5G Network Slice Resource Overbooking: An Opportunity for Telcos to Boost their Revenue

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***Abstract*—The global impact of COVID-19 has been unprecedented, with over-the-top (OTT) services consumption growing at a staggering rate. While OTT does consume revenue-generating data, OTT services are gradually substituting the traditional primary sources of revenue, voice and SMS services, with "freemium-based" alternatives such as WhatsApp and Telegram. This has driven telcos to reconsider their strategies and revenue sources. We believe that 5G network slicing (a type of 5G infrastructure sharing) is a potential solution that telcos could adopt to boost their revenue. In particular, this paper introduces the concept of network slice resource overbooking. We consider leveraging machine learning (ML) to maximise network resource utilisation which translates to maximum revenue gains for telcos. The concept of overbooking is unique and novel in network slicing. To realise this objective, we intend to build a mathematical model of the overbooking strategy, and integrate the model into a resource orchestration platform for evaluation on an emulated 3GPP (Release 16) compliant 5G testbed.**

***Index Terms*—5G, Network slicing, Machine learning, Revenue management, Resource overbooking, Forecasting, Infrastructure sharing**

I. INTRODUCTION

One of the biggest issues telcos have had to respond to is the growing adoption and consumption of OTT services. As mobile broadband penetration and smartphone proliferation increase, the popularity of OTT services has exploded. These services used to largely involve video-on-demand (VoD) offerings such as Netflix and YouTube. Today, OTT also covers a wide variety of audio, video conferencing, and messaging platforms such as Microsoft Teams, Zoom, WhatsApp, and Skype. A growing issue is that these services are close substitutes for the traditional voice and SMS services, which are the principal revenue stream for telcos. Moreover, most of these OTT services are offered following a "freemium-based" business model. This means that as a consumer only only needs to pay for mobile data to access these services and pay a subscription fee for premium features. This model and a wide variety of options have massively contributed to the shift in consumer preferences towards OTT services, posing a credible threat to telcos' revenue. Although telcos also generate revenue from data subscriptions, the data revenue has not offset the drastic decline in voice and SMS revenue [1]. COVID-19 forced more people to work and study from home, resulting in even more consumption of OTT services.

Telcos have to date, developed and adopted various strategies to defend and increase their revenues against OTT services. One of the popular strategies adopted is product-bundle pricing, where the telco bundles voice, data and SMS together in their top-up products to receive desired average revenue per user (ARPU). In exchange of bundling, the telco provides discounted prices to its customers. Other telcos (especially small players in markets with entrenched incumbents) have resorted to partnering with OTT players to gain market share. A typical partnership strategy adopted by these telcos is to offer zero-rated OTT services (such as WhatsApp and Facebook) in an attempt to lure users to their mobile network. Few countries have taken a more aggressive approach of banning OTT services to protect voice and SMS revenue or throttle them so that the voice conversation over these services became near impossible. Another long-term strategy in the pipeline for most telcos is to introduce their own OTT services. To achieve this, telcos would need to grow the necessary expertise in-house or acquire a company with the necessary skills and technology base. A clear downside of this strategy is that it would require significant capital and the approach is quite risky for telcos that do not have the necessary skills to launch OTT services.

A promising next-generation strategy to reverse the decline in telcos' revenues is to adopt 5G network slicing. Network slicing presents an opportunity for telcos to not only open their infrastructure to OTT service providers and mobile virtual network operators (MVNOs), but also to vertical industry segments (such as healthcare, construction, automotive, and agriculture), which have traditionally been alien to the telecommunication industry. In their quest to digitally transform their businesses, vertical industries require connectivity. Unfortunately, it is expensive for these industries to build their own infrastructure. It usually is more cost-effective to pay for obtaining a dedicated "slice" from incumbent operators to fully realise their digital transformation objectives [2]. These industries have conflicting quality of service (QoS) requirements, including ultra-low latency, high reliabilty, high throughput, high security, high availability, and high connection density. It is virtually impossible to satisfy each of these service requirements using the legacy monolithic networks. This is because legacy networks are designed to operate on best-effort, where all devices, services, use cases and customers are treated the same.

