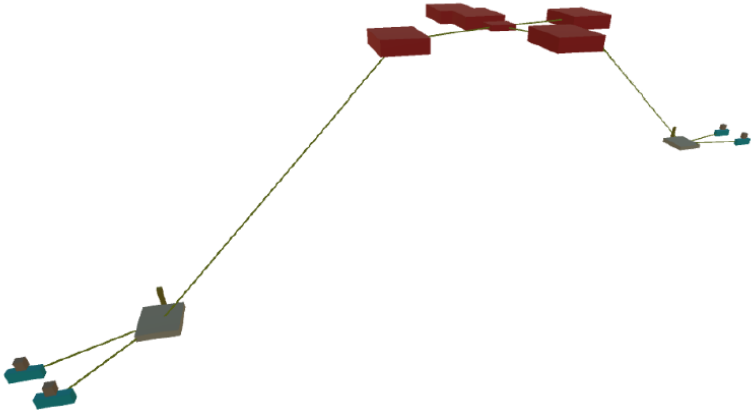


6G-PATH Use Case: Holographic Cyber Education



- Infrastructure Service Provider's view of the network



- Infrastructure Service Consumer's view of the network

6G-PATH Digital Twins for 6G Infrastructures

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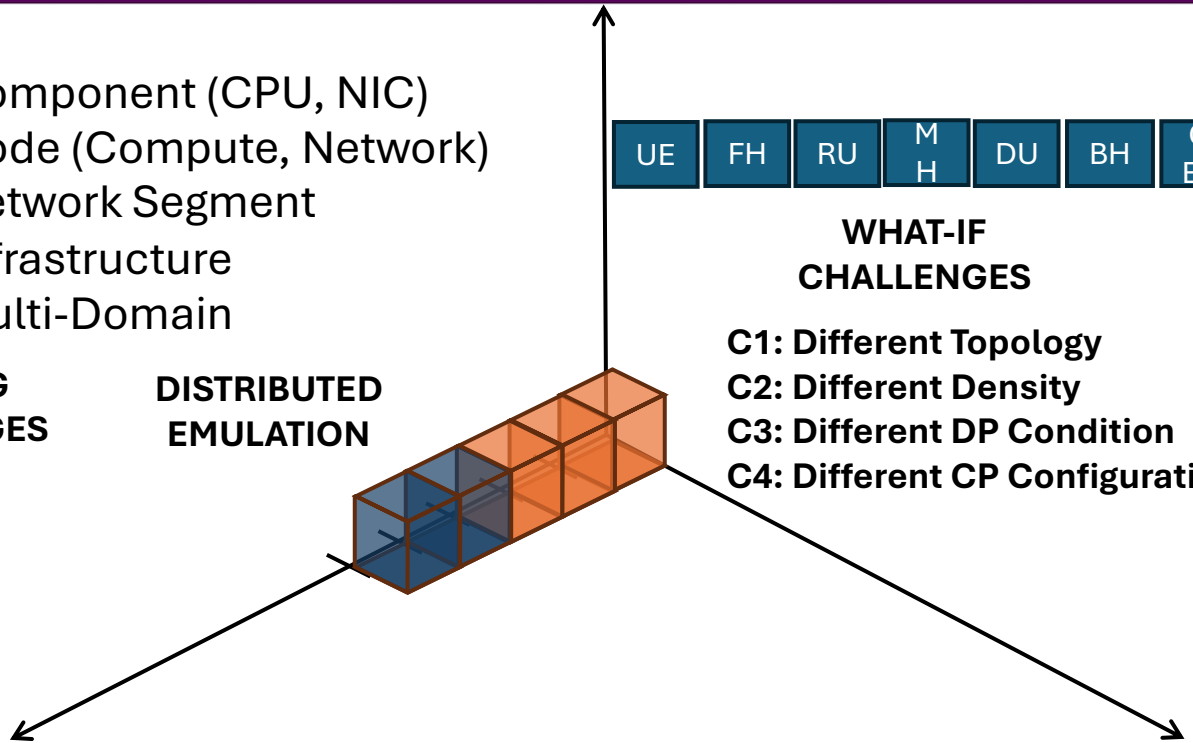
L1: Component (CPU, NIC)
L2: Node (Compute, Network)
L3: Network Segment
L4: Infrastructure
L5: Multi-Domain

SCALING CHALLENGES

SCOPE

DISTRIBUTED EMULATION



UE | FH | RU | M H | DU | BH | CU/ Edge | T | Core/ Cloud | B | IPX

WHAT-IF CHALLENGES

C1: Different Topology
C2: Different Density
C3: Different DP Condition
C4: Different CP Configuration

