Universidad Carlos III de Madrid

NETWORKED DIGITAL TWIN: LEARNING BY EXPERIENCE

OUTSIDE-INSIGHT SESSION
DIGITAL TWIN HERE AND NOW

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PREDICT-6G

UNICO I+D

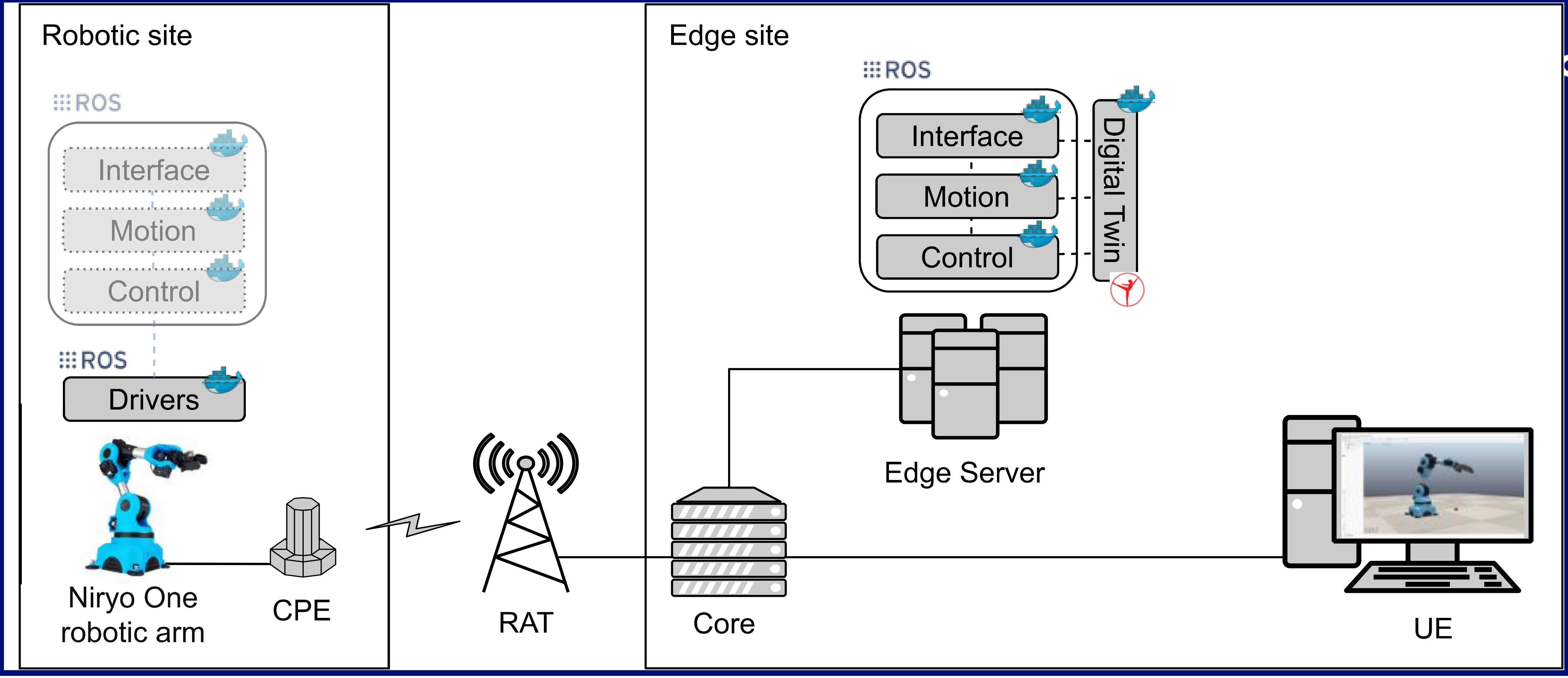
PRESENTATION OUTLINE

DT work at UC3M started as playground to demonstrate the opportunities of 5G networks for low latency communications, edge research and distributed systems

Two main contributions:

