LESSONS LEARNED ON

REAL-TIME AND SECURITY

ALIAS ROBOTICS
Robot Cybersecurity

VÍCTOR MAYORAL VILCHES

Robotics engineer

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1. REAL-TIME OR REAL-FAST?

REAL-TIME DEFINITION
(control)

Real-time control system means that the control system must provide the control responses or actions to the stimulus or requests within specific times, which therefore depend not just on what the system does but also on how fast it reacts.

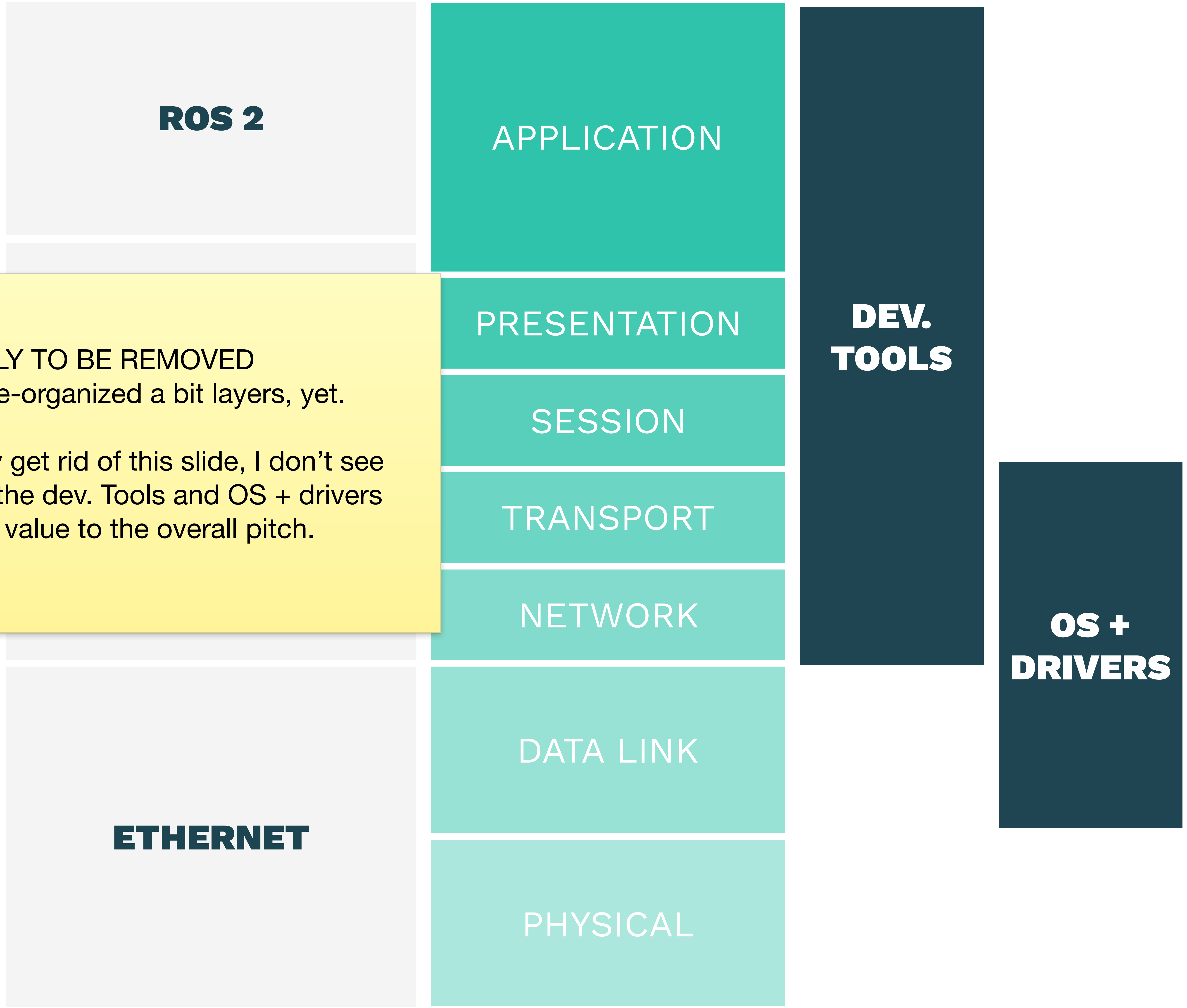
Zhang, P. (2008). Industrial control technology: a handbook for engineers and researchers. William Andrew.

REAL-TIME DEFINITION
(security)

...Real-time, zero-latency technologies capable of detecting attacks that target running applications and protecting against those attacks.

Feiman, Joseph. "What Is Real-Time Security and Why It Is Needed." Veracode, 25 May 2016, www.veracode.com/blog/2016/01/what-real-time-security-and-why-it-needed.

REAL-TIME
ROBOT STACK



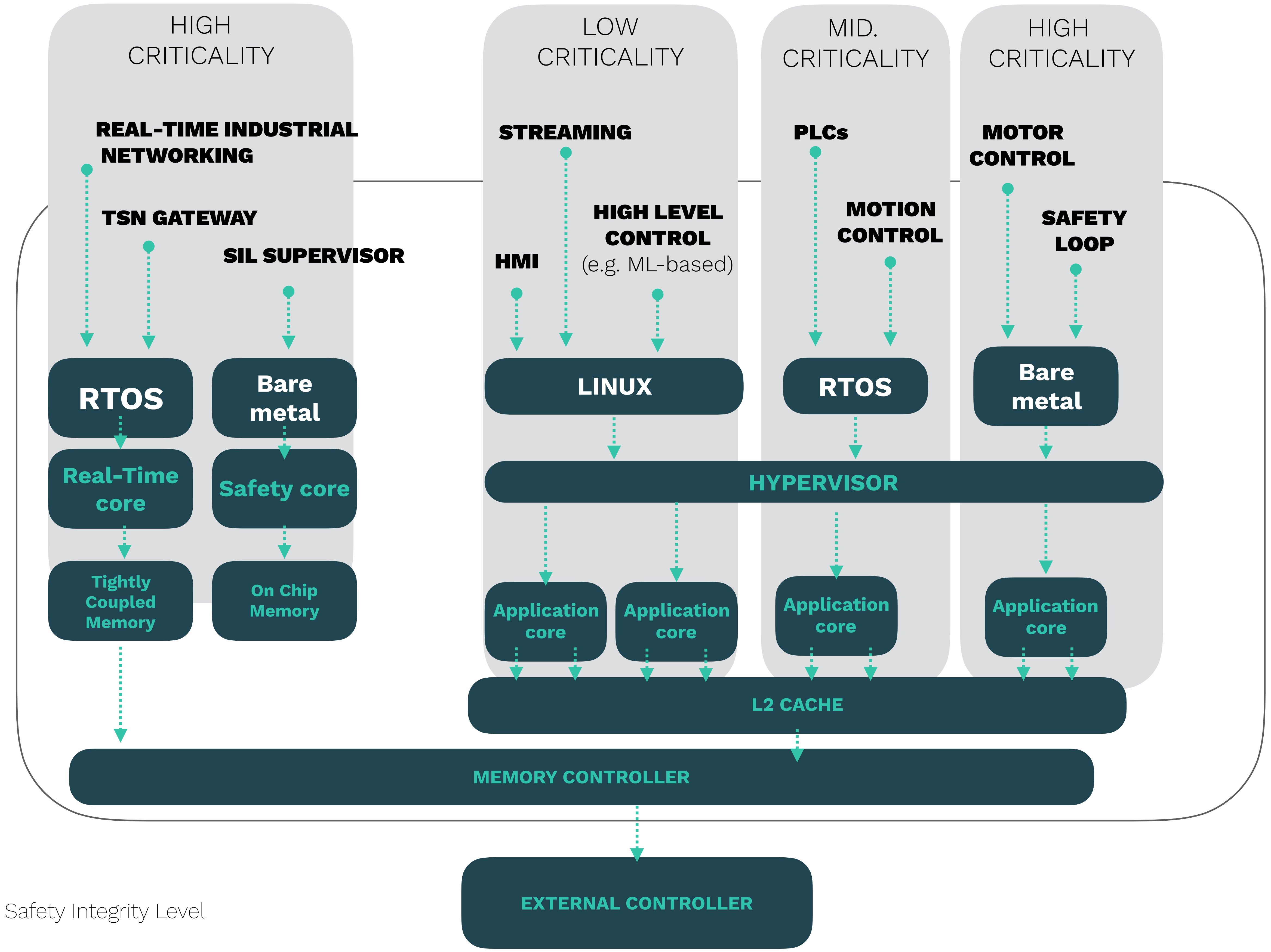
LIKELY TO BE REMOVED
I've re-organized a bit layers, yet.

I may get rid of this slide, I don't see how the dev. Tools and OS + drivers adds value to the overall pitch.

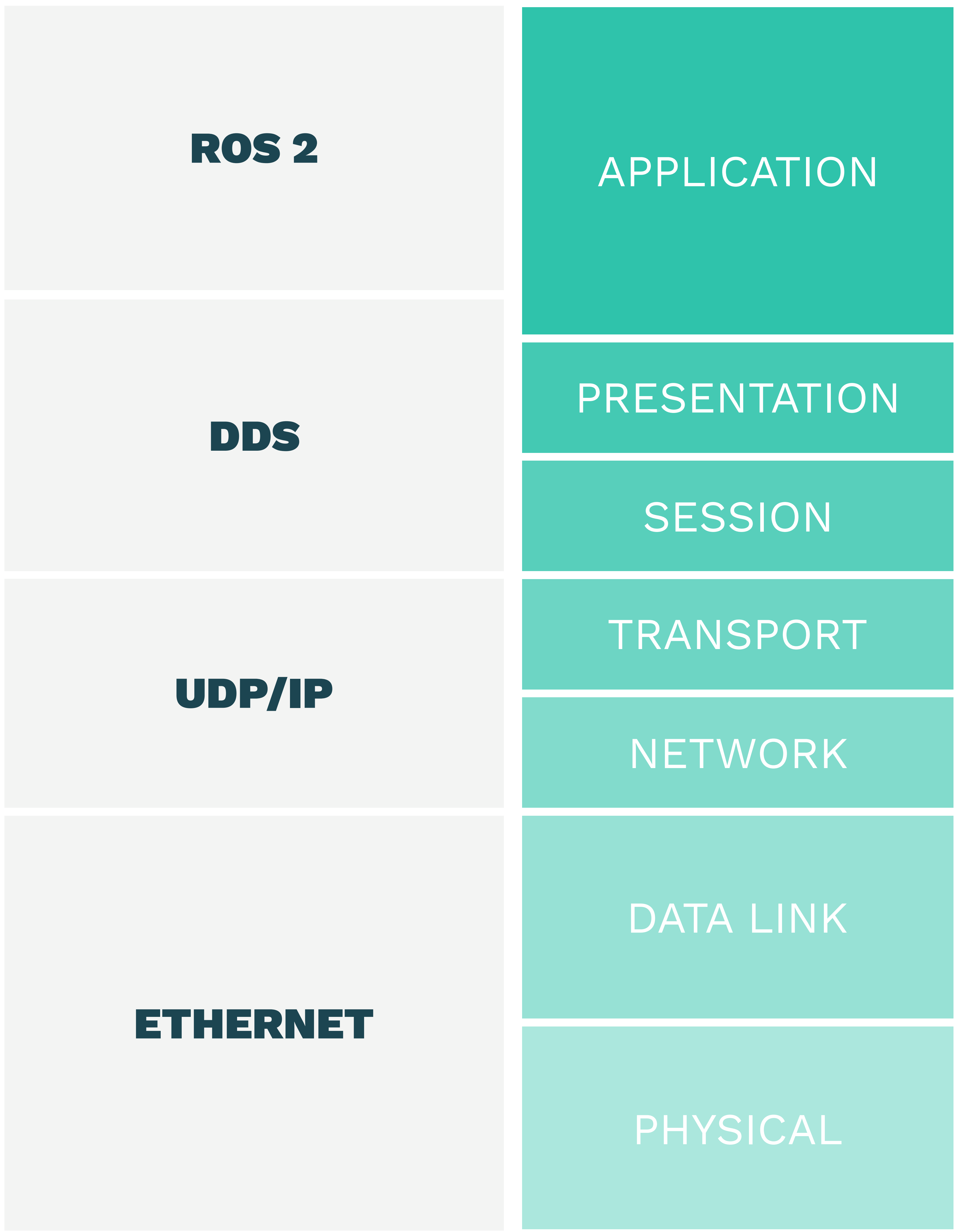
2. HARDWARE RELEVANCE

BOTTOM UP **HARDWARE** AND **SOFTWARE**

COMPLIANCE WITH DEADLINES



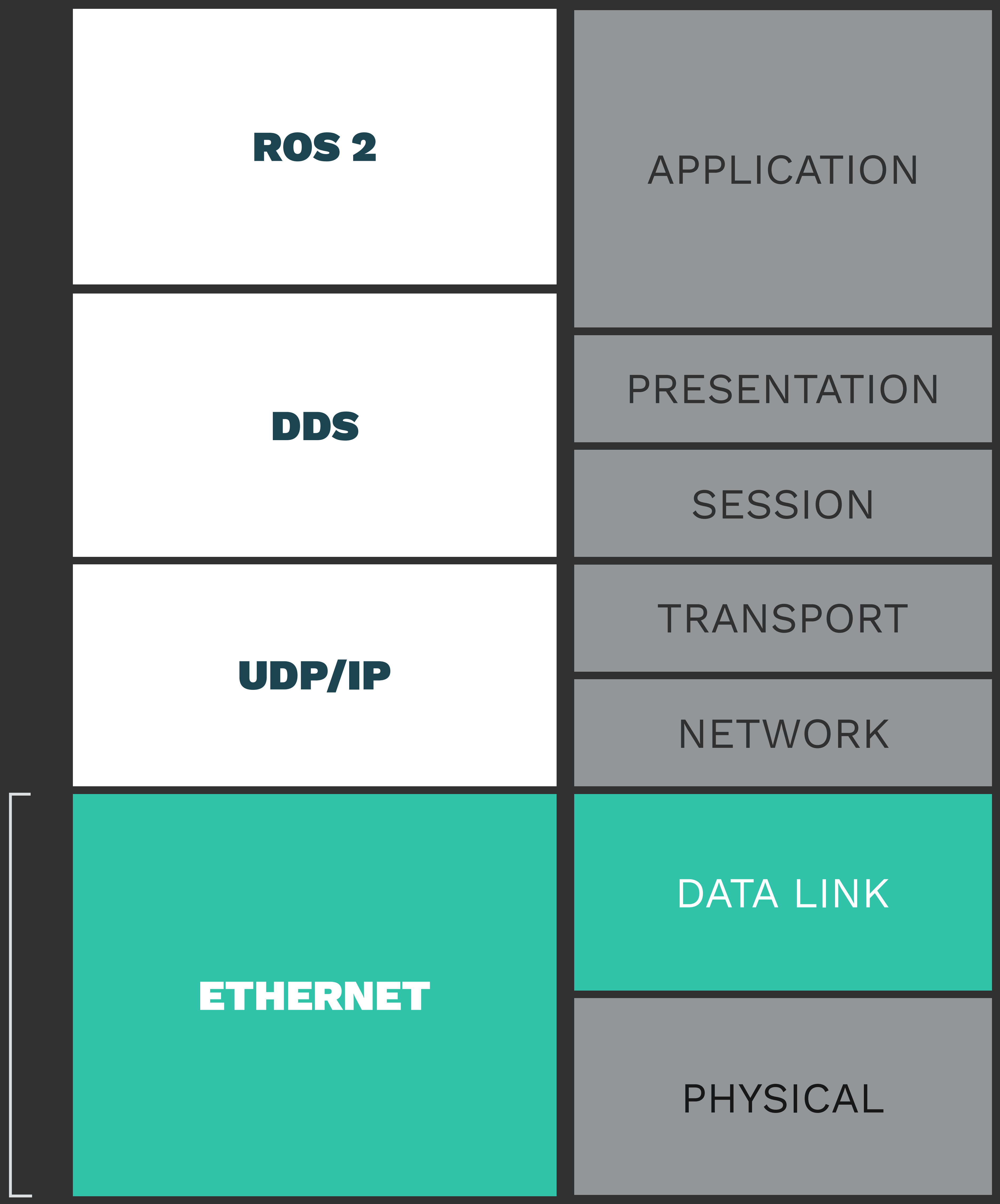
SIL: Safety Integrity Level



3. HARDWARE COMM. LEVEL
REAL-TIME (CAPABLE) LINK LAYER

REAL-TIME ROBOT STACK

REAL TIME **CAPABLE LINK LAYER**



HARDWARE
COMM. LEVEL

TOWARDS A REAL TIME **CAPABLE LINK LAYER**

REAL-TIME ETHERNET SOLUTIONS

BASED ON TCP/IP NON REAL-TIME PROTOCOLS	**BASED ON TCP/IP** REAL-TIME	**STANDARD ETHERNET** IEEE 802.3	**MODIFIED ETHERNET** MEDIA ACCESS
PROFINET ETHERNET/IP DDS NON REAL-TIME PROTOCOLS	PROFINET ETHERNET/IP DDS REAL-TIME PROTOCOLS	POWER LINK PROFINET RT	ETHERCAT SERCOS III PROFINET IRT
TCP/UDP/IP	TCP/UDP/IP		
ETHERNET	ETHERNET	ETHERNET	MODIFIED ETHERNET
ETHERNET CABLING			

[3] Gutiérrez, C.S.V., Juan, L.U.S., Ugarte, I.Z., & Vilches, V.M. (2018).
Time-Sensitive Networking for robotics.
arXiv preprint arXiv:1804.07643.