SCOPING CHALLENGES

C1: Data Plane
C2: DP + Control Plane
C3: DP + CP + Mgmt Plane

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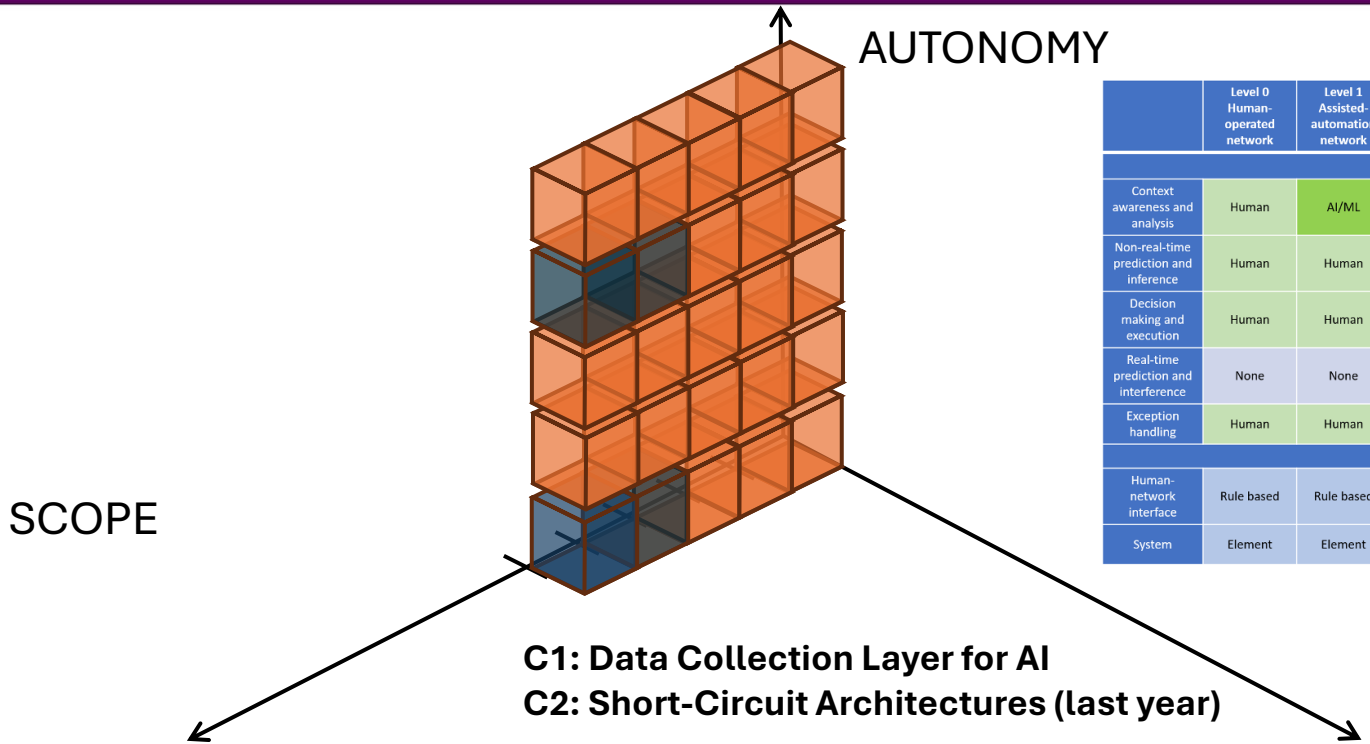
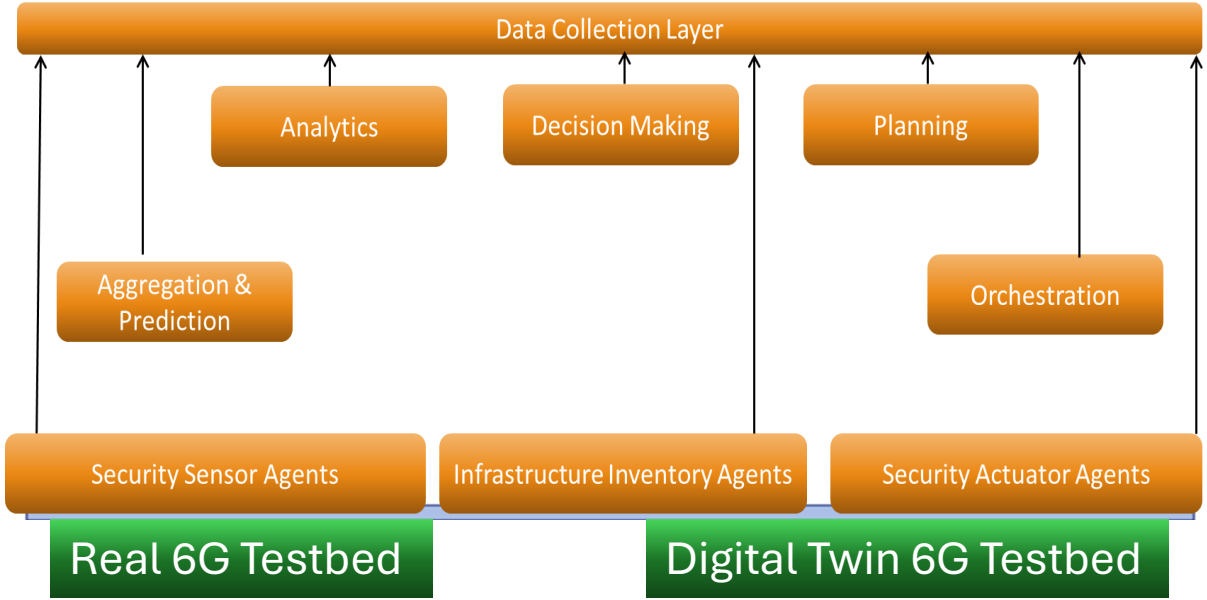


	Level 0 Human-operated network	Level 1 Assisted-automation network	Level 2 Advanced-automation network	Level 3 Partially autonomous network	Level 4 Advanced autonomous network	Level 5 Fully autonomous network
Dimensions						
Context awareness and analysis	Human	AI/ML	AI/ML	AI/ML	AI/ML	AI/ML
Non-real-time prediction and inference	Human	Human	AI/ML	AI/ML	AI/ML	AI/ML
Decision making and execution	Human	Human	Human	AI/ML	AI/ML	AI/ML
Real-time prediction and interference	None	None	None	None	AI/ML	AI/ML
Exception handling	Human	Human	Human	Human	AI/ML	AI/ML
Features						
Human-network interface	Rule based	Rule based	Open loop	Open and closed loop	Mostly closed loop, partly intent based	Closed loop, intent based
System	Element	Element	Element, subsystem	Element, subsystem	Mostly subsystem	End-to-end

ARCHITECTURAL CHALLENGES

C1: Data Collection Layer for AI
C2: Short-Circuit Architectures (last year)

6G-PATH Advance 6G Testbed Features



End-to-End Dynamic Network Slicing
AI/ML-Driven Close Control Loops

RIGOURous

RIGOURous is funded by the European Union's Research and Innovation Programme Horizon Europe under Grant Agreement no. 101095933

Social media:

