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Network Links

LAB02

MOHAMED ELSHAIKH

SCHOOL OF COMPUTER AND COMMUNICATION ENGINEERING, UNIMAP

Link Capacity and the Shannon-Hartley Theorem

There has been an enormous body of work done in the related areas of signal processing and information theory, studying everything from how signals degrade over distance to how much data a given signal can effectively carry. The most notable piece of work in this area is a formula known as the Shannon-Hartley theorem. Simply stated, this theorem gives an upper bound to the capacity of a link, in terms of bits per second (bps); as a function of the signal-to-noise ratio of the link, measured in decibels (dB); and the bandwidth of the channel, measured in Hertz (Hz). (As noted previously, bandwidth is a bit of an overloaded term in communications; here we use it to refer to the range of frequencies available for communication.) As an example, we can apply the Shannon-Hartley theorem to determine the rate at which a dial-up modem can be expected to transmit binary data over a voice-grade phone line without suffering from too high an error rate. A standard voice-grade phone line typically supports a frequency range of 300 Hz to 3300 Hz, a channel bandwidth of 3 kHz. The theorem is typically given by the following formula:

$$\mathbf{C = B \log_2(1+S/N)}$$

Where C is the achievable channel capacity measured in bits per second, B is the bandwidth of the channel in Hz (3300 Hz−300 Hz = 3000 Hz), S is the average signal power, and N is the average noise power. The signal-to-noise ratio (S/N, or SNR) is usually expressed in decibels, related as follows:

$$SNR = 10\times\log10(S/N)$$

Thus, a typical signal-to-noise ratio of 30 dB would imply that S/N = 1000.

Thus, we have

$$\mathbf{C = 3000\times\log_2(1001)}$$

Which equals approximately 30 kbps. When dial-up modems were the main way to connect to the Internet in the 1990s, 56 kbps was a common advertised capacity for a modem (and continues to be about the upper limit for dial-up). However, the modems often achieved lower speeds in practice, because they didn’t always encounter a signal-to-noise ratio high enough to achieve 56 kbps. The Shannon-Hartley theorem is equally applicable to all sorts of links ranging from wireless to coaxial cable to optical fiber. It should be apparent that there are really only two ways to build a high-capacity link: start with a high-bandwidth channel or achieve a high signal-to-noise ratio, or, preferably, both. Also, even those conditions won't guarantee a high-capacity link it often takes quite a bit of ingenuity on the part of people who design channel coding schemes to achieve the theoretical limits of a channel. This ingenuity is particularly apparent today in wireless links, where there is a great incentive to get the most bits per second from a given amount of wireless spectrum (the channel bandwidth) and signal power level (and hence SNR).

Estimating the bottleneck capacity of an Internet path is a fundamental research problem in computer networking; knowledge of such capacity is critical for efficient network design, management and usage. In the past few years, with the growing popularity of emerging technologies such as overlay, peer-to-peer (P2P), sensor, grid and mobile networks, it is becoming increasingly desirable to have a simple, fast and accurate tool for capacity estimation and monitoring. To accommodate the diversity in network arrangements, an ideal capacity estimation tool must also be scalable and applicable to a variety of network configurations.

Example 2.1

A PPP link connects between client and server with 1.5Mbps bandwidth and 50 ms RTT is meant to send a 15MByte file. Analyze the network in terms of packet size firstly with theoretical calculation and secondly with simulation scenario.

Answer:

Theoretical calculation:

Assuming data is sent once (all data is 1 packet).

2 initial RTT's (100ms) + 15MB/1.5Mbps (transmit) + RTT/2 (propagation

= 25ms)

= 100 ms + 80 s + 25 ms = 80.125 s

In a TCP protocol each time a packet sent must wait for ack (waiting for RTT after each packet sent).

= 2 RTT + number of packets (RTT + packet transfer time)

Number of packets = Data size/Packet Size

Packet transfer time = packet size / bandwidth

RTT (s)	Pkt Size (B)	Bandwidth (Mb/s)	Data (MB)	# packe	pkt time (s)	total time (s)
0.05	500	1.5	15	30000	0.000267	1508.1
0.05	600	1.5	15	25000	0.00032	1258.1
0.05	700	1.5	15	21428.57	0.000373	1079.529
0.05	800	1.5	15	18750	0.000427	945.6
0.05	1000	1.5	15	15000	0.000533	758.1
0.05	2000	1.5	15	7500	0.001067	383.1

Simulation

Form a scenario of a client and server, the client is to request a video with 15 MByte size from a server. The server is to reply with variable packet size. Run the simulation for different packet size and collect results as in table:

Pkt Size	Total time (simulation "s")
500	1582.9
600	1320.75
700	1133.5
800	993.05
1000	796.45
2000	403.25

Now compare between simulation and theoretical results and give your observations.

Exercise

A network composed of two hosts H1,H2 connected with PPP link. Given that the PPP link is 10Mbps bandwidth and 40ms RTT. Assuming that the H1 is to send data with 100MByte in size. Find the following:

(1, 2 compare between theoretical and simulation. 3 is simulation only)

1- Analyze the effect of different packet size to transfer the data
2- Assuming a fix packet size (2kbyte) analyze the effect of different link bandwidths.
3- Assuming that N hosts are connect in this network, and all host are to request the same video from a server, use a simulation to find the maximum throughput of the network.

“Throughput: is the successful received data in a second (bits/Second)”

Hint: use a hub to connect.