Leveraging SDN slicing isolation for improved adaptive satellite-5G downlink scheduler

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***Abstract*—Software-Defined Network (SDN) and network function virtualization (NFV) technologies are emerging paradigms and enablers for the progress towards service delivery in satellite-terrestrial networks. In This Paper, we propose a significant improvement of our previous proposal, which consists of a downlink scheduling strategy in heterogeneous satellite–LTE-A network, while leveraging SDN and NFV and their role in network slicing. Thus, the main goal of this improved scheduler is to profit from slice isolation to boost the effectiveness of radio resources management. So, as slices are fully independent, we propose adaptive scheduling metric strategies specified according to the network conditions and traffic types. Performance evaluation shows that reliability can be enhanced by reducing the packet of loss ratio achieved via isolation between slices. Results show that the QoS degradation may decrease the metrics of traffic however, this cannot influence the quality of experience in the other slices.**

***Index Terms*—SDN, NFV, Satellite, Scheduler, Slicing, isolation, adaptive**

I. Introduction

5G technologies must be able to significantly enhance the performance, scalability, and flexibility of current mobile networks. Furthermore, optimized spectrum usage should be applied whether for licensed, shared, or unlicensed spectrum bands. As a consequence, three significant 5G service categories can be defined as follows: eMBB (Enhanced Mobile Broadband): Video streaming, as an instance, we cite the data-intensive application that requires a significant amount of bandwidth. Mission-Critical Control (MCC) or Ultra-reliable and Low-latency Communications (uRLLC) are services that are latency-sensitive and require extreme reliability, availability, and protection such as autonomous driving [1]. Specific technologies have been developed for specific uses, including Vehicle-to-everything (V2X) and real-time communications systems for cellular drone communications... Massive Machine Type Communications (mMTC) or Massive Internet of Things (IoT) require low-cost, low-energy systems with limited data loads deployed in huge numbers, such as smart cities.

Since the 5G network has to accommodate both 3GPP and non-3GPP access technologies, interoperability between some of the different access technologies will be crucial. 5G could include services leveraging satellite access for global coverage, service availability, and radio resource utilization. Satellites, in particular, could be used to fully boost the rapid development of the promising 5G industry. Recently, a promising hybrid networking architecture of satellite networks and LPWA (Low Power Wide Area Network) technologies has been proposed. In [2], authors introduced and described Direct-to-Satellite-IoT as a promising research area where existing protocols need to be updated and adjusted. We classify traditional LEO satellite constellation-based IoT application scenarios into two categories to emphasize the current capabilities and potential possibilities that LEO constellation-based IoT systems possess: 1) delay-tolerant applications (DTAs) (e.g., tracking and forecasting applications); 2) delay-sensitive applications (DSAs) (for instance, enhanced supervisory control and data acquisition (SCADA) and military applications).

In this paper, we propose to improve our previous proposal, H-MUDoS (hybrid multi-user diversity downlink scheduler) which consists of a downlink scheduling strategy in heterogeneous satellite–LTE-A network, while leveraging SDN and NFV and their role in network slicing. In fact, by introducing SDN/NFV, our motivation is to make easier the radio resources management and facilitating satellite integration and deployment in the future 5G network. Slicing is done by the SDN controller based on Slice/Service Type (SST).

The remainder of this is paper is organized as follows: in section II, we first introduce the SDN and NFV technologies in addition to their roles in network slicing. In section III, slicing is performed to define our enhanced smart scheduler. Performance evaluation of our scheduling strategy is presented in section IV. The last section concludes our work and suggests future research axes.

II. Slicing in 5G

The key feature of SDN is the separation of both the control and data planes, which is performed by the SDN controller in a centralized location [5]. The whole network is fully managed by this controller which forwards the commands to the different entities in the radio network. In contrast to traditional telecommunication networks where functions are strictly tightened to devices, NFV allows network functions