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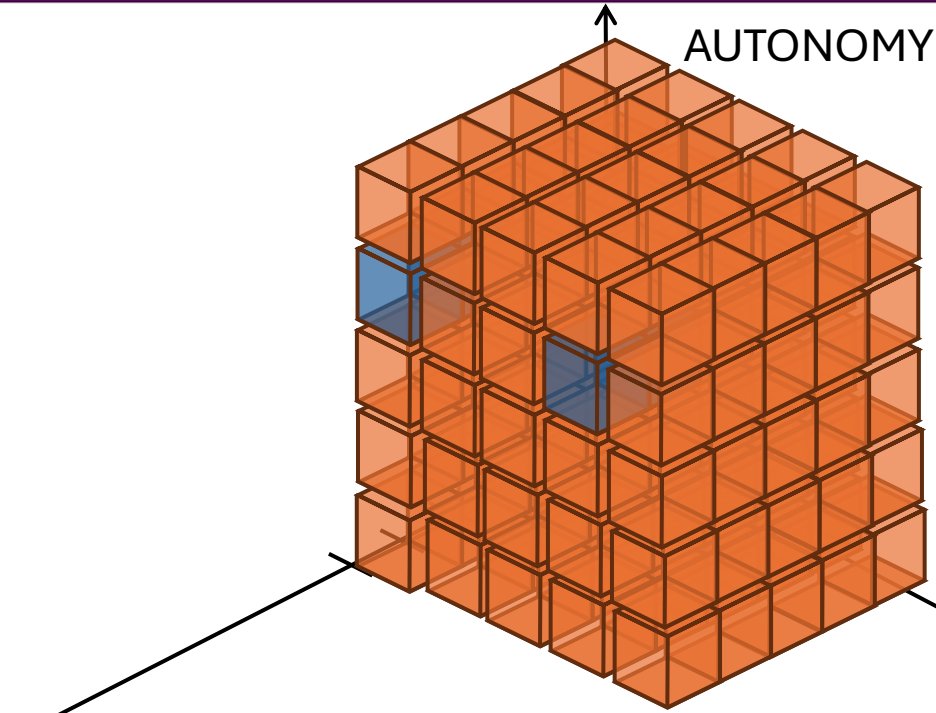

L1: Single-Loop Individual Purpose
L2: Multi-Loop Individual Purpose
L3: Multi-Loop Multi Purpose Single-Mngt
L4: Multi-Loop Multi Purpose Multi-Mngt
L5: Complete Self-Managed System

EXTENSIBILITY CHALLENGES

C1: Resources, Flows & Services
C2: Heterogeneous Executions Env

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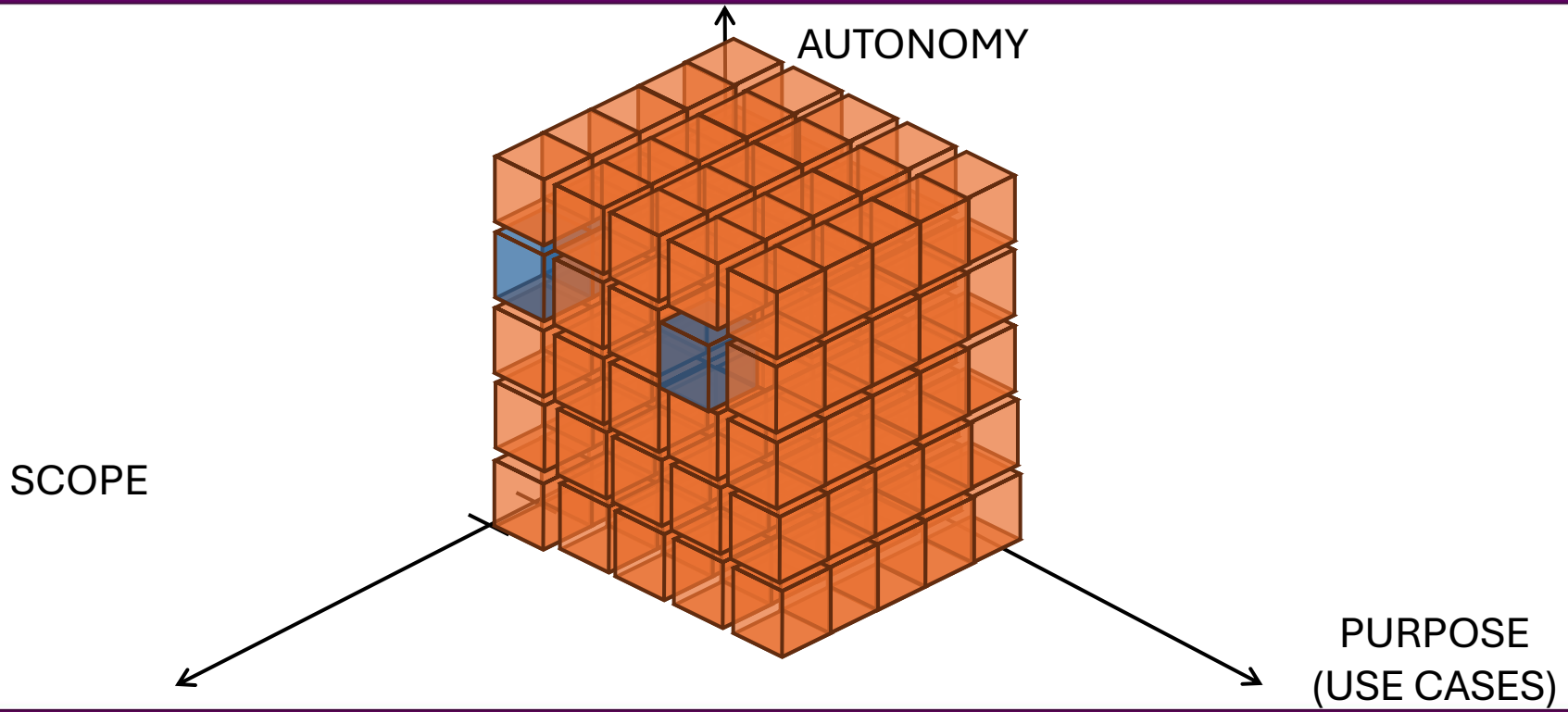

Digital Twins: What-If Scenarios

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Range Topologies
Range DP Condition
Range CP Configuration

