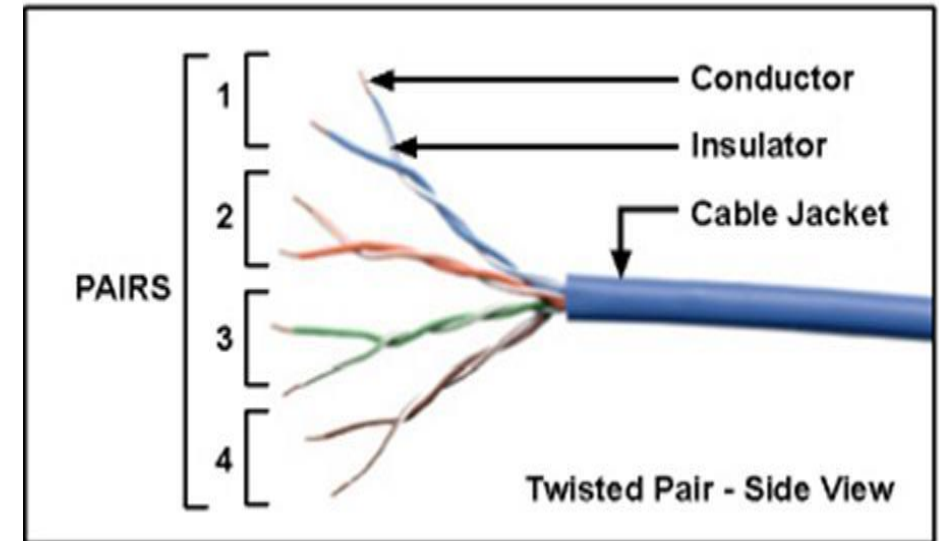


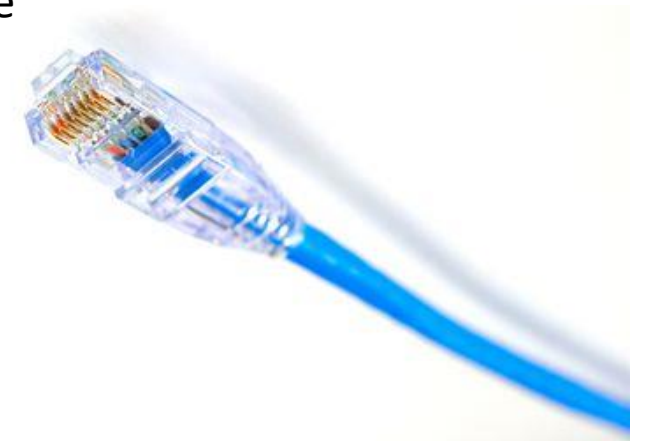
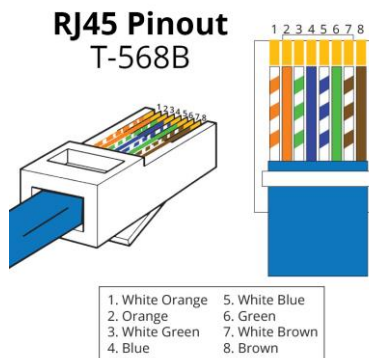
Crimping LAN/Ethernet cables



