An Evolution Process Model for the Internet Topology*

Sangjoon Park¹, Insook Cho², and Byunggi Kim²

¹ Information & Media Technology Institute, Soongsil University

² School of Computing, Soongsil University
{lub, bgkim}@archi.ssu.ac.kr

Abstract. Instead of actual experiments to network protocols, network simulators are useful to analyze these network protocols for lower analysis cost. The Internet topology is dynamically evolving and growing, and then shows changing characteristics based on time flow. Studies of Internet topology have been motivated by the demands for analysis and simulation to the modeling of real networks. Hence, to develop the Internet simulator, proper characteristics to Internet topology should be studied. In this paper, we propose topology models to the Internet topology showing node addition and deletion.

1 Introduction

Real experiments to large scale network are ideal to correctly analyze performance evaluations to researched network protocols. However, it is very difficult since researched protocols cannot be directly tested in real networks, and the evaluation cost based on real experiments is very high. Hence, the modeling and the simulation to the large scale network such like Internet are useful to assess researched protocol performances. Advantages of the modeling and the simulation for such network structure are as follows:

- Evaluation cost:* Generally, the experimental evaluation to the actual network is very difficult and expensive. However, by using a simulator to the source network system, it can spend much lower evaluation cost compared with actual experiments.
- Flexibility:* The experimental implementation has the limitation of application flexibility caused by environment problems when an additional scheme is newly adapted to the source network systems. In simulation environments, the addition of a new scheme is much easier than it on the experimental environments.
- Applicability:* Network simulators developed in the modeling can be used to analyze variety network mechanisms.

The Internet was developed for military and research-oriented prototypes, but it has grown into very large scale network that connects many computers around the world without any centralized control or administration. Hence, to implement simulations related to network protocols on the Internet, it is important to study the properties of and policies of the Internet (e.g., network scale, connection types between different

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networks and network evolution model). Therefore, most researches to the Internet focus topology models that try to represent the characteristics of the real Internet topology accurately [1] [2] [7]. In this paper, we propose an Internet topology model that has the functionalities of adding and deleting nodes and processing the isolated nodes to accurately apply the changes in the real Internet. We consider a node change model for showing characteristics of Internet evolution.

2 Internet Topology Property

2.1 Evolution Model

There are power-laws among the several properties that characterize the Internet topologies [5], [6], [9]. At present, the well-known key power-laws are the following: First, the power-law relationship between the degree of a node (d_v) and the rank of a node (r_v) is presented by

$$d_v \propto r_v^R \quad (1)$$

where v is a node in the Internet, and R is the power of a constant (rank exponent).

Secondly, a power-law appears between an degree (d) and the frequency (f_d) as follows:

$$f_d \propto d^O \quad (2)$$

where O is the degree exponent..

Thirdly, a power-law is the relationship between a calculated eigen value (λ_i) and a rank (i) as follows:

$$\lambda_i \propto i^\varepsilon \quad (3)$$

where ε is the eigen exponent.

The rank is arranged in ascending order by the eigen value using a close matrix. If all nodes are connected, it is represented by 1, and if not connected, it is expressed by 0.

2.2 Topology Model

Waxman model is the distance-based connection that links of nodes are added to a network considering the distance between nodes arranged in random positions on 2D grid [10]. The rate of generating link between the two nodes u and v is different depending on the distance of the node from the node, and it is determined using the connection rate as follows. Waxman model is usually used to create a random network.

$$P(u, v) = \alpha e^{-\frac{d}{\beta L}} \quad (5)$$

where d is euclidean distance from node u to v , L is the maximum distance between two nodes in a graph, and $0 \leq \alpha, \beta \leq 1$.

Barabasi-Albert model is the degree-based connection method that a characteristic of the Internet evolution shows a power-law distribution by providing incremental growth and preferential connectivity to the degree frequency [3][4].

$$P(j) = \frac{d_j}{\sum_{k \in V} d_k} \quad (6)$$

where d_j is the degree of the node (j) and V is the collection of all nodes connected in the network. $\sum_{k \in V} d_k$ is the degree sum of all existing nodes.

