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Internet Autonomous Systems (ASes) Level Topology Modeling

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Abstract: The aim of this paper is to develop a prediction model for Autonomous systems **(**ASes) internet growth. The Border Gateway Protocol (BGP) is taken as primary data source. BGP raw data (RIBS) collected from University of Oregon Route Views Project Archive. Data from 2001 to 2009 are used in this study. Statistical methods are applied to analyse the collected data. A model is developed based on the outcome of the data analysis. It is found that the internet growth follows Logistic Regression Model with a rate of growth equal 0.014. The link growth is also investigated and found to have followed an exponential pattern with a rate of growth equal 0.017.

Keywords*:* *Internet; Autonomous Systems; Modeling; Power Law Distribution*

1. INTRODUCTION

The internet can be considered as a prominent example of self-organized system that combines human associative and technical skills. It is composed of tens of thousands of loosely connected networks, known as Autonomous Systems (ASes) which exchange reachability via the Border Gateway Protocol (BGP). The ASes topology and structures characterized by continuous exponential growth, without well-defined design and control rules, i.e. can be classified as scale-free network. Thus, statistical analysis is regarded as the most appropriate technique that to use in study the internet architecture. That includes the prediction of the evolution properties and evaluation of the network protocols.

Recently, Internet topology analysis and modeling has received substantial attention, as the topology affects the network routing, performance, protocol, quality of service, traffic engineering, diversity, and many other factors. The internet topology is important for researchers as well as Internet Service Providers (ISP), in order to find the needed capacity and connections.

In this paper internet AS-level topology modeling and analysis is considered. A topology database is developed, which reflects the current resource allocations. A topology model is developed for prediction and analysis. The study is carried out in four phases; (i) data collection, (ii) data preparation and filtering, (iii) building AS topology, and (iv) AS topology analysis.

2. AUTONOMOUS SYSTEMS MODELS

Generally, scale-free networks are classified as assortative, disassortative and neutral network [1-3]. In assortative networks the high-degree nodes are prefered to be attached to other high-degree nodes; while in disassortative networks the high-degree nodes tend to connect with low-degree nodes. The AS-level internet topology may be considered as a disruptive network [4,5]. However, this property does not always imply that the high-degree nodes are tightly interconnected to each other.

Various models for the describing the growth of internet topology are reported in the literature. The models list includes Barabasi and Albert Model (BA) [6], Positive-Feedback Preference (PFP) Model, Multiclass Preferential (MP) Model, Moore's law, and others. In this review only the most important models are considered.

The BA Model showed that it is possible to predict the growth of a network with a power law distribution by using a preferential-growth mechanism when starting from a small random network. The network growth by attaching a new node with j links to m existing different "old" nodes. The probability that the new node will be connected to node i, with degree k_i is given by:

$$\Pi(i) = \frac{k_i}{\sum_j k_i} \quad (1)$$

This model generates networks with power-law exponent $\gamma = 3$. A quite large number of models are developed based on this model. All of these models suffer from some sort of inaccuracy in determining the internet growth, especially for the rich-club connectivity between high-degree nodes and the maximum degree of the network [7]. This is because only source of growth is assumed an addition to the new node.

Historical data imply that the Internet growth is mainly due to two factors: (i) the addition of new nodes as described by the BA model and (ii) the addition of new internal links between existing nodes. The Interactive Growth (IG) model uses these two procedures to generate the network topology [8]. Here a new internal link starts from the host node (old node) to which new node is attached and the two growth processes are simultaneous and interdependent. The model starts with a small random network, then at any time (i) a new node is attached to one host node with probability $\rho \in (0,1)$ and two new internal links appear between the host node and two other old nodes (peer nodes, and (ii) a new node is attached to two host nodes with a probability$1-p$, and one new internal link appears between one of the host nodes and the peer node. According to this model, the traffic volume increases and its pattern changes as a result of the network growth. Thus the new links connecting host nodes to peer nodes are added to balance the network traffic and optimize the performance. The value $p = 0.4$ is reported in literature, which is obtained by numerical simulation [8]. The IG model used the BA model linear preference (1) to attach a new node and the appearance of new internal links. Studies showed that (i) the majority of new nodes is added by attaching them to one or two old nodes, i.e. $m \leq 2$, and (ii) the degree distribution of the AS graph is not a strict power-law, but has more nodes with degree two than nodes with degree one, with probabilities P(m=2)=0.38 and P(1) = 0.26. Generally, the IG model closely represents both power-law degree distribution and rich-club connectivity of the AS graph. Nevertheless, this model suffers from the limitation in predicting the number of nodes with the maximum node degree k_{max}, which is overestimated.