1.- 5G as enabler for Edge-assisted Digital Twin technologies

2.- Cyber-physical system enhanced interaction through DT



5G AS ENABLER FOR EDGE-ASSISTED DIGITAL TWIN TECHNOLOGIES

How can we offload processes from the robot to the network and what are the gains obtained

GOAL OF THE WORK

INVESTIGATE the impact of Information and Communication Technologies on Digital Twin systems

DESIGN an Edge Robotic Digital Twin

IMPLEMENT a prototype of the proposed solution in 5TONIC

EVALUATE the performance

CHALLENGES

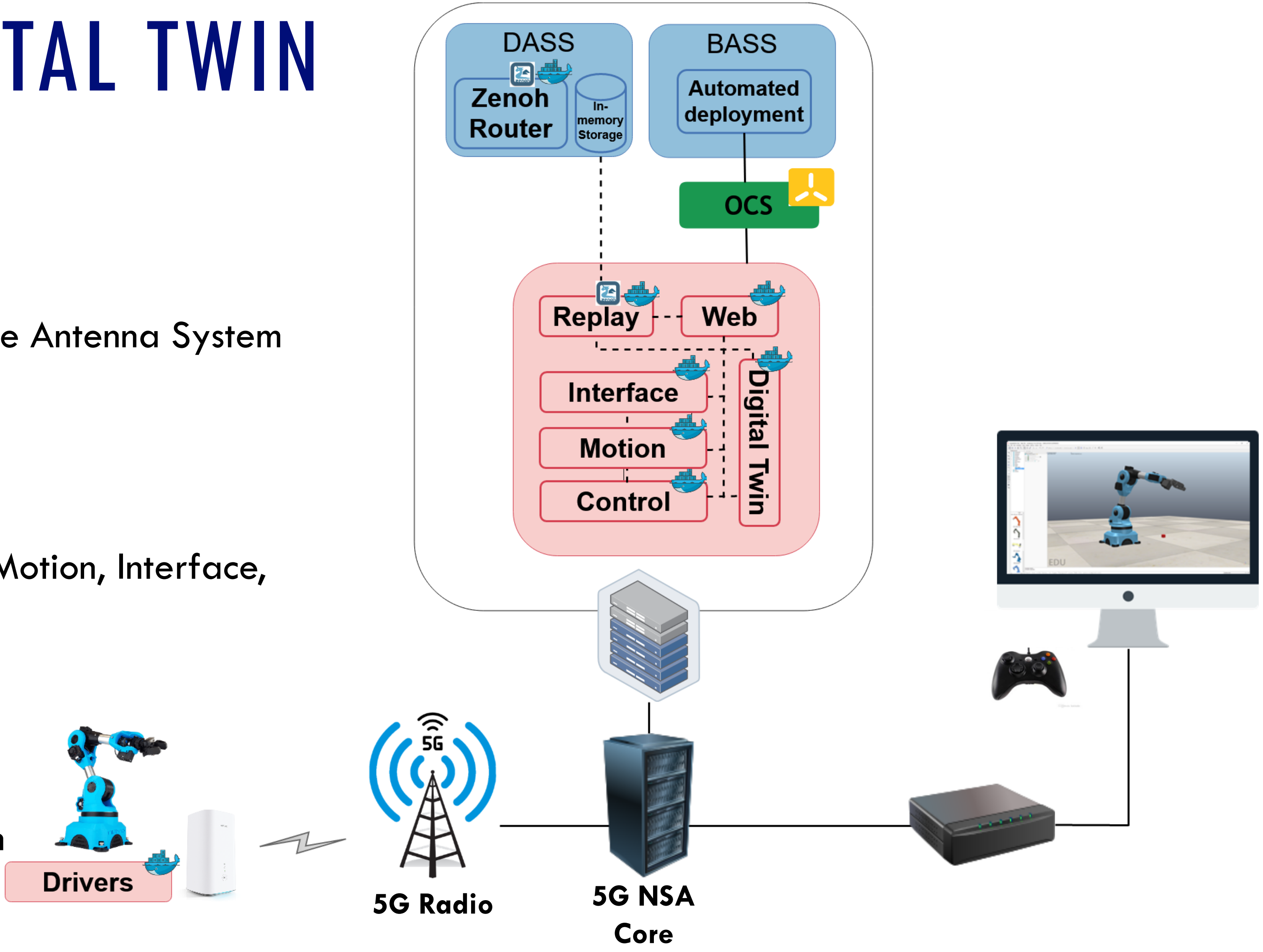
CHALLENGE 1: How to bring wireless technologies to the factory floor ?

