The Structure of Service Level Agreement of Slice-based 5G Network

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Abstract—Network slicing is considered to be one of the key enablers to Fifth Generation (5G) communication system. Legacy telecommunication networks have been providing various services to all kinds of customers through a single network infrastructure. In contrast, with the deployment of network slicing, operators are now able to partition entire network into different slices, each with its own configuration and Quality of Service (QoS) requirements. There are many applications across industry, each needs an independent slice with its own functions and features. All these applications open new business opportunities, which require new business models and therefore most SLAs between service provider and tenant or between service provider and tenant. The requirements and characteristics of various service types in legacy telecommunication networks are almost identical, therefore, most SLAs between service provider and tenant contain same metrics. However, in slice-based 5G networks, every slice needs an individual SLA, which would have unique elements, metrics and structure in comparison to the SLAs of other slices within same network.

Index Terms—Network Slicing, Slice, Tenant, Service Provider, Service Level Agreement, Metrics, 5G.

I. INTRODUCTION

The 5G communication system is going to fulfill diverse service requirements of all aspects of human life. It will enable different kinds of services and various types of vertical industries such as automotive, logistic, health-care, manufacturing, agriculture, etc. In addition, the 5G communication system is expected to support ultimate service experiences such as Ultra High Definition (UHD) video, online gaming, augmented/virtual reality, cloud desktop, etc. in scenarios with ultra-high traffic density, high mobility, extremely high connection density, and wider coverage area.

Most existing communication networks are monolithic, where an One-Size-Fits-All architecture is used to provide services. In order to support various types of 5G applications and fulfill diverse service requirements beyond 2020, the monolithic architecture is no longer sufficient. Therefore, the new concept of Network Slicing is emerged, where a network operator logically divides its network into multiple virtual networks called Slice [1]. All slices of an operator are maintained over the same infrastructure, while each slice has its own features such as QoS, engineering mechanism, architecture and configuration. Network slicing allows operators to partition networks in a structured, elastic, scalable and automated manner in order to reduce total cost, decrease energy consumption, and simplify network functions.

As briefly discussed earlier, each use case of 5G communication system needs its own slice that consists of independent functions, requirements, and characteristics. For example, a slice may be dedicated to Critical-Machine Type Communication (C-MTC) such as remote surgery, which is typically characterized by high reliability, ultra-low latency and high throughput. Another network slice may be specified to support water meters reading, which requires a very simple radio access procedure, small payload volume and low mobility. Furthermore, the enhanced Mobile Broadband (eMBB) services may require a separate slice, which is characterized by a large bandwidth in order to support high data rate services such as HD video streaming. All these mentioned and other types of slices open new business opportunities, which require new business models.

The requirements and characteristics of various service types in legacy telecommunication networks are almost identical, therefore, most SLAs between service provider and tenant contain same metrics. However, in slice-based 5G networks, every slice needs an individual SLA, which would have unique elements, metrics and structure in comparison to the SLAs of other slices within same network.

As its name implies, the SLA is an official agreement between service provider and tenant or between service providers, based on which the level of rendered service is precisely defined. According to the International Telecommunication Union (ITU), “the SLA is a formal agreement between two or more entities that is reached after a negotiating activity with the scope to assess service characteristics, responsibilities and priorities of every part” [2]. It agrees common understanding about a service with all relevant aspects such as performance, availability, responsibility, etc. Each SLA includes a specific number of elements, which are called metrics. These metrics are used to describe the level and volume of communication services and to measure the performance characteristics of
the service objects. Every SLA includes technical, economic and legal statements in order to cover all aspects that are supposed to be agreed between the service provider and the tenant. In order to efficiently measure the performance and describe the level of service, the management of SLA should be automated for the sake of accountability of various network conditions and variety of user patterns over different slices. The automated management function of slice-based SLA is achieved through network programmability, virtualization, and controlling functions.