The Positive Feedback (PF) Model based on the fact driven from Internet History that implies the node degree increases very slowly. And in the course of time the node degree grows more and more rapidly. In this model the probability that a new node link with a low-degree old node is taken to be a linear preferential attachment, and given by (1) [4,5]. The IG model can be modified by using nonlinear preferential attachment to yield the PFP model as [9]

$$\Pi(i) = \frac{k_i^{1+\delta \log_{10} k_i}}{\sum_j k_j^{1+\delta \log_{10} k_j}} \qquad (2)$$

where $\delta \in [0,1]$is constant. Using numerical simulation, the relieved value for δ in the literature is given as 0.0048 which produces the closest results to the Internet data compared with BA and IG models. The PFP model starts with a small random network. At each time, three actions take place, that is: (i) a new node attached to the host node with the probability $p \in [0,1]$ and one new internal link appears between the host and peer node; (ii) a new node attached to the host node with probability $q \in [1-p]$ And two new internal links appear between the host node and the two peer node and (iii) a new node attached to the host node with probability $1-p-q$ and one new internal link appears between one of the host node and the peer nodes. The PFP model can successfully reproduce accurately many accurate topological properties of the AS-level Internet, including: degree distribution, rich-club connectivity, the maximum degree, shortest path length, short cycles disassortative mixing and between nescentrality. This model overcomes the limitations of the earlier models that failed to predict the rich-club connectivity between high-level nodes and maximum degree of the network.

The MP model is based on a different concept. That is the classification of the AS nodes and links and then model them according to these classified. In the MPA model AS nodes are classified as: Peering, Bankrupt, Multi-homing and Geography nodes. The links are classified, based along the economic AS Internet definitions, as links connecting customer AS to their provider (c2p links) and links connecting ISPs to their peers (p2p links). Generally, the relationships between Assess change over time. With the assumptions that for all customers ASes generates similar volume of traffic. High-degree ASes would exchange high traffic volume and rationally seek to establish reciprocal peering with other high degree Ass. With multihoming the complete MPA model is defined by [10]:

$$\gamma = 2 + \frac{1-\mu}{1+2\nu+m\rho+2c+\mu} \qquad (3)$$

where c is the rate at which peering link appear, v is the rate at which multihoming links appear in the system (per unit time), m the number of providers at non-ISP multihome, μ is the rate of bankruptcy (i.e. a connection shifts from one ISP to another. The model used annotated Route Views data [11] and from AS relationships in order to obtain the empirical distribution of the number of ISPs to which ASes is multi-home. The average number of providers that ISPs multi-home was found to be 2 ($i.e.\ \nu = 2$); and the average number of providers that non-ISPs multi-home was 1.86 ($i.e.\ m = 1.86$). Dimitropoulos et al. [12] showed that roughly 90% of the links are of customer-provider type (i.e. has transit relationships with payments always going to the provider ISP); with a lower bound of 10% of the links are peering (has bilateral traffic exchange without payment).

Recently, some researchers [13] suggested that Moore's law can be used to describe the growth of the internet. The results show that the Internet will double in size every 5.32 years.

3. DATA COLLECTION AND SOURCES

The main challenge that faces the Internet AS level topology modeling is the difficulty to obtain real data. Network providers are often reluctant to reveal details of their internal topology for security, commercial and/or marketing reasons. Internet topology is a necessary component of router-level topology, here the AS level topology is hidden.

Data sources are very critical in modeling the internet topology. There are three data sources available to be used to construct AS-level of the internet:

1. BGP data which is collected from several geographically distributed routers. In this topology structure, there is no guarantee that the merged views include all ASes in the Internet. The BGP topology

seen by the public routing tables refers to the control plane, in which the routing decisions in forwarding internet traffic among all public internet routers enforces. This source of data is believed to be the most accurate one for Internet AS topology. However, it suffers from some inaccuracy due to incompleteness, collection failures, instability and invalid information.

