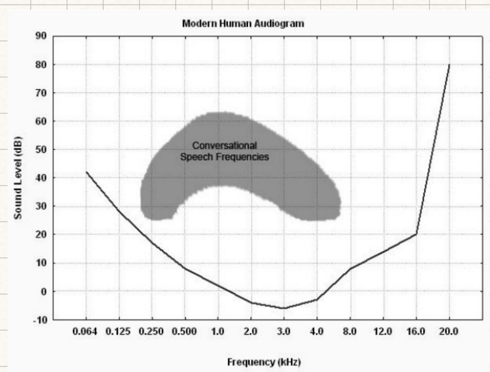
# Lecture 2

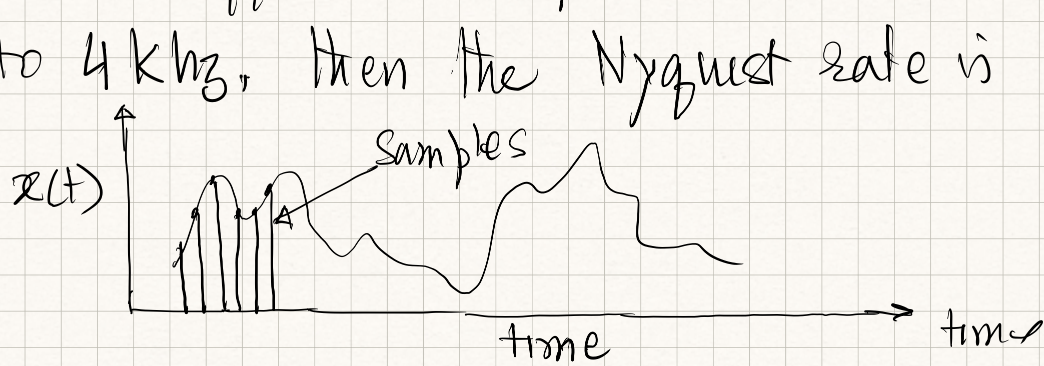
## Traffic Source Characteristics


### Nyquist - Shanon Sampling Theorem

For a band limited signal $x(t)$ with a maximum frequency of B hz, the signal is completely determined by samples taken at a rate of 2B samples per second.

If we approximate speech to be band limited to 4 khz, then the Nyquist rate is 8Khz



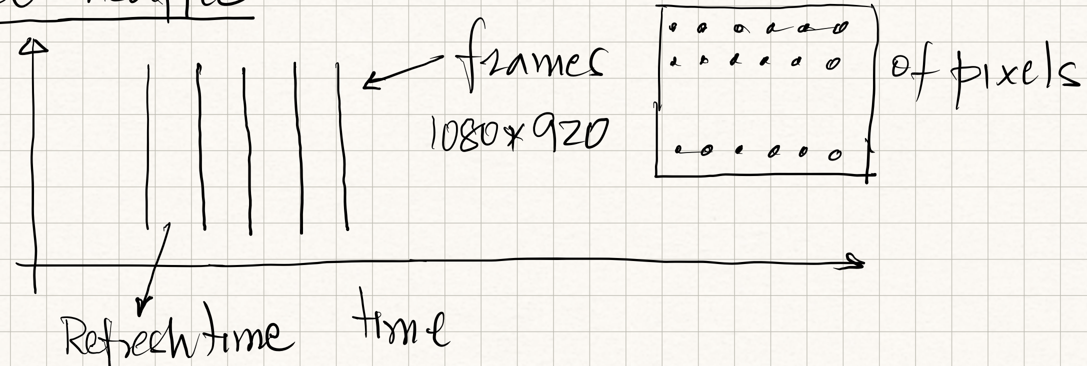
Inter-sample time is $\frac{1}{8000}$ secs = 0.125 μsec