CHALLENGE 2: How to achieve real-time connections, synchronization and energy efficient optimization in Digital Twin applications ?

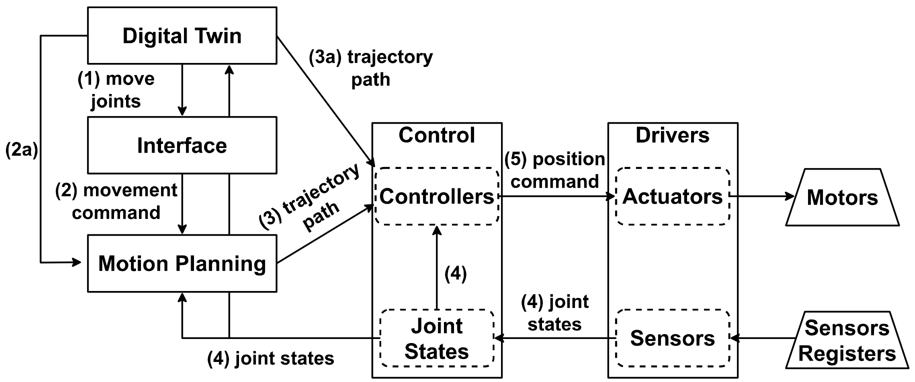
CHALLENGE 3: How to achieve unification and exchange of information by different Digital Twin applications ?

EDGE ROBOTICS DIGITAL TWIN

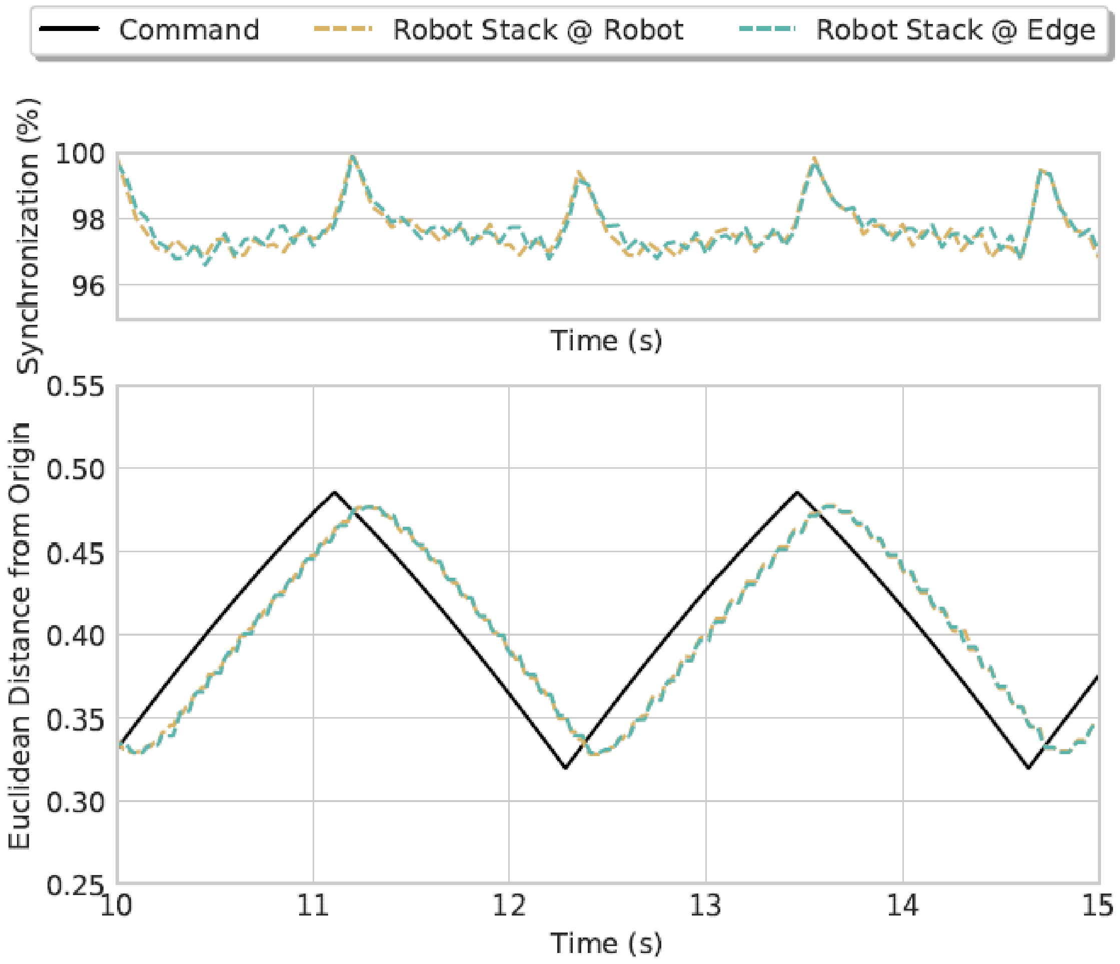
- **5G Connectivity:**
  - 5G CPE Pro Baloong 500
  - 5G NSA (BB630 baseband and Advance Antenna System AIR 6488)
- **Edge computing:**
  - **Virtual functions at the Robot:** Drivers
  - **Virtual functions at the Edge:** Control, Motion, Interface, Digital Twin, Replay and Web
- **Robotic system:** Niryo One
- **Digital Twin:** CoppeliaSim
- **Controller:** XBOX controller, Web application



