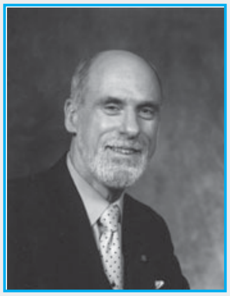
AN INTERVIEW WITH...

Vinton G. Cerf



Vinton G. Cerf is Vice President and Chief Internet Evangelist for Google. He served for over 16 years at MCI in various positions, ending up his tenure there as Senior Vice President for Technology Strategy. He is widely known as the co-designer of the TCP/IP protocols and the architecture of the Internet. During his time from 1976 to 1982 at the US Department of Defense Advanced Research Projects Agency (DARPA), he played a key role leading the development of Internet and Internet-related data packet and security techniques. He received the US Presidential Medal of Freedom in 2005 and the US National Medal of Technology in 1997. He holds a BS in Mathematics from Stanford University and an MS and PhD in computer science from UCLA.

What brought you to specialize in networking?

I was working as a programmer at UCLA in the late 1960s. My job was supported by the US Defense Advanced Research Projects Agency (called ARPA then, called DARPA now). I was working in the laboratory of Professor Leonard Kleinrock on the Network Measurement Center of the newly created ARPAnet. The first node of the ARPAnet was installed at UCLA on September 1, 1969. I was responsible for programming a computer that was used to capture performance information about the ARPAnet and to report this information back for comparison with mathematical models and predictions of the performance of the network.

Several of the other graduate students and I were made responsible for working on the so-called host-level protocols of the ARPAnet—the procedures and formats that would allow many different kinds of computers on the network to interact with each other. It was a fascinating exploration into a new world (for me) of distributed computing and communication.

Did you imagine that IP would become as pervasive as it is today when you first designed the protocol?

When Bob Kahn and I first worked on this in 1973, I think we were mostly very focused on the central question: How can we make heterogeneous packet networks interoperate with one another, assuming we cannot actually change the networks themselves? We hoped that we could find a way to permit an arbitrary collection of packet-switched networks to be interconnected in a transparent fashion, so that host computers could communicate end-to-end without having to do any translations in between. I think we knew that we were dealing with powerful and expandable technology but I doubt we had a clear image of what the world would be like with hundreds of millions of computers all interlinked on the Internet.

What do you now envision for the future of networking and the Internet? What major challenges/obstacles do you think lie ahead in their development?

I believe the Internet itself and networks in general will continue to proliferate. Already there is convincing evidence that there will be billions of Internet-enabled devices on the Internet, including appliances like cell phones, refrigerators, personal digital assistants, home servers, televisions, as well as the usual array of laptops, servers, and so on. Big challenges include support for mobility, battery life, capacity of the access links to the network, and ability to scale the optical core of the network up in an unlimited fashion. Designing an interplanetary extension of the Internet is a project in which I am deeply engaged at the Jet Propulsion Laboratory. We will need to cut over from IPv4 [32-bit addresses] to IPv6 [128 bits]. The list is long!

Who has inspired you professionally?

My colleague Bob Kahn; my thesis advisor, Gerald Estrin; my best friend, Steve Crocker (we met in high school and he introduced me to computers in 1960!); and the thousands of engineers who continue to evolve the Internet today.

Do you have any advice for students entering the networking/Internet field?

Think outside the limitations of existing systems—imagine what might be possible; but then do the hard work of figuring out how to get there from the current state of affairs. Dare to dream: A half dozen colleagues and I at the Jet Propulsion Laboratory have been working on the design of an interplanetary extension of the terrestrial Internet. It may take decades to implement this, mission by mission, but to paraphrase: "A man's reach should exceed his grasp, or what are the heavens for?"

CHAPTER 5

The Link Layer: Links, Access Networks, and LANs

In the previous chapter, we learned that the network layer provides a communication service between *any* two network hosts. Between the two hosts, datagrams travel over a series of communication links, some wired and some wireless, starting at the source host, passing through a series of packet switches (switches and routers) and ending at the destination host. As we continue down the protocol stack, from the network layer to the link layer, we naturally wonder how packets are sent across the *individual links* that make up the end-to-end communication path. How are the network-layer datagrams encapsulated in the link-layer frames for transmission over a single link? Are different link-layer protocols used in the different links along the communication path? How are transmission conflicts in broadcast links resolved? Is there addressing at the link layer and, if so, how does the link-layer addressing operate with the network-layer addressing we learned about in Chapter 4? And what exactly is the difference between a switch and a router? We'll answer these and other important questions in this chapter.

In discussing the link layer, we'll see that there are two fundamentally different types of link-layer channels. The first type are broadcast channels, which connect multiple hosts in wireless LANs, satellite networks, and hybrid fiber-coaxial cable (HFC) access networks. Since many hosts are connected to the same broadcast communication channel, a so-called medium access protocol is needed to coordinate frame transmission. In some cases, a central controller may be used to coordinate transmissions; in other cases, the hosts themselves coordinate transmissions. The second type of link-layer channel is the point-to-point communication link, such as that often found between two routers connected by a long-distance link, or between a user's office computer and the nearby Ethernet switch to which it is connected. Coordinating access to a point-to-point link is simpler; the reference material on this book's web site has a detailed discussion of the Point-to-Point Protocol (PPP), which is used in settings ranging from dial-up service over a telephone line to high-speed point-to-point frame transport over fiber-optic links.

