

From Circuit Switched to IP-Based Networks

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INTRODUCTION

The founding of the Bell Telephone System, the public switched telephone network (PSTN), has evolved into a highly successful global telecommunications system. It is designed specifically for voice communications, and provides a high quality of service and ease of use. It is supported by sophisticated operations systems that ensure extremely high dependability and availability. Over the past 100 years, it has been a showcase for communications engineering and led to groundbreaking new technologies (e.g., transistors, fiber optics).

Yet it is remarkable that many public carriers see their future in Internet protocol (IP) networks, namely the Internet. Of course, the Internet has also been highly successful, coinciding with the proliferation of personal computers. It has become ubiquitous for data applications such as the World Wide Web, e-mail, and peer-to-peer file sharing. While it is not surprising that the Internet is the future for data services, even voice services are transitioning to voice over Internet protocol (VoIP). This phenomenon bears closer examination, as a prime example explaining the success of the Internet as a universal communications platform. This chapter gives a historical development of the Internet and an overview of technical and nontechnical reasons for the convergence of services.

HISTORICAL PERSPECTIVE

The origins of circuit switching have been well documented (AT&T, 2006). A year after successfully patenting the telephone in 1876, Alexander Graham Bell, with Gardiner Hubbard and Thomas Sanders, formed the Bell Telephone Company. In 1878, the first telephone exchange was opened in New Haven, Connecticut. For a long time, long distance switching was carried out by manual operators at a switchboard. Until the 1920s,

the operator wrote down the number requested by the customer, and called the customer back when the other party was on the line. The route for a call was built link by link, by each operator passing the information to another operator who looked up the route for the call. Once a circuit was established, it was dedicated to that conversation for the duration of the call.

The national General Toll Switching Plan was put into effect in 1929. This established a hierarchical, national circuit switching network. Calls went to local offices connected to more than 2,000 toll offices and 140 primary centers, and up to eight interconnected regional centers. Sectional centers were added in the 1950s. This hierarchical network, augmented with direct links between the busiest offices, continued up to the 1980s.

In the 1960s, transmission facilities were converted from analog to digital, such as the T-1 carrier (a time-division multiplexed system allowing 24 voice channels to share a 1.5-Mbps digital transmission link). Digital transmission offers the advantages of less interference and easier regeneration. Digital carriers used time division multiplexing (TDM) instead of frequency division multiplexing (FDM). In FDM, each call is filtered to 4 kHz and modulated to a different frequency to share a physical link. In TDM, sharing is done in the time domain rather than frequency domain. Time is divided into repeating frames. Each frame includes a number of fixed time slots. For example, 24 voice calls share the T-1 carrier which is 1.544 Mb/s. Each frame is 193 bits and takes 0.125 ms. In a frame, one bit is used for framing while the remainder is divided into 24 time slots of eight bits each. The first time slot is used by the first voice call, the second time slot by the second call, and so forth.

Automated electromechanical circuit switches appeared in the 1940s starting with a No. 4 crossbar switch in Philadelphia. These switches were able to understand operator-dialed routing codes or customer-

dialed numbers to automatically route calls. In 1976, the first No. 4 electronic switching system (ESS) was installed in Chicago. Electronic switches were special-purpose computers with programmability.

Advances in digital circuits and computers not only improved the performance of telephone switches, but also changed the nature of network traffic. Starting in 1958, modems allowed computers to transmit digital data over voice-grade analog telephone circuits. In the 1960s, computers were still large, and personal computers would not appear until the late 1970s. However, there was an evident need for computers to share data over distances. Digital data increased dramatically in the late 1970s with the proliferation of Ethernet local area networks and personal computers (e.g., Apple II in 1977, IBM PC in 1981).

The origins of the Internet began in 1969 with the ARPANET funded by the Advanced Research Projects Agency (ARPA, now DARPA). The ideas for a packet-switched computer network were supported by Lawrence Roberts and J. Licklider at ARPA, based on packet switching concepts promoted by Leonard Kleinrock and others (Leiner, Cerf, Clark, Kahn, Kleinrock, Lynch et al., 1997). The first packet switches were made by Bolt Beranek and Newman (now BBN Technologies) and called IMPs (interface message processors). The first connected nodes were UCLA, Stanford Research Institute, University of California at Santa Barbara, and University of Utah.

The principles for IP, along with a transport layer protocol called transmission control protocol (TCP), were conceived in 1974 by Vinton Cerf and Robert Kahn (1974). Cerf was experienced with the existing host-to-host protocol called network control protocol (NCP). TCP was initially envisioned to provide all transport layer services, including both datagram and reliable connection-oriented delivery. However, the initial implementation of TCP consisted only of connection-oriented service, and it was decided to reorganize TCP into two separate protocols, TCP and IP (Clark, 1988). All information is carried in the common form of IP packets. The IP packet header mainly provides addressing to enable routers to forward packets to their proper destinations. IP was deliberately designed to be a best-effort protocol with no guarantees of packet delivery, in order to keep routers simple and stateless. IP can be used directly by applications that do not need error-free connection-oriented delivery. Above IP, TCP provides reliability (retransmissions of lost packets as

needed) and flow control for applications that need perfectly reliable and sequential packet delivery. TCP/IP was adopted as a U.S. Department of Defense standard in 1980 as a way for other networks to internetwork with the ARPANET. Acceptance of TCP/IP was catalyzed by its implementation in BSD Unix.

The Internet may have remained an isolated network only for researchers except for two pivotal events. In 1992, the Internet was opened to commercial traffic, and later to individuals through Internet service providers. In 1993, the Mosaic browser introduced the public to the World Wide Web. The Web browser is a graphical interface that is far easier for most people to use than the command line used for earlier applications. The Web has become so popular that many people think of the Web as the Internet. Widely available Internet access and popular applications have driven data traffic growth much faster than voice traffic growth. Around 2000 or so, the volume of data traffic exceeded the volume of voice traffic.

TECHNICAL DIFFERENCES IN CIRCUIT AND PACKET SWITCHING

Circuit switching is characterized by the reservation of bandwidth for the duration of a call. This reservation involves an initial call establishment (set-up) phase using signaling messages, and the release of the bandwidth in a call termination (clear) phase at the end of a call. In modern digital networks, reserved bandwidth means periodically repeating time slots in time division multiplexed (TDM) links, as shown in Figure 1.

Circuit switching works well for voice calls, for which it is designed. All voice is basically the same rate, 64 kb/s without compression, that is, 8,000 samples/s and 8 bits/sample. TDM can easily handle bandwidth reservations of the same amount. Also, voice calls require minimal delay between the two parties because excessive delays interfere with interactivity. Circuit switching imposes only propagation delay through the network, which is dependent only on the distance. Delay is considered one of the important quality of service (QoS) metrics. There is also minimal information loss, another QoS metric, because the reserved bandwidth avoids interference from other calls.

A number of drawbacks to circuit switching are typically cited for data. The first drawback is inefficiency when data is bursty (meaning intermittent data

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