vRGW: Towards Network Function Virtualization Enabled by Software Defined Networking

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***Abstract*—It has been a significant challenge for network carriers to deploy and provision a large number of Customer-Premises Equipment (CPE) devices located at subscribers' premises and connected to a carrier's network infrastructure. In this paper, we make a first systematic attempt to fundamentally re-shape the access networks into a software defined networking architecture by virtualizing the network functionality of residential gateways (vRGW). Our approach can be generalized to other CPE such as set-top boxes. Our analysis suggests that vRGW can achieve significant economic benefits ranging from up to 90% reduction on the call center cost and up to 46% reduction on the product return cost.**

I. Introduction

In today's network architectures, carriers typically deploy a large number of Customer-Premises Equipment (CPE) in residential networks. These devices are a part of the access networks, and are managed by individual network carriers. For instance, residential subscribers' home networks usually consist of one or many CPE devices (*e.g.*, ADSL routers and/or set-top boxes), which typically provide the network connectivity to terminals (*e.g.*, iPhones, laptops and/or networked TVs) via either cable or wireless technologies.

However, such an architecture has been facing many significant challenges in recent years. First, deploying CPE devices in a large number of customers' home networks incurs potentially significantly high investment costs to carriers. Second, complex CPE configurations for diverse terminals usually incur significantly high operational costs to network carriers. Third, the existing home network architecture typically restricts the deployment of new services. Last but not least, there exists tremendous diversity in home networks within even an individual carrier, as a result of home networks being constantly evolving (due to, *e.g.*, new service offering, CPE device firmware updates); thus, carriers see high operational costs of managing such highly diversified access networks.

Recognizing these challenges, we believe that virtualizing network functions, which can be enabled by the software defined networking (SDN) architectures (see, *e.g.*, [1]), could be a feasible and cost-efficient approach to addressing the aforementioned challenges. SDN is a best enabler because it provides an open environment for facilitating fast introduction of new virtual appliance services and third party solutions. In addition, SDN also provides significant cost savings by providing resource sharing among virtual appliances.

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In this paper, we take the residential gateway devices as an example, and propose a framework of network function virtualization, referred to as the *virtualized residential gateway framework* (*vRGW* for short), which shifts the CPE functionality and complexity into the carriers' networks. However, the tremendously large number of virtualized residential gateway devices pose significant challenges on the provision of controllers. We divide and organize the virtualized devices in smaller sub-networks and deploy a set of controllers, one for each of these sub-networks, to provision all devices collectively. Additionally, we adopt an east-west interface for multiple controllers to communicate with each other in an efficient, distributed and scalable manner. Due to the space limit, we mainly focus on the vRGW framework in the paper.

II. Framework for Virtualizing RGW

We now present our vRGW framework for virtualizing residential gateways. In the framework, we migrate the decoupled RGWs' network layer (and higher-layer) functionality into vRGWs, and place vRGWs in the edge network. As result, network layer devices are removed from the last mile, access and metropolitan networks, which could greatly simplify the network management. In this framework, only simple layer-2 devices are deployed at customers' premises, the layer-3 (and above) network functions are migrated into vRGWs in the edge network. Each CPE device has a corresponding, dedicated vRGW which handles the network layer (and above) functions for that customer's traffic.

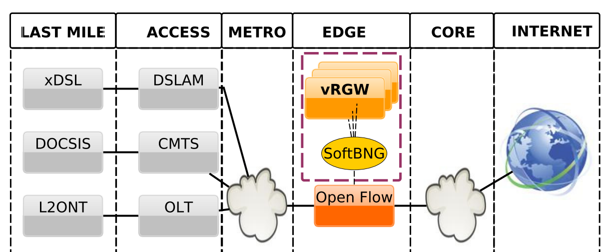

Fig. 1: A framework for virtualizing residential gateway devices.

We illustrate in Fig. 1 an example where the CPE devices such as RGWs are virtualized and placed in the edge network. Rather than deploying CPE devices with complex network functions (*e.g.*, network-layer functions such as IP routing and NAT, higher-layer functions such as firewall) at customers' premises in the current approach, our new approach of virtualizing CPE devices significantly simplify the network functions that such devices are equipped with.

Note that vRGWs can be implemented as virtualized services integrated into BNGs in the edge network, and thus the latter become software defined BNGs (referred to as “softBNG” in Fig. 1). However, vRGWs do not have to be placed at the network edge. For instance, when taking into account performance concerns, a carrier may prefer to place vRGWs in the metropolitan network (still close to end users).

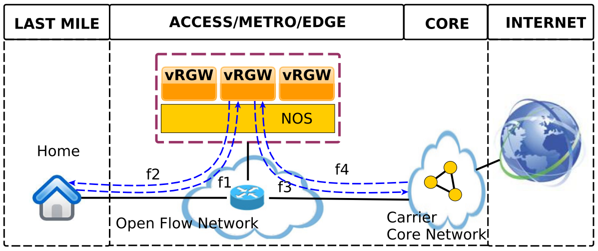

Fig. 2: Provision of vRGW using SDN.