BASELINE PERFORMANCE

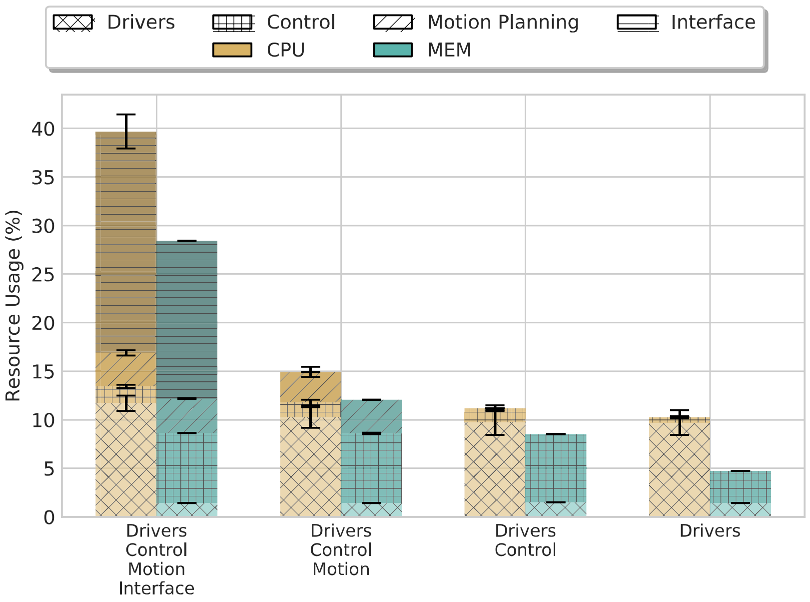


Interfacing Layer		Closed-loop (ms)	Processing delay (ms)
Interface	Robot	497.976 ± 5.023	109.723 ± 1.106
	Edge	409.535 ± 0.896	66.284 ± 0.145
Motion Planning	Robot	388.253 ± 2.365	365.178 ± 2.224
	Edge	343.251 ± 4.291	320.199 ± 4.002
Control	Robot	23.075 ± 0.005	3.075 ± 0.001
	Edge	23.052 ± 0.003	3.052 ± 0.001