Fig. 1. Random topology (Arrangement of nodes without links)

3 Internet Topology Model

In this paper, we design an Internet topology model showing changeable network configuration. In the time flow, network nodes can be deleted or added to the growing Internet topology.

3.1 Method to Make a Topology in the Beginning

Firstly, to present the initial Internet topology, we use the node information (1999 year-network information) to the Korea Internet network. The node generation pattern is that the initial node is generated and then will be arranged in the network. Furthermore, after creating a node in small-sized topology, the arrangement to the node uses a random method. A link connection between two nodes uses the node connection rate [equation (5)] in Waxman model and the degree-based connection method [equation (6)]. Fig. 1 shows the beginning topology created using a random method. The AS number is 149 in 1999.

3.2 Node Addition

After initial topology generation, if a new node is created and is connected to another node, the node addition method is same as above mentioned subsection 3.1: Firstly, the node connectivity rate considering Euclidean distance between two nodes and secondly degree-based connection method using the connectivity rate of the Barabasi-Albert model. In Barabasi-Albert model, a higher degree node presents higher connectivity rate in the existing network [3] [10].

3.3 Node Deletion

Current Internet models only consider the network growing modeling. However, note that a network node can be deleted from social or technical problems. Hence, though the Internet is continuously growing, each network node has its life cycle so that it can be died. In this paper, we derive two node deletion scenarios based on equation (5) and (6). First scenario is based on the distance between two nodes as follows.

$$P_i = \frac{l_i}{\sum l_k} \quad (7)$$

where l_i is the distance value of a node i , and $\sum l_k$ is the distance sum of all nodes.

In distance-based scheme, if a node (i) is far away from a core node and has the maximum distance value l_i , the rate P_i to i is the maximum value. Hence, the node i having the maximum rate value will be deleted. For the second method, it is the case that considers the degree and the distance simultaneously. Hence, even though a node has the maximum distance value, if the degree of node is high, the node can alive. If $\{I_0, I_1, I_2, \dots, I_n\}$ is the distance set of all nodes from a core node, $\{d_0, d_1, d_2, \dots, d_n\}$ is the degree set of all nodes, and the total number of node is m , the rate P_i is given by

$$P_i = \psi \frac{l_i}{\sum_{i \in V} l_i / m} - \delta \frac{d_i}{\sum_{i \in V} d_i / m} \quad (8)$$

where ψ and δ are the shape parameters, $\sum_{i \in V} l_i / m$ and $\sum_{i \in V} d_i / m$ are the average values, and $V = \{0, 1, 2, \dots, n\}$ is the set of all nodes.

Here, we use the average value for each node to make the same effects about the degree and the distance.

3.4 Processing an Isolated Node

After deleting a core node or a node having high degree, the process to isolated neighbor nodes (with zero degree) is required. Hence, it needs to create a new link and

Fig. 2. Processing an isolated node: (a) Before node deletion and (b) After node deletion

connect to another node. As an example, Fig. 2 shows the node isolation process. In Fig. 2(a), the node (*C*) has 4 degrees. If the node (*C*) is deleted, node (*A*) and node (*B*) are isolated. Hence, node (*A*) and node (*B*) should be connected another node [here, node (*G*)]. To create new links, it uses a method similar to that of adding a link when a new node is created: Waxman's node connectivity rate [equation (5)] and the degree-based connection method [equation (6)].

4 Performance Evaluation

We evaluate the correlation between each topology model and the power-law by using three power-law equations (in Section 2.1) [8]. To evaluate the proposed model, we created the network topology in two ways. Table 1 show the current network models without the node deletion function, and Table 2 presents the proposed models that includes the node deletion function and the isolated node process. In the distance-based method, Waxman parameter α and β are 0.6 and 0.4, respectively [see equation (5)].

