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Understanding QoS applicability in 5G transport networks

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Abstract— **5G transport networks will need to accommodate a wide spectrum of services on top of the same physical infrastructure and network slicing is seen as a suitable candidate for providing the necessary quality of service (QoS). Traffic differentiation is usually enforced at the border of the network in order to ensure a proper forwarding of the traffic according to its class through the backbone. With network slicing, the traffic may now traverse many slice edges where the traffic policy needs to be enforced, discriminated and ensured, according to the service and tenants needs. The goal of this article is hence to analyze the impact of different QoS policies in case of having multiple network slices carrying fixed and mobile traffic.**

Keywords—5G, transport network, QoS, network slicing, characterization, simulation

I. INTRODUCTION

5G transport networks will need to accommodate different kind of services with very distinct requirements [1] on top of the same physical infrastructure. 5G services can be grouped in three main categories [2], namely enhanced Mobile Broadband (eMBB), ultra-Reliable and Low Latency Communications (URLLC), and massive Internet of Things (MIoT). Each of them present different inherent characteristics spanning from ultra-low latency to high bandwidth and high reliability. According to NGMN [3], these multiple services may be provided by customized network slices, which provide the necessary traffic treatment over the same physical substrate. Moreover, the traditionally separated fronthaul, backhaul, fixed, and mobile networks are now converging into an integrated transport to alleviate the static provisioning of resources. All of this poses significant challenges to the design of the transport networks which will need to simultaneously fulfil the disparate traffic and tenant requirements. Finally, sharing the physical network assets through multi-tenancy is seen a viable path for reducing the ever-increasing costs involved in the deployment and management of future networks [4]. This fact is key to understand the new quality of service (QoS) capabilities that are required to be supported in 5G transport networks.

Existing networks can be considered as a continuum from the access to the interconnections points forming an end-to-end path. Traffic differentiation is enforced at the access border of the network in order to ensure a proper forwarding of the traffic according to its class through the backbone, where it is more feasible to have high capacity. However, network slicing breaks this situation since now the end-to-end path becomes a composition of segmented paths within different slices that could even pertain to distinct administrative organizations or providers. This means that the end-to-end path traverses now many edges where the traffic should be enforced, discriminated and ensured, according to the service and tenants needs. Thus, transport networks move from a single-edge continuum towards a multiple-edges structure in 5G. Apart from the technical complexity added, cost implications can be expected, since the specialized and more expensive hardware used today just in the border for implementing fine-grained QoS should be generalized to the internals of the network.

To tackle the above requirements from a network protocol perspective, Ethernet is considered a suitable candidate in terms of performance, costs, and management for providing packet-based services in a transport network [5]. As a matter of fact, Ethernet-based fronthaul interfaces [6] have been recently proposed with the goal of easing the integration of the fronthaul segment in 5G transport networks. Additionally, the IEEE is extending current Ethernet standards to (i) support link speeds up to 200Gbit/s [7], and to (ii) provide enhancements for time-sensitive traffic (i.e. fronthaul) [8] which are of particular relevance in the context of 5G. Indeed, transport networks will need to provide huge bandwidth, traffic differentiation, and tailored QoS which, in packet-based networks, is enforced by a scheduler residing on the network nodes. The scheduler is in charge of deciding which packet to transmit next when multiple packets are available.

While several works are available in literature about QoS in 5G networks, they mainly focus on the radio interface and do not delve into the transport network and its support for network slicing, especially in the context of multiple edges. Therefore, the goal of this article is to analyze the impact of different QoS policies in case of having multiple network slices, namely eMBB, URLLC, and MIoT, dealing with fixed and mobile traffic under the performance requirements defined in [1].

