A Marketplace for Real-time Virtual PON Sharing

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***Abstract*—We propose a marketplace where multiple network operators coexisting on the same passive optical network (PON) infrastructure can share their excess capacity. We designed a double auction to assure efficient allocation of optical access capacity.**

***Index Terms*—Passive Optical Networks, Network sharing, Infrastructure sharing, Auction.**

I. Introduction

The accelerating changes in the average Internet users' behavior have caused a surge in high-throughput traffic classes such as online video streaming that causes periodical peak demands, i.e., sudden surges in bandwidth demand. Where, the conventional over-provisioning of the bandwidth is very costly not economically justifiable. According to Cisco [1] peak-hour (or the busiest 60 minute period in a day) Internet traffic is growing faster than the average Internet traffic. Peak-hour Internet traffic increased 51 percent in 2016, compared with 32-percent growth in average traffic. Infrastructure and resource sharing can considerably reduce the operational cost of the network by bridging the gap between the average and the peak hour internet usage, i.e., diversifying the infrastructure incumbents (Residential, Mobile and Business network operators) will fill this gap through multiplexing gain, assuming network sharing can be appropriately implemented and provide the required economic incentives [2]. However, two main obstacles remain open for network sharing. First, to make full use of the network sharing it is essential to facilitate service diversity in the network. This obstacle has been addressed in our previous work [3], where we introduce the concept of virtual dynamic bandwidth allocation to enable the coexistence of diverse service operators on the same PON. Second, in a shared network, where each operator has a static dedicated share of the resources, a considerable percentage of the resources can go to waste when the operators are not able to share their excess capacity with others. To address this obstacle, we introduce a marketplace, where the operators can receive monetary compensation in return for sharing their excess resources (upstream PON transmission capacity). We make use of an auction mechanism to ensure sharing incentives and satisfaction of the typical economic market properties, including truthfulness.

The following will benefit from the proposed marketplace:

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- The Virtual Network Operators (VNOs) will be able to monetize their idle resources and also provide higher peak information rate (PIR) for their customers without over-provisioning.
- The Infrastructure Provider (InP) can more efficiently utilize its infrastructure, allowing it to support more operators with no extra CAPEX.
- The end-users can enjoy more realistic information rates offered by the operators and reach a better quality of experience (QoE).

II. Related Works

Marketization of telecommunication networks' resource and infrastructure sharing has been the focus of many research works [4]. The idea is to expose the VNOs to the market power with the objective of more efficient utilization of the resources. Furthermore, network virtualization has been a strong tool to enable flexible and fine-grained sharing of the network [5]. Meanwhile, more recent attention from telecommunications industry players has focused on developing flexible access system architectures [6]. The Standardization body, Broadband Forum (BBF) is building a common platform for sharing of the access network infrastructures [7].

Double auction, which organizes trades in major foreign exchanges (FX) or stock exchanges (such as NASDAQ and NYSE), allows traders to submit their bids and asks, and then it provides a matching service to efficiently distribute the available resources among the buyers and provide monetary compensation for the sellers. The applications of the auction are not limited to financial markets. Computer and telecommunication systems have widely made use of auction mechanisms, e.g., cloud networking [8], online advertising [9], and wireless spectrum allocation [10].

III. The Proposed Marketplace and Auction Mechanism

We propose a marketplace, where multiple VNOs can engage in the trade of excess resources and more specifically, PON's upstream transmission opportunity (bandwidth).

The market consists of a set of M sellers $\mathbb{S} = \{s_1, s_2, ..., s_i\},\ i \in M$ and a set of N buyers $\mathbb{B} = \{b_1, b_2, ..., b_j\},\ j \in N$ and one auctioneer. The sellers and buyers will report a pair of values (q, v), Where q is the number of excess/demanded items (frame blocks) and v is their per-item valuation. Fig. 1 illustrates the described marketplace. Our proposed double auction mechanism is based on McAfee

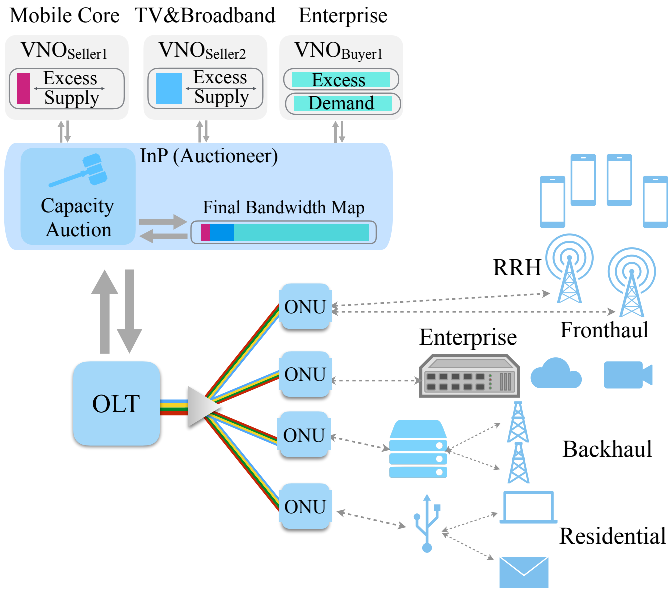


Fig. 1: The Multi-Tenant PON Capacity Marketplace

[11] algorithm. Similar to McAfee our mechanism uses a trade reduction technique to disjoint the trading price and the trader-reported values to achieve truthfulness. The mechanism matches the highest bidding bidders with the lowest asking sellers. The auction is a sealed-bid auction (i.e., the asks/bis are only announced once by the traders to the auctioneer) and there is no additional tterative communication between the traders and the auctioneer.

