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Computer Networks

Lecture [16]: Data Rate Limits

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Topics discussed in Today's Lectures

- Data Rate Limits
- Nyquist Bit Rate
- Noisy Channel: Shannon Capacity
- Performance of Network

Data Rate Limits

- How fast we can send data, in bits/sec, over a channel
- Data rate depends on three factors:
  i. Bandwidth available
  ii. Level of the signals we use
  iii. Quality of the channel (Level of noise)
- Two **theoretical formulas** were developed to calculate Data Rate:
  i. Nyquist for a Noiseless channel
  ii. Shannon for a Noisy channel

Noiseless Channel: Nyquist Bit Rate

- For noiseless channel, Nyquist bit rate formula defines the theoretical max. bit rate

$$\text{BitRate} = 2 \times \text{bandwidth} \times \log_2 L$$

- In this formula:
  - Bandwidth is the bandwidth of the channel
  - L is the number of signal levels used to represent data
  - BitRate (Max. Capacity/Data Rate of Channel) is the bit rate in bits/sec
- According to formula, given a specific bandwidth, we can have any bit rate we want, by increasing the No. of signal levels

Noiseless Channel: Nyquist Bit Rate

Effect of Increasing Signal Levels

- When we increase the # of signal levels, we impose a burden on the receiver
- If # of levels in a signal is just 2, receiver can easily distinguish b/w 0 and 1
- If level of a signal is 64, receiver must be able to distinguish b/w 64 different levels
- So increasing the levels of a signal, reduces the reliability of the system

Noisy Channel: Shannon Capacity

- In reality, we cannot have a noiseless channel; the channel is always noisy
- A formula, called the Shannon capacity, is used to determine the theoretical highest data rate for a noisy channel:

$$\textbf{Capacity} = \textbf{bandwidth} \times \log_2(1 + \textbf{SNR})$$

- In the formula there is no indication of signal level, which means no matter how many levels we've, we can't achieve a data rate > capacity of channel
- The Shannon capacity gives us the *upper limit;*
- While the Nyquist formula tells us *how many signal levels we need.*

Performance of Network

- Performance of the network means how good is it?
- Quality of service means an overall measurement of network performance

Bandwidth

- One characteristic that measures network performance is bandwidth
- Bandwidth can be measured as: in Hertz and Bits/sec
- **Hertz** is Range of frequencies:
  - Contained in a composite signal
  - A channel can pass
    - i.e., we can say bandwidth of a subscriber telephone line is 4 kHz
- **Bits per second** that a channel, a link, or a network can transmit
  - i.e. one can say the bandwidth of a Fast Ethernet network is a max. of 100 Mbps
  - It means this network can send 100 Mbps

Performance of Network

Throughput

- It is a measure of *how fast we can actually send data through a network*
- Bandwidth in bits/sec & throughput seem same, but they are different
- A link may have a bandwidth of B bps, but we can only send T bps through this link with T always < B
- In other words, Bandwidth is a potential measurement of a link; Throughput is an actual measurement of how fast we can send data
- E.g., we may have a link with a bandwidth of 1 Mbps, but devices connected to end of the link may handle only 200 kbps (Throughput)
- This means that we can't send more than 200 kbps (Throughput) through this link

Performance of Network

Latency (Delay)

- It defines how long it takes for an entire message to completely arrive at destination from time the first bit is sent out from the source
- We can say that latency is made of four components:

  i. Propagation time

  ii. Transmission time

  iii. Queuing time

  iv. Processing delay

Latency = propagation time + transmission time + queuing time + processing delay

Performance of Network

Latency (Delay)

i. Propagation time

- Propagation time measures the time required for a bit to travel from the source to the destination
- It is calculated by dividing the distance by the propagation speed

Propagation time = Distance / (Propagation Speed)

- For example, in a vacuum, light is propagated with a speed of 3 × 10^8 m/s
- It is lower in air; it is much lower in cable.

Performance of Network

Latency (Delay)

ii. Transmission Time

- In data comm. we don't send just 1 bit, we send a message
- 1^{st} bit may take a time equal to the propagation time to reach its destination; the last bit also may take the same amount of time
- However, there is a time b/w 1^{st} bit leaving sender and the last bit arriving at the receiver
- 1^{st} bit leaves earlier & arrives earlier; last bit leaves later and arrives later
- Transmission time of a message depends on size of the message & bandwidth of the channel

Transmission time = (Message size) / Bandwidth

Performance of Network

Latency (Delay)

iii. Queuing Time

- It is the time needed for each intermediate or end device to hold the message before it can be processed
- This time changes with the load imposed on the network
- When there is heavy traffic on the network, the queuing time increases
- An intermediate device, i.e. a router, queues the arrived messages and processes them one by one
- If there are many messages, each message will have to wait.

