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Internet Topology Model: in a Nutshell

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Abstract—*Internet architecture modeling is important to enhance Internet performance in many research areas, such as protocols design, routing and searching algorithm, virus spreading protection, and node failure effect. Based on the characteristic of AS-level Internet topology, is proposed by applying dynamic rates in node growing, different level link connecting and link disconnecting in modeling process. An Internet topology with any given node number within area can be built by this model.*

Keywords—*Internet topology; topology modeling; complex network;*

1. INTRODUCTION

Internet has evolved into an indispensable part of our daily lives. A detailed understanding of Internet topology is critical for evaluating the performance of network protocols, assessing the effectiveness of proposed techniques to fight against malicious intrusions and attacks, or developing improved designs for resource provisioning. Yet as a decentralized-managed complex network, Internet topological structure still can't be precisely illustrated, especially how it evolves over time. Internet is one of the tangible complex systems in reality and shares some common structural characteristics of complex network, such as the small-world properties, the power-law degree distribution, and the degree correlation.

The earliest Internet model at AS level was stochastic model, e.g. Waxman model [1], where a set of nodes are distributed in a plane uniformly at random, and then a link is added between each pair of nodes with a constant or a varying probability. Transit-Stub model [2] with three level domains are constructed to reflect the hierarchical domain structure and locality presented in the Internet. Later the studies reveal that real Internet topology is neither completely random nor completely regular (hierarchical), but with a prominent haracteristic which the degree distribution of nodes follows a power-law form. Internet topology modeling steps into a quantified attributes modeling stage.

Many grow and preferential attachment models have been proposed, such as BA model [3], GLP model [4], PFP model [5] and MLW model [6]. They closely mimic some of the characteristics of Internet.

Average node degree, average clustering coefficient, and average node distance are vary from time to time. Those models can only show the network structure at a given moment while it can't illustrate actual Internet dynamic growing process.

Besides, a local-world node deleting evolving network model [7] is proposed focusing on node adding, local preferential attachment, and node deleting. A model under IPv6 also has been studied [8].

To mimic the real Internet evolving, we propose a time varying evolving Internet topology model which takes advantage of the thoughts in multi-layer and preferential attachment models. By comparing the simulation network properties with statistical Internet ones in years, the model precisely describes Internet dynamic node growing process with adjustable parameters. Any simulated Internet network with nodes between 3000 and 22000 can be generated for other researches.

A. Thoughts and Settings for Modeling

At AS level, where each AS is approximately mapped to an Internet Service Provider, Internet has backbone connection and multi-level local connection. A new AS usually only connects to ASs in the same region which makes local preferential connection. This results in a tighter local connection. Moreover, a new AS intends to connect to a high-degree AS to minimize the communication delay instead of randomly connect to any AS. Instead of using static growth rate during the whole modeling process, we gradually adjust each operation's probability according to a growth rate function to simulate the real growing process of Internet. At any step of the modeling process, the network topology is a simulated Internet topology for the nodes at that moment. Let G=(V, E) denote the network topology, which is a undirected graph with nodes set V and link set E (a set of links connecting all nodes in V). We define two types of networks, WAN and LAN, which represent two different layers. WAN is a network which constituted of geographical adjacent nodes. As usual, the links within WAN are more than those between WAN s,

For any node Vi E V, let Qi denote a node set for all adjacent nodes of Vi.

$$\Omega_i = \{v \mid vv_i \in E, v \in V\}$$

For any node $v_i \in V$, let Ω_i' denote a node set for all adjacent nodes of any node in Ω_i.

$$\Omega_i' = \{v \mid vv' \in E, v \in V, v' \in \Omega_i\}$$

Both Ω_i and Ω_i' are node set of LANs.

B. Modeling Process

The time-varying evolving model is generated by the following scheme. Start with no isolated WANs. Each WAN has mo nodes and eo links without isolated nodes. At each step, perform one of the following four operations at random:

1) With probability p, a new node is added to a randomly selected WAN r.

