LESSONS LEARNED ON
REAL-TIME AND SECURITY

ALIAS ROBOTICS
Robot Cybersecurity

VÍCTOR MAYORAL VILCHES

Robotics engineer

victor@aliasrobotics.com

https://bit.ly/2pLNI4l

LINK TO SLIDES

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.

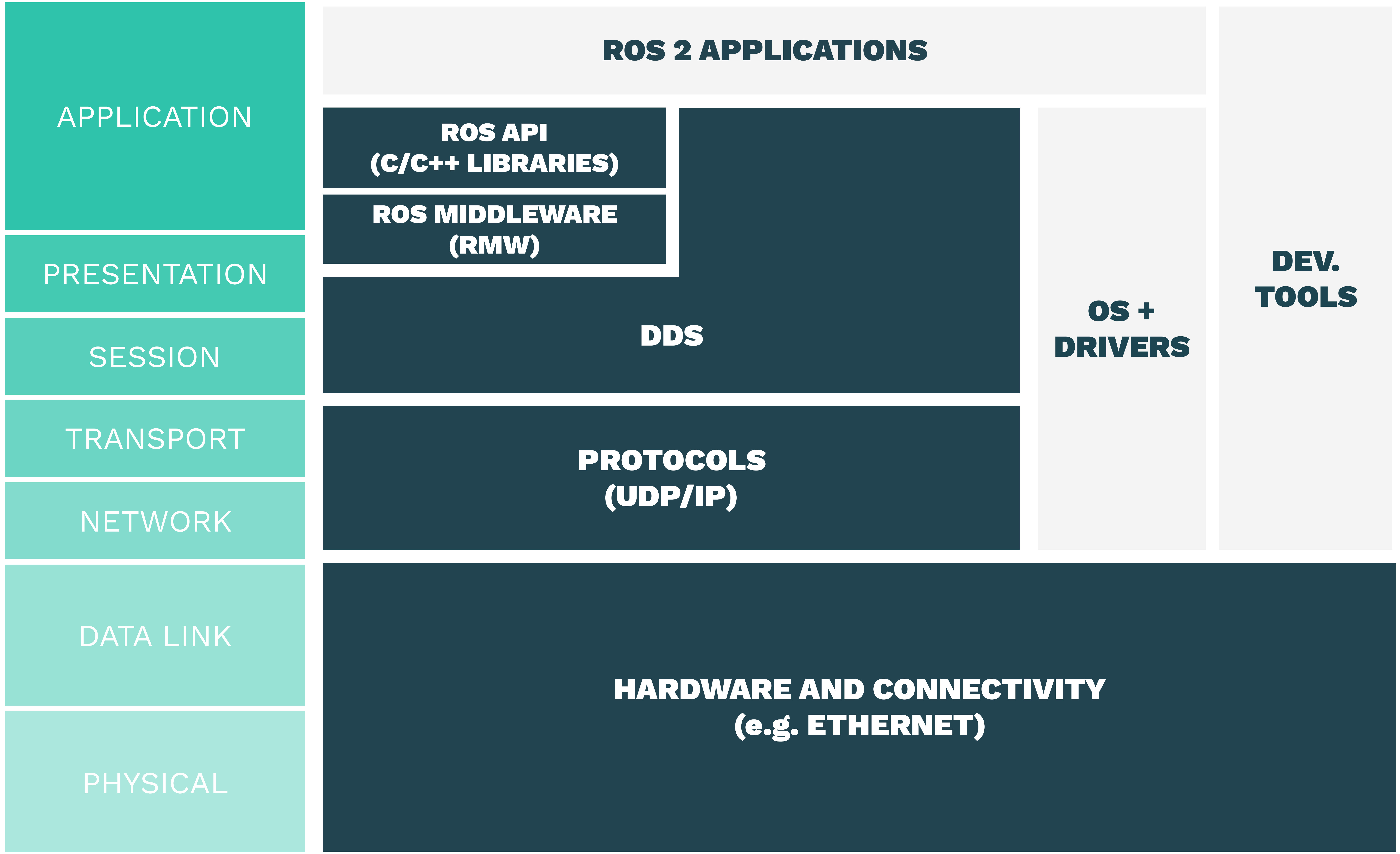
Zhang, P. (2008). Industrial control technology: a handbook for engineers and researchers. William Andrew.

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.

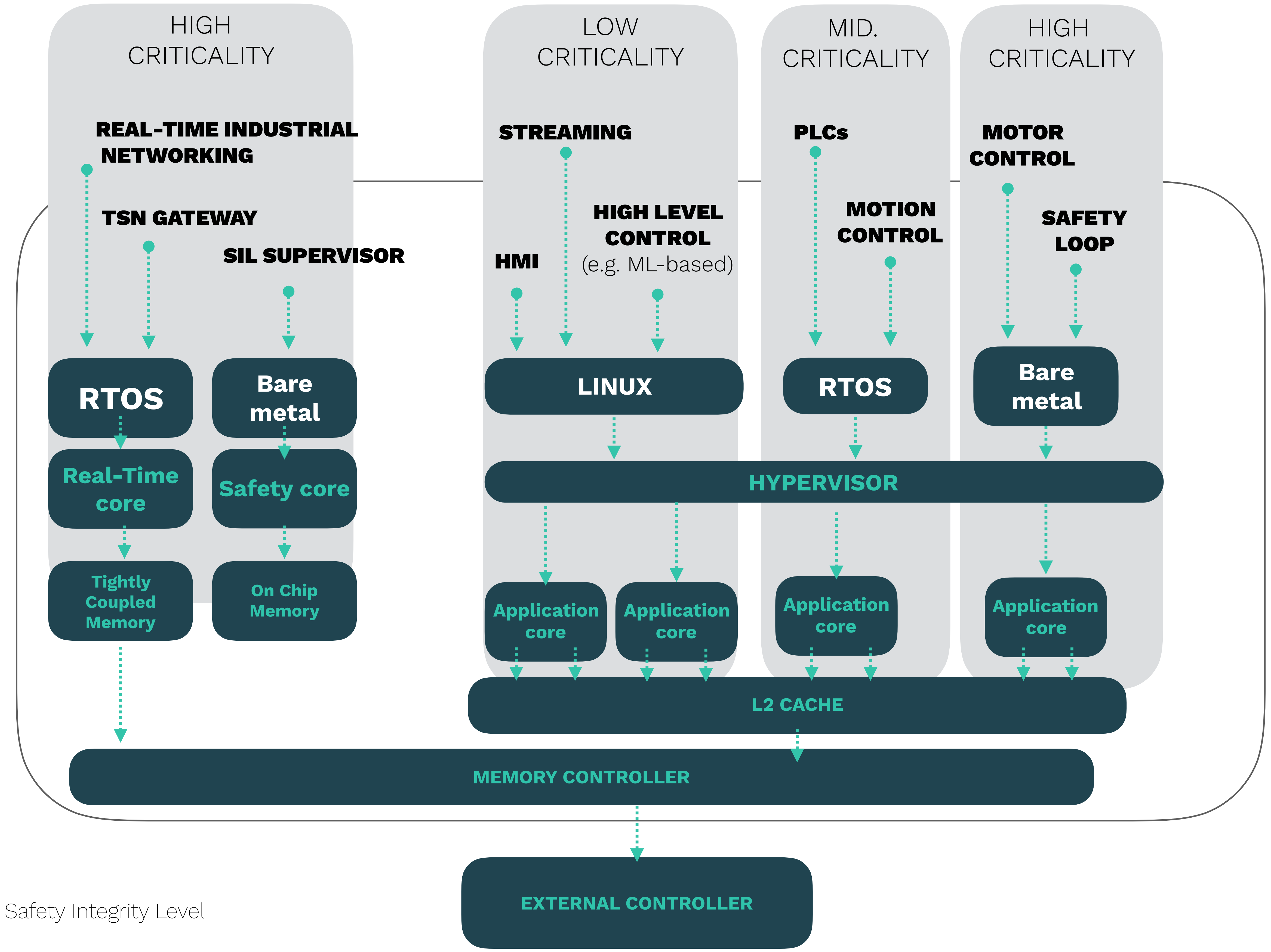
REAL-TIME ROBOT STACK



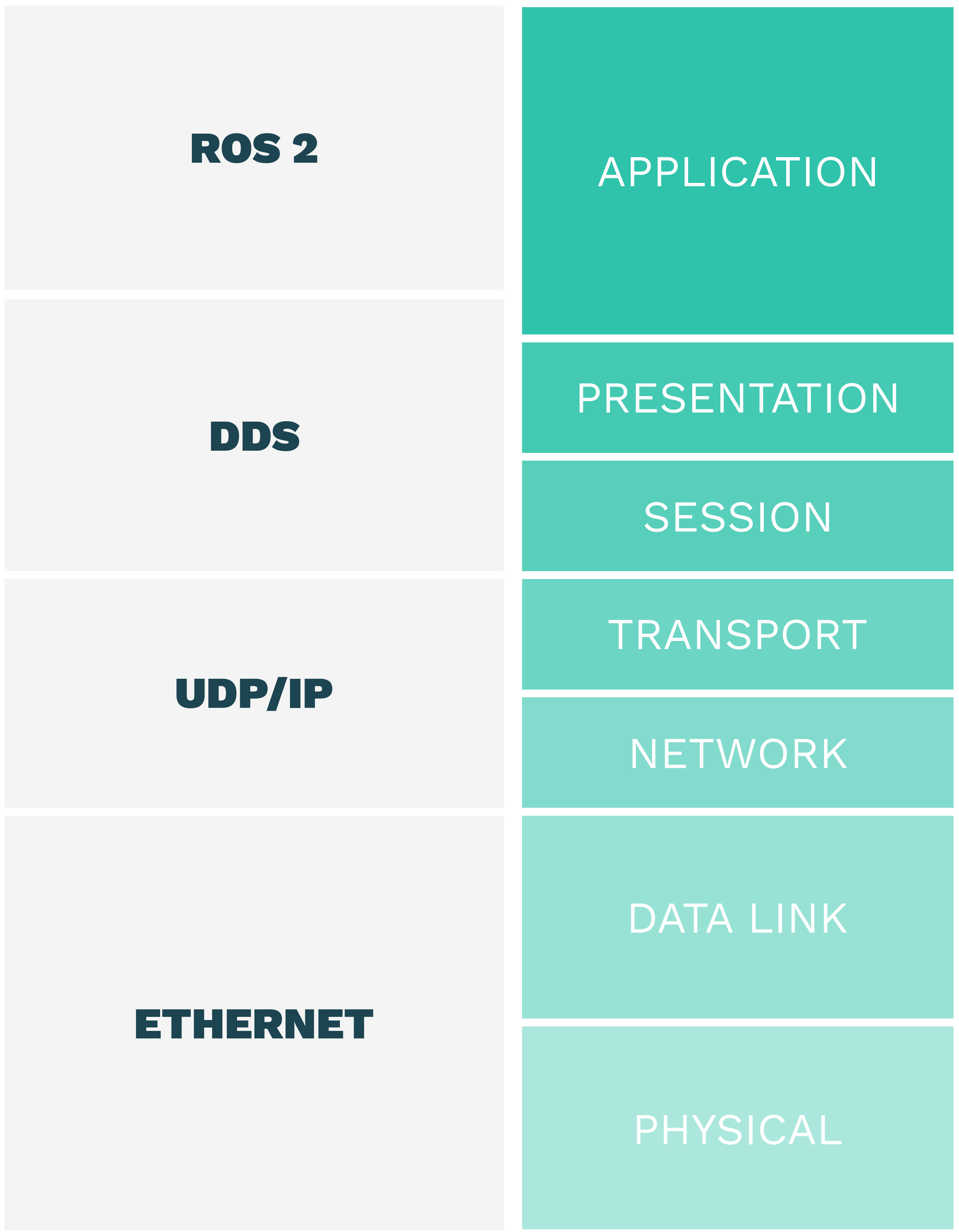
2. HARDWARE RELEVANCE

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

COMPLIANCE WITH DEADLINES



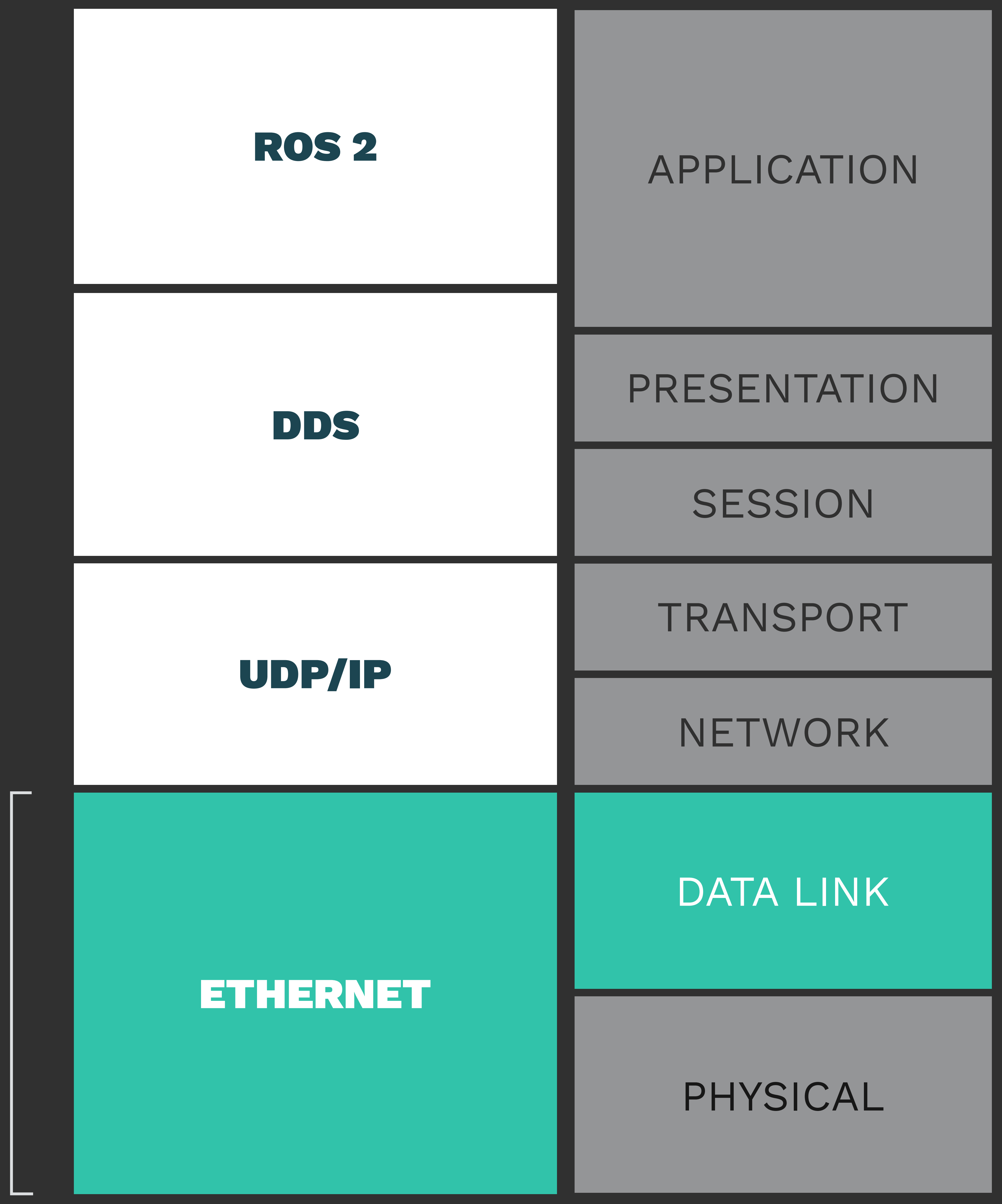
SIL: Safety Integrity Level



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**

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**

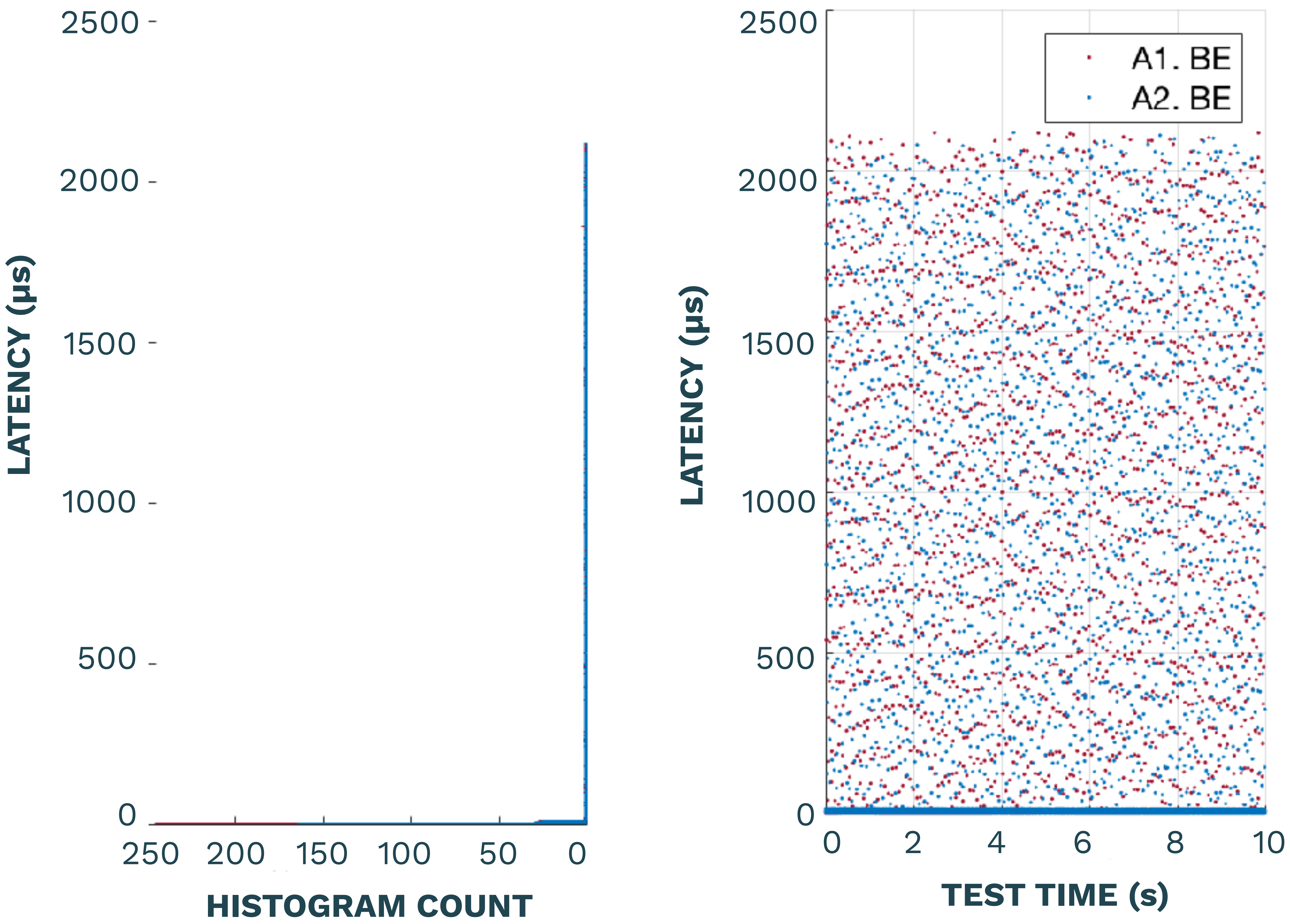
	REAL-TIME ETHERNET SOLUTIONS		
BASED ON TCP/IP NON REAL-TIME PROTOCOLS	**BASED ON TCP/IP** REAL-TIME	**STANDARD ETHERNET** IEEE 802.3	**MODIFIED ETHERNET** MEDIA ACCESS
PROFINET ETHERNET/IP DDS NON REAL-TIME PROTOCOLS	PROFINET ETHERNET/IP DDS REAL-TIME PROTOCOLS	POWER LINK PROFINET RT	ETHERCAT SERCOS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

