A Joint Utility Optimization Based Virtual AP and Network Slice Selection Scheme for SDWNs

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***Abstract*—The proliferation of mobile demands and increasingly multifarious services pose challenges to both the radio access networks (RANs) and the core network (CN). Unfortunately, the traditional networks can hardly meet the increasing requirements. Software-defined network (SDN) and network virtualization (NV) are considered as innovative paradigms to stress these problems. By extending SDN to wireless networks, software-defined wireless network (SDWN) consisting of both RANs and CN can be obtained. In this paper, the RANs and CN of SDWN are virtualized to virtual access points (VAPs) and network slices respectively based on NV technology. Considering the system scenario that a SDWN consists of overlapping RANs, an optimal joint VAP and network slice selection scheme is proposed. To characterize the complicated transmission performance of VAPs and network slices, the concepts of utility function and network calculus are introduced, and the joint utility of VAPs and network slices is formulated based on which the optimal VAP and network slice combination corresponding to the maximal joint utility can be selected. The simulation results demonstrate the efficiency of the proposed scheme.**

***Index Terms*—Access Selection; Software-defined Wireless Network; Network Virtualization; Utility Function; Network Calculus.**

I. Introduction

The rapid development of broadband data services poses challenges to both the radio access networks (RANs) and the core network (CN). However, traditional networks can hardly meet the increasing requirements of user services due to tightly-coupled control and date plane, inflexible network architecture, and complicated network and service management mechanisms. To stress these problems, software-defined network (SDN) technology has been proposed which is expected to dramatically simplify network control process, enable the development of sophisticated networking functions, and support user applications with guaranteed quality of service (QoS) [1]. To facilitate efficient utilization and flexible management of network resources in SDN, the network resource may be partitioned into multiple network slices of various transmission performance by applying network virtualization (NV) technology [2].

Applying the concept of SDN to wireless networks, we obtain software-defined wireless network (SDWN) [3] which inherits the typical advantages of SDN and supports centralized management of wireless networks. As one RAN may connect to various network slices, to achieve information interaction with corresponding nodes, user equipment (UE) in SDWN may choose one access point (AP) of RANs for wireless connection and one network slice connected to the selected AP for packet transmitting over CN. In the case that a SDWN consists of overlapping RANs with multiple APs, UEs may have to select one AP and network slice for data transmission. As the performance of APs and network slices may affect user QoS significantly, efficient joint AP and network slice selection scheme should be designed.

In recent years, the problem of AP selection has been studied for various types of wireless networks [4], [5], and the AP selection schemes have been proposed in which the transmission performance of APs is examined and the one with the optimal performance is selected. However, the transmission performance of the CN fails to be considered jointly. The access control problem in SDNs has also been considered in [6] and [7]. In [6], a SDN-based framework is proposed for enterprise wireless local area networks (WLANs), in which a programming abstraction, i.e., light virtual access points (VAPs) is proposed to support seamlessly accessing and handovers of UEs. A scalable architecture that supports fine-grained policies for mobile devices in cellular core networks is proposed in [7]. By using commodity switches and servers, efficient access control of UEs can be achieved. However, detail access selection schemes fail to be discussed.

In this paper, we apply NV technology to both RANs and CN of a heterogeneous SDWN and propose a virtual SDWN architecture, in which, the physical access points (PAPs) in RANs are mapped into VAPs which may offer various access performance to UEs, meanwhile, the transmission resource of CN is virtualized to various network slices. By introducing the concepts of utility function and network calculus, the joint utility of the VAPs and network slices is formulated and examined, based on which, an optimal joint VAP and network slice selection scheme is proposed.

The rest of the paper is organized as follows. In Section II, a heterogeneous SDWN architecture is described. In Section III, the utility modeling of both VAPs and network slices is conducted and the optimal joint VAP and network slice selection scheme is presented. Simulation results are presented in Section IV. Finally, conclusions are drawn in Section V.

II. Architecture

In this section, a heterogeneous SDWN architecture is proposed in which both the RANs and the CN are virtualized based on NV. To apply NV on the RANs, the PAPs of the RANs are mapped into multiple VAPs which are the abstraction of access interfaces of RANs, such as cellular system and WiFi, etc. We assume that the mapping from the PAPs to the VAPs follows one-to-many mapping rule, more specifically, one PAP can be mapped into

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multiple VAPs with the same or different wireless transmission performance.