WHAT-IF INFRASTRUCTURE SCENARIO GENERATOR

SCENARIO N

WHAT-IF Topologies & Density

- Domain=1 # n Administrative Domains
- ISP Edges=2 # n Edges Nodes
- ISP Cores=1 # n Cloud Nodes
- CSPs=2 # n MNOs (Telcos in Tenant)
- UEs x RRH=2 # n UE per RRH
- RRHs X CSP=1 # n RRH per Tenant (no MOCN in this scenario)
- Servers X Core=2 # Servers connected to Core

- Create ISP Mgmnt=1 # Create Management Network for ISP
- Create CSP Mgmnt=0 # Create Management Network for DSP

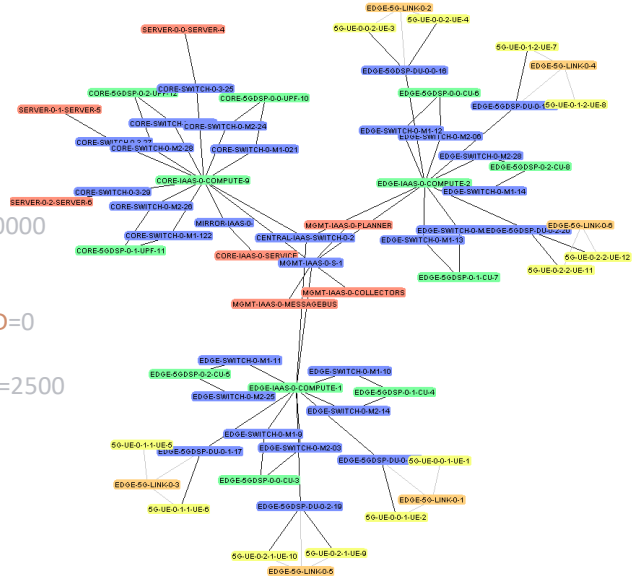
- Create ISP Mirror=1 # Create ISP Service Network
- Create CSP Mirror=0 # Create ISP Service Network

- CSP DP Not Across Domain=0 # CSP Dataplane across domains
- ISP and CSP Separated Mgmnt=0 # ISP & DSP Mgmt Seperated or Not
- CSP Mgmt Across Domains=0 # CSP Mgmt Across Domains

WHAT-IF DP Conditions

WIRED_BANDWIDTH_MB=10000
WIRED_DELAY=0.1
WIRED_PACKET_LOSS=0
WIRED_PACKET_DUPLICATED=0

WIRELESS_BANDWIDTH_MB=2500
WIRELESS_RANGE=700
WIRELESS_DELAY=6
WIRELESS_ERROR_RATE=0
WIRELESS_JITTER=1



Digital Twins in Practice

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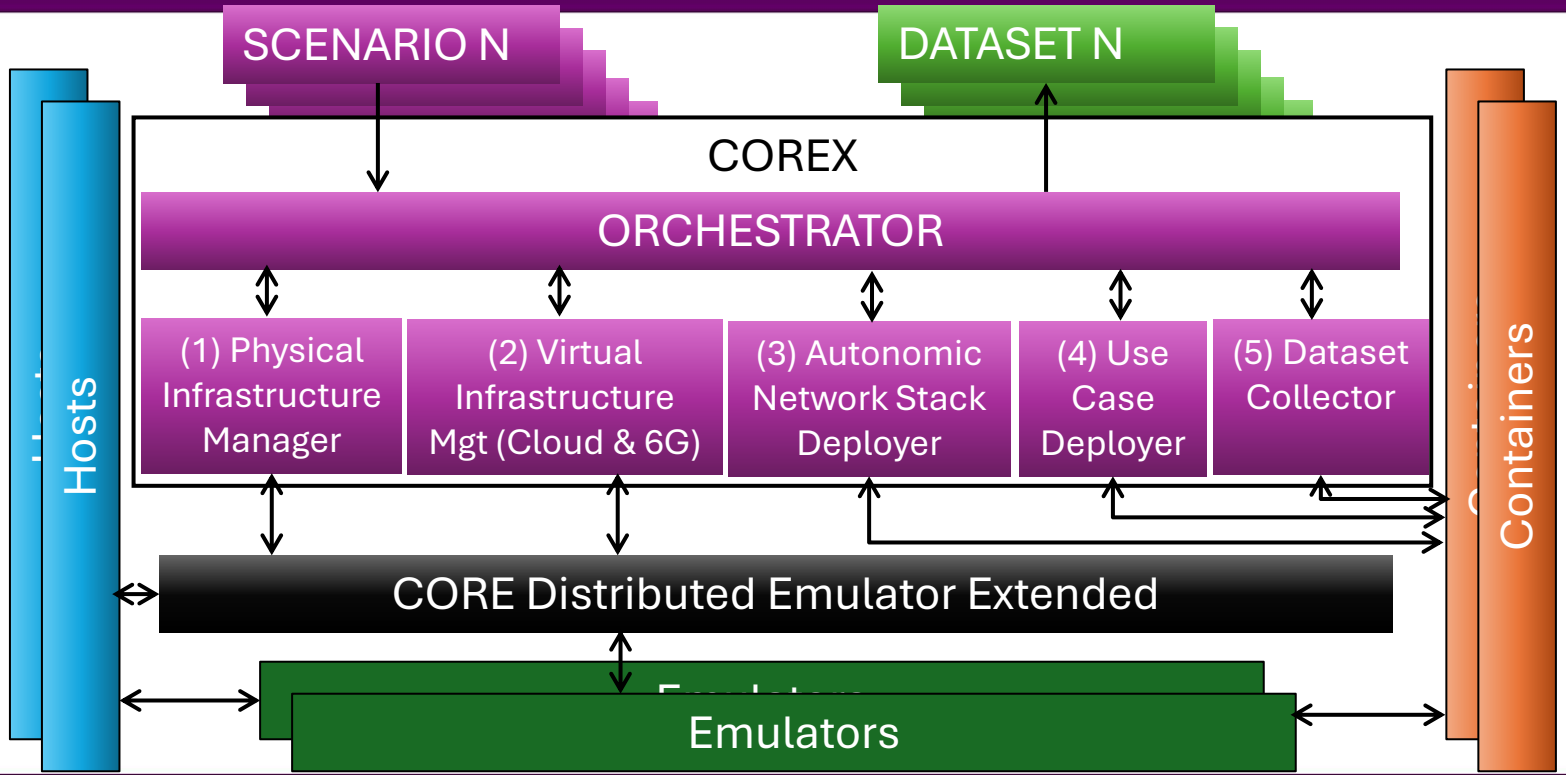
Digital Twin with 34881 Nodes Emulated!

