

# VISUALIZATION OF MEASURED AND ESTIMATED NETWORK CHARACTERISTICS OF THE INTERNET

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Abstract: Information provided by research on the measurement and estimation of network characteristics of the Internet is vast; therefore, it is difficult to understand and analyze it. We developed a system that includes tools to analyze and visualize both measured and estimated network characteristics of the Internet in order to obtain useful information from these characteristics. Our tools can process large amount of data on network characteristics that were preliminarily measured and estimated. The tools use geographic information for analysis and visualization; users can add codes and extend the functions of analysis and visualization. Moreover, users can easily analyze and visualize the network characteristics of the Internet for various purposes. This paper describes the visualization of network characteristics of the Internet by the tools.

## 1 INTRODUCTION

There are numerous studies on the measurement of the network characteristics of the Internet. Because it is difficult to measure the characteristics of all network links and nodes on the Internet, these studies measure the network characteristics of some of the links and estimate the network characteristics of others by using the measured characteristics. Most of the studies concentrate on performing measurement and estimation correctly; therefore, techniques for analyzing the measured and estimated data and effectively utilizing them are not adequately studied. Because the measured and estimated data on the network characteristics of the Internet is vast, it is difficult to understand and analyze this data.

We developed a system that includes tools to analyze and visualize the network characteristics of the Internet in order to reveal useful information. This system has the following features:

- It analyzes and visualizes large amount of data of the network characteristics that are preliminarily measured and estimated.
- It can process network characteristics by using locations of nodes.
- Users can easily extend the functionality of analysis and visualization.

Most tools for visualizing network information are used to monitor networks, detect abnormalities, and

collect statistical information. With such tools, it is important to analyze packet transmission in real time. However, because the Internet has a large number of nodes, it is difficult to process the measured data in real time. Therefore, it is important to analyze the data using various methods for investigating the network characteristics of the Internet.

In a network that has nodes spread over a wide area such as the Internet, distances between nodes have considerable impact on network characteristics. Our system uses geographic information for analyzing and visualizing network characteristics.

The system supports various uses by allowing users to freely set visualization styles. Moreover, users can add codes for visualizing data and extend system functionality so that they can easily analyze and visualize network characteristics for various purposes.

## 2 NETWORK CHARACTERISTICS

### 2.1 Visualization

Various studies on visualization of network information proposed several systems; these systems have the following features as the key functions of visualization:

- Monitoring network packets and displaying their information in real time.
- Providing statistical graphs of network traffic among nodes.

These features are important and useful for managing networks. However, these features are not well suited for analyzing the characteristics of a network having nodes spread across a wide area such as the Internet. Our proposed system has the following features:

- It supports networks having many nodes physically spread across a wide area.
- It is browser-based and applicable in various environments.
- Its functions are sufficiently flexible, and thus can be used for various purposes.

Because there are many nodes on the Internet, the number of network links among these nodes that need to be managed and analyzed is extremely large. Our system can manage data from a large number of links and can provide graphs of the data pertaining to specific nodes according to user demands. In a widespread network such as the Internet, the locations of nodes are important information. Our system has a function for displaying nodes on a map, thus allowing users to visually understand geographical relationships among the nodes.

Although some existing systems can display network information on a map (Wawrzoniak et al., 2004), their functions do not sufficiently support the analysis of network characteristics. On the other hand, network managers, network researchers, and internet application developers require different information on network characteristics. Assuming them as users, the proposed system has various functions for analyzing network characteristics. The functions of this system include displaying information and providing graphs in various forms; therefore, the system can flexibly support demands of different users as well as can be applied in various desktop and mobile environments.

## 2.2 S3

We used the network characteristics data collected by S3 (a scalable sensing service) (Yalagandula et al., 2006) that runs on PlanetLab. S3 is a system for measuring a wide area network; it measures the Internet using the nodes of PlanetLab. In the S3 system, software components called sensor pods run on each node and measure the characteristics of the links among the nodes. Each sensor pod has modules that measure various parameters such as latency, loss, and

bandwidth(Sharma et al., 2006; Ribeiro et al., 2003; Strauss et al., 2003; Mahajan et al., 2003). The sensor pods run their modules at appropriate periods and perform the necessary measurement.