Table 1. Topology model without a deletion function

Model name	Node addition	
	Node creation	Link connection
A1	Incremental method	Distance-based method
A2	Incremental method	Degree-based method

Table 2. Topology model with a deletion function

Model name	Node addition		Node deletion	Processing to isolated nodes
	Node Creation	Link connection		
B1	Incremental method	Distance-based method	Distance-based method	Distance-based method
B2	Incremental method	Degree-based method	Distance-based method	Distance-based method
B3	Incremental method	Degree-based method	Distance-based method	Degree-based method
B4	Incremental method	Degree-based method	Degree and distance-based method	Distance-based method
B5	Incremental method	Degree-based method	Degree and distance-based method	Degree-based method

In this paper, we used the status of the number of national AS announced by the Korea Network Information Center (KRNIC) [11]. The yearly status of the number of AS to Korea and the world is shown in Table 3. The actually used data in this simulation is from January 1999 to May 2003.

Table 3. AS number from 1999 to 2003

Year	Korea		World	
	AS	Growth rate	AS	Growth rate
1999	149	1.00	11,232	1.00
2000	300	2.01	15,710	1.39
2001	391	2.62	20,128	1.79
2002	433	2.90	23,822	2.12
2003	494	3.31	24,827	2.21

4.1 Evaluation Results

Unfortunately, we can show evaluation results to only the model A2 and the model B5 because of the limited paper space. Fig. 3 and Fig. 4 show graphs that the network topology grows from 149 AS nodes to AS 494 nodes. Hence, to the network growth, the power-law is examined by the growth characteristic of each topology, and results are plotted on the Log-log scale. Fig. 3 is a result using the model (A2) without a node deletion function.

Fig. 3. The network model (A2) : (a) Rank versus degree (b) Degree versus frequency and (c) Rank versus eigenvalue

Fig. 4. The network model (B5) : (a) Rank versus degree (b) Degree versus frequency (c) Rank versus eigenvalue

Fig. 5. The predicted network model (B5) after 3 years: (a) Rank versus degree (b) Degree versus frequency and (c) Rank versus eigenvalue

Fig. 6. A network topology example based on the model (B5): (a) core nodes (b) core nodes with leaf nodes

In Fig. 3, three sub-graphs [(a), (b) and (c)] show that each result presents the power-law property because A2 uses a node addition using a gradual increase method and a link creation using the degree-based method. Each CC is -0.95, -0.95, -0.97. Here, CC means the correlation coefficients between the network model and the power-law property. Fig. 4 shows the result of using the model (B5) including a node deletion function and the isolated node process. In Fig. 4, each CC is -0.96, -0.98 and -0.98. The correlation coefficient for the model (B5) show better results of 0.01, 0.03, 0.01 than the ones for the A2 model. Fig. 5 shows the prediction results to the model (B5) after 3 years. We determine the future node number by calculating the average value to all of growth rates in Table 3. After 3 years, the correlation coefficient of B5 is -0.96, -0.98, -0.98. The correlation coefficient of the model (B5) shows better results than that of the model (A2) with 0.01, 0.03 and 0.02. Fig. 6 shows an example of the network topology by the model (B5). The total number of AS node is 490. In Fig. 6(a), the core nodes are firstly generated, and the leaf nodes having the low degree are secondly generated and connected to the core nodes in Fig. 6(b). The proposed model in this paper deals not only with the addition of nodes but it also applies to the node deletion. Hence, we can show more elaborate network model for the Internet evolution.

5 Conclusions

In this paper, we propose an Internet topology model reflects the status of changing topologies caused by the creation and deletion of nodes. The model that we have proposed with the function of node deletion reflects the real Internet topology modeling better compared with current models that simply adds nodes. Furthermore, it shows that the proposed model (B5) has better result values than the model (A2) for predicting the Internet topology in the future. Therefore, the proposed model can better satisfy the power-law that is the characteristic of the Internet compared with current models without the deleting function. We hope the proposed network model that can apply to the topology generator to implement the Internet protocol simulation.

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