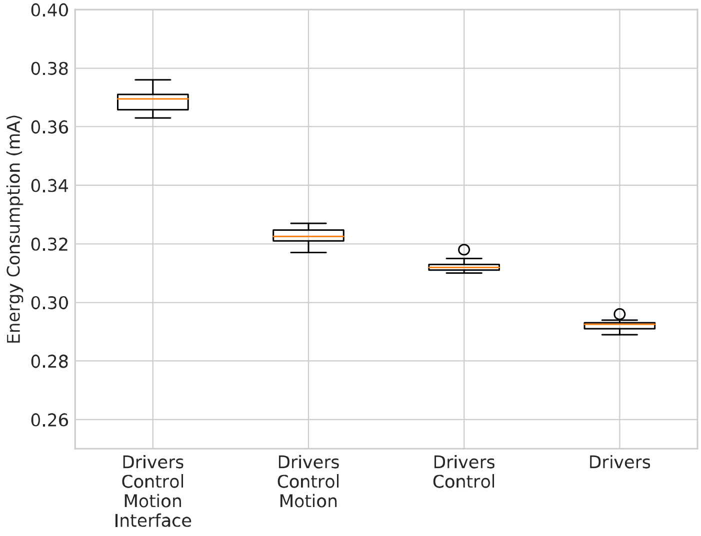


THIS FIGURE SHOWS THE CONTROL OF THE ROBOT OFFLOADED TO A NF LOCATED IN THE EDGE, CONNECTED THROUGH ETHERNET -> IT DEMONSTRATES MOVING THE CONTROL TO THE EDGE IS FEASIBLE

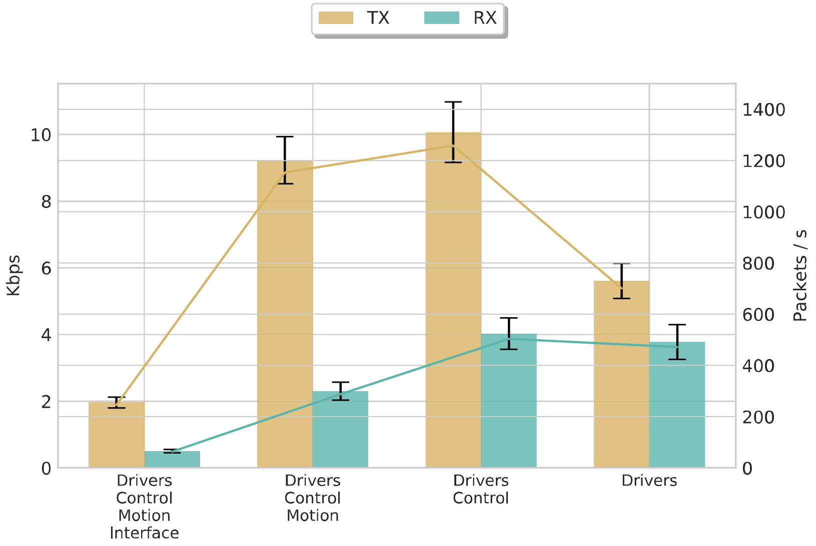
RESOURCE CONSUMPTION AND SAVINGS POTENTIAL



