Network Topology Evolution based on Traffic Distribution and Increase

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Summary
Following the traffic of a backbone increase near to the capacity of the network, the evolution of backbone topology takes place. In this paper, three main types of evolution methods: link upgrading only method, node upgrading method, and the combination of previous two are explored. To shunt the saturated traffic efficiently, we propose several node upgrading algorithms, Traffic Adaptive Topology gEnerators (TATEs), based on the condition of current traffic distribution and node burden. TATEs choose the congested link as the main shunting object. The difference among TATEs lies that they have diverse strategies to choose a node in the congested link as the second shunting aim.
Simulation shows that: the type of TATEs that picks the burdened node in the saturated link as the second shunting object has the most effective shunting result. Compare with most of current topology generators such as [BRITE] in [1] which consider little about traffic increase distribution, TATEs are more efficient to satisfy traffic increase.
Key words:
Topology evolution, link upgrading, node upgrading, saturated link, traffic increase model, burdened node, traffic shunting

1. Introduction

The coming of the modern information age has brought about phenomenal growth in telecommunications-based services, driven primarily by the Internet. Recent studies show that the Internet traffic doubles every year [2]. Once where megabits were sufficient, even terabits do not suffice. When the traffic of a backbone network is near to the network capacity, the topology evolution takes place. In such case, backbone network operators have three options to upgrade their network topology: first, only updating saturated link capacities such as replace link capacity from OC-3 to OC-12, OC-48, etc (called **link upgrading only method**); second, adding new routers and links with the same link capacity to the network (called **node upgrading method**); third, adding new routers and links with larger link capacity at the same time (called **upgrading both node and link method**). Though it is easy to know these three upgrading methods will satisfy the traffic increase requirement, how to upgrade topology efficiently and economically in each type of method is still value to study.

To tackle problems easily, in this paper, we provide quantity analysis of the first two topology evolution methods: replacing saturated link with large capacity; adding new routers and links with the same link capacity. And from these two topology evolution methods, we can easily conclude the effect of the last topology upgrading method. In the whole paper, router and node are used interchangeably in our discussion.

Earlier research community [3, 4, 5, 6, 7, 8, and 9] did some studies about topology generator methods. Many of them only proposed random network topology generators using as network topology simulation tools without considering practical network traffic increase evolution. Other generators try to imitate the Internet topology. These studies unveiled several existing laws that may provide good insight of how the Internet topology should be look like. These are, the outdegree of node (domain or router) versus rank; the number of nodes versus outdegree; the number of node pairs within a neighborhood is proportional to the number of hops to the power of a constant; and the eigenvalues of a graph are proportional to the order to the power of a constant. These studies investigated current Internet network topology law from the network connectivity or structural characteristics. But they didn't aim to solve current backbone network evolution problem. In some extent, we call these topology generators as static topology generator because they consider little about the traffic increase model in the process of topology evolution. Thus, their efficiency is not high to adapt network traffic increase. Recent study [10] unveiled some parts of distinct features in topology evolution process. But its analysis is based on these static topology generators.

In this paper, we incorporate most existing network topology research results, while keeping some distinct features and providing some network topology evolution generators (TATEs) based on traffic increase model that are not presented in any other existing network topology studies. The differences are the following: 1) our topology generators are based on traffic increase model; 2) Our generators has more efficient than the other generators to adapt traffic increase; 3) Our generators can utilize the current embedded fibers and deploy easily with low cost in some times; 4) we compare the ratios of total routers capacities and effective connection throughput in different

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types of topology generators including the method that only increase saturated link capacity; 5) Our studies give some points for network operators to upgrade the network topology efficiently and economically.

Everyone knows that the Internet traffic increase very quickly. Unfortunately, detailed information about traffic distribution and load on individual links is surprising scarce. In this study, we base our analysis on the data published for the original NSFNET [11] and scale it up to simulate backbone traffic increase.

This paper is organized as follows. In Section 2, we propose several network topology generators (TATEs). These generators upgrade the network topology by adding new routers and links with the same link capacity as the previous installed links. As a whole, these generators belong to node upgrading method. In Section 3, we use the original NSFNET [11] traffic data to simulate and compare the different types of TATEs proposed by Section 2. We also compare TATEs with the generators proposed by other researchers. Section 3 also provides the simulation of link upgrading only method and compares it with TATEs. Finally, we make the conclusion in section 4.