We'll explore several important link-layer concepts and technologies in this chapter. We'll dive deeper into error detection and correction, a topic we touched on briefly in Chapter 3. We'll consider multiple access networks and switched LANs, including Ethernet—by far the most prevalent wired LAN technology. We'll also look at virtual LANs, and data center networks. Although WiFi, and more generally wireless LANs, are link-layer topics, we'll postpone our study of these important topics until Chapter 6.

5.1 Introduction to the Link Layer

Let's begin with some important terminology. We'll find it convenient in this chapter to refer to any device that runs a link-layer (i.e., layer 2) protocol as a **node**. Nodes include hosts, routers, switches, and WiFi access points (discussed in Chapter 6). We will also refer to the communication channels that connect adjacent nodes along the communication path as **links**. In order for a datagram to be transferred from source host to destination host, it must be moved over each of the *individual links* in the end-to-end path. As an example, in the company network shown at the bottom of Figure 5.1, consider sending a datagram from one of the wireless hosts to one of the servers. This datagram will actually pass through six links: a WiFi link between sending host and WiFi access point, an Ethernet link between the access point and a link-layer switch; a link between the link-layer switch and the router, a link between the two routers; an Ethernet link between the router and a link-layer switch; and finally an Ethernet link between the switch and the server. Over a given link, a transmitting node encapsulates the datagram in a **link-layer frame** and transmits the frame into the link.

In order to gain further insight into the link layer and how it relates to the network layer, let's consider a transportation analogy. Consider a travel agent who is planning a trip for a tourist traveling from Princeton, New Jersey, to Lausanne, Switzerland. The travel agent decides that it is most convenient for the tourist to take a limousine from Princeton to JFK airport, then a plane from JFK airport to Geneva's airport, and finally a train from Geneva's airport to Lausanne's train station. Once the travel agent makes the three reservations, it is the responsibility of the Princeton limousine company to get the tourist from Princeton to JFK; it is the responsibility of the airline company to

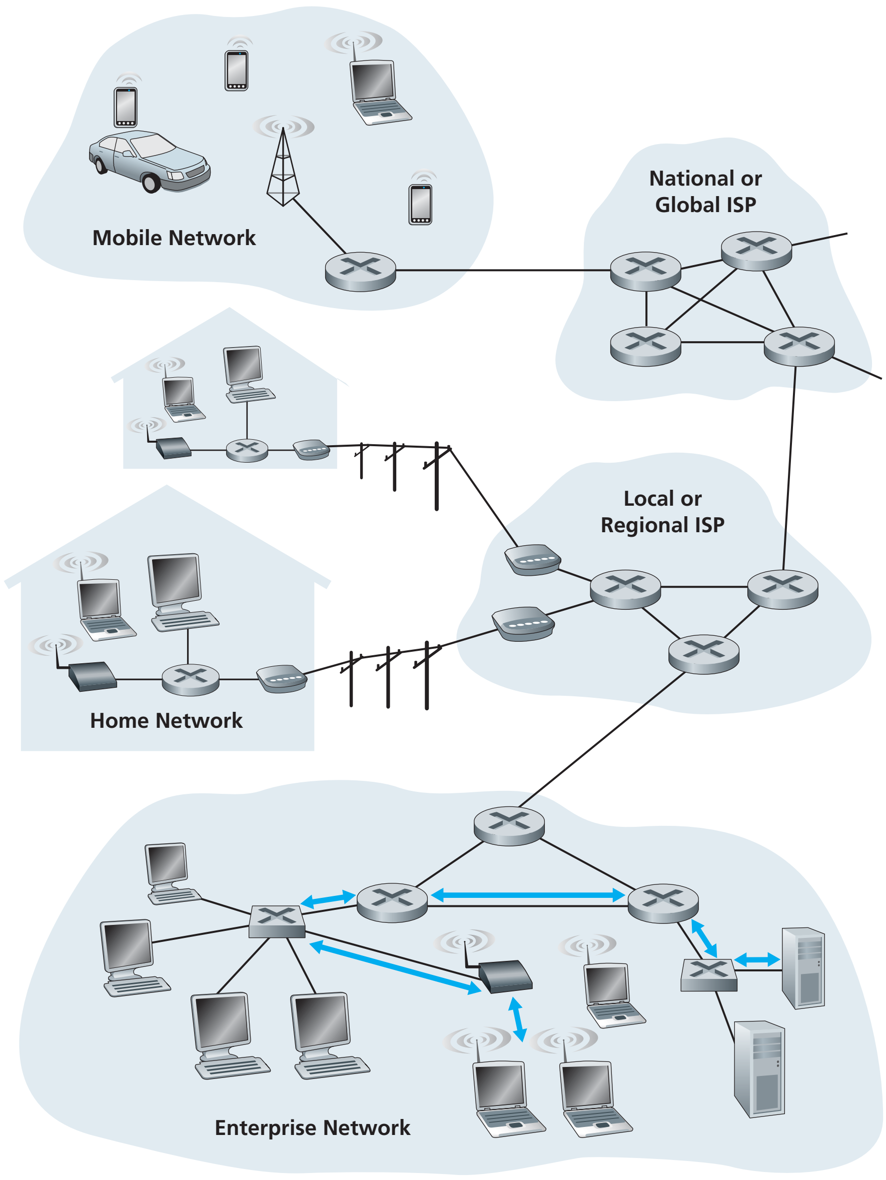


Figure 5.1 ♦ Six link-layer hops between wireless host and server