Cable/Network Crimping tool



Network cable



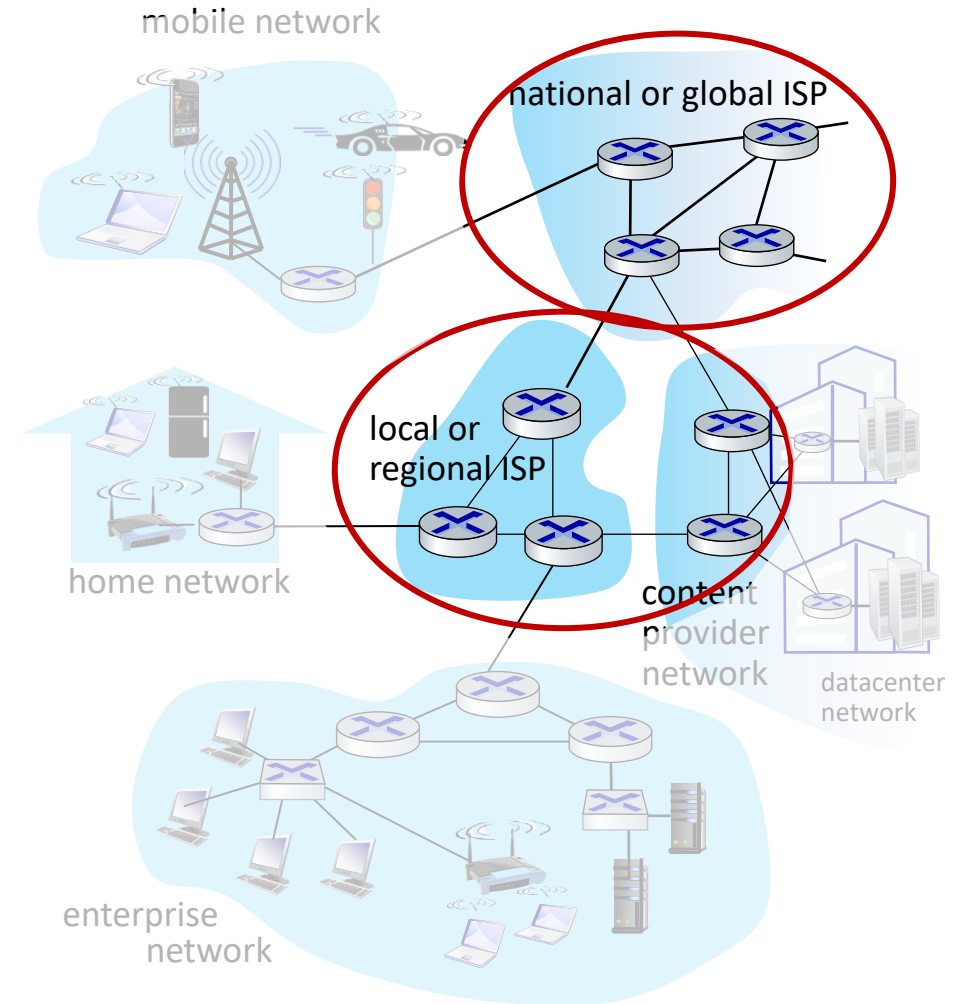
Chapter 1: roadmap

- What *is* the Internet?
- What *is* a protocol?
- Network edge: hosts, access network, physical media, Internet structure
- **Network core:** packet/circuit switching
- Performance: loss, delay, throughput
- Security
- Protocol layers, service models
- History

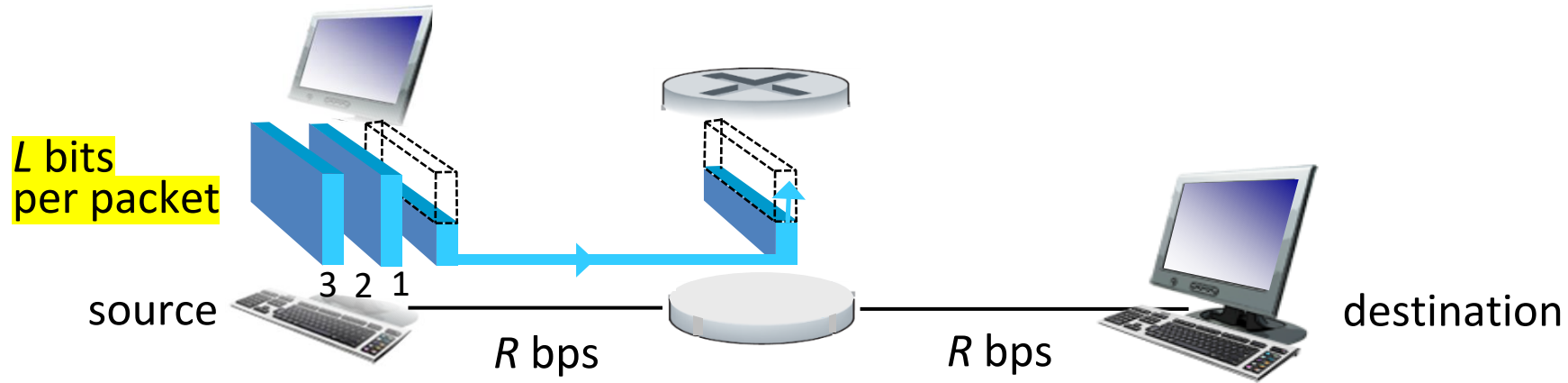


The network core

- mesh of interconnected routers
- **packet-switching**: hosts break application-layer messages into **packets**
 - forward **packets** from **one** router to the **next**, across links on path from source to destination
 - each packet **transmitted** at **full** link **capacity**



