Optimal Upstream Spectrum Resource Allocation on IP-over-EONs Access Links

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Abstract: We propose a resource allocation strategy on IP-over-EONs access links. It realizes the dynamic self-adaptive spectrum resource adjustment applying to traffic fluctuations and handles the performance requirements under the circuit/packet hybrid architecture.

OCIS codes: (060.4256) Networks, network optimization; (060.4264) Networks, wavelength assignment.

1. Introduction

When a client network (e.g. a Datacenter) is connected to the EON (elastic optical network) supporting both circuit connections and packet services, spectrum allocation on the access link has important implications for the utilization and performance on the link itself. It also may affect the operation of the EON, as resource adjustments at the edge will inevitably lead to traffic volatility in the circuit and packet services throughout the core network.

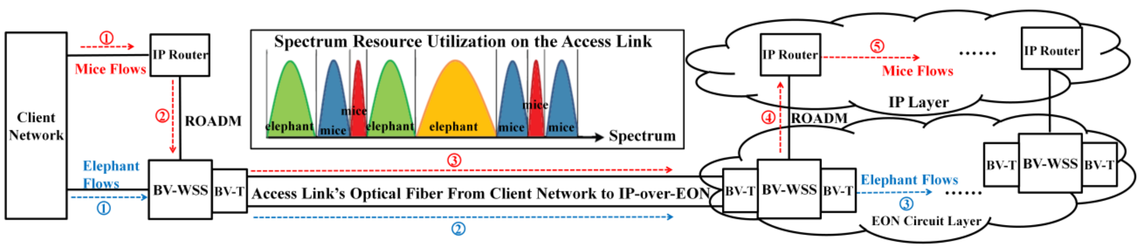

Fig. 1. The transmission scenario of access link.

As shown in Fig. 1, upstream traffic from the client network is classified into packet streams (for mice flows) and circuit connections (for elephant flows) before injected to the access link [1]. Upon entering the core network, these two types of traffic will be carried respectively by the IP layer and the EON circuit layer [2-4]. Resulting from the time-varying traffic, the spectrum resource allocated to different traffic types needs to be dynamically adjusted, such that performance of both types of traffic can be satisfied. On the other hand, adjusting the resource allocation on access links will bring in the need for reconfigurations in the core network. A reasonable pursuit of resource allocation algorithms for access links would be maximizing the resource utilization and minimizing the number of network reconfigurations, under the condition that the worst case performance requirements on both types of traffic are satisfied.

In this paper, we investigate the dynamic self-adaptive upstream resource allocation problem on IP-over-EONs access links. By providing the resource preemptive priority, the amount of spectrum allocated to circuit connections or packet services is capable of dynamic self-adaptive adjustment. We further formulate the upstream resource allocation problem as a stratified multi-objective optimization model, which balances the performance requirements and minimizes the impacts of preemptions.

2. Models and Assumptions

Let the total amount of FSs (frequency slots) on the access link be C, out of which a minimum of r is reserved for the packet service. The spectrum allocation problem can be characterized by a single value: d, the amount of FSs allocated to the packet service (Fig. 2(a)). With r, the worst case quality of the packet service can be guaranteed. And d is closely related to the traffic load and composition, both of which are assumed to be known. Increasing d will lead to reduced packet delay for the packet service, while reducing d means that more circuit connections need to be established and some spectrum resources that are currently allocated to packet services have to be preempted.

Packet loss is assumed to be caused by the queue in the IP router before the access link (as shown in Fig. 1) [5], and follows RED (random early detection) mechanisms. Resulting from the preemptive priority shown in Fig. 2(a), the actual amount of FSs serving for packet services is time-varying, which dynamically adjusts in the interval between the value of *r* and *d*.

To obtain the performance of circuit connections, we model the circuit provisioning process as Markov chain, with the state defined as the number of light paths set up for circuit connections (Fig. 2(b)). We assume that the elephant flows arrive in Poisson process with arrival rate λ_{ele}, and the light path for each circuit connection requires several FSs, denoted as n. The preemption happens when the FSs allocated to circuit connections are inadequate for the new arriving elephant flows. As shown in Fig. 2(b), we may obtain the probability of preemption, which happens between states $\left\lfloor \frac{C-d}{n} \right\rfloor + 1$ and $\left\lfloor \frac{C-r}{n} \right\rfloor$. Besides, it also illustrates the blocking situation when there is no free FSs, which is represented as the state $\left\lfloor \frac{C-r}{n} \right\rfloor$.

