



How the internet works

An explanation for a layperson

by Darob Malek-Madani

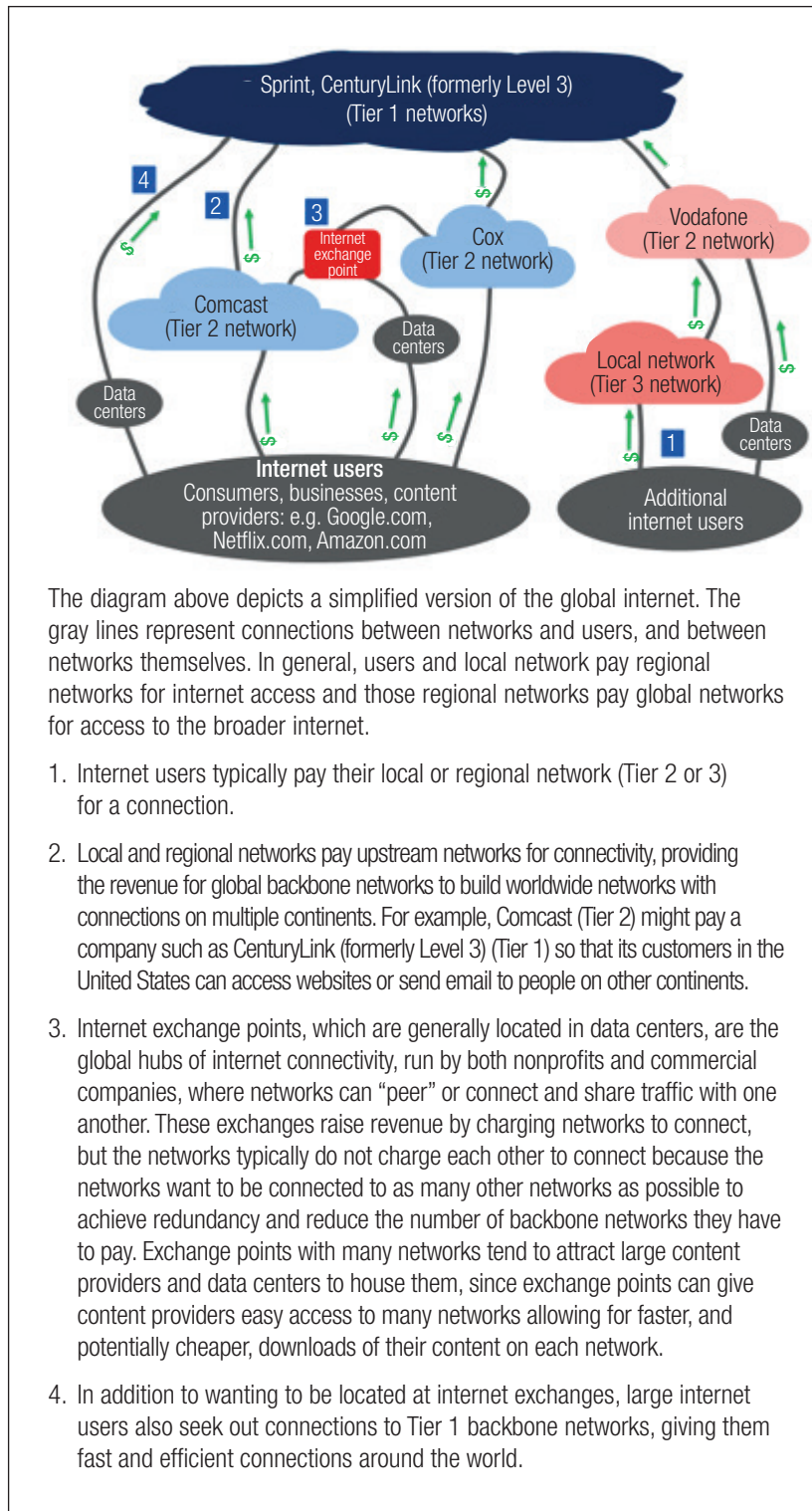
The internet is something we rely on for a variety of everyday activities, from sending emails, to streaming movies, to finding the locations of our favorite food trucks. In fact, according to the Pew Research Center, while most Americans go online several times a day, a quarter of us are online essentially constantly. While many other technologies are just as saturated into our lives as the internet, such as electricity, few are as invisible as the internet. The average user of electricity cannot explain Ohm's Law, just as the average user of the internet cannot write computer programs, but almost everyone is familiar with the massive investments in infrastructure that bring electricity to our homes. Not only are we accustomed to seeing overhead power lines and utility trucks in our neighborhoods, millions of us spend our vacations visiting places like the Hoover Dam learning about how electricity is generated. Unfortunately, there are no similar attractions allowing tourists to gawk at and learn about the massive underpinnings of the internet.