2. Trace route data, which is obtained by using UDP or ICMP probe packets to destination to capture the sequence of IP hops along the forward path from the source to the destination. This method refers to data (traffic plan). The public BGP tables are used to map the IP addresses in the gathered IP paths to AS numbers in order to construct the AS-level topology. Generally, this method suffers inaccuracy due to mapping distortion. Collection failures and incompleteness.
3. WHOIS data, which is a collection of databases with AS peering information. These databases are manually maintained by the Internet Registry (IR). The WHOIS data refer to the management plane. It may suffer inaccuracy due to entering inaccurate information and (ii) updating time.

In this work the BGP data are used as primary data source for constructing internet AS topology. An accurate modeling of the internet topology requires giving especial attention to the time validity, i.e. the interval of the inspected data. It is highly recommended to avoid uncorrelated periods (transient) and to focus only on the steady state.

3.1 BGP Data Collection and sampling

The main source of BGP data is the University of Oregon Route Views project, this source represents the richest resource for BGP routing table database. The project uses several collectors worldwide, in the USA, UK and Japan. Each collector has a number of globally placed peers (or vantage points) that collect BGP messages.

Generally, the growth of BGP routing tables overtime, can be categorized in three periods: the pre-Internet boom prior to 1999, the sharp upward growth during the boom period from 1999 until early 2001, and the post-boom data. In the present work all data collected before 2001 are ignored as they will not fit into today's internet AS topology. This is because during that time the internet was not fully public commercialized and its architecture was centralized. The data collected during the period from 31^{st} of October 2001 to 31^{st} March 2009 are used. These data are grouped in monthly basis; i.e. 92 samples. These samples are seen to be enough to construct an accurate model.

The RGP snapshots (RIBS data) are heavily compressed using bzip2 software, with an average size of 46.7 MB for one sample file. The file sized was reduced to 44.3 MB after compression.

3.2 BGP Data Preparation and Filtering

In order to construct the AS-level, the collected BGP data need some pre-processing, that is due to missing of information and extra information associated with the data related to the BGP policies. Thus, the data shall be filtered to generate and gather the primary one. The filtering and processing operations includes: (i) appending the collector's AS number in all AS paths in the BGP data, (ii) filtering private ASes, (iii) removing prepending, and (iv) BGP confederation treatment.

3.3 Node Degree and Clustering Coefficient

Fig. 1 shows the distribution of node degree, given in a log-log scale. The node distribution follows power law distribution which is best fit with the relation:

$$\log(P) = 0.65(\log(d))^2 - 3.65\log(d) + 0.51 \qquad (4)$$

where d is the node degree. For this fitting, the square of the correlation between the response values and the predicted response values (R^2) equals to 0.9203.

Fig 2 shows the plot of ASes and link degree. Both follow exponential growth.

3.3 ASes and Link Growth Estimation

Figs 3 and 4 show the estimated growth in the number of ASes. The growth is estimated by the logistic model, which found to be the best fit for the measured date. The model is given by:

$$N = \frac{N_o K}{N_o + (K - N_o)e^{-rt}} \qquad (5)$$

where t is the time, N is the number of ASes at time t, N_o is the initial number of ASes at $t=0$ (October 2001), K is the maximum number of ASes, and r is the rate of growth. The 16-bits and 32-bits AS numbering schemes used for Fig. 3 and 4, respectively.