(a) CPU and MEM



(b) Energy Consumption

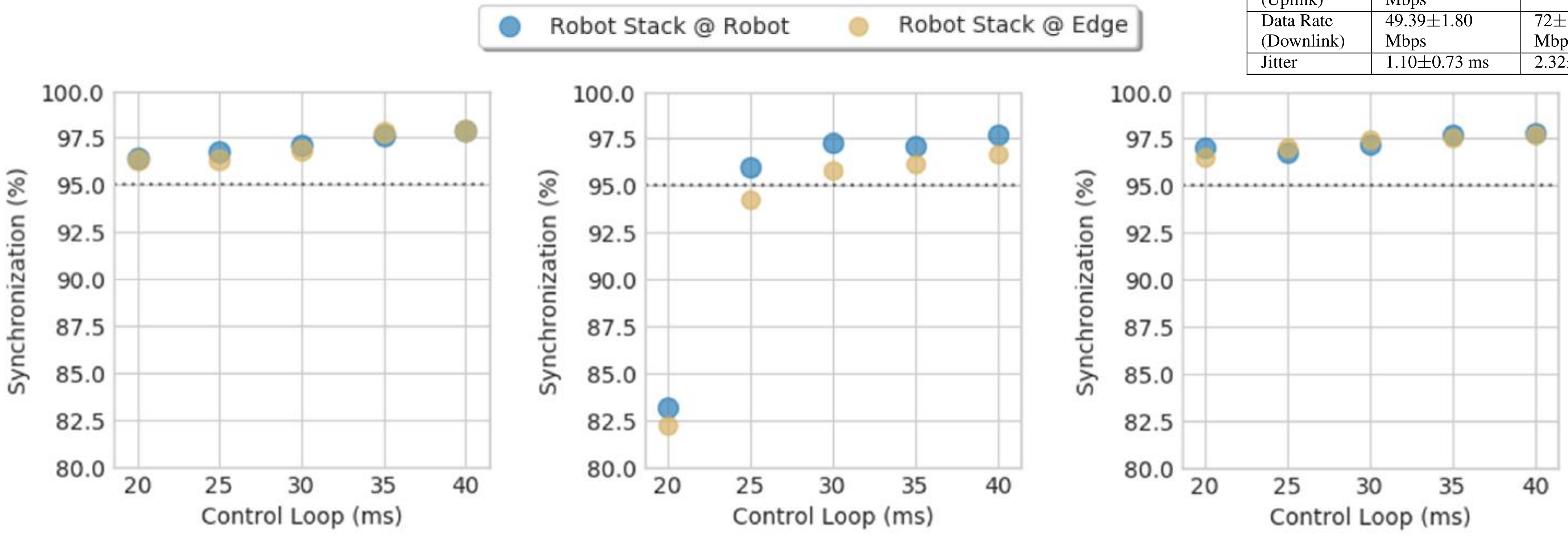


(c) TX and RX

FIGURES SHOW THE CPU AND MEM REQUIRED FOR EACH COMPONENT OF THE DT, THEIR ENERGY CONSUMPTION AND THE TX AND RX REQUIRED TO LOCATE IT IN THE EDGE -> INTERFACE AND MOTION PLANNING KEY CANDIDATES TO OFFLOADING, CONTROL MAY BE OFFLOADED BASED ON NETWORK

IMPACT OF RADIO ACCESS TECHNOLOGIES

Metric	WiFi [2.4Ghz]	4G	5G NSA[7]
E2E Latency	1.77±0.68 ms	23.88±5.84 ms	6.56±1.04 ms
Packet-loss	0.11±0.35%	0%	0%
Data Rate (Uplink)	37.76±7.71 Mbps	44±0.20Mbps	96±1.81Mbps
Data Rate (Downlink)	49.39±1.80 Mbps	72±1.04 Mbps	600±13.50 Mbps
Jitter	1.10±0.73 ms	2.32±0.35 ms	0.46±0.18 ms



(a) Using WiFi (b) Using 4G (c) Using 5G NSA

FIGURES SHOW WIFI AND 5G HAVE SIMILAR PERFORMANCE (IN LAB, NO INTERFERENCE). 4G DOES NOT ALLOW TO OFFLOAD WITH 20ms CONTROL LOOP

CYBER-PHYSICAL SYSTEM ENHANCED INTERACTION THROUGH AI AND DT

GOAL OF THE WORK

PROPOSE an ML based command recovery mechanism for real-time remote-control in robotic systems