The following is an introduction to the infrastructure of the internet, who owns it and how it works.

WHAT IS THE INTERNET AND WHERE DID IT COME FROM?

The concept of allowing computers to communicate over a network originated shortly after the invention of the digital computer in the 1950s. In the late 1960s, the defense department funded ARPANET, which was a network that initially connected computers in the computer science departments of UCLA, UCSB, Stanford and the University of Utah. The network grew to encompass dozens of universities and government institutions in the United States. The physical network was comprised primarily of private phone line connections leased from the telephone networks and managed by the U.S. Department of Defense. The primary purpose of the network was to give computer science departments around the country direct

How the internet connects



Source: National Real Estate Advisors, LLC

access to the most powerful computers owned by just a few universities. Despite its largely academic intentions, the communication power of the network was apparent by the mid-1970s, when 75 percent of the traffic was email among users rather than commands sent

A bit of terminology

Router: A networking device that operates as a switch at the intersections of networks directing data traffic. Routers operate at every network connection, reading the destination IP address of each data packet coming to them and then sending them along a network path. Each router that a data packet encounters guides it closer and closer to its destination. Routers come in a spectrum of sizes, from home routers with a couple connected computers and one outside internet connection to massive machines operating in internet exchanges and data centers interfacing between the world's largest networks.

Modem: A device that converts data from one format to another, allowing data to travel from a computer onto cable or phone lines, over radio waves or onto fiber optic lines and back again.

Fiber optic cable: A cable made of strands of glass or plastic filament, which transmit data as pulses of light. Each filament can carry data on multiple frequencies at the same time and over long distances with little power, making fiber optic cables generally the most efficient way of transmitting data. Fiber optic cables often have immense capacities, allowing multiple networks to lease space on the same cable using different filaments or frequencies to transmit data.

Host or server: Any computer connected to a network is a host. A computer that provides services to other computers on a network is a server. For example, a computer where a website is located (also referred to as hosting a website) is a server, since it can be accessed by other computers viewing that website. Websites can be hosted by servers as simple as a single computer connected to a home network providing access to a seldom-visited website, or they can be hosted by arrays of computers filling football-field-size data centers spread around the world, allowing millions of people to access sites such as YouTube or Facebook.

Data center: A building or other space dedicated to housing computer systems or telecommunications infrastructure. Data centers house the servers hosting the websites and analyzing the data used by consumers and businesses. Desirable data centers have access to reliable and affordable power, as well as access to several large networks to access the internet.

to mainframe computers. In the 1970s and 1980s, additional networks were assembled outside of military control, and by the 1980s it became clear that it would be a far more efficient system if users could communicate with each other across all of the networks.

