its neighbor. As the key component of content delivery, the packet-scheduling algorithm to each peer aims to utilize available bandwidth from individual neighbors in order to maximize its received quality, or the number of received descriptions.

Swarm-like content delivery utilizes available resources in the system in a scalable fashion if available content among peers is diverse during the session. A file-swarming mechanism (such as BitTorrent) can accommodate this goal, as all content is available at the source. However, in a live streaming session content is progressively generated over time and must be delivered in a timely fashion. To effectively incorporate swarming into live P2P streaming, participating peers can maintain the same playout time, which is τ seconds behind the source's playout time; each peer views the content with a τ-second delay. This delay continuously provides τ-seconds worth of content that can be used by peers for swarming. In essence, τ determines the maximum available time for delivery of each segment, as well as the minimum required buffering at individual peers. The greater the value of τ, the more effective the swarm-like content is able to utilize the outgoing bandwidth of a larger group of participating peers; the cost is a longer playout delay between the source and the participating peers [3].

The P2P streaming approach has become increasingly popular among developers. P2P streaming software (and applications) is available for downloading on the Web, including wwitv (www.wwitv.com) and sopcast (www.sopcast.com), and is being used to broadcast popular events (such as the World Cup 2006) to thousands of concurrent viewers over the Internet. While no technical information is publicly available about them, they appear to use a modified version of BitTorrent to swarm a recent window of content, as discussed earlier.

These systems illustrate the feasibility of using mesh-based P2P streaming for scalable broadcasting of video over the Internet. However, several fundamental design issues about this approach are not well understood and require further investigation:

Overlay properties. The effect of overlay properties (such as peer degree, or number of neighbors, and directed vs. undirected pairwise connections) on the performance of content delivery is important but has not yet been fully studied. For example, increasing the peer degree improves the availability (and potential diversity) of content among an individual peer's neighbors but reduces bandwidth connectivity from each of these neighbors;

Pattern of content delivery. The collective effect of packet scheduling at individual peers determines the overall pattern of content delivery from the source to individual peers through a randomly connected overlay mesh. How the similarity (or difference) of the packet-scheduling algorithm among participating peers affects the performance of content delivery is an open question;

Coding issues. MDC codecs are still only research prototypes able to generate a limited number of descriptions (often two or three). The codecs are neither widely available nor flexible enough to use in P2P streaming systems; and

Security and incentives. The open nature of the P2P communication model raises concerns about security, as well as about the incentives used to motivate individual peers to contribute resources. These issues must be addressed to limit the potential damage that might be caused by misbehaving users on the system.

All these issues are being explored by researchers and developers at the University of Oregon (mirage.cs.uoregon.edu/PRIME) and Microsoft Research (research.microsoft.com/projects/CoopNet), as well as at other research organizations.

Conclusion

Mesh-based P2P streaming is a promising approach for enabling computer users to broadcast video from their desktops and devices to a large number of users across the Internet, hosting their own shows from home. Even though P2P streaming systems are available today, further research is required to deepen our understanding of the performance, robustness, and limitations of this approach in practice. C

Reza Rejaie (reza@cs.uoregon.edu) is an assistant professor in the Department of Computer and Information Science at the University of Oregon, Eugene, OR.