HARDWARE
COMM. LEVEL

TOWARDS A REAL TIME **CAPABLE LINK LAYER**

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HARDWARE
COMM. LEVEL

TOWARDS A REAL TIME **CAPABLE LINK LAYER**

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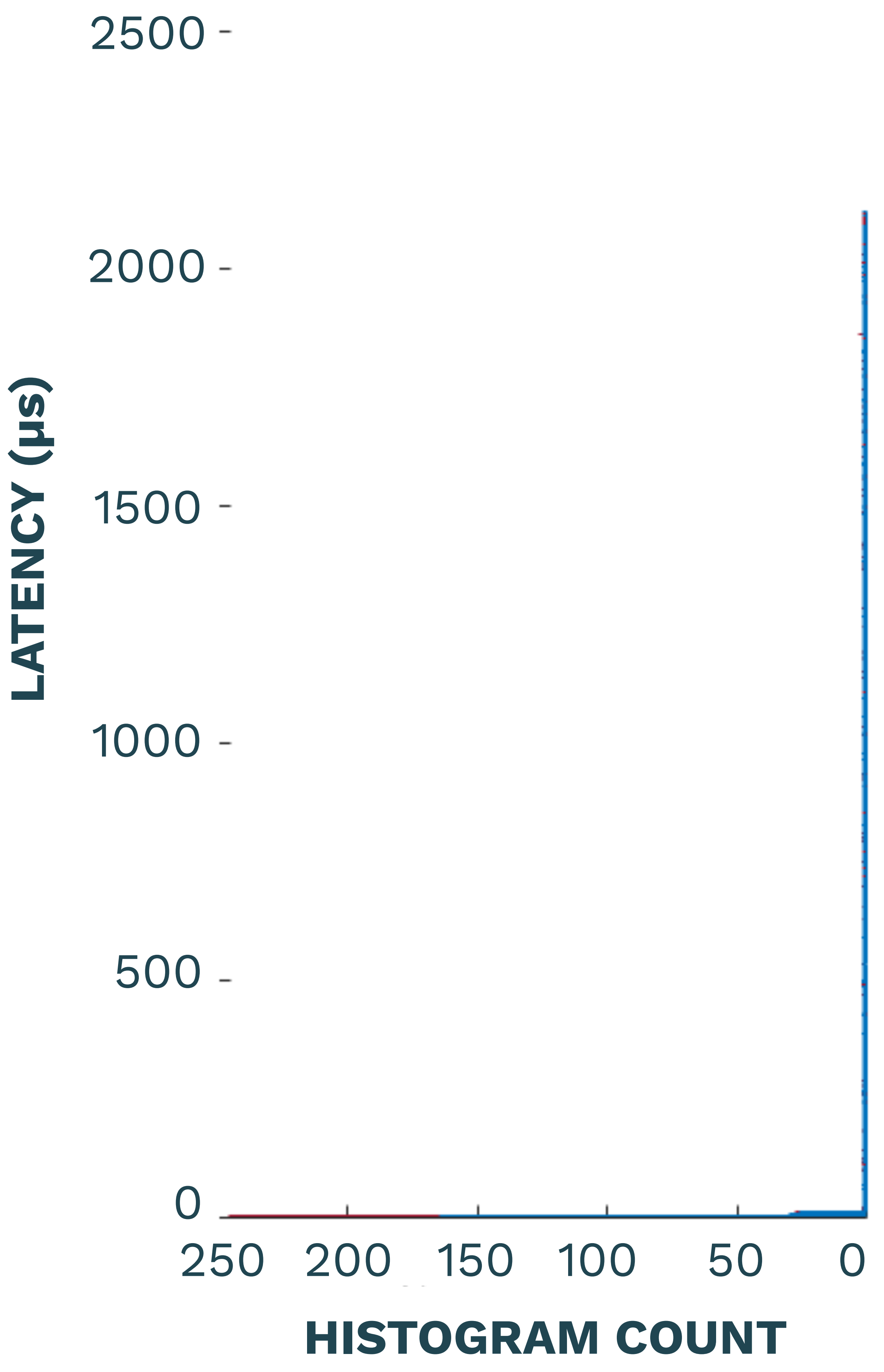
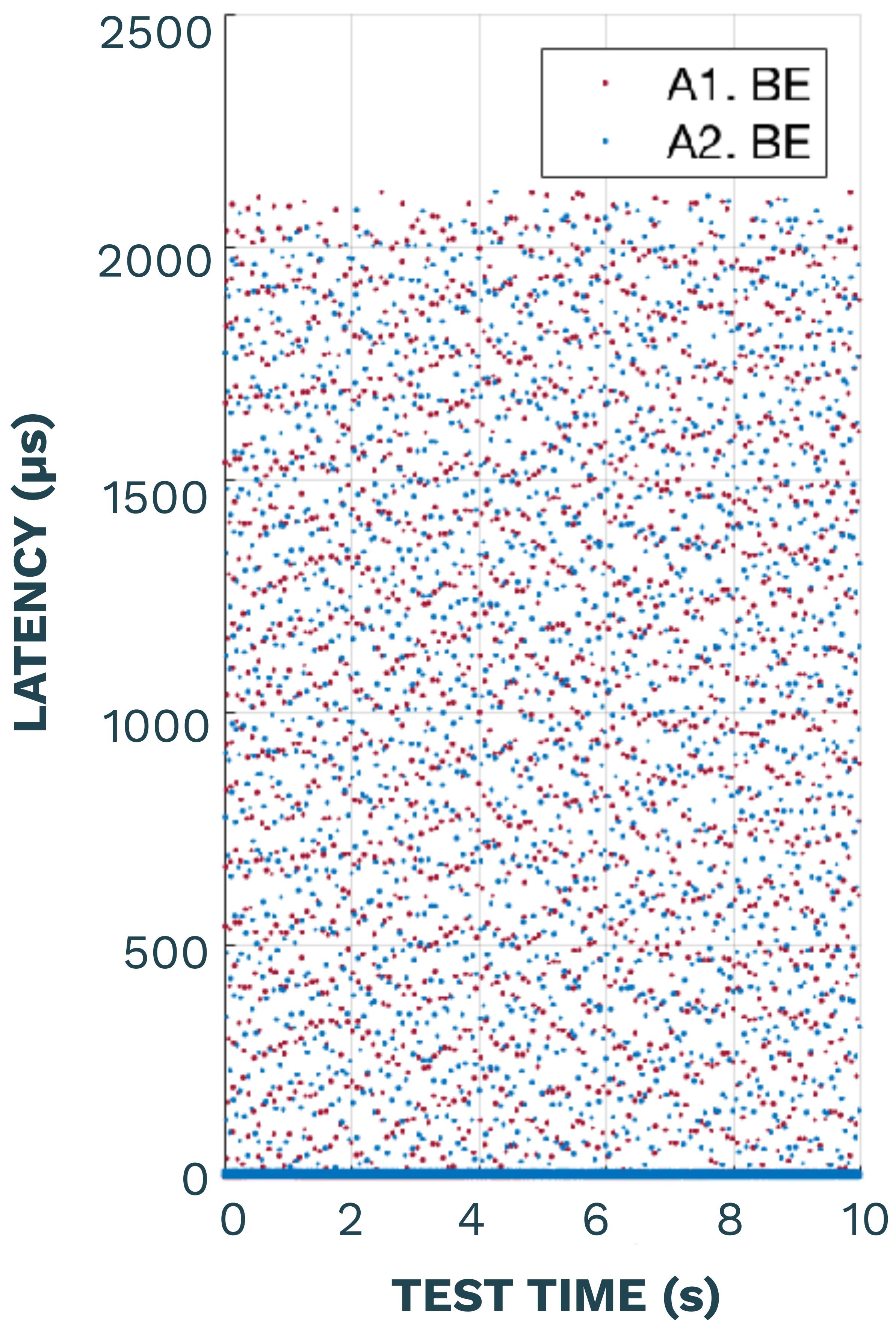
HARDWARE
COMM. LEVEL

NO REAL TIME **CAPABLE LINK**

LINK CAPACITY 1Gbps. NETWORK LOAD = 900Mbps





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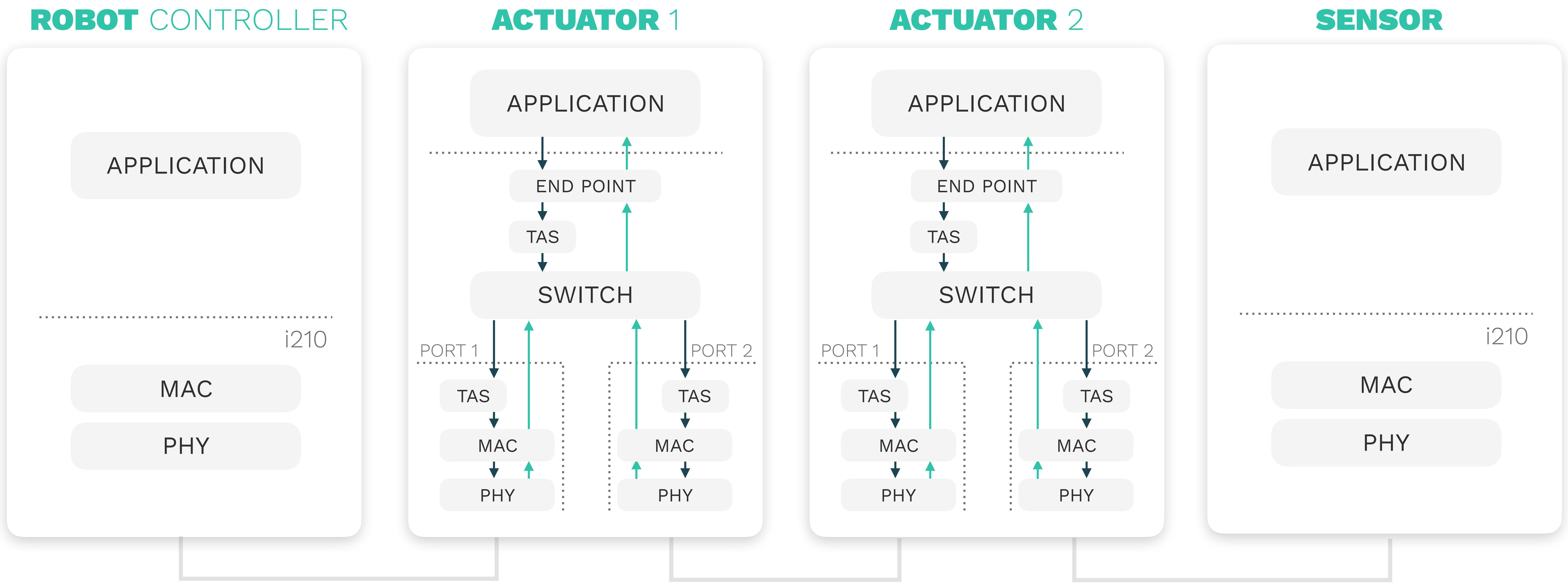
arXiv preprint arXiv:1804.07643.

HARDWARE COMM. LEVEL

IEEE 802.1QBV TIME-**AWARE SCHEDULER**



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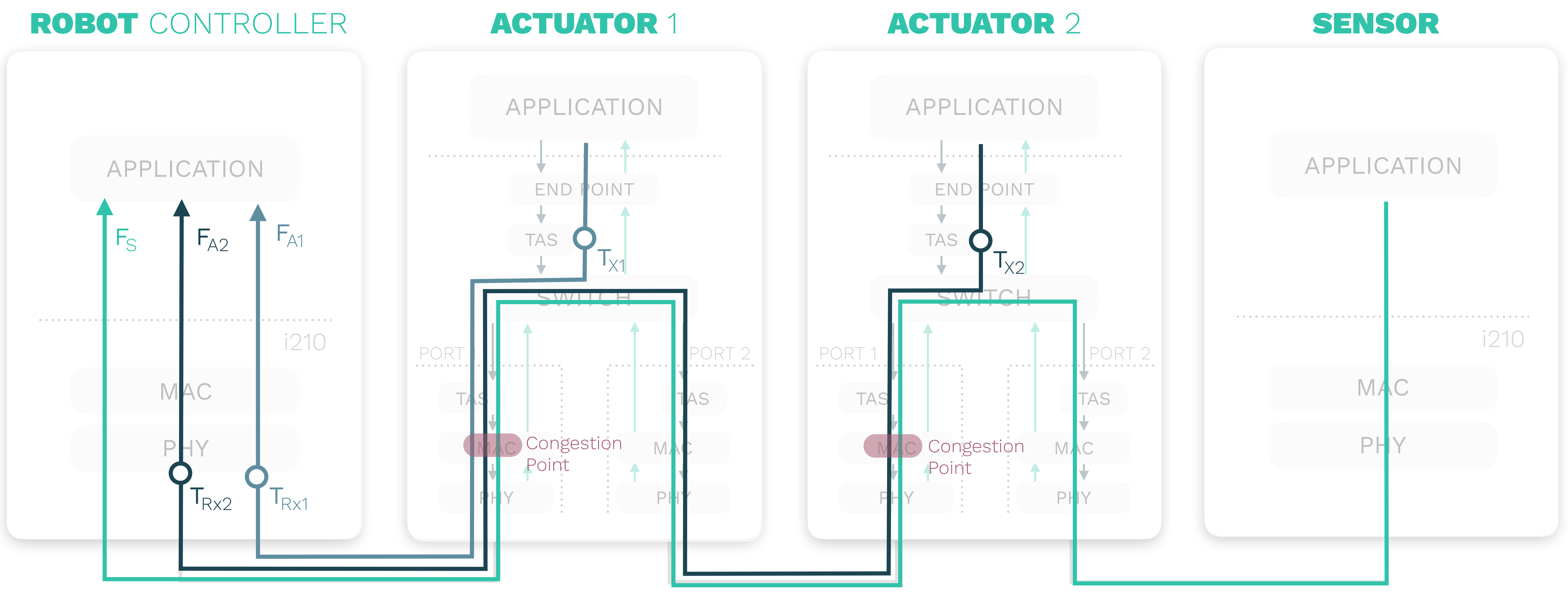
HARDWARE COMM. LEVEL

REAL TIME **CAPABLE LINK LAYER**



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HARDWARE
COMM. LEVEL

REAL TIME **CAPABLE LINK**

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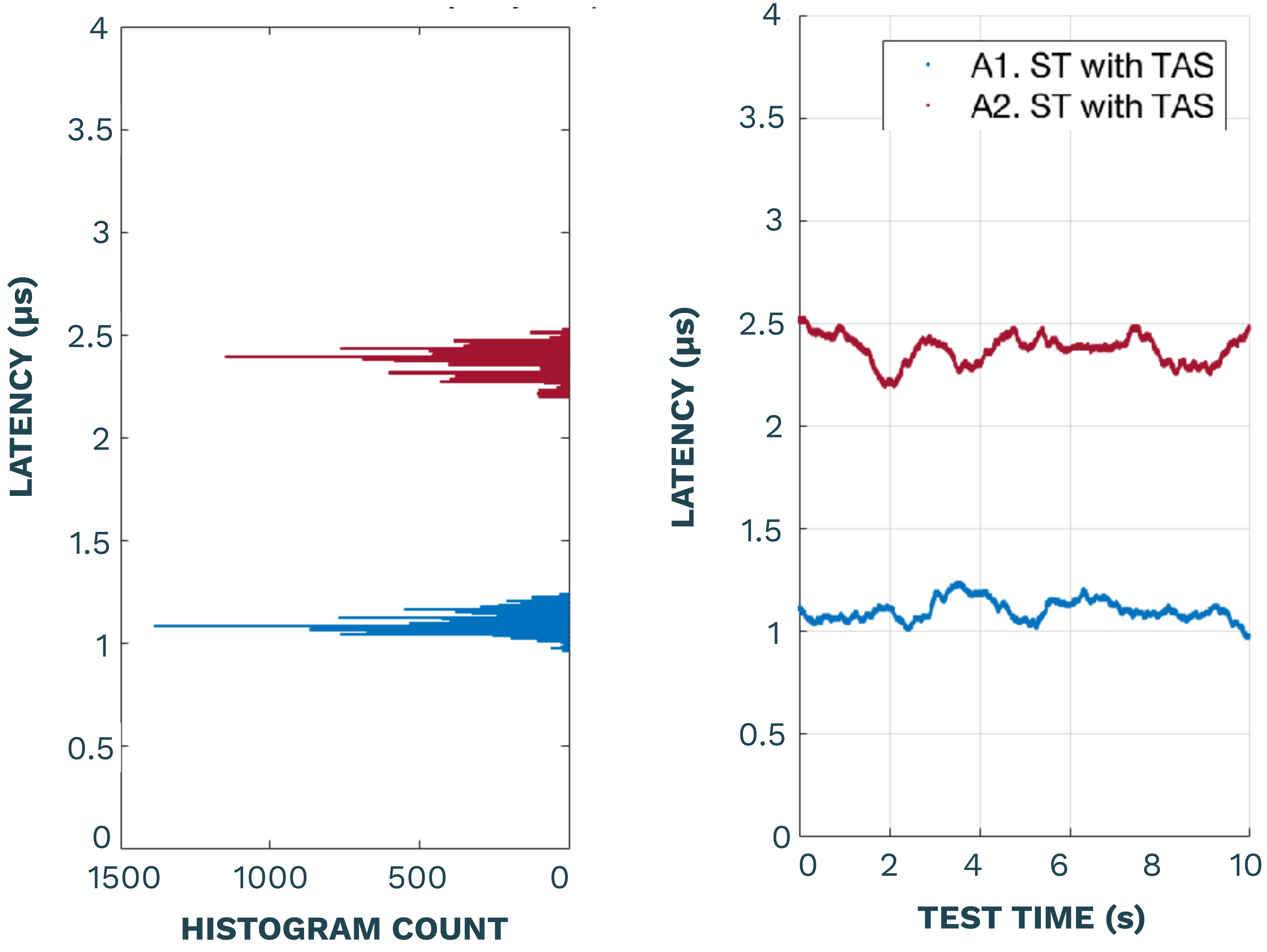