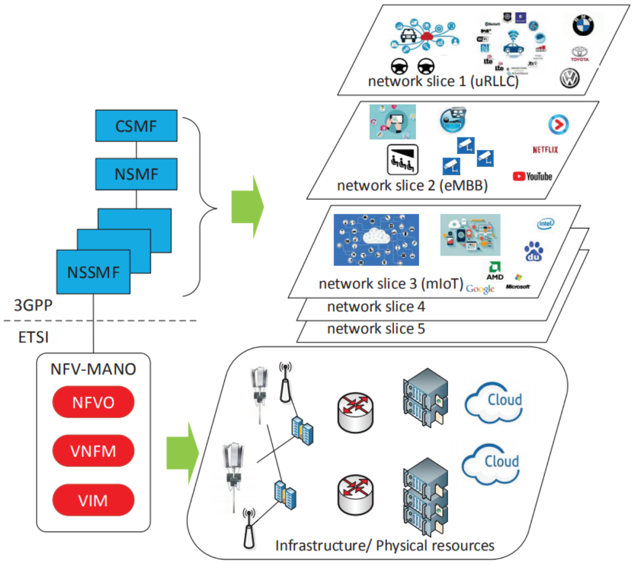


Fig. 1: 3GPP MO architecture of network slicing [6].

to operate on general-purpose servers in the form of software appliances [5].

European Telecommunication Standards Institute (ETSI) proposed the NFV management and orchestrator (NFV-MANO) that is responsible for the flexible and efficient management of virtual resources. NFV-MANO is composed of three main entities which are FV orchestration (NFVO), VNF managers (VNFMs), and virtualized infrastructure managers (VIMs).

Programmability, scalability, and flexibility are the main characteristics of the SDN and NFV which allow network slicing where slices are easily and with low cost created and updated by the NFV-MANO. SDN allows the separation of the CP and the UP, which permits a flexible implementation of the network functions.

To allow the description of a network slice requirement and the deployment of a network slice with its life cycle management, the Third Generation Partnership Project (3GPP) give a basic management and orchestration (MO) architecture, presented in figure 1, of network slicing including communication service management function (CSMF), network slice management function (NSMF), and network slice subnet management function (NSSMF) [6].

Operators could profit from network slicing to establish personalized connections between different functionalities (priority, billing, policy control, protection, and mobility), as well as different technical requirements (latency, mobility, availability, reliability, and data rates) or maybe even satisfy specific applications (such as MPS users, Public Safety users, corporate customers, and so on). A network can be made up of one or even many slices, each of which performs all of the network's functionalities (radio access network functions, core network functions). We can illustrate the management rules of network slicing among them, based on specifications from [8] we may

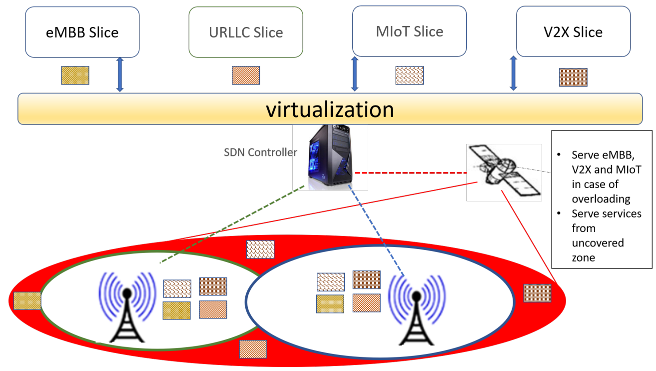


Fig. 2: Proposed hybrid architecture with slices isolation .

outline the network slicing management rules among them by recalling that traffic and services handled through one slice may have no impact on traffic and services carried in other slices, and a network operator should be able to identify a priority order across various network slices.

Another main advantage of slicing is the elasticity in radio resource allocation as the scheduler can share physical radio blocks (PRBs) to accommodate traffic requirements, varying channel conditions as well as Quality of Service (QoS) requirements.

III. Enhanced Smart Slicing Scheduler

All the above-mentioned advantages of network slicing, motivated us, with confidence in enhancement, to extend our previous scheduling proposal [7] which aims at leveraging the multiuser diversity and implement a new metrics computation method for hybrid satellite-LTE downlink scheduler (H-MUDoS). In the proposal, thanks to offloading the congested network and to the smart scheduling metric computation, we enhanced the overall system QoS, as the main requirement by modern telecommunication networks.

However, as our previous findings prove, the degradation of quality, mainly the increase of the packet of the loss ratio in the satellite network, affected the performance of the whole hybrid network. In this proposal, the separation between slices is adapted first to surpass this problem and second to profit from our smart scheduling metrics computation which was designed to compute different scheduling metrics depending on the carried traffic.