A. Network Slicing: Concept Definition

Network slicing promises unprecedented flexibility, agility, and the ability to create multiple logical dedicated networks, known as “slices”, on top of shared physical infrastructure. An underlying rationale behind network slicing is that the current “one-size-fits-all” nature of legacy networks is an inefficient way to run the network and would not suffice to meet the needs of next-generation use cases. Network slicing offers telcos the ability to differentiate their data pipes with various QoS, allowing a genuine service differentiation and supporting new uses cases beyond mobile broadband. 3GPP has defined five standardised 5G network slice types in TS 23.501 [3], namely:

- **enhanced Mobile Broadband (eMBB)**: to cater for data-intensive use cases which require high bandwidth, such as UHD video streaming, immersive experience with augmented reality (AR) and virtual reality (VR), and a long tail of others [4].
- **Ultra-Reliable Low Latency Communication (URLLC)**: this slice type is designed to support use cases that require extremely low latency with high reliability, availability, and security. Examples of such use cases are autonomous vehicles, product line automation, tele-surgery, or any Tactile Internet application [5].
- **Massive Machine-Type Communications (mMTC)**: this slice is designed to support IoT use cases where low-cost, low-energy devices (e.g., sensors, actuators and smart devices) with low data volume connect on a massive scale (i.e. up to one million devices per square kilometre). Some of these use cases include smart farming, traffic management, fleet management, and waste management. Notably, 3GPP has ratified Narrowband IoT (NBIoT) [6] and LTE Machine Type Communication (LTE-M) [7], as suitable cellular standards for low power wide area IoT deployments.
- **High-Performance Machine-Type Communications (HMTC)**: this slice is designed to cater for use cases that require high throughput and low connection density, including industrial IoT applications such as asset tracking, and predictive maintenance.
- **Vehicle-to-everything (V2x) Communications** this slice is tailored to serve the needs of next-generation use cases, such as autonomous cars, truck platooning in transportation [8], connected ambulances in healthcare, and unmanned aerial vehicles for instance.

Empowered chiefly by network function virtualisation (NFV) [9], software-defined networking (SDN)[10], cloud computing and artificial intelligence (AI) integration, network slicing is envisaged to shorten the time to market new services from months to hours [11]. This is because instead of building dedicated networks for their enterprise customers case by case, network slicing makes it possible for telcos to create new networks on-demand, by simply connecting virtual network functions running in virtual machines or containers.

B. Architectural Options

There are different kinds of network slicing architectures with varying degrees of sharing, namely: (i)*radio access network (RAN) slicing*: where passive (power, land, masts, etc.) and active elements (spectrum/time resources) of the access network are shared (ii) *core slicing*: where 5G core network functions as well as computing and storage resources are shared and (iii) *end-to-end slicing*: where the entire network infrastructure (including the RAN, backhaul links, edge network and core network functions) is shared. In most cases, the RAN has been targeted for slicing to maximise cost savings. This is because the RAN usually constitutes the largest portion of infrastructure cost [12]. To date, several prototypes have been developed to demonstrate the possibility of active RAN slicing with, [13], and [14] being among notable deployments. However, enforcing slices on the RAN remains challenging [15], especially when a dynamic slicing model has been adopted and RAN slices must be flexibly re-configured while ensuring slice isolation.

II. PROBLEM STATEMENT

Although Network Slicing has the potential to increase revenue sources for incumbent network operators and improve broadband penetration, it involves several technical challenges that must be carefully considered. These challenges are more pronounced in scenarios where the dynamic network slicing model is employed. A slicing-enabled network is typically bombarded with an influx of requests from disparate tenants i.e. OTT providers, MVNOs, and industry verticals, who require concurrent access to shared and limited network resources. From the network tenant’s perspective, QoS guarantee and slice affordability are typically top priorities. In contrast, profitability is a top priority for the telco. Satisfying these contrasting objectives under the dynamically changing network load is not a trivial task. Thus there is a need to devise a solution that will balance this trade-off between QoS guarantees for the network tenant and optimal resource utilisation, which translates to maximum revenue collection by the telco. Ultimately, a sliced network should optimise network resource utilisation (especially scarce resources such as spectrum) while managing existing service level agreements (SLAs) with existing tenants.

III. PROMISING SOLUTION: NETWORK SLICE RESOURCE OVERBOOKING

Overbooking is a common practice in the travel and hospitality industries, where more reservations are accepted than can be accommodated in an effort to minimise losses and maximise business revenue. For example, in the airline industry, overbooking strategies are used to decide, based on the number of seat reservations, whether or not to accept or reject new reservation requests taking into account the probability of some passengers cancelling their reservations or failing to show up at the departure gate. Traditional overbooking strategies are based on “blind” projections of no-show passengers [16]. The “blind” overbooking approach is susceptible to error and sometimes results in more passengers showing up than anticipated. Importantly, overbooking is performed with an associated penalty or compensation (such as travel vouchers, seat upgrades or flight points) that must be applied in cases where all passengers show up and are unable to board an overbooked flight. Notably, South Africa has consumer laws in place, i.e. the consumer protection act (CPA) [17], which safeguards consumers against overbooking and overselling goods and services. In other words, service providers are legally prohibited from accepting payment for services that cannot be delivered. Therefore, when implementing overbooking, it is critical for the overbooking strategy to be as accurate as possible to minimise unmet consumer bookings. To improve forecast accuracy and passenger experience, airlines are exploring machine learning-based optimal overbooking strategies [18]. In this approach, a machine learning model is trained with historical user behaviour data to gain full insight into booking cancellation patterns.