II. 5G TRANSPORT NETWORK CHRACTERIZATION

An indispensable step for performing the analysis is to properly define the network scenario. At this end, we depart from the 5G transport network reference architecture proposed in [9] and illustrated in Figure 1. The transport architecture comprises three segments: (i) access, (ii) aggregation, and (iii) core. The access comprises 6 Active Antenna Units (AAUs) for each node M1 connected via a point-to-point link, and 6 nodes M1 connected in a ring topology. Thus, each access ring hence connects a total of 36 AAUs. Next, each aggregation ring comprises 6 M2 nodes, each of which serves as gateway to 4 access rings. Finally, each aggregation ring is served by two M3 nodes for redundancy reasons, while each M3 node provides gateway capabilities to 2 aggregation rings. The mobile packet core network is not considered in this article since the focus is on the transport network, therefore composed of access and aggregation segments. It is worth noticing that the M1 and M2

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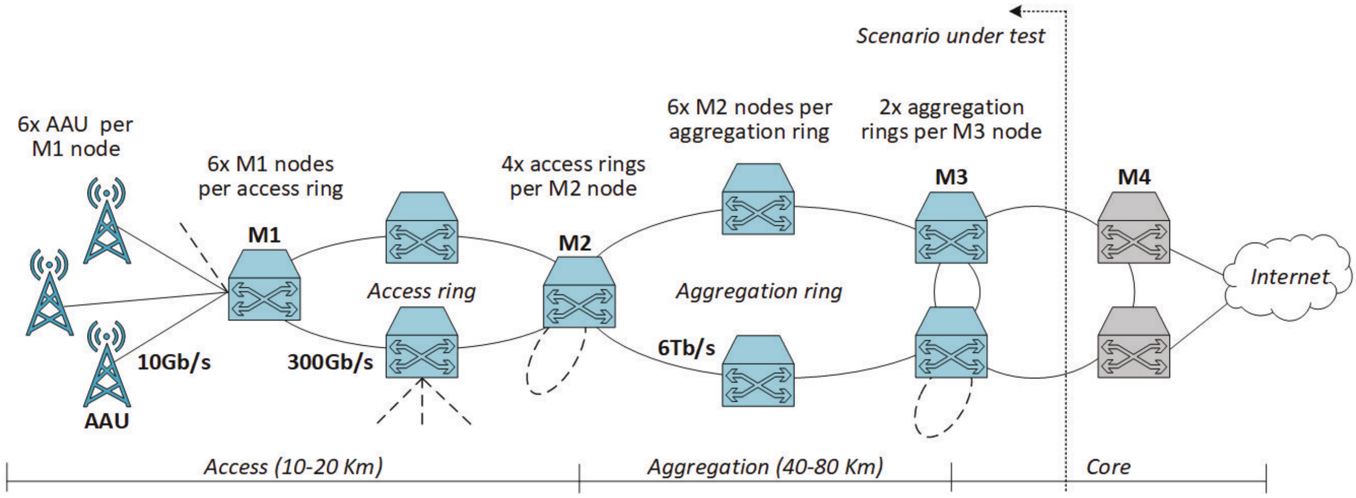

Figure 1: Reference network scenario [9]

nodes are configured in a ring topology (access and aggregation rings, respectively) only at electrical level while at logical level are considered in this analysis to be connected point-to-point to their corresponding gateways (M2 and M3, respectively). This means that packets are enqueued only at gateway level and not every time they traverse a node in the ring. Finally, the link speeds reported in Figure 1 are the result of traffic requirement calculations as described in the following.

After having defined the reference architecture, which identifies the number of hops and multiplexing points in the network, the next step is to identify and define the traffic flow mixture and slices the network needs to transport. In [12] and [1], 3GPP has defined 3 types of slices, namely eMBB, URLLC, and MIoT, and a set of flows with the corresponding traffic requirements for the eMBB and URLLC slices. A set of traffic requirements for the MIoT slice is defined instead by NGMN in [13]. Table 1 presents an integrated version of the original separated tables. It is worth highlighting that this table does not include those flows that are expected to have a limited or ad-hoc deployment, such as broadband access in a crowded event (e.g., limited to stadium/venues), high-speed train (e.g., only along the railway), airplanes connectivity (e.g., sporadic terrestrial base stations), and those flows whose requirements are not fully defined yet, such as tactile interaction and remote control.