To achieve the NV of CN, we introduce the concept of virtualized forwarding device (VFD) and virtualized network link (VNL), which are the abstractions of wired network resources of CN, such as switches, routers and links, etc. By applying multi-dimensional network slicing, the resources of CN can be segmented into numerous network slices which are managed by a single or multiple SDWN controllers through open southbound application programming interfaces (APIs).

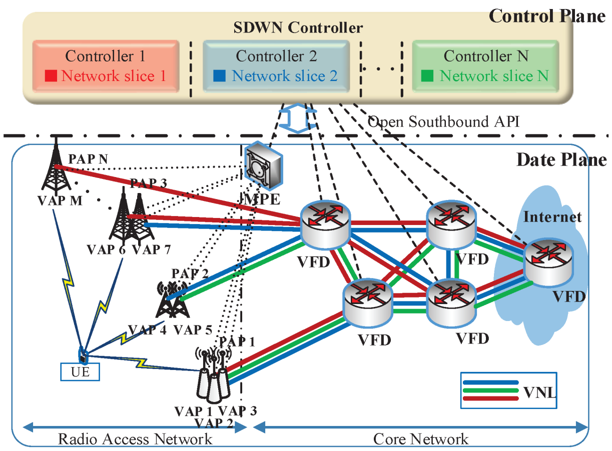

Fig. 1: Proposed virtual heterogeneous SDWN architecture

In the proposed virtual network architecture, many-to-many connections between VAPs and network slices are allowed, thus UEs accessing to the same VAP may connect to various network slices. To achieve the centralized management over VAPs and network slices, middle processing entity (MPE) is introduced, which acts like a middlebox and is responsible for status aggregation, protocol conversion, signal processing and algorithm implementation inside the VAPs. Fig. 1 shows an example of the proposed virtual SDWN architecture consisting of multiple VAPs and multiple network slices, which are marked in different colors. As shown in Fig. 1, UEs may access to different VAPs, through which, transmit information over various network slices.

III. Access Performance Modeling

In the proposed virtual architecture, each VAP may access to various network slices and each network slice may correspond to multiple VAPs at different RANs. For UEs in the overlapping area of multiple VAPs, both the VAPs and the network slices should be selected. For convenience, we use the i-jth VAP and slice pair to represent the transmission path via the ith VAP and the jth network slice, $1 \leq i \leq M$, $1 \leq j \leq N$, M and N denote the number of VAPs and network slices, respectively. As the performance of the VAP and slice pair may affect the access performance of UEs significantly, to jointly characterize the performance of VAPs and network slices, we introduce the concept of utility function, and define the joint utility of the i-jth VAP and slice pair.

A. Normalization Framework of Parameters

As both the performance of VAPs and network slices are characterized by multiple transmission parameters, to evaluate the effects of various parameters of VAPs/slices in a relatively fair manner, we first classify the parameters into two types and then define a unified normalization framework for both kinds of parameters.

The parameters for evaluating the QoS of VAPs/slices can be classified into two categories, i.e., reward parameters and cost parameters. The reward parameters are referred to as the parameters of which the larger quantity results in better user QoS, thus is expected to be as large as possible. The parameters such as transmission bandwidth and signal-to-noise ratio (SNR), etc. are typical examples of reward parameters. The cost parameters are referred to as the parameters of which the smaller quantity gives better user QoS and thus are expected to be as small as possible, for instance, access delay, power consumption of UEs, etc.