In the context of network slicing, we define overbooking as the act of allocating more resources than presumably allowed by the leftover capacity, in anticipation that some of the slices will ultimately not use their booked capacity. Applying an overbooking strategy to a slicing-enabled network has a great potential to generate additional revenue for telcos, since it maximises overall network resource utilisation. As reported in [18], a good overbooking strategy is based on machine learning (ML) to aid its decision-making. Usually, the quality of service provided by a telecom operator is governed by service level agreements (SLAs). Ultimately, overbooking should maximise revenue without compromising SLAs. Achieving both revenue and SLA fulfilment can only happen with accurate demand forecasting algorithms.

This paper describes our plan to study the feasibility of integrating overbooking (leveraging on big data analytics and existing ML algorithms) to a network slicing capable 3GPP-compliant 5G testbed. The ultimate goal of our project is to produce “real data” driven recommendations on how to optimally implement overbooking in network slicing to maximise network resource utilisation (which translates to maximum revenue generation for the telco), without incurring excessive penalties.

IV. SIMILAR WORK

To the best of our knowledge, there are only limited studies focusing on overbooking resources to maximise network slicing resource efficiency and overall revenue gains. Moreover, a few existing studies especially [19], [20], and [21], only focused on mathematic modelling without evaluating their models on a real 3GPP-compliant testbed. The authors of [22] did not fully disclose the implementation details of their overbooking strategy. Instead, they provided a very high-level overview of their testbed implementations. The lack of literature on network slice overbooking is probably linked to the slow commercial uptake of network slicing [23]. Most mobile network equipment vendors (such as Ericsson and Nokia, who are among the leaders of network slicing) have mostly been focusing on the technical requirements and implementation of the network slicing architecture (such as integrability of network slicing solutions to legacy network assets and security [24]), and not so much on the business architecture. Based on these observations, the link between slicing and resource overbooking, which supports a business strategy has not been explored.

V. METHODOLOGY

Inspired by our work in [25], we intend to build our demonstration on top of a fully-fledged 3GPP-compliant 5G testbed, equipped with network function slicing capabilities. Figure 1 below provides a high-level architectural design of the key building blocks of the testbed.

A. *Infrastructure Layer*

The bottom tier, i.e. infrastructure layer will be built using 3GPP-compliant open-source software platforms on top of generic hardware. Specifically, we plan to implement the RAN using the 3GPP compliant 5G new RAN (gNB) from the Open Air Interface (OAI) open-source project [26], which runs on top of a dockerised environment. The core network will be deployed using 5G Core network functions, following a microservice architecture. The core network and mobile edge will be deployed on top of an OpenStack data center. Subject to availability, the transport network is likely to be deployed using mmWave and microwave wireless links as well as wired (either ethernet or optical) transport network using software-defined (SDN) programmable switches for configuration of different network topologies with predefined capacity and delay characteristics.

B. *Orchestration Layer*

The top tier is an orchestration platform responsible for admission control, resource management and slice lifecycle management (preparation, commissioning, run-time monitoring and decommissioning of slices). To date, there is a plethora of open-source ETSI MANO [27] compliant orchestration platforms as reported by [28]. Of them, ONAP and OSM are rated as the best in terms of their ability to orchestrate resources across multiple technological (such as SDN, cloud, and NFV) and administrative domains (RAN, edge, and core networks), production readiness, scalability, flexibility, and adoption coverage. Our project intends to integrate and extend one of the prominent orchestrators with overbooking intelligence, by implementing an optimal ML-based overbooking algorithm on top of the admission control engine. A decision on which orchestrator to adapt will be made after doing thorough benchmarking experiments of the available orchestration solutions. Orchestration platforms are inherently modular and generally constitute components such as the resource manager, admission controller, monitoring modules, slice, classifiers, and so forth. Our study primarily utilises extended versions of the following modules:

Classifier: uses slice templates and supervised ML to classify slice requests into the three 5G use case families