All sensor pods work in cooperation, and the information measured by them is collected by the S3 server. In addition, the S3 server estimates network characteristics. For latency, as an example, the S3 system does not measure the latencies of all links; it measures the latencies of only a part of the links and estimates the latencies of other links by using the measured latencies.

## 3 VISUALIZATION

Because information on the network characteristics measured and estimated by S3 is vast, it is difficult for users to intuitively understand it. In addition, since the network characteristics of the Internet have not been extensively researched, the measured or estimated data are not sufficiently analyzed. Therefore, it is difficult to directly obtain useful information from the measured or estimated data, and the data of the characteristics obtained from existing research are not practically used. As a result, because no effective method has been established to obtain valuable information on network characteristics, it is important to understand the data and reveal whatever valuable information can be obtained. We have developed a system for visualizing the measured and estimated network characteristics of the Internet.

### 3.1 Display on a World Map

Our system has a database of the network characteristics preliminarily measured or estimated and tools for visualizing them. Figure 1 shows a tool of the system that visualizes the network characteristics on a world map. This tool displays the locations of source and destination nodes and the links between them using Google Maps. This tool has the following features:

- Users can see geographical relationships among nodes.
- Users can select a node and see measured and estimated data on the basis of the selected node.
- Users can use the tools in various environments.

To understand the characteristics of a network in which nodes are spread across a wide area such as the Internet, consideration of node locations is important. This is because the distances between nodes can be exceedingly long and can affect the performance of network links; some of the links are spread across

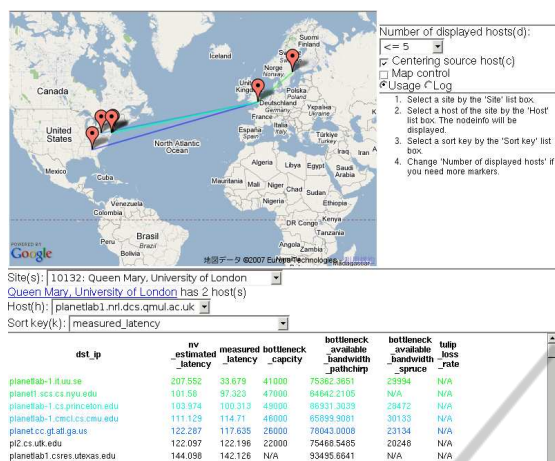


Figure 1: Nodes and links displayed on the world map.

national boundaries and seas. In addition, geographical locations of the nodes should be considered for understanding the measured and estimated characteristics of their links. Our tool enables users to easily see geographical relationships among nodes by displaying the nodes and their links on a world map.

Moreover, this tool can display a table that lists the measured and estimated characteristics of all links of a source node that is specified by a user. The user can sort data with respect to various parameters such as latency or bandwidth, and the tool can display the results of the best links on the map. Owing to this function, users can easily see the measured and estimated characteristics of the links on the basis of specific nodes along with geographic information.

In addition, another advantage of the tool is that it can be run in various environments. The tool is written in JavaScript, and users can run it by using their web browsers. Most of the popular environments have web browsers that can run JavaScript; therefore, users can use the tool in most of the environments. Users can access the web page and the script of the tool from a web server. In addition, the tool gets data of the network characteristics from the web server. Therefore, only web browsers are required to use the tool. Because most environments have web browsers, in most cases, users can run the tool and visualize the network characteristics without any preparation.

### 3.2 Display of More Detailed Information

We developed another tool for analyzing and visualizing the measured and estimated network characteristics in detail using Squeak. This visualization tool allows users to add codes and extend the functionality of analysis and visualization. The users can easily

add their code by using the environment provided by Squeak. Moreover, because a Squeak plugin enables popular browsers to run Squeak programs, the tools can be run in many environments.

Although the measured and estimated network characteristics of the Internet are valuable for network managers and Internet application developers, they require different parts of these large data in different forms. The tool allows users to freely define the form of displaying the network characteristics and provides application flexibility for various purposes. For example, there are certain types of graphs and tables that can be displayed as units and users can freely arrange them in a window of the tool. These units are called views (Figure 2). Following types of views are available: *System information*, *Node information*, *Histogram of all links*, *Filtered link graph*, *Node list*, *Link table*, *Spiral graph*, *Closest node set graph*, *Grid graph*, *Histogram*, and *Node correlation*.

*System Information* is a view that displays information about the tool and the visualized data such as the number of links measured and estimated and the number of sites and nodes used for measurement. *Node information* displays detailed information about a node such as host name, IP address, and its site.

