Engineering College

Computer Network

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1.1 Bandwidth

Bandwidth is defined as the amount of information that can flow through a network connection in a given period of time. It is important to understand the concept of bandwidth for the following reasons.

- **Bandwidth is Finite**. Regardless of the media used to build a network, there are limits on the network capacity to carry information. Bandwidth is limited by the laws of physics and by the technologies used to place information on the media. For example, the bandwidth of a conventional modem is limited to about 56 kbps by both the physical properties of twisted-pair phone wires and by modem technology. DSL uses the same twisted-pair phone wires. However, DSL provides much more bandwidth than conventional modems. So, even the limits imposed by the laws of physics are sometimes difficult to define. Optical fiber has the physical potential to provide virtually limitless bandwidth. Even so, the bandwidth of optical fiber cannot be fully realized until technologies are developed to take full advantage of its potential.
- **Bandwidth is not free**. It is possible to buy equipment for a LAN that will provide nearly unlimited bandwidth over a long period of time. For WAN connections, it is usually necessary to buy bandwidth from a service provider. In either case, individual users and businesses can save a lot of money if they understand bandwidth and how the demand will change over time. A network manager needs to make the right decisions about the kinds of equipment and services to buy.
- **Bandwidth is an important factor that is used to analyze network performance, design new networks, and understand the Internet**. A networking professional must understand the tremendous impact of bandwidth and throughput on network performance and design. Information flows as a string of bits from computer to computer throughout the world. These bits represent massive amounts of information flowing back and forth across the globe in seconds or less.
- **The demand for bandwidth continues to grow**. As soon as new network technologies and infrastructures are built to provide greater bandwidth, new applications are created to take advantage of the greater capacity. The delivery of rich media content such as streaming video and audio over a network requires tremendous amounts of bandwidth. IP telephony systems are now commonly installed in place of traditional voice systems,

which further adds to the need for bandwidth. The successful networking professional must anticipate the need for increased bandwidth and act accordingly.

1.2 Digital Versus Analog

Bandwidth Radio, television, and telephone transmissions have, until recently, been sent through the air and over wires using electromagnetic waves. These waves are called analog because they have the same shapes as the light and sound waves produced by the transmitters. As light and sound waves change size and shape, the electrical signal that carries the transmission changes proportionately. In other words, the electromagnetic waves are analogous to the light and sound waves. Analog bandwidth is measured by how much of the electromagnetic spectrum is occupied by each signal. The basic unit of analog bandwidth is hertz (Hz), or cycles per second. While analog signals are capable of carrying a variety of information, they have some significant disadvantages in comparison to digital transmissions. The analog video signal that requires a wide frequency range for transmission cannot be squeezed into a smaller band. Therefore, if the necessary analog bandwidth is not available, the signal cannot be sent. In digital signaling all information is sent as bits, regardless of the kind of information it is. Voice, video, and data all become streams of bits when they are prepared for transmission over digital media. This type of transmission gives digital bandwidth an important advantage over analog bandwidth. Unlimited amounts of information can be sent over the smallest or lowest bandwidth digital channel. Regardless of how long it takes for the digital information to arrive at its destination and be reassembled, it can be viewed, listened to, read, or processed in its original form. It is important to understand the differences and similarities between digital and analog bandwidth. Both types of bandwidth are regularly encountered in the field of information technology. However, because this course is concerned primarily with digital networking, the term bandwidth will refer to digital bandwidth.

1.3 Bandwidth Measurement

In digital systems, the basic unit of bandwidth is bits per second (bps). Bandwidth is the measure of how many bits of information can flow from one place to another in a given amount of time. Although bandwidth can be described in bps, a larger unit of measurement is generally used Table.(1). Although the terms bandwidth and speed are often used interchangeably, they are not exactly the same thing. One may say, for example, that a T3 connection at 45 Mbps operates at a higher speed than a T1 connection at 1.544 Mbps. However, if only a small amount of their data-carrying capacity is being used, each of these connection types will carry data at roughly the same speed. For example, a small amount of water will flow at the same rate through a small pipe as through a large pipe. Therefore, it is usually more accurate to say that a T3 connection has greater bandwidth than a T1 connection. This is because the T3 connection is able to carry more information in the same period of time, not because it has a higher speed.