NO REAL TIME **CAPABLE LINK**

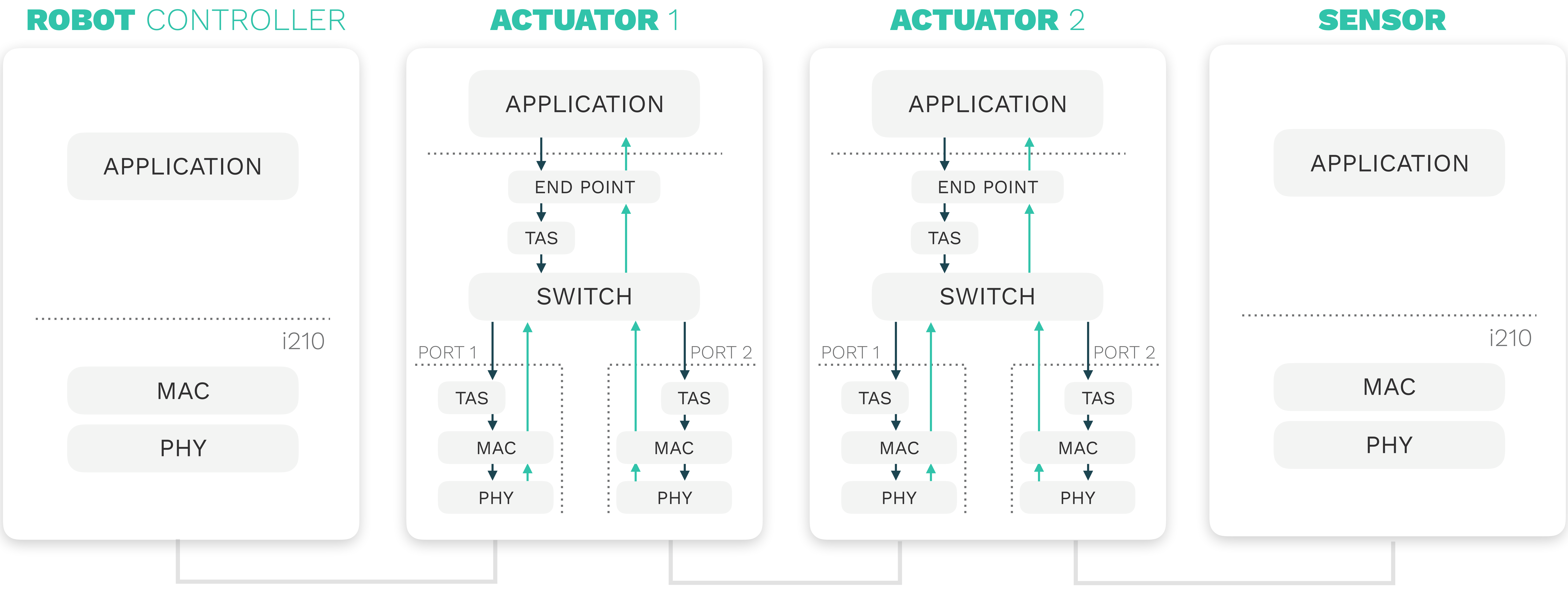
LINK CAPACITY 1Gbps. NETWORK LOAD = 900Mbps



[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

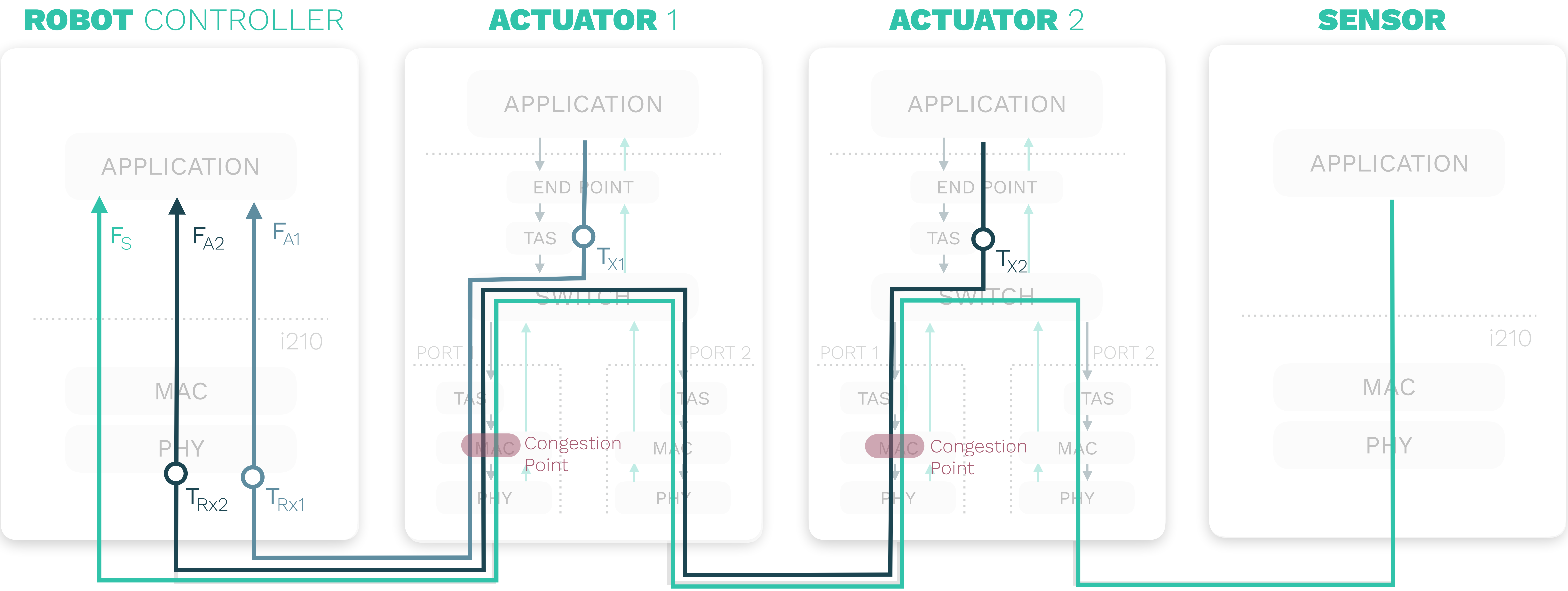
IEEE 802.1QBV TIME-**AWARE SCHEDULER**



[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

REAL TIME **CAPABLE LINK LAYER**

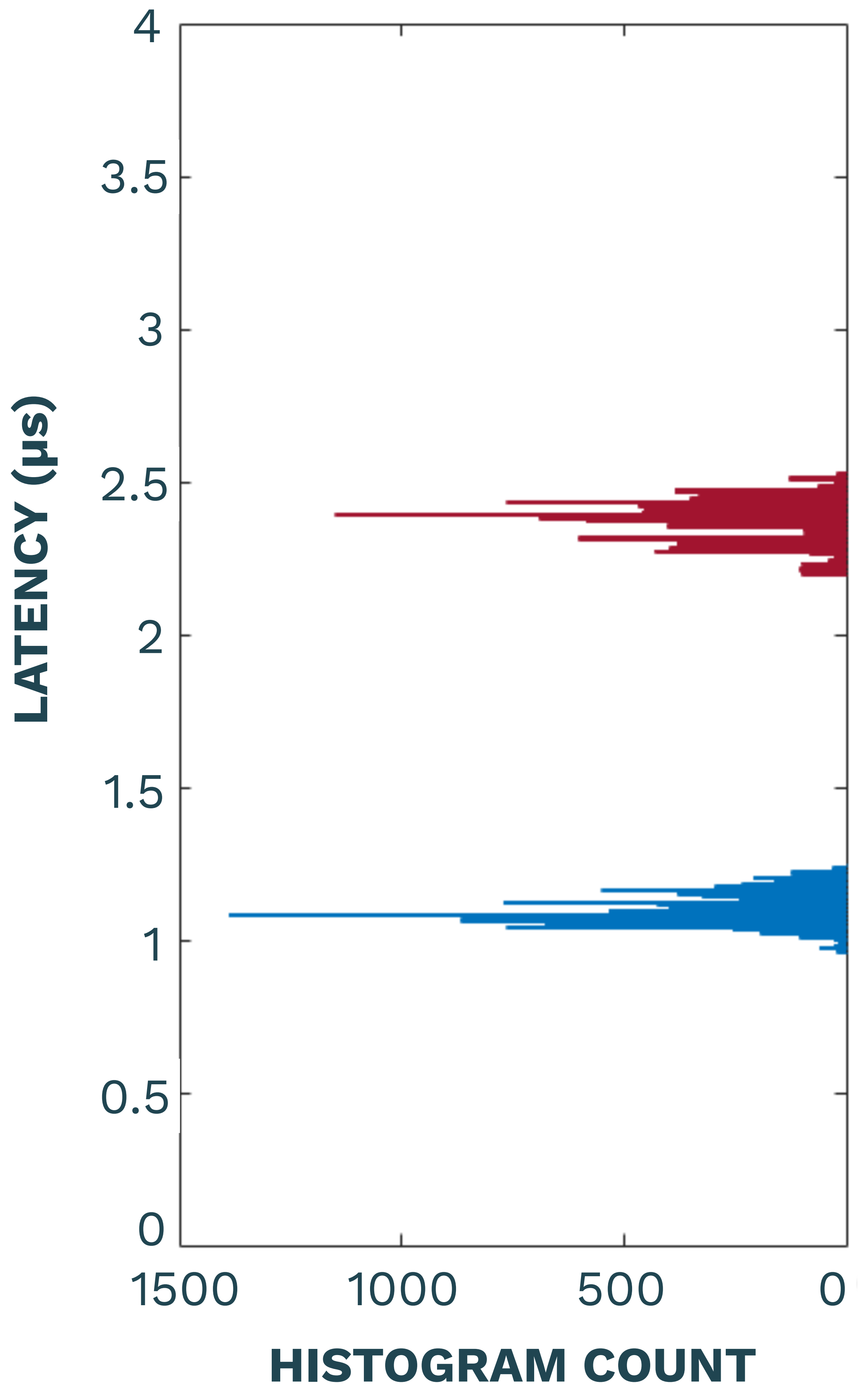


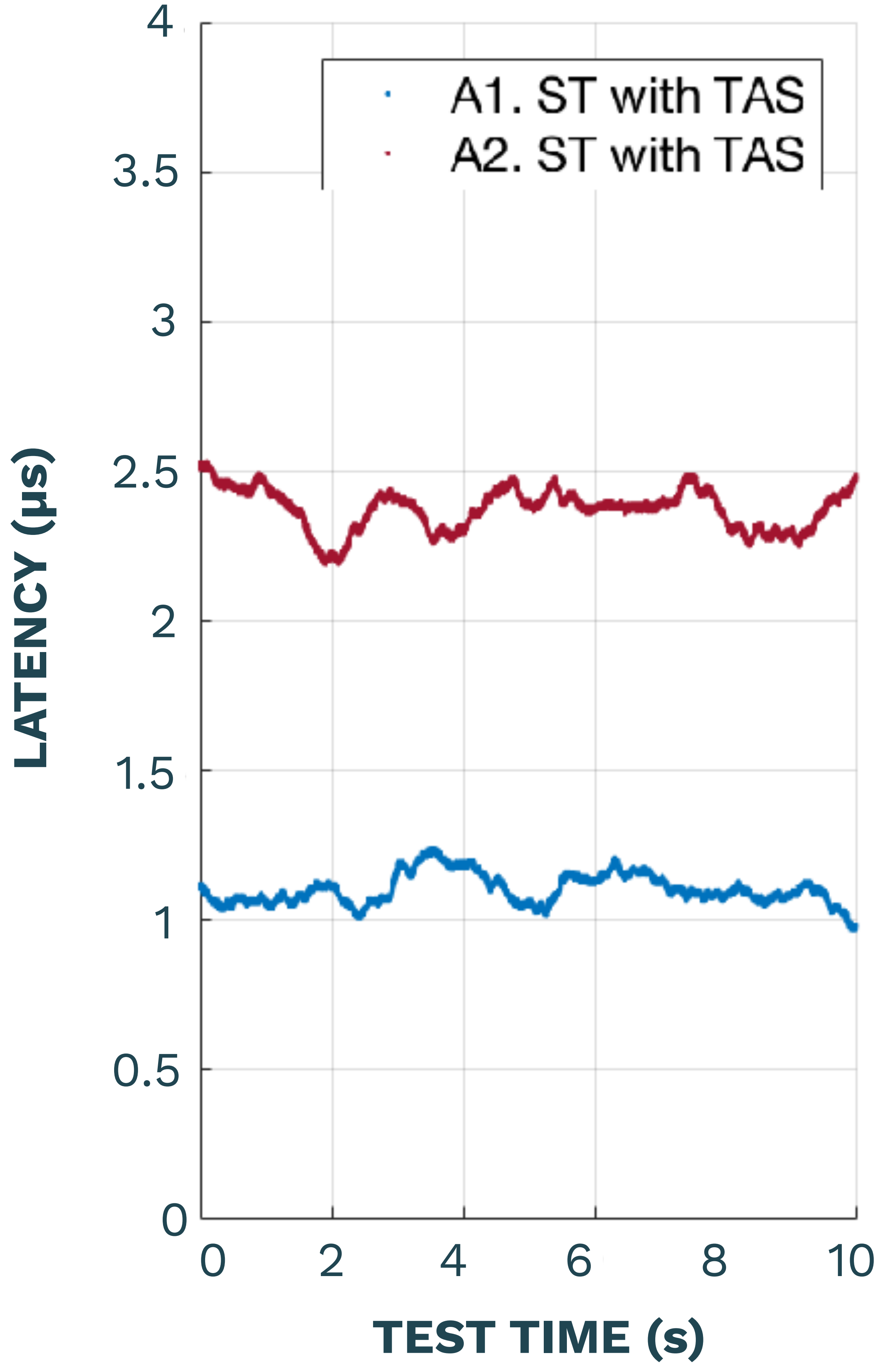
[3] Gutiérrez, C.S.V., Juan, L.U.S., Ugarte, I.Z., & Vilches, V.M. (2018).
Time-Sensitive Networking for robotics.
arXiv preprint arXiv:1804.07643.