*Histogram of All Links* is a view that displays a histogram of the measured or estimated network characteristics of the Internet. Because data of all links are displayed, users can see the state and trend of the entire network.

*Filtered Link Graph* is a view that displays the links that satisfy a condition of the network characteristics specified by the user. The links are displayed in a graph and users can easily see the size of the parameters. For example, when *Filtered link graph* draws nodes and links using latency, the nodes are arranged as distances between the nodes in the graph and are proportional to the latencies between the nodes. Users can see these latencies intuitively by examining the lengths of the lines between the nodes.

In addition to displaying information of the entire network, the tool can display the network characteristics of an individual node selected by a user in detail. *Node List* is a view that displays host names of all nodes, and users can easily select a node in this view.

*Link Table* is a view that displays the network characteristics of the links whose source node selected by the user in a tabular form. The user can sort data with respect to latency and bandwidth and can easily see the nodes that have good links with the source node.

*Spiral Graph* is a view that displays the links between a specified source node and the destination nodes that have the best links with the source node in

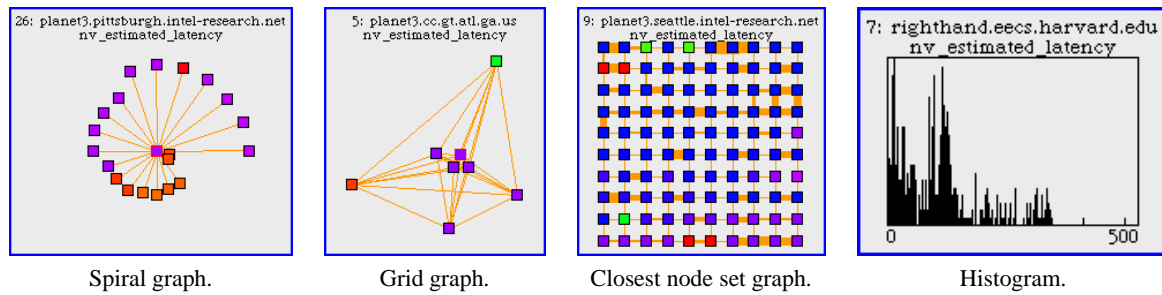


Figure 2: Views.

a spiral form. Nodes are drawn as boxes and are color-coded according node locations. Users can intuitively see that the nodes of similar colors are closely located. Users can select a parameter to extract good links and set the number of links to be drawn in the graph. The source node is arranged at the center of the graph and the distances between the source node and each destination node are set according to the network characteristics. For example, for the case in which latency is used for the evaluation of links, a destination node that has a small latency link with the source node is drawn close to the source node. The destination nodes are sorted by the network characteristics and arranged on the graph in a spiral form.

*Closest Node Set Graph* is a view that displays the graph of a specified node and some nodes that have the best links with the specified node. The distances between each node are calculated according to network characteristic parameters such as latency and bandwidth, and the nodes are arranged according to the calculated distances between them. Users can change the parameters to calculate distances and the number of nodes to be displayed.

*Grid Graph* is a view that displays the graph of nodes that have good links in a grid form. This view draws nodes starting with a node specified by the user and arranges other nodes with the best link side by side. The evaluation of links is expressed by the thickness of the lines that connect the nodes. For example, lines of small latency links are thick.

*Histogram* displays all the links of a specified source node. Users can select a parameter to display, such as latency or bandwidth. Although some views such as *spiral graph* display only a part of the links of a specified source node, *histogram* displays all the links of a specified source node, and users can easily see the state and trend of the links of the node.

*Node Correlation* is a view that displays correlations between a specified node and other nodes. Users can select a parameter to calculate correlations, such as latency or bandwidth. It is believed that nodes with strong correlations are closely located.

Users can arrange these views in the window of the tool and visualize the network characteristics in various ways. Because of this flexibility, the tool can be used by users for different purposes

## 4 CONCLUSIONS

This paper describes the tools of system for analyzing and visualizing the network characteristics of the Internet. The tools of the system can process large amount of data on network characteristics that were preliminarily measured and estimated. The tools use geographic information for analysis and visualization and enable users to add codes and extend the functionality of tools of the system. Users can easily analyze and visualize the network characteristics of the Internet for various purposes.

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