Packet-switching: store-and-forward

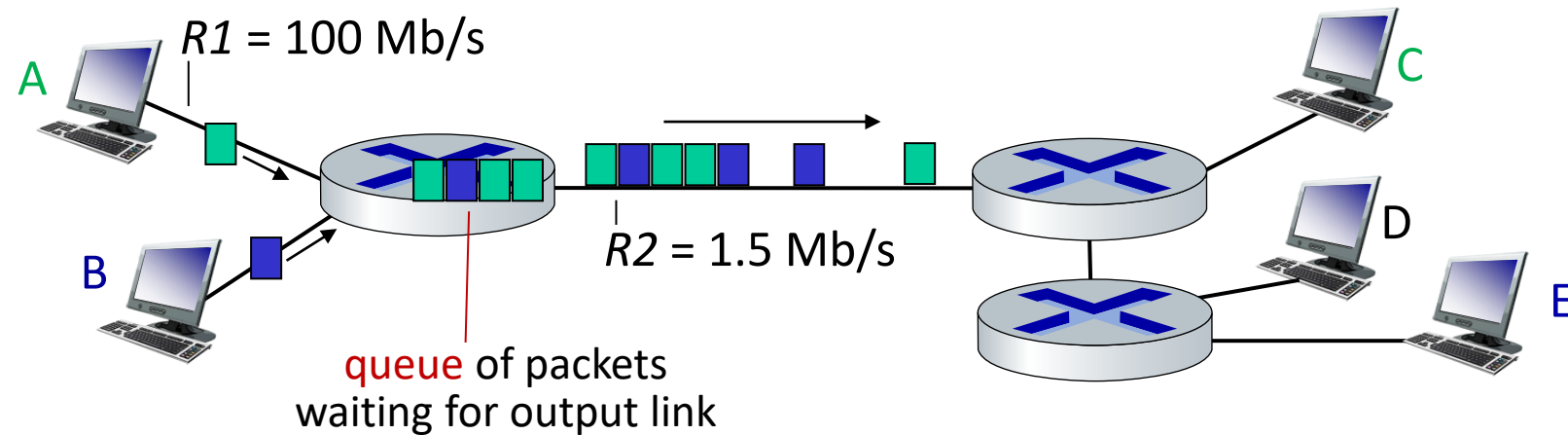


- **Transmission delay:** takes L/R seconds to transmit (push out) L -bit packet into link at R bps
- **Store and forward:** entire packet must arrive at router before it can be transmitted on next link
- **End-end delay:** $2L/R$ (above), assuming zero propagation delay (more on delay shortly)

One-hop numerical example:

- $L = 10$ Kbits
- $R = 100$ Mbps
- one-hop transmission delay = 0.1 msec

Packet-switching: queueing delay, loss



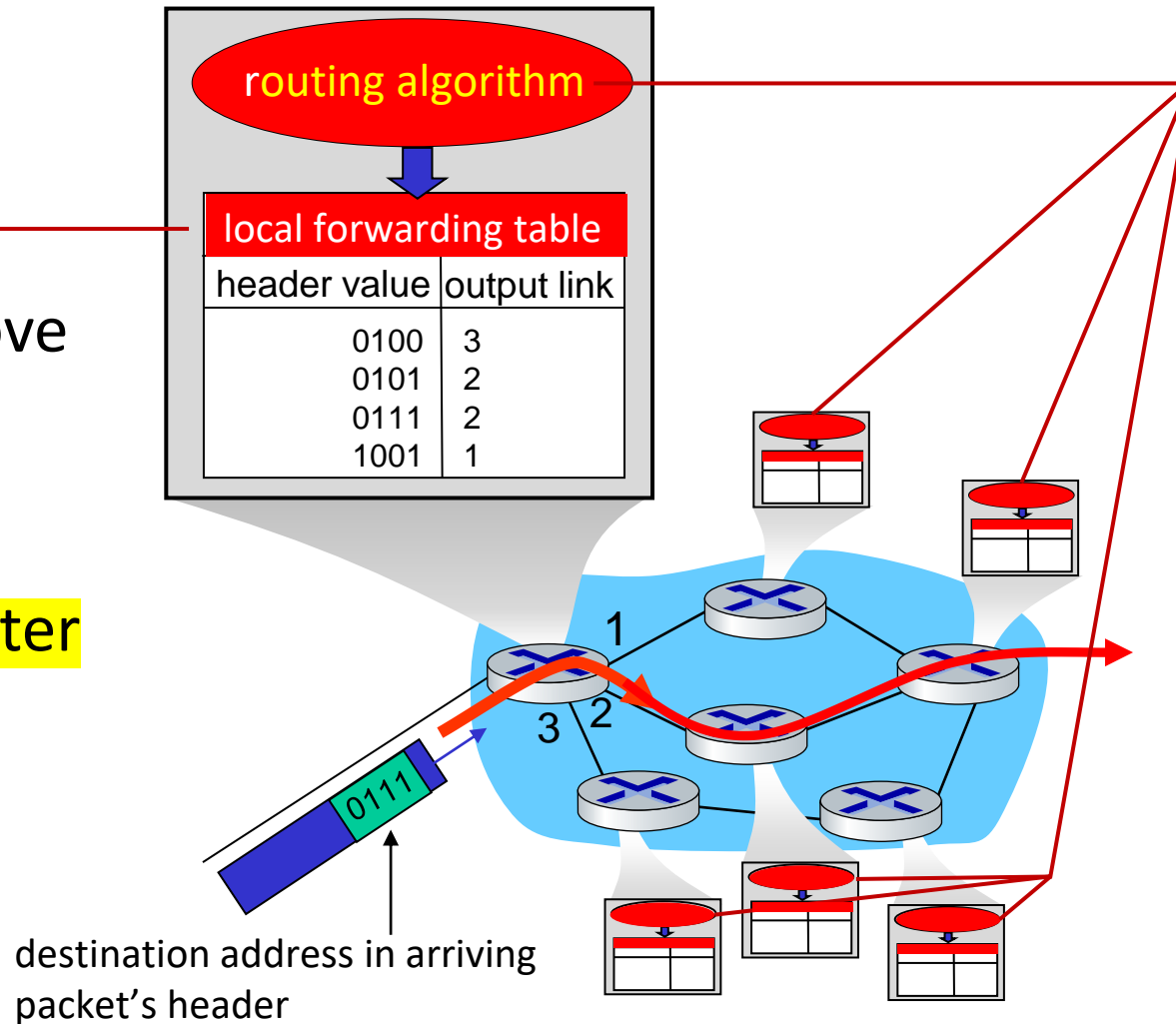
Packet queuing and loss: if arrival rate (in bps) to link exceeds transmission rate (bps) of link for a period of time:

- packets will queue, waiting to be transmitted on output link
- packets can be dropped (lost) if memory (buffer) in router fills up

Two key network-core functions

Forwarding:

- **local action:** move arriving packets from router's input link to appropriate router output link