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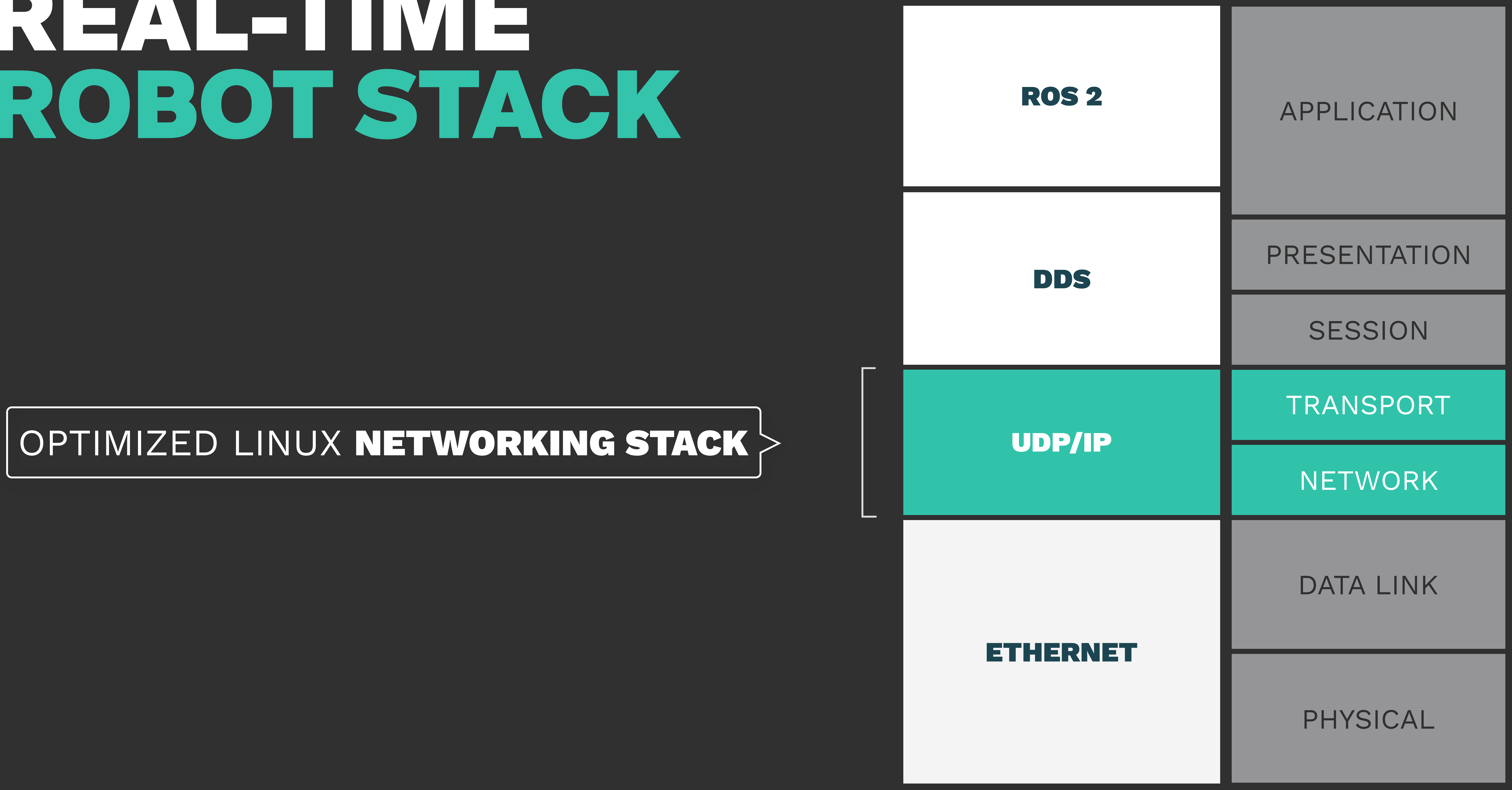
4. RTOS AND NETWORKING STACK

OPTIMIZED LINUX NETWORKING STACK

REAL-TIME ROBOT STACK



RTOS AND NETWORKING STACK

OPTIMIZED LINUX **NETWORKING STACK**

no-rt
we use a vanilla kernel.

rt-normal
we use a PREEMPT-RT kernel without binding the round-trip programs and network IRQs to any CPU.

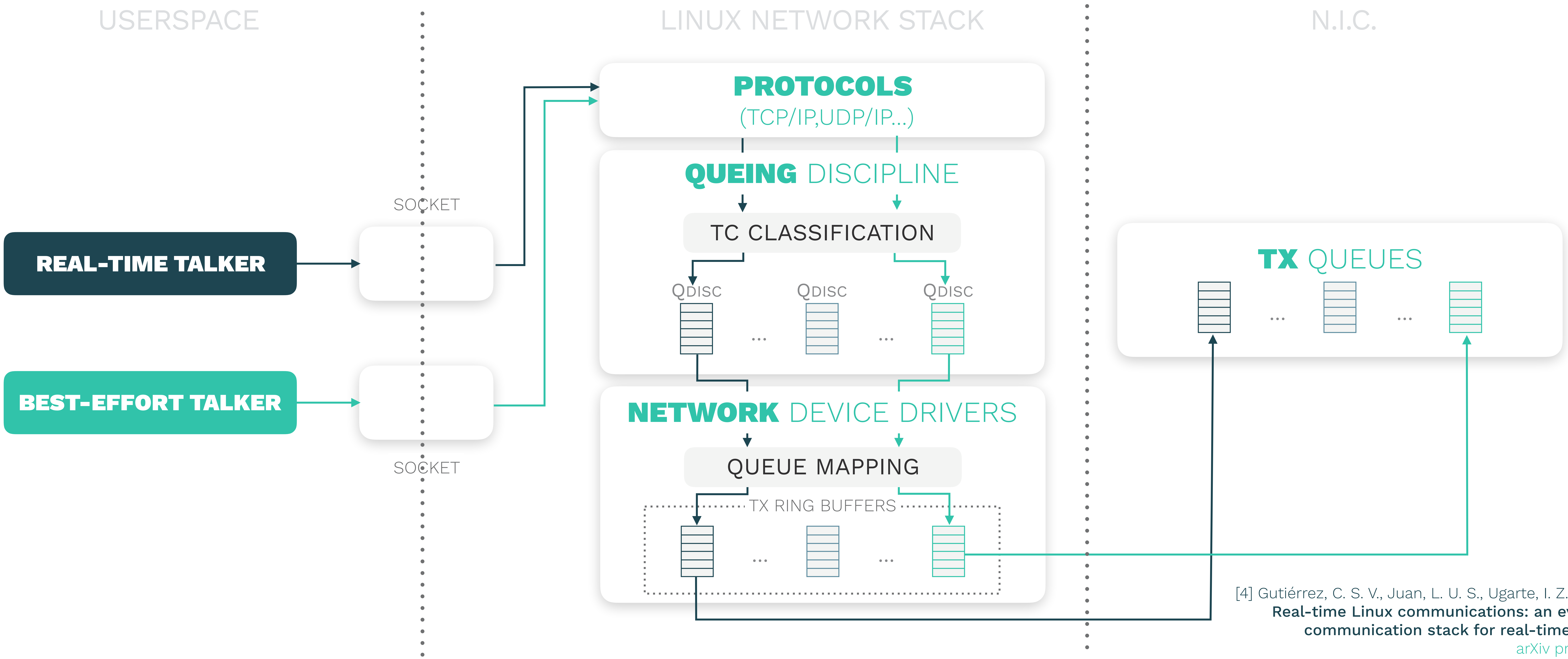
rt-affinities
we bind the IRQ thread of the priority queue and the client and server programs to CPU 1 of each device.

rt-isolation
we run the roundtrip application in an isolated CPU.

[4] Gutiérrez, C. S. V., Juan, L. U. S., Ugarte, I. Z., & Vilches, V. M. (2018). **Real-time Linux communications: an evaluation of the Linux communication stack for real-time robotic applications.** arXiv preprint arXiv:1808.10821.

RTOS AND NETWORKING STACK

OPTIMIZED LINUX **NETWORKING STACK**



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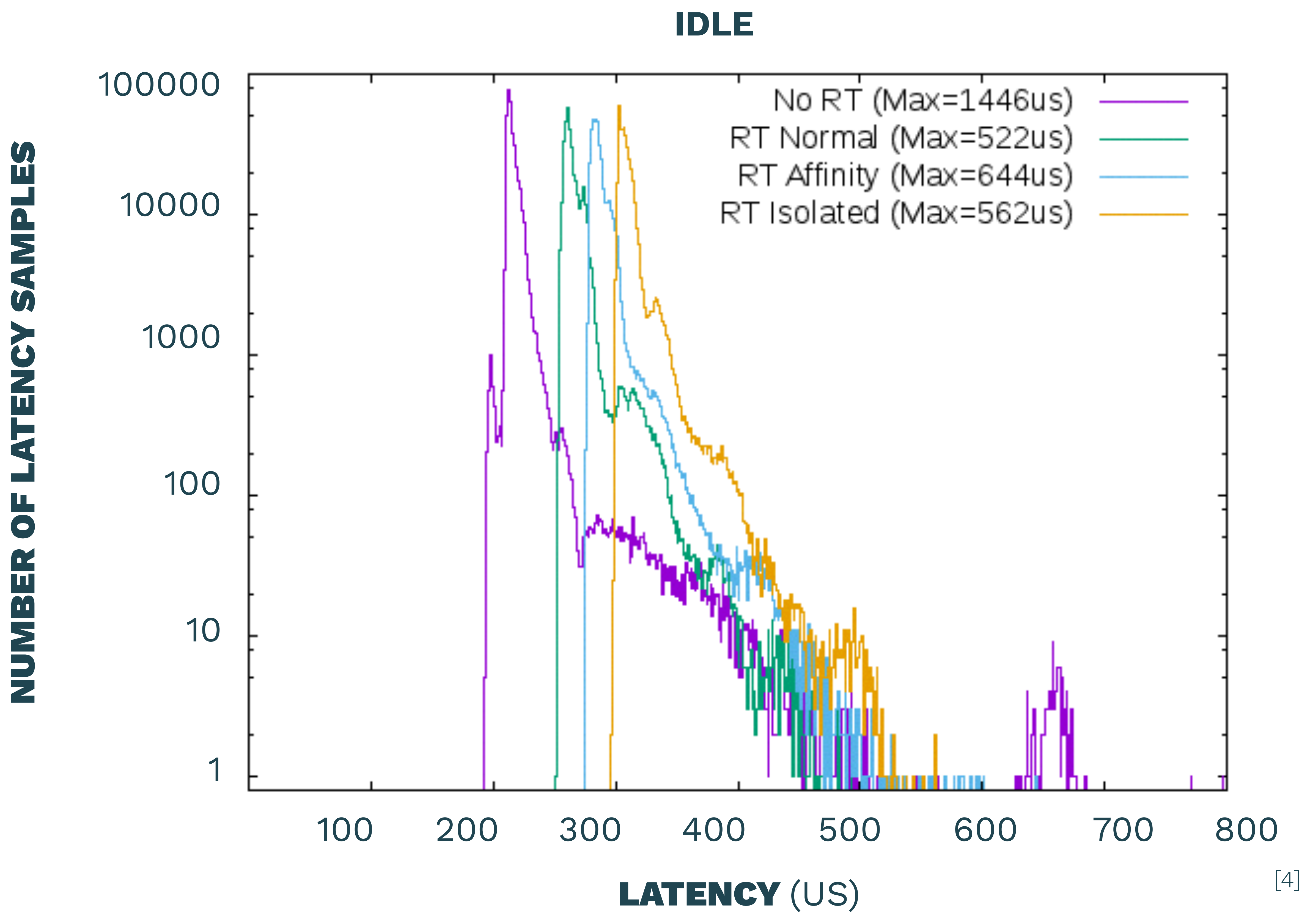
RTOS AND NETWORKING STACK

OPTIMIZED **LINUX** NETWORKING STACK



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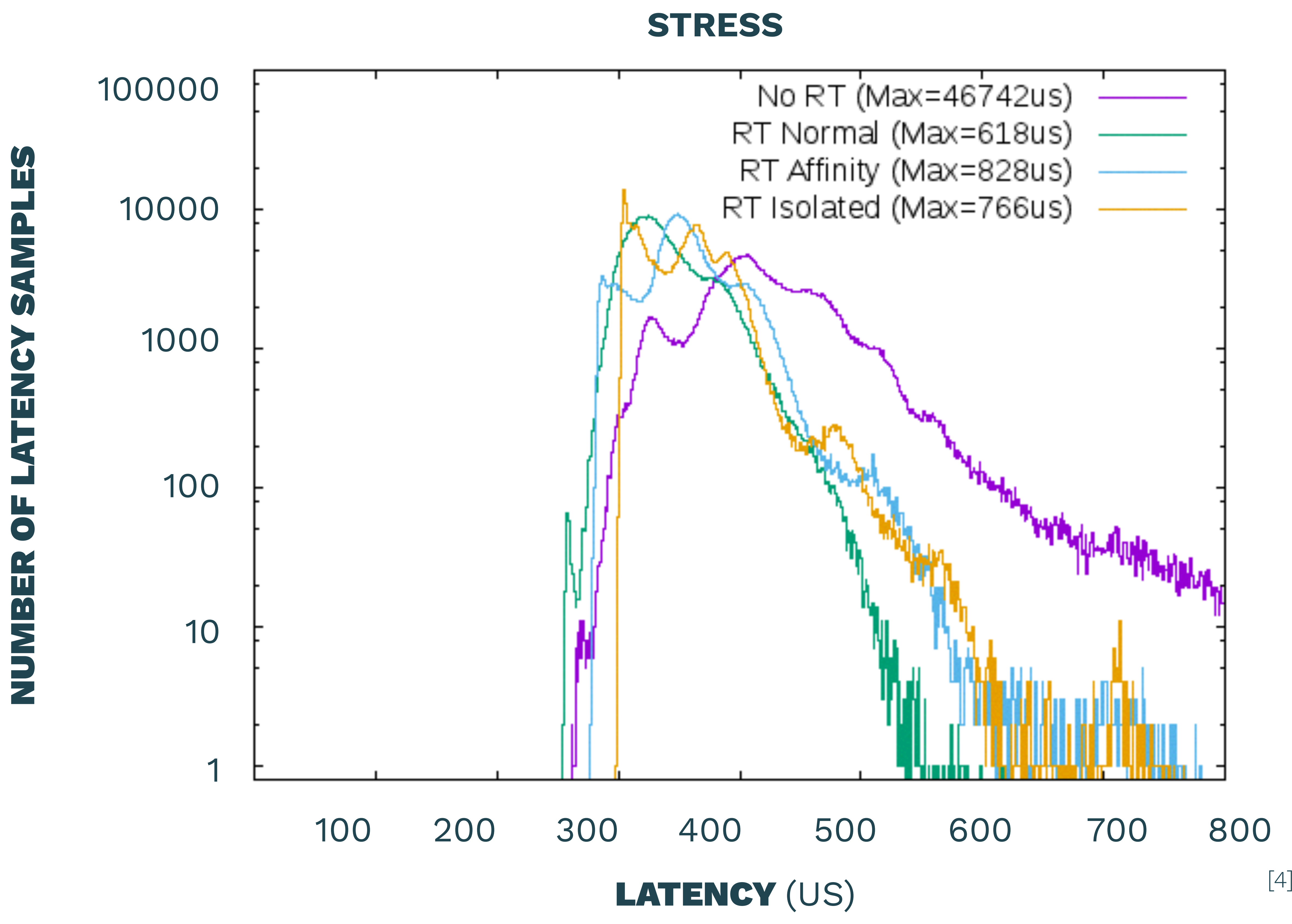