Performance of Network

Bandwidth-Delay Product

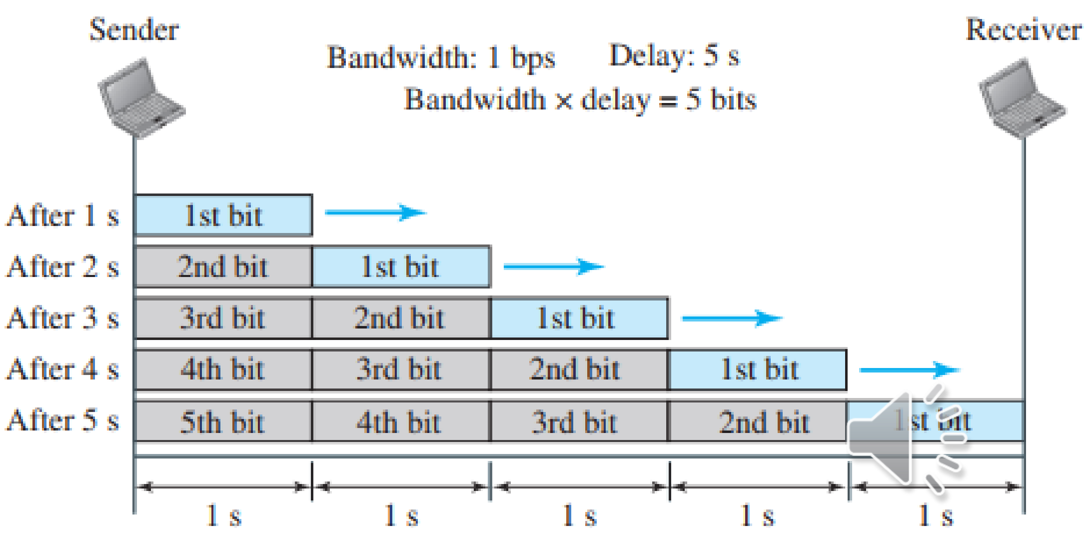
- Bandwidth and delay are two performance metrics of a link
- The product of these two is very important, the bandwidth-delay product

Case 1

Bandwidth-delay product means:

- We can say that this product 1x5 is the max. number of bits that can fill the link
- There can be no more than 5 bits at any time on the link.

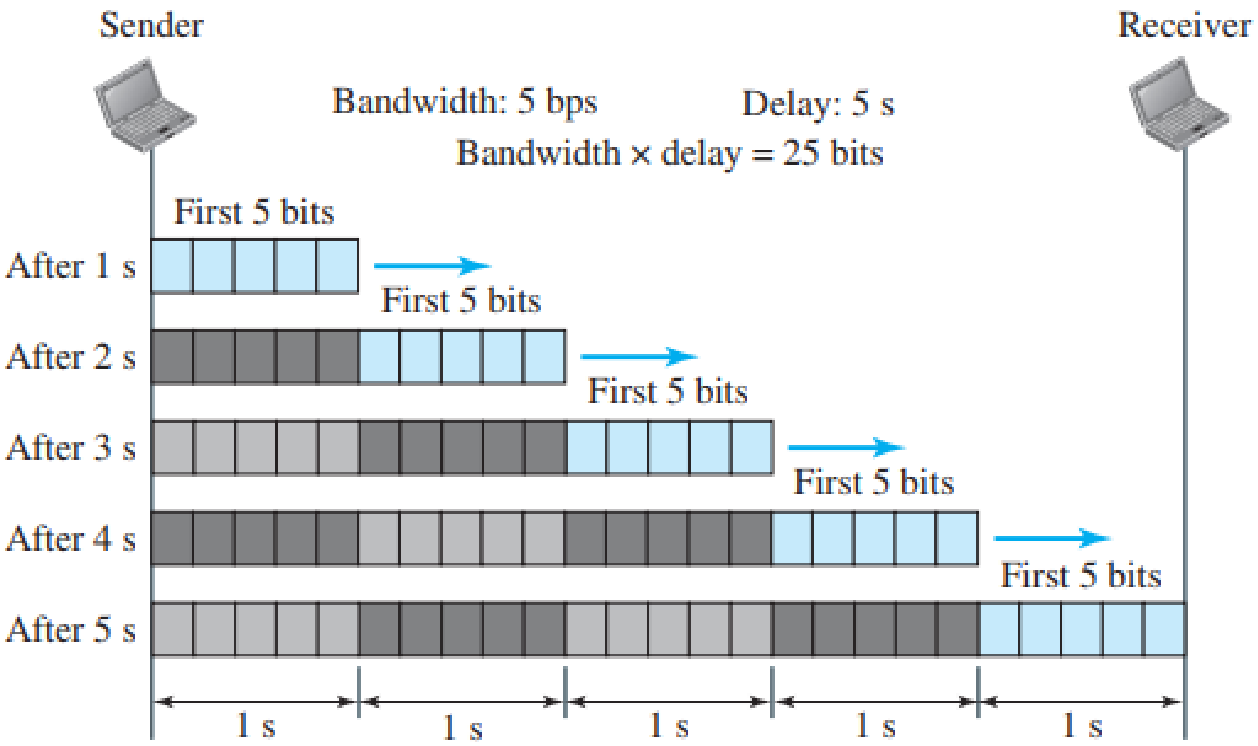
Filling the link with bits for case 1



Performance of Network

Case 2

- Assume we've a bandwidth of 5 bps
- Fig. shows that there can be max. 5×5=25 bits on the line
- Reason is that, at each second, there are 5 bits on the line; the duration of each bit is 0.20 s.



Above two cases show that product of bandwidth and delay is the number of bits that can fill the link

Performance of Network

Jitter

- It is a problem if :
  - Different packets of data encounter different delays and
  - Application using the data at the receiver site is time-sensitive e.g. audio, video data
- If the delay for the 1st packet is 20 ms, for 2nd is 45 ms, and for 3rd is 40 ms, then the real-time application that uses the packets undergoes jitter

References

Chapter 3

Data Communication and Networking (5th Edition)

By Behrouz A. Forouzan

THANKS