Each traffic flow is provided with an Area Traffic Capacity, both in Uplink and Downlink, which identifies the expected traffic density expressed in Gbps/Km^2. Next, an Activity Factor indicates the percentage of time the devices generating that type of traffic are expected to be alive. Finally, a Service Area Dimension specifies as scaling factor the percentage of space a given flow is considered to be present. Therefore, the total amount of bandwidth (Gbps) required per area unit (Km^2) is given by the following formula:

Total Traffic per Area Unit = (Area Traffic Capacity) x (Activity Factor) x (Service Area Dimension)

Given the considerably large distance traversed by the transport network (up to 100 Km), a wide variety of scenarios is expected to be present in terms of traffic characterization. To reflect this aspect, we defined three scenarios: urban, industrial, and rural. An urban scenario is exemplified by a city environment where dense connectivity, intelligent transportation system, high-speed vehicle, and indoor hot-spots are present. In turn, an industrial scenario is characterized by the presence of URLLC traffic related to discrete automation. Finally, the rural scenario considers an open environment with a trafficked 4-lane road. For the sake of clarity, a given scenario considers a specific traffic flow only when the Service Area Dimension is non-zero in Table 1.

The next step is to calculate the number of AAUs required to cover an area unit (1 Km^2). Additional considerations are required in this case given to the different physical deployments. For instance, a service dimension area for the indoor hotspot is 0.040. This result is obtained by considering a tall building with 15 floors with a base of 0.2x0.2 Km^2. The total bandwidth to provide would be 600 Gbps spread over the 15 floors, thus 40 Gbps on each floor. As a result, 4 AAUs per floor are required, considering a peak data rate of 10 Gbps for the AAU. A total of 72 AAUs are hence required to cover 1 Km^2 in an urban scenario. A similar consideration is made for the industrial scenario where the service area dimension is considered of either 0.01 Km^2 or 0.09 Km^2 depending on the type of traffic. A total of 12 AAUs is hence required to satisfy the traffic demand of 1 Km^2 in an industrial scenario. Finally, for the rural scenario, a 4-lane road 16 meters wide is considered resulting in a surface of 0.016 Km^2. Subsequently, 1 AAU provides enough capacity to cover 1 Km^2 in a rural scenario. Table 2 reports those results in addition to the average load experienced by each AAU in each scenario. In turn, Table 3 reports the bandwidth breakdown for a single AAU for each traffic flow and scenario.

One additional consideration is required for understating how the AAUs for each scenario are deployed in the network. Given the expected physical deployment of the AAUs, as well as the expected traffic mix, the access rings are considered to be separated for each scenario that is the traffic mix present on any AAU on the same access ring is the same (e.g., urban, rural,

Table 1: Traffic flow composition per slice, activity factor, and service area dimension

Slice	Traffic flow	Area Traffic Capacity ($Gbps/Km^2$)		Activity Factor	Service Area Dimension		
		Downlink	Uplink		Urban	Industrial	Rural
eMBB	Urban macro	100	50	0.200	1.000	1.000	0.000
	Rural macro	1	0.5	0.200	0.000	0.000	1.000
	Indoor hotspot	15000	2000	1.000	0.030	0.000	0.000
	Dense urban	750	125	0.100	0.040	0.000	0.000
	Broadcast-like services	20	0	1.000	1.000	0.000	0.000
	High-speed vehicle	700	50	0.500	0.020	0.000	0.016
URLLC	Motion control	1000	1000	1.000	0.000	0.010	0.000
	Discrete automation	1000	1000	1.000	0.000	0.010	0.000
	Remote control	100	100	1.000	0.000	0.090	0.000
	Process monitoring	10	10	1.000	0.000	0.090	0.000
	Electricity distribution – Med. voltage	10	10	1.000	0.020	0.010	0.001
	Electricity distribution – High voltage	100	100	1.000	0.010	0.010	0.001
	Intelligent transport systems – Backhaul	10	10	1.000	0.032	0.032	0.032
MIoT	Massive low-cost/long-range MTC	0	200	0.100	1.000	0.090	0.010

Table 2: Traffic load per AAU per scenario

Scenario	Total traffic per area unit ($Gbps/Km^2$)		#AAU per area unit (Km^2)	Traffic load per AAU (Gbps)	
	Downlink	Uplink		Downlink	Uplink
Urban	501.52	92.52	72	6.97	1 25
Industrial	51.32	43.12	12	4.27	3 59
Rural	6.23	1.13	1	6.23	1 13