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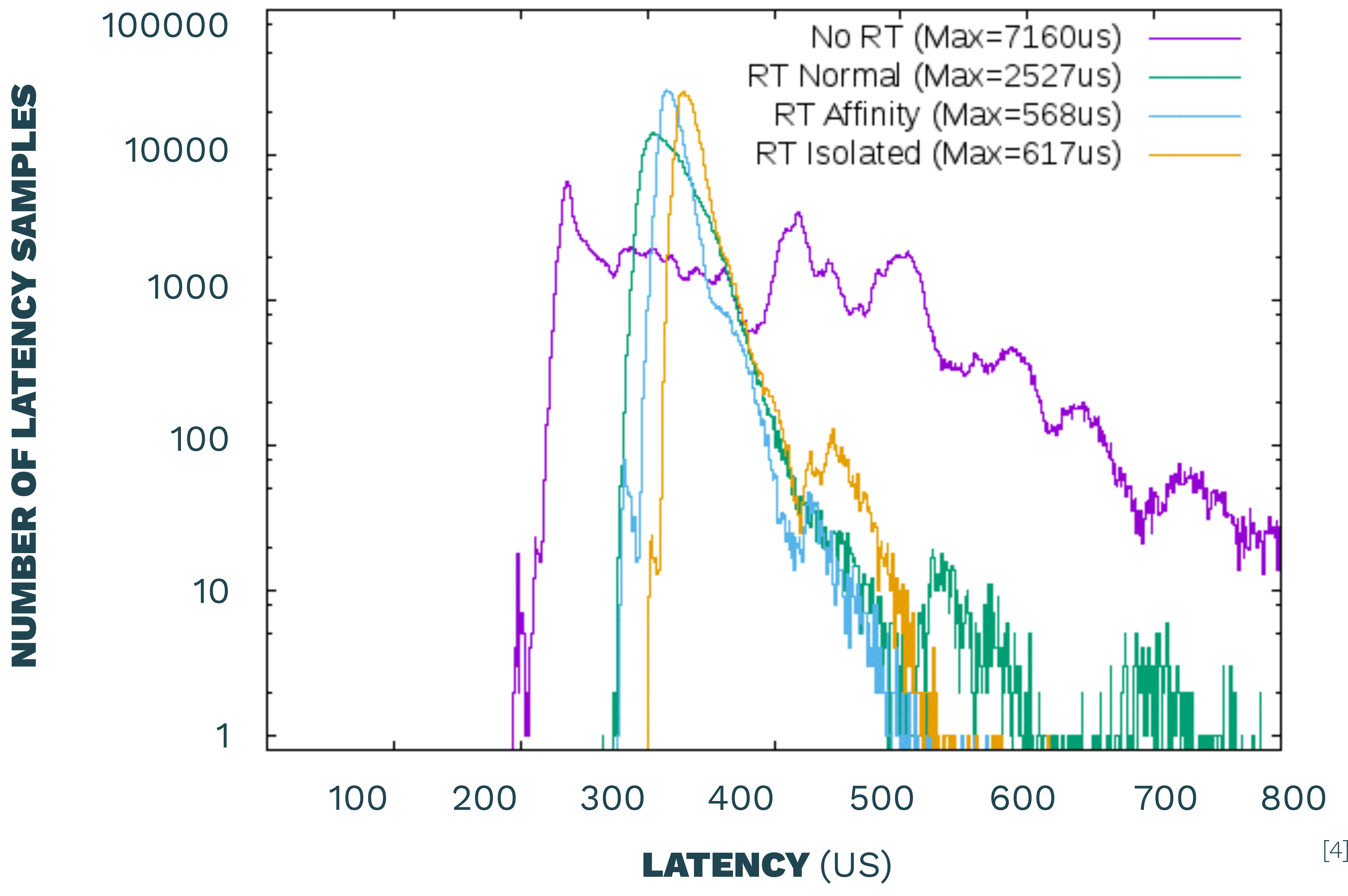
arXiv preprint arXiv:1808.10821.

RTOS AND NETWORKING STACK

OPTIMIZED **LINUX** NETWORKING STACK

TX TRAFFIC 100MBPS



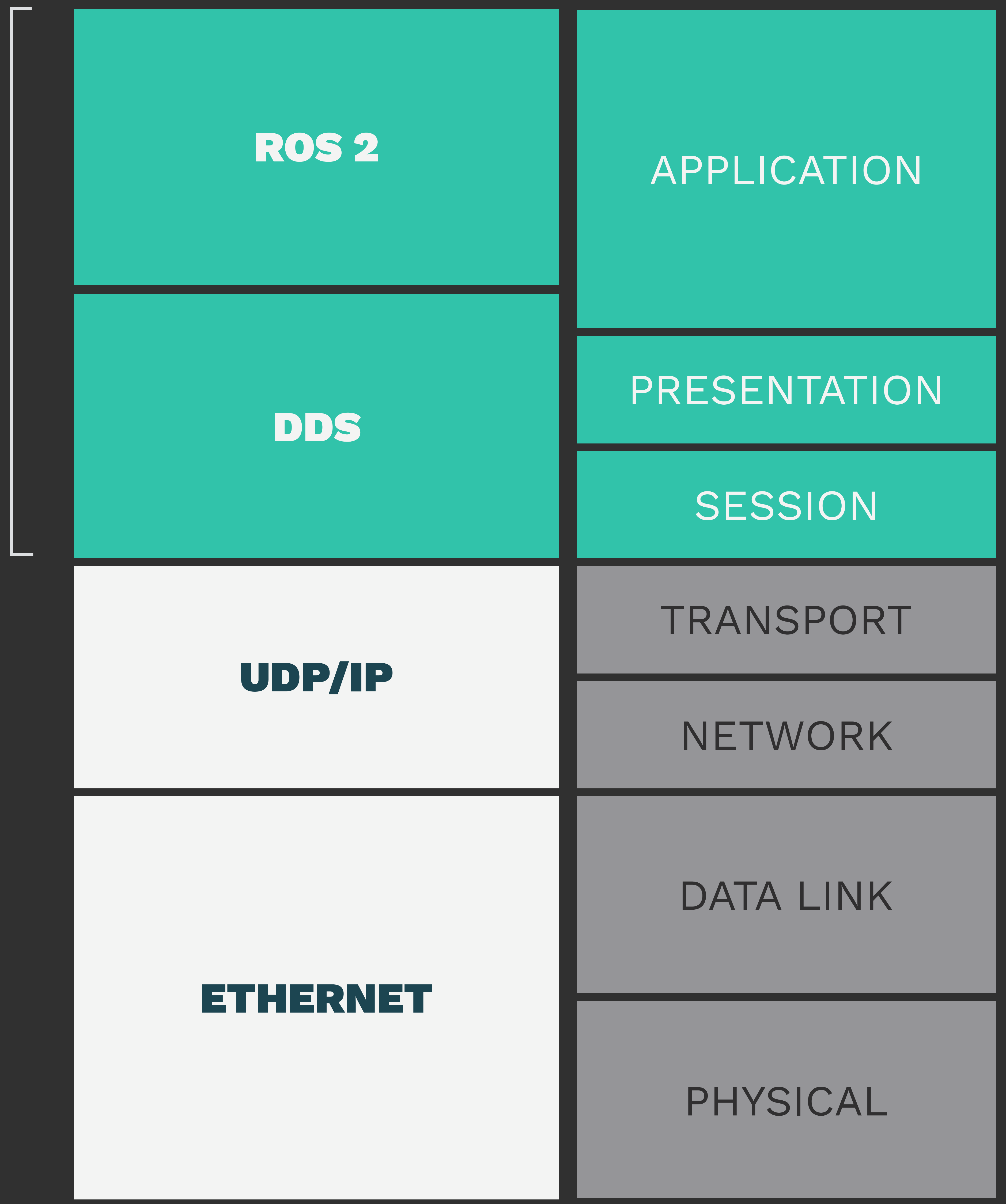
[4] Gutiérrez, C. S. V., Juan, L. U. S., Ugarte, I. Z., & Vilches, V. M. (2018). **Real-time Linux communications: an evaluation of the Linux communication stack for real-time robotic applications.** arXiv preprint arXiv:1808.10821.

5. ROBOTICS FRAMEWORK & COMMUNICATION MIDDLEWARE

ROS 2.0 FOR REAL-TIME

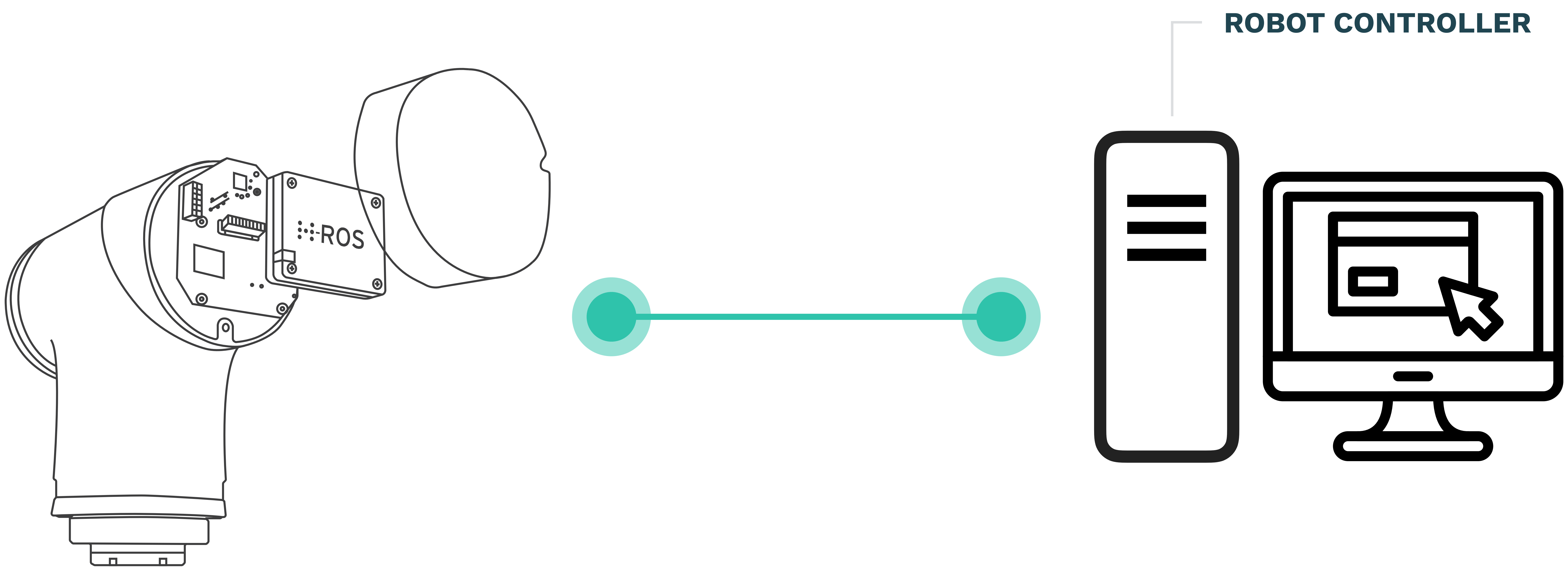
REAL-TIME
ROBOT STACK

ROS 2.0 **FOR REAL-TIME**



ROBOTICS FRAMEWORK & COMMUNICATION MIDDLEWARE

ROS 2.0 FOR REAL-TIME



[5] Gutiérrez, C. S. V., Juan, L. U. S., Ugarte, I. Z., & Vilches, V. M. (2018). Towards a distributed and real-time framework for robots: Evaluation of ROS 2.0 communications for real-time robotic applications. arXiv preprint arXiv:1809.02595.

ROBOTICS FRAMEWORK & COMMUNICATION MIDDLEWARE

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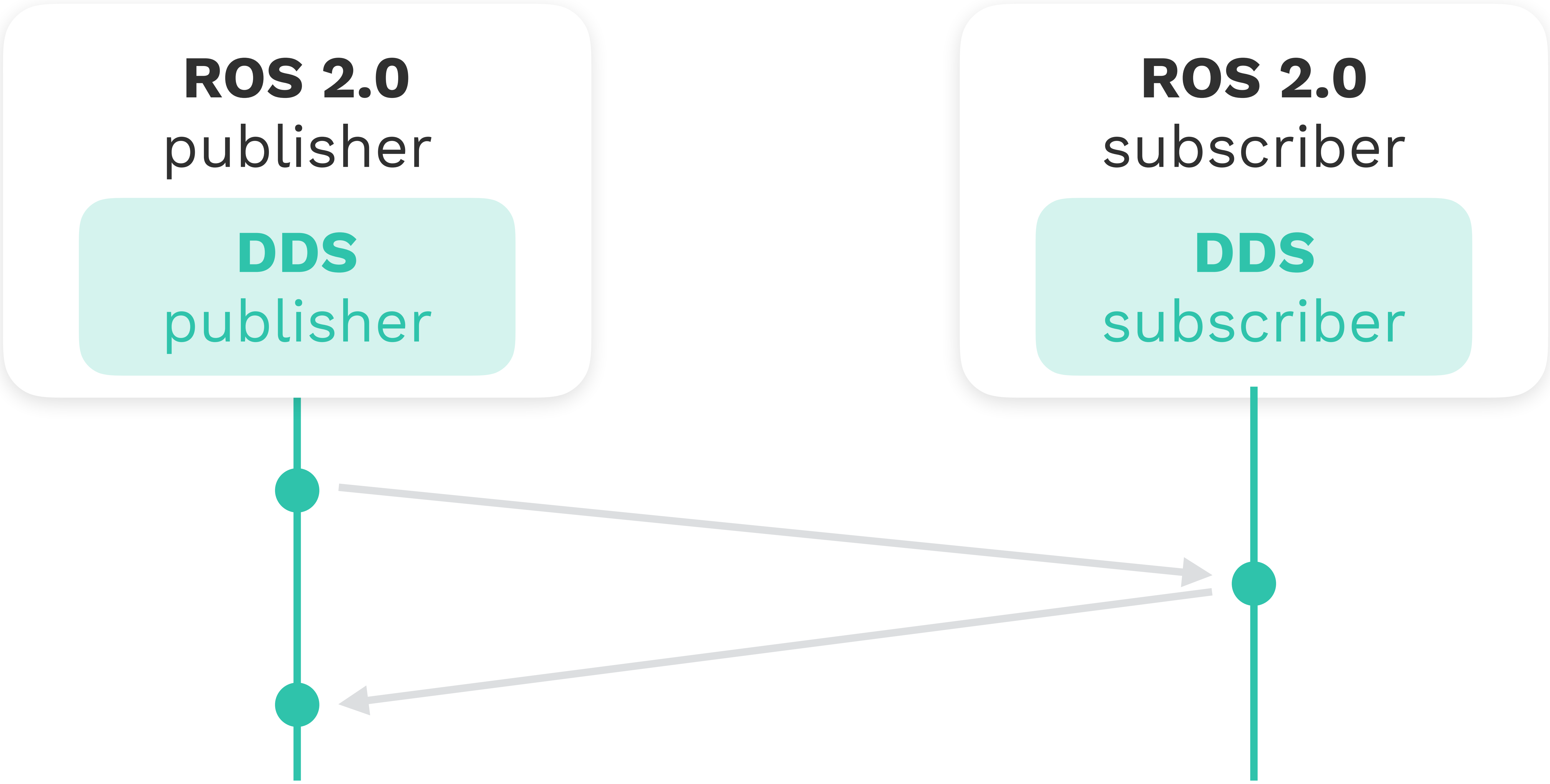

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ROBOTICS FRAMEWORK & COMMUNICATION MIDDLEWARE

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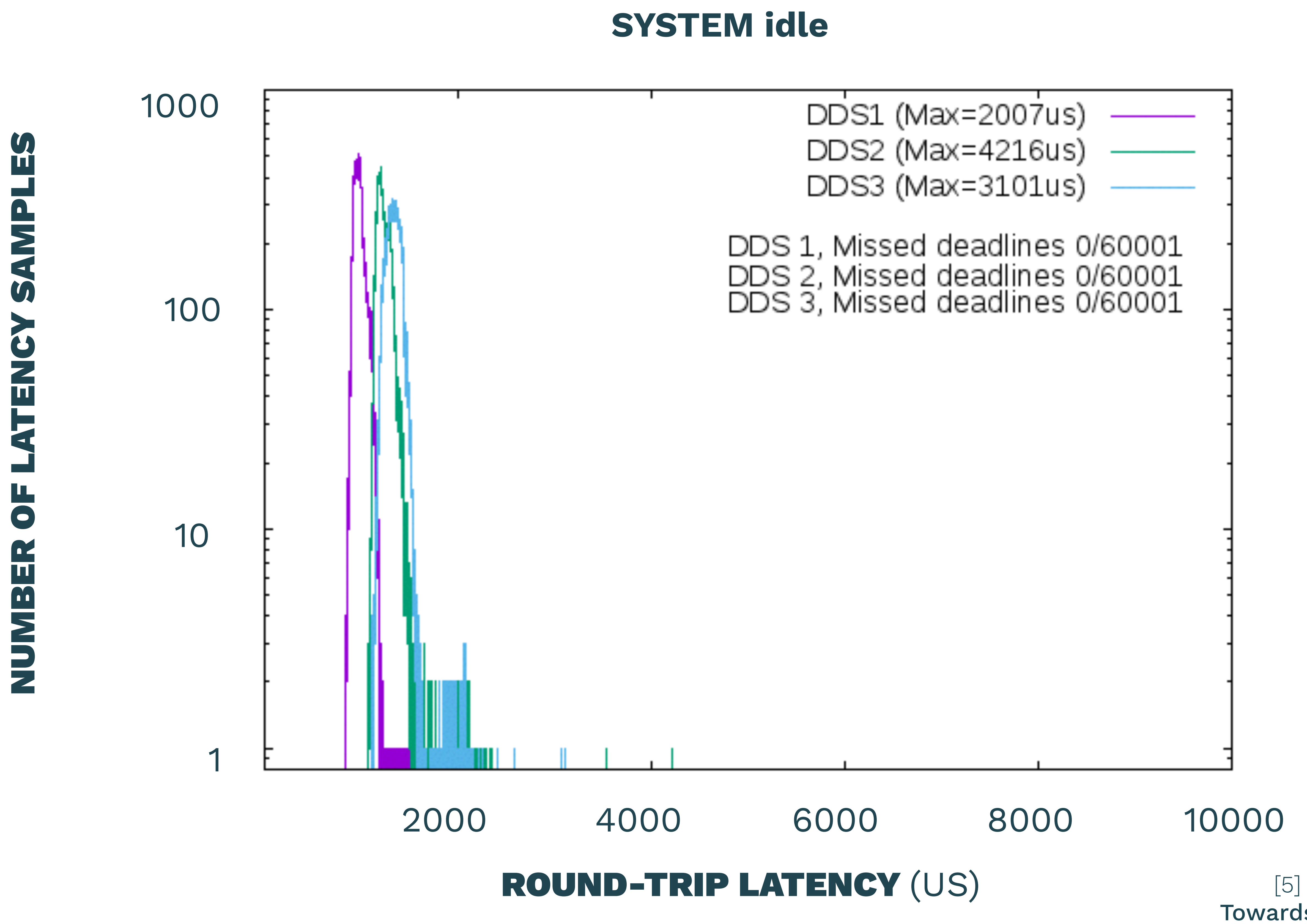