Recently, the SLA in telecommunication networks has been exclusively studied. The ITU proposed a generic structure of SLA in multi-service providers telecommunication environment in recommendation E.860 [2]. The proposed SLA defines all QoS-related terms, and furthermore describes the entire procedure of an end-to-end SLA. The European Telecommunications Standards Institute (ETSI) has conducted numerous studies on SLA that are available in [3], [4], and [5]. The reference [3] explores two main aspects of SLA, the development phases and the template, and then discusses further about the contents, technical features, QoS metrics and commitments, charging and billing, and reporting of an SLA. The reference [4] investigates the life cycle of SLA and penalty. The reference [5] studies user demands and various offers, which are provided to the tenant. Moreover, an end-to-end structure of QoS-oriented SLA and a framework of real-time management of SLA of multi-service packet networks are investigated in [6]. The authors presented a monitoring scheme, which is capable to generate revenue by admission flows, and calculates penalty when flows are lost. Although, no study to date has been conducted to explore the SLA between tenant and service provider of slice-based 5G network.

In this paper, we are going to propose an end-to-end structure of SLA for slice-based 5G communication network. We will further discuss the metrics of our proposed SLA, which are needed to be considered by both service provider and tenant during the agreement. The rest of the paper is organized as follows: The concept and structure of our proposed SLA is thoroughly discussed in Sec. I. Subsequently, we are going to analyze the metrics of our proposed SLA in Sec. II. Last but not least, Sec. IV summarizes major conclusions and outlines future research directions.

II. THE STRUCTURE OF PROPOSED SLA

In this section, we introduce and thoroughly describe an end-to-end structure of our proposed slice-based SLA between tenant and service provider of 5G communication system. Moreover, we discuss two types of slice-based SLA, Static SLA and Dynamic SLA, which we think are useful to simplify the operation process of different categories of services over different kinds of slices of a single 5G communication network. The static SLA is predefined SLA, where all metrics, the quality of assured service, legal and financial matters, etc. are predefined between tenant and service provider. When the static SLA starts, the service runs according to the agreement, neither of the parties could bring any change such as increasing the throughput, decreasing the latency, etc. during its lifetime. However, in the lifetime of dynamic SLA, the values of metrics randomly change according to the requirements of the tenant. For example, the tenant of a low latency slice could pay according to the amount of bandwidth, the more he/she spends the bandwidth the more he/she has to pay. Or may require full control on the slice and assured extremely low latency service during remote surgery, but, when the surgery completes, the slice may stops providing the service.

The entire life-cycle of a sliced-based SLA consists of three phases: the creation phase, the operation phase, and the termination phase. In the creation phase, the tenant chooses a service provider that is able to fulfill its requirements. After that both sides agreeing and establishing the SLA, the service starts running over the slice. In the operation phase, the service remains under maintenance and consistently monitored by both sides. In case of any violation of the SLA, a corresponding penalty is executed. In the termination phase, which can be triggered by either violation of agreement or contract expiration, the slice stops providing services and the SLA is terminated. Once decided to eliminate the slice and terminate the SLA, it is recommended to remove all information associated with service configuration, service requirements of the tenant, and service maintenance from the system. However, some tenants or service providers may prefer to archive the information related to their services for a certain period.

The detailed procedure of our proposed SLA is depicted in Fig. 1. In the creation phase, the tenant and service provider agree on all terms and conditions of agreement. In the context of this agreement, the tenant is promised to be provided with assured QoS for a certain period of time, which is called the lifetime of SLA. Upon agreement, the service provider and the tenant sign the documents and the SLA is officially established.

In the operation phase, the operator provides and maintains service to the tenant through an individual slice, which is acknowledged by the tenant. Meanwhile, a set of QoS metrics of the slice service, such as security, power, throughput, latency, etc., are constantly monitored in real time. The monitoring function of should be accessible to both sides in order to ensure proper service configuration, management, and maintenance.