Table 3: Traffic flow load per AAU for the different scenarios and slices

Slice	Traffic flow	Urban (Mbps)		Industrial (Mbps)		Rural (Mbps)	
		Downlink	Uplink	Downlink	Uplink	Downlink	Uplink
eMBB	Urban macro	277.78	138.89	1666.67	833.33	0.00	0.00
	Rural macro	0.00	0.00	0.000	0.000	200.00	100.00
	Indoor hotspot	6250.00	833.33	0.000	0.000	0.00	0.00
	Dense urban	41.67	6.94	0.000	0.000	0.00	0.00
	Broadcast-like services	277.78	0.00	0.000	0.000	0.00	0.00
	High-speed vehicle	97.22	6.94	0.000	0.000	5600.00	400.00
URLLC	Motion control	0.00	0.00	833.33	833.33	0.00	0.00
	Discrete automation	0.00	0.00	833.33	833.33	0.00	0.00
	Remote control	0.00	0.00	750.00	750.00	0.00	0.00
	Process monitoring	0.00	0.00	175.00	175.00	0.00	0.00
	Electricity distribution – Med. voltage	2.78	2.78	8.33	8.33	10.00	10.00
	Electricity distribution – High voltage	13.89	13.89	83.33	83.33	100.00	100.00
	Intelligent transport systems – Backhaul	4.44	4.44	26.67	26.67	320.00	320.00
MIoT	Massive low-cost/long-range MTC	0.00	277.78	0.00	150.00	0.00	200.00

Table 4: Packet size for each traffic flow

Slice	Traffic flow	Downlink	Uplink
eMBB	Urban macro	Figure 2 shows the packet size distribution obtained from real traffic capture in a mobile network. Lower peak at 64 bytes, higher peak at 1450 bytes.	Figure 3 shows the packet size distribution obtained from real traffic capture in a mobile network. Main peak at 64 bytes.
	Rural macro		
	Indoor hotspot	Figure 4 shows the packet size distribution obtained from real traffic capture in a fixed network. Lower peak at 64 bytes, higher peak at 1480 bytes.	Figure 5 shows the packet size distribution obtained from real traffic capture in a fixed network. Lower peak at 1450 bytes, higher peak at 64 bytes.
	Dense urban	Same as Urban and Rural macro.	Same as Urban and Rural macro.
	Broadcast-like services	1374 bytes [11]	No uplink traffic.
	High-speed vehicle	Same as Urban and Rural macro.	Same as Urban and Rural macro.
URLLC	Motion control	255 bytes [12]	255 bytes [12]
	Discrete automation	1358 bytes [12]	1358 bytes [12]
	Remote control	160 bytes [12]	160 bytes [12]
	Process monitoring	640 bytes [12]	640 bytes [12]
	Electricity distribution – Med. voltage	128, 256, 512, 1024 bytes [14]	128, 256, 512, 1024 bytes [14]
	Electricity distribution – High voltage	128, 256, 512, 1024 bytes [14]	128, 256, 512, 1024 bytes [14]
	Intelligent transport systems – Backhaul	320 bytes [12]	320 bytes [12]
MIoT	Massive low-cost/long-range MTC	No downlink traffic	94, 144, 234, 327, 699 bytes [15]

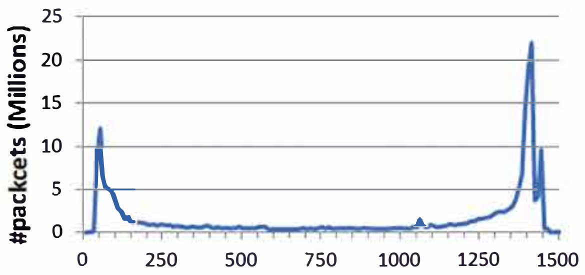

Figure 2: Mobile downlink packet size distribution (bytes)

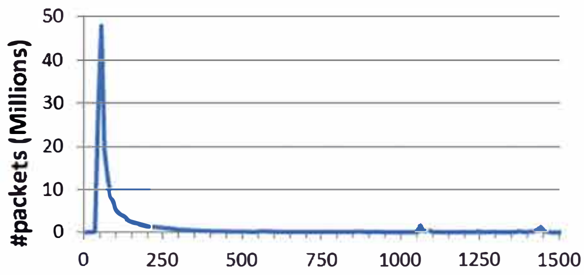

Figure 3: Mobile uplink packet size distribution (bytes)