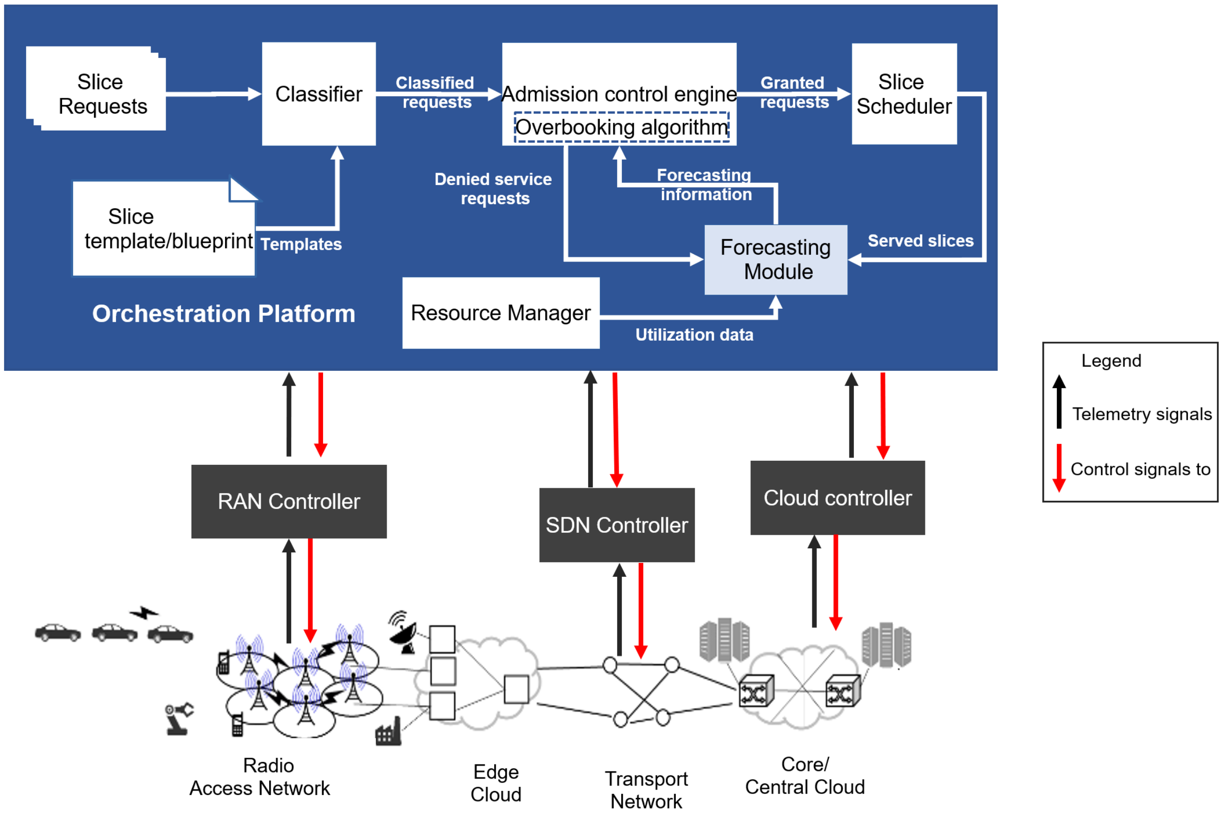

Fig. 1: High level architecture of the system to be developed

namely, eMBB, URLLC, and mMTC. A slice template is a set of attributes such as availability, throughput, latency, reliability, security, priority, etc., used to define the characteristics of a slice upon receipt of tenant requirements. Essentially, all requirements from a potential tenantare mapped into a specific slice template that best describes said requirements. Slice requests are introduced via a dashboard and sent to the orchestrator via a REST API (RESTful API).

Forecasting module: Future slice requests are predicted by building traffic profiles generated using cumulative data collected over a profiling time window. The admission controller uses the outcome of these predictions for enriched decision-making as it pertains to optimal resource allocation to current demands, while reserving resources to serve potential future demands. Traffic profiles are built using supervised ML techniques. The forecasting variables used to build traffic profiles include environmental conditions, timestamps, day of the week, season of the year, special events, and so forth. From a technical viewpoint, traffic patterns vary at certain times (e.g. during working hours versus leisure time), on certain days of the week (e.g. weekends and weekdays), and with certain events (e.g. soccer matches and elections) and with environmental conditions (eg. rainy conditions which generally decreases the amount of movement). The aforementioned forecasting variables can also be used to gain deeper insight into demand cancellation patterns, which is critical when developing an overbooking strategy. Due to time constraints, this research study will utilise a publicly available resource demand dataset to train its forecasting module. To enable adaptive forecasting, the module will also be fed with real-time network utilisation data from the resource manager and slice provisioning data from the slice scheduler.

