Real and Generated Internet AS Topologies: Structure, Spectrum, Robustness *

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The Internet AS (Autonomous System) topology structure is a subject of high interest as performance of Internet protocols and algorithms can depend heavily on the topology. Besides other reasons, a good model for the Internet topology may lead to a realistic generator, used for simulations. Power-law degree Internet topology generators, now state-of-the-art, result in different kinds of graphs. It has already been observed that power-law distribution creates hierarchy, although the type of hierarchy differs from model to model. Also, one should take into account the influence of BGP policies by considering them as part of the AS topology model. We looked at the real and generated Internet Topology in order to find relevant and computationally simple metrics to evaluate differences. Preliminary results using the Normalized Laplacian Spectrum, which can be calculated in polynomial time, show that it is a good candidate to differentiate classes of topologies.

Some of the questions we are interested in are:

– **What can we conclude about topology from the normalized spectrum of the graph?**

Preliminary results: Observation of the difference between the multiplicities of the eigenvalue 1 in the Normalized Laplacian Spectrum of graphs created by Inet 2 (Inet Topology Generator, University of Michigan) and of corresponding AS graphs lead us to a new hierarchical representation of the AS graph. We partition the graph into 4 components: P, Q, R and I. Taking into account BGP policies, we confirmed our conclusions about the functionality of each component (roughly, the edge and the core). Following the components' evolution over time, we could extract some trends: more nodes are added to the edge, but more new links are added to the core. Experiments on other multiplicities showing occurrences of specific subgraphs, convexity and concavity of the parts of the spectrum are still part of our research.

– **What is the relevance of other metrics from graph theory?**

Preliminary results: Vertex Cover, Maximum Independent Set and Maximum Clique are some examples of *NP*-complete problems, that are efficiently solvable on the Internet AS topologies. Although primarily of theoretical interest, some of these metrics can be attractive for practical reasons too, being efficiently computable. A positive example is the optimal placement of the DDoS protection filter in the Vertex Cover set.

– **How can we measure robustness in the whole network and in its parts? Can we improve "topological" robustness of a part of the network without overdesign?**

Preliminary results: We looked at the number of node-disjoint paths from Oregon to all ASs in the graph model and in the data obtained from BGP tables with respect to the direction of traffic forwarding. We have to stress that the information from the BGP tables is inaccurate and (because of *NP*-completeness of the problem) heuristics are used for the measurements. However, there is a significant difference between the two results.

Remark: Some of the preliminary results on the spectrum of the AS graphs are already published (more information could be found on http://www.tik.ee.ethz.ch/∼the/topology/).

*Partially supported by European Commission - Fet Open project COSIN IST-2001-33555, with funding provided by BBW Switzerland.