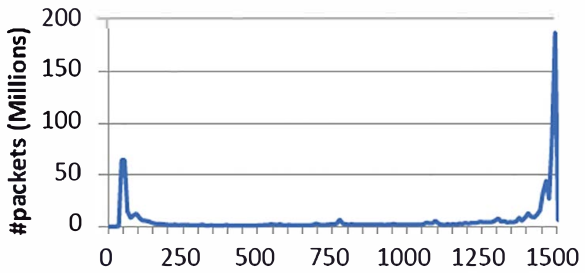

Figure 4: Fixed downlink packet size distribution (bytes)

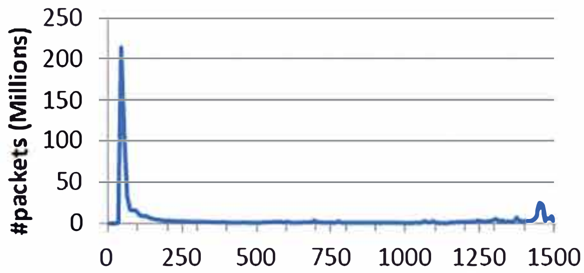

Figure 5: Fixed uplink packet size distribution (bytes)

industrial). Furthermore, the composition of access rings connecting to a M2 node is the following: 2 urban, 1 industrial, 1 rural. Summarizing, at M1 level the traffic multiplexed is separated per scenario (e.g., there is no urban and industrial traffic multiplexing), while at M2 and M3 level traffic belonging to different scenarios is instead multiplexed.

The last traffic characterization relevant for the QoS analysis is the packet size distribution of each traffic flow. Indeed, the length of each packet influences the transmission delay and the jitter as result of the interaction between packets in the queue. Table 4 reports the packet size distribution for each traffic flow, which is derived from both experimental observation of a real mobile network, and reference values. Particularly, Figure 2 and Figure 3 show the packet size distribution for downlink and uplink mobile data respectively. Those packet size distributions are associated to the *urban* and *rural macro*, *dense urban*, and *high-speed vehicle* traffic flows. It is worth highlighting that traffic generated by high-speed vehicles in this case belong to the eMBB slice, which identifies the multimedia traffic (e.g., generated by people in the car or car infotainment). On the contrary, the traffic flow *intelligent transport systems* belongs to the URLLC slice and encompasses the Vehicle-to-Infrastructure (V2I) traffic. Finally, the *indoor hotspot* traffic flow is considered to have a similar traffic pattern to fixed access due to the stationarity nature of the users of such AAUs. To this end, the downlink and uplink fixed packet size distributions (see Figure 4 and Figure 5) are considered for the *indoor hotspot* traffic flow. The rest of packet sizes are reported in Table 4 with the corresponding references.

III. METHODOLOGY AND RESULTS

To perform the simulations necessary to understand the QoS applicability in 5G transport networks, a simulation framework based on SimPy[3], namely SimPype, has been developed and published as open-source [10]. SimPype relies on the concepts of resource and pipe, and decouples the resource from its queue (pipe) in such a way that multiple queueing techniques can be used with the same resource. For this reason, SimPype is well-suited to simulate scenarios where the queueing disciplines and the resources occupation are key parts of the system (e.g., packet-based network). SimPype also allows to create both custom resource and pipe models that can be reused in multiple simulations. In particular, in our QoS analysis we considered the following queueing policies: First-In, First-Out (FIFO), Strict Priority, and Strict Priority with Preemption.