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ROBOTICS FRAMEWORK & COMMUNICATION MIDDLEWARE

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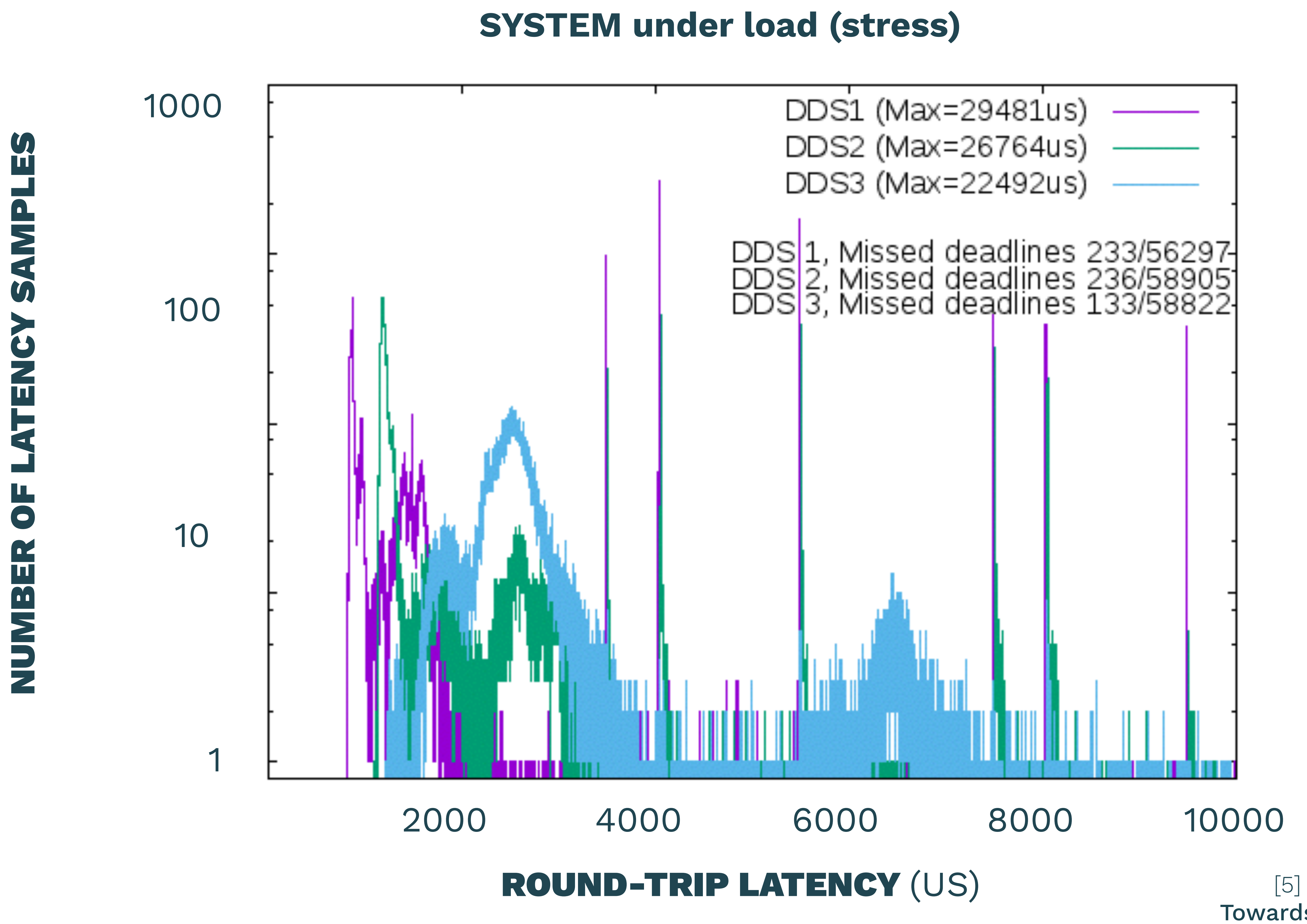

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ROBOTICS FRAMEWORK & COMMUNICATION MIDDLEWARE

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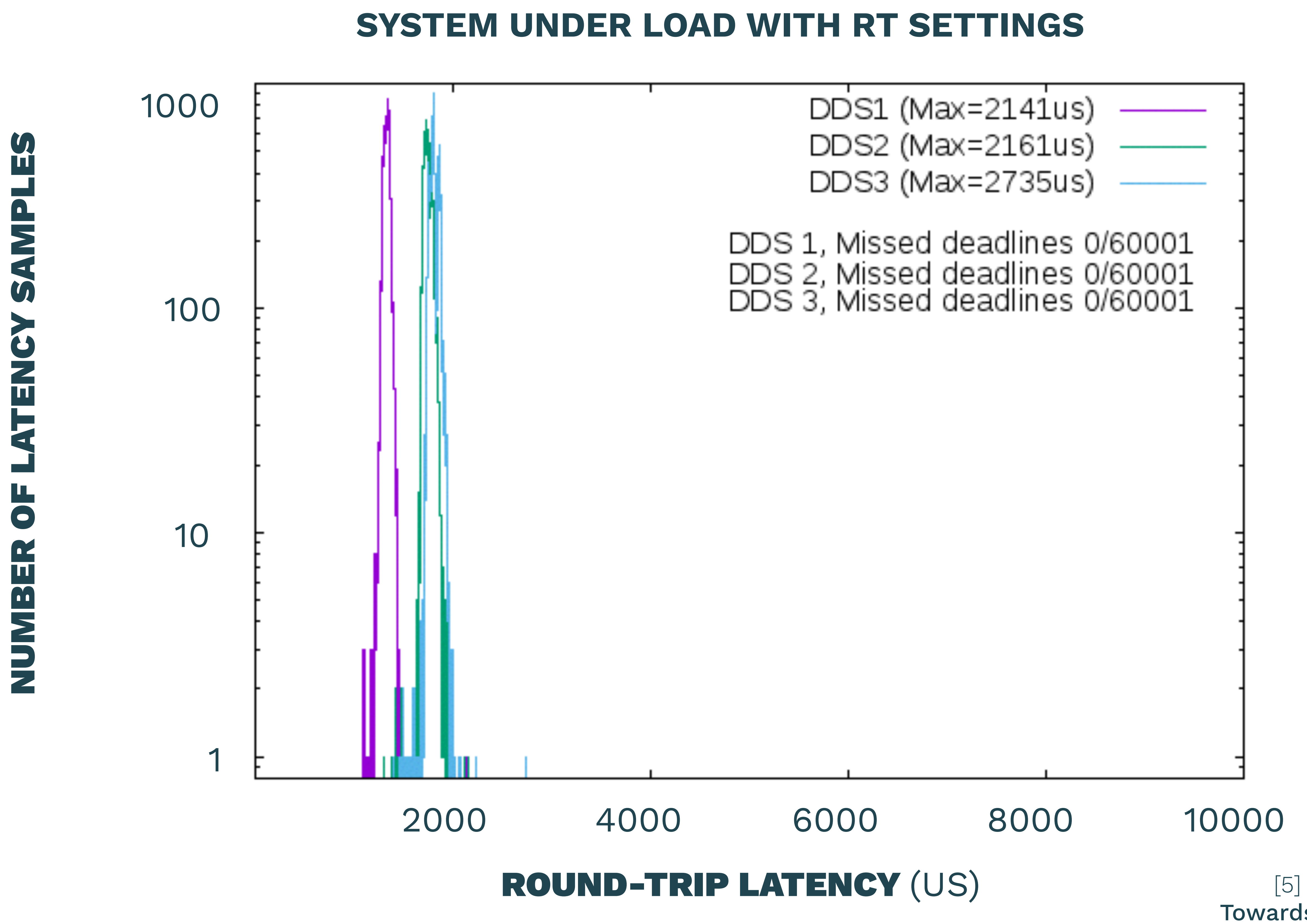

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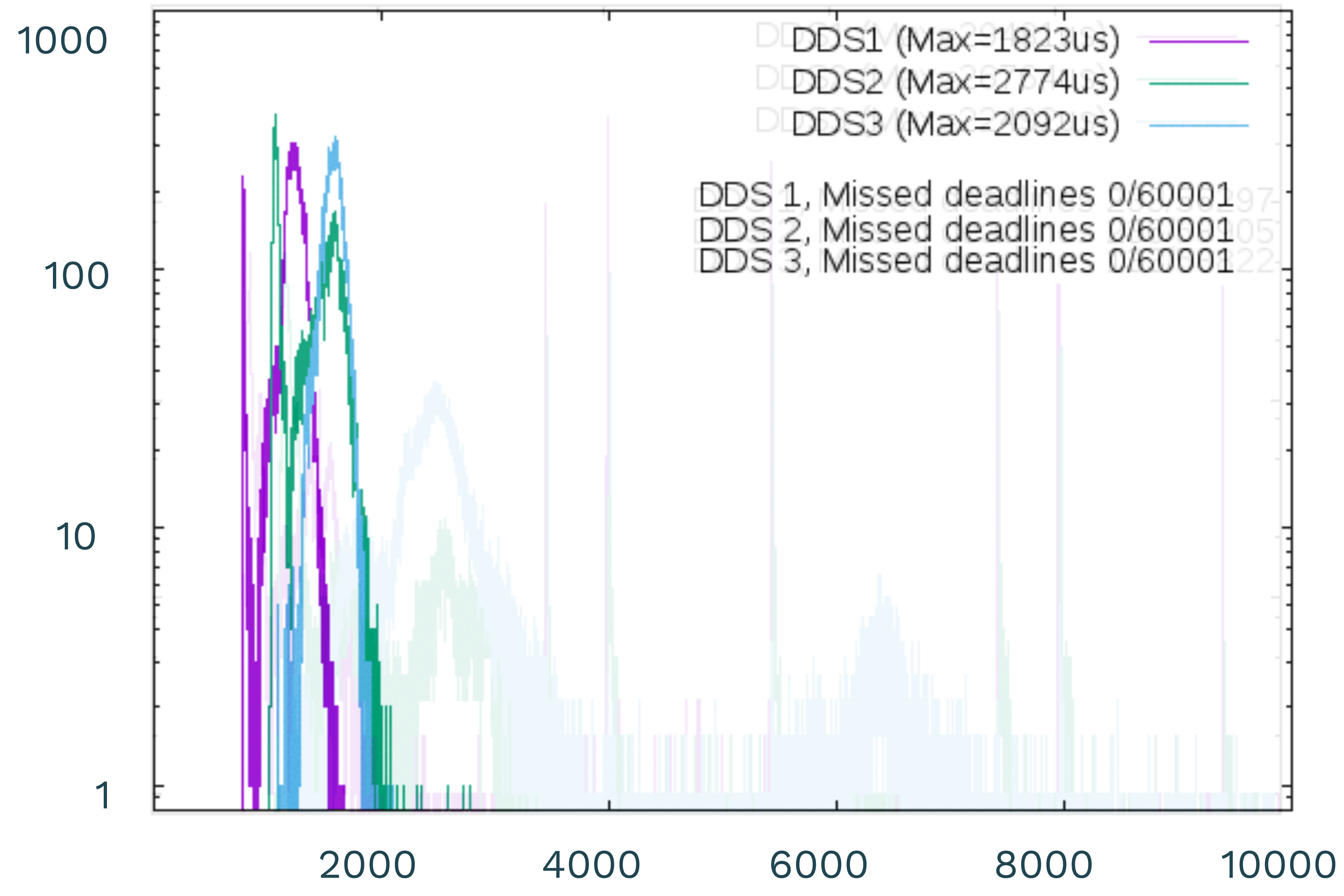
ROBOTICS FRAMEWORK & COMMUNICATION MIDDLEWARE

ROS 2.0 FOR REAL-TIME

SYSTEM UNDER LOAD WITH RT SETTINGS



NUMBER OF LATENCY SAMPLES

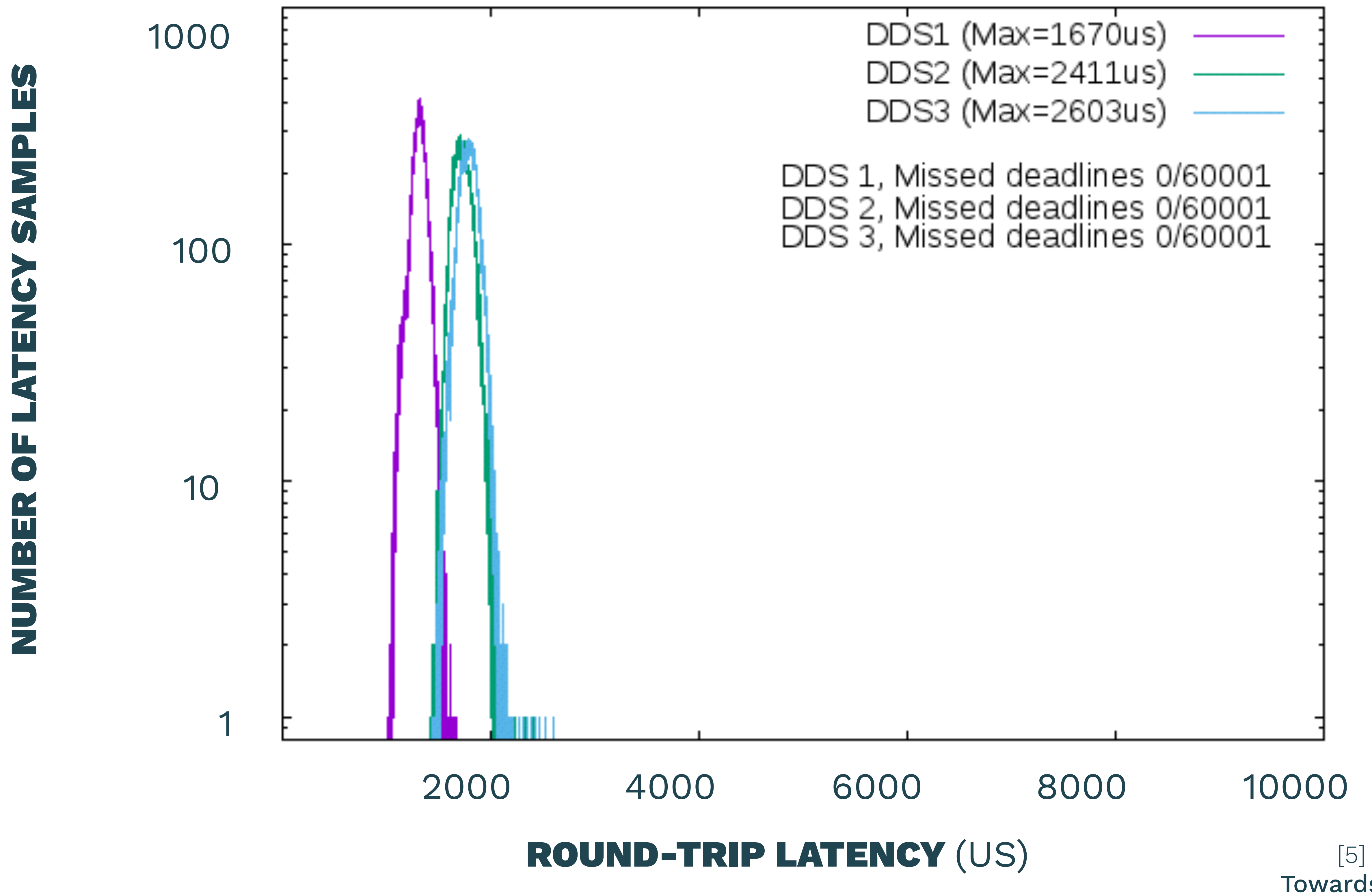
ROUND-TRIP LATENCY (US)

[5] Gutiérrez, C. S. V., Juan, L. U. S., Ugarte, I. Z., & Vilches, V. M. (2018). Towards a distributed and real-time framework for robots: Evaluation of ROS 2.0 communications for real-time robotic applications. arXiv preprint arXiv:1809.02595.