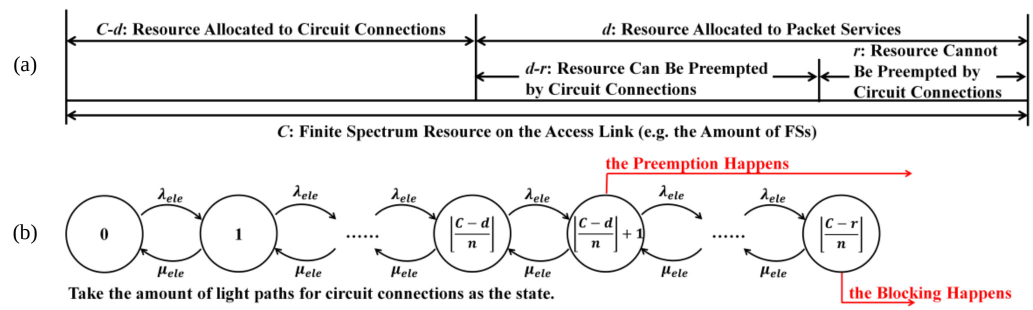

Fig. 2. System models: (a) The resource allocation model, (b) Modeling the circuit provisioning process.

3. Formulation

As can be seen from our discussion in Section 2, choosing a proper *d* is in fact a tradeoff between the achievable packet service performance and the number of reconfigurations required. With the performance definition in the previous section, we can formulate the problem into a stratified multi-objective optimization model as below:

Notations:

C: The total amount of FSs on the access link.

n: Amount of FSs required for each circuit connection.

$\lambda_{ele}/\lambda_{mice}$: The arrival rate of elephant/mice flows.

k: The amount of light paths for circuit connections

p_k: Probability of state *k* in Markov chain.

$P_{expectation}$: Expectation of preemption probability.

$P_{block}max$: The maximum of blocking probability.

$P_{lost}max$: The maximum of packet loss probability.

r: The amount of FSs reserved for packet services (constant).

s: The actual amount of FSs serving for packet services, $r \le s \le d$.

f(s): Function between s and delay for mice flows.

p(s): Function between s and packet loss probability.

Variables:

d: The amount of FSs allocated to packet services.

Objective Functions:

$$1)\ \mathrm{Min}\ \left[\sum_{k=0}^{\left\lfloor \frac{C-d}{n} \right\rfloor} p_k \cdot f(d)\right] + \left[\sum_{k=\left\lfloor \frac{C-d}{n} \right\rfloor+1}^{\left\lfloor \frac{C-r}{n} \right\rfloor} p_k \cdot f(s)\right] \quad (1)$$

$$2)\ \mathrm{Min}\{\mathrm{Max}\ [(\sum_{k=\left\lfloor \frac{C-d}{n} \right\rfloor+1}^{\left\lfloor \frac{C-r}{n} \right\rfloor} p_k) - P_{expectation}]\} \quad (2)$$

$$3)\ \mathrm{Max}\ \frac{\left[\sum_{k=0}^{\left\lfloor \frac{C-r}{n} \right\rfloor} p_k \cdot n \cdot k\right]}{\left[\sum_{k=0}^{\left\lfloor \frac{C-d}{n} \right\rfloor} p_k \cdot (C-d)\right] + \left[\sum_{k=\left\lfloor \frac{C-d}{n} \right\rfloor+1}^{\left\lfloor \frac{C-r}{n} \right\rfloor} p_k \cdot n \cdot k\right]} \quad (3)$$