As our proposed architecture (fig. 2) presents, we can attach services to either satellite or terrestrial networks. Services are isolated into four main slices, depending on their requirements. Whenever slicing is performed, we assign a special formula for metric computation, as well as services attachment to terrestrial and satellite network, are to be detailed in the following sections.

A. Priority metrics computation

As mentioned above, 5G operators would be able to identify and upgrade the slices of services and features offered in each slice using the 5G framework [8] however 3GPP provides standardized SST values, TABLE I, for establishing global interoperability for slicing so that Public Land Mobile Network (PLMNs) will be able to efficiently support the roaming use cases for the most commonly used Slice/Service Types [9]. e

Slice/Service type	SST value	Characteristics
eMBB	1	Slice suitable for the handling of 5G enhanced Mobile Broadband.
URLLC	2	Slice suitable for the handling of ultra-reliable low latency communications.
MIoT	3	Slice suitable for the handling of massive IoT.
V2X	4	Slice suitable for the handling of V2X services.

TABLE I: Standardised SST values [9]

As the name indicates, URLLC services require ultra-reliability (1-10^{-5} for 32 bytes with a user plane latency of 1ms) as well as low latency (0.5ms for UL, and 0.5ms for DL) where reliability is evaluated by determining the success probability of transmitting X bytes within a certain delay, which is the time it takes to deliver a small data packet from the radio protocol layer 2/3 SDU ingress point to the radio protocol layer 2/3 SDU egress point of the radio interface, at a certain channel quality [9]. For eMBB, the budget latency is equal to 4ms for uplink and 4 ms for downlink. The limit for application layer RTT latency can be as high as 600ms for GEO satellite systems, up to 180ms for MEO satellite communications, and up to 50ms for LEO satellite systems if a satellite link delay is included in communication with a device. [9]. However, low complexity, low data rate, and energy efficiency are the main requirements of IoT devices. For V2X services, communication reliability and resilience, as well as user-plane latency of transmission of a 300-byte packet, reliability of 1-10-5 is required, with a user plane latency of 3-10 msec.

Subsequently, URLLC, eMBB, and V2X all require high reliability as well as very low latency. Thus, for these slices, the scheduler will adapt our previous function for metric computation (function (2) in [7]). The performance evaluation we performed proved that the proposed function for metric computation enhanced the overall system requirements in terms of low delay, enhanced spectral efficiency, and fairness. However, in this proposal, we aim to enhance the reliability by reducing the packet of loss ratio achieved via isolation between slices.

B. Hybrid Satellite-Terrestrial Scheduling

In figure 3, we present the concept of hybrid architecture in which we show the use cases of satellite and terrestrial networks. Since our network is hybrid, terrestrial and satellite are included to guarantee better and extended coverage. However, URLLC requires ultra-low latencies and then they can not be served by the satellite, which increases the latency due to the propagation delay.

In [2], authors show that IoT traffic can be categorized into two groups: Delay Sensitive Applications (DSA) and Delay Tolerant Applications (DTA). DSA requires more strict