ROBOTICS FRAMEWORK & COMMUNICATION MIDDLEWARE

ROS 2.0 FOR REAL-TIME

SYSTEM UNDER LOAD WITH 1 Mbps
CONCURRENT TRAFFIC AND RT SETTINGS



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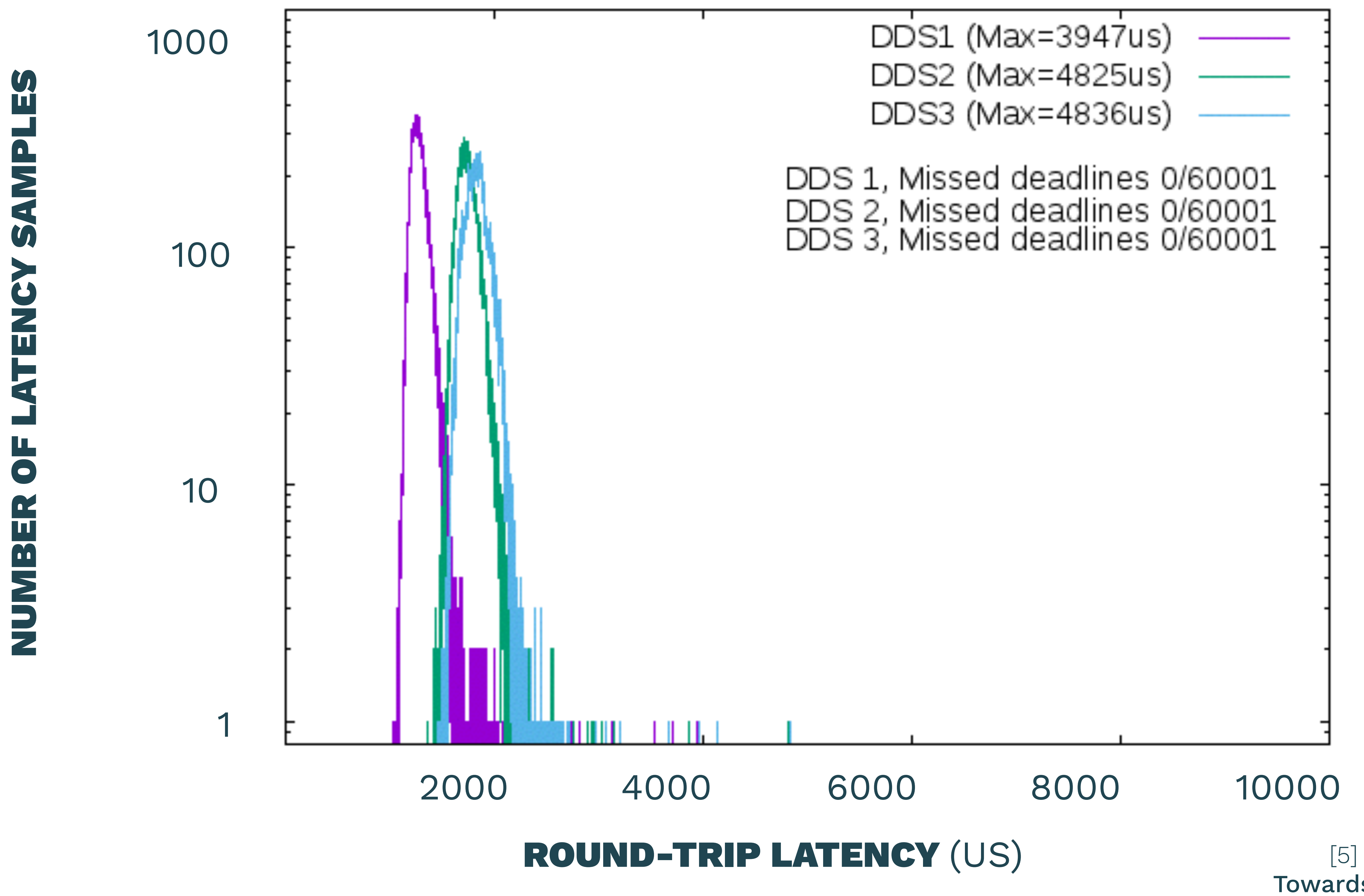
ROBOTICS FRAMEWORK & COMMUNICATION MIDDLEWARE

ROS 2.0 FOR REAL-TIME

SYSTEM UNDER LOAD WITH 40 Mbps
CONCURRENT TRAFFIC AND RT SETTINGS



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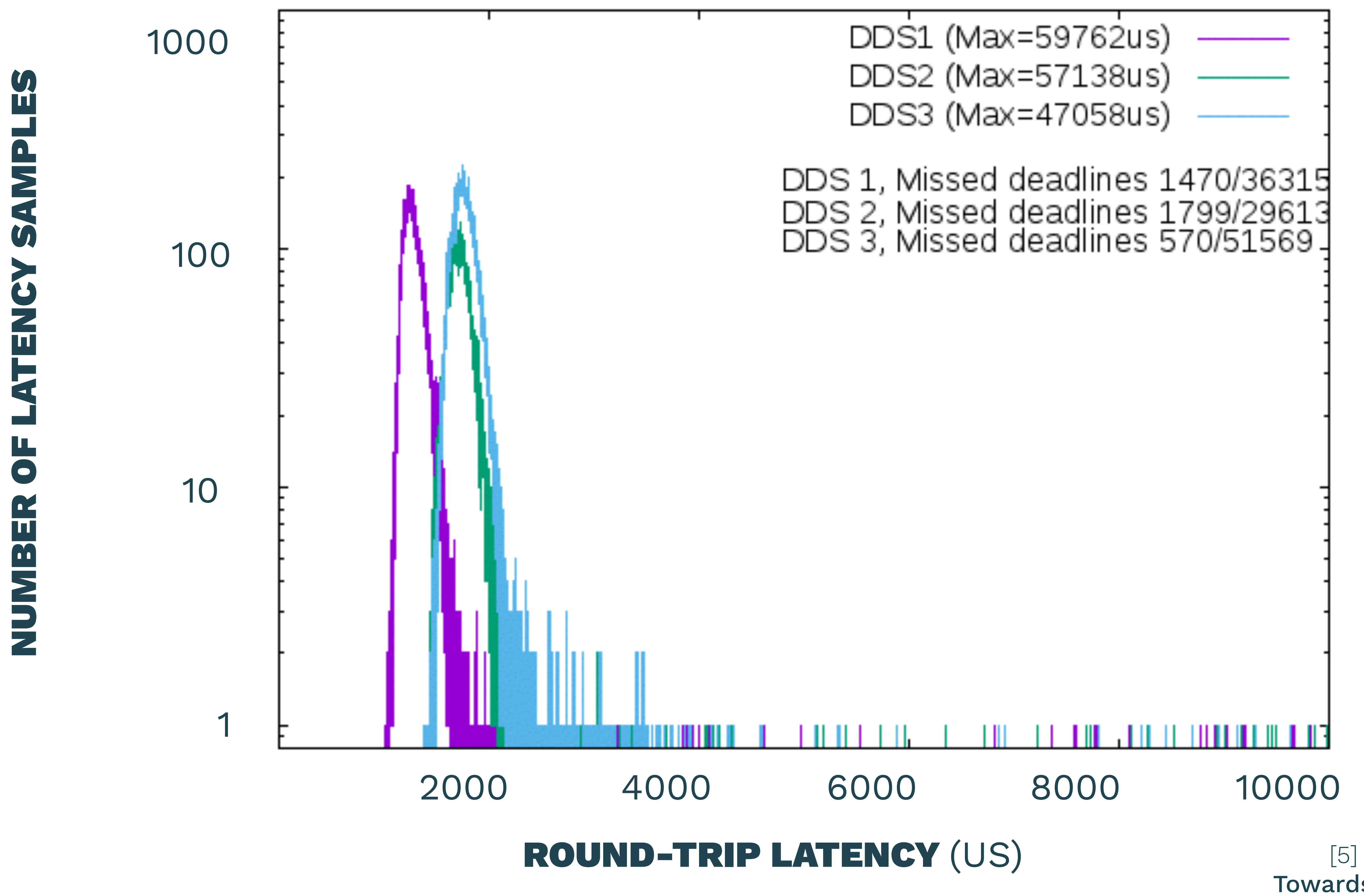
ROBOTICS FRAMEWORK &
COMMUNICATION MIDDLEWARE

ROS 2.0 FOR REAL-TIME

SYSTEM UNDER LOAD WITH 80 Mbps
CONCURRENT TRAFFIC AND RT SETTINGS



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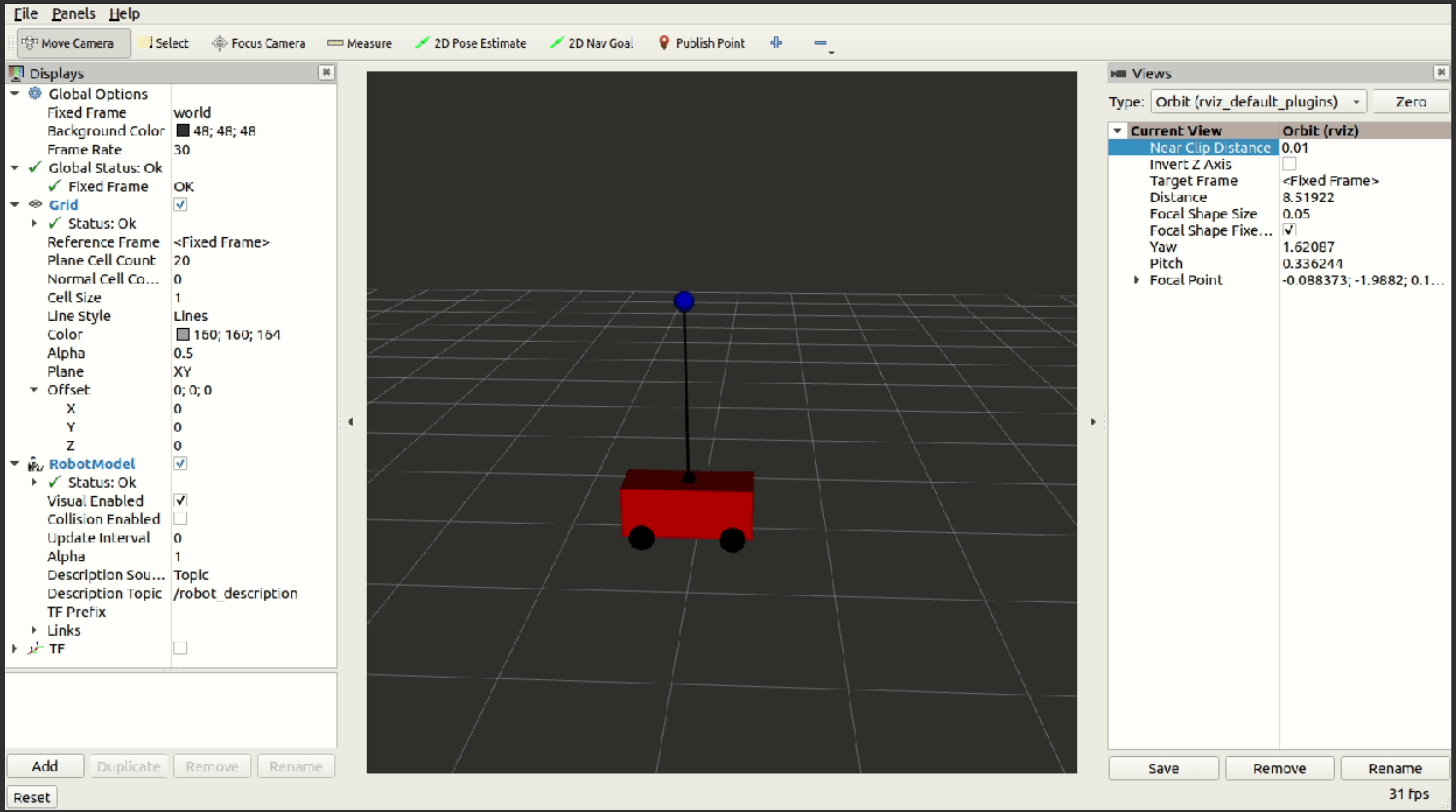
REAL-TIME
REFERENCE DEMO

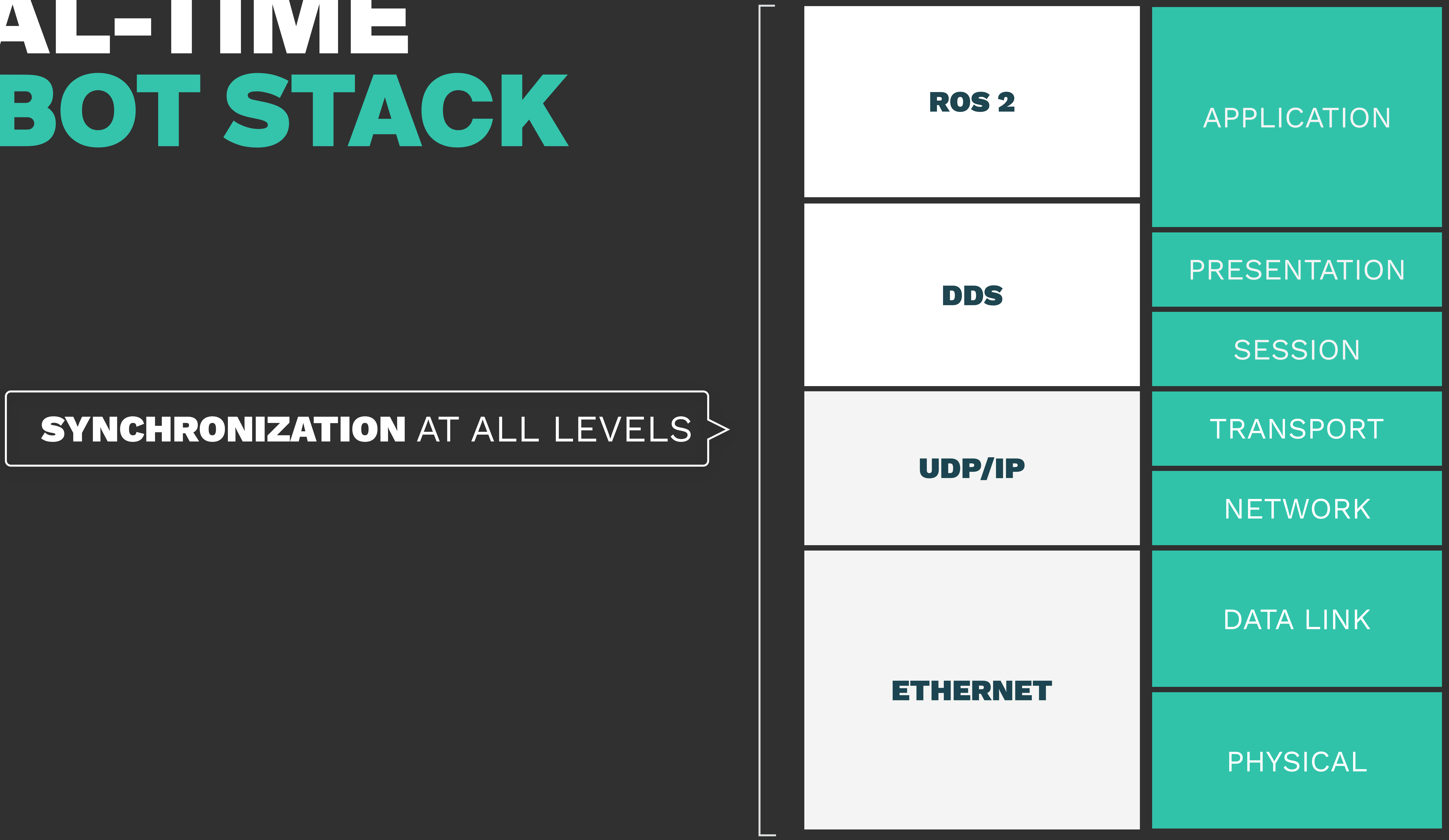


Gutiérrez, C. S. V., San Juan, L. U.,
ROS2, real-time, control, pendulum
https://github.com/ros2-realtime-demo/pendulum