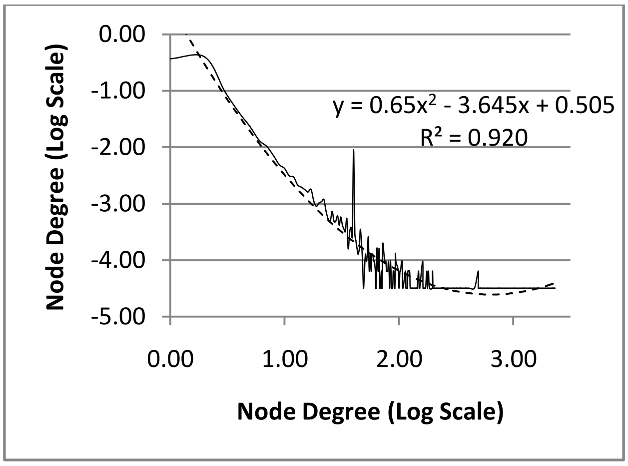

Fig.1. Node Degree Distribution

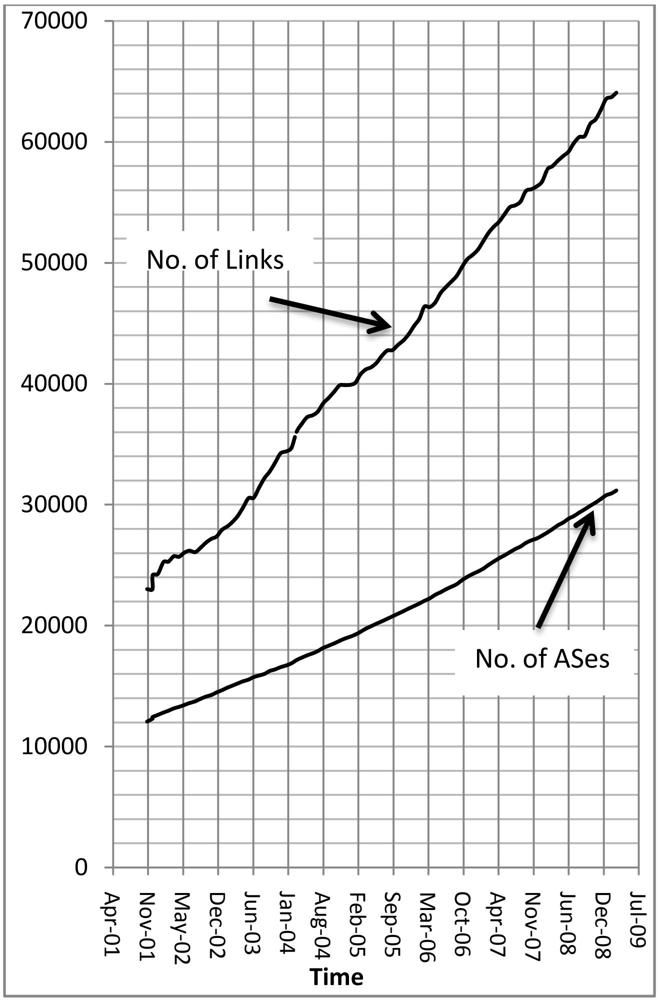

Fig. 2. ASes and links growth

Integers, which allowed for a maximum of 65536 assignments (i.e. K= 65536) in this case r= 0.017; while in Fig. 4, the AS numbers were defined as 32-bit integers, which allowed for a maximum of 4,294,967,295 assignments (i.e. K= 4,294,967,295) and r = 0.014. It is noticed that, for large values of K, the Logistic model approaches exponential model as k → ∞, i.e.

$$N = N_o e^{rt} \tag{6}$$

The model given in (5) is used to estimate growth of the links, since there is no upper limits for the number of links (i.e. k → ∞), as the value of is for the link rate of growth is 0.015.

Theoretically, the 16-bit AS numbering scheme can identify up to 65535. However part of this range from 54272 to 64511 is reserved by IANA, which makes the actual number of address to be 54271. From the suggested logistics model, this range will be used completely by October 2016.

