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Demonstrating Wi-Fi Slicing Capabilities for Enhancing Performance of Industrial Applications

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***Abstract*—In the rapidly evolving Industry 4.0 landscape, the integration of industrial robots and Artificial Intelligence (AI) is revolutionizing the processes involved in storing and managing goods. While these advancements hold the promise of enhancing operational efficiency, they necessitate a robust and high-performing indoor network infrastructure. This demo paper introduces a dynamic network slicing mechanism tailored for Wi-Fi networks, capitalizing on readily available Commercial Off-The-Shelf (COTS) devices, and seamlessly incorporating In-Band Network Telemetry (INT) within a Software Defined Networking (SDN) framework. To effectively navigate the intricacies and uncertainties of network environments, we employ Fuzzy Logic to oversee queueing disciplines (qdisc), which directly influence airtime—the duration a device allocates to transmitting or receiving data over a wireless channel. Through a series of experimental demonstrations, we highlight the effectiveness of our proposed mechanism in maintaining stringent Quality of Service (QoS) standards even in conditions of network saturation. Our solution guarantees uninterrupted and streamlined operations, even in high-demand scenarios**

***Index Terms*—Network Slicing, Airtime, Wi-Fi, Testbed, In-band Network Telemetry, Fuzzy Logic.**

I. Introduction

Collaborative robots (Cobots), Automated Guided Vehicles (AGVs), and Artificial Intelligence (AI) serve as pivotal solutions to address the challenges of Industry 4.0. Such challenges encompass the streamlining of intricate supply chains, ensuring operator safety, integrating communication systems, and optimizing time efficiency in production processes. The World Robotics 2023 report provides comprehensive statistics on the global robotics industry revealing 517,385 new industrial robots have been introduced worldwide [1] during 2022. The growing demand for industrial robots, such as Cobots and AGVs, demonstrates the real appeal from companies. Cobots are primarily used for tasks such as picking and placing, working alongside humans. AGVs focus on indoor transportation. For the reliable operation of Cobots and AGVs, the industry employs sensors, cameras, and LIDAR for obstacle detection. Additionally, the Simultaneous Localization and Mapping (SLAM) technique is used for efficient navigation. Multi Access Edge Computing (MEC) plays a crucial role, particularly in real-time data processing i.e. large data flows from AGV cameras. The proximity of MEC to data sources reduces end-to-end latency and response time, making MEC a key component for ensuring quick and precise robotic operations.

However, the effectiveness of MEC depends on the reliability and quality of service delivered by the underlying network infrastructure. Wi-Fi networks play an essential role in indoor environments due to their technological maturity, ability for flexible and scalable deployment, and the provision of high Quality of Service (QoS). However, uplink and downlink capacity pose challenges to Wi-Fi networks. Access Points (AP) often become overloaded when confronted with an excessive volume of data packets awaiting processing and transmission. Overloaded APs can compromise QoS and potentially disrupt the functionality of critical mobile devices such as AGVs.

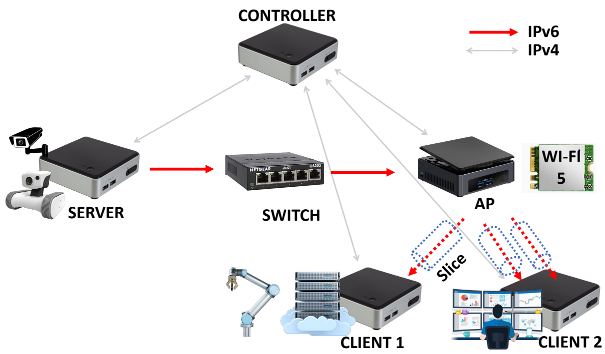

Fig. 1. Testbed Architecture.

In this scenario, the Queueing Disciplines (qdisc) in Wi-Fi APs play a crucial role in effective network traffic management. The qdisc regulates the transmission order of data packets, directly affecting Airtime, which represents the amount of time a Wi-Fi AP dedicates to the transmission of data for a specific service. An effective mechanism for managing Airtime proves fundamental in scenarios where real-time communication is essential for the correct operation of AGVs and other intelligent devices. Recent advancements in the networking field, such as Software Defined Networking (SDN), In-band Network Telemetry (INT) [2], and network slicing [3], offer promising tools to address these challenges, such as AP overload that causes increased waiting time in queues. This demo paper presents a dynamic network slicing mechanism for Wi-Fi networks, developed using Commercial Off-The-Shelf (COTS) devices, integrating INT monitoring within an SDN controller. Our configuration enhances Wi-Fi network adaptability by facilitating the strategic scheduling of network traffic flows. Given the unpredictable and complex behavior of network environments which proves challenging to model, a decision is made to manage the qdisc, and consequently, the Airtime, utilizing a Fuzzy Logic technique. The purpose of our work is to use network slicing to uphold the QoS demanded by certain critical services, even under adverse network conditions, thereby augmenting the reliability of indoor Wi-Fi networks.