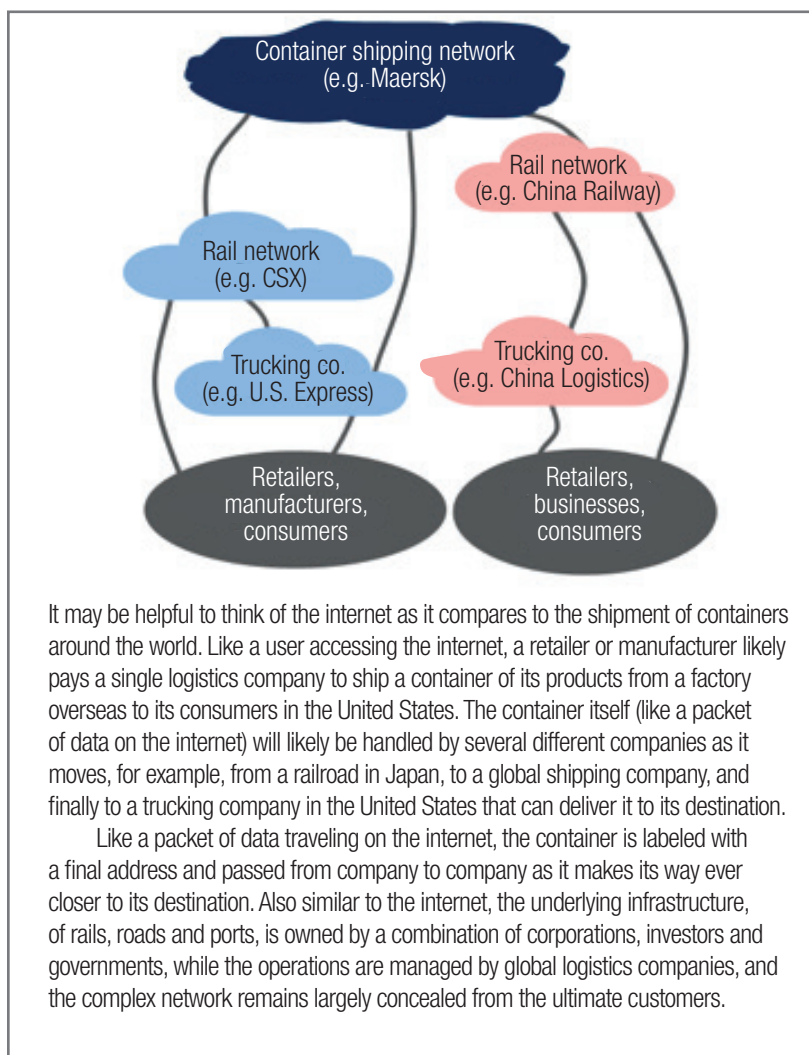
In 1983, ARPANET switched to a universal protocol system, which allowed the multiple existing networks to interlink.

Over the following decades, these networks opened to the public and eventually for commercial use. In the process, they expanded, commercialized, changed ownership, modernized and multiplied — producing the worldwide network composed of tens of thousands of smaller and mostly private networks collectively known as the internet. These smaller networks take various forms ranging from giant internet service providers such as Comcast or Verizon, connecting millions of regional internet users; to backbone networks linking dispersed smaller networks together, such as CenturyLink (formerly Level 3), Cogent or Sprint; to content-delivery networks built by companies such as Google, Akamai or Amazon Web Services to strategically access other networks, allowing for the fastest download times of their content. The complexity and private nature of these networks create a generally seamless but opaque online user experience. By digging into the underlying mechanics of how data travels across these networks on the web, we can begin to understand a bit more about the underlying infrastructure of the internet.

HOW THE MODERN INTERNET WORKS: STRUCTURE

The internet is primarily set up as series of internet Service Providers (ISP). ISPs are the networks that provide users access to the broader internet. These networks are typically owned and operated by for-profit companies, with the large telecom companies such as Sprint, Comcast and Verizon operating some of the most extensive networks in the United States. Networks of any size are made up of the same ingredients of routers, modems, fiber-optic lines, cell towers, and satellites and, from a user's perspective, data travels unimpeded and efficiently across all connected networks to reach its destination, regardless of who owns the network. For example, a person who subscribes to Comcast will not notice any difference between sending an email to someone subscribing to Verizon, Cox Communications or even NTT in Japan, even though the data must travel from the Comcast network onto an adjacent network in the United States or across the

Shipping network



It may be helpful to think of the internet as it compares to the shipment of containers around the world. Like a user accessing the internet, a retailer or manufacturer likely pays a single logistics company to ship a container of its products from a factory overseas to its consumers in the United States. The container itself (like a packet of data on the internet) will likely be handled by several different companies as it moves, for example, from a railroad in Japan, to a global shipping company, and finally to a trucking company in the United States that can deliver it to its destination.

Like a packet of data traveling on the internet, the container is labeled with a final address and passed from company to company as it makes its way ever closer to its destination. Also similar to the internet, the underlying infrastructure, of rails, roads and ports, is owned by a combination of corporations, investors and governments, while the operations are managed by global logistics companies, and the complex network remains largely concealed from the ultimate customers.