As the absolute values of the various parameters may fall in different regions and may not be comparable. In this paper, instead of examining and evaluating the absolute values of the parameters, we introduce the concept of normalized offset ratio of the parameters, which is defined as the relative value of the parameters compared to the possible maximum or minimum values. Denoting x as the parameter, the normalized offset ratio of x is defined as:

$$x^{\mathrm{nor}} = \begin{cases} \frac{x - x^{\min}}{x^{\max} - x^{\min}}, & \text{if } x \in \text{reward parameters} \\ \frac{x^{\max} - x}{x^{\max} - x^{\min}}, & \text{if } x \in \text{cost parameters} \end{cases} \tag{1}$$

where $x^{\min}$ and $x^{\max}$ denote, respectively, the minimum and maximum value of x required by user applications. It can be seen from (1) that x^{nor} indicates the actual offset of x compared to $x^{\min}$ and $x^{\max}$. It is clear that $0 \leq x^{\mathrm{nor}} \leq 1$, and the larger the x^{nor}, the better the transmission performance offered by the network.

B. Sigmoid Function Based Utility Modeling of VAPs/Slices

Based on the normalized offset ratios of parameters, a quantification model for evaluating the transmission performance of both VAPs and the network slices in SDWN can be formulated based on the sigmoid function which is originally applied in machine learning [8]. Denoting U as the utility function of the VAPs or network slices, we define

$$U = \frac{V}{1 + \exp\left(-S \sum_{l=1}^{L} w_l \left(x_l^{\mathrm{nor}} - x_l^{\mathrm{cen}}\right)\right)} \tag{2}$$

where x_l^{nor} denotes the normalized offset ratio of the parameter x_l, $1 \leq l \leq L$, L denotes the number of parameters affecting the utility, $w_l \in [0, 1]$ and x_l^{cen} denote the sensitivity factor and the tolerable offset ratio of the lth parameter, respectively, and V and S are both scale constants. It can be seen from (2) that performance of VAPs and network slices can be characterized by a multi-dimensional curved surface with each normalized offset ratio of the parameters being the axis of the surface and the parameters w_l and x_l^{cen} determine respectively the steepness and the inflection point of the surface, which can be chosen according to service requirements.

C. Joint Utility Function

As both the performance of RANs and that of CN will play important roles in determining the QoS of UEs, the utility function of the end-to-end performance of UEs can be formulated by jointly considering the utility of VAPs and network slices. Denoting U_{ij} as the joint utility function of the i-jth VAP and slice pair, we define

$$U_{ij} = \delta_{ij}(\sigma_1 U_i^{(1)} + \sigma_2 U_j^{(2)}) \tag{3}$$

where $U_i^{(1)}$ and $U_j^{(2)}$ denote the utility function of the ith VAP and the jth network slice, respectively, $1 \le i \le M$, $1 \le j \le N$, σ_1 and σ_2 are respectively the weighting factors of the RAN and the CN, which satisfy $0 \le \sigma_1, \sigma_2 \le 1$ and $\sigma_1 + \sigma_2 = 1$, $\delta_{ij} \in \{0, 1\}$ denotes the binary connection variable between the ith VAP and the jth network slice, i.e., $\delta_{ij} = 1$ indicates that the connection between the ith VAP and the jth network slice is available, thus UEs may transmit to their corresponding network devices via the ith VAP and the jth network slice, while $\delta_{ij} = 0$ indicates that the connection between the ith VAP and the jth network slice is unavailable, thus UEs cannot choose to transmit via the ith VAP and the jth network slice simultaneously. The mathematical formulations of $U_i^{(1)}$ and $U_i^{(2)}$ will be introduced in the following subsections.

D. Utility Function of VAPs

The transmission performance of VAPs is jointly determined by multiple parameters. Among these parameters, user data rate and channel access delay are the most important parameters for the majority of user services. In this paper, the parameters of user data rate and channel access delay are applied to evaluate the performance of VAPs. The mathematical expressions of both user data rate and channel access delay are described in this section.

1) User Throughput: The channel transmission rate of the ith VAP can be calculated as:

$$C_i = B_i \log_2(1 + \gamma_i) \tag{4}$$

where B_i denotes the network bandwidth of the ith VAP, γ_i denotes the SNR of the ith VAP, which can be calculated as $\gamma_i = p_i h_i/(N_0 B_i)$, p_i denotes the transmit power of the ith VAP, h_i denotes the channel gain of the link between the ith VAP and the UE, N_0 denotes the power spectral density (PSD) of additive white Gaussian noise (AWGN).