In the context of slice-based SLA, incidents that may happen to a slice, which we categorize into three levels: minor incidents (I_{mi}), major incidents (I_{ma}) and critical incidents (I_{cr}). The I_{mi} indicates a noncritical condition on the slice that, if left unchecked, might cause an interruption to service or degradation in performance. When it occurs, it does not usually interrupt the entire slice, but may damage a small portion of service. The I_{ma} always requires an immediate response, because the integrity of the network is severely at risk such as low/high load of traffic. The I_{cr} indicates a more critical situation on the slice, which is mostly resulted by hardware components failures.

Once an incident occurs, all monitoring metrics shall be automatically checked for troubleshooting and evaluation of contract breach as well as to figure out the types of incident.
If the $I_{ma}$ happens to the slice, it should be solved as soon as possible. After solving the the $I_{ma}$, a penalty $P$ is calculated according to the source and degree of incident, which the service provider is supposed to pay the tenant. In case of $I_{ma}$, we recommend the service provider and tenant to agree on an individual threshold of each monitoring metric for penalty. In this context, the tenant does not impose any penalty on the service provider despite of an incident, if it can be solved without violating any of the predefined thresholds. Otherwise, the tenant imposes a penalty $P$ on service provider, and explicitly remind the service provider to solve the incident as soon as possible and furthermore assure the quality of agreed services to the tenant.

Assuming that either $I_{ma}$ or $I_{cr}$ happens to the slice, compared to the $I_{ma}$, $I_{ma}$ and $I_{cr}$ are usually more challenging to solve. Therefore, we recommend there to be a clear agreement in the SLA about how effectively $I_{ma}$ and $I_{cr}$ have to be solved. In case of $I_{ma}$ or $I_{cr}$, the tenant and service provider can re-negotiate and furthermore optimize the SLA upon major and critical incidents, which helps both sides to avoid further interception to the service.

Furthermore, a long-term track on the occurrences of $I_{ma}$ and $I_{cr}$ is designed, so that the tenant can terminate the SLA in prior to its lifetime and turn to other qualified service providers, in case such serious incidences continuously happen. Otherwise, the SLA remains valid until that it finally expires its lifetime, where the slice stops running the service, and both service provider and tenant finalize all matters including financial and legal during their business period.

### III. Metrics of Proposed SLA

One of the main purposes of SLA is to define appropriate and realistic elements for the service that the provider is delivering to the tenant. These metrics are needed to be constantly monitored in order to detect agreement breaches. In this section, we discuss some critical concepts in the slice-based network SLA, including the service availability, penalty, cost, revenue, profit and QoS-related metrics.

#### A. Service Availability

The measurement of service availability has a long history in telecommunication industry. It is one of the most important metrics of SLA for both tenant and service provider, and has to be defined as much clear and convenient as possible in order to avoid any misunderstanding between both sides. The International Organization for Standardization (ISO) defines the availability as “the ability of a functional unit to be in a state to perform a required function under given conditions at a given instant of time or over a given time interval, assuming that the required external resources are provided” [7]. In its simplified manner, the availability is the successful transferring of service/data from point A to point B, which is measured in either percentage or unit of time (e.g. hour, mint, etc.). The time a network/slice is not able/delivering service/data to the customer/tenant is defined as downtime. If we consider the total time $T_h$ of a service dedicated to a certain slice and the total unavailable time $T_u$ of that specific service to that slice, the service availability can be provided by

$$A = \frac{T_h - T_u}{T_h}$$  

We divided service availability of a slice into three ranges: high availability (e.g. $= 100\%$), average availability (e.g. $\geq 99.5\%$), and low availability (e.g. $< 99\%$) in order to help both the service provider and the tenant evaluate whether the measured metrics of a slice meet, exceed, or fall below the predefined levels in a certain period of time. Both sides should formally agree upon conditional guarantees, e.g. if the average availability of service of a slice in a certain period of time is less than 99%, then the service provider has to pay penalty to the tenant.