HARDWARE
COMM. LEVEL

REAL TIME **CAPABLE LINK**

LINK CAPACITY 1Gbps. NETWORK LOAD = 900Mbps

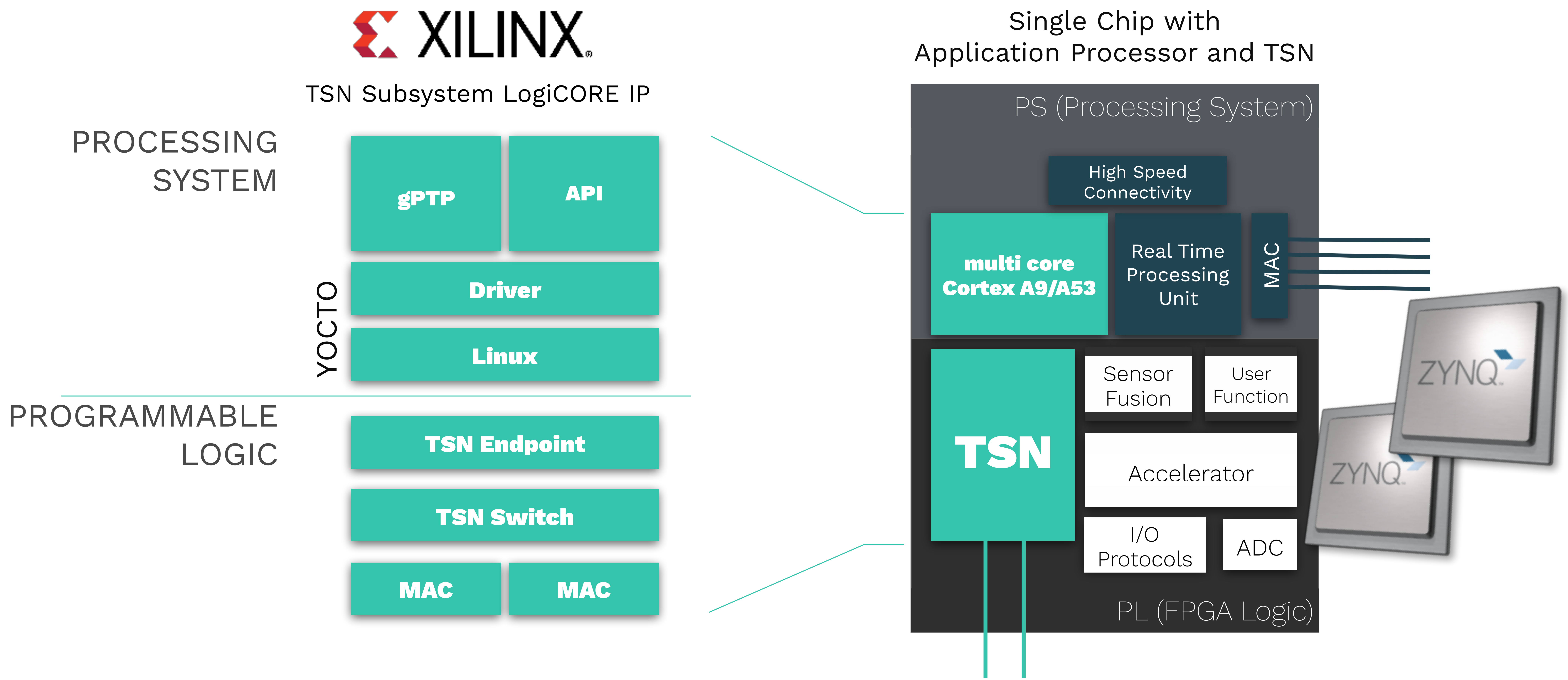




[3] Gutiérrez, C.S.V., Juan, L.U.S., Ugarte, I.Z., & Vilches, V.M. (2018).
Time-Sensitive Networking for robotics.
arXiv preprint arXiv:1804.07643.

HARDWARE ARCHITECTURE

XILINX PROVIDE **MIXED CRITICALITY SOLUTIONS** THAT CONNECT TO **TSN**

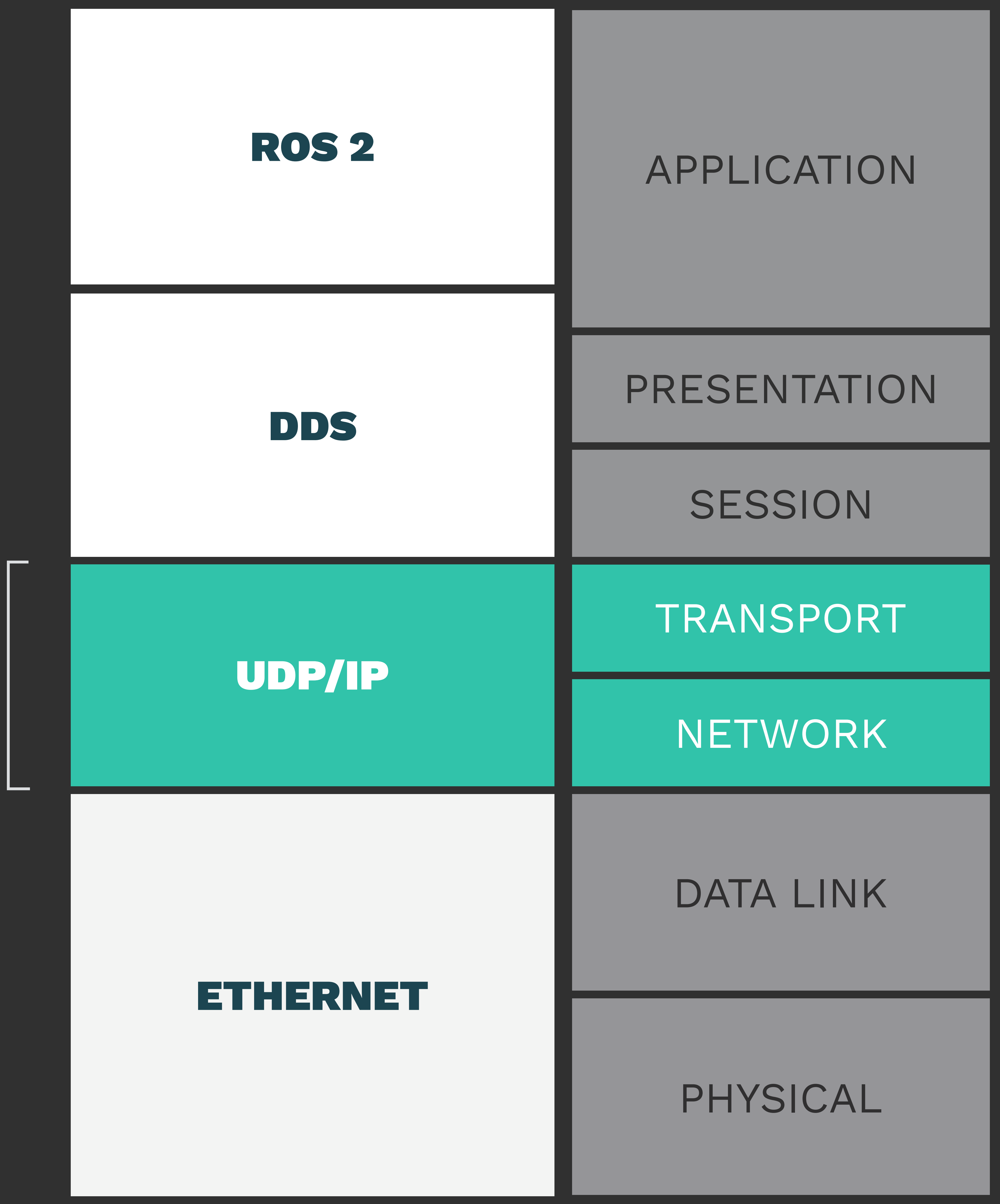


4. RTOS AND NETWORKING STACK

OPTIMIZED LINUX NETWORKING STACK

REAL-TIME
ROBOT STACK

OPTIMIZED LINUX **NETWORKING 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.

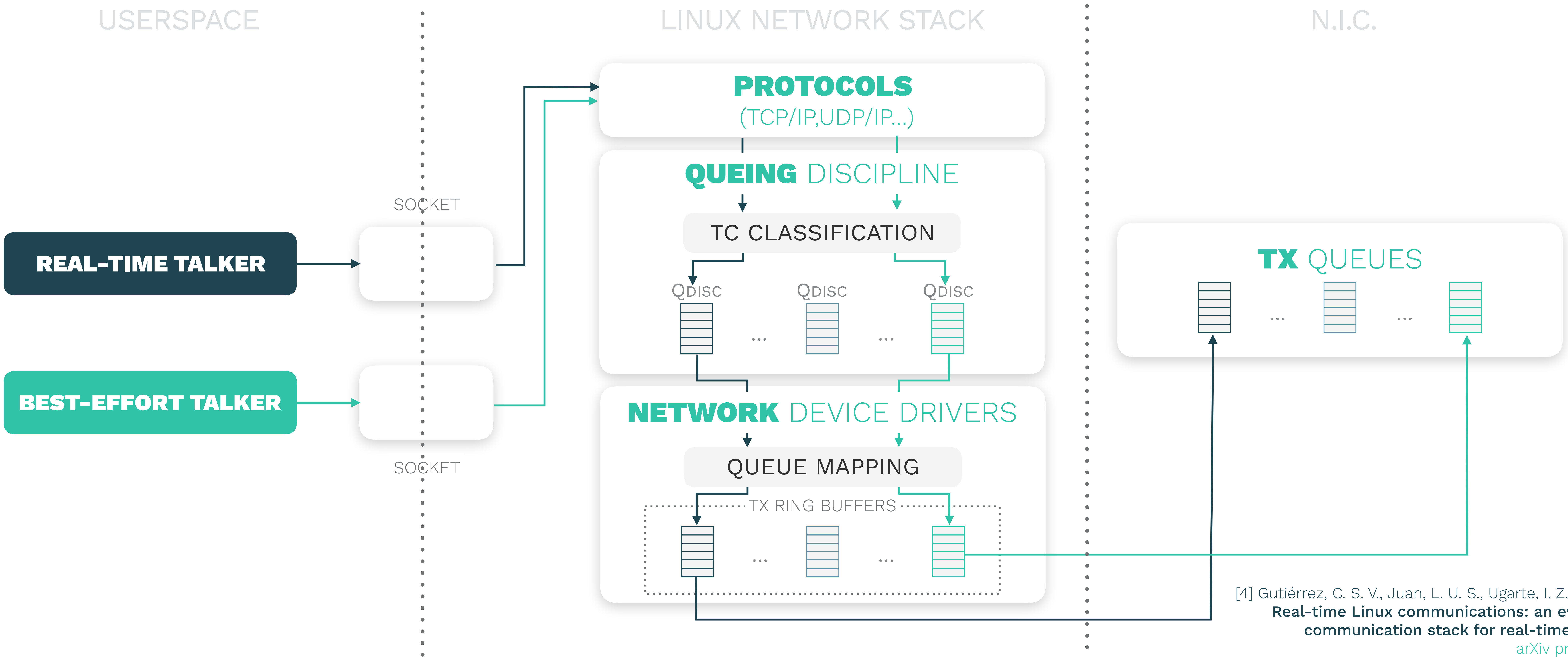
rt-affinities
we bind the IRQ thread of the priority queue and the client and server programs to CPU 1 of each device.