C_i in (4) shows the achievable data rate of the link between the ith VAP and the UE when only considering link performance at physical layer, however, the actual throughput of UEs may also be affected by multiple high layer factors, such as resource allocation schemes and channel access schemes. To characterize the effects of high layer factors, we introduce the parameter transmission efficiency, denoted as η_i, $0 < \eta_i \le 1$ for the ith VAP, and model the throughput of the link between the ith VAP and the UE as:

$$T_i = \eta_i C_i = \eta_i B_i \log_2(1 + \gamma_i) \tag{5}$$

2) Channel Access Delay: As different channel accessing and resources management schemes might be employed for different RANs, when UEs accessing to different RANs, various channel access delay might be resulted. For instance, cellular system in general applies centralized network management scheme, thus no channel competition occurs when multiple UEs accessing to the base station (BS) at the same time, resulting in negligible channel access delay. On the other hand, distributed resource management and random channel accessing schemes are applied in WLAN, resulting in relatively long channel access delay, especially when a large number of UEs tend to access the channel simultaneously.

Denoting D_i^C as the channel access delay of of the ith VAP, we assume that $D_i^C \approx 0$, when UEs accessing to cellular BSs. In the case that the ith VAP belongs to a PAP of WLAN, D_i^C can be calculated as [9]:

$$D_i^C = N_w T_s + \frac{1-(1-\tau)^{N_w} - N_w \tau (1-\tau)^{N_w - 1}}{\tau (1-\tau)^{N_w - 1}} T_c + \frac{1-\tau}{\tau}\delta \tag{6}$$

where N_w denotes the total number of UEs in the coverage area of the VAP, T_s and T_c denote respectively, the duration of successful transmission time and the average channel busy time, τ and δ denote respectively, user transmission probability and the duration of an empty slot.

According to the discussions presented in subsections III.A and III.B, the utility function of the ith VAP, $U_i^{(1)}$, $1 \le i \le M$, can be obtained by first applying normalization procedure on T_i and D_i^C based on (1), then replacing x_l^{nor} by the normalized offset ratio of T_i and D_i^C in (2).

E. Utility Functions of Network Slices

In this section, the transmission performance of network slices is evaluated by applying the theory of network calculus which presents a theoretical framework for analyzing the performance of queuing system, such as the CN of Internet. As network calculus is capable of transforming complex non-linear network systems into analytically tractable linear systems by using alternate algebras, i.e., the min-plus algebra and max-plus algebra, it has been applied for the modeling and analysis of various types of networks, including wireless sensor networks, switched Ethernet, systems-on-chip, etc. [10], [11].

1) A Brief Introduction of Network Calculus: In this subsection, some important concepts defined in the theory of network calculus will be introduced briefly.

Arrival Curve: Denoting $I(t)$ as the input function of a flow, a wide-sense increasing function $\alpha(t)$ is defined as the arrival curve of $I(t)$, if and only if for all $s \le t$, $\alpha(t)$ meets the condition:

$$I(t) - I(s) \le \alpha(t - s), \; t \ge 0. \tag{7}$$

Introducing the convolution operation in min-plus algebra [10], the convolution of two wide-sense increasing functions $f(t)$ and $g(t)$ can be defined as:

$$(f \otimes g)(t) = \inf_{0 \le s \le t} \{f(t-s) + g(s)\} \tag{8}$$

(7) can be re-written as:

$$I(t) \le (I \otimes \alpha)(t) \tag{9}$$

Service Curve: Given a system S and a flow through S with input and output function being $I(t)$ and $O(t)$, a wide sense increasing function $\beta(t)$ can be defined as a service curve offered by S, if and only if $\beta(t)$ meets following conditions:

$$\beta(0) = 0 \tag{10}$$

$$O(t) \geq (I \otimes \beta)(t) \tag{11}$$

Effective Bandwidth: Considering a system S and a flow through S with an arrival function $\alpha(t)$, for a fixed but arbitrary delay D, we define the effective bandwidth $e^{(D)}(\alpha)$ of the flow as the required bit rate at t to serve the flow in a work conserving manner, i.e.:

$$e^{(D)}(\alpha) = \sup_{t \geq 0} \left(\frac{\alpha(t)}{t + D} \right) \tag{12}$$