Table.(1) Unit of Bandwidth

Unit of Bandwidth	Abbreviation	Equivalence
Bits per second	bps	1bps=fundamental unit of bandwidth
Kilobits per second	kbps	1kbps=1,000bps=10^3bps
Megabits per second	Mbps	1Mbps=1,000,000bps=10^6bps
Gigabits per second	Gbps	1Gbps=1,000,000,000bps=10^9bps
Terabits per second	Tbps	1Tbps=1,000,000,000,000bps=10^{12} bps

1.4 Bandwidth Limitation

Bandwidth varies depending upon the type of media as well as the LAN and WAN technologies used. The physics of the media account for some of the difference. Signals travel through twisted pair copper wire, coaxial cable, optical fiber, and air. The physical differences in the ways signals travel result in fundamental limitations on the information-carrying capacity of a given medium. However, the actual bandwidth of a network is determined by a combination of the physical media and the technologies chosen for signaling and detecting network signals. For example, current information about the physics of unshielded twisted-pair (UTP) copper cable puts the theoretical bandwidth limit at over 1 Gbps. However, in actual practice, the bandwidth is determined by the use of 10BASE-T, 100BASE-TX, or 1000BASE-TX Ethernet. The actual bandwidth is determined by the signaling methods, NICs, and other network equipment that is chosen. Therefore, the bandwidth is not determined solely by the limitations of the medium.

Table.(2) Shows some common networking media types along with their distance and bandwidth limitations

Typical Media	Maximum Theoretical Bandwidth	Maximum Theoretical Distance
50-Ohm Coaxial Cable (10BASE2 Ethernet; Thinnet)	10Mbps	185m
50-Ohm Coaxial Cable (10BASE2 Ethernet; Thicknet)	10Mbps	500m
Category 5 Unshielded Twisted Pair (UTP) (10BASE-T Ethernet)	10Mbps	100m
Category 5 Unshielded Twisted Pair (UTP) (100BASE-TX Ethernet)	100Mbps	100m
Category 5 Unshielded Twisted Pair (UTP) (1000BASE-TX Ethernet)	1000Mbps	100m
Multimedia Optical Fiber (62.5/125µm) (100BASE-Fx Ethernet)	100Mbps	220m
Multimedia Optical Fiber (62.5/125µm) (100BASE-Fx Ethernet)	1000Mbps	220m
Multimedia Optical Fiber (50/125µm) (1000BASE-Sx Ethernet)	1000Mbps	550m
Singlemode Optical Fiber (9/125µm) (1000BASE-Lx Ethernet)	1000Mbps	5000m

Table.(3) Summarizes common WAN services and the bandwidth associated with each service

WAN Service	Typical User	Bandwidth
Modem	Individuals	56kbps=0.056Mbps
DSL	Individuals, Telecommuters, and Small Businesses	128kbps to 6.1Mbps= 0.128Mbps to 6.1Mbps
ISDN	Telecommuters and Small Businesses	128kbps=0.128Mbps
Frame Relay	Small institutions (schools) and reliable WANs	56kbps to 44.736Mbps (U.S.) or 34.368Mbps (Europe)= 0.056Mbps to 44.736Mbps (U.S.) or 34.368Mbps (Europe)
T1	Large entities	1.544Mbps

E1	Large entities	2.048Mbps
T3	Large entities	44.736Mbps
E3	Large entities	34.368Mbps
STS-1 (OC-1)	Phone companies; Data-Comm company backbones	51.840Mbps
STM-1	Phone companies; Data-Comm company backbones	155.52Mbps
STS-3 (OC-3)	Phone companies; Data-Comm	155.251Mbps
STS-3 (OC-3)	Phone companies; Data-Comm company backbones	155.251Mbps
STM-3	Phone companies; Data-Comm company backbones	466.56Mbps
STS-48 (OC-48)	Phone companies; Data-Comm company backbones	2.488320Gbps