2. Adapting Traffic Evolution Topology Generators

2.1 Motivation

To motivate these topology generator algorithms, consider the following **network and traffic increase model:** each node in the network is considered as a router having multiple interfaces, which connect to neighbor nodes. The capacity of each interface can be either one of the following OC-3, OC-12, OC-48, OC-192 and OC-768. All the links are bi-directional and have symmetric capacity. We assume that the maximum allowable load on each link is 60% of its capacity. Following the traffic increase, some of the link traffic load is saturated while the other links can still hold more traffic. At this time, the backbone operator should adjust the network topology to satisfy the increasing traffic. Apparently, upgrading network topology without considering traffic increase is not efficient. Normally, the node in a backbone topology represents as a large network connection port through which many network traffics connect to local areas. So, the network operators cannot remove any node when upgrade the topology. What they can do to upgrade the topology is adding new nodes and links.

As discussed in Section 1, there are three methods to upgrade the network topology: **link upgrading only method**, **node upgrading method** and **upgrading both node and link method**. The first method is simple compared with other two methods. We only need find the saturated links and replace them with larger link capacity. We assume that the corresponded nodes have enough computing resources to process the increased traffic. The major problem of the second approach is how to add routers and links of the same link capacity in network to distribute the traffic effectively and efficiently. In practical use, the network topology is met with both capacity enlargement and topology extension requirement due to traffic increase and new connection port necessity. Under such condition, the last method will satisfy the request. It is the combination of the previous two methods and we can easily infer the effect of this topology upgrading method from the previous two. Due to upgrading link capacity only method only need replace saturated the link with larger capacity and is easy to understand, while the second method has many varieties of topology extension. Thus, finding a type of topology generator to adapt network traffic efficiently the second approach is our main discussion object.

2.2 Topology generators approach

Based on our survey, some current topology generators such as Waxman [12] generator, BRITE generator [1], can be used to upgrade the topology when the network traffic is saturated. Though they use different laws to produce the topology, in our views, these generators are all thought as static topology generators from intrinsic property because they produce new nodes and links without considering the factor of traffic distribution and increase model - some links are experienced congestions while the other links can still accommodate more traffic in the network, during topology evolution. From the viewpoint of adapting traffic distribution and increase, they belong to the type of random topology. Thus the efficiency of using these static topology generators to add new routers and links to distribute the traffic is not high. Our generators (TATEs) notice this traffic distribution and increase model and choose the saturated links as the shunting aim. As we know, in the backbone network, most of routing algorithms are based on the varieties and extensions of the shortest path routing algorithm. And in the shortest routing algorithm, the nearer links are more relevant to shunt the traffic connection requirement. From this analysis, we design our algorithms. Before describing TATEs, we give some technical terms in the following:.

- **Saturated link:** a link is called as saturated link when the traffic of this link is near the link capacity. For example, if a link capacity is OC-3 and the traffic is equal to 60% of OC-3, we call this link as saturated link.
- **Saturated ratio:** the ratio of link traffic to link capacity.
- **Heavy burdened node:** a node is called as heavy burdened node or burdened node when the total

traffic processed by this node is larger than it processed by the other node in the same link.

- **Light burdened node:** compared to burdened node, a node is called as light burdened node when the total traffic processed by this node is smaller than it processed by the other node in the same link.
- **Descending node list:** given a node, sort all the links connected to this node based saturated ratio. The node list exclude itself in the sorted links is call descending node list.

The algorithm of TATEs includes following steps:

1) Find the most saturated link.

2) Choose a node in the saturated link. We call this selected node as referring node. There are several varieties of choosing the **referring node**: choose the heavy burdened node (TATE-1 algorithm), choose light burdened node (TATE-2 algorithm), or randomly select a node (TATE-3 algorithm) between these two nodes in the saturated link.

3) Based on the given node degree requirement, calculate the number (denoted as N) of links that may be added in the topology when the network is added a new node.

4) For the referring node, find the descending node list and collect up to N-1 nodes in the descending node list. We call these N-1 nodes as **mirror nodes**.

5) Add one new node and N links as what follows:

- Add one new node: if the topology evolution gives the new router's location, use this location. Otherwise we can add this new node close to **referring node**. Under such condition, we can utilize the current embedded fibers as new links to update the topology. We only need new fiber connection between the new added router and referring router and the distance between them is very close, thus decreasing the cost of deploying a new node.
- Add one link between the referring node and this new node;
- Add N-1 links from the new added node to the N-1 **mirror nodes**.

To describe TATEs clearly, we use a network topology evolution sample to explain. In Figure 1a, the numbers near the links are the traffic units of these links (relative unit, can be delegated anything that routing algorithm uses such as link length, number of node, etc.). In this figure, the capacity of each link is same and equal to 20 units and the node density is 3. We assume a link as a saturated link when the saturated ratio is larger or equal to 60%. Based on above assumptions, our algorithms produce a new topology from the original one with the following steps:

1) In Figure 1a, link AE is the saturated link.