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

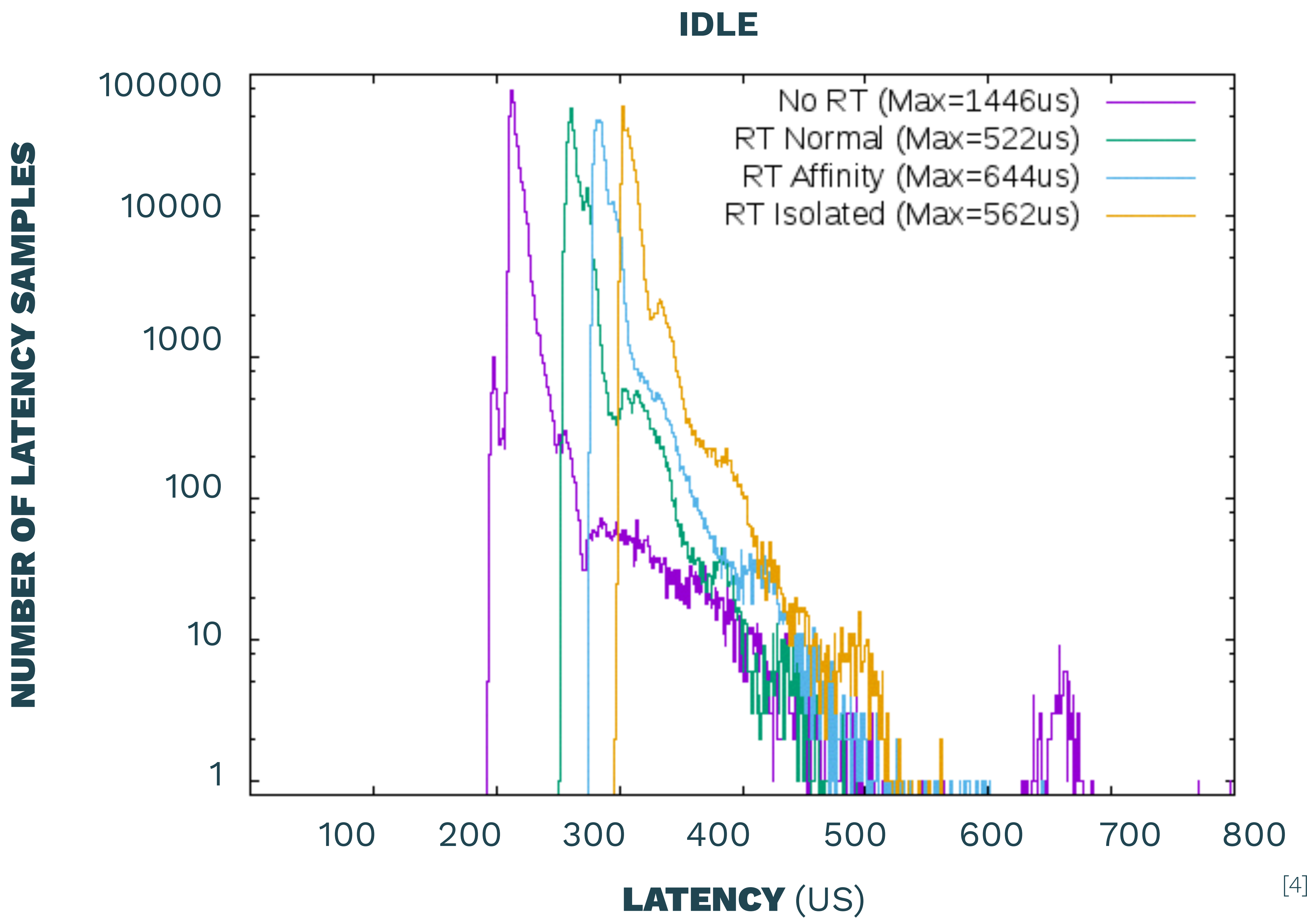
OPTIMIZED LINUX **NETWORKING STACK**



[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

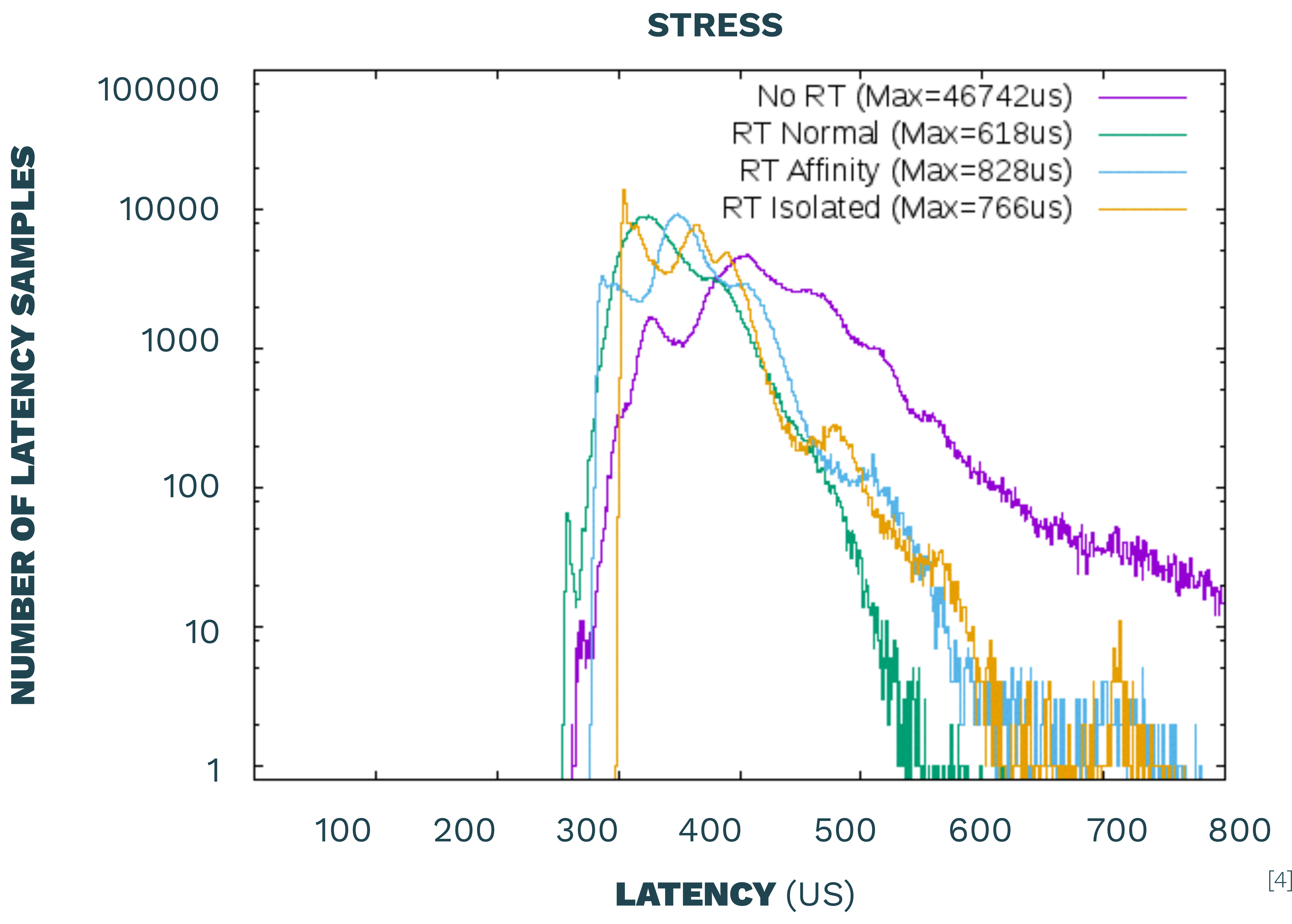
OPTIMIZED **LINUX** NETWORKING STACK



[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

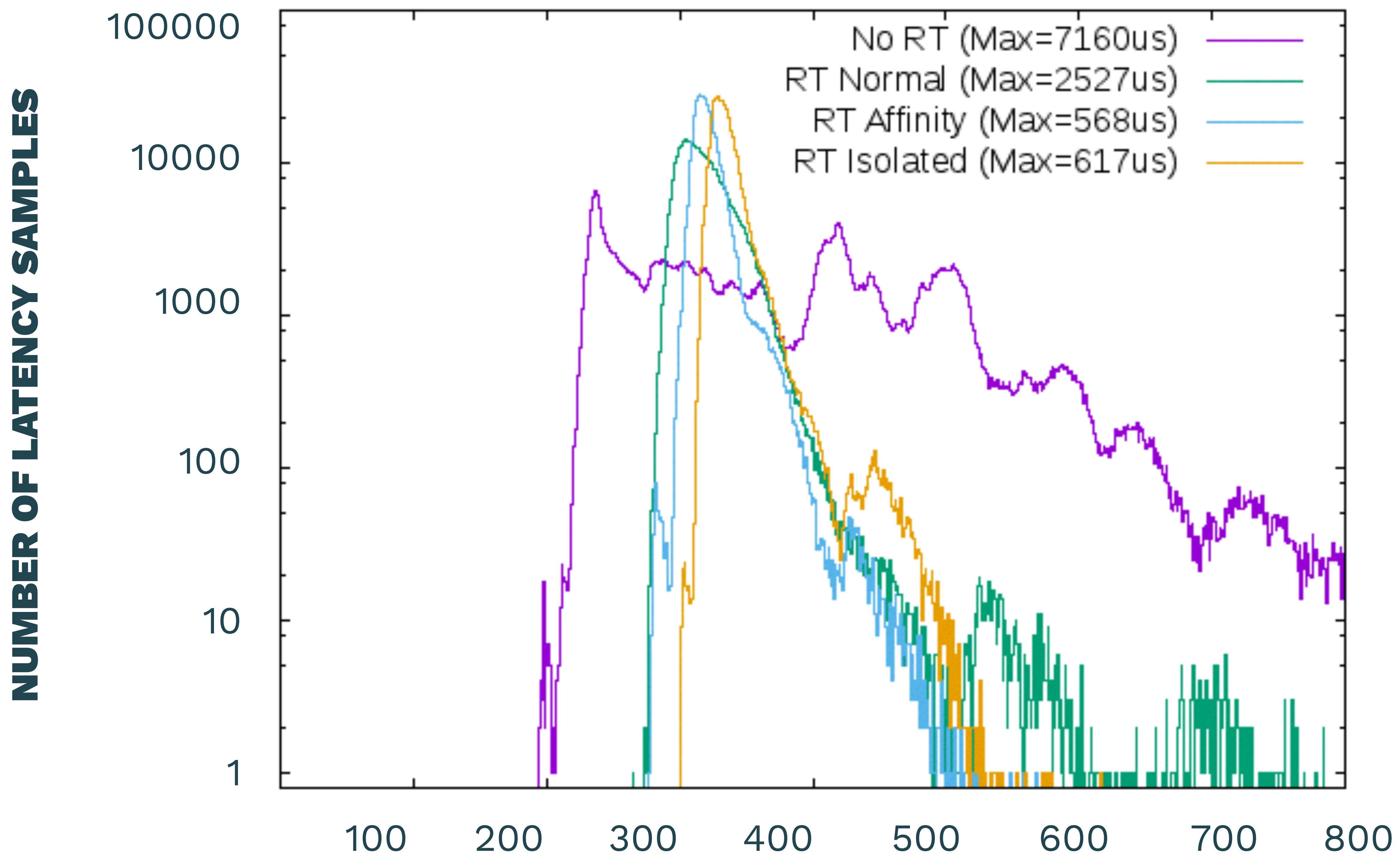


[4] Gutiérrez, C. S. V., Juan, L. U. S., Ugarte, I. Z., & Vilches, V. M. (2018). **Real-time Linux communications: an evaluation of the Linux communication stack for real-time robotic applications.** arXiv preprint arXiv:1808.10821.

RTOS AND NETWORKING STACK

OPTIMIZED **LINUX** NETWORKING STACK

TX TRAFFIC 100MBPS



LATENCY (US)

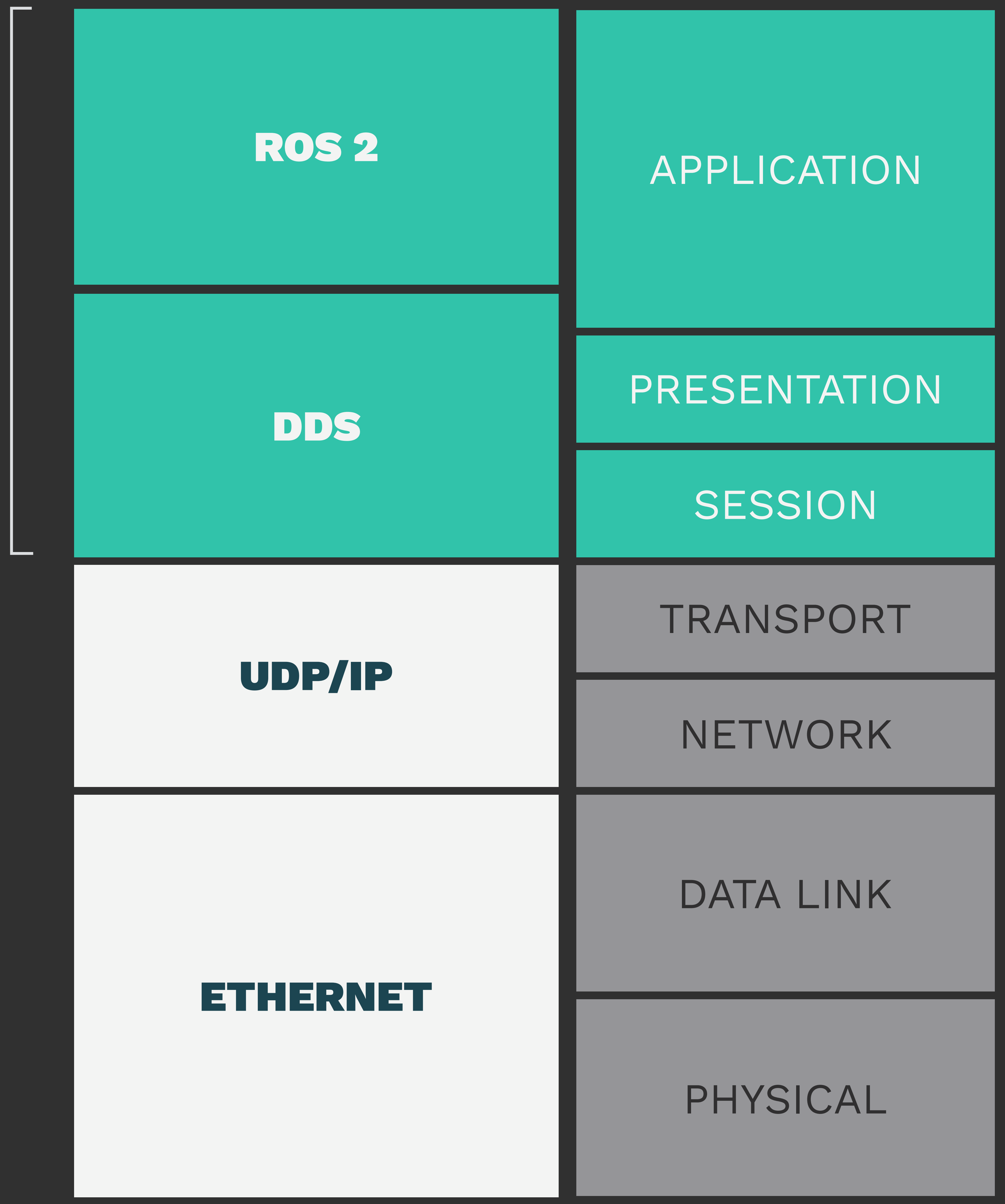
[4] Gutiérrez, C. S. V., Juan, L. U. S., Ugarte, I. Z., & Vilches, V. M. (2018). **Real-time Linux communications: an evaluation of the Linux communication stack for real-time robotic applications.** arXiv preprint arXiv:1808.10821.

5. ROBOTICS FRAMEWORK & COMMUNICATION MIDDLEWARE

ROS 2.0 FOR REAL-TIME

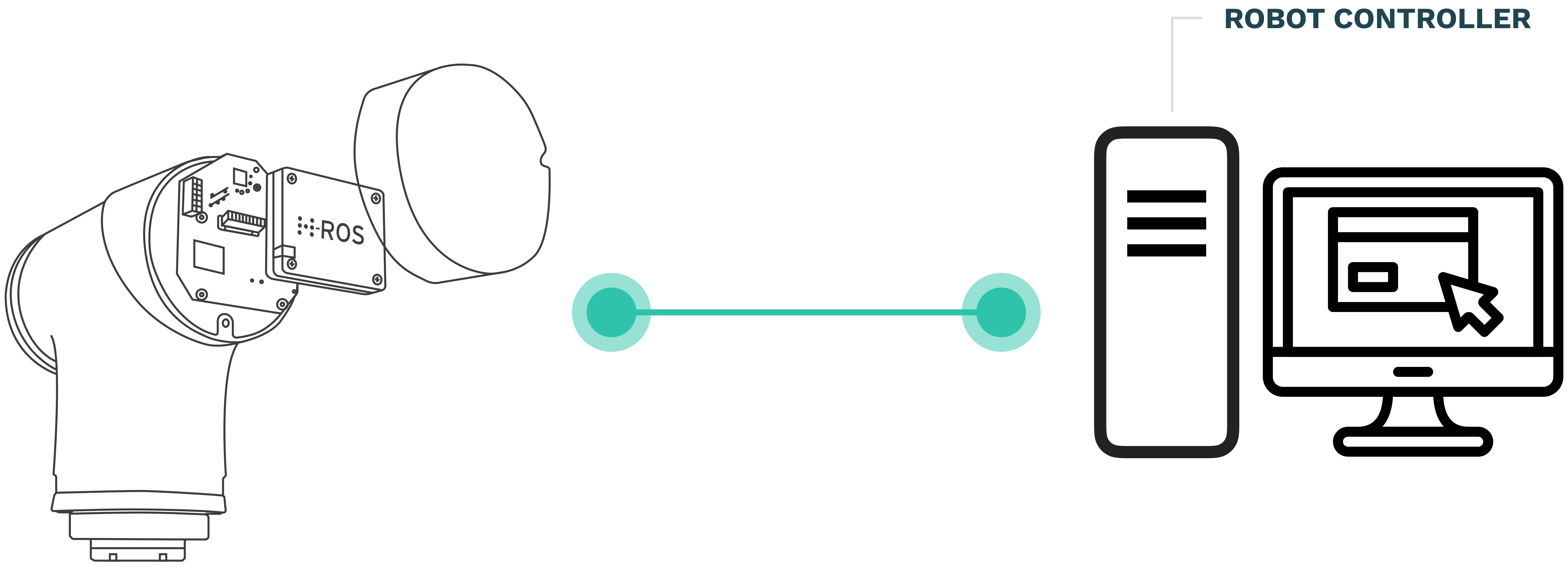
REAL-TIME
ROBOT STACK

ROS 2.0 **FOR REAL-TIME**



ROBOTICS FRAMEWORK & COMMUNICATION MIDDLEWARE

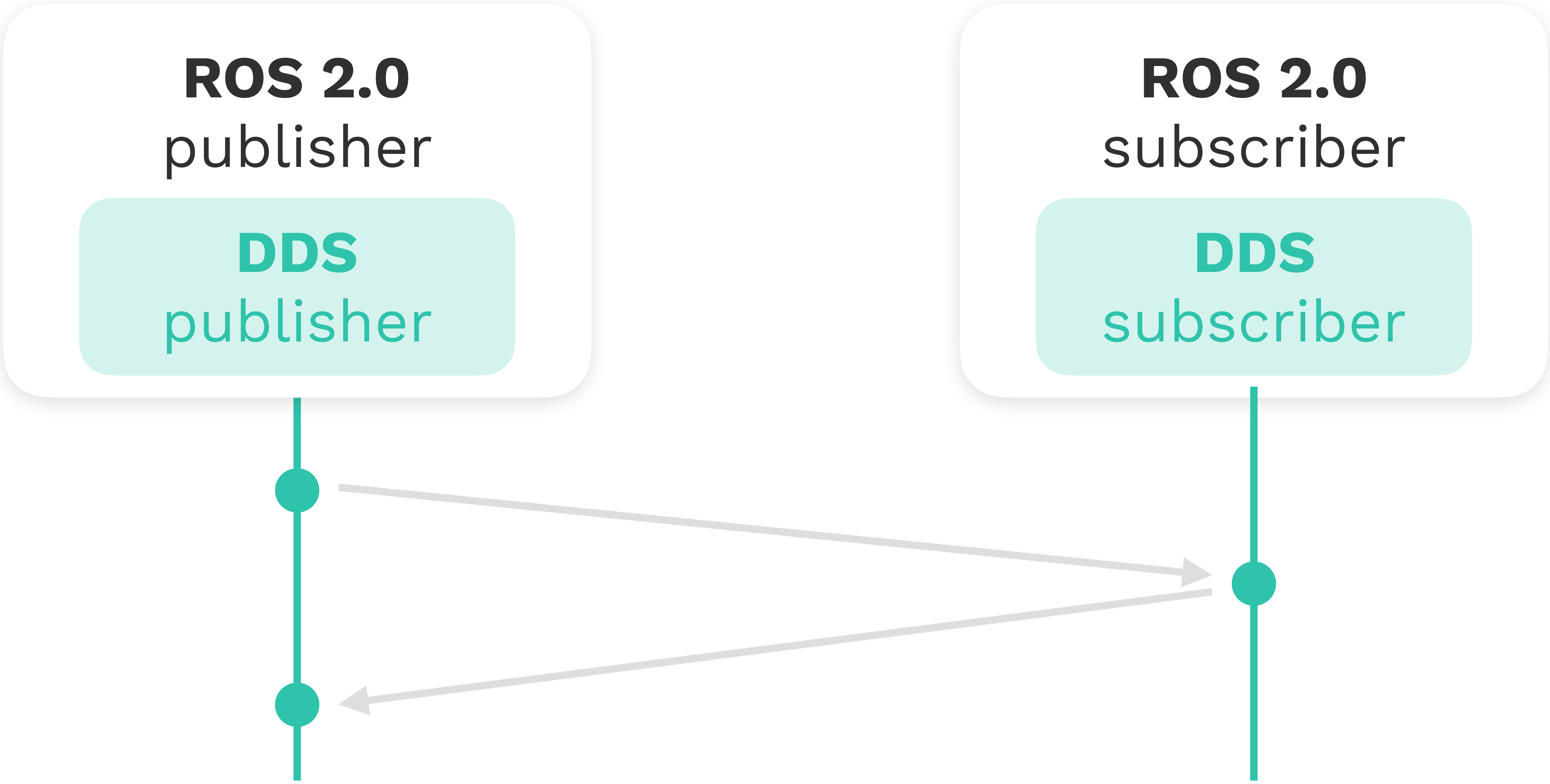
ROS 2.0 FOR REAL-TIME



[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

ROS 2.0 FOR REAL-TIME

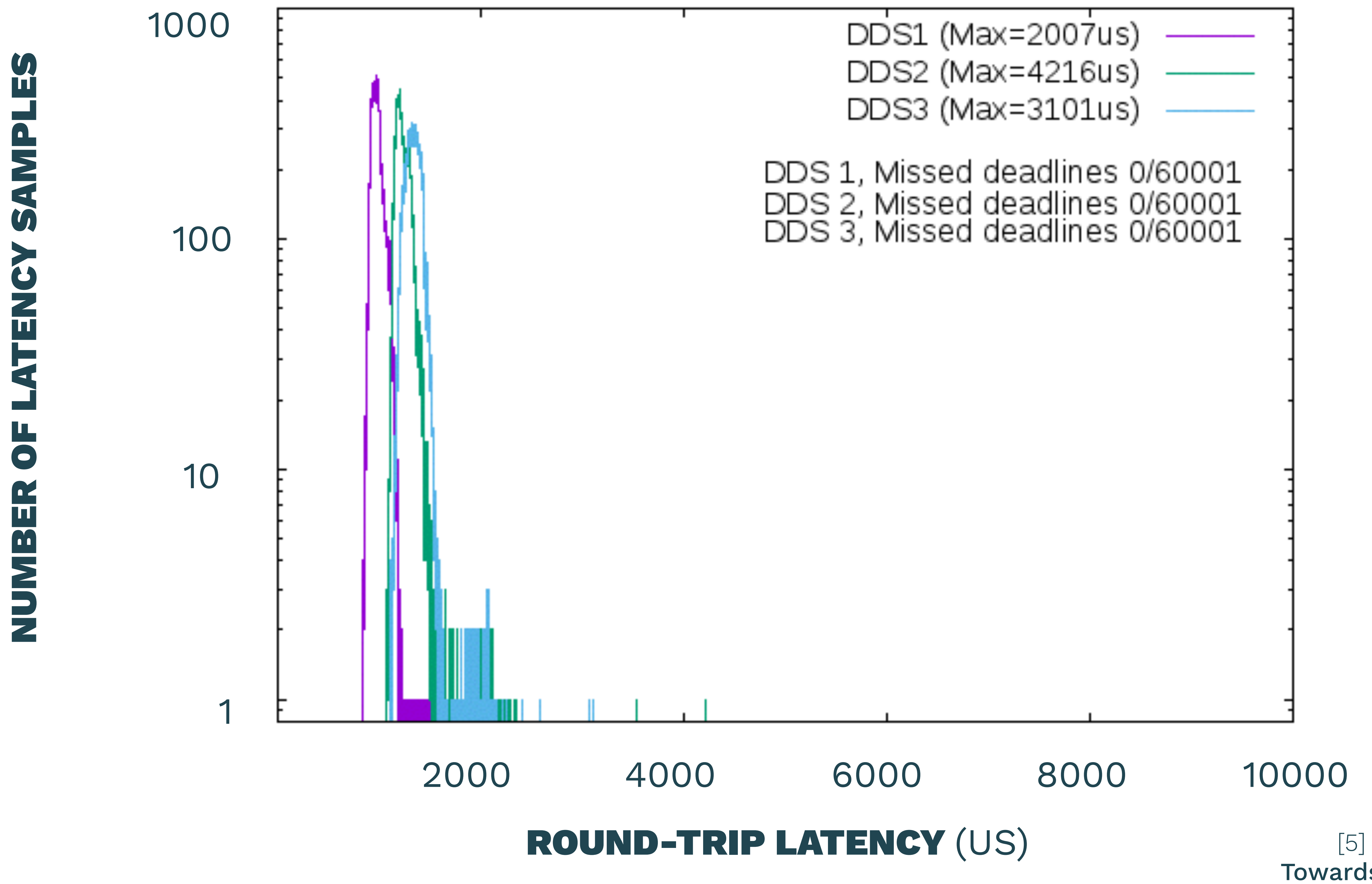


[5] Gutiérrez, C. S. V., Juan, L. U. S., Ugarte, I. Z., & Vilches, V. M. (2018). Towards a distributed and real-time framework for robots: Evaluation of ROS 2.0 communications for real-time robotic applications. arXiv preprint arXiv:1809.02595.