Assuming that a flow with an arrival curve $\alpha(t)$ passes through a server with the service curve being $\beta(t)$, denoting $d(t)$ and $b(t)$ as the service delay and the backlog of the flow, it can be proved that $d(t)$ and $b(t)$ meet following constraints:

$$d(t) \leq d^{\max}(\alpha, \beta) = \sup_{t \geq 0} \{\inf\{T : T \geq 0; \alpha(t) \leq \beta(t+T)\}\} \tag{13}$$

$$b(t) \leq b^{\max}(\alpha, \beta) = \sup_{t \geq 0} \{\alpha(t) - \beta(t)\} \tag{14}$$

where $d^{\max}(\alpha, \beta)$ denotes the upper bound of $d(t)$, which is the maximum horizontal distance between $\alpha(t)$ and $\beta(t)$, $b^{\max}(\alpha, \beta)$ denotes the upper bound of $b(t)$, which is the maximum vertical distance between $\alpha(t)$ and $\beta(t)$.

2) Modeling Arrival Curve of Network Slices: Without loss of generality, we assume that each network slice supports the aggregation of a number of flows with identical arrival curve model which can be characterized by traffic-specification (T-SPEC) developed by IETF [12]. Given a T-SPEC $(r^{(p)}, s^{(m)}, r^{(s)}, s^{(b)})$, the arrival curve of flows can be modeled as:

$$\alpha(t) = \min\{r^{(p)}t + s^{(m)}, r^{(s)}t + s^{(b)}\} \tag{15}$$

where $r^{(p)}$ and $s^{(m)}$ represent the peak rate and the maximum packet size, respectively, $r^{(s)}$ and $s^{(b)}$ represent the sustainable rate and the burst tolerance, respectively.

For the jth network slice, the number of flows is denoted by N_j, and the T-SPEC of all the N_j flows is $(r_j^{(p)}, s_j^{(m)}, r_j^{(s)}, s_j^{(b)})$, then the arrival curve of the aggregated flow at the jth slice can be expressed as:

$$\begin{aligned} \alpha_j(t) &= N_j \min\{(r_j^{(p)}t + s_j^{(m)}), (r_j^{(s)}t + s_j^{(b)})\} \\ &= \min\{N_j(r_j^{(p)}t + s_j^{(m)}), N_j(r_j^{(s)}t + s_j^{(b)})\} \end{aligned} \tag{16}$$

3) Modeling Service Curve of Network Slices: In this paper, we assume the servers of network slices are Latency-Rate (LR) system [13], of which the service curve can be modeled as:

$$\beta(t) = R(t - \theta)^+ \tag{17}$$

where R and θ are respectively the service rate and the latency provided by the server, $(x)^+ = \max\{x, 0\}$.

As each network slice may consist of multiple servers, the service curve of the network slice can be calculated as the convolution of the service curves of all the servers belonging to the network slices. Denoting K_j as the number of servers of the jth network slice, $\beta_{jk}(t)$ as the service curve of the kth server belonging to the jth network slice, we can obtain the service curve of the jth slice, denoted as $\beta_j(t)$:

$$\beta_j(t) = \beta_{j1}(t) \otimes \beta_{j2}(t) \otimes \cdots \otimes \beta_{jK_j}(t) = R_j(t - \theta_j)^+ \tag{18}$$

where $R_j = \min\{R_{j1}, R_{j2}, \ldots, R_{jK_j}\}$ and $\theta_j = \sum_{k=1}^{K_j} \theta_{jk}$. (18) indicates the jth network slice offers an equivalent LR service curve with R_j and θ_j being the two parameters.