#### B. Penalty

Most of the time, telecommunications service providers are promising guarantee high level of network performance. These promises are not always kept, therefore, it is recommended for both service provider and tenant to redefine an appropriate penalty value in the SLA. This penalty should be imposed by tenant, when the service provider fails to deliver assured...
services. In the context of an SLA, some limited levels of incidents or unavailability of service could be acknowledged, but below than those limited levels would not be accepted and the service provider should be punished according to the agreement. Sometimes, the tenant tries to maximize penalty in order to push service provider to ensure proper level of service. On the other hand, service provider may try to convince tenant to accept low level of penalty in the case of failure occurrence, or may try to include some terms in the contract, which lead to decrease level of services. However, smart service providers/tenants would not agree to such terms, which could result them in very large penalties/decreased services. It is worth nothing that “penalty” as the most common term used by both tenant and service provider is not legally correct. If readers are interested to use the most legal terminology for this concept, the “fee reduction” phrase is recommended [8].

We have divide penalty into two types: Linear Penalty and Non-linear Penalty. In linear penalty, tenant charges service provider with a certain predefined amount of penalty when the availability of service falls down by a given predefined level. As depicted in Fig. 2 we have considered 100% as agreed availability, 99.8% as accepted availability, and 98.4% as terminated availability. In between terminated and accepted availabilities, the penalty should be imposed considering certain predefined value. We have further assumed that by each 0.2% of shortfall in availability, the service provider is charged 5% of penalty. Based on these assumptions, we can analyze from the result shown in Fig. 2 that with 99.6% of availability 5% of penalty is imposed, with 99.4% of availability 10% of penalty is charged, etc. In non-linear penalty, the service provider and the tenant agree on irregular predefined amount of penalty considering different predefined levels of availability. It specifically means that there is no regularity or linear relationship between level of availability and amount of penalty. We have assumed that service provider should be imposed by 5% of penalty, if the availability falls 0.2% below than accepted availability, and then it should be charged with 2% of extra penalty for each of extra 0.1% shortfall until it reaches 99.1% of availability. Moreover, if the level of availability falls below than 99.1%, the service provider should be imposed with 10% of penalty until it reaches 99%, and below than 99% of availability 5% of penalty should be imposed until it reaches the terminated availability. Based on these assumptions, and according to the result shown in Fig. 2, the amount of penalty reaches 25% when the level of availability falls down to 99%, with 98.8% of availability 35% of penalty is imposed, etc.

It is worth nothing that if the availability of service falls below than predefined terminated availability, the tenant may terminate the slice and shift to a different operator, who is capable of providing assured QoS. Moreover, if we compare both linear and non-linear penalties, we can figure out that correlation among level of availability and amount of penalty is the only point that make them different from each other.

Both above mentioned linear and non-linear penalties do not answer to all questions of various scenarios of complicated slice-based network’s SLA. In sliced-based network, the demands of tenants are different from slice to slice, on the other hand, each slice would also have its own quality of service requirements, therefore, we need to further investigate various dimensions of penalty such as the importance of the moment when the breach happens to the slice, the total numbers of failures in a certain period of an SLA, duration of each failure, and total duration of all failures in a certain duration of an SLA. In order to find answers to all these questions, we need to further mathematically develop the concept of penalty in the context of slice-based network SLA [9].

During a certain period of an SLA, e.g. one month, the incident or unavailability of service may occur multiple times. In order to figure out penalty for all failures, we assumed that in an SLA contract the expectation of number of contract breaches is n, each breach is imposed with a certain amount of penalty V. Thus, the total amount of penalty Pn based on number of incidents could be estimated as:

\[ P_n = Vn \]  \hspace{1cm} (2)

We take a step forward and calculate penalty based on duration of time of an incident or unavailability i.e. penalty for a duration of one hour of unavailability. We assume that t is a certain unit of time of unavailability i.e. one minute and w is the amount of penalty for each unit of time of unavailability. In order to calculate the amount of penalty for each unit of time of failure Pi, then the following equation could be used:

\[ P_i = wt \]  \hspace{1cm} (3)