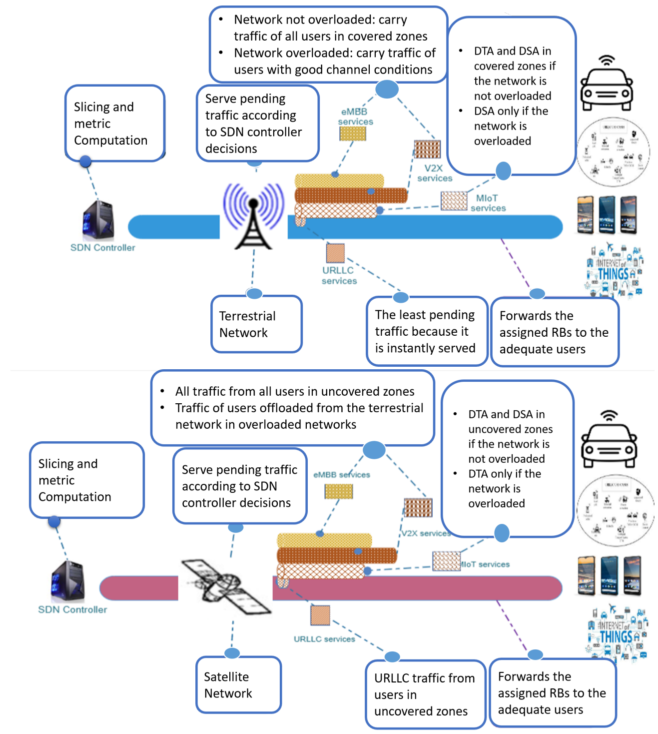


Fig. 3: Proposed hybrid architecture for traffic offloading

requirements and therefore it will be served via terrestrial networks, while DTA can be served via satellite in the event of overloading. For metric computation, we propose to use a proportional fair scheduler since it guarantees fairness among connected sensors. For eMBB and V2X, in the ideal conditions, traffic is sent via the terrestrial network and in case of overloading, the satellite will be included to offload the network with a guarantee of acceptable QoS, and of course, uncovered zones are served by the satellite. The process of our algorithm is summarized in flow chart fig.4.

C. Improvement for ultra-low latency and better reliability

The proposed scheduling strategy, presented in the flow chart fig 4, determines how priorities among services of the same slice are computed. However, due to the variety of requirements among different slices, we propose algorithm 1, which specify the policy that will be applied to guarantee low latency as well as ultra-reliability [1].

Algorithm 1 for ultra low latency and better reliability

1. Pre-compute priority scheduling metrics
2. Repeat
3. if URLLC service's average delay >=Budget delay then
4. Instantly serve pending URLLC traffic
5. else if Average Packet of Loss Ratio (PLR) of eMBB and V2X >= budget PLR
6. Instantly serve emergent pending eMBB or V2X traffic
7. else
8. Apply Proposed scheduler for slices' metric computation

[1]Standard values for the budget delay and budget PLR, used in algorithm 1 are given in Table 5.7.4-1 in [9]

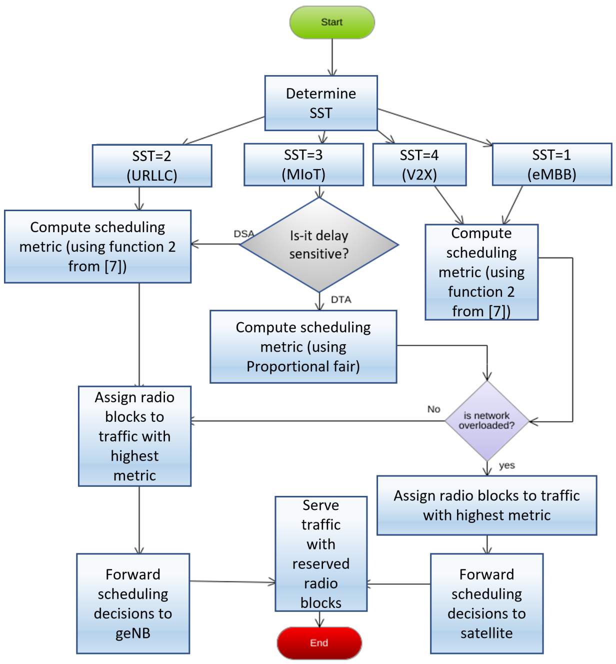


Fig. 4: Flowchart of Hybrid satellite terrestrial scheduling process.

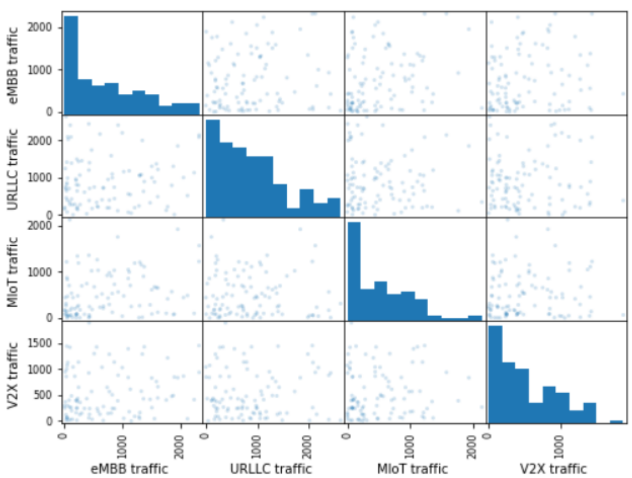
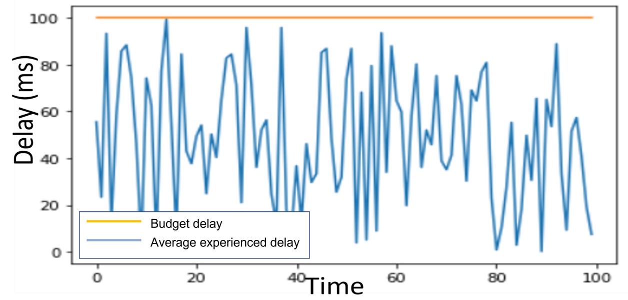