We integrate OpenFlow and vRGW, as shown in Fig. 2, to allow carriers to provision vRGWs in a flexible, scalable and fine-grain manner. More specifically, All packets injected into a carrier’s network by home terminals are forwarded first to their corresponding vRGWs and then to their final destinations (*e.g.*, hosts in the Internet). Similarly, the packets destined for terminals at homes are forwarded first to the corresponding vRGWs and then to the final destinations (*i.e.*, terminals at homes). Therefore, the network paths that the packets traverse consist of two segments: (1) the segment between network terminals at homes and their corresponding vRGWs, referred to as the *LAN segment* (note that there is a notion of LAN for all terminals at a home and the vRGW corresponding to that home), and (2) the segment between vRGWs and hosts in the Wide Area Network (WAN), referred to as the *WAN segment*. We referred to the paths f_1 and f_3 as the forward paths, and the paths f_2 and f_4 as the backward paths. Note that vRGWs are the rendezvous points for the LAN/WAN segments and the forward/backward paths.

III. Performance Evaluation

We deployed a small-scale vRGW system in a Tier-1 carrier’s network. Fig. 3 below depicts an example of such deployment. This allows us to conduct online experiments to quantify the performance perceived by end users. We also simulate the RGW and vRGW frameworks using the network simulator ns-3 for three application scenarios, *i.e.*, Web, VoIP, and progressive video downloading, respectively.

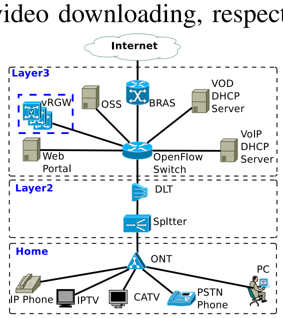

Fig. 3: An illustrative example of vRGW deployment.

We plot the normalized average throughput of downloading objects with varying sizes and average RTT results in Fig. 4 and Fig. 5, respectively. We observe that the vRGW framework achieves approximately 15–20% higher throughput than RGW. This happens because the vRGW is more powerful than the RGW in terms of packet processing, thus yields higher throughput. We also observe that in the on-net case (intradomain on-net server is used for RTT measurements), vRGW can reduce the round-trip time between clients and on-net servers by approximately 30%. Additionally, the vRGW framework can also significantly reduce the RTT variance. This observation is counter-intuitive on the first look. However, our investigation shows that compared to the vRGW, the RGW has much limited packet processing capability. In practice, RGWs may use hardware components with less computational or networking capability, or the RGW software implementation may not be as efficient. All these factors can contribute to the longer latency of processing packets by RGWs.

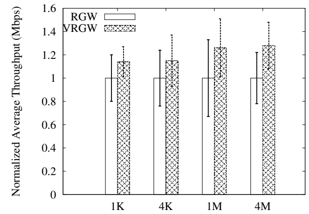

Fig. 4: Average throughput.

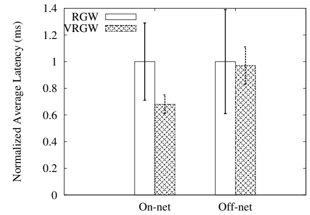

Fig. 5: Average RTT.

We also adopt simple yet rigorous models (see, *e.g.*, [2], [3], [4], [5]) to quantify the economic benefits, using both proprietary and public datasets from anonymized Internet service providers (referred to as Carrier A, B and C, respectively). We plot in Fig. 6 the estimated yearly call center cost and in Fig. 7 the results of product return cost for the three carriers. The results suggest that with vRGW, all carriers achieve a significant reduction of call center cost, ranging from 78% to 90%, and that the return costs can be significantly reduced by a percentage ranging from 30% to 46%.

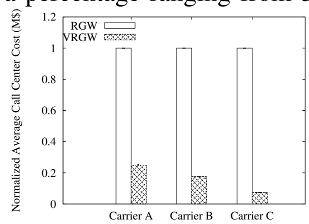

Fig. 6: Call center cost.

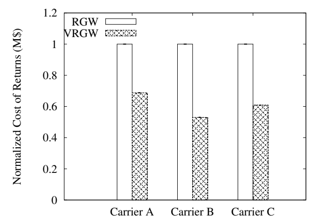

Fig. 7: Product return cost.

IV. Conclusion and Future Work

We proposed an SDN-based vRGW framework as a cost-efficient supporting mechanism for access network functionality virtualization. The framework can lead to significant economical benefits, *e.g.*, up to 90% reduction on the call center cost, and up to 46% reduction on the product return cost. For future work, we plan to conduct live online application-specific experiments to understand the impacts and design requirements of the vRGW framework. We also plan to generalize the framework for other CPE devices such as the set-top boxes and small businesses’ access routers.

Acknowledgment

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