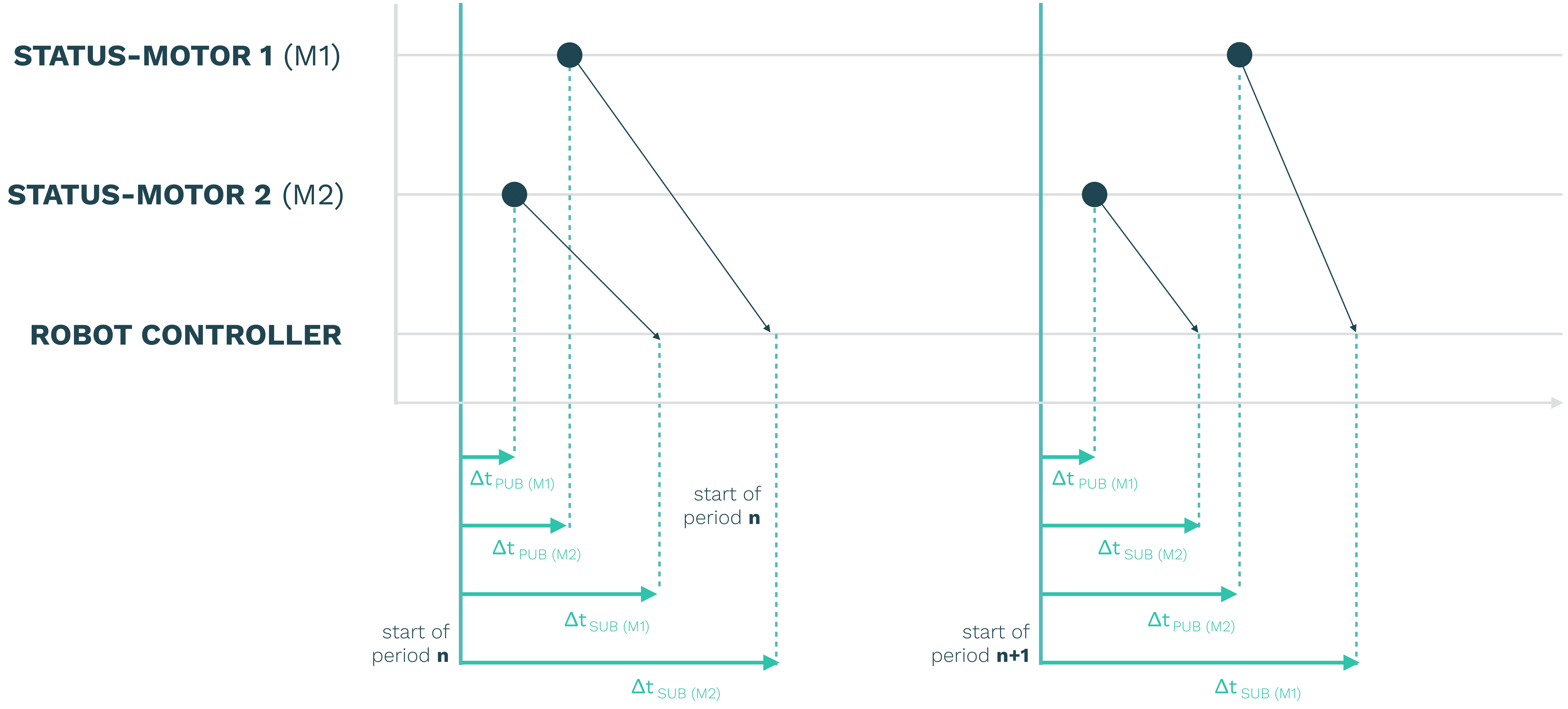
REAL-TIME **PENDULUM**

6. TIME SYNCHRONIZATION
IN ROBOT MODULES

REAL-TIME
ROBOT STACK



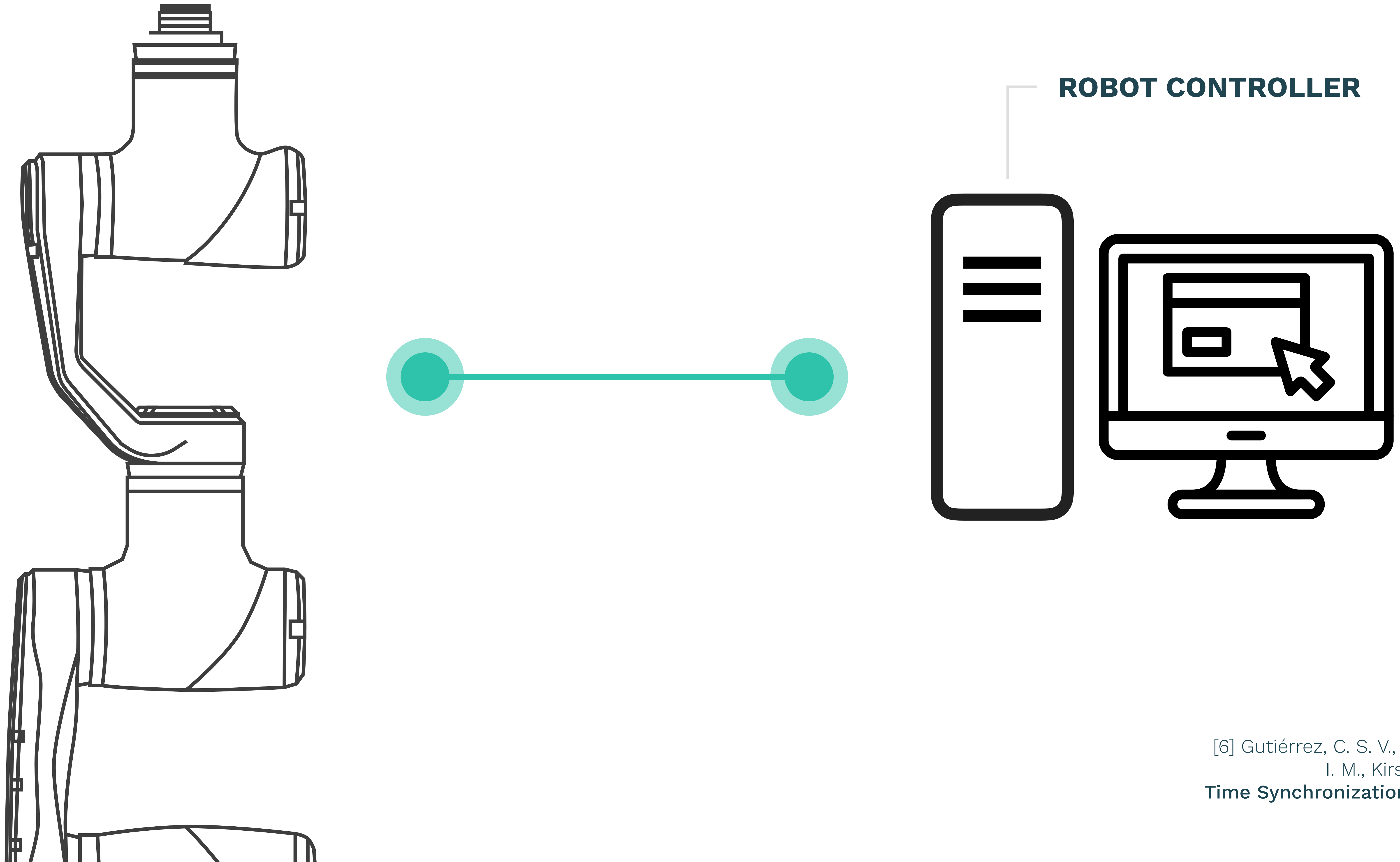
TIME SYNCHRONIZATION IN ROBOT MODULES



- $\Delta t_{PUB\ (M1)}$ → motor1 publishing time offset
- $\Delta t_{SUB\ (M1)}$ → Motor1 arrival time offset
- $\Delta t_{PUB\ (M2)}$ → Motor1 publishing time offset
- $\Delta t_{SUB\ (M2)}$ → Motor1 arrival time offset

[6] Gutiérrez, C. S. V., Juan, L. U. S., Ugarte, I. Z., Goenaga, I. M., Kirschgens, L. A., & Vilches, V. M. (2018). **Time Synchronization in modular collaborative robots.** arXiv preprint arXiv:1809.07295.

TIME SYNCHRONIZATION
IN ROBOT MODULES



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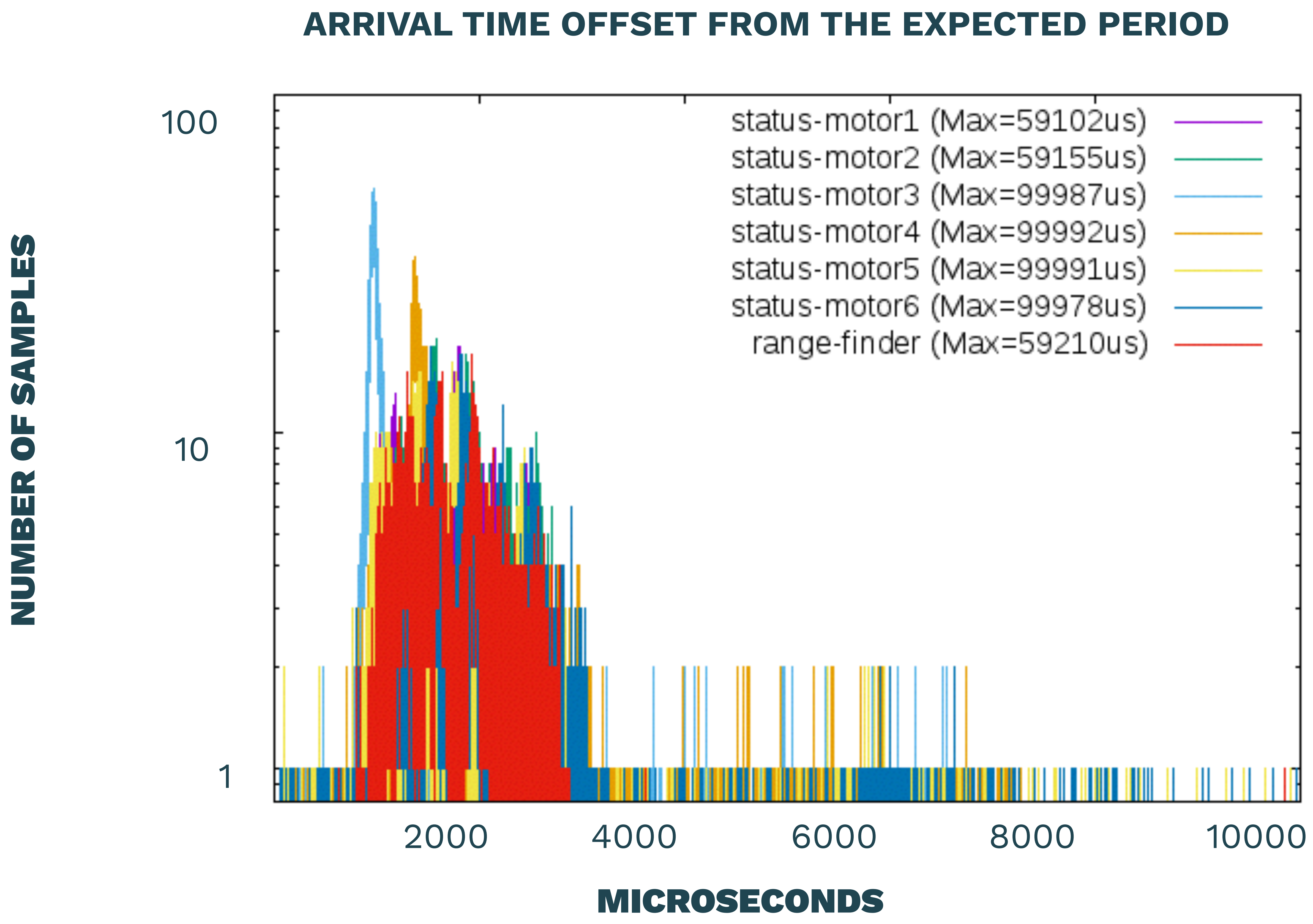

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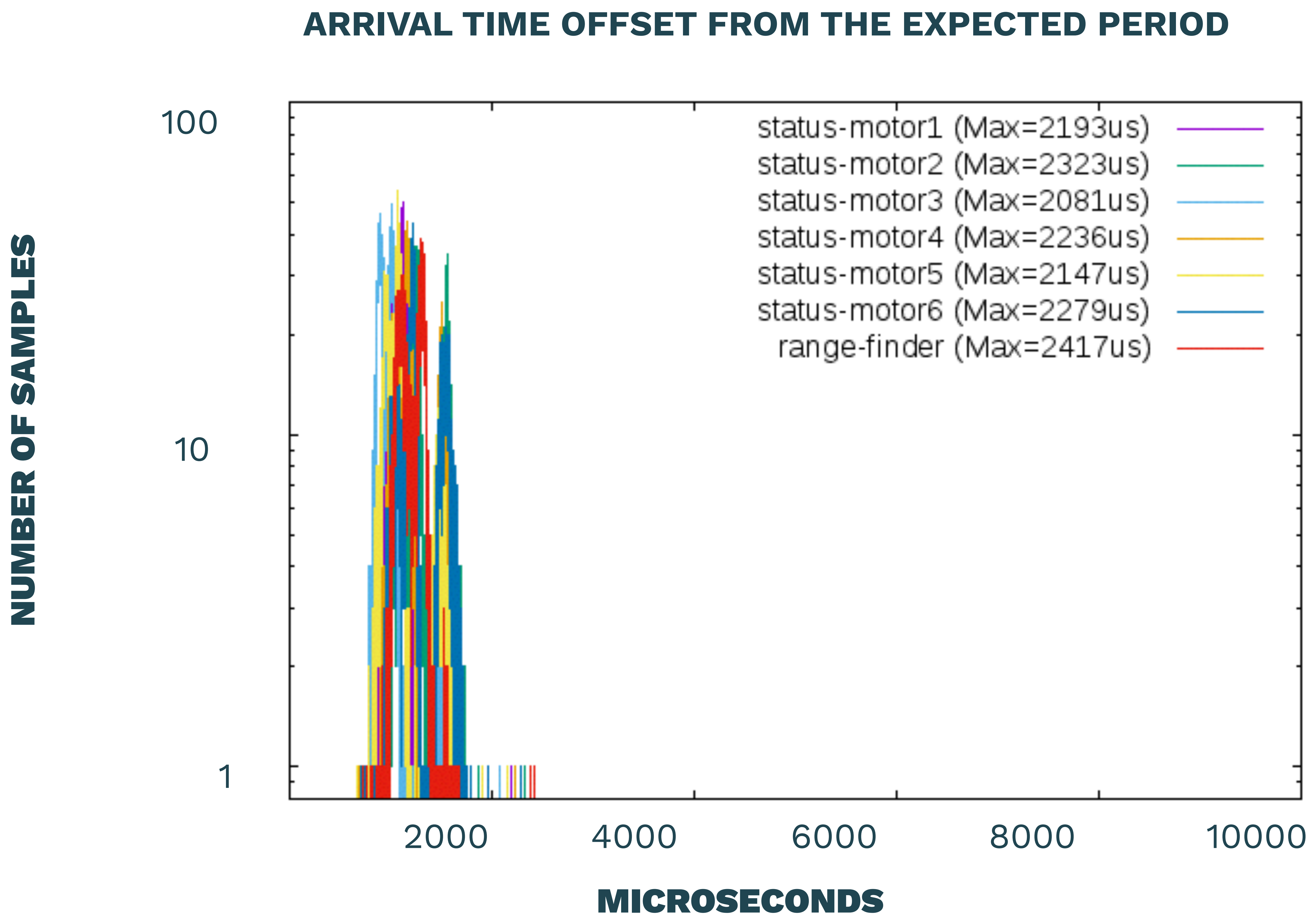

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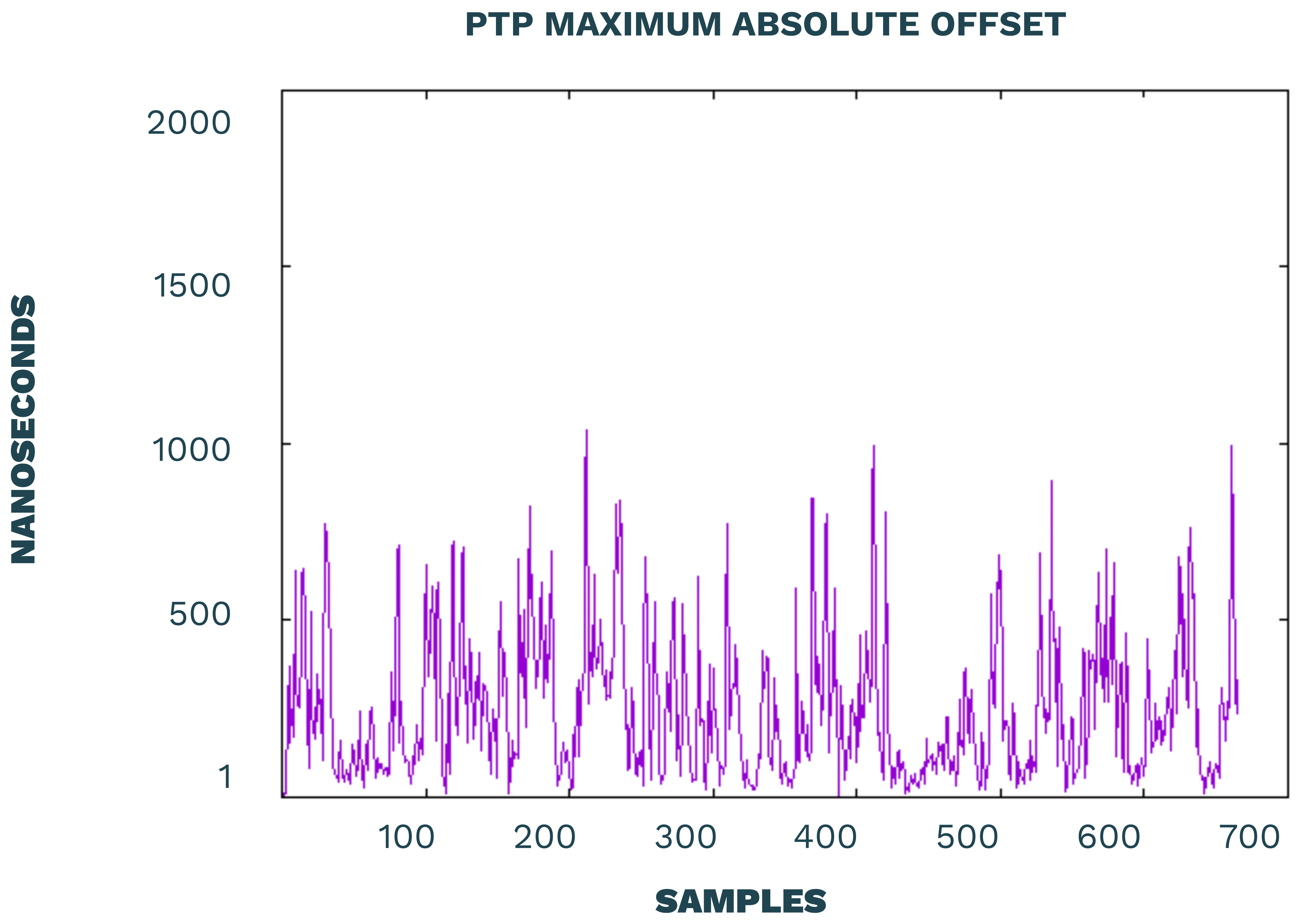
TIME SYNCHRONIZATION
IN ROBOT MODULES