ROBOTICS FRAMEWORK & COMMUNICATION MIDDLEWARE

ROS 2.0 FOR REAL-TIME

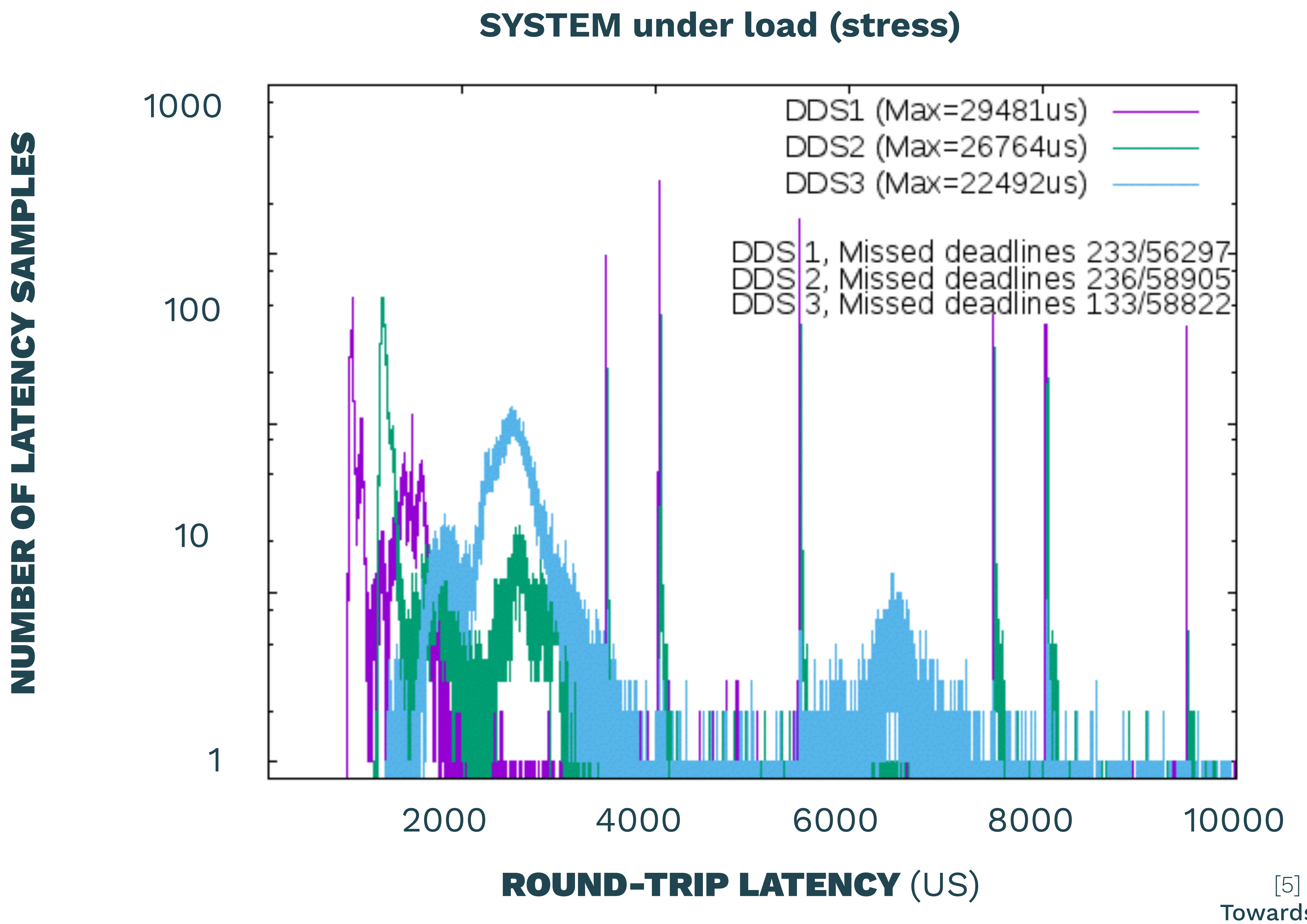
SYSTEM idle



[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

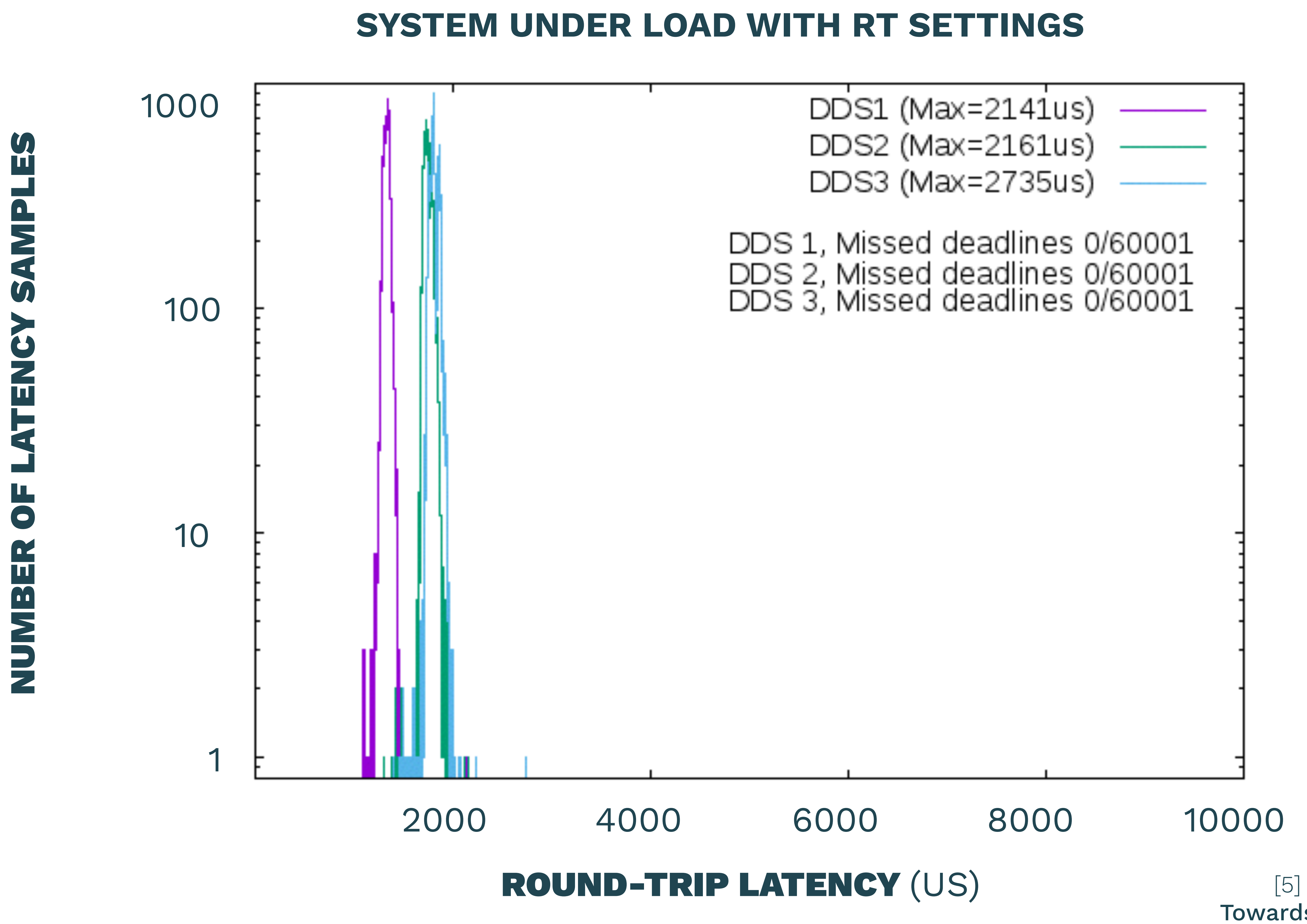
ROS 2.0 FOR REAL-TIME



[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

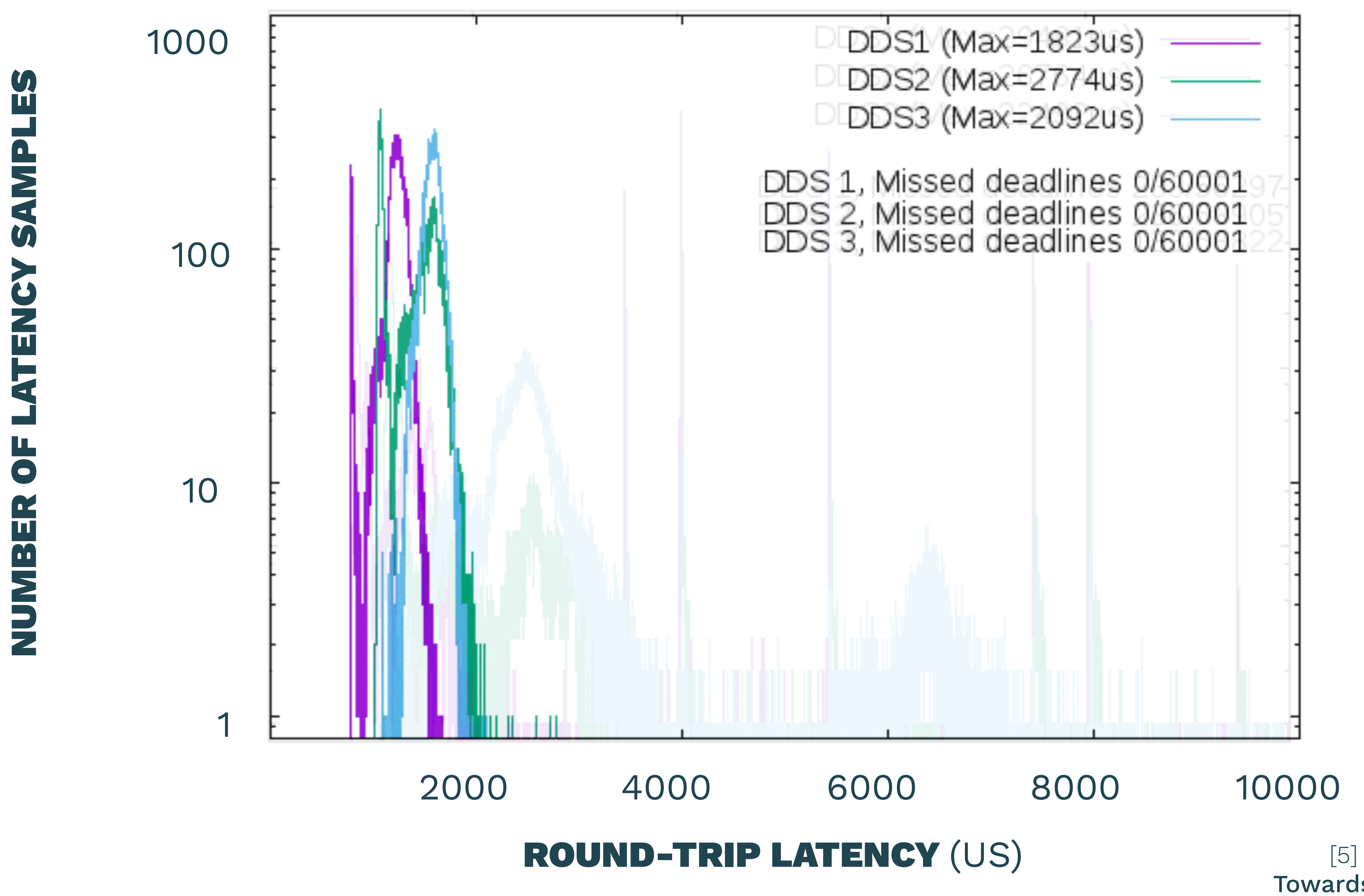


[5] Gutiérrez, C. S. V., Juan, L. U. S., Ugarte, I. Z., & Vilches, V. M. (2018). Towards a distributed and real-time framework for robots: Evaluation of ROS 2.0 communications for real-time robotic applications. arXiv preprint arXiv:1809.02595.