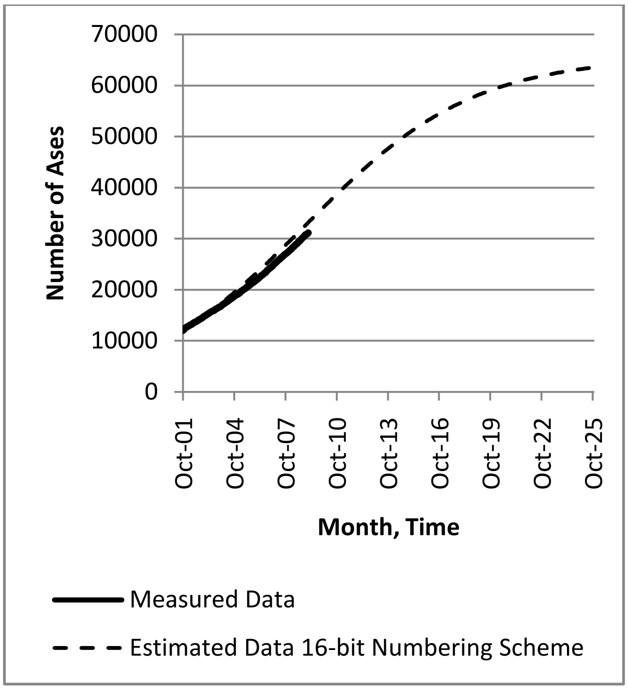

Fig. 3: ASes growth Prediction (16-bit numbering scheme)

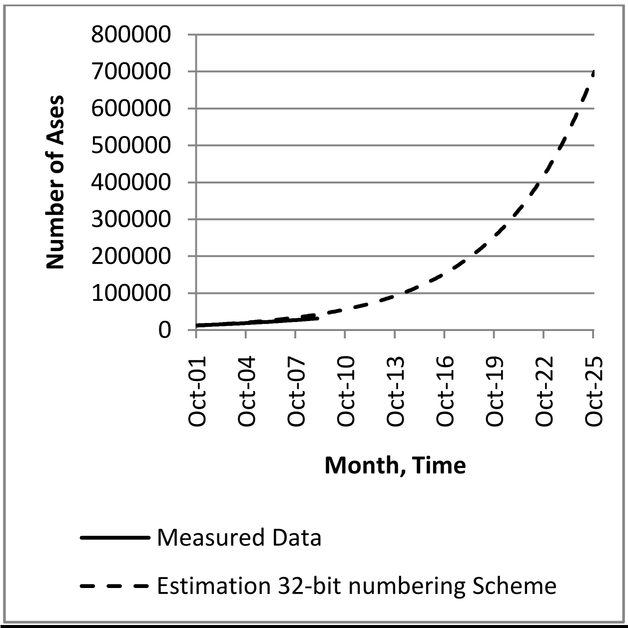

Fig. 4. ASes growth Prediction (32-bit numbering scheme)

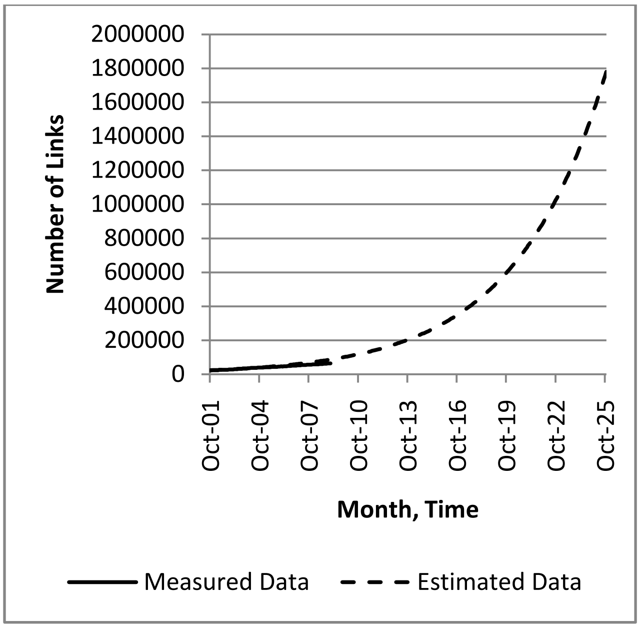

Fig. 5. Links growth prediction

4. CONCLUSIONS

Analysis of BGP data showed that the internet ASes growth followed Logistic Regression Model with a rate of growth equal 0.014 when 16-bit AS number scheme is used and equal to 0.017 when 32-bit AS number scheme. The model indicates that all available ASes addresses provided by the 16-bit AS numbering scheme can be used by October 2016. The link growth was found to have followed the exponential model with a rate of growth equal to 0.017. The ASes growth model suggested in this study indicates that the internet will not grow in the future as it used to be in the past.

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