And then a node in r is chosen with a probability given by to connect to the new node.

$$\Pi(k_i) = \frac{k_i}{\sum k_j} \qquad (1)$$

A. Properties for Evaluating Comparison

We provide a comparison of several properties. In particular, we consider the node degree distribution, average clustering coefficient, and average node distance. These quantities will provide a preliminary image of the network. 1) Node Degree Distribution Node degree distribution function P(k) is defined as the proportion of nodes with degree k in all nodes. It shows the possibility of getting a node with degree k from the network. Network average degree is the average degree of the sum of all node degree.

The scale-free nature of the Internet has been pointed out by inspecting the node degree probability distribution, and it implies that the fluctuations around the average connectivity are not bounded. Internet node degree distribution P(k) matches power-law distribution, i.e. P(k) □ k-Y The exponent is believed to between 2 and 3. In order to provide a full characterization of the scale-free properties of the Internet, we analyze the distributions for different time snapshots of the Internet topologies. These distributions exhibit an algebraic behavior and are characterized by exponent that is stationary in time.

2) Average Clustering Coefficient

Average clustering coefficient is a parameter for describing the network cluster characteristic from global view and the distances between a node's adjacent nodes from local view. Let C denote clustering coefficient of a node Vi with degree ki' C = 2Ei I ki(k i+ 1) (3)

Ei is the total links between adjacent nodes of Vi.

Let C denote network average clustering coefficient,

C = I.CI N (4) N is the total nodes in the network.

Research [9] shows that Internet has fairly high average clustering coefficient and current router policies are the reason.

B. Parameters Selection

1) Exponent selection

The elegance and simplicity of the power laws provide a novel perspective of Internet structure. Node degree

CASE B:

distribution P(k) is in proportion to k-Y According to the statistical analysis [10], the evolution of the power-law exponents keeps stable for years which is fluctuating round 2.2. In our model, exponent y is fixed at 2.2 during the simulation process for simplicity.

2) Operations probability selection

According to the statistical result (collected form [11] and related resources) of (k, C, d) from 1997 to 2005, we compute the (p, q, r, s) combination respectively for each year with fixed growth rate, i.e. without changing (p, q, r, s) during the evolving process. A fitted curve for rate change during this period is generated for growth rate equation for (p, q, r, s). 3) Initial values selection

For the selection of no, mo, and eo, any small numbers can be applied. At least a few thousand nodes in Internet simulated network, the probability selection during the modeling process will eliminate the effect of the original small number.

We compare the simulation results with no = 4, no = 6, and no = 8. There is no obvious difference between the final network topologies. For mo= 4, mo= 6, and mo= 8, we have similar conclusion.

For the selection of eo, it should not be too big since a link can't be added to a complete graph. Otherwise as no and mo, any small eo can do.

2) Power-law in node degree distribution

Power law characteristic. When we randomly select a number between 3000 and 22000 and take a look at the node degree distribution, the image looks alike.

Many low-degree nodes and a few high-degree nodes show that it's a scale-free network which is robust in random network breakdown and vulnerable in intentional attack.

3) Hierarchy and locality

In the way the model is building, WAN and LAN give the network a hierarchical structure while LAN reflects the local characteristic. The model is born with hierarchy and locality which fit the Internet characteristics well [13].

2. CONCLUSION AND DISCUSSION

We have shown a time-varying evolving Internet topology model at AS level and analyse its properties by comparing it with statistical data. This model takes dynamic growth rate, preferential attachment, hierarchical nodes and geographical location into account and captures scale-free node degree distribution, high clustering co efficiency and small average node distance properties during the simulations. As we repeat the modeling process times and times again, the model stably shows similar topology properties. Given any node number between 3000 and 22000, we can build a simulated Internet topology by running this model until the specific nodes is reached. This help the researches on Internet communication protocols, transmission mechanism, virus spreading, and congestion control under a realistic network topology.

Most of the data we collected are based on NLANR Project which aimed to give a picture of global ISP interconnectivity by AS number. Since NLANR project had been suspended for some time, our test data are out of date. The rates we set in our model can only work for the node range as stated before. The dramatic increase in 2005's data leaves this model is not a good one for prediction. We need further research to obtain the new data to build a better model for predicting the future topology of Internet.

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