A FIFO queue is the simplest type of queue where all the packets have the same priority and the decision of which packet needs to be transmitted next is only based on the time of arrival of the packet. For this reason, a FIFO queue is also known as First-Come, First-Served (FCFS). In turn, a Strict Priority policy assigns a priority to each packet to be transmitted, meaning that the selection of the packet is based on the priority rather than on the time of arrival. As a result, packets with higher priority are always transmitted first. Lastly, the Strict Priority with Preemption policy works in an analogous way to Strict Priority with the exception that a packet with highest priority can preempt an ongoing transmission of a packet with lower priority. That means that the transmission of a low priority packet is suspended in favor of the transmission of a higher priority packet. The transmission of the low priority packet is then

[3] https://simpy.readthedocs.io/en/latest/

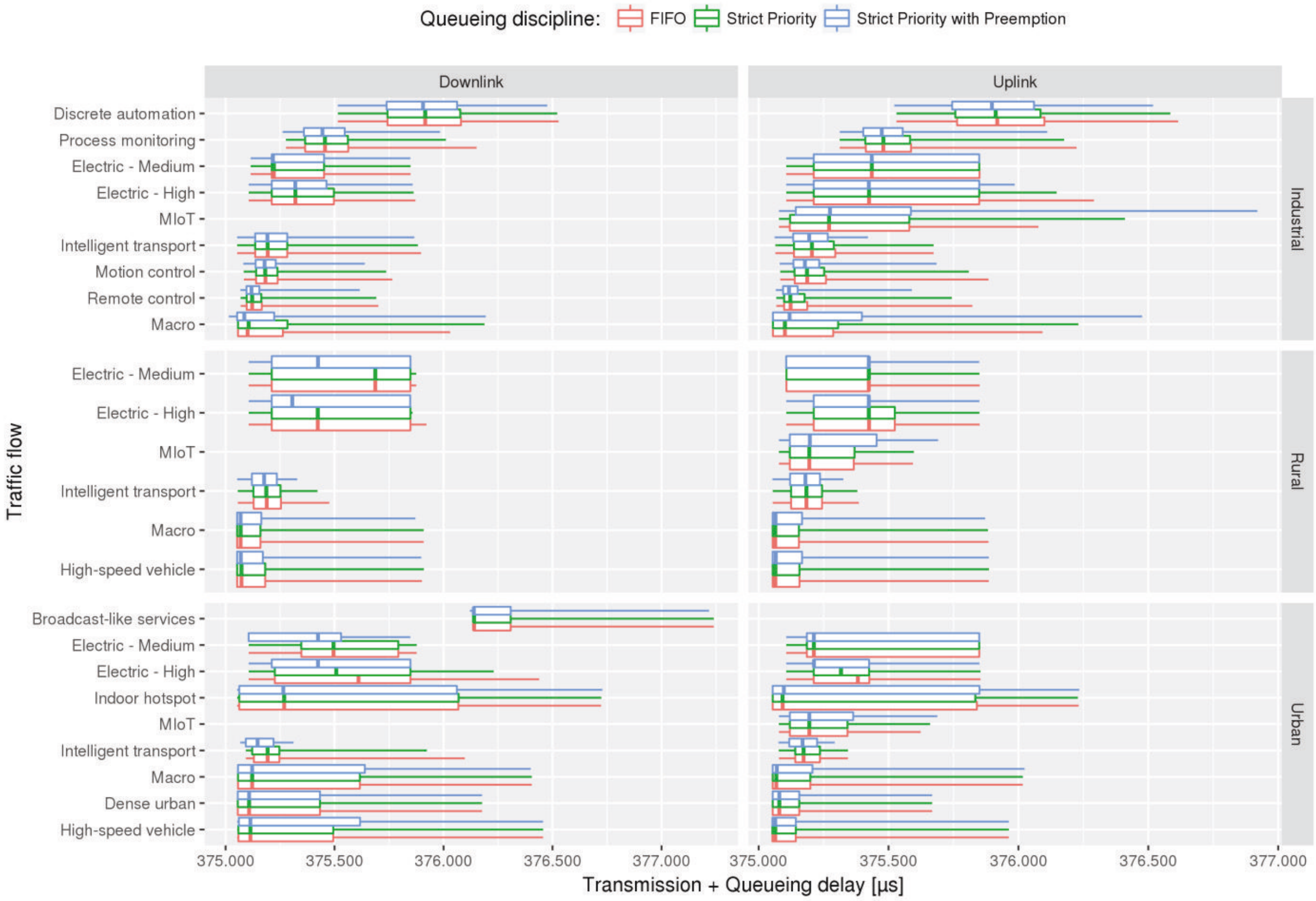

Figure 6: End-to-end transmission and queueing delay for different scenarios and traffic flows