ROBOTICS FRAMEWORK & COMMUNICATION MIDDLEWARE

ROS 2.0 FOR REAL-TIME

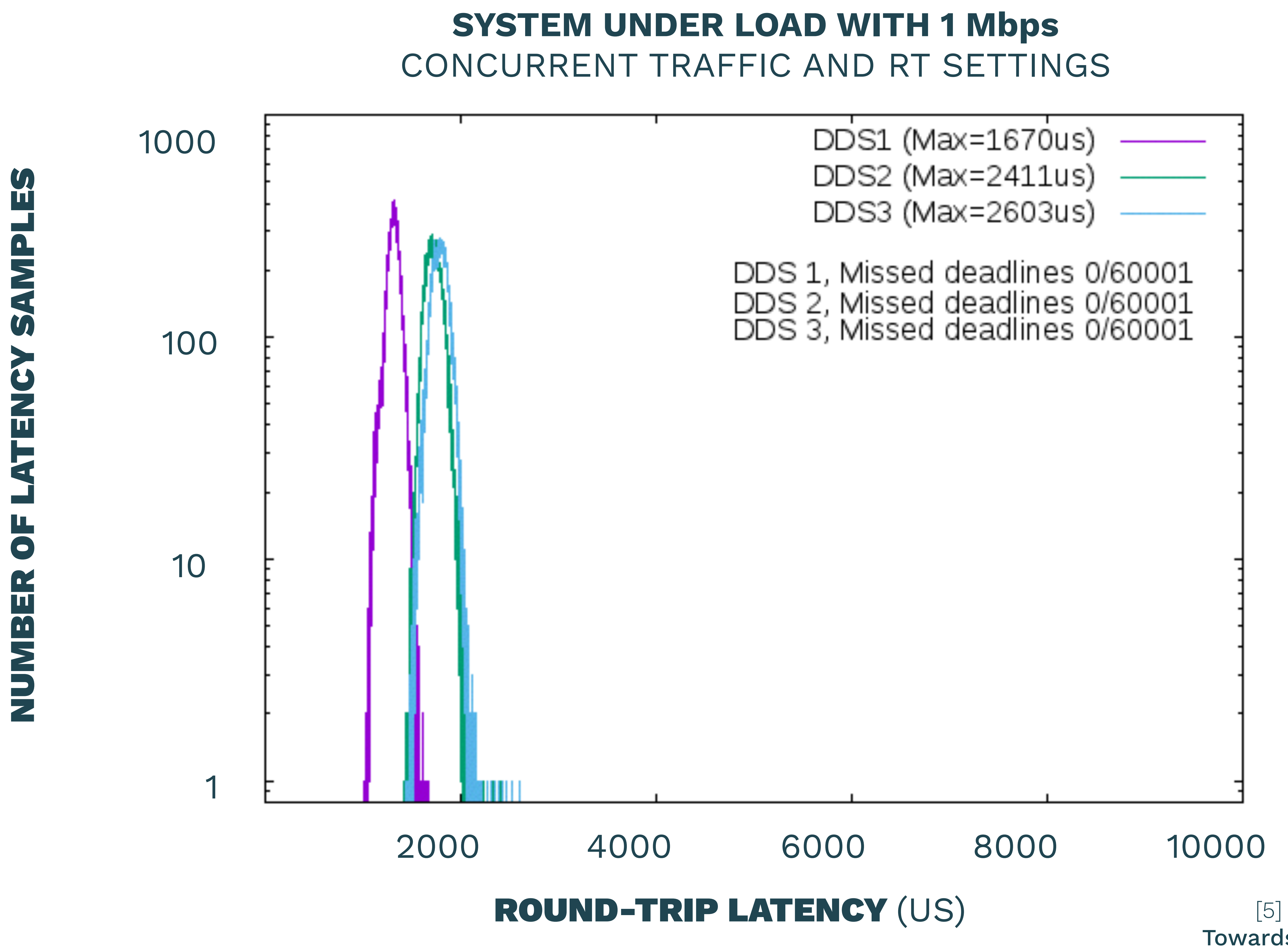
SYSTEM UNDER LOAD WITH RT SETTINGS



[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

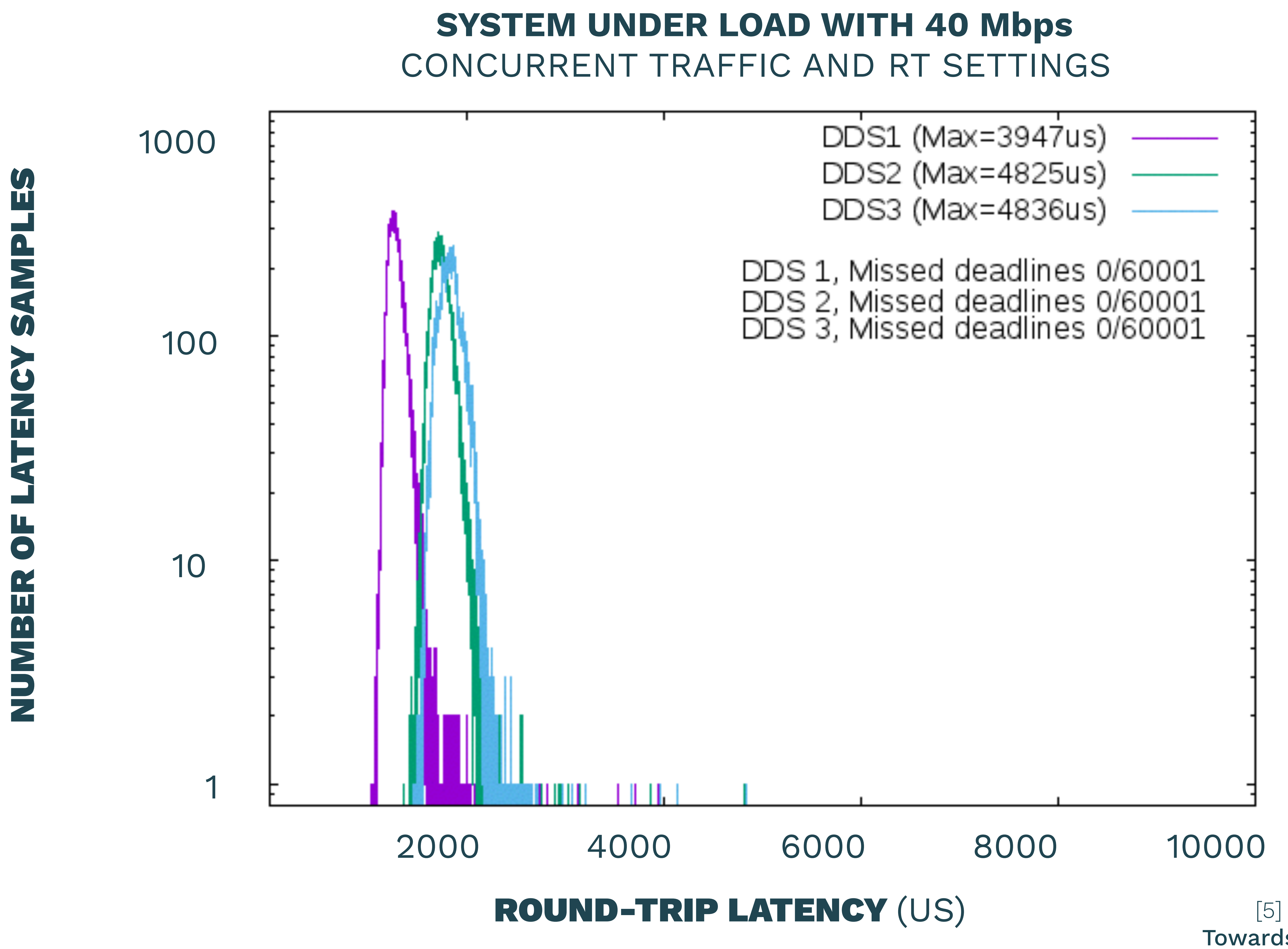
ROS 2.0 FOR REAL-TIME



[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

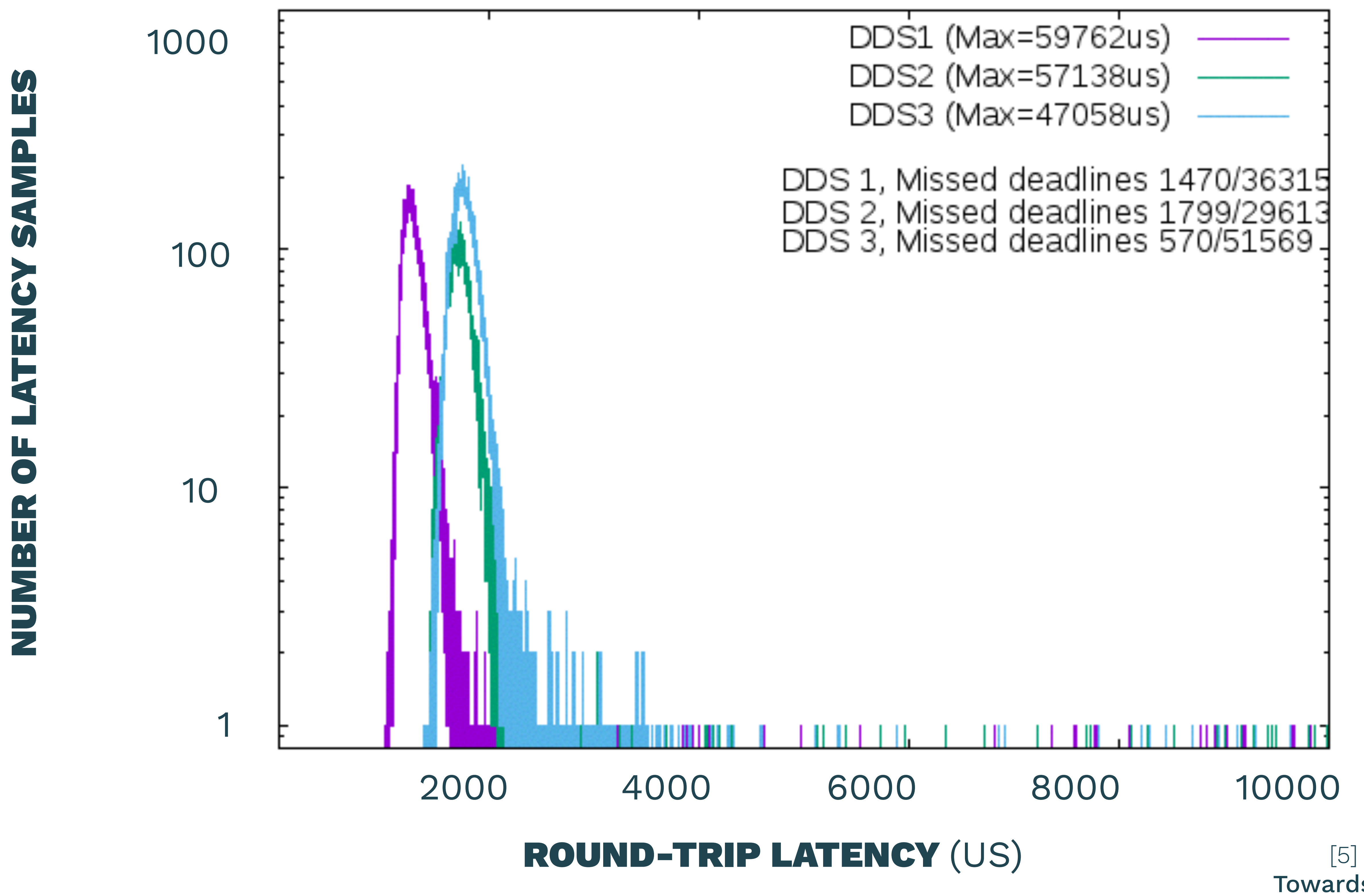


[5] Gutiérrez, C. S. V., Juan, L. U. S., Ugarte, I. Z., & Vilches, V. M. (2018). **Towards a distributed and real-time framework for robots: Evaluation of ROS 2.0 communications for real-time robotic applications.** arXiv preprint arXiv:1809.02595.

ROBOTICS FRAMEWORK & COMMUNICATION MIDDLEWARE

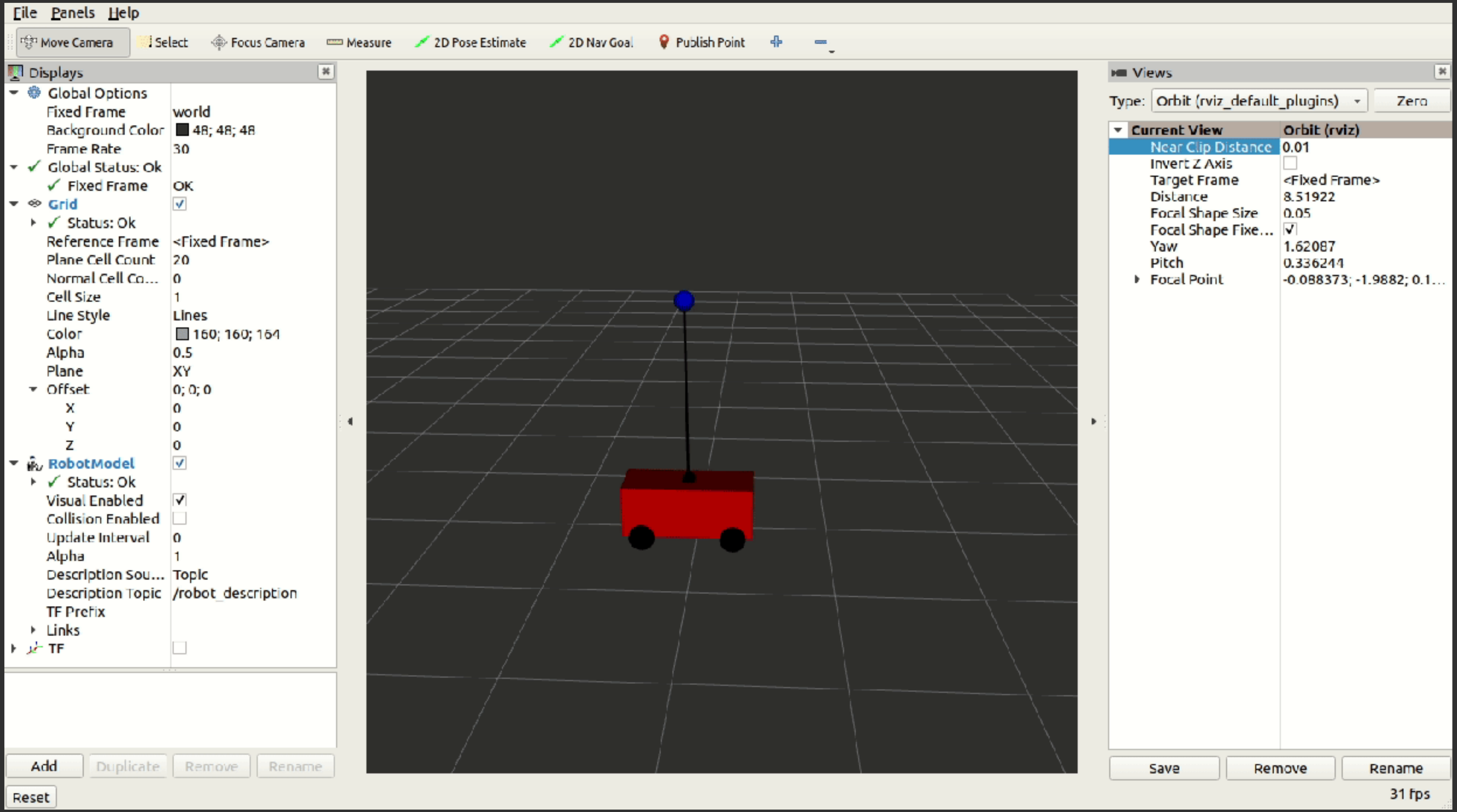
ROS 2.0 FOR REAL-TIME

SYSTEM UNDER LOAD WITH 80 Mbps
CONCURRENT TRAFFIC AND RT SETTINGS



[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.

REAL-TIME
REFERENCE DEMO



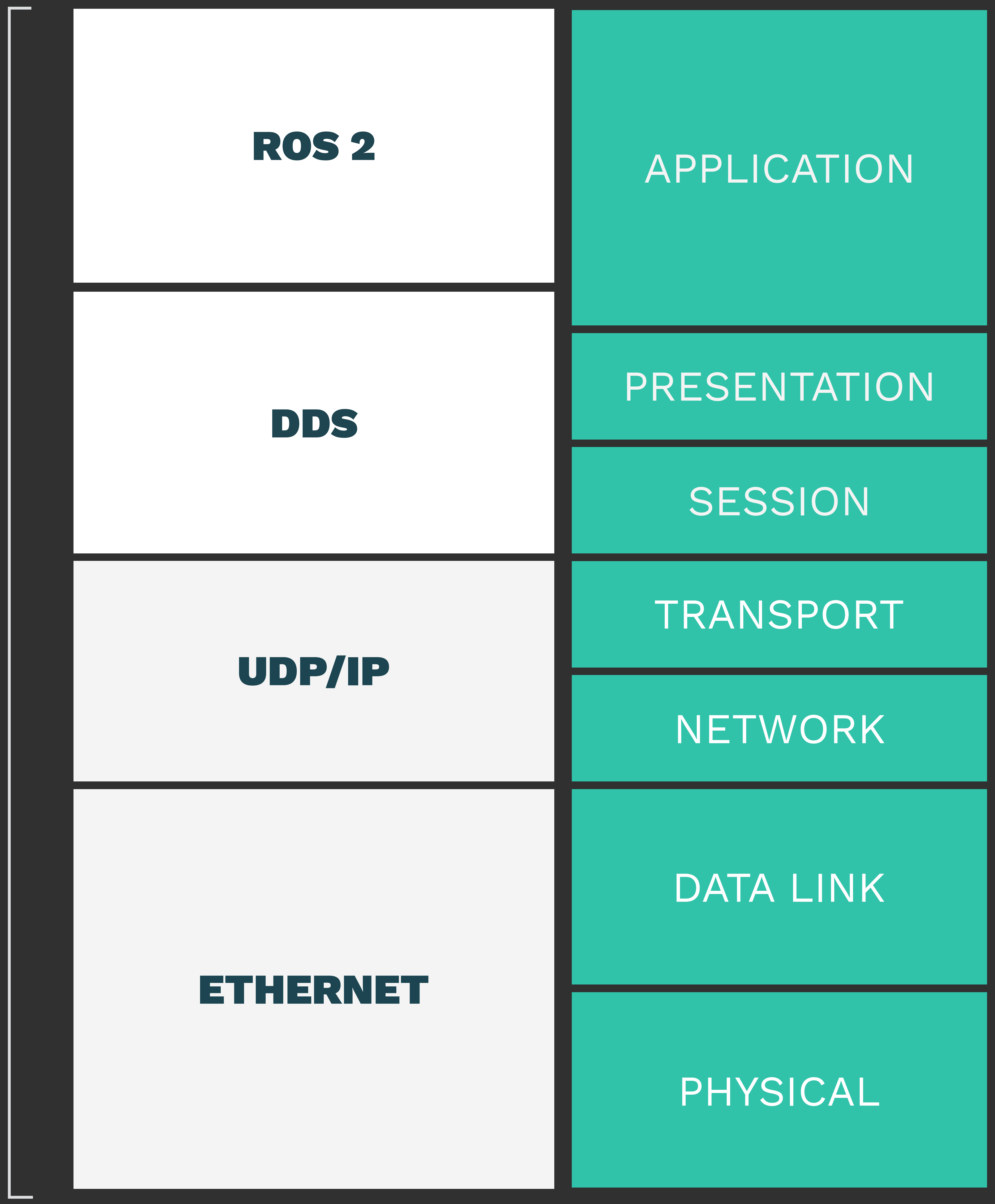
Gutiérrez, C. S. V., San Juan, L. U.,
ROS2, real-time, control, pendulum
https://github.com/ros2-realtime-demo/pendulum

REAL-TIME **PENDULUM**

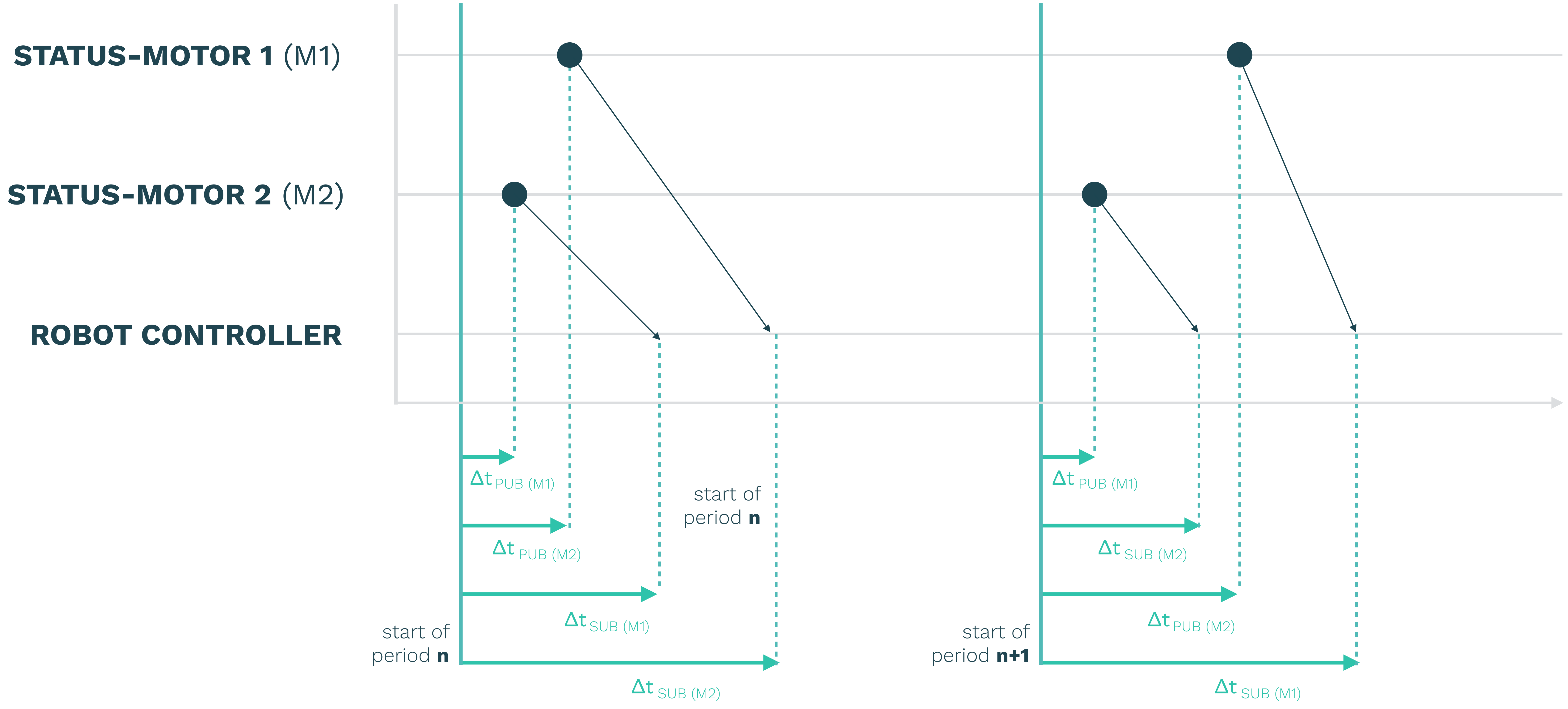
6. TIME SYNCHRONIZATION
IN ROBOT MODULES