4) Performance Parameters of Network Slices: Replacing $\alpha(s)$ and $\beta(s)$ in (12)-(14) by $\alpha_j(t)$ and $\beta_j(t)$ formulated in (16) and (18), and after some simple mathematical manipulations, we can obtain the upper bound of service delay and backlog, and the effective bandwidth of the jth network slice, i.e.:

$$d_j^{\max} = \max\{\frac{\alpha_j(\Gamma_j)}{R_j} + \theta_j - \Gamma_j, \frac{N_j s_j^{(m)}}{R_j} + \theta_j\} \tag{19}$$

$$b_j^{\max} = \max\{\alpha_j(\theta_j), \alpha_j(\Gamma_j) - \beta_j(\Gamma_j)\} \tag{20}$$

$$e_j^{(D)} = \max\left\{N_j r_j^{(s)}, \frac{N_j s_j^{(m)}}{D_j}, \frac{N_j(s_j^{(m)} + r_j^{(p)}\Gamma_j)}{\Gamma_j + D_j}\right\} \tag{21}$$

where $d_j^{\max}$ and $b_j^{\max}$ denote respectively the upper bound of the service delay and backlog of the jth network slice, $e_j^{(D)}$ denotes the effective bandwidth of the jth network slice, and $\Gamma_j = (s_j^{(b)} - s_j^{(m)})/(r_j^{(p)} - r_j^{(s)})$.

Similar to the utility modeling for VAPs, the utility function of the jth network slice, i.e., $U_j^{(2)}$, $1 \leq j \leq N$ can be obtained by first applying normalization procedure on $d_j^{\max}$, $b_j^{\max}$ and $e_j^{(D)}$ based on (1), and then replacing x^{nor} by the normalized offset ratios in (2). Replacing $U_i^{(1)}$ and $U_j^{(2)}$ obtained in (3), the end-to-end utility of the transmission path via the ith VAP and the jth network slice, denoted as U_{ij} can be calculated.

F. Optimal Access Selection Scheme

According to the performance evaluation approaches discussed in previous subsections, the end-to-end transmission performance of the SDWN can be examined. For the transmission path via the ith VAP and the jth network slice, the utility function, denoted as U_{ij} can be calculated by choosing w_l and Γ_l reasonably and replacing $U_i^{(1)}$ and $U_j^{(2)}$ obtained in (3), $1 \leq i \leq M$, $1 \leq j \leq N$.

Given U_{ij}, a maximal utility based access selection scheme is proposed in this paper. More specifically, for the (i, j)th VAP and slice pair which meets $\delta_{ij} = 1$, the utility function is examined and compared, and the optimal (i^*, j^*)th pair which corresponds to the maximal utility can then be selected:

$$(i^*, j^*) = \arg\max_{i,j} U_{ij} = \arg\max_{i,j} \left(\sigma_1 U_i^{(1)} + \sigma_2 U_j^{(2)}\right) \tag{22}$$

IV. Simulation Results

In this section, the performance of the proposed optimal joint utility based VAP and network slice selection scheme is examined and compared with the traditional AP selection scheme which only chooses the best AP in RANs without considering the performance of CN. The numerical simulations are conducted using MATLAB. In the simulation, we consider a heterogeneous SDWN consisting of multiple PAPs, VAPs and network slices. Table I illustrates the corresponding relations of PAPs, VAPs and network slices, where '✓' represents the connection between one VAP and one network slice is available.

Table II and Table III show the simulation parameters of RANs and CN respectively. In the simulation scenario, we assume that

TABLE I: Pairs of PAPs, VAPs and network slices

		Slice 1	Slice 2	Slice 3
PAP 1	VAP 1	✓		
	VAP 2		✓	
	VAP 3			✓
PAP 2	VAP 4		✓	
	VAP 5			✓
PAP 3	VAP 6	✓		
	VAP 7		✓	
PAP 4	VAP 8	✓		
	VAP 9		✓	

VAPs share the transmission performance of the PAPs which they belong to. The pass-loss model of PAPs is set specifically as follows [14]:

$$PL(d) = 128.1 + 37.6 \log 10(d) \tag{23}$$

$$PL(d) = 140.7 + 36.7 \log 10(d) \tag{24}$$

$$PL(f, d) = 32.4 + 20 \log 10(f) + 20 \log 10(d) \tag{25}$$

where d denotes the distance between UEs and the PAP, and f denotes the frequency of carrier.