Each sample is encoded using 8 bits

⇒ data rate = 8000 * 8 = 64 Kbp

- This is a Constant Bit Rate (CBR) source
  8 bits every 0.125 μsec

## Video Traffic



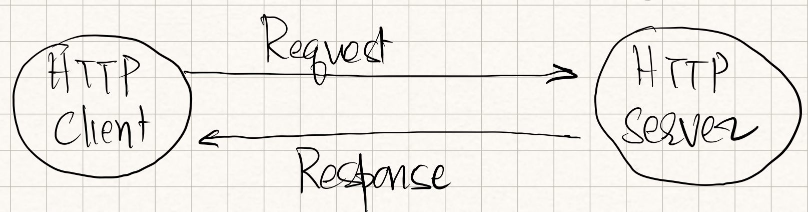

each pixel is encoded using 24 bits

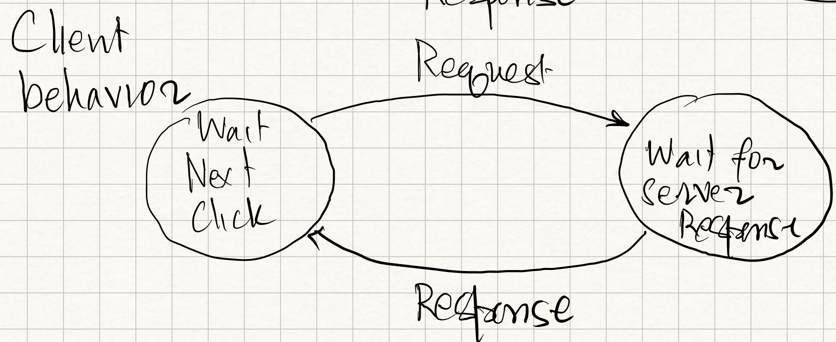
⇒ Constant Bit Rate

Different encoding & compression technique makes video traffic Variable Bit Rate (VBR)

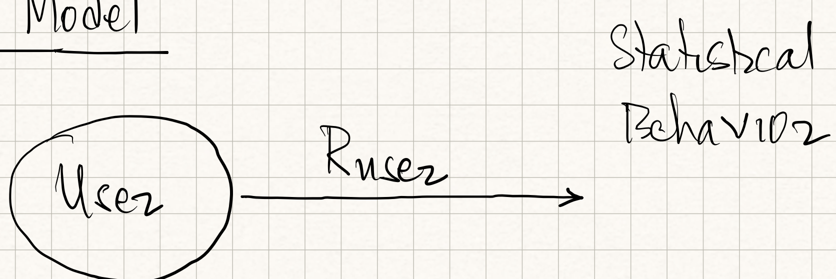
## Data Traffic

Many different types { FTP, Telnet, HTTP }




## Simple Model



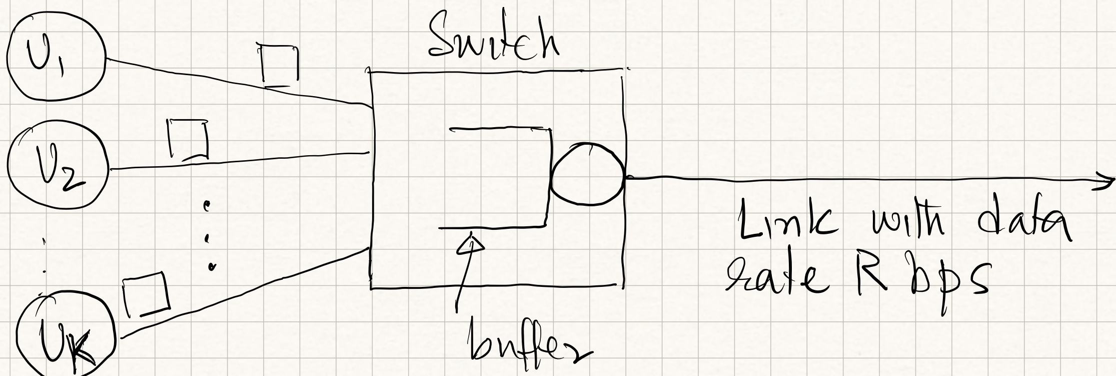

- User when active sends data at $R_{user}$
- User is active with probability $p$

Example: User transmits @ 100Kbps when active. User is active 10% of the time

# Packet Switching

1. Message is broken into small chunks which are called <u>packets</u> (or datagram)

2. User transmits the packets one at a time (whenever packets are ready)




3. Each user transmits data @ $R_{user}$ when active. Each user is active with probabity p

4. Suppose $R_{user} = R$. If more than $n=1$ user is active simultaneously, total arrival rate (of bits) is greater than link data rate

   ⇒ Congestion

   ⇒ Buffer to hold the excess

If $R_{user} < R$ then $n = \lceil \frac{R}{R_{user}} \rceil$ will cause congestion

Example: $R = 1$ Mbps

$R_{user} = 100$ kbps

$n > 10$ simultaneously active users will cause congestion

## Probability of Congestion

P( aggregate arrival rate > link rate)

Example:

$K = 35$ users

$R_{user} = 100$ kbps

$p = 0.1$

$R = 1$ Mbps

P(congestion) = P(11 or more users are active simultaneously)