Algorithm 1: Multi-Item Double Auction

1 Sort sellers ascending so $v_1^B > v_2^B > ... > v_m^B$
2 Sort buyers descending so $v_1^S < v_2^S < ... < v_n^S$
3 Find $max(S_L, B_K)\ \forall\ v_L < v_K$ **and** $\sum_1^{\mathrm{K}} q_j^B \leq \sum_1^{\mathrm{L}} q_i^S$
4 $\gamma = \frac{1}{2} \times (v_{\mathrm{L+1}} + v_{\mathrm{K+1}})$
5 **if** $\gamma \in [v_L, v_K]$ **then**
6 $\quad \Theta = \min(\sum_1^{i=L} q_i, \sum_1^{j=K} q_j)$
7 $\quad p^B = p^S = \gamma$
8 **else if** $\gamma \notin [v_L, v_K]$ **then**
9 $\quad \Theta = \min(\sum_1^{i=L-1} q_i, \sum_1^{j=K-1} q_j)$
10 $\quad p^B = v_K$
11 $\quad p^S = v_L$

The auction mechanism (shown in Algorithm. 1) takes in the reported information from the VNOs and decides the total trade quantity (Θ) and the trade price for the sellers (p^S) and the buyers (p^B). In line 5, we check if the average (γ) of the first non-qualifying seller and buyer ($S_{\mathrm{L+1}}$,$B_{\mathrm{K+1}}$) falls between the valuation of the last qualifying traders ($S_{\mathrm{L}}, B_{\mathrm{K}}$). If the condition is met, no trade reduction is required and the traders trade in the price (γ) thus the market has a 100% allocative efficiency. If the condition does not apply (line 8), the last qualifying pair of traders are banned from trading and the remaining qualifying traders trade in their ($S_{\mathrm{L}}, B_{\mathrm{K}}$)'s reported prices.

The utility (profit) function of the sellers, buyers and the InP are defined as u_i^{S}, u_j^{B}, and u^{Auc}. The utility of a seller (u_i^{S}) is the difference between the per-item selling price and the asking price of that seller, times the number of items sold θ_i^{S}:

$$u_i^{\mathrm{S}} = \theta_i^{\mathrm{S}} \times (p^{\mathrm{S}} - v_i^{\mathrm{S}}) \tag{1}$$

Similarly for the buyers:

$$u_j^{\mathrm{B}} = \theta_j^{\mathrm{B}} \times (v_j^{\mathrm{B}} - p^{\mathrm{B}}) \tag{2}$$

The utility of the auctioneer is the difference between the amount paid by the buyers and the amount to be paid to the sellers:

$$u^{Auc} = (p^{\mathrm{B}} - p^{\mathrm{S}}) \times \Theta \tag{3}$$

Where θ_i^{S} is the items sold by the i^{th} seller for the price of p^{S}, θ_j^{B} is the items won by the j^{th} buyer with the price of p^{B}, and Θ is the total number of items traded.