Admission control engine: receives the classified slice requests from the classifier and is extended with advanced overbooking policies, to ensure autonomous and rational slice requests admission or denial according to current and future demand forecasting information it received from the forecasting module. Based on the forecasting information received, the admission controller determines the optimum slicing ratios and virtual network function placement on the infrastructure layer. Furthermore, the admission controller forwards all denied requests to the forecasting module to optimise forecasting accuracy.

Slice scheduler: All granted requests, along with the appropriate slice resources, are forwarded by the admission controller to the slice scheduler, which schedules (allocates) slicing resources with minimal time duration. The schedular either serves the requests within the current time window or defers the requests to the next time window. The slice scheduler provides feedback to the forecasting module regarding current resource utilisation to close the optimisation loop.

Resource manager: The resource manager has a global view of the current system load, the queuing status of awaiting requests, and the amount of idle resources in the network [29]. To maintain a satisfactory user experience (through a consistent SLA enforcement), decrease the probability of service denial, and maximise profit for the InP, slice resource re-dimensioning is applied by the resource manager according to the varying traffic demands and resource availability. The resource manager uses "run-time" telemetry data (such as network utilisation, anomalies, SLAs status, etc.) from domain controllers to enforce its resource orchestration decisions.

For our project, we intend to evaluate the performance of each of the aforementioned orchestration modules from a standalone viewpoint. This is to gain deeper insight into the functionality of each module and to determine the best integration approach for our overbooking strategy. The overbooking strategy will be modelled using MATLAB before integration with the orchestration platform, where performance evaluation will be conducted.

C. Control Layer

Another critical component of our testbed is the control layer, which constitutes the RAN controller, Transport SDN controllers, and Cloud controller. These controllers are responsible for providing monitoring information to the orchestrator, particularly the resource manager, which uses said information to enforce orchestration decisions (such as slice instantiation, termination, resource re-dimensioning, and so forth) on the data plane. The orchestrator and the controllers will communicate via the northbound interface (NBI) using REST APIs. The orchestration platform is the only entity that maintains state information. At the same time, the controllers are stateless to guarantee consistency of information and avoid stale information sharing. A prominent software-defined RAN controller called FlexRAN [30] is planned to be adapted to manage the underlying RAN infrastructure. Furthermore, inspired by our work in [31], we plan to use the ONOS SDN controller to handle forwarding decisions in the transport network. For orchestration of cloud resources, we plan to use Openstack's Heat service [32].

D. OSS/BSS

The operation support system/business support system (OSS/BSS) will be implemented using TICK Stack, which constitutes four components namely, Telegraph, InfluxDB, Chronograph, and Kapacitor. Telegraph is a metrics collection agent that sends time-series data (such as monitoring data, internet of things (IoT) data, and real-time analytics) to InfluxDB ensures high-availability storage and retrieval of said data. Chronograph is used for real-time visualisation of the accumulated data. Kapacitor is used for processing both stream and batch data from the InfluxDB database. Last but not least, we intend to use commercial off-the-shelf (COTS) smartphones as the user equipment (UEs). The smartphones will be used as traffic generators under the eMBB, guaranteed bit rate (GBR) applications (such as conversational voice (VoIP)) and non-GBR best-effort applications (such as video streaming and file transfer).

VI. CONCLUSION

In order to capitalize on the growing demand for connectivity (fueled by the aggressive digital transformation efforts by various vertical industries), telcos are exploring ways to re-architect their network infrastructure, and reimagine their business and operating models. An important network capability required to satisfy the contrasting needs of vertical customers is to offer personalised quality of service. 5G network slicing inherently enables differentiated quality of service and is thus believed to be a suitable solution for supporting vertical industries. Network slicing presents a win-win solution for all stakeholders involved. On the one hand, it eliminates the customers' (vertical industries, OTTs, and MVNOs) infrastructure investment concerns by leasing network resources on-demand and following a consumption-based pricing model. This is usually more cost-effective than building one's own dedicated network. On the other hand, network slicing presents an opportunity for telcos to unlock countless revenue streams from leasing their infrastructure to a wider customer base.

This paper introduced the concept of network slice resource overbooking as a potential solution to fully unlock the revenue potential of network slicing and to defend telcos' revenue against OTT services.The main business driver behind overbooking is to ensure 100% resource utilisation, resulting in maximum return on investment. This paper provided high-level architecture of a 3GPP-compliant, network slicing-capable 5G testbed we plan to build as part of our research project. Building such a testbed is not a trivial task as it involves the integration of multi-vendor solutions, ranging from closed proprietary platforms to open source virtualized network platforms. The ultimate objective of our project is to investigate the feasibility and benefit thereof of network slice resource overbooking empowered by machine learning techniques.

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