However, for the sake of calculation of penalty of entire duration of an incident, We assume that k is the number of exceeded subcontracts, wi is the penalty unit price for i subcontract, and ti is the total time of failure of i service. In order to calculate total amount of penalty based on entire duration of unavailability, the below given equation could be modeled:
\[ P_i = \sum_{i=1}^{k} w(i) t_i \]  

(4)

One of the key dimensions of penalty in slice-based SLA is to consider the importance of the moment of failure or the unavailability of service. For the tenant, some services would have different degrees of importance during various intervals of time, for example, the availability of service of a low latency slice is very important during remote surgery, or the availability of mobile broadband service is important for a tenant at 11:00 AM than at 02:00 AM. Therefore, we need to study penalty of those moments which are more critical and important for the tenant. In order to mathematically discover penalty considering importance of time of failure occurrence, we assume that \( \delta t \) is the time between measurements, \( t_j \) is time of moment \( j \), \( w \) is penalty unit price, \( I(t_j) \in (0, 1] \) is the function of service importance, \( T \) is the period of failure occurrence, and \( \Delta T \) is the length of period of failure occurrence. Considering these parameters, we have achieved the formula below that is used to calculate penalty during a moment of failure, which is very important for the tenant.

\[ P_j = \frac{\Delta T}{\delta t} \sum_{j=1, t_j \leq T} w I(t_j) \delta t \]  

(5)

In a certain period of an SLA, the failure may occur more than one time. In order to take all subcontracts into account, we assume \( k \) the number of exceeded subcontracts when the given SLA, \( \delta t_i \) is the time between measurements \( i \), \( t_j \) is the time of moment \( j \), \( w_i \) is the penalty unit price, \( I(i, t_j) \) is the function of sub-service importance, \( T_i \) is the period of failure occurrence of service \( i \), and \( \Delta T_i \) is the length of period of failure occurrence of service \( i \). Therefore, the formula for calculation of the penalties of all critical moments in a certain period of an SLA is modeled as given below.

\[ P_{ji} = \sum_{i=1}^{k} \sum_{j=1, t_j \leq T_i} w_i I(i, t_j) \delta t_i \]  

(6)

So far, we have mathematically discovered penalty from three dimensions (number of failure, period of failure, and the importance of failure). For all these three cases, we have developed five mathematical equations, which are used to calculate penalty in the context of slice-based SLA. But, in order to periodically calculate total amount of penalty \( P \) in a certain period of lifetime of an SLA, then, we need to sum up all five equations of above mentioned three cases.

\[ P = P_n + P_t + P_i + P_j + P_{ji} \]  

(7)

We can take Eq. (7) further by replacing the equivalents of each of the equations, where Eq. (8) is achieved, that is considered to be the final equation, which calculates total amount of penalty in a certain period of lifetime of slice-based SLA.

\[ P = Vn + wt + \sum_{i=1}^{k} w(i)t_i + \sum_{j=1, t_j \leq T} w I(t_j) \delta t + \sum_{i=1}^{k} \sum_{j=1, t_j \leq T_i} w_i I(i, t_j) \delta t_i \]  

(8)

C. Cost, Revenue, and Profit

The cost models of legacy telecommunication networks are usually built based on Capital Expenditure (CAPEX) and Operational Expenditure (OPEX). Both CAPEX and OPEX in classical models are estimated according to the traffic volume, number of base stations, and energy consumption [10]. However, this methodology is no longer appropriate to be used for estimation of cost models of slice-based 5G networks. In sliced networks, each resource can be shared by several slices, and the slicing scheme does also vary from one resource to another. Therefore, OPEX cannot be estimated for the entire slice-based physical network, and we need to define a novel slice-oriented cost model in order to estimate total cost, revenue, profit, and penalty of every single slice, which leads to clarify the SLA between tenant and provider.