Table 5: Jitter for Motion control traffic flow

Config.	Policy	Jitter (µs)	
		DL	UL
M3 URLLC Unified	FIFO	1.957	3.152
	Strict Priority	1.957	2.575
	Strict Pr. with Preemption	1.949	2.575
M1 URRLC Unified	FIFO	2.364	2.375
	Strict Priority	2.120	1.951
	Strict Pr. with Preemption	2.120	1.951
M1 URLLC Separated	FIFO	2.670	2.556
	Strict Priority	1.370	1.304
	Strict Pr. with Preemption	0.549	0.446
M2 URRLC Unified	FIFO	2.250	4.125
	Strict Priority	2.250	2.704
	Strict Pr. with Preemption	2.250	2.661
M2 URLLC Separated	FIFO	2.250	4.125
	Strict Priority	1.582	1.447
	Strict Pr. with Preemption	0.510	1.117

resumed only when the higher priority packet is successfully transmitted. Packet preemption in Ethernet networks is defined in [8].

The simulation implements the network scenarios and the traffic flow reported in Section II while considering a failure-free environment where the protection rings are not activated. We preformed 100 simulations of a 10 ms timeframe across all the transport network including the generation and transmission of ~6 million packets. For the access and aggregation segments we considered a distance of 15 km and 60 km, respectively, with a transmission delay of 5µs/km [16]. Regarding the priority and preemption policies, packets are prioritized according to their slice with the URLLC having the highest priority and MIoT the lowest. Moreover, preemption is allowed only for URLLC packets against eMBB and MIoT packets whilst eMBB packets do not preempt MIoT ones. Finally, packet generation follows an exponential arrival time.

Figure 6 reports the simulation results for the considered scenarios, traffic flows, and queueing disciplines both in uplink and downlink. The depicted boxplots report the 5^{th}, 25^{th}, 50^{th}, 75^{th}, and 95^{th} percentile of the end-to-end delay, that is from AAU to M3 for uplink and from M3 to AAU in downlink. As it can be noticed, the largest delay component is the transmission delay (75 km · 5 µs/km = 375 µs). The queueing contributes with an additional delay between 0.05 µs and 4.91 µs depending on the traffic flow. For sake of simplicity, we did not consider any additional delay introduced by any processing time at switch level. The traffic flow with the minimum delay is *intelligent transport systems* in *urban* scenario with the *strict priority with preemption* queueing policy. In turn, the traffic flow with maximum value is *MIoT* in *industrial* scenario with the *strict priority with preemption* queueing policy.

Comparing the results with the traffic requirements defined in [1], all the traffic flows fulfil the requirements in terms of delay and jitter except the *motion control* in *industrial scenario*. Specifically, 3GPP defines a maximum jitter of 1 µs for the remote control of actuators in industrial robots which is not satisfied in the scenario under test. Table 5 reports the jitter values in µs for the *motion control* traffic flow for different configurations. The first configuration, namely *M3 URLLC Unified*, considers URLLC traffic traversing all the network from the AAU to M3 nodes (and vice versa) and all URLLC packets have the same priority regardless the traffic flow they belong to. As it can be noticed, the minimum jitter in downlink (1.949 µs) and uplink (2.575 µs) is achieved with the *strict priority with preemption* queueing discipline. However, such value exceeds the maximum admissible value of 1 µs. Therefore, we performed additional simulations as to find a configuration capable of fulfilling the traffic requirements.

The new scenario terminates all the URLLC traffic at M1 level meaning that URLLC traffic does not traverse M2 and M3 nodes neither in downlink or uplink. In the first configuration of this new scenario (labelled as *M1 URRLC Unified* in Table 5), traffic flows belonging to the same slice (i.e., URLLC) have the same priority. As it can be noticed, even terminating the *motion control* at M1 level does not allow to comply with the traffic requirements. Indeed, the minimum jitter in downlink (2.120 µs) and uplink (1.951 µs) is achieved with the *strict priority with preemption* queueing discipline. It is worth highlighting that downlink jitter in this configuration is higher compared to the one obtained by terminating the traffic at M3 level. This is because packets in downlink are enqueued and transmitted at higher speed at M3 level and arrive already sorted at M1 nodes which do not need to perform additional prioritization at lower speed. The last configuration considers assigning a higher priority to the *motion control* compared to the other URLLC flows. Table 5 shows that the target jitter is fulfilled only when the *strict priority with preemption* queueing discipline is used and results in a jitter of 0.549 µs in downlink and 0.446 µs in uplink. Using a similar approach, we simulated URLLC traffic terminating at M2 level with both unified and separated URLLC prioritization. As it can be noticed, the 1 µs jitter is satisfied only in downlink when the *strict priority with preemption* queueing discipline is used while is not fulfilled in uplink.