II. Demo

To illustrate and evaluate the efficiency of our mechanism, we have created an experimentation setup with real COTS devices connected to the same network and the same AP. Through our configuration, we emphasize the direct impact of Wi-Fi APs efficiency on the transmission of data from cameras and robotic sensors to the MEC, with potential implications on warehouse or logistics operations. Each application within the network is assigned a distinct priority, identified by the Differentiated Services Code Point (DSCP). To induce network saturation, additional background traffic is introduced mimicking the traffic

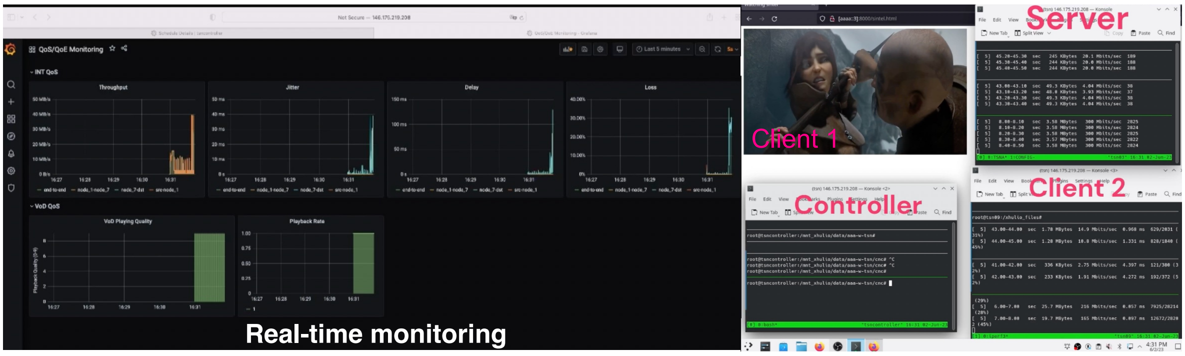

Fig. 2. The image shows a capture of the demo. On the left side, is shown the dashboard related to the network KPI and the KPI related to the video. On the right side, is shown the back-end of the traffic generator and the video service in streaming.

coming from other devices in logistics environments where different robots, cameras, and other users, are connected on the same network. This setup enables a comparative analysis of the network performance with and without the implementation of the network slicing technique, thereby enabling an assessment of the effectiveness of the proposed mechanism in managing network traffic under saturated conditions.

A. Architecture

Our testbed has five nodes and a controller Fig 1. We use IP version 4 (IPv4) for control and IP version 6 (IPv6) for data. This aids the application of INT techniques due to the larger packet size of IPv6, allowing for additional data in IP packets, like datetime information [2]. Three nodes act as endpoints - two clients and a server, while two nodes act as bridge, switch, and AP. Clients connect to the same AP with Wi-Fi 5 enabled. The AP connects to a switch, facilitating data transfer with external networks. The switch links to a server via Ethernet. All nodes connect to a central controller via IPv4. Traffic starts at the server and reaches the clients through the network.

B. Traffic

To analyze the behavior of the network, we generate multiple downlink traffic, flowing from the server to the client nodes as a combination of real and emulated traffic: a real video server is implemented for high-definition video-streaming service [4] to emulate cameras data coming from AGVs and directed to the MEC, while iperf[1] serves as the traffic generator for emulating other types of services, as the Internet of Things (IoT) devices or AI outputs from the MEC to the Cobot or control center.

C. KPI

We set up a QoS monitor using INT techniques in the SDN controller framework. It captures packet sequences to compute network metrics like throughput, delay, jitter, and packet loss ratio (PLR). Throughput measures bytes transmitted over a set time, while delay and jitter are assessed by comparing packet timestamps generated using INT at the final stop. PLR is evaluated by comparing sent and received packets over a period. We also examined video playback quality and speed (playback rate) to eventually evaluate if the video frames have enough quality to be computed from the MEC.

D. Algorithm

Our approach employs a systematic airtime management protocol, including configuration initiation, network metric aggregation, analysis, and policy determination. Upon getting KPI values via INT, if the desired QoS metrics for application performance remain unachieved, an adaptive network slice is instantiated. Utilizing fuzzy logic, which approximates human reasoning, the necessary airtime for the Wi-Fi network to meet QoS standards is determined, ensuring application functionality. Our computational model delineates specific fuzzy subsets corresponding to diverse network indicators, employing membership function methodologies to transmute precise inputs into fuzzy categories. This facilitates a tailored control mechanism contingent on the slice category, guaranteeing judicious resource distribution and peak network efficiency.

[1] iperf - Traffic generator, https://iperf.fr/

III. Applications

In this research we propose a mechanism for the deployment of an optimized and resilient Wi-Fi network. In indoor contexts, such as warehouses, the intensive cooperation between AGVs, IoT devices, and collaborative robots, combined with data processing through MEC, can easily lead to network saturation. This overload could affect robot mobility, obstacle detection, and the accuracy of localization, implying risks for operator safety and compromising operational efficiency. Concurrently, hospitals could utilize this enhanced infrastructure for prioritizing critical medical devices and real-time patient monitoring. The retail sector benefits by improving indoor navigation in malls, enhancing the user experience. In smart buildings, the solution aids in integrating and optimizing IoT devices, from advanced security to energy management. Convention centers can leverage this network for real-time translations and seamless digital interactions during events.

Acknowledgments

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