REAL-TIME
ROBOT STACK

SYNCHRONIZATION AT ALL LEVELS



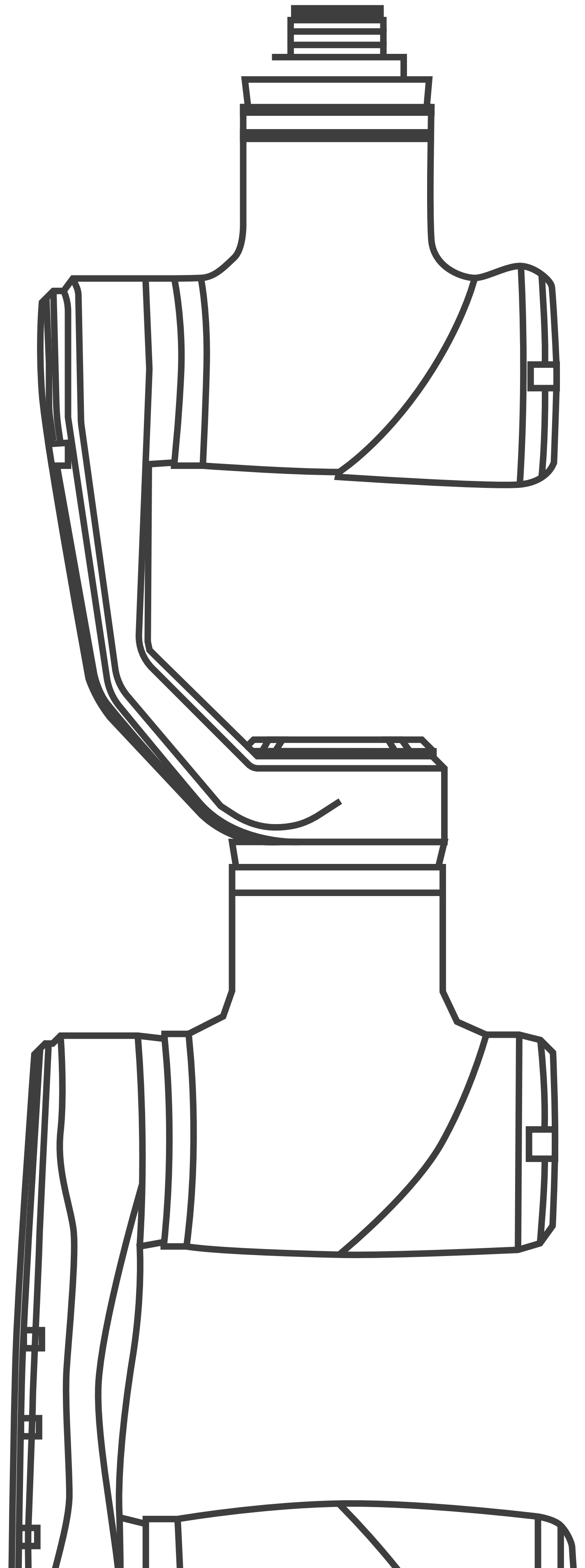
TIME SYNCHRONIZATION
IN ROBOT MODULES

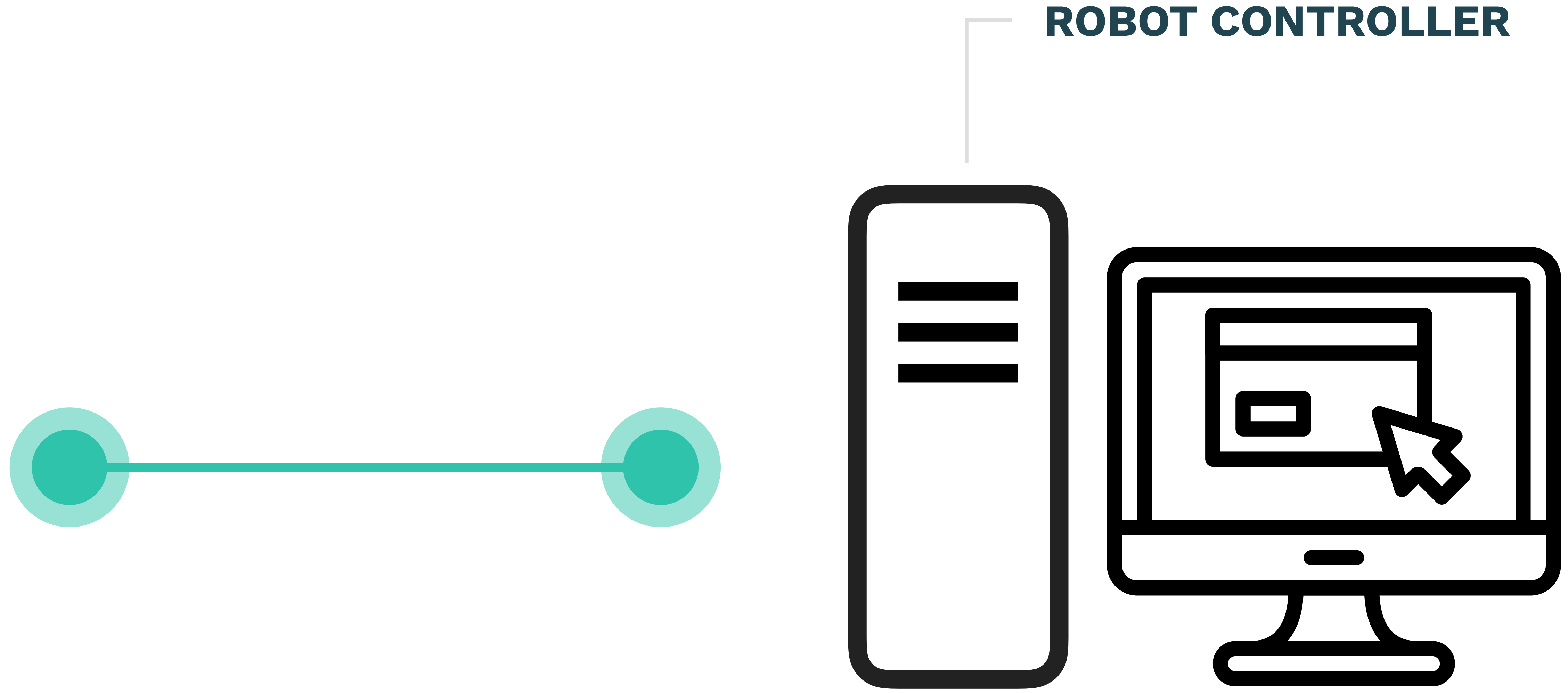


- $\Delta t_{PUB\ (M1)}$ → motor1 publishing time offset
- $\Delta t_{SUB\ (M1)}$ → Motor1 arrival time offset
- $\Delta t_{PUB\ (M2)}$ → Motor1 publishing time offset
- $\Delta t_{SUB\ (M2)}$ → Motor1 arrival time offset

[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

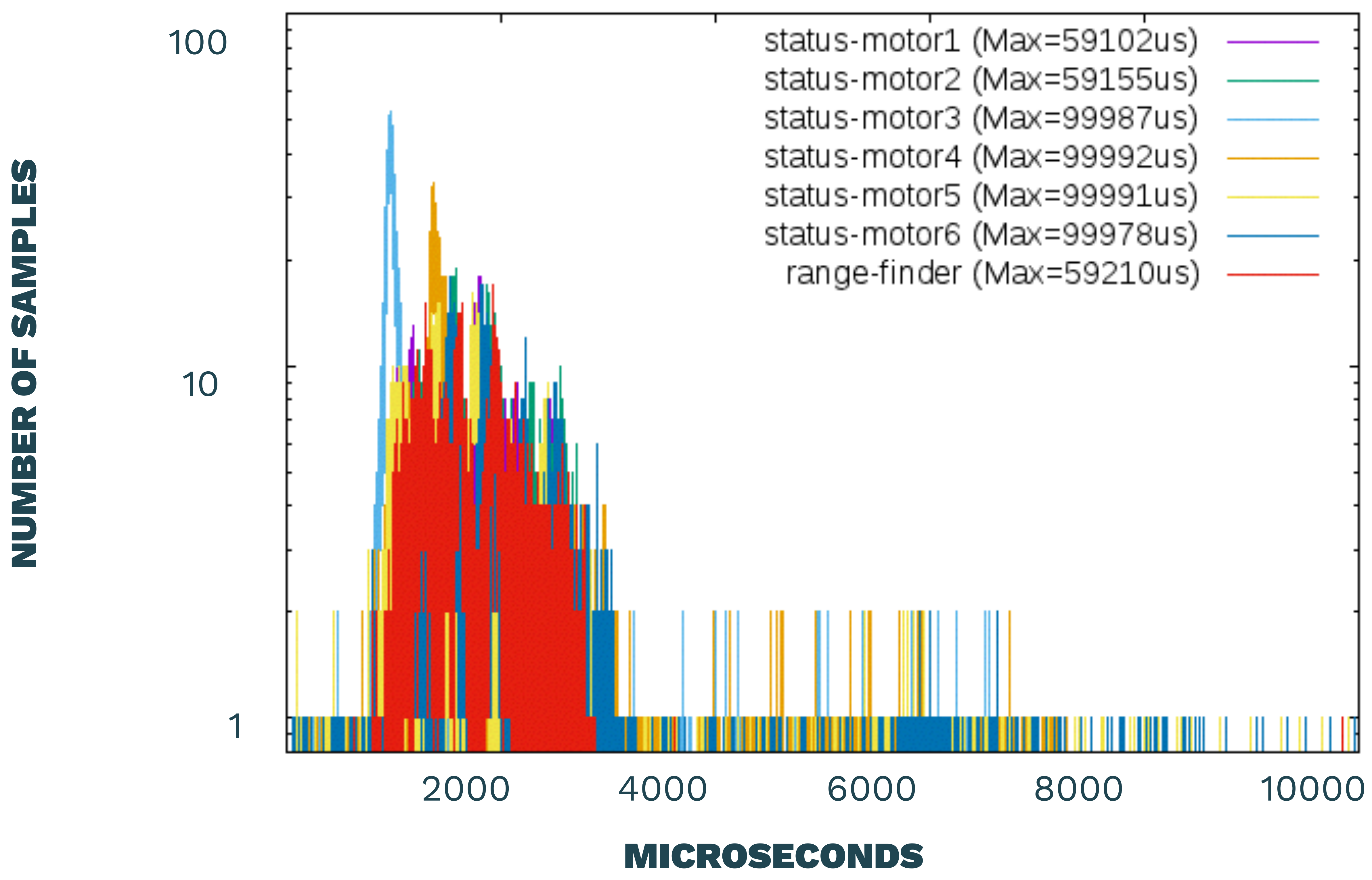




[6] Gutiérrez, C. S. V., Juan, L. U. S., Ugarte, I. Z., Goenaga,
I. M., Kirschgens, L. A., & Vilches, V. M. (2018).
Time Synchronization in modular collaborative robots.
arXiv preprint arXiv:1809.07295.

TIME SYNCHRONIZATION IN ROBOT MODULES

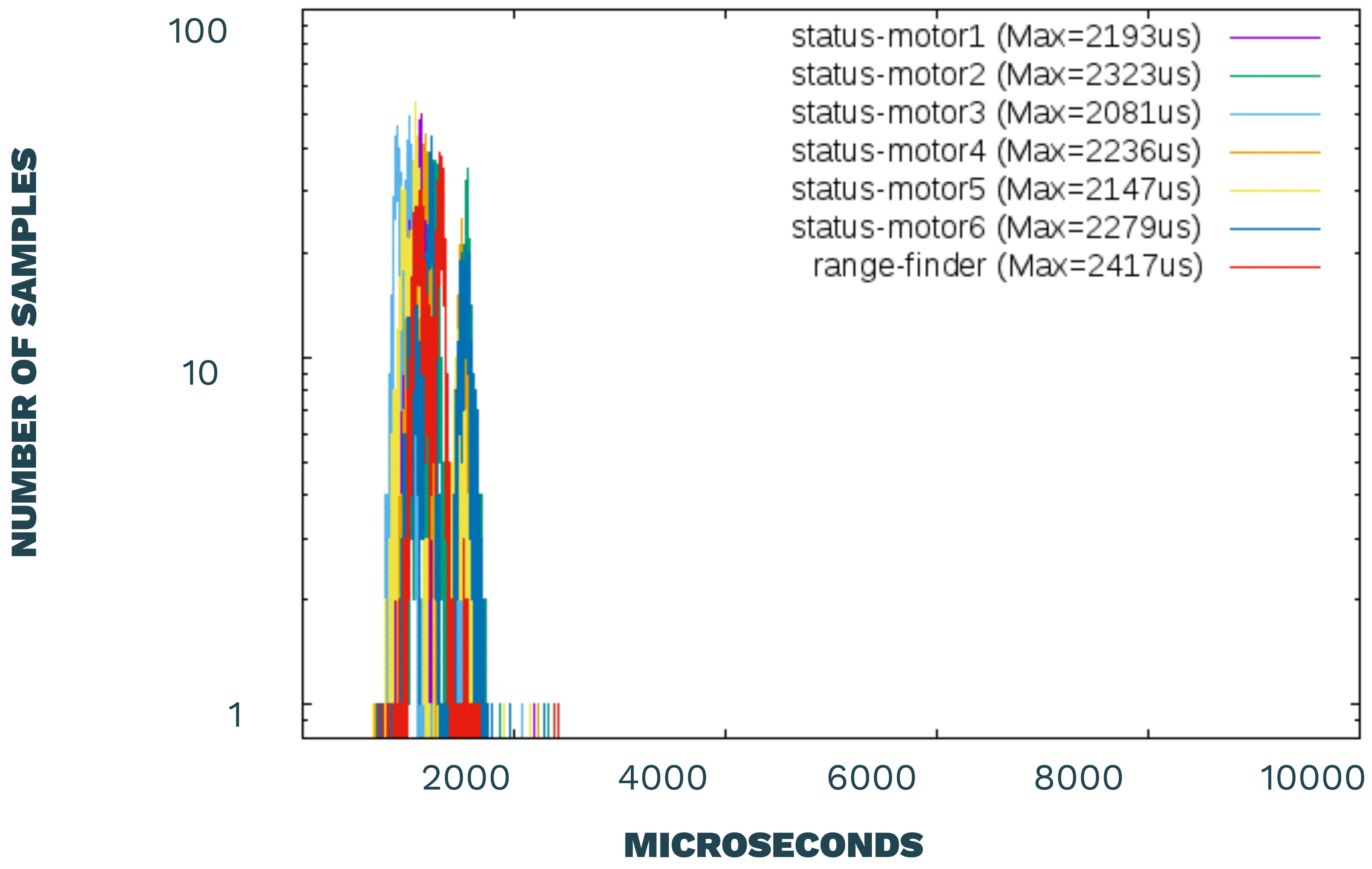
ARRIVAL TIME OFFSET FROM THE EXPECTED PERIOD



[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.