Constraints:

$$\left[\sum_{k=0}^{\left\lfloor \frac{C-r}{n} \right\rfloor} p_k \cdot p(s)\right] \le P_{lost}max \quad (4)$$

$$p_{k=\left\lfloor \frac{C-r}{n} \right\rfloor} \le P_{block}max \quad (5)$$

The first objective shown in equation (1) is minimizing the delay of mice flows, after considering that the elephant flows have preemptive priority which certainly guarantees the QoS (quality of service). Based on the best delay performance, we take the probability of preemption as the second objective which is distinctive. It is obvious that high preemption probability means the frequent reconfigurations, which finally influence the network stability and the extra expenditure spent on preempted mice flows' re-routing algorithm [6]. It is also infeasible for the low preemption probability, because of the direct proportion to the resource utilization. The appropriate preemption probability is given referring to access link's hardware performances and traffic requirements. We use equation (2) to describe the approximation to $P_{expectation}$. And the resource utilization is the third objective in equation (3). Under the influence of optimization priority, its performance tradeoff will be shown in Section 4. Finally, we take the packet losing probability and connection blocking probability as constraints in equation (4) and (5).

4. Numerical Results

We consider the stratified multi-objective optimization model under different traffic loads. The overall capacity of the access link is assumed to be 1 THz with 6.25GHz per FS. The resource allocation results are presented in Fig. 3(a) as d and r in percentage form. Employing the proposed resource allocation results, circuit connections guarantee the high QoS based on the resource preemptive priority, and the stratified multi-objective optimization model promises packet services a low delay performance around 2 ms to 3.5 ms shown in Fig. 3(b). Take a specific traffic composition as an example, e.g. $\lambda_{ele}:\lambda_{mice} = 1:2 \times 10^3$. Fig. 3(c) describes the phenomenon that the preemption probability fluctuates in the minimum expected interval (10%$\pm$2%), which fits the purpose that the impacts of preemptions are under control. The sacrifice of resource utilization comparing with the global optimum, mentioned in Section 3, is provided in Fig. 3(d). The curve fluctuates in some areas on the common effect of traffic load and d value. While the influence of traffic load is greater, and leads to the overall tendency that the third objective is trying to approach the global optimum.

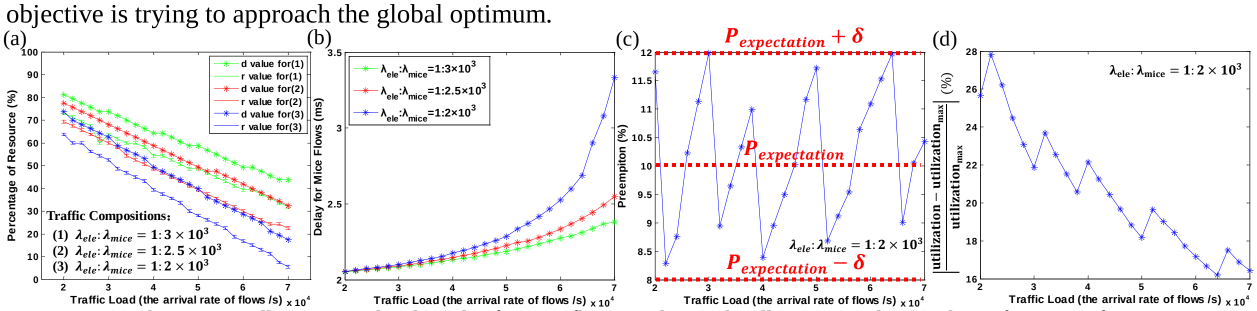

Fig. 3. (a) The resource allocation results, (b) Delay for mice flows employing the allocation results, (c) The performance of preemption probability when $\lambda_{ele}:\lambda_{mice} = 1:2 \times 10^3$, (d) The performance of resource utilization when $\lambda_{ele}:\lambda_{mice} = 1:2 \times 10^3$.

5. Conclusion

We provide a practical spectrum allocation strategy to manage and control the dynamically adjustable resource between circuit connections and packet services on IP-over-EONs access links. It can be applied to a dynamic transmission situation where elephant flows and mice flows coexist with various requirements. Employing the stratified multi-objective optimization model, we realize a low packet delay transmission for mice flows on the promise of high QoS for elephant flows. Besides, the impacts of resource preemption are minimized to the expectation, and the resource utilization is promoted to the maximum degree.

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