Research Statement

Ellen W. Zegura
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Overview

The over-arching theme of my work has been the development of wide-area (Internet) networking services. Wide-area services are utilized by applications that are distributed across multiple administrative domains (e.g., web, file sharing, multi-media distribution). My focus has been on services implemented both at the network layer, as part of network infrastructure, and at the application layer. My work in this area falls into three categories: (1) measurement and modeling, (2) development of new services, and (3) investigation of paradigms and platforms to support new services. My work has been supported primarily by NSF and DARPA, with additional support from NASA, Hitachi, Cisco and the Georgia Tech Broadband Institute.

Measurement and Modeling

One thread of my work has concerned the measurement of key Internet services. These measurements are important for multiple reasons: they contribute to understanding the performance of applications that utilize the services, they point to opportunities for improvement, and they provide measurement data that can be used to construct more accurate simulations of wide-area applications.

As an example, I recently worked with my students Richard Liston and Sridhar Srinivasan on \textit{measurements of the performance of the Domain Name System (DNS)} from a diverse set of Internet locations (II.C.1-52). The DNS is a critical component of the Internet infrastructure, and the key servers that affect performance are located with extreme concentration in the United States and, to a lesser degree, parts of Europe. Our work represents the largest known study of wide-area DNS performance. We find that some performance measures are relatively insensitive to location (e.g., fraction of names whose lookups succeed), while others vary widely (e.g., overall response time, and response time from root and second level name servers). We also find that performance of root servers has a negligible effect on perceived performance, while reducing the response time of second level name servers (possibly via more equitable placement) has the potential to noticeably impact perceived performance. The information in our study will be helpful in guiding engineering of the DNS, as well as influencing the design of future studies that are affected by DNS performance.

Since the mid 1990s, I have worked in the area of \textbf{Internet topology modeling}, with support from an NSF ITR award. The topology of the Internet is the interconnection structure of its routers and links, typically represented as a graph. A model for topology is a crucial component for simulations and analysis of Internet algorithms and protocols. Our Infocom 1996 paper on the topic of Internet modeling was among the first to highlight the importance of topology and to bring the principles of Internet design (locality and hierarchy) into topology (II.B.4, II.B.6, II.C.1-10, with Ken Calvert and student Bobby Bhattacharjee). Prior work had used very simple and regular topologies or purely random topologies. The transit-stub model for topology (developed
with Ken Calvert) has been the defacto standard for router-level Internet modeling. The tool that implements the transit-stub model, GT-ITM, is widely used throughout the networking research community. Perhaps most importantly, topology modeling, discovery and analysis has developed into a well-recognized subfield of computer networking.

Other work in measurement includes use of a proxy to measure client-side web performance (II.C.1-41, with Liston), analysis of dial-up user session data from a large ISP (II.C.1-43, with student Ron Hutchins), and measurement of a campus wireless network (II.C.1-46, with Hutchins). I have also worked on an architecture for a peer-to-peer measurement infrastructure (II.C.1-45, II.C.1-58, with student Sridhar Srinivasan).

New Services

A second focus area has been the investigation of new services. A long-running thread in this area has been the study of mechanisms to improve the performance of Internet content distribution, with support from NSF and the Georgia Tech Broadband Institute. This work began in the mid 1990s with the proposal of an application-layer architecture to select from replicated Internet servers (II.B.12, II.C.1-16,II.C.1-19, with Mostafa Ammar and students Bobby Bhattacharjee and Zongming Fei). This work represents one of the first examples of a traditional network-layer function (routing) realized at the application layer, a trend that is widely prevalent in current networking research on overlays and peer-to-peer systems. One distinguishing feature of our work in this area has been consideration of the global impact of server selection decisions, whereas most other work in this area has considered only the performance improvement of a single client. We found, for example, that the advantages of smart selection decisions (over random choice) degrade when more clients are attempting to be smart.

We have pursued this thread in considerable depth. With students Zongming Fei and Lenitra Clay, we developed algorithms, mathematical analysis and protocols to select among replicated multicast servers (II.B.14,II.C.1-32, II.C.1-50). With student Fang Hao, we designed an architecture for replicated server selection in a networking environment with support for quality of service (II.B.13,II.C.1-39). Both multicast and quality of service represent potential future network capabilities that significantly change the server selection problem. With student Pradnya Karbhari, we identified a key fairness and resource allocation issue that arises when multiple servers are used to deliver content in parallel (II.C.1-55). Recently, we have carried this thread into the arena of content distribution over peer-to-peer networks, where the roles of clients and servers are merged in endsystems (see below).

Paradigms for New Service

A third focus area has been the investigation of new paradigms and platforms to support the development of new Internet services. New services are notoriously difficult to test and deploy because of the difficulty of modifying the existing base of router code. I have worked in two areas that aim to ease experimentation and deployment of new protocols.

First, I have worked in the area of active networking, with support from two DARPA awards over more than five years. This area has challenged conventional thinking, fostering both new ideas and expanded thinking about the architecture and function of networks. Active networking
advocates a paradigm shift, from networks that primarily forward packets to networks that also apply computation to packets. Such a proposal has been controversial in the networking community, because it represents a radical departure from today’s Internet. The focus of my work in this area has been the development of applications that demonstrate the advantages offered by such a capability, as well as the creation of an architecture that is compatible with current networks. Our group developed one of the first full-fledged applications, using processing in the network to adapt more quickly and gracefully to congestion (a classic networking problem). The key insight in this application was the recognition that active networking provided the ability to combine application knowledge (how to respond to congestion) with network knowledge (where congestion was occurring) to offer significant performance improvements over classical end-to-end approaches. (e.g., II.B.10, II.C.1-15, II.C.1-20, II.C.1-36, with Ken Calvert and students Bobby Bhattacharjee and Shashidhar Merugu)

Another disruptive technology currently being embraced by the community – overlay and peer-to-peer networks – has many facets in common with active networking, and both arise from a desire to do more than is possible in today’s environment of closed routers. I have recently been working in the area of peer-to-peer networks, primarily for file sharing and content distribution, with support from the Georgia Tech Broadband Institute and a recent award from NSF. Peer-to-peer systems have substantially different characteristics than traditional client-server systems — popular content is much more highly replicated; peers generally experience significant dynamics, joining and leaving on short time scales; peers are diverse in geographic location and connectivity; replication is driven by interest, rather than controlled by providers. This differences have substantial implications for the architecture and services of the Internet. Our work in this area has focused on the unstructured file sharing networks that have been so popular with users. For example, I recently worked with student Shashidhar Merugu on adding structure to unstructured networks, in the form of “small world” graph characteristics (mixing short and long edges), to improve search and retrieval performance (II.C.1-60).

Much of the work in this area is still in progress. I mention several such projects, chosen because they integrate multiple focus areas. With Mostafa Ammar and student Pradnya Karbhari, we have drawn on the measurement thread to investigate the performance of the bootstrapping servers that play a key role in allowing users to join existing peer-to-peer networks. With Russ Clark and student Shashidhar Merugu, I am exploring the use of network support to enhance peer-to-peer performance, drawing on ideas from the active networking domain.