Source: National Real Estate Advisors, LLC

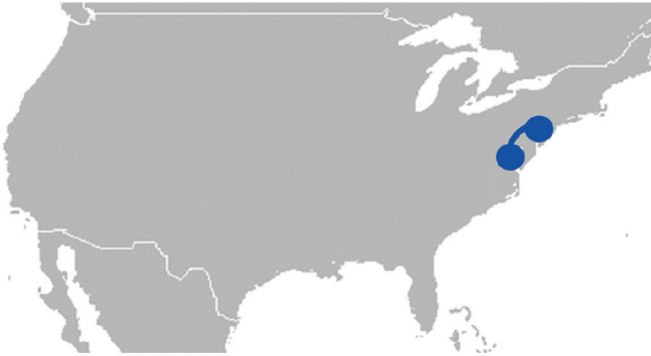
ocean, likely on an intermediary backbone network, to reach Japan.

Every internet network uses the same language to communicate (internet Protocol, or IP), allowing data to be sent over the internet regardless of the particular network it is traveling on. For this system to work, each computer connected to the internet is assigned a unique IP address. This address allows any connected computer to send data to another one by sending out packets of data labeled with its destination IP address. This address allows all the routers that the data packets encounter, on each network along the way, to route the data closer and closer to its destination. When accessing a website, for example, you begin by clicking on a link or typing in the web address. This address (e.g., www.google.com) is converted into Google's IP address and your request is sent to Google. When Google's computer receives your

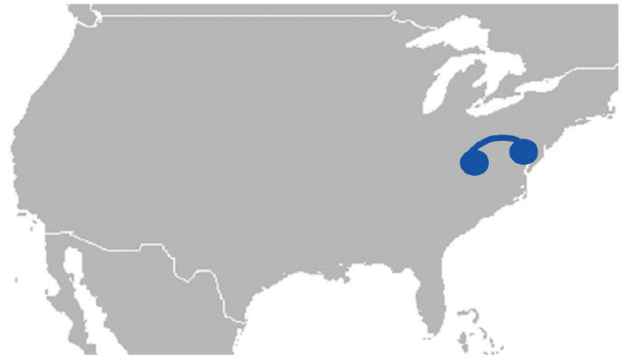
Transmission examples

Although it is difficult to track exactly what path data travels on the internet due to the private and proprietary nature of the infrastructure owners, it is usually possible to see which networks are used, providing a sense of the structure of the internet. Below are a few examples of the journey that data traveled to fulfill some of the Philadelphia-based author's recent website visits.