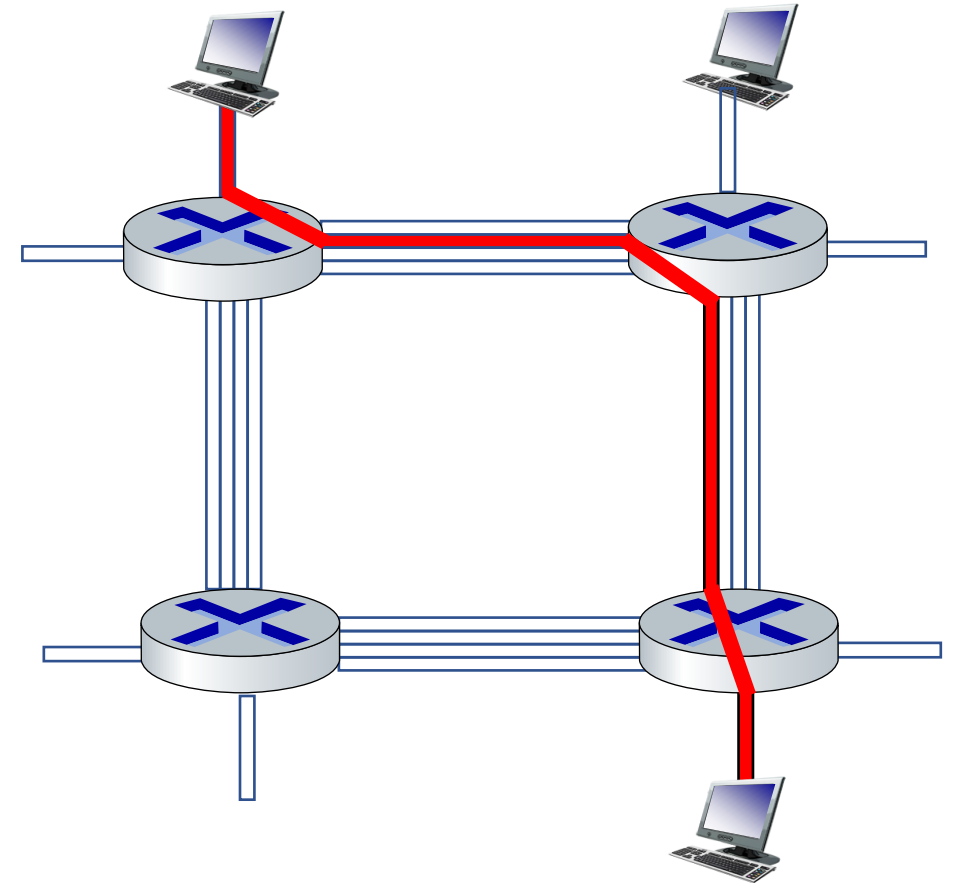
Routing:

- **global action:** determine source-destination paths taken by packets
- routing algorithms

Alternative to packet switching: circuit switching

end-end resources allocated to, reserved for “call” between source and destination

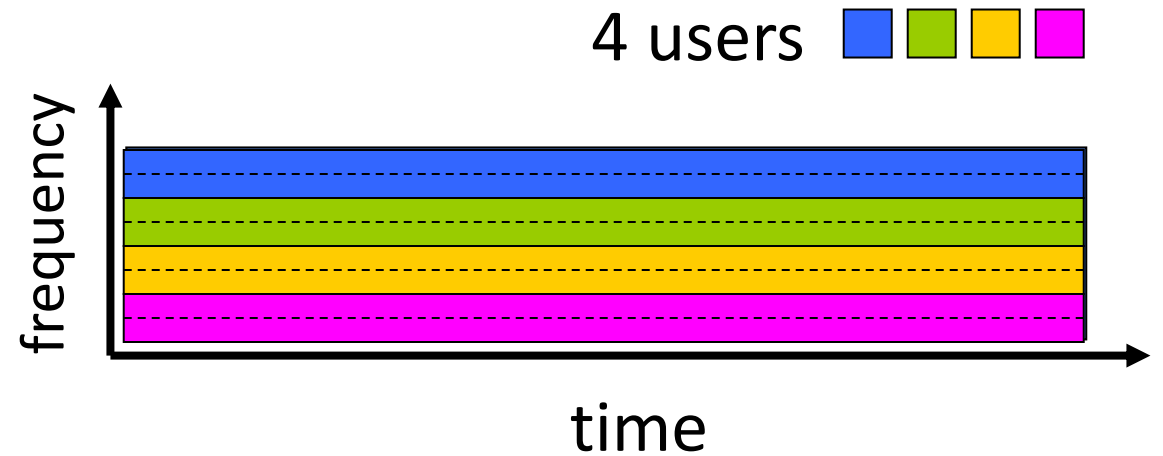
- in diagram, each link has four circuits.
 - call gets 2nd circuit in top link and 1st circuit in right link.
- dedicated resources: no sharing
 - circuit-like (guaranteed) performance
- circuit segment idle if not used by call (no sharing)
- commonly used in traditional telephone networks