2) In the saturated link AE, we calculate the burden load of node A and E by adding up all the link traffics directly connected to them. For example, burden load of A= total traffics of link AB, AC and AE. We find node A's burden (30) is larger than node E's burden (21). TATE-1 algorithm chooses the heavy burdened node as referring node (Figure 1b selects node A as the referring node). TATE-2 algorithm chooses the light burdened node as the referring node (Figure 1c selects node E as referring node). TATE-3 algorithm chooses a referring node randomly in the saturated link.

3) Due to the node density of this example is 3, we need 3 new links when 1 new node is introduced in the topology. In this sample, we designate the new added router as node F.

4) Collect mirror nodes. In Figure 1b, descending node list of node A is E, C and B. We collect 2 nodes E and C as mirror nodes. In the same way, we collect node A and D as mirror nodes in Figure 1c.

5) Add the new node and links. Follow the algorithm, we add new node F near referring node A and new links as FA, FE and FC in Figure 1b. In Figure 1c, we add new node F near referring node E and new links as FE, FA and FD. All the new added node and links are expressed by dashed line in the figure 1.

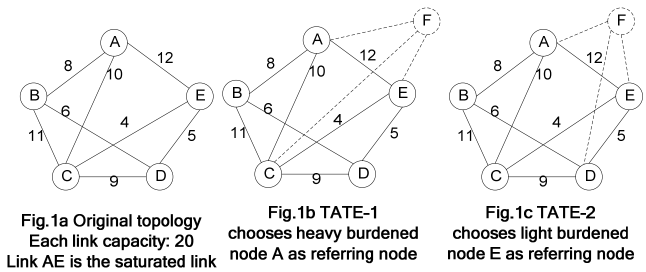

Figure 1. TATE introduction

Due to different referring node choosing methods, we classify the TATEs as TATE-1, TATE-2 and TATE-3. These three types of TATE generators use the same steps except the key difference of choosing the referring node.

3. Simulations and Results

3.1 Simulation premise and steps

As discussed in above sections, most of the former generators consider little about the traffic distribution and increase model during topology evolution. From this viewpoint, they belong to the type of random topology generators. And their efficiency to the topology evolution should be similar. Thus, in our simulations, we simulate one type of these static topology generators – BRITE [1] for comparison analysis.

Our simulation bases on the following simulation premise and steps:

1) Simulation Starts from a 14-node network NESFNET [11] and evolves topology over 30 iterations;

2) Increasing the current traffic in the same relative ratio;

3) When the traffic load on a link reached 60%, we use topology generators to upgrade the topology.

4) Traffic shunting approach: picking from the referring node, and splitting half of its end-to-end traffic requests (with +20% variations) to the new node. Traffic demand between these two nodes is assumed to be 10% of the total traffic handled by the referring node.

The algorithm for **link upgrading only method** is very simple: it only replaces the saturated link from small interface to high interface. That's mean using the following interface series: OC3, OC-12, OC-48, OC-192 and OC-768.

3.2 Results and analysis

All of the following simulation results are based on node degree equals to 3. We also simulated these comparisons based on other node degree values. All of these simulations have the same comparison results. Our first object is to show that TATE-1 has the best traffic shunting results. Figure 2 shows the traffic shunting results under different types of TATEs. Figure 2 shows: TATE-1 (the algorithm which chooses the heavy burdened node in the saturated link as the second shunting object) has the best evolution efficiency; TATE-2 (the algorithm which chooses the light burdened node in the saturated link as the second shunting object) has the worst evolution efficiency among the three TATEs. TATE-3 ((the algorithm which chooses the light burdened node in the saturated link randomly) is in the middle. This is easy to get. Shunting the traffic of saturated link and heavy burdened router should have the most efficient topology evolution result, vice versa.

Figure 3 shows the evolution effects of TATEs and BRITE generator. We generated BRITE with nodes placed randomly and interconnected according to the Barabasi Albert Model [9]. From this figure we easily get the conclusion: TATEs generators have more efficient to adapt network topology evolution than BRITE topology generator. As discussed in Section I, BRITE is the representative of earlier static generators [3, 4, 5, 6, 7, 8, 9]. We can get the conclusion: TATEs has more efficient than static generators to adapt the network topology evolution.

The main reason lies: TATEs add new nodes and links near the saturated links and burdened nodes and they can shunt the traffic more effective than randomly adding new nodes and links in topology evolution as static generators do.