WHAT-IF Topologies & Density

- Domain=2 # n Administrative Domains
- ISP Edges=64 # n Edges Nodes
- ISP Cores=8 # n Cloud Nodes
- CSPs=2 # n MNOs (Telcos in Tenant)
- UEs x RRH=64 # n UE per RRH
- RRHs X CSP=1 # n RRH per
- Servers X Core=2 # Servers connected to Core

Digital Twin Architecture



Pablo Benlloch-Caballero, Pablo Salva-Garciaa, Qi Wang, Jose M. Alcaraz-Calero. COREX: Framework for distributed digital twins of 5G / 6G network topologies and automated experiment executions. Computer Networks. Elsevier (under review)

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Use Case

Using DT to answer:

What AI/ML Algorithm is more resilient Against Topological Changes and Attacker Behavioural Changes when Detection DDoS Attack ?

DDoS Attacks over Digital Twins

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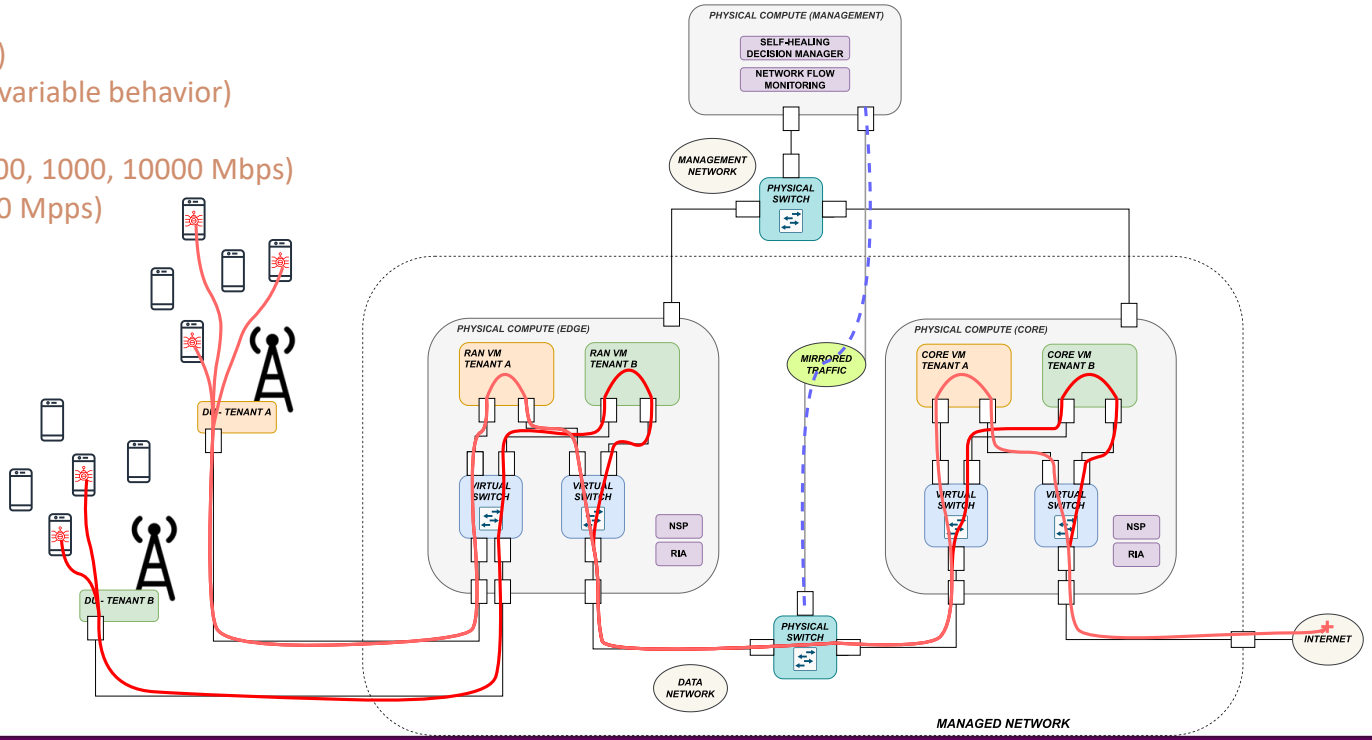
WHAT-IF use Case

- DDoS Attack Vector (UDP, TCP, ICMP)
- DDoS Dynamicity (variable payload, variable behavior)
- DDoS Target (variable, 1, N)
- DDoS Volumetry x Attacker (1, 10, 100, 1000, 10000 Mbps)
- DDoS Flooding (1Mpps, 10Mpps, 100 Mpps)