Circuit switching: FDM and TDM

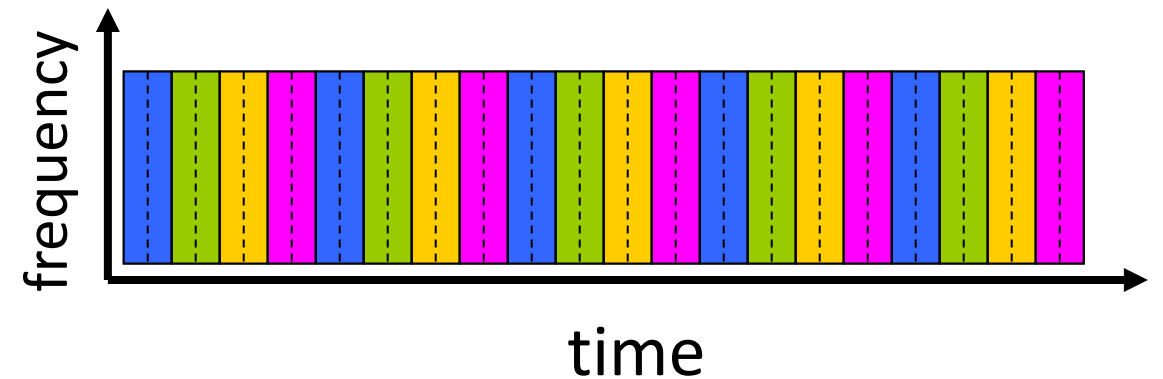
Frequency Division Multiplexing (FDM)

- optical, electromagnetic frequencies divided into (narrow) frequency bands
- each call allocated its own band, can transmit at max rate of that narrow band



Time Division Multiplexing (TDM)

- time divided into slots
- each call allocated periodic slot(s), can transmit at maximum rate of (wider) frequency band, but only during its time slot(s)

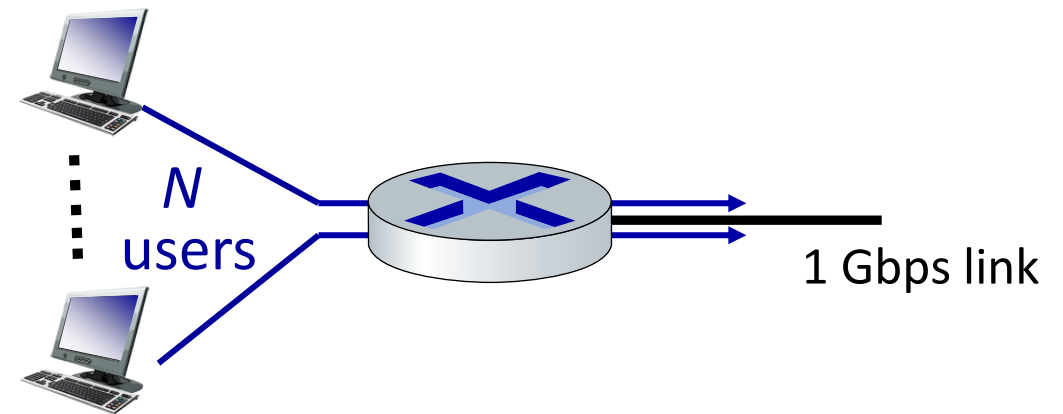


Packet switching versus circuit switching

packet switching allows more users to use network!

Example:

- 1 Gb/s link
- each user:
 - 100 Mb/s when “active”
 - active 10% of time
- *circuit-switching*: 10 users
- *packet switching*: with 35 users, probability > 10 active at same time is less than .0004 *



Q: how did we get value 0.0004?

Q: what happens if > 35 users ?

* Check out the online interactive exercises for more examples: http://gaia.cs.umass.edu/kurose_ross/interactive

- $N = 35$ users
- $P(\# \text{ Active Users} > 10) = 1 - P(\# \text{ Active Users} = 10) - P(\# \text{ Active Users} = 9) - P(\# \text{ Active Users} = 8) \dots P(\# \text{ Active Users} = 1)$
- $P(\# \text{ Active Users} = 10) = C(35, 10) * 0.1^{10} * 0.9^{25}$
- Note: Binomial Distribution

Probability of k out of n ways:

$$P(k \text{ out of } n) = \frac{n!}{k!(n-k)!} p^k (1-p)^{(n-k)}$$

The General Binomial Probability Formula

Packet switching versus circuit switching

Is packet switching a “winner”?

- great for “bursty” data – sometimes has data to send, but at other times not
 - resource sharing
 - simpler, no call setup
- excessive congestion possible: packet delay and loss due to buffer overflow
 - protocols needed for reliable data transfer, congestion control
- Q: How to provide circuit-like behavior?
 - bandwidth guarantees traditionally used for audio/video applications