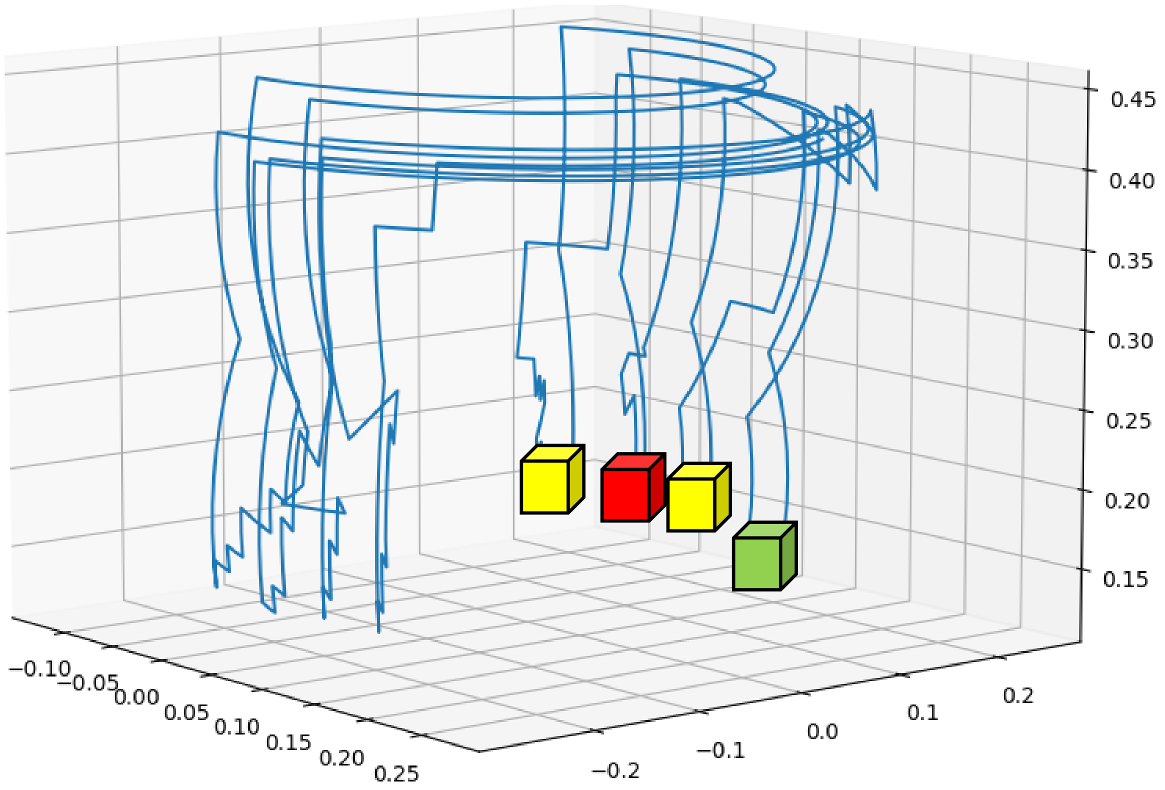
AUTOMATE the dataset generation through DT

