2nd International Workshop on the Internet of Time-Critical Things (IoTime 2023)

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***Abstract*—With the advances in the interconnection of devices and applications, industrial and consumer applications have adopted the Internet of Things (IoT) as a core component of their systems. In such contexts, precise time and timeliness in task execution are fundamental requirements for emerging IoT applications and new experiences. Industry 4.0, mobile and collaborative robots, autonomous systems, and immersive and interactive human-cyber experiences are only examples of IoT-based domains where precise time, computing, and communication with bounded latencies are strictly required. Furthermore, these applications might be time-critical and safety-critical as they often involve interactions between humans and machines. Such stringent time and safety requirements bring new practical challenges and opportunities to revolutionize computing and communication infrastructure's traditional design, deployment, and management. New concepts in software-defined systems and networks, cloud/edge computing, Time-Sensitive Networking (TSN), Wi-Fi 6/7, 5G, 6G, dynamic, AI-driven resource orchestration, and Edge AI are emerging as potential building blocks to enable the transformation of computing and communications infrastructure to enable emerging time-critical applications.**

***Index Terms*—IoT, Time-Critical Things, TSN, Industrial IoT.**

I. Introduction

In recent years, the exponential growth of devices connected to the Internet has generated a new breed of technologies and applications in several domains. Further, new solutions were proposed to address those novel challenges regarding the multiple aspects of the IoT research field. Such solutions often share a common constraint: *time*. Time is a crucial and sensitive matter in most IoT-based systems. Smart factories, mobile and collaborative robots, autonomous systems, and virtual/mixed reality are examples of the next wave of applications that rely on accurate time and bounded (low) latency computing and communications.

The Time-Sensitive Networking research community has been active and growing in recent years; hence, the purpose of the second IoTime workshop is to bring together practitioners and researchers from academia and industry to have meaningful discussions and technical presentations on applications, architectures, and solutions for IoT-based systems in which time plays a significant factor.

The topics addressed in the workshop encompass many fields, such as wireless communication, time-sensitive networking, Industry 4.0 predictive maintenance, Information-Centric Networking (ICN), and edge computing. Hence, it constitutes a genuinely *multidisciplinary* workshop, which covers multiple heterogeneous topics through a common theme: the impact of *time* on IoT-based Systems.

Consequently, IoTime is a place for discussions and technical presentations that showcase approaches from different perspectives. Hence, a presentation focused on Time Slotted Channel Hopping (TSCH) optimization in Industrial IoT to spend less energy. In contrast, other work addressed the problem of fast image classification using machine learning algorithms to prompt an action of industrial equipment.

The workshop provided original contributions to the state of the art of research. The workshop provided a perfect arena for young PhDs and researchers who received provocative ideas, visions, and guidelines on new potential research directions on methodologies, techniques, algorithms, and multidisciplinary aspects.

II. Technical Presentation

During the workshop, five papers – which were peer-reviewed by at least three different reviewers – high-quality papers were presented. A common theme between the two papers is that they leverage Reinforcement Learning (RL) algorithms to optimize the parameters of the network; however, in one case, minimizing latency was the goal, while in the other, latency was the constraint to be respected. In detail, in the paper "A BLE Mesh Edge Framework for QoS-aware IoT Monitoring Systems," the authors introduced a framework tailored for Bluetooth Low Energy (BLE) Mesh networks. This framework enabled the monitoring of Quality of Service (QoS) metrics and adjusting network parameters through an edge device. Subsequently, the authors developed an RL algorithm to determine the optimal BLE Mesh parameters for a given configuration, focusing on meeting various QoS requirements, including optimizing latency. To validate their framework and algorithm, the authors conducted real-world experiments. These experiments showcased that their proposed technique could achieve different objectives, such as maximizing Packet Delivery Ratio (PDR), minimizing delay, or striking a suitable trade-off between these metrics, all in alignment with the specific needs of the users. On the other hand, in "QL-TSCH-plus: A Q-learning Distributed Scheduling Algorithm for TSCH Networks," the authors discuss the challenges of addressing the requirements of the Industrial Internet of Things (IIoT) in the context of Industry 4.0. They highlight how the TSCH protocol (IEEE 802.15.4e) is a potential solution to the mentioned challenge, but they highlight that there is no defined scheduling procedure in the standard; thus, the main contribution of the paper is the proposal of a scheduler for TSCH. In detail, the authors introduced "QL-TSCH-plus," an enhancement to the existing QL-TSCH scheduler. QL-TSCH-plus improves energy efficiency by implementing a distributed Action Peeking mechanism. Unlike continuous monitoring of neighboring nodes' communication, QL-TSCH-plus enables nodes to broadcast learned transmission slots, updating Action Peeking Tables and allocating reception slots. This approach reduces energy consumption by up to 47% when compared to QL-TSCH while still maintaining reliability and timeliness. The paper demonstrates that QL-TSCH-plus has significant potential for efficient scheduling in TSCH networks, particularly in the context of the IIoT.

Another aspect investigated by IoTime authors was in the field of Wireless TSN. The paper "Wireless TSN Extension to Enable Deterministic Connectivity: Implementation and Performance Evaluation" evaluates different network configurations to understand their impact on latency and reliability in industrial settings. The authors also assess the effectiveness of prioritization, preemption, and credit-based shaping policies to optimize time-sensitive traffic management. The results emphasize Wi-Fi's suitability for industrial automation, highlighting its potential to enhance precision, safety, and human-robot interaction through reduced latency and real-time communication.

In the paper "Time-Sensitive Airborne Fog Computing as a Named Serverless Microservices Framework," the authors discuss the challenge of deploying and executing services for Internet of Things (IoT) applications in intermittent networks, using a swarm of drones as resources. It introduces a serverless service approach designed for networks with intermittent connectivity, leveraging an Information-Centric Networking framework to reduce response time for IoT applications. These IoT services are microservices deployed on-demand on multiple drones through Software Defined Networking. The paper presents a framework named "Airborne Fog Computing" and illustrates its operation through a use case involving the fusion of videos and sounds from various IoT sources.

The paper "Flexible Automated Optical Inspection Architecture for Industry 4.0" won IoTime **Best Paper Award**. The authors designed, developed, and evaluated an architecture to perform automated optical inspections in Industry 4.0 that can be replicated in other settings with minimal re-configuration. In those scenarios, the system must act with a low latency since the algorithm output prompts the physical action of machinery. However, meeting low latency requirements is challenging since multiple interconnected components share data and perform computation to decide if a manufactured piece should be discarded, from machine learning classification algorithms to sensor data acquisition. The proposed architectures were deployed in a real-world testbed, which could cope with the latency requirements.

III. Conclusion

Time is a common and paramount complication in several IoT-based systems. There is a need to guarantee low latency in systems that are often unreliable and have several networking, power, and processing constraints. The IoTime workshop addresses this topic by considering solutions from the whole IoT vertical – from sensors to applications. In this edition, five papers were presented that covered issues such as edge computing and TSN.