As we mentioned in section 1 every slice is defined to support a specific use case, and has its own characteristics, QoS mechanisms, and architecture, thus, it is needed to be identified by a subset of KPI requirements that is obtained from a given set of KPI requirements \( k = [k_1, k_2, \ldots, k_\ell] \) through Virtual Network Function (VNF). In order to estimate the required volume of network resources, we need to consider the VNF implementation \( (v) \) and the size of slice \( (s) \) (the maximal number of user applications, which can be served by a slice). There are various kinds of network resources, which can be enumerated such as spectrum/bandwidth, power, time, human resources, infrastructure, etc. If we record the required amount of them in a vector \( r = [r_1, r_2, \ldots, r_N] \), where \( (N) \) is the number of resource types. Considering cost of each resource, we can further convert resource requirements into the expenditure (EXP), in a similar way as in classical network cost models. So that we have:

\[ EXP = EXP(r), \]  

(9)

\[ r = r(k, s, v). \]  

(10)

We also know that a certain price must be paid by the tenant for the service that is provided by the slice. Thus, given the service price \( (p) \), the slice size \( (s) \) and the customer size \( (c) \) (the number of user applications requesting service from the slice), the revenue (REV) of a slice can be modeled as:

\[ REV = REV(p, s, c). \]  

(11)

In order to obtain the profit \( (w) \) generated by a slice, we subtract the cost from the revenue as shown:

\[ w = REV(p, s, c) - EXP(r) = w(r, p, s, c). \]  

(12)
It is important to remember that the KPI-to-resource mapping as described in Eq. [10] is very complex and highly dependent on the selection of VNF implementation \((v)\). Nevertheless, as the network operator is responsible for the VNF implementation, it always holds a full knowledge about it. Therefore, in the operators' point of view, it is reasonable to assume the function \(r(k, s, v)\) as a-priori known.

D. QoS related metrics

In slice-based 5G networks, each unit of QoS related metrics such as latency, delay, data rate, capacity, throughput, mobility, security, energy consumption, connection density, response time, level of service, etc. are already predefined by standardization organizations i.e. ITU, ETSI, etc. As widely discussed in the literature, the slice-based 5G network supports 1000-fold gains in system capacity, 10 Gbps maximum and 100 Mbps average individual user experience, prolonged battery life of 1000-fold lower energy per bit, 90% reduction in network energy usage, 500 Km/hr mobility for high speed users (e.g. high speed trains), 3-fold spectrum efficiency, perception of 99.999% availability, 100% coverage, and latency from one millisecond to few millisecond [11] [12]. Each slice is created from a subset of these metrics in order to server specific number of users. The business model, the structure of SLA, the specification of QoS, and the level of service are different from slice to slice. Neither tenant nor the service provider are able to bring changes in the volume of these metrics, however, it is possible to decrease or increase the value by multiplying or subtracting the units of these metrics. Therefore, the tenant and service provider are requested to include the volume of these standardized metrics in the SLA according to the standardization organizations.

IV. CONCLUSIONS

In this paper, we have presented a comprehensive end-to-end structure of SLA between tenant and service provider of slice-based 5G network, which aims to balance the interests of both sides. Our proposed SLA is expected to define reliability, availability, and performance of delivered telecommunication services in order to ensure that right information gets to the right destination at right time, safely and securely. We have also discussed the metrics of slice-based network SLA such as throughput, penalty, cost, revenue, profit, and QoS related ones, which we think are critical during the agreement. In future, we intend to explore different types of slice-based network SLA i.e. shared (an SLA to be shared between specific number of tenants that use the same slice) or hybrid SLA (an SLA that is expected to serve certain tenants first and then serves the authorized tenants of the same slice). Moreover, this work should be complemented with a deep analysis of some extra QoS related metrics such as tightening the security, decreasing the latency, and increasing the bandwidth.

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