1. Comcast desktop visit to Amazon.com:



2. AT&T phone visit to Google.com:



3. Comcast desktop visit to thetimes.co.uk:



4. AT&T phone visit to nzherald.co.nz:

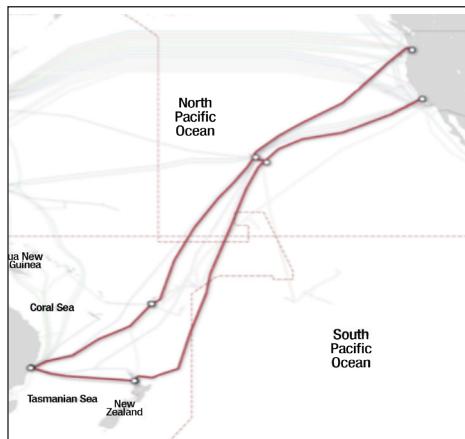


1. Visiting Amazon.com from a computer connected to the Comcast network on the East Coast resulted in connecting almost directly to Amazon servers in Ashburn, Va. This suggests that Amazon is also directly connected to Comcast. This scenario illustrates how large content providers like Amazon locate their content around the world in many data centers connected to large networks in order to provide fast and reliable downloads to their users.
2. Visiting Google.com from an AT&T phone on the East Coast similarly resulted in connecting almost directly to Google servers. Google does not label its network as clearly as Amazon, so it is unclear where precisely the servers are located. Yet, Google likely pursues a similar strategy to Amazon of locating its content in many data centers as close to its consumers as possible.
3. A visit to thetimes.co.uk resulted in the data traveling across Comcast's network, connecting to NTT's network in New York and crossing the Atlantic Ocean to France. From there, the data continued traveling and connected to Amazon Web Services in a data center in Ireland where thetimes.co.uk is evidently hosted.
4. A visit to the *New Zealand Herald* from a phone worked similarly. From the phone, the data was sent via radio signal to the nearest cell station on a tower or nearby building. There it transferred from AT&T's mobile network to its long-distance fiber optic network and travelled to Los Angeles. In Los Angeles, the data appears to have been routed to the Tata Communications Network, on which it traveled up to Seattle and then across the Pacific Ocean to New Zealand. In New Zealand, it transferred to Vodafone's network and connected to the *Herald's* servers.

These examples of visiting smaller websites outside of the United States show how data must transfer across multiple networks owned by different corporations as it travels around the world. The two examples also suggest a different ownership structure of the servers in the data centers hosting the two publications. *The Times* appears to lease space on Amazon Web Services servers, while the *Herald* appears to control its own servers and data center space more directly.

Source: National Real Estate Advisors, LLC

Infrastructure ownership: Southern Cross Cable



Graphic No. 4 on page 30 shows data traveling directly from the Seattle area to New Zealand on Tata Communications' network. There are relatively few cables connecting New Zealand directly to the United States and none of them is owned by Tata Communications. Tata does, however, lease bandwidth on the Southern Cross Cable (mapped to the left connecting the mainland United States, Hawaii, Fiji, Australia and New Zealand) owned by a joint venture between Spark New Zealand, SingTel and Verizon Business. Thus, it is likely that part of the *New Zealand Herald's* internet and my phone plan's subscription dollars pass from Vodafone and AT&T, respectively, on to Tata and again on to the cable operating company.

Source: National Real Estate Advisors, LLC

request, it sends the data required to display its webpage back to your IP address and, therefore, your computer. This basic process is repeated for any task online, whether it is accessing websites, sending email, or streaming music. The process will continue to work regardless of which networks connect you and Google. The crucial component that changes if you switch networks is your assigned IP address (and therefore the route the data travels to get to you). For example, if you access Google on your computer plugged into your home router, you are connected to your local ISP (e.g., Comcast), which is in turn connected to the global internet. But, if you access the internet from your smart phone, your data will be sent via radio waves to a cell tower connected to the carrier's hardwired network (e.g., AT&T) before being transferred to another network and on to Google.

THE BUSINESS OF NETWORKS

Although all networks are made up of the same general building blocks, they operate at different scales and geographies. Backbone networks operate undersea cables and fiber optic lines, which span continents connecting distant cities. Local and regional networks focus on connecting lots of homes and businesses in dense networks, which in turn connect to the backbone networks and the broader internet. A network's market position is largely determined by its size. Networks are conventionally broken down into three tiers. Tier 1, or backbone networks (operated by companies such as CenturyLink (formerly Level 3), Sprint or Tata Communications), are global networks connecting local and regional networks around the world. These networks earn revenue by charging smaller networks for access. Tier 2 and 3 networks (such as

Comcast or Cox Communications) are made up of local and regional cable and fiber optic connections. These are the networks that, for a fee, consumers and businesses connect to in order to access the internet. Revenue generally flows upwards from consumers and businesses subscribing to the internet on local and regional networks to larger and more connected networks.

Although networks own significant parts of their infrastructure, they can often more efficiently build networks by sharing infrastructure. Networks frequently lease bandwidth on fiber optic cables and satellites that give access to distant locations. They may also lease space on redundant network pathways that would be prohibitively expensive to own creating resilience that networks and Internet users crave. Networks may even lease local infrastructure in areas they don't have expertise or to achieve economies of scale such as space in Internet exchanges or cell tower locations. Networks even lease individual connection points on cell towers resulting in towers in prominent locations holding equipment for Verizon, AT&T, T-Mobile and Sprint all at the same time. In addition to network operators, content providers may own and operate their own data centers and servers, but they may also lease space within multi-tenant data centers or even on servers within data centers where small-scale players can gain access to dense network connections. Ownership structures like these can create opportunities for private investors, particularly in the most capital-intensive parts of networks like data centers and undersea cables. ♦

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