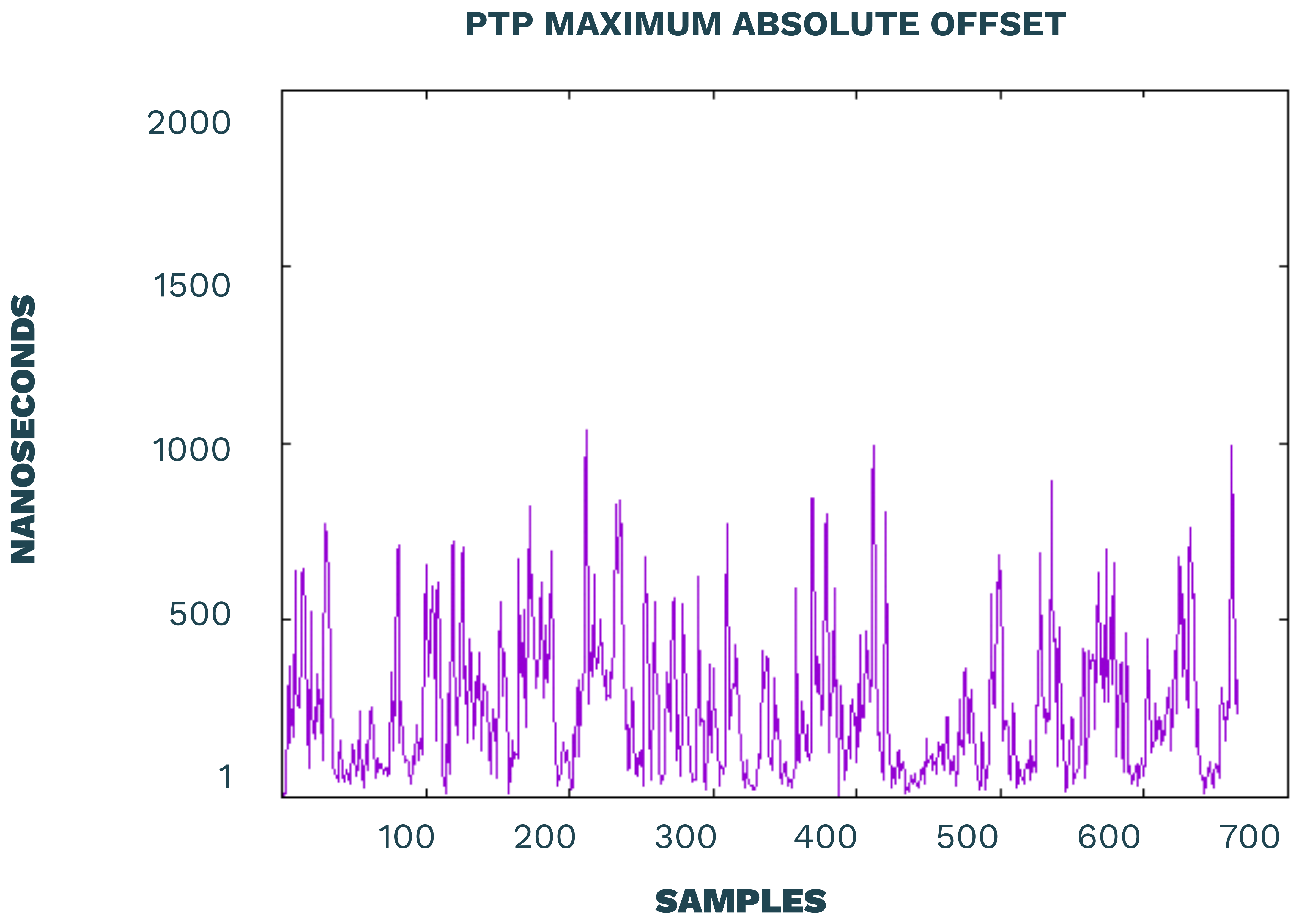
TIME SYNCHRONIZATION
IN ROBOT MODULES

ARRIVAL TIME OFFSET FROM THE EXPECTED PERIOD



[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

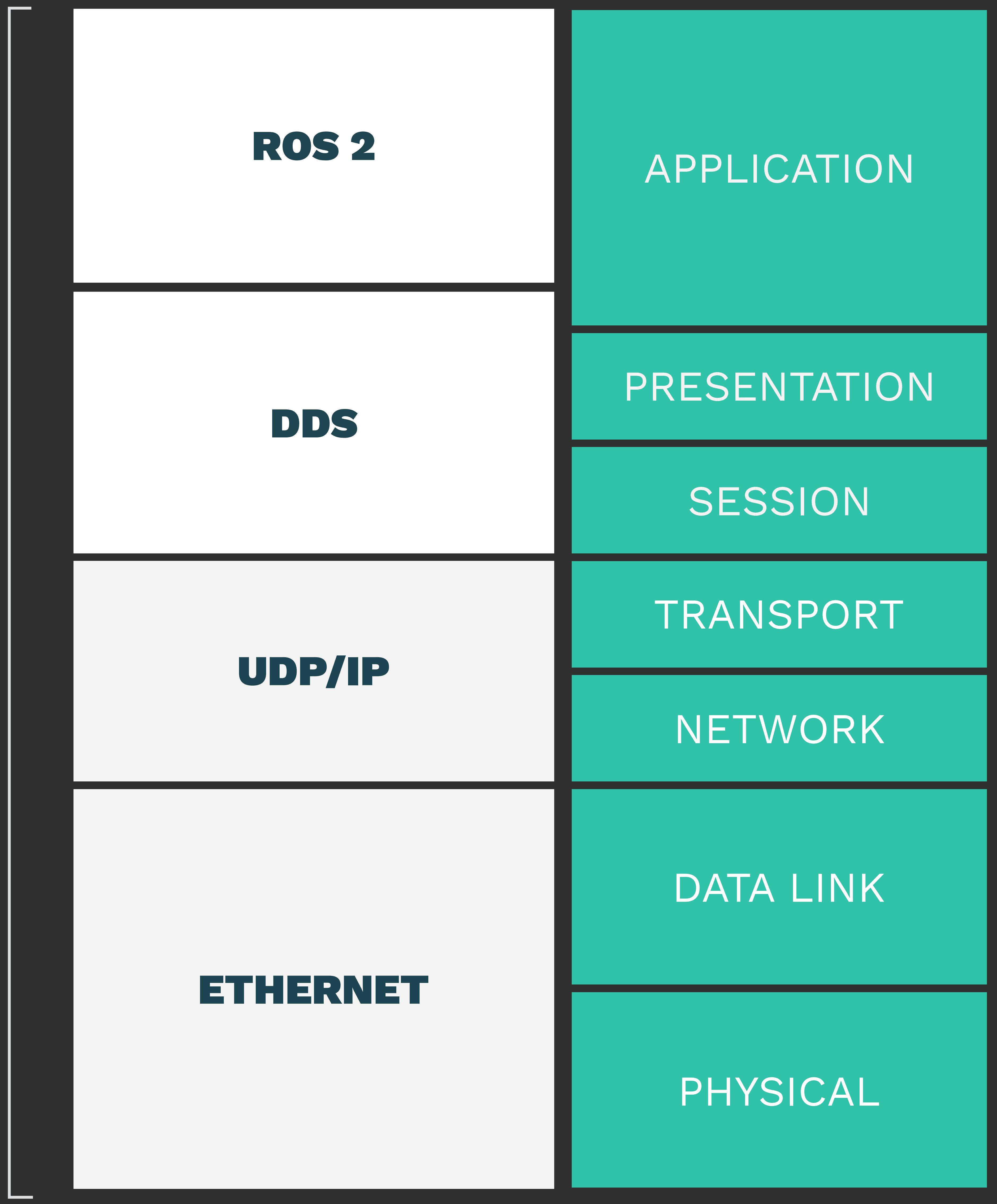


[6] Gutiérrez, C. S. V., Juan, L. U. S., Ugarte, I. Z., Goenaga, I. M., Kirschgens, L. A., & Vilches, V. M. (2018). **Time Synchronization in modular collaborative robots.** arXiv preprint arXiv:1809.07295.

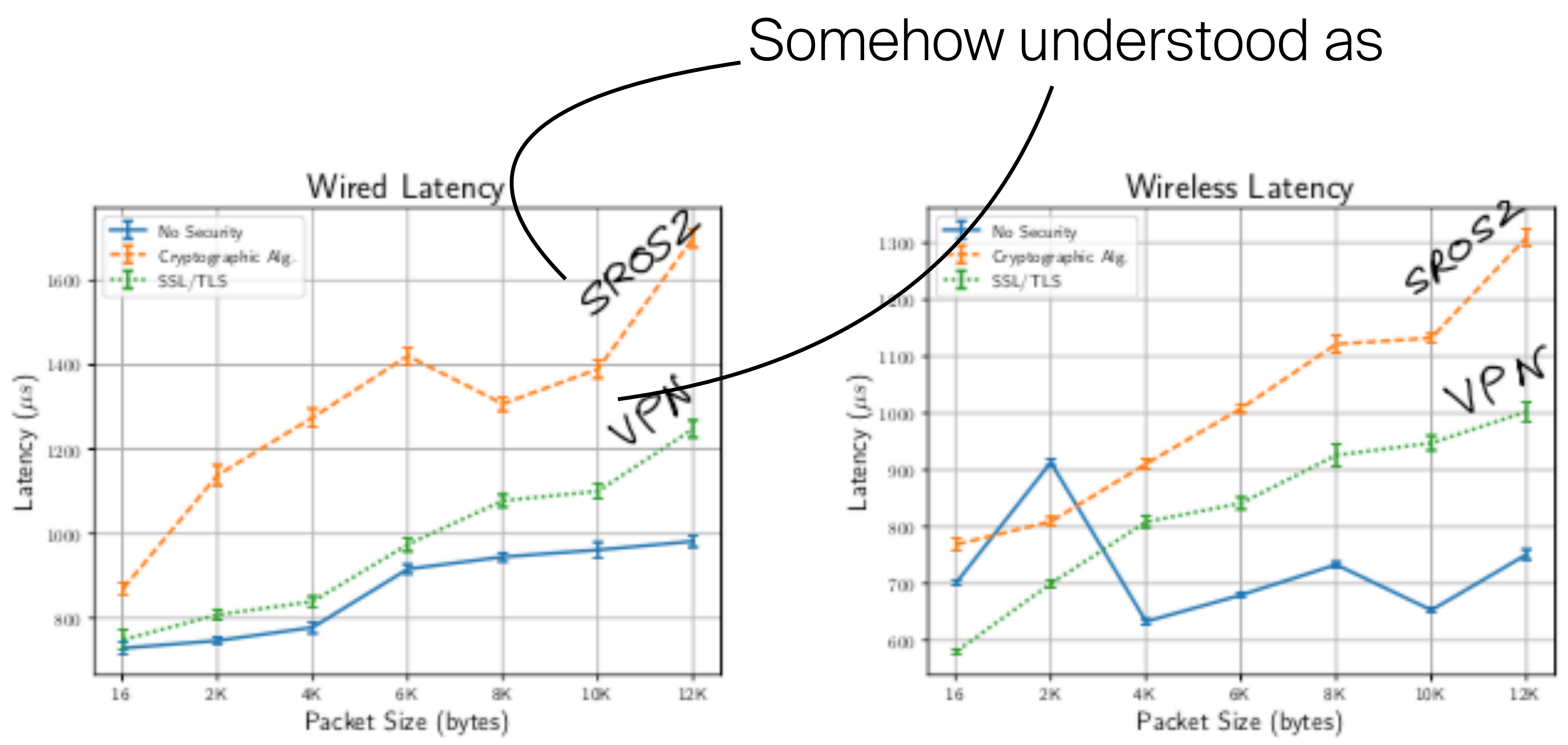
7. REAL-TIME SECURITY

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.

Table 4. Security measurement comparison.

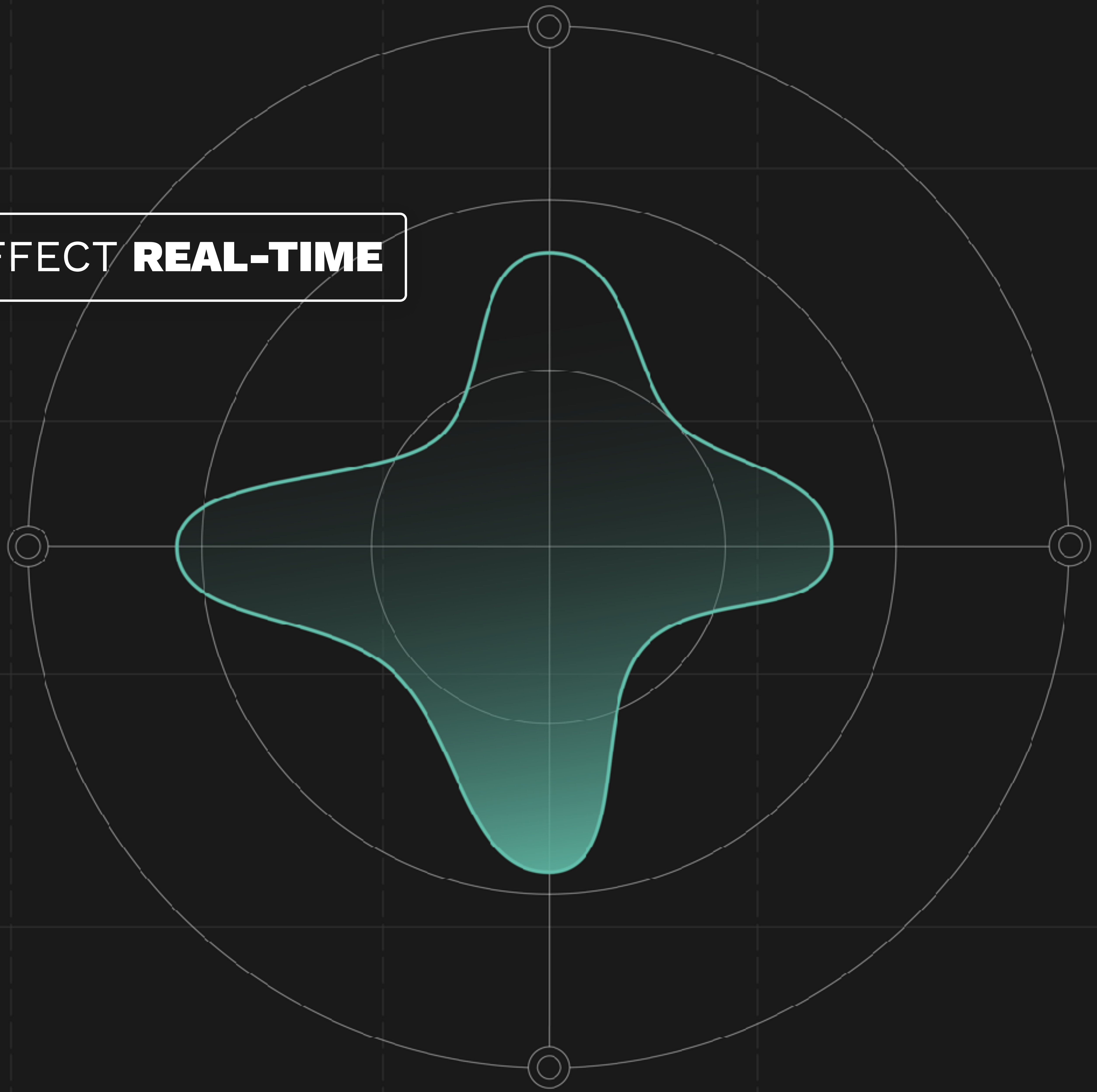
Security enabled	Latency (average μs)	Throughput (average packets/s)	Speed (average Mbps)
Plain	260	70,772	35,669
Full	1363	14,382	72,485

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.

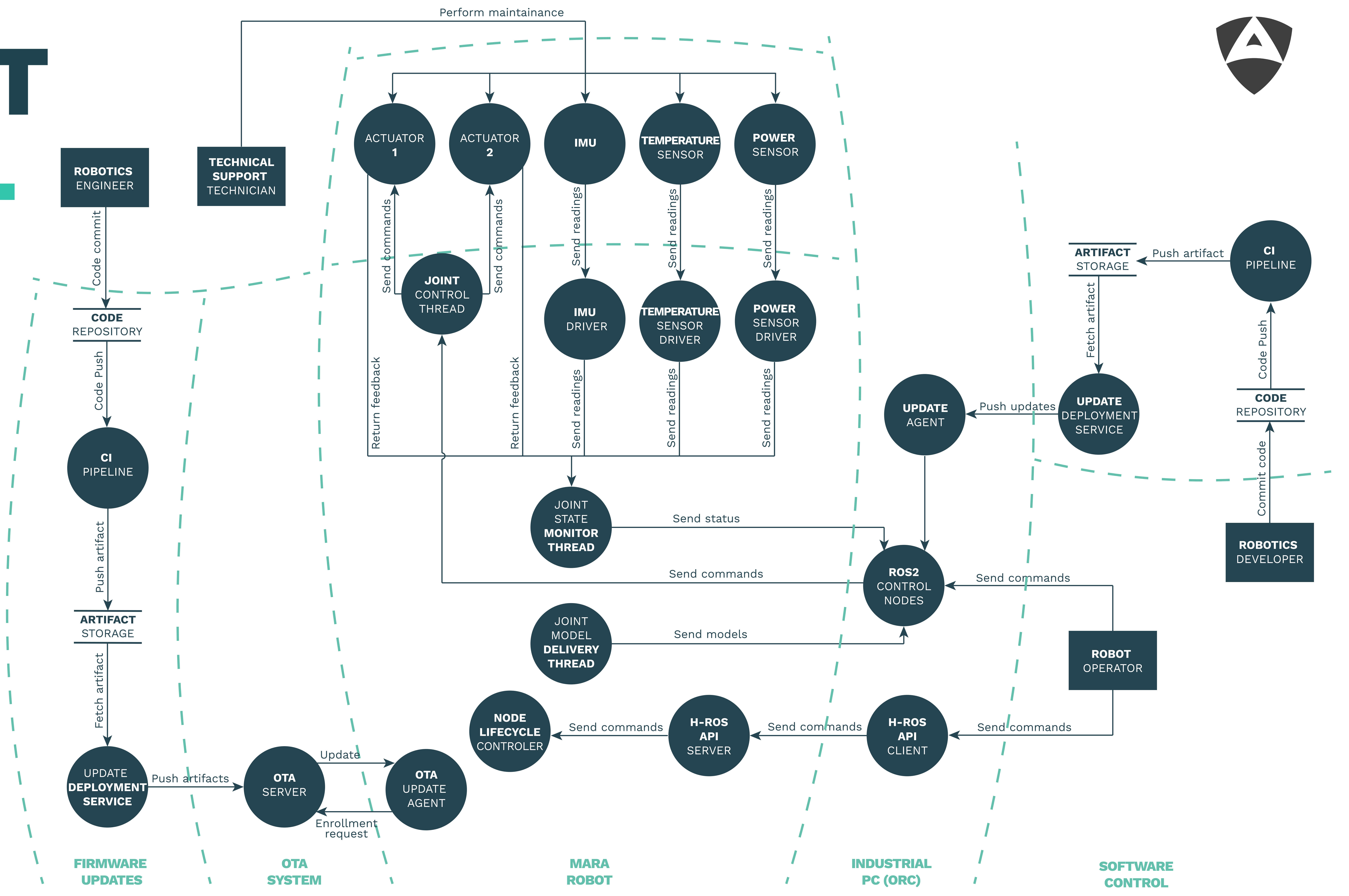
DiLuoffo, V., Michalson, W. R., & Sunar, B. (2018).
Robot Operating System 2: The need for a holistic security approach to robotic architectures.
International Journal of Advanced Robotic Systems, 15(3), 1729881418770011.

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

THREAT
MODEL



THREAT MODEL



SECURITY SOLUTIONS
ALIAS ROBOTICS

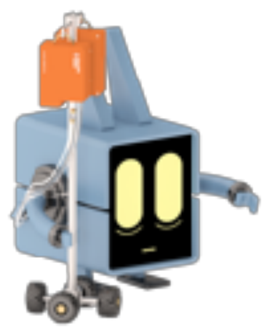
SERVICES — PRODUCTS

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 ™

RECORDS

- 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

www.**aliasrobotics**.com

victor@aliasrobotics.com