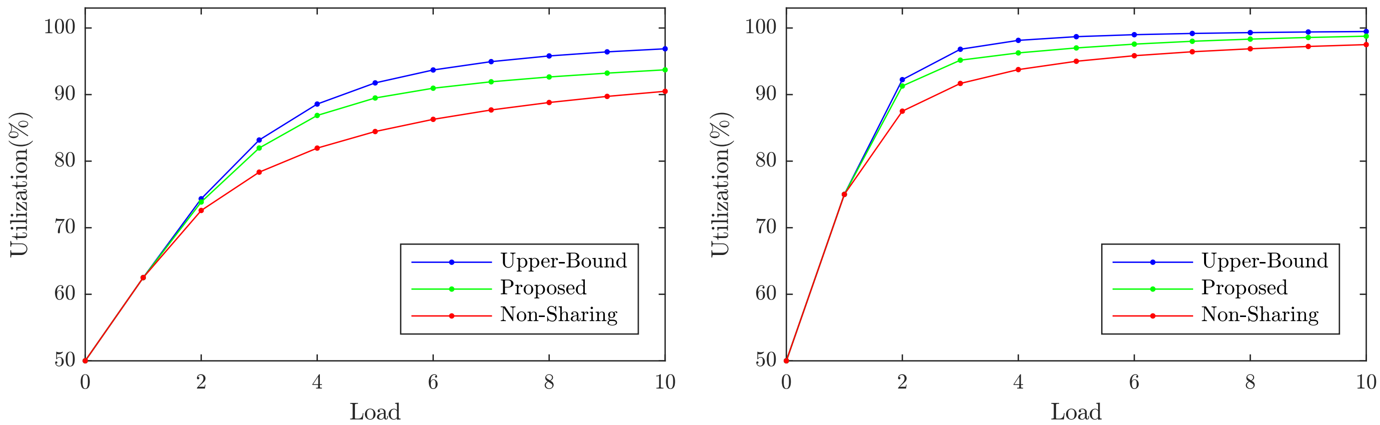
IV. Results

We measure the market allocative efficiency by the total number of items traded in one round of auction (Θ). This factor reflects the effect of auctioning the capacity on PON's efficiency.

We take an XGS-PON [12] with 10 Gbit/s symmetrical capacity as the reference network. The network comprises of ten VNOs each with an equal share of the upstream bandwidth that is ≈1-Gbit/s. This is 972 frame blocks (16 bytes) per frame (125 μs). Each VNO will ask for a number of blocks depending on its users' instantaneous demand. This number determines that if the VNO is a seller (if asking for a lower than the pre-defined share), a buyer (if asking for higher) or a non-trader (if asking for the exact same amount).

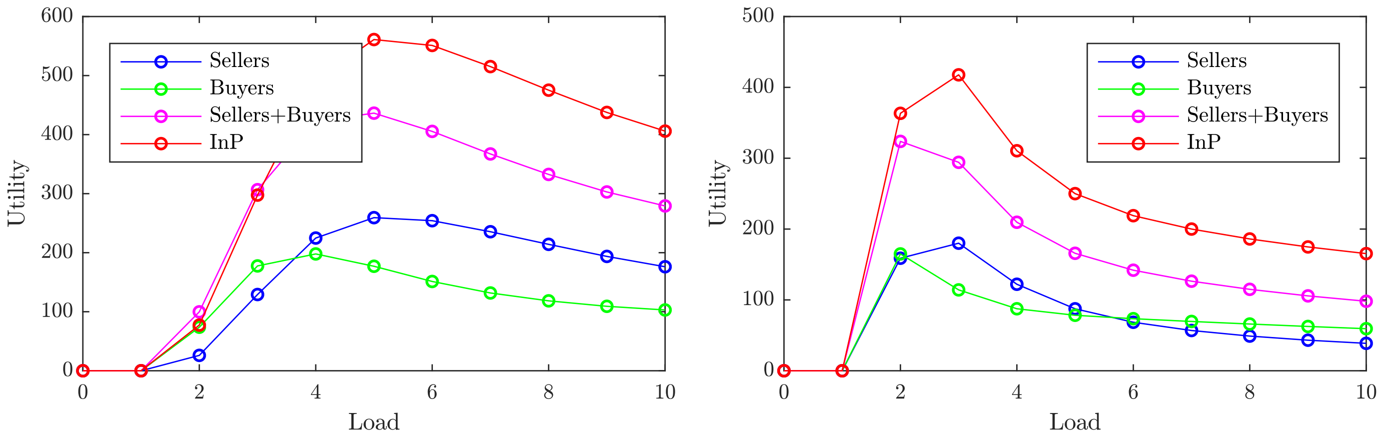
Fig. 2 illustrates the performance comparison of the proposed mechanism with non-sharing and the upper-bound cases. The *"Upper-Bound"* is the maximum reachable utilization while overlooking the economic properties.

Fig. 2a, and 2b show the PON utilization (averaged over the simulation period) in the unbalanced (randomly weighted) and balanced (equally weighted) network loads, respectively. The horizontal axis represents the average incoming load of each VNO, and the vertical axis is the utilization of each mechanism in a given load. The highest utilization in achieved in the *"Upper-Bound"* case where the VNOs are trusted to report their values truthfully and no trade is removed from the market. However, this approach fails to guarantee that the VNOs will not try to manipulate the market to their own profit (reporting fraudulent information) and harm the overall efficiency of the market. Therefore, considering that the Upper-Bound efficiency is not feasible, our proposed double auction mechanism improves the network utilization compared to the non-sharing case in different balanced and unbalanced network loads.



(a) Unbalanced (b) Balanced

Fig. 2: Multi-Tenant PON Utilization



(a) Unbalanced (b) Balanced

Fig. 3: Utility Distribution in the Marketplace

Fig. 3 shows the utility distribution between the trades and the InP. The utility of all the traders decline as the load saturates the network and the volume of offered capacity drops. Consequently, the total number of trades experiences reduction. In this work, we have proposed a marketplace design that enables farther improvements in the optical access capacity utilization by allowing real-time trade of idle capacity. Moreover, the proposed double auction mechanism assures positive utility for all the market participants.

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