TABLE II: Simulation parameters of the RANs

	PAP 1/2	PAP 3	PAP 4
Coverage (m)	100	200	1100
Available bandwidth (MHz)	5 or 22	10	1.25
Carrier frequendy (GHz)	2.4	2	2
Maximum transmission power (dBm)	16	23	43
PSD of AWGN (dBm/Hz)	-162		

TABLE III: Simulation parameters of the CN

	Slice1	Slice2	Slice3
Peak rate ($r_j^{(p)}$) (Mbps)	0.6	2	29
Maximum packet size ($s_j^{(m)}$) (Kbit)	15	1	1
Sustainable rate ($r_j^{(s)}$) (Mbps)	0.03	0.7	0.7
Burst tolerance ($s_j^{(b)}$) (Kbit)	92	10∼290	184
Number of flows (N_j)	10	10	10
Equivalent service rate (R_j) (Mbps)	4∼10	10∼50	20∼100
Equivalent latency (θ_j) (ms)	3∼30	15∼60	60∼150

In the simulation, we consider three service types, i.e., conversational class, streaming class and background class, Table IV shows for different service types, the weighting factors of parameters applied in the evaluation of utility function of both VAPs and network slices.

TABLE IV: Weighting factors of parameters

	Conversational Class	Streaming Class	Background Class
User Throughput (T_i)	0.8	0.2	0.4
Channel Access Delay (D_i^C)	0.2	0.8	0.6
Delay bound ($d_j^{\max}$)	0.8	0.2	0
Backlog bound ($b_j^{\max}$)	0	0	0.7
Effective bandwidth ($e_j^{(D)}$)	0.2	0.8	0.3

Fig. 2 shows the impacts of burst tolerance of Slice 2 on the effective bandwidth and delay bound of UEs with conversational

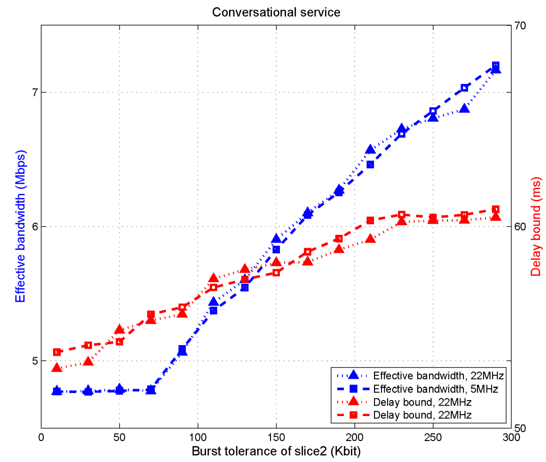

Fig. 2: Effective bandwidth, delay bound vs. burst tolerance of Slice 2

service. It can be seen from the figure that effective bandwidth change slightly for small burst tolerance, then increases with the increase of burst tolerance, while the delay bound increases with the increase of burst tolerance. The reason is that the effective bandwidth and delay bound are both positively correlated with burst tolerance, as shown in (21) and (19). Comparing the performance of the effective bandwidth and delay bound of UEs with different available bandwidth of VAPs, i.e., $22Mhz$ and $5Mhz$, we can see that both performance parameters are barely affected by the available bandwidth of PAPs, the reason is that conversational service has no strict requirement on available bandwidth.

