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The phenomenal success of the Internet has been mostly attributed to its open, public and global communication capabilities. Peer-to-peer technology (P2P) has been hailed as a next crucial step in Internet evolution because it allows Internet end-users and corporations to accelerate information distribution, improve resource usage and thus leverage the effectiveness of communication infrastructures. This article provides a nutshell overview on this value-adding trend in networking and distributed processing and explains how it can serve companies in day-to-day business.

technology and trends

The commercialization of the World Wide Web in the late 1990s turned the Internet into an extremely popular tool to distribute and access information. The number of Internet users worldwide is projected to surpass two billion in 2003. The established Internet communication model primarily supports content delivery and information exchange among clients by giving control over the content to the network provider. This is due to the fact that the current Internet delivery model is based on IP unicast communication, with single hosts interacting as clients or servers, and routers configuring the optimal paths between them on the fly. Furthermore, because IP multicast has not been adopted by Internet Service Providers and is unlikely to become widespread any time soon, the Internet today does not support multipoint communication efficiently. Peer-to-peer computing, in analogy to person-to-person communication, allows services and data to be exchanged directly between computers without the need for a data center. Because it eliminates a fixed division into clients and servers by building loose federations of distributed computing resources, it is also classified as "disruptive technology".

An Old Paradigm Revisited

Peer-to-peer services are in principle familiar from the telephone communication model and have been used in computer networking since the deployment of IP routing and LAN technology. Direct exchange among peers represents a shift from network-centric communication to edge-centric communication. Opposite to the traditional TCP/IP-driven Internet model, where clients interact with each other through servers across paths computed by routers, clients in the peer-to-peer model are servers at the same time and hence bypass the need for dedicated servers as "middlemen". This radically different approach is a departure from static and centralized information repositories common for the web and databases. In P2P hosts play an active role and contribute as equals in ad hoc information sharing. Progress in distributed computing in recent years has made it much easier to set up and maintain P2P networks and may explain the revitalized interest in peer-to-peer services.

Not only does P2P networking save infrastructure costs and utilize more efficiently any idle host resources, it can also avoid bottleneck problems at overloaded servers by dynamically distributing the computing and storage load across clusters of peering hosts. In addition, client and server

interaction over paths that are prone to congestion, long latencies, and jitter can be avoided. Bandwidth, which remains a major constraint in the majority of world markets for the Internet, may hence be utilized more efficiently.

On the other side, deployment of P2P solutions is also problematic due to trust, security, information quality, scalability, and management issues. Admission policies must be established to assure authenticity and content quality standards, and avoid problems with freeloading, hacking, spurious presence and low-grade links. These issues are currently left largely to self-regulation among peer groups. Non-technical problems such as copyright violations, most notably in online music trading, have also been a major impediment to the more widespread deployment of peer-to-peer applications.

Architectures

Peer-to-peer computing is based on the simple idea that end-hosts act as "servants" and share their resources such as disk space, compute time, or content directly with each other. The view on network partner nodes is lateral and bottom-up, rather than hierarchical and top-down. Napster, Gnutella and FreeNet exemplify peer-to-peer computing, differing substantially in their architectures and the types of resources being shared. The essential difference besides the application purpose is how users find and connect to each other, and how content is transferred between users. Peer-to-peer architectures need to be evaluated similar to their corresponding client-server applications and distributed systems with regard to security, reliability, manageability, extensibility, performance, scalability, resilience, and end-user features.

The core topologies of P2P networks determine the protocols and features of applications. Centralized systems, such as the now defunct Napster, offer simplicity in terms of data coherence, consistency, and ease of management. They are relatively easy to secure, but are also fault-intolerant and their scalability is constrained by server capacity. Ring topologies offer similar advantages, with better fault tolerance and scalability, but incur limited extensibility. Hierarchical systems are highly scalable, but offer only limited extensibility, coherence or security. Finally, decentralized systems offer almost the opposite characteristics in comparison with centralized architectures. They are more difficult to manage and prone to security problems due to scattered information indexing and the lack of authoritative nodes to manage information flow in the system. On the other hand, they offer excellent resilience, extensibility and theoretically good scalability, which correlates with the overhead among nodes to achieve information coherency. The choice of topology is entirely dependent on the needs of an application. Hybrids of these pure architectures have been deployed for various applications to obtain the best of strengths without the disadvantages. In general, the combination of a decentralized core with other simpler architectures is a promising roadmap.

Application Areas

Peer-to-peer communication can be applied in intranets and the Internet in a variety of domains, such as distributed data storage and mining, exchange of multimedia files, online auctions, multiplayer gaming, video conferencing, or distance learning. Industry leaders such as Intel or Sun have launched peer-to-peer initiatives and reshaped their enterprise infrastructures. P2P has also been proposed as a cheaper alternative to content caching and routing. Two areas have given P2P the most prominence: real-time music exchange forums, accessible through applications such as Napster or Gnutella, and the harnessing of unused compute cycles in personal computers, which allows to form virtual grid-supercomputers. This sharing of compute time has been used for philanthropic projects such as the Search-for-Extra-Terrestrial-Intelligence (SETI) or in medical research, and for industry projects in aviation, seismic analysis, or crash analysis.

Another interesting area is human-to-human collaboration support, which may prove more essential than any of the other application areas over time. The growing popularity of instant messaging, video conferencing and multiplayer gaming between personal computers, as well as short-message-service in the cell-phone market, indicates a rising interest of users in zero-delay interaction with each other across data networks. To date, distributed group work is hampered by crude methods of how users can cooperate and jointly structure information. In contrast to legacy workflow systems, which often suffer from complicated support due to a centralized server architecture, P2P collaboration is a natural solution by giving distributed people the distributed software to work together.

Several issues are unique to peer-to-peer applications. For example, collecting information on joining and leaving users and their corresponding IP addresses can be solved by a central registration server, or a distributed protocol that systematically collects and distributes contact information. Communication requests and interactions among offline users in applications such as electronic auctions can be logged with a transaction server. Billing of peer-to-peer services may be based on resource usage or exchange quantities, similar to the billing paradigm in telephone services.

Conclusion

Peer-to-peer is a revived paradigm of direct communication and computing between end-hosts dating back to the first days of the Internet before the birth of client-server systems. It supports distributed content management and data warehousing within and across enterprises and bypasses the dependency on data centers. Companies can virtualize their assets by linking together distributed computing resources. Users get more choice and direct control through unmediated information sharing and can connect directly with each other to build ad hoc online communities. P2P has introduced a shift to edge-based content distribution, away from network centrality and server-based communication, and toward sporadically connected end-hosts. In contrast to centralized content aggregation, P2P allows for more efficient and resilient use of bandwidth, processing cycles, storage, and real-time information exchange. Despite the superior novel possibilities in distributed information sharing, P2P also presents major challenges. Solutions for effective management, secure content classification and quality distribution are needed to fully realize the potential of P2P systems. Large organizations may adopt P2P networks best in a hybrid fashion by integrating it into the existing centralized infrastructure with customized in-house applications. For individual users and smaller organizations, third-party software may be the best solution. In simple terms, P2P leverages inexpensive usage of distributed computing resources and information exchange through direct linkage of end-systems. With P2P networking maturing, as an ancillary service model for intranets and the Internet, enterprises may achieve a competitive advantage by complementing their client-server systems with otherwise unavailable information distribution mechanisms.

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