The AS network possesses an implicit hierarchical structure, i.e., the ASes can be categorized as backbones, national, regional, and local providers as well as customer. There have been many attempts to extract the hierarchy, for example based on the customer-provider relationship \[1\], on external information or on neighborhood information. All of these properties are only indirectly reflected in the graph structure. We used the graph-theoretical concept of \(k\)-cores \([2, 3]\) to track the general shape of the AS network over time. Cores have been frequently used for network analysis, for example \([4, 5]\). The visualization technique presented in \([5]\) relates the coreness of an AS to its position in the layout very well, i.e., nodes with large coreness are in the center and nodes with small coreness are placed in the periphery.

During the period of April 2001 till now, we observed that the number of nodes increased by roughly 2,000 nodes per year, the number of edges increased by roughly 5,000 edges per year and the maximum core number increased form 18 to 26. Although the network increased in absolute terms, the relative size of the core levels remains stable. Furthermore, the relative distance of the ASes to the ‘center’ in the visualizations remains roughly the same. There is a positive correlation of 0.67 – 0.75 between the distance and the corelevel. Usually, this is not a significant correlation, in this context the following two facts increase the significance. First, nodes in the 1-core are placed very close to their anchor nodes in higher core levels, which can be quite scattered, and second, nodes with coreness two or three constitute the majority of nodes and occupy an annulus rather than a ring.

The above pie chart (right figure) illustrates the temporal evolution of the relative proportion of the \(k\)-shells. In the figure, the thickness of one slice corresponds to the fraction of nodes that have a given coreness. The lowest strip represents the maximum core while the highest strip reflects the 1-core. Besides the stability of \(k\)-shells with \(k \leq 15\), it is also observable that the size and coreness of the maximum core slightly increases over time. The growth in the coreness is not monotonic and has big fluctuations.

The graph of the Autonomous Systems, i.e., collection of computer devices under the same administrative authority that establish global connection in the Internet, is an instance of a small complex system. Out of the vast range of issues that have been addressed in the context of this network, we focus on revealing structural information via visualization. In the following, we present several examples in the context of temporal evolution between 2001 and now, overlay networks, i.e., comparing Gnutella communication and AS peering relations and the comparison of data sources from different dimensions.

Analytic Visualizations and their Applications for the Autonomous System Graph

Summary

The AS network possesses an implicit hierarchical structure, i.e., the ASes can be categorized as backbones, national, regional, and local providers as well as customer. There have been many attempts to extract the hierarchy, for example based on the customer-provider relationship \([1]\), on external information or on neighborhood information. All of these properties are only indirectly reflected in the graph structure. We used the graph-theoretical concept of \(k\)-cores \([2, 3]\) to track the general shape of the AS network over time. Cores have been frequently used for network analysis, for example \([4, 5]\). The visualization technique presented in \([5]\) relates the coreness of an AS to its position in the layout very well, i.e., nodes with large coreness are in the center and nodes with small coreness are placed in the periphery.

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The recent times have witnessed a lot of interest in evaluating overlay networks, particularly the topological discrepancy of overlays with the underlying network. In \([3]\), we found that the neighborhood selection process of a P2P protocol like Gnutella is fairly random. Here, we start with investigating this observation using visualization.

<table>
<thead>
<tr>
<th>Year</th>
<th>Number of Nodes</th>
<th>Number of Edges</th>
<th>Core Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>2002</td>
<td>1,000</td>
<td>2,000</td>
<td>18</td>
</tr>
<tr>
<td>2003</td>
<td>2,000</td>
<td>5,000</td>
<td>19</td>
</tr>
<tr>
<td>2004</td>
<td>3,000</td>
<td>8,000</td>
<td>20</td>
</tr>
<tr>
<td>2005</td>
<td>4,000</td>
<td>10,000</td>
<td>21</td>
</tr>
</tbody>
</table>

The Oregon Routeview Project has become one of the major repositories for snapshots of the AS network using looking glasses. In contrast, the DIMES project extracts AS relations using traceroute experiments. The figure one the right shows the network combining two data samples using the visualization technique of \([5]\). The edge color codes the origin, i.e., black for common, yellow for Oregon Routeview only, and cyan for DIMES only. An interesting observation is that many edges that were only discovered by DIMES are incident to the core. The following table shows the coreness of endnodes of the edges versus their rank. The two data samples, Oregon and DIMES, are fairly similar, while the two exclusive sets (without common edges) show different distributions. Especially, the minimum coreness distribution for only DIMES is not as steep as the one of Oregon Routeview. Overall, the two data sets have very similar structural properties. Understanding and explaining the differences is part of our ongoing research.

References


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