1.5 Bandwidth Throughput

Bandwidth is the measure of the amount of information that can move through the network in a given period of time. Therefore, the amount of available bandwidth is a critical part of the specification of the network. A typical LAN might be built to provide 100 Mbps to every desktop workstation, but this does not mean that each user is actually able to move 100 megabits of data through the network for every second of use. This would be true only under the most ideal circumstances. Throughput refers to actual measured bandwidth, at a specific time of day, using specific internet routes, and while a specific set of data is transmitted on the network. Unfortunately, for many reasons, throughput is often far less than the maximum possible digital bandwidth of the medium that is being used. The following are some of the factors that determine throughput: Internetworking devices Type of data being transferred Network topology Number of users on the network User computer Server computer Power conditions The theoretical bandwidth of a network is an important consideration in network design, because the network bandwidth will never be greater than the limits imposed by the chosen media and networking technologies. However, it is just as important for a network designer and administrator to consider the factors that may affect actual throughput. By measuring throughput on a regular basis, a network administrator will be aware of changes in network performance and changes in the needs of network users. The network can then be adjusted accordingly.

1.6 Round-trip time (RTT)

The second performance metric, latency, corresponds to how long it takes a message to travel from one end of a network to the other. (As with bandwidth, we could be focused on the latency of a single link or an end-to-end channel.) Latency is measured strictly in terms of time. For example, a transcontinental network might have a latency of 24 milliseconds (ms); that is, it takes a message 24 ms to travel from one coast of North America to the other. There are many situations in which it is more important to know how long it takes to send a message from one end of a network to the other and back, rather than the one-way latency. We call this the *round-trip time (RTT)* of the network.

1.7 Data Transfer Calculations

Network designers and administrators are often called upon to make decisions regarding bandwidth. One decision might be whether to increase the size of the WAN connection to accommodate a new database. Another decision might be whether the current LAN backbone is of sufficient bandwidth for a streaming video training program. The answers to problems like these are not always easy to find, but one place to start is with a simple data transfer calculation. Using the formula transfer time = size of file / bandwidth (T=S/BW) allows a network administrator to estimate several of the important components of network performance. If the typical file size for a given application is known, dividing the file size by the network bandwidth yields an estimate of the fastest time that the file can be transferred.

$$Latency = Propagation + Transmit + Queue$$

$$Propagation = Distance/SpeedOfLight$$

$$Transmit = Size/Bandwidth$$

$Best\ Download\quad \mathrm{T} = \frac{\mathrm{S}}{\mathrm{BW}}$ $Typical\ Download\ \mathrm{T} = \frac{\mathrm{S}}{\mathrm{P}}$

BW	Maximum theoretical bandwidth of the “slowest link” between the source host and the destination host (measured in bits per seconds)
P	Actual throughput at the moment of transfer (measured in bits per seconds)
T	Time for file transfer to occur (measured in seconds)
S	File size in bits

Two important points should be considered when doing this calculation.

1- The result is an estimate only, because the file size does not include any overhead added by encapsulation.
2- The result is likely to be a best-case transfer time, because available bandwidth is almost never at the theoretical maximum for the network type. A more accurate estimate can be attained if throughput is substituted for bandwidth in the equation.

For example:

Consider a digital library program that is being asked to fetch a 25-megabyte (MB) image—the more bandwidth that is available, the faster it will be able to return the image to the user. Here, the bandwidth of the channel dominates performance. To see this, suppose that the channel has a bandwidth of **10 Mbps**. It will take 20 seconds to transmit the image

T=25 × 106 × 8 bits ÷10 × 106 Mbps = 20 seconds

Figure 1 gives you a sense of how latency or bandwidth can dominate performance in different circumstances. The graph shows how long it takes to move objects of various sizes (**1 byte, 2 KB, 1 MB**) across networks with RTTs ranging from 1 to 100 ms and link speeds of either 1.5 or 10 Mbps. We use logarithmic scales to show relative performance. For a 1-byte object (say, a keystroke), latency remains almost exactly equal to the RTT, so that you cannot distinguish between a 1.5-Mbps network and a 10-Mbps network. For a 2-KB object (say, an email message), the link speed makes quite a difference on a 1-ms RTT network but a negligible difference on a 100-ms RTT network. And for a 1-MB object (say, a digital image), the RTT makes no difference—it is the link speed that dominates performance across the full range of RTT.