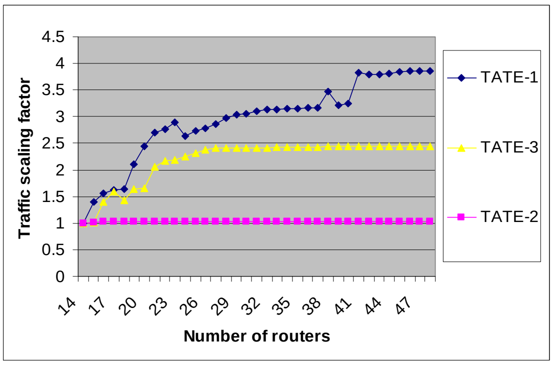

Figure 2. Traffic shunting effects in TATEs

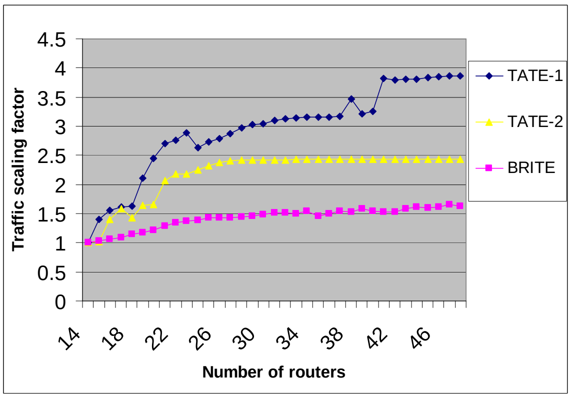

Figure 3. Evolution effect comparison between TATEs and Brite algorithm

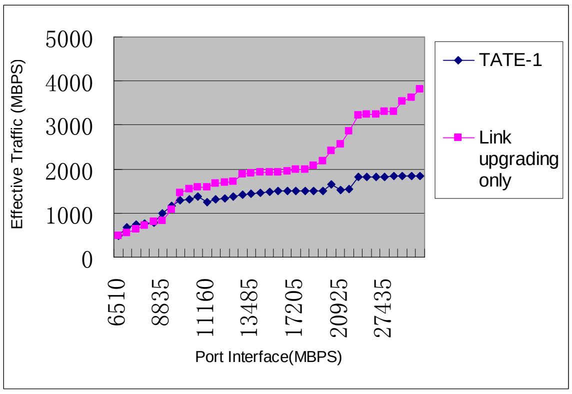

Figure 4. Efficiency comparison between TATE-1 and the generator of link upgrading only method

Figure 4 shows the efficiency between the total link capacity and effective traffic throughput for TATE-1 and the link upgrading only method. From this figure, we can get the follows conclusion: increasing the link capacity has more effective result from long evolution views; in short time, TATE-1 has similar efficiency with the link upgrading only method in network topology evolution period. TATE-1 may have better economical result because the link upgrading only method need larger port interface installed in router and this requires more budgets. For example, the latter evolution method may need an OC12 link to replace an OC3 saturated link to ease the saturated traffic while the TATE-1 method may only need two or three OC3 links to satisfy the easing requirement with smaller investment. When the network operators need adding new routers to upgrade the topology, the link upgrading only method will lost effect. In such case, we should use the upgrading both node and link method to satisfy the requirement of both topology evolution and traffic increase. If we combine TATEs and link upgrading together, we will satisfy the evolution requirement as well as obtain the desirable traffic shutting result. The traffic shutting efficiency totally should be in the middle of these two types of generators.

4. Conclusion

In this paper, we analyze three topology evolution methods: link upgrading only method, node upgrading method, and the combination of previous two - upgrading both node and link method. Due to link upgrading only method merely need replace the saturated link with larger link capacity and is easy to understand, while the second method has many varieties of topology extension. Under such condition, to find an efficient type of topology generator has some values. We analyze the intrinsic static property of current topology generators leading to low efficiency of shunting traffic in topology evolution. To adapt the traffic increase efficiently, we propose TATEs based on network traffic distribution and increase model. Simulations show that: TATEs have better efficiency to adapt the traffic distribution and increase model than current generators; link upgrading only method has better efficient result than any node upgrading method from long views; and upgrading both node and link method is in the middle.

In practical use, sometimes the network topology is met with both capacity enlargement and topology extension requirement due to traffic increase and new connection port necessity. Under such condition, combining TATEs and link upgrading only method will satisfy the request efficiently. Of course, in real traffic evolution process, network operators must construct the traffic distribution and increase model to presuppose the future traffic before using the theory of TATEs at most. In the same time, they must consider the current embedding fibers, amplifiers, the total evolution cost, etc. Based on all of these considerations, they can get an efficient and economical tradeoff evolution result.

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