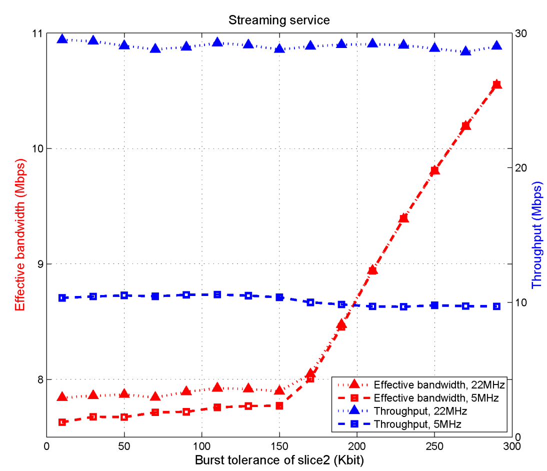

Fig. 3: Effective bandwidth, throughput vs. burst tolerance of Slice 2

Fig. 3 shows the impacts of burst tolerance of Slice 2 on effective bandwidth and throughput of UEs with streaming service. It can be seen from the figure that the effective bandwidth of UEs does not change for small burst tolerance, then increases with the increase of burst tolerance, this is because for a relatively large burst tolerance, the performance of Slice 2 is improved, thus UEs may choose to access Slice 2, resulting in an increases of effective bandwidth for larger burst tolerance. It can also be seen from the figure that the throughput of UEs does not change dramatically with the increase of burst tolerance, the reason is that the performance of VAPs and network slices is relatively independent. Comparing for the effective bandwidth and throughput of UEs accessing VAPs with different bandwidth, we can see that while the effective bandwidth of network slices is similar, the throughput of VAPs is quite different for the available bandwidth of VAPs plays an important role in determining the throughput of UEs.

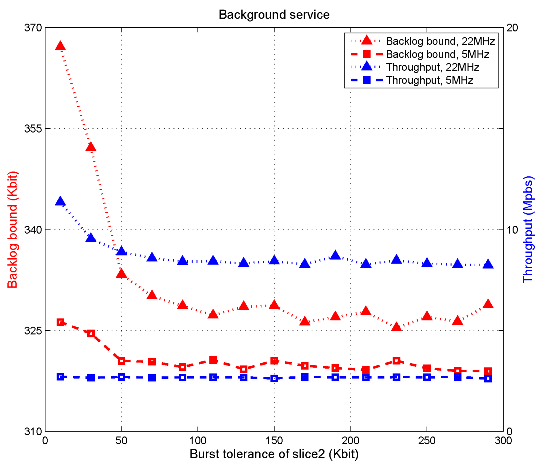

Fig. 4: Backlog bound, throughput vs. burst tolerance of Slice 2

Fig. 4 shows the impacts of burst tolerance of Slice 2 on the backlog bound and throughput of UEs with background service. It can be seen from the figure that the throughput of UEs varies slightly with the increase of burst tolerance, while the backlog bound first decreases to certain value then does not change dramatically with the increase of burst tolerance. This is because the background service is relatively sensitive to the backlog bound, hence, UEs may access Slice 1 which offers smaller backlog bound compared to Slice 2.

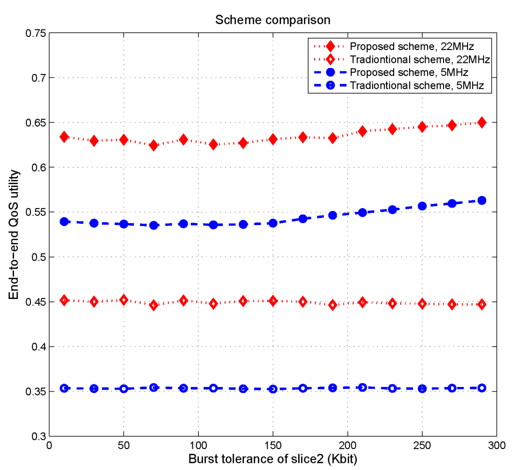

Fig. 5: End-to-end QoS utility analysis

Fig. 5 shows the end-to-end QoS utility of proposed scheme compared to traditional scheme which chooses the AP with the best wireless performance without considering the performance of the CN. It can be seen from the figure that the end-to-end QoS utility of the proposed scheme offers better performance compared to the traditional scheme. Furthermore, the utility of the proposed algorithm increases slightly alongside the increase of burst tolerance of Slice 2, this is because the effective bandwidth increases with the increase of burst tolerance, hence resulting a larger end-to-end utility. On the contrary, the utility of the traditional algorithm fails to increase with the performance enhancement of the wired network, which is highly undesired.

V. Conclusions

In this paper, we study the access selection scheme of heterogeneous SDWNs and propose a joint utility optimization based VAP and network slice selection scheme. By applying NV, the RANs and CN of the SDWN are virtualized to VAPs and network slices, respectively. By introducing the concepts of utility function and network calculus, the transmission performance of VAPs and network slices are formulated, and the jointly utility of different pairs of VAPs and network slices is modeled and examined, based on which, the optimal VAP and network slice pair corresponding to the maximum joint utility can be selected. Simulation results demonstrate the efficiency of the proposed algorithm.

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