IV. CONCLUSIONS AND NEXT STEPS

This article presented a characterization of a 5G transport network and the expected traffic mixture. Several simulations have been performed to understand the role of queueing disciplines in different scenarios, such as urban, industrial, and rural. This characterization is key for properly engineering operator's networks to support next 5G services and satisfy the very stringent and diverse needs intrinsic to each of them. The results have been compared with the constraints of the traffic requirements defined in 3GPP and criticality has been identified for the motion control traffic part of the URLLC slice. Jitter requirements for such flow are only satisfied when the traffic is terminated in the access ring and a strict priority with preemption queueing discipline is used. Regarding the other flows and slices, traffic requirements are fulfilled in a failure-free scenario where the protection ring in the access and aggregation is not activated. Future work is expected to analyze logical ring topologies and the role of queueing disciplines and congestion avoidance mechanisms when an error occurs in the network and traffic needs to be rerouted on the protection rings, thus increasing the total amount of traffic transmitted and multiplexed on the same transport link.

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REFERENCES

[1] 3GPP, "Service requirements for next generation new services and markets," TS 22.261, Release 15, Mar. 2017.

[2] ITU-R, "IMT Vision – Framework and overall objectives of the future development of IMT for 2020 and beyond", ITU-R Recommendation M.2083-0, Sept. 2015.

[3] NGMN Alliance, "Description of network slicing concept," NGMN 5G P, vol. 1, 2016.

[4] K. Samdanis et al., "From network sharing to multi-tenancy: The 5G network slice broker," in IEEE Communications Magazine, vol. 54, no. 7, pp. 32-39, July 2016.

[5] A. D. La Oliva et al., "Xhaul: toward an integrated fronthaul/backhaul architecture in 5G networks," in IEEE Wireless Communications, vol. 22, no. 5, pp. 32-40, Oct. 2015.

[6] eCPRI, "Common Public Radio Interface: Requirements for the eCPRI Transport Network," v1.0, Oct. 2017.

[7] IEEE, "Standard for Ethernet Amendment: Physical Layers and Management Parameters for 50 Gb/s, 100 Gb/s, and 200 Gb/s Operation," P802.3cd, Dec. 2017.

[8] IEEE, "Standard for Local and Metropolitan Area Networks -- Bridges and Bridged Networks -- Amendment 26: Frame Preemption," P802.1Qbu, Dec. 2017.

[9] ITU-T, "Consideration on 5G transport network reference architecture and bandwidth requirements," ITU-T Study Group 15, Contribution 0462, Feb. 2018.

[10] SimPype, http://simpype readthedocs.io/en/latest/

[11] S. Fowler et al., "Evaluation and prospects from a measurement campaign on real multimedia traffic in LTE vs. UMTS," in 4th International Conference VITAE, Aalborg, 2014, pp. 1-5.

[12] 3GPP, "System Architecture for the 5G System," TS 23.5011, Release 15, Mar. 2018.

[13] NMGN, "5G White Paper," Feb. 2015.

[14] T. J. Wong et al., "Modelling and analysis of IEC 61850 for end-to-end delay characteristics with various packet sizes in modern power substation systems," 5th Brunei International Conference on Engineering and Technology, Bandar Seri Begawan, 2014

[15] A. Sivanathan et al., "Characterizing and classifying IoT traffic in smart cities and campuses," 2017 IEEE Conference on Computer Communications Workshops, Atlanta, GA, 2017, pp. 559-564.

[16] 5G-Crosshaul, "D2.1: Study and assessment of physical and link layer technologies for Crosshaul," Sep. 2016.