$P_c$

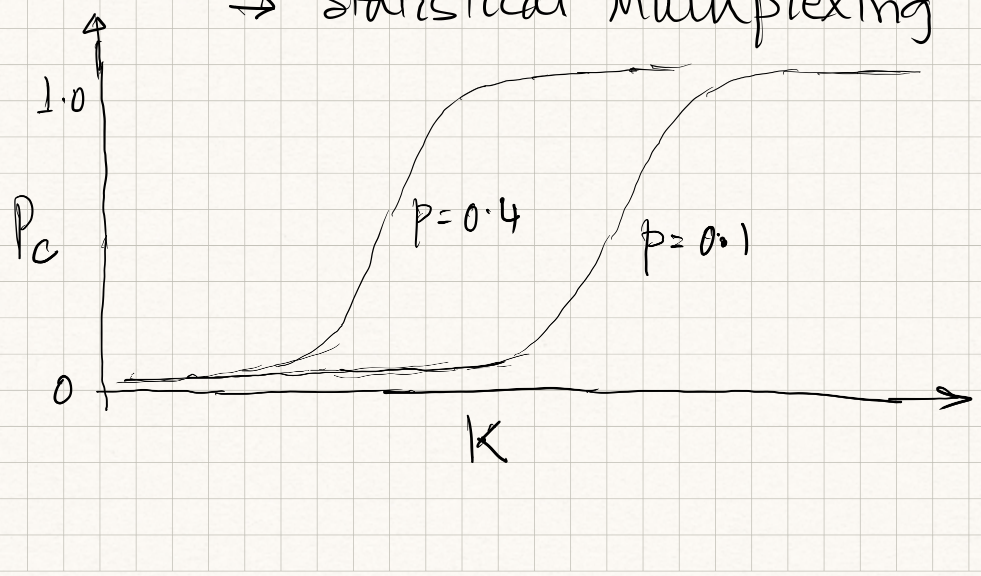
$$= \sum_{i=1}^{35} \binom{35}{i} p^i (1-p)^{35-i}$$

$= 0.0004$

- We can connect 35 users and have a very low $P_c$

- In comparison with circuit switching we can only connect 10 users
  → circuits must be created to accomodate for the peak rate

- In packet switching we are leveraging the fact that users are not active all the time
  → Statistical Multiplexing

- 

- We derived $P_c$ for a specific value $K$, $R_{user}$, $R$, $p$

  It is easy to generalize

<u>Aside:</u> Binomial distribution

$$X \sim \text{Binom}(n, p)$$

$$P(X = k) = \binom{n}{k} p^k (1-p)^{n-k} \quad k = 0, 1, 2, \ldots, n$$

<u>Interpretation</u>

The random variable $X$ denotes the number of success in $n$ independent Bernoulli trials.

Bernoulli trial is an experiment in which there are only 2 outcomes (success and failure) (1, 0)

$$Y \sim \text{Bern}(p)$$

$$P(Y = 1) = p \quad Y(Y = 0) = 1 - p$$

(Think tossing an uneven coin with $P(\text{head}/\text{success}) = p$ and hence $P(\text{tail} / \text{failure}) = 1-p$

$X \sim \text{Binom}(n, p)$

$P(X=k) = P($k success in n independent Bernoulli trials tosses$)$

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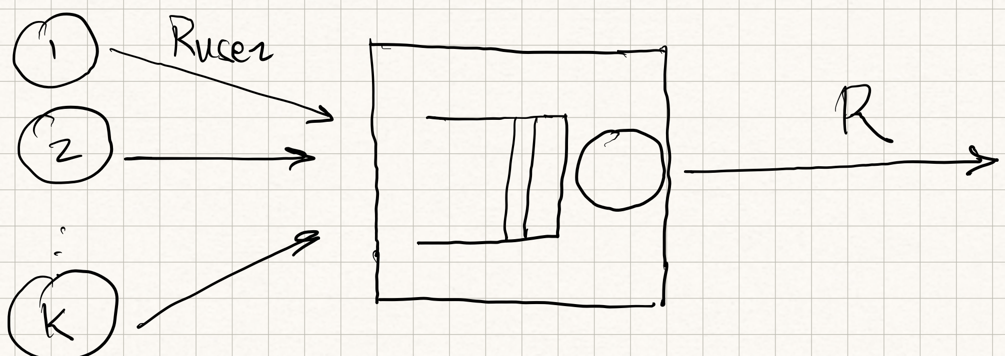
## Cost of Statistical Multiplexing

- A positive $P_c$ : at times the input rate will be greater than the output rate




- A buffer is needed to handle excess data during times of congestion

- Queuing delay: packets wait in the buffer before it can be transmitted