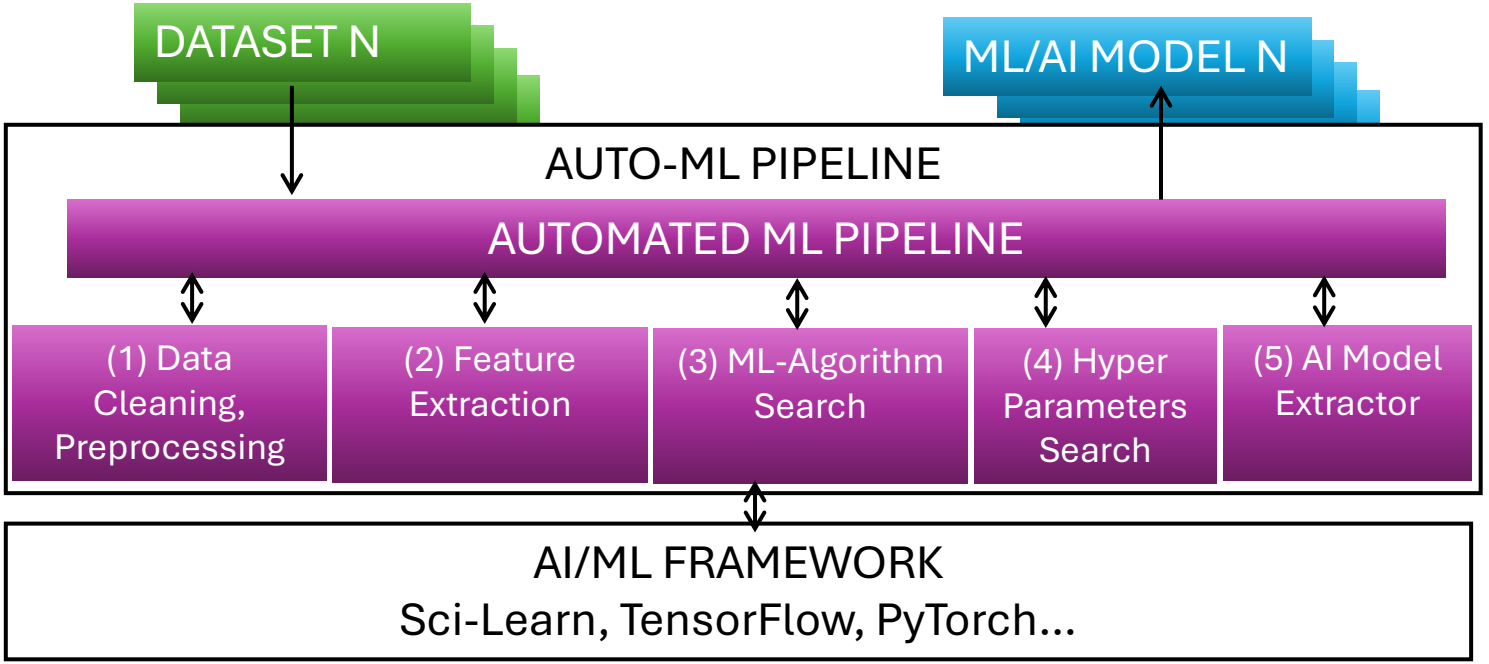
Digital Twin Lifecyle in Non-Distributed Emulation

- Domains=1 # n Administrative Domains
- ISP Edges=2 # n Edges Nodes
- ISP Cores=2 # n Cloud Nodes
- CSPs=2 # n MNOs (Telcos in Tenant)
- RRHs X CSP=1 # n RRH per Tenant (no MOCN in this scenario)
- Servers X Core=2 # Servers connected to Core

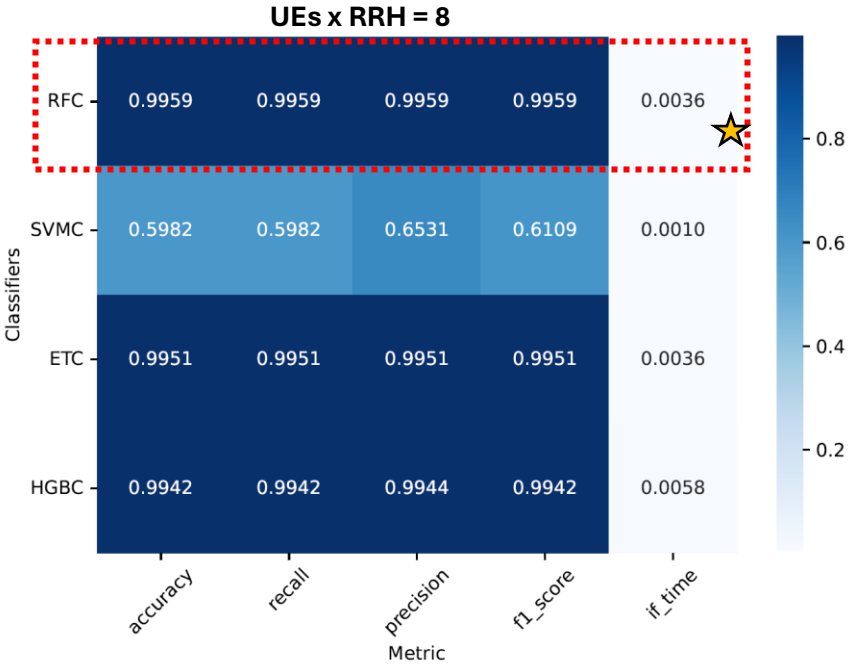
	1&2	3	4	5		
UEs	**Deployment**	**Configuration**	**Attack**	**Log Collection**	**Restoring**	**Total**
2	87.0	168.0	133.0	289.0	40.0	717.0
4	95.0	172.0	134.0	257.0	41.0	699.0
8	112.0	180.0	134.0	263.0	42.0	791.0
16	145.0	196.0	134.0	266.0	44.0	785.0
32	212.0	230.0	137.0	285.0	136.0	1000.0
64	347.0	303.0	140.0	259.0	142.0	1191.0

