Time Sensitive Networking Testbed with Wireless Real-Time Connectivity via Li-Fi and Energy Efficiency Analysis

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ABSTRACT This study presents a recently developed TSN Li-Fi testbed, capable of achieving bidirectional 1 Gbit/s full-duplex device verification for a large set of supported TSN standards. It is the first time a device under test (DUT) has been presented in a TSN testbed using high-speed, wireless real-time Li-Fi technology. This is an important development for industrial automation, communication and robotic systems, particularly in smart factories.

TESTBED NOVELTY

- The testbed provides a deterministic, low-latency, user-friendly environment.
- Supports IEEE 802.1Qbv-2015, IEEE 802.1Qbu-2016, IEEE 802.1AS gPTP, IEEE 802.1CB-2017.
- Features precise timestamps, package prioritization, real-time capability and redundant paths.
- Measures energy consumption across wired and wireless devices.

SYSTEM CONCEPT

- Two IPMS TSN switched endpoints (SEs) for real-time end-to-end communication.
- A TSN Ethernet tester observes critical real-time parameters, such as data rate, correct time synchronization and frame utilization.
- An accurate power meter for measuring the energy consumption of two DUTs.
- An oscilloscope for validation measurements.

Fig. 2: Fraunhofer IPMS Li-Fi technologies (from left to right: Grathus®, Li-Fi GigaSpot 1GHS, Li-Fi Arthus III) [1].

TABLE 1: Comparison of Li-Fi devices tested in the testbed [1].

Characteristics	IPMS Li-Fi Technologies		
	Grathus®	GigaSpot 1GHS	Arthus III
Max. data rate [Mbps]	>1000	1000	10 / 100
Max. range [m]	300	12	1.5
Real-Time Latency [ms]	0.01	2	0.022
Typology	P2P	P2P, P2MP	P2P
Avg. power consumption [W]	7.5	5	1.6

MEASUREMENTS AND RESULTS

- Examined three Li-Fi technologies for TSN compliance & enhanced the most efficient technology.
- Implemented intelligent transmitter bias control on the GigaSpot 1GHS frontend.
- Results show further energy savings of up to 27.5%, by shutting off the 1GHS LED driver during idle states.
  - Light load or idle situations benefit more from the bias control loop.
  - Different TSN package sizes do not affect energy consumption.

EXPERIMENTAL SETUP

- Measured energy consumption of three different IPMS Li-Fi devices per bit.
- Analyzed varying traffic loads in the network.

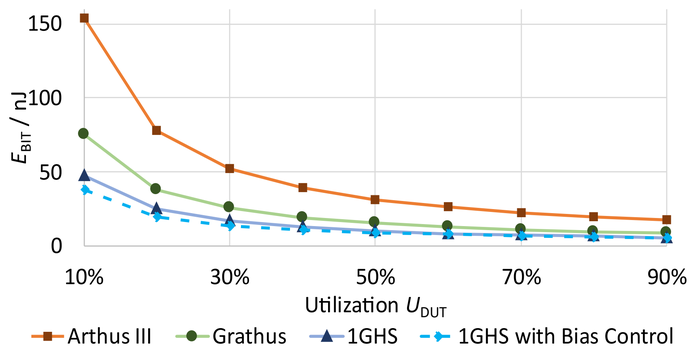

Fig. 3: Average energy consumption per bit E_{BIT} over the utilization rate U_{DUT} in percent of three Li-Fi technologies.

SUMMARY This testbed provides a first set of TSN-compliant benchmark results on the bit-wise energy efficiency of reliable, wireless real-time capable Li-Fi devices. It can help to validate, compare and transform networks into a TSN Ethernet network for smart factories, robotic systems or general fabric automation and high-speed communication systems.

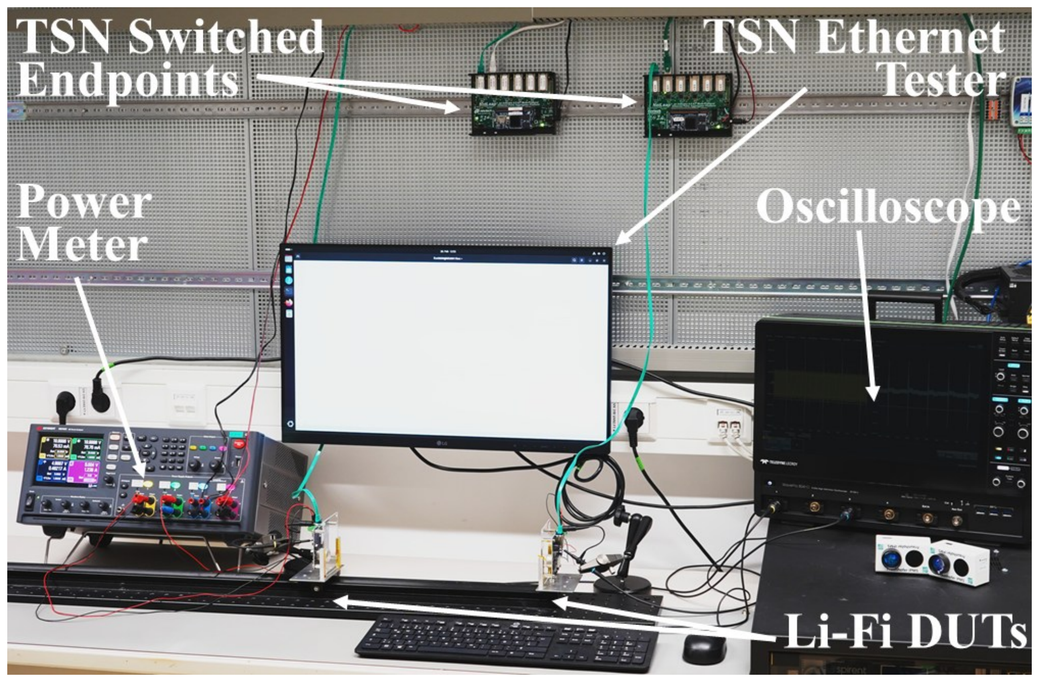

Fig. 1: TSN Li-Fi testbed hardware setup with two Li-Fi DUTs.

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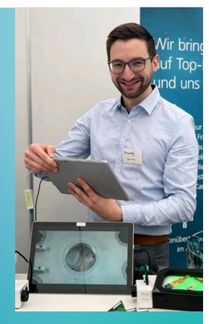

1 R. Kirrbach, M. Faulwaßer, M. Stephan, T. Schneider, and F. Deicke, "High Power Eye-Safe Optical Wireless Gigabit Link Employing a Freeform Multipath Lens," IEEE Commun. Lett., vol. 26, no. 6, pp. 1343–1347, 2022, DOI: 10.1109/LCOMM.2022.3162642.

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