SHOWCASE the complete solution in a real test-bed

EVALUATE the performance

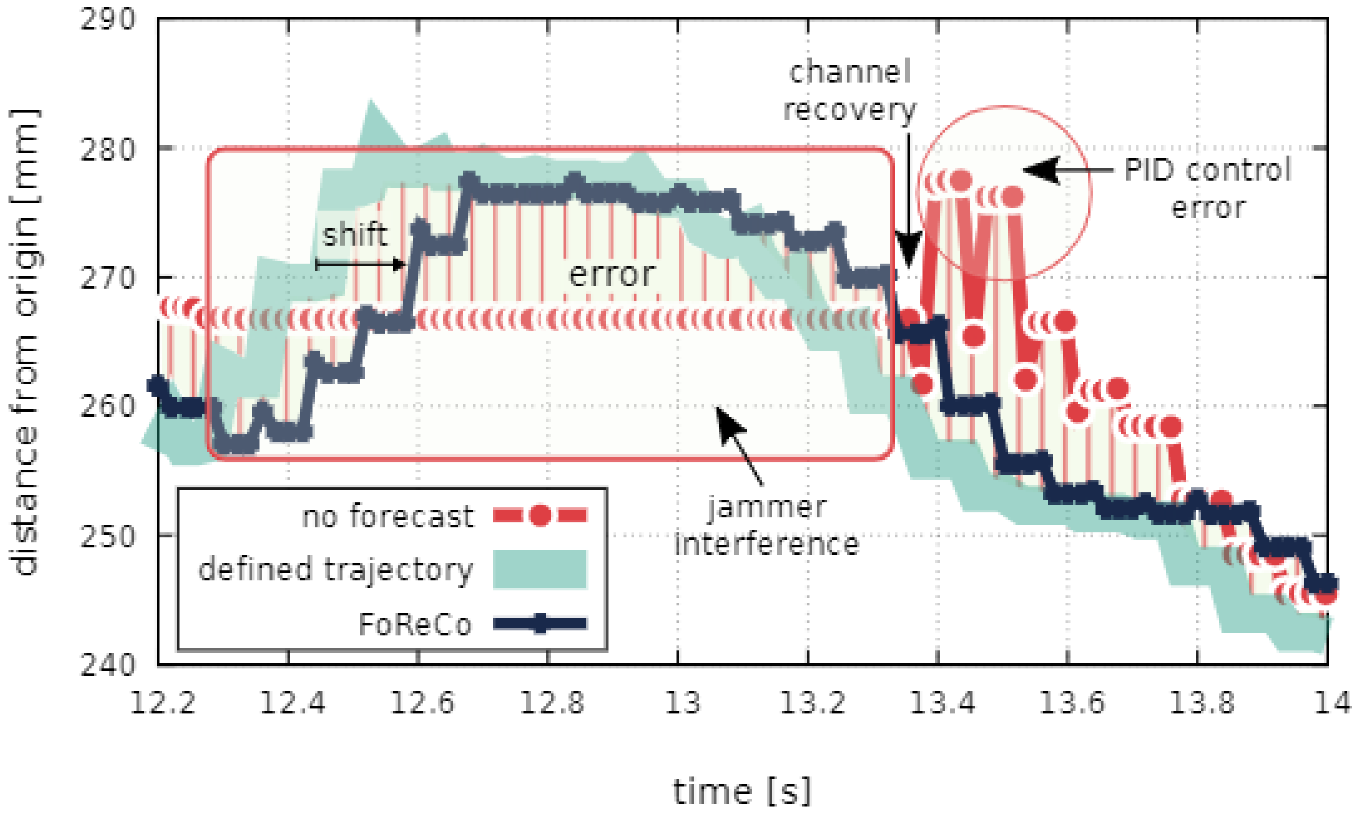
DATASET COLLECTION

- Human operator was performing pick and place actions of 4 cubes
- DT replicates the movement with random inducted trajectories
- Command was issued every 150ms resulting in dataset that contains 7011 commands
- 80% of the dataset was used for training while 20% was used for remote control and testing



uc3m

ROBOT TRAJECTORY UPON IEEE 802.11 JAMMER INTERFERENCE



CONCLUSION & FUTURE WORK

1.- 5G as enabler for Edge-assisted Digital Twin technologies

- Offloading of the robotic functions to the Edge improved the performance due to the availability of more powerful resources
- Offloading robotic functions to the Edge introduced a potential savings of 30% in terms of CPU and 26% MEM usage
- 5G enables a control loops of **20ms -> and this will only improve in the future**

2.- Cyber-physical system enhanced interaction through DT

- Use of DT as a mean to train an ML model working on top of the real cyber-physical system
- Feasibility of applying predictive remote-control in robotic systems

FOR MORE INFORMATION

Publications

- Toward intelligent cyber-physical systems: Digital twin meets artificial intelligence - Link: https://ieeexplore.ieee.org/abstract/document/9530501
- An Intelligent Edge-based Digital Twin for Robotics - Link: https://ieeexplore.ieee.org/abstract/document/9367549
- Demo: AIML-as-a-Service for SLA management of a Digital Twin Virtual Network - Link: https://ieeexplore.ieee.org/abstract/document/9484610
- Dissecting the Impact of Information and Communication Technologies on Digital Twins as a Service - Link: https://ieeexplore.ieee.org/abstract/document/9490216
- Assessing the need for 5G drive Edge and Fog solutions for Digital Twin systems - Link: https://dl.acm.org/doi/abs/10.1145/3411276.3414697
- Resource Requirements of an Edge-based Digital Twin Service: An Experimental Study - Link: https://www.sciencedirect.com/science/article/pii/S2096579622000468