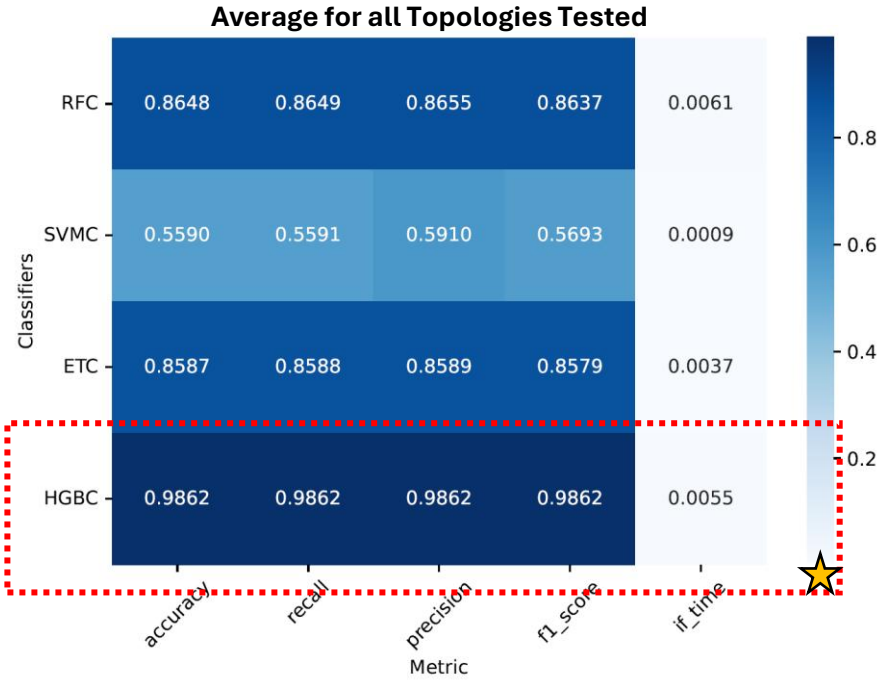
Pablo Benlloch-Caballero, Pablo Salva-Garciaa, Qi Wang, Jose M. Alcaraz-Calero. COREX: Framework for distributed digital twins of 5G / 6G network topologies and automated experiment executions. Computer Networks. Elsevier (2025)

Auto-ML Pipeline



Topology Resistant AI/ML for DDoS Attack Detection





Experiments executed with the distributed mode with 4 physical machines.

Pablo Benlloch-Caballero, Jose M. Alcaraz-Calero, Qi Wang. Enhanced Protection of 5G-IoT and Beyond Infrastructures: Evolving Intelligent Strategies for DDoS Attack Multiclass Classification. EuCNC 6G Submit. 3-6 June 2025, Poznan, Poland. (published)

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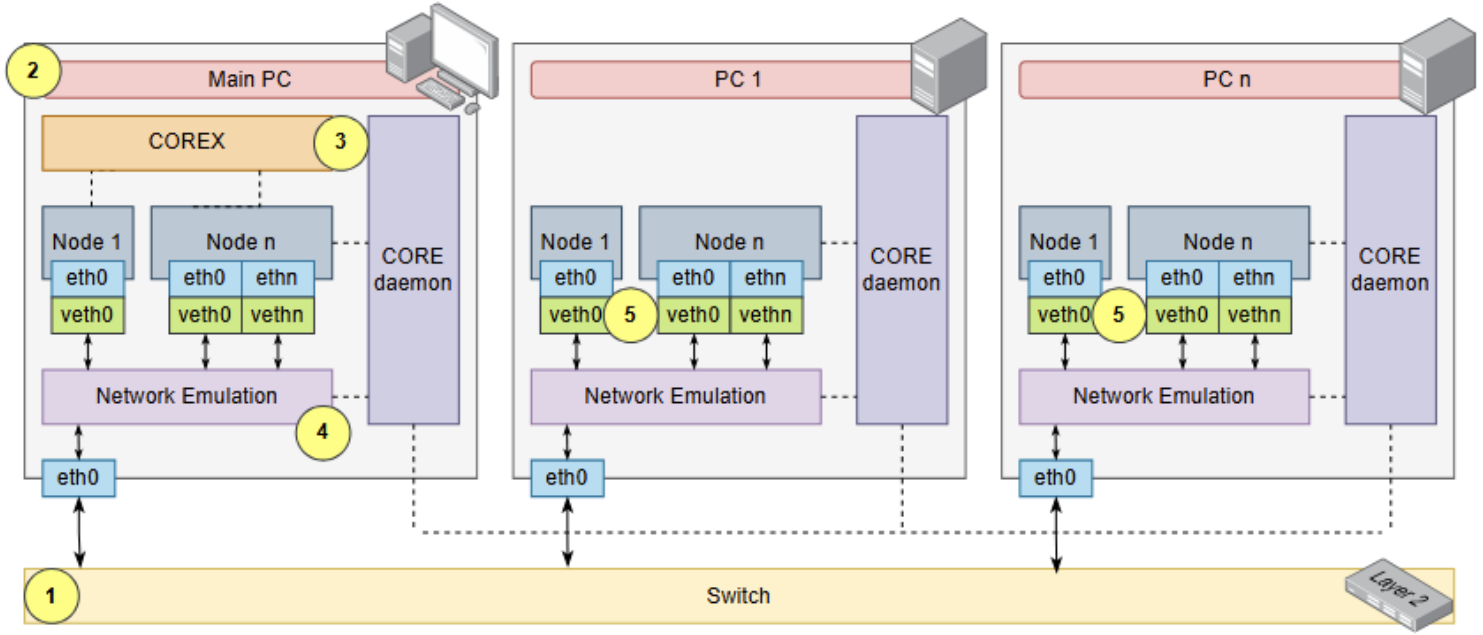
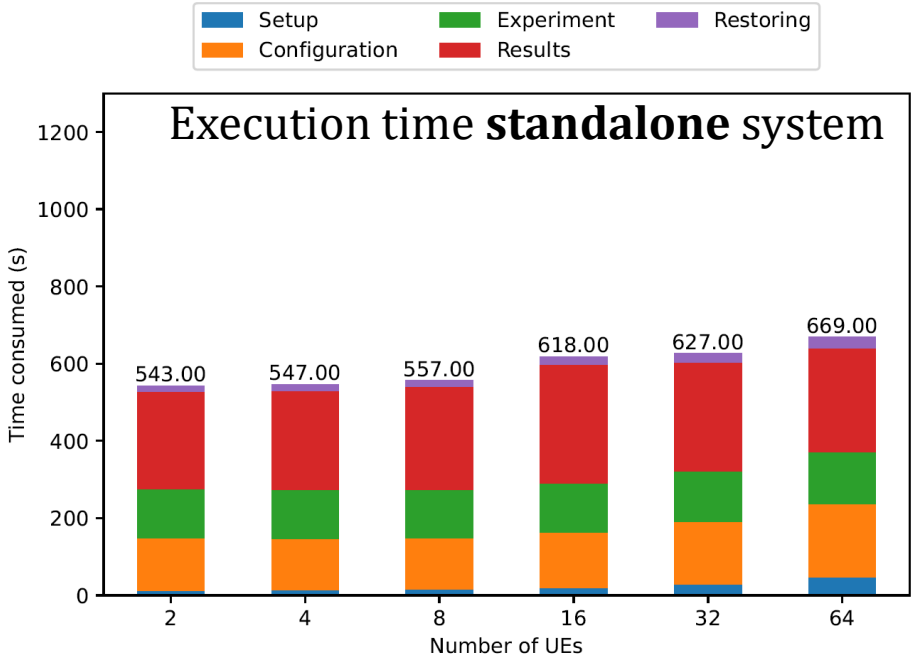
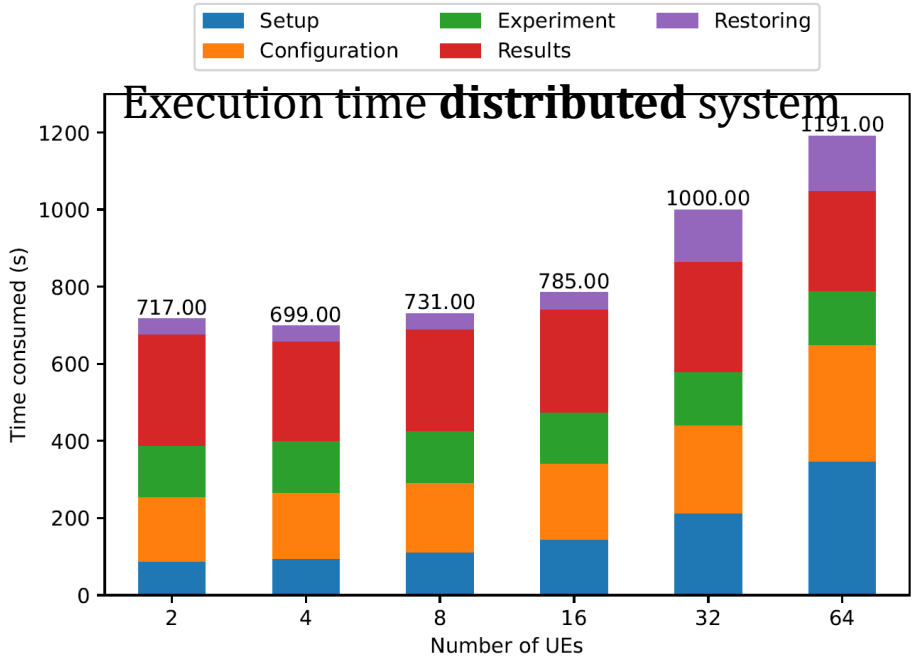
Distributed Emulation





