Modeling the Dynamics of the Internet AS-Level Structure: an Economic Perspective

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1 Introduction

We study the phenomena of the power-law degree and high clustering present in the Internet AS-level topology and offer a theory explaining it from an economic perspective. Different from traditional methods like preferential attachment and central optimization, our approach suggests that wealth may play a major role during the evolution of an ISP's degree and its decision of new peering points could be solely based on local knowledge. We propose a topology model, called *Wealth-based Internet Topology* (WIT), that utilizes a bounded multiplicative stochastic process to model each ISP's wealth and uses random walks for construction of new edges. We demonstrate through simulations that this new model performs in better than the existing algorithms in terms of the evolution of graph metrics, i.e., degree distribution, clustering coefficient $\gamma(G)$, and characteristic path length L.

2 Model

The framework of WIT is illustrated in Figure 1(a), where ISPs' wealth controls degree and random walks decide connectivity. Suppose that ISP i joins the system at random time t_i and define $w_i(t)$ to be its wealth at time t. Initially, $w_i(t_i)$ is set to a constant w_0 and then $w_i(t)$ evolves according to a multiplicative stochastic process, which mimics randomness in financial income. When $w_i(t)$ drops below the boundary w_b, ISP i is removed from the system, which represents bankruptcy. An example of the wealth process is demonstrated in Figure 1(b). To account for maintenance cost of links, we also allow each ISP i to adjust its degree to be proportional to its wealth, where the ratio is specified by a constant C: new neighbors are added as long as $w_i(t)$ allows more links and existing peering relationships are terminated when an ISP cannot sustain all of its links. The final note is that the selection of new neighboring ISPs is based on l-step random walks, which start from ISP i and randomly walk over the existing graph to find possible candidates.

3 Main Result

Denote by ξ the ratio of the boundary against the initial wealth, i.e., $\xi = w_b/w_0$. In the generated graphs, we obtain power-law degree distributions with exponent α that can be approximated by:

$$\alpha \approx \frac{1}{1-\xi}, \tag{1}$$

and observe that the clustering coefficient is mainly determined by walk length l.

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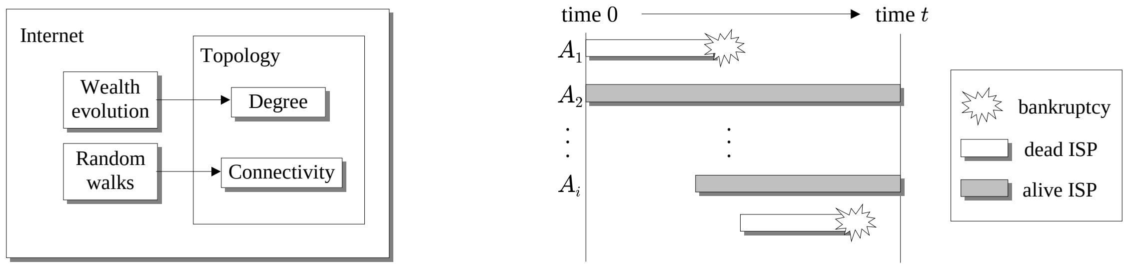
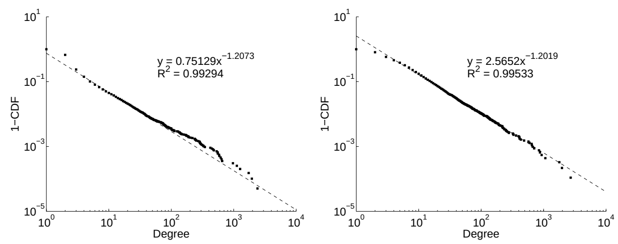


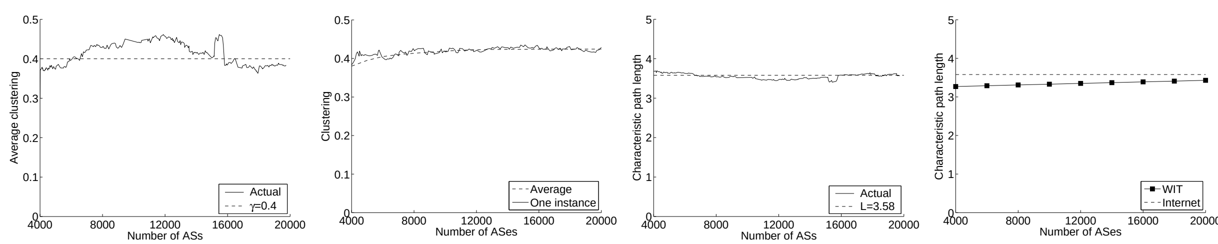
(a) framework (b) wealth process

Figure 1: (a) Components of the wealth-based evolution model. (b) An example of birth-death wealth evolution.



(a) Internet (b) WIT

Figure 2: Degree distributions of the Internet and WIT.



(a) Internet $\gamma(G)$ (b) WIT $\gamma(G)$ (c) Internet L (d) WIT L

Figure 3: Evolutionary comparison of the Internet and WIT.

By setting proper ξ and l, we are able to achieve both power-law degree distributions with $\alpha \approx 1.2$ and high clustering of 0.45 as witnessed in the Internet. Figure 2 plots the degree distribution of the Internet AS-level graph obtained on April 26th, 2005[1] as well as that generated by WIT. More importantly, we find as shown in Figure 3(a)-(b) that the clustering coefficient of WIT matches that of the Internet during the *entire evolution* of the graph (i.e., as the size of the system increases) rather than for a single value of n as usually examined in prior work. Additional simulations show in Figure 3(c)-(d) that WIT's characteristic path length is also close to that of the Internet and exhibits invariance with respect to n. From these results, one must conclude that the proposed topology algorithm is viable in explaining the structural evolution of the Internet.

[1] Other AS snapshots have similar degree distributions.