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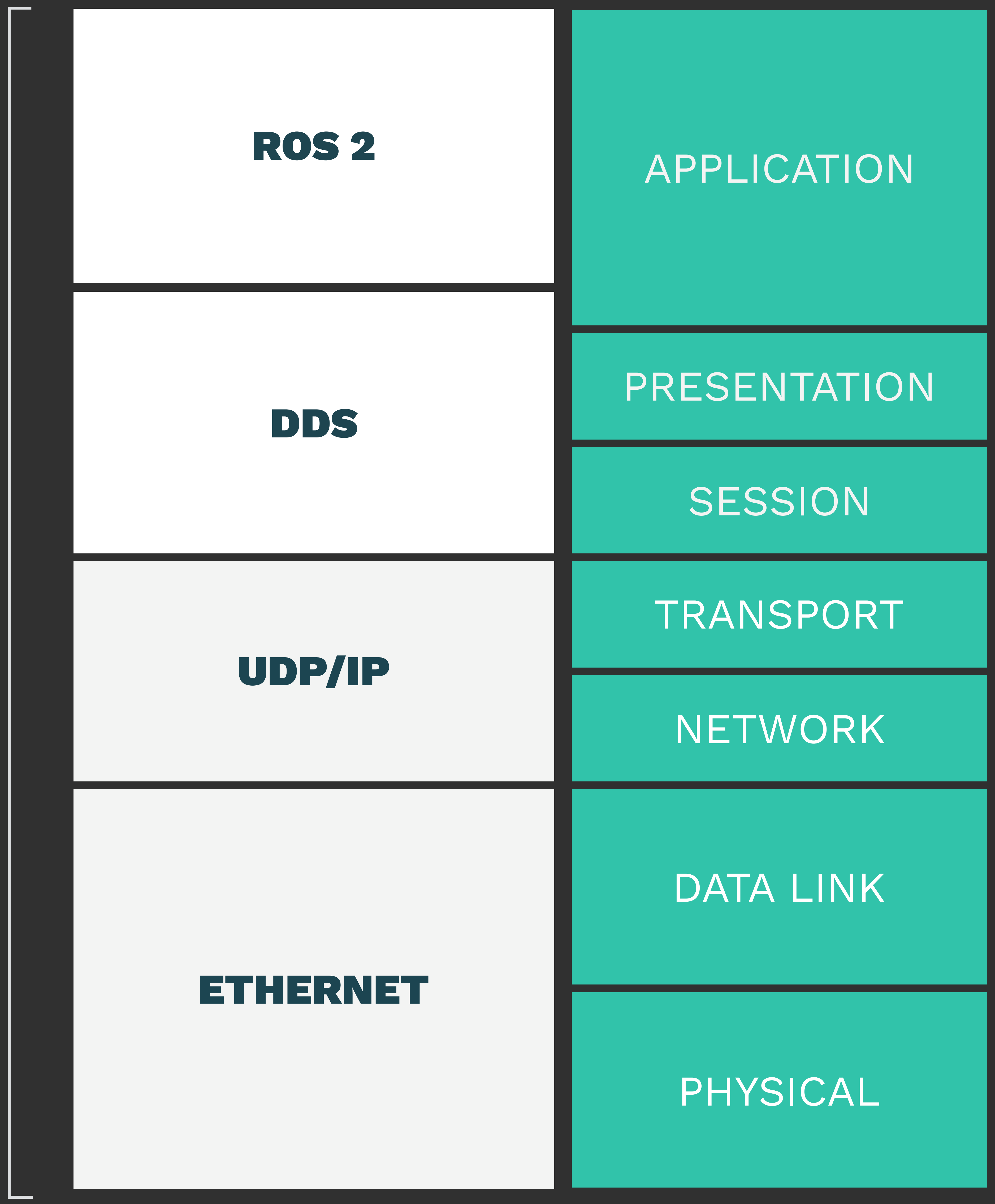
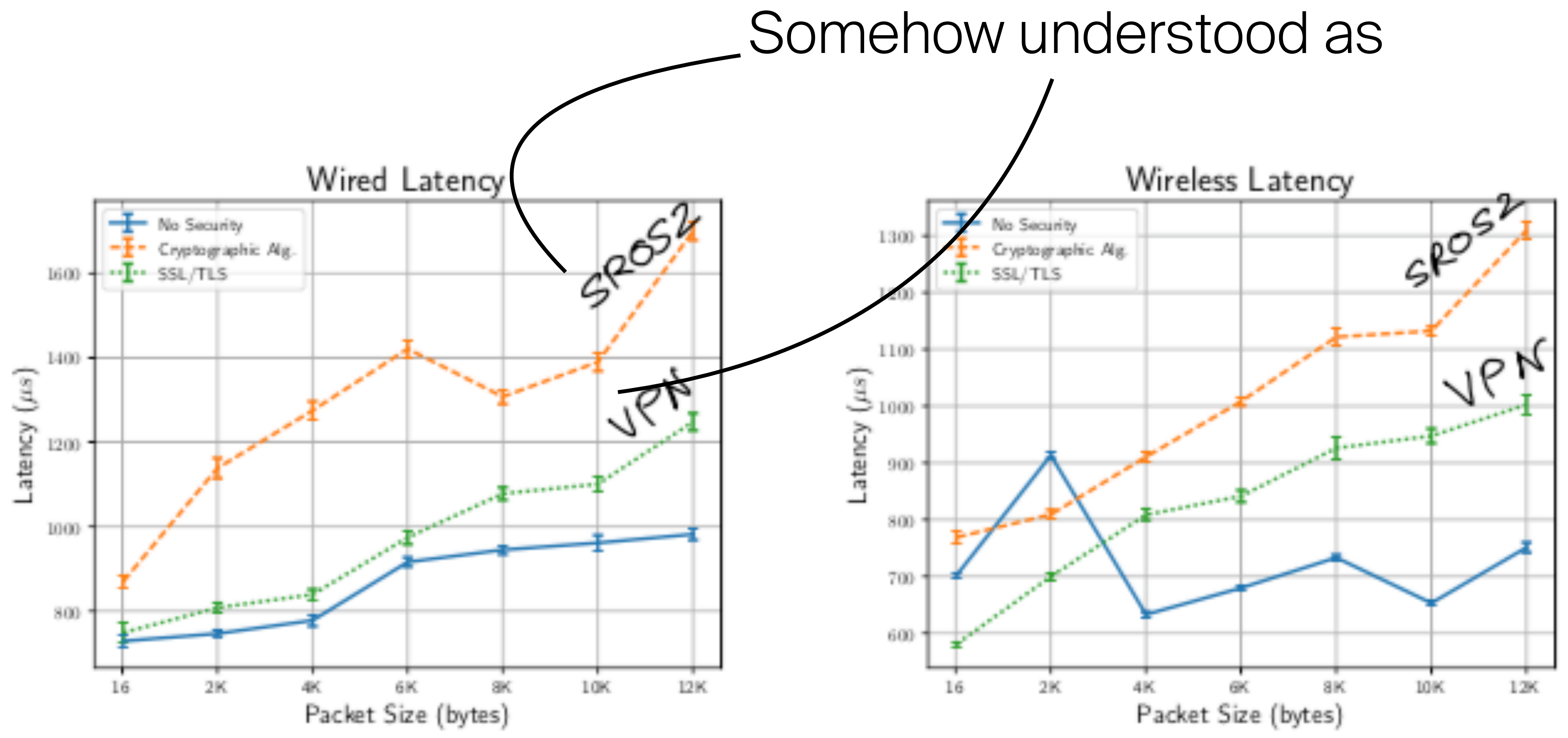
7. REAL-TIME SECURITY

REAL-TIME
ROBOT STACK

REAL-TIME RESILIENCE TO SECURITY BUGS?



REAL-TIME SECURITY



(a) Wired Network (b) Wireless Network

Fig. 1: Latency per packet size in wired and wireless networks.

Kim, J., Smereka, J. M., Cheung, C., Nepal, S., & Grobler, M. (2018).
Security and performance considerations in ros 2: A balancing act.
arXiv preprint arXiv:1809.09566.

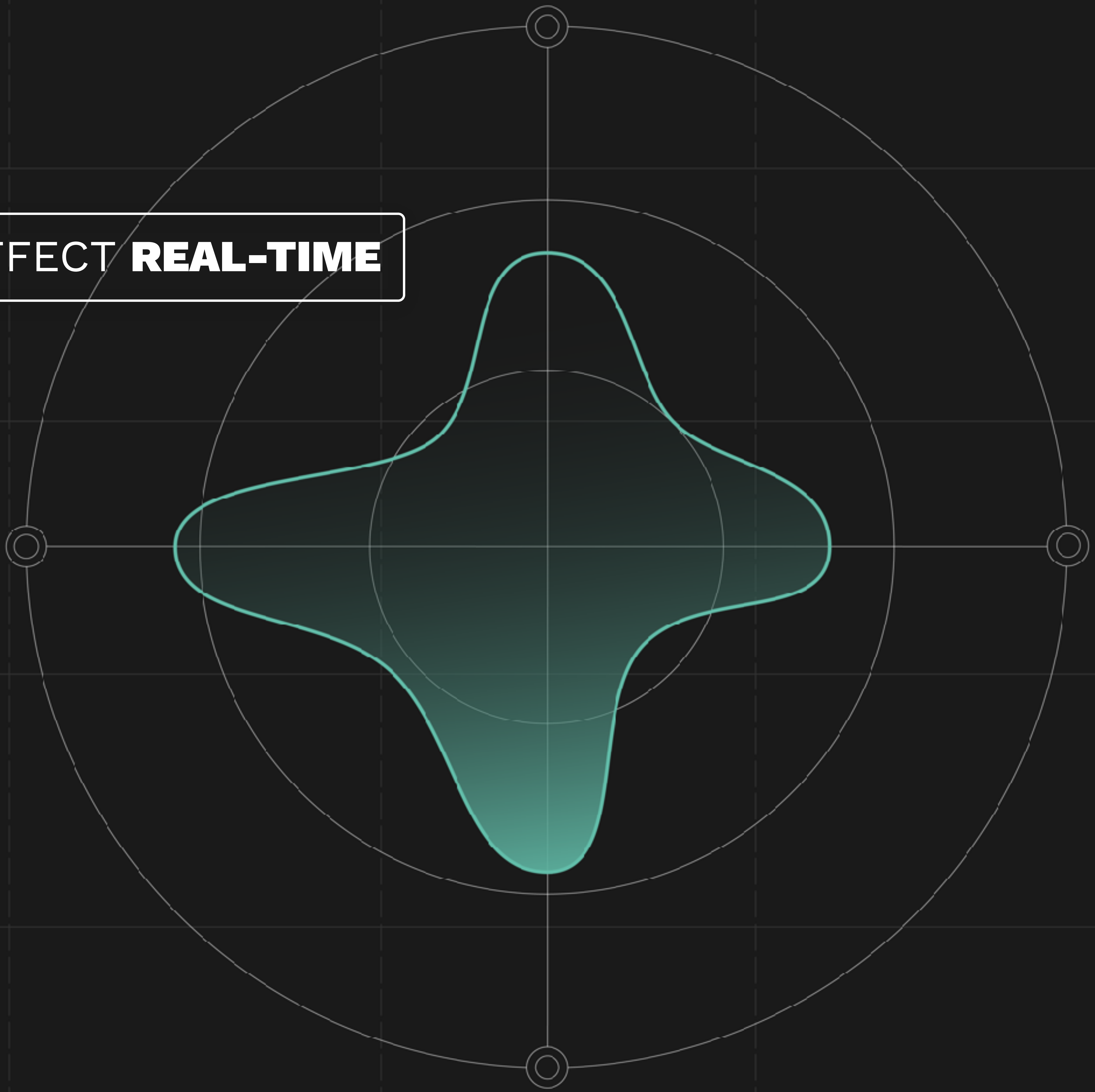
Table 4. Security measurement comparison.

Security enabled	Latency (average µs)	Throughput (average packets/s)	Speed (average Mbps)
Plain	260	70,772	35,669
Full	1363	14,382	72,485

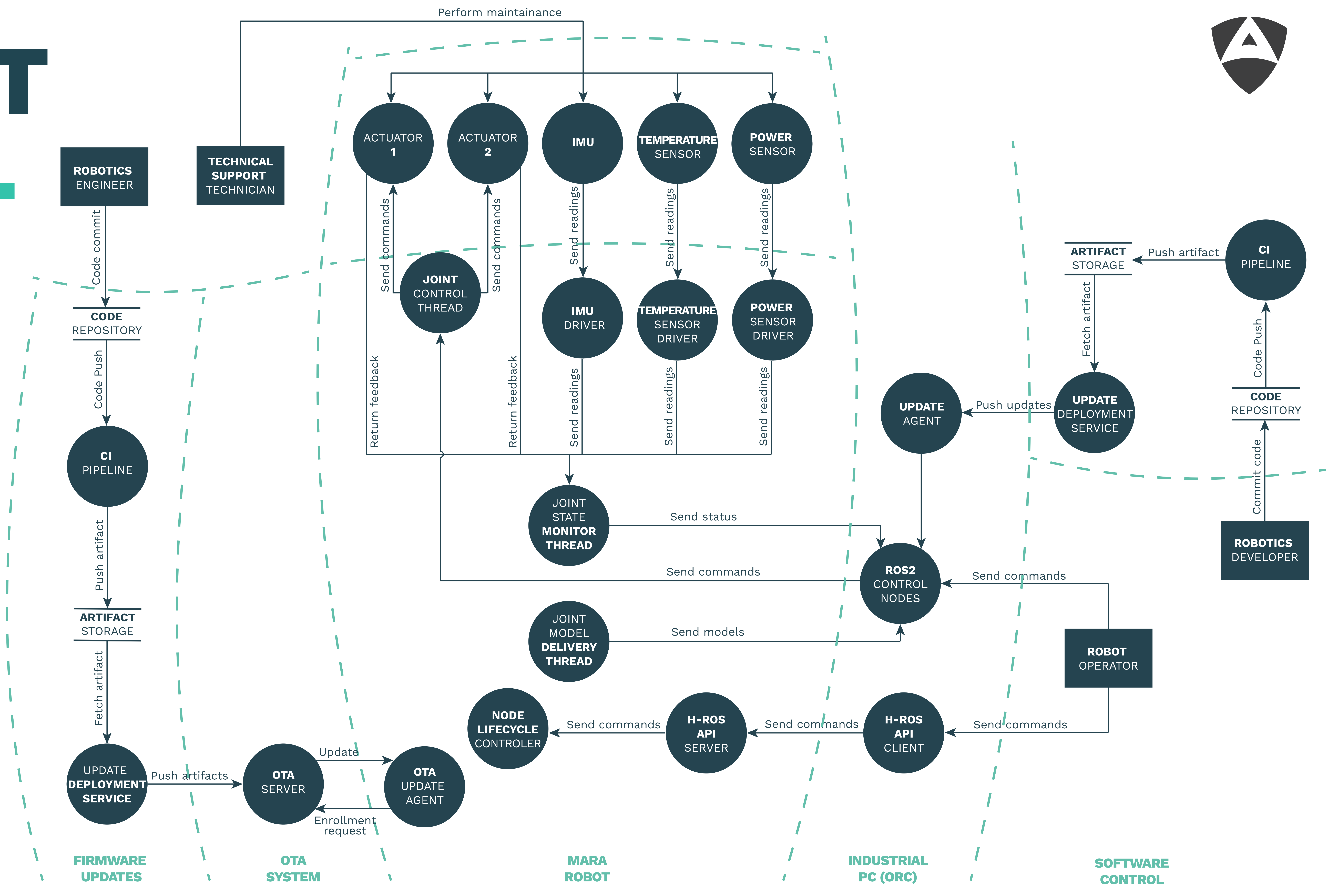
DiLuoffo, V., Michalson, W. R., & Sunar, B. (2018).
Robot Operating System 2: The need for a holistic security approach to robotic architectures.
International Journal of Advanced Robotic Systems, 15(3), 1729881418770011.

UNDERSTAND THE **ATTACK VECTORS** THAT AFFECT **REAL-TIME**

THREAT
MODEL



THREAT MODEL



SECURITY SOLUTIONS
ALIAS ROBOTICS

SERVICES —— PRODUCTS

Robot security
ASSESSMENTS

PHYSICAL ROBOT HACKING

VIRTUAL ROBOT HACKING

CODE TESTING

FORENSICS ROBOT SECURITY

Security
CONSULTING

THREAT MODEL ANALYSIS

SECURITY STANDARDS COMPLIANCE

ROBOTIC SOFTWARE DEVELOPMENT LIFECYCLE

BLACK BOX™

MONITORS

- Records all robot data
- Enables forensic investigation

RIS™

ROBOT IMMUNE SYSTEM

- Detects threats by **learning** usual comms
- Non-intrusive. Real-time. No latencies
- Hardware agnostic. Plug & Play

REMOVING 0-DAYS

FROM ROBOTICS

ALIAS ROBOTICS
Robot Cybersecurity

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