Fig. 5: Scheduling metrics samples form the four slices .

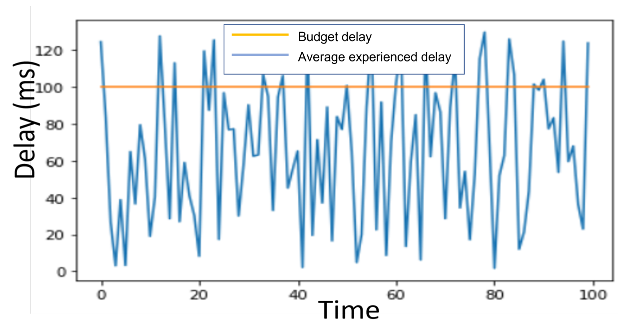
IV. Performance of Scheduling Strategy

A. Metrics computation

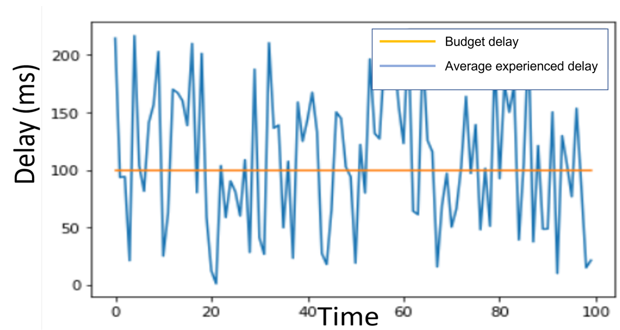
As the main goal of this improved scheduler is to profit from slice isolation, we draw the variation of metrics computed for each slice. As clearly reported by fig. 5, the variation of metrics is independent between slices. QoS degradation in one slice does not affect the QoS of other slices. From each slice, radio resources are assigned to traffic with the highest metrics. The degradation of QoS may decrease the metrics of traffic however, this cannot influence metrics of the other



(a) Non-Overloaded Network



(b) Low-Overloaded Network



(c) High-Overloaded Network

Fig. 6: Average delay variation in case of non-overloaded(a), low-overloaded(b) and high-overloaded networks(c)

slices. Besides, metrics values have different ranges depending on the conditions of each slice.

The significant variances in values, clearly shown in fig 5. will not affect scheduling decisions of the centralized controller thanks to the complete isolation between slices. This helps us to reach our main goal which was the decrease of the impact of PLR increase caused by the integration of satellite links, during the proposed network offloading strategy.

B. Network Offloading

As clearly shown by fig. 6, in the non-overloaded network, the average delay is always under the budget delay. The QoS, in this case, is successfully achieved and the terrestrial network is used to serve users in covered areas. In the second and third cases, the experienced delay exceeds the average delay, due to overloading. Traffic with high delays will be withdrawn as they are expired. This will increase the packet of loss ratio so the reliability will not be achieved. In our proposal, traffic experiencing high delays have to be passed by the satellite to offload the whole network which will decrease pending traffic, delays, and so decrease the PLR and enhance the system reliability.

V. Conclusion and Future Work

In This Paper, we introduce a slicing isolation strategy performed by SDN/NFV paradigms. We present a significant improvement of our previous proposal, which consists of a downlink scheduling strategy for adaptive satellite-5G. Simulation results show that the QoS degradation may decrease the metrics of traffic however, this cannot influence metrics of the other slices.

Obtained results open the perspective to a more specific slicing strategy in which we may also cluster traffic of each slice according to both the experienced channel condition and the 5G QoS indicators (5QI). Also, we will implement our module for the simulation of slicing isolation in a hybrid terrestrial-satellite 5G network.

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