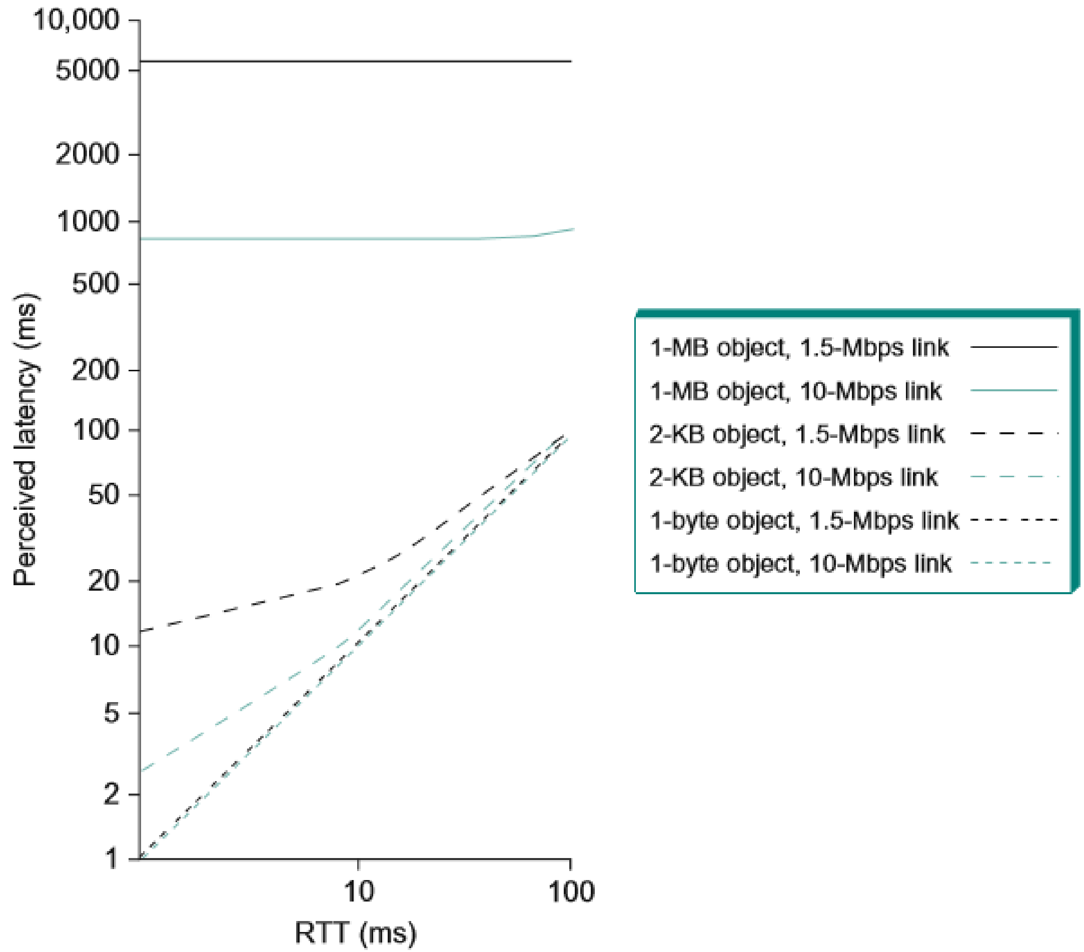

Figure 1. Perceived latency (response time) versus round trip time for various object sizes and link speeds.