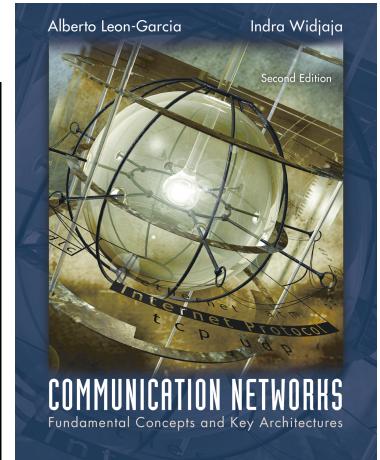
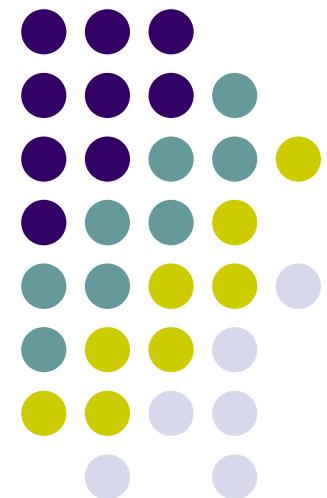


Chapter 5

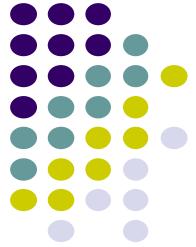
Framing in Data Link Layer



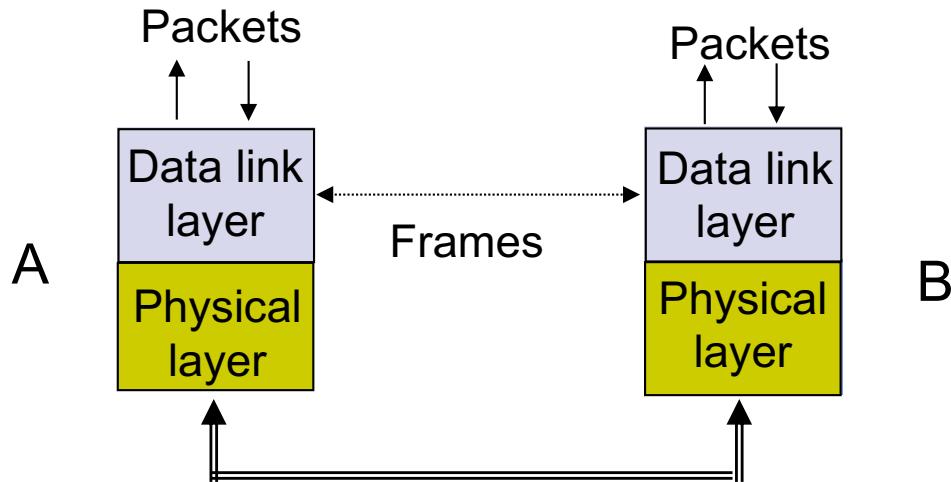
Framing
pp 325-329



Point-to-Point Protocol
pp 329-333



Data Link Protocols



Data Links Services

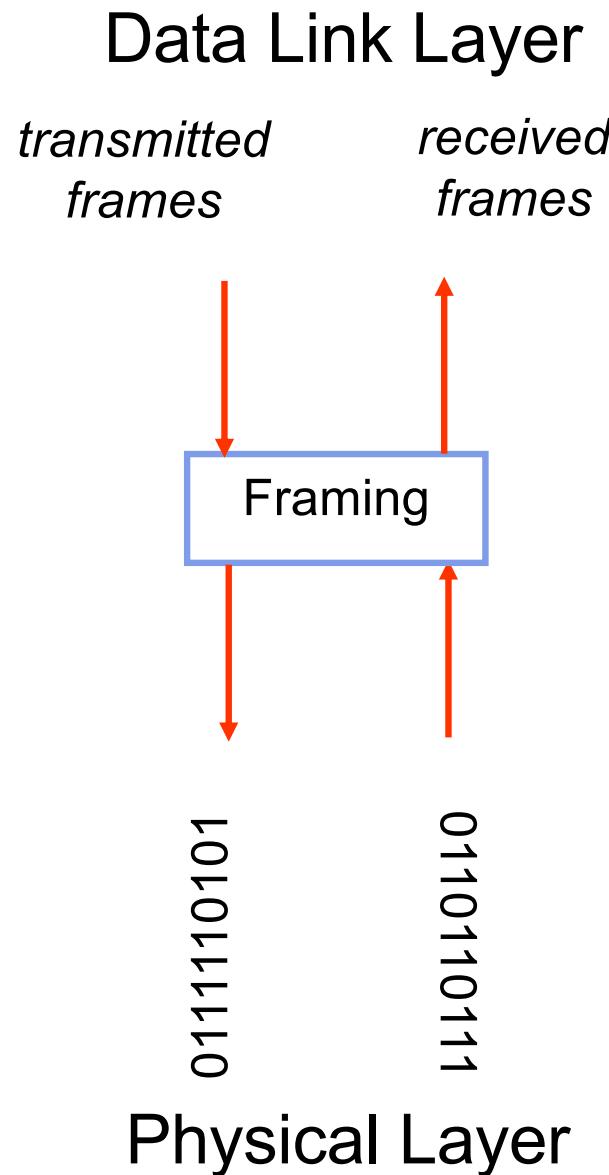
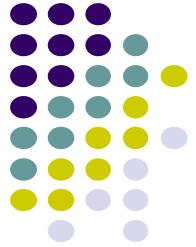
- Framing
- Error control
- Flow control
- Multiplexing
- Link Maintenance
- Security: Authentication & Encryption

- Directly connected, wire-like
- Losses & errors, but no out-of-sequence frames
- Applications: Direct Links; LANs; Connections across Wide-Area Networks

Examples

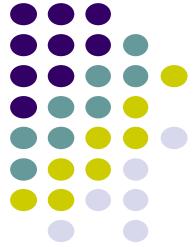
- PPP
- HDLC
- Ethernet LAN
- IEEE 802.11 (Wi Fi) LAN

Framing

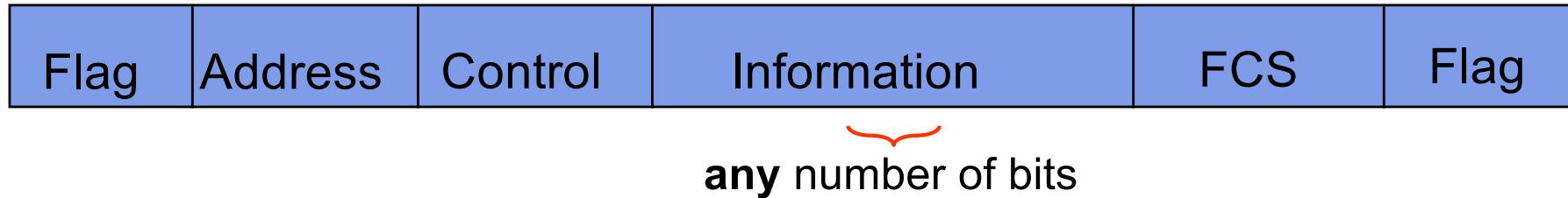


- Mapping stream of physical layer bits into frames
- Mapping frames into bit stream
- Frame boundaries can be determined using:
 - Character Counts
 - Control Characters
 - Flags
 - CRC Checks

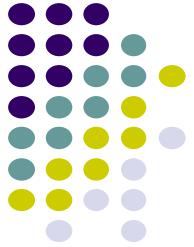
Framing & Bit Stuffing in High-Level Data Link Control Protocol



HDLC frame



- Frame delineated by flag character
- HDLC uses *bit stuffing* to prevent occurrence of flag 01111110 inside the frame
- Transmitter inserts **extra 0** after each consecutive five 1s *inside* the frame
- Receiver checks for five consecutive 1s
 - if next bit = 0, it is removed
 - if next two bits are 10, then flag is detected
 - If next two bits are 11, then frame has errors



Ex: Bit stuffing & de-stuffing

(a)

Data to be sent

0110111111111100

After stuffing and framing

01111110011011111011111000001111110

(b)

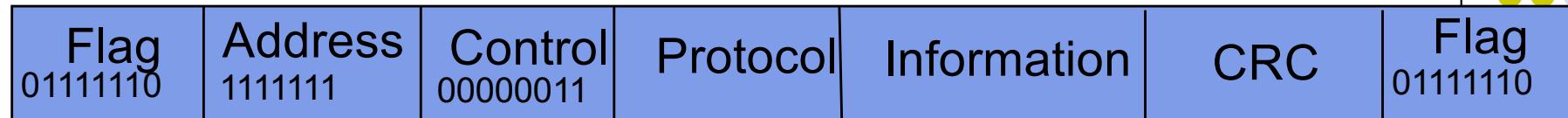
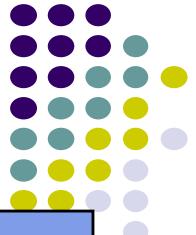
Data received

0111110000111011111011111011001111110

After destuffing and deframing

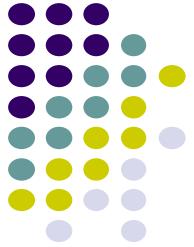
000111011111-11111-110

Point-to-Point Protocol (PPP) Frame



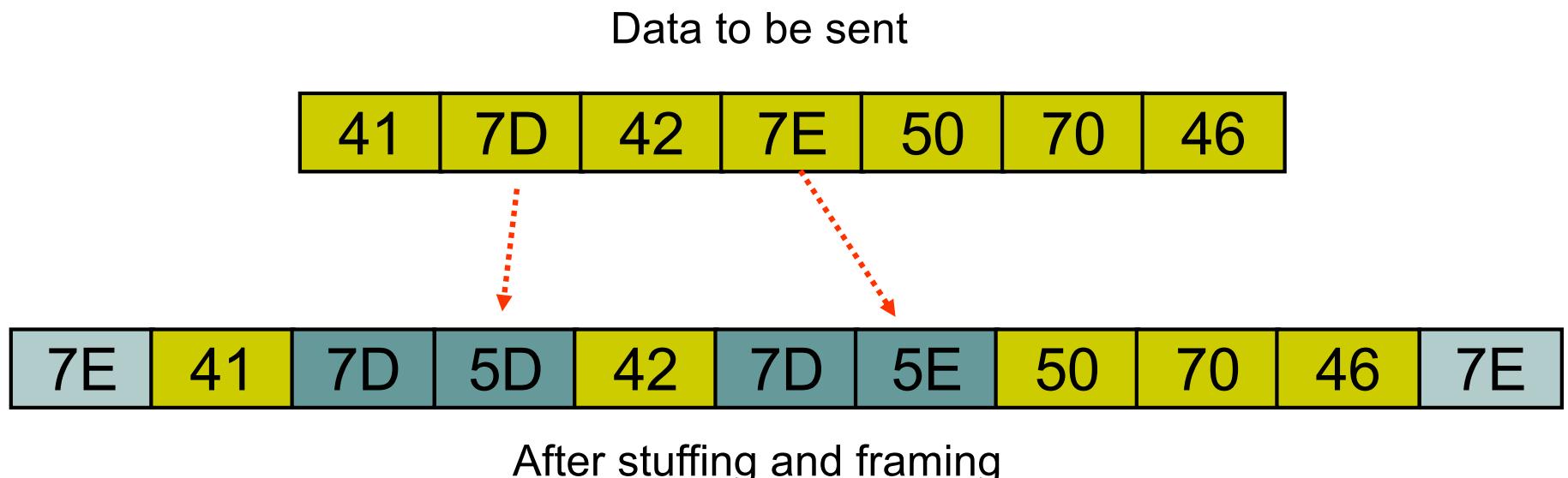
All stations are to accept the frame Unnumbered frame Specifies what Layer-3 packet is contained in the payload, e.g., LCP, NCP, IP.

- Data link for point-to-point connections
- PPP uses similar frame structure as HDLC, except
 - Protocol type field
 - Payload contains an *integer* number of **bytes**
- PPP uses the same flag, but uses *byte stuffing*
- Problems with PPP byte stuffing
 - Size of frame varies unpredictably due to byte insertion
 - Malicious users can inflate bandwidth by inserting 7D & 7E