physical machine for entire emulation



4 physical machines for entire emulation

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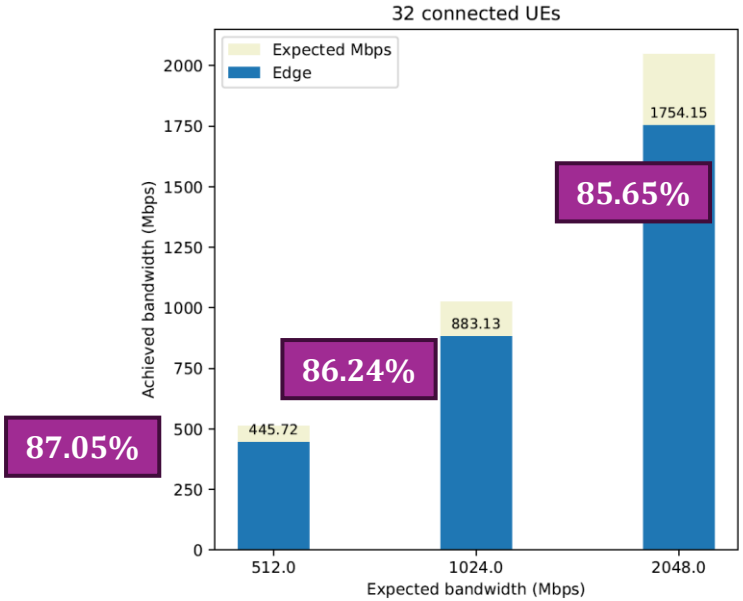
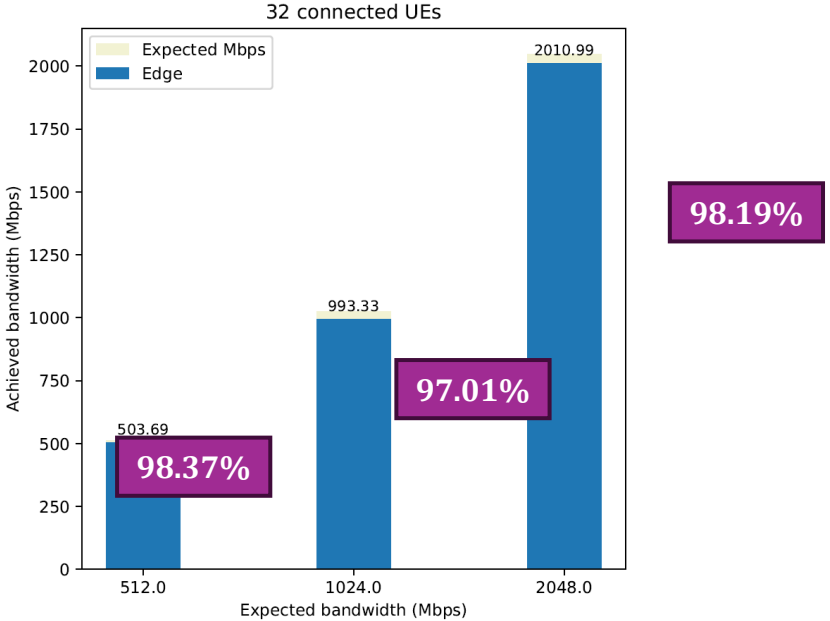
BW achieved **standalone** system



1 physical machine for entire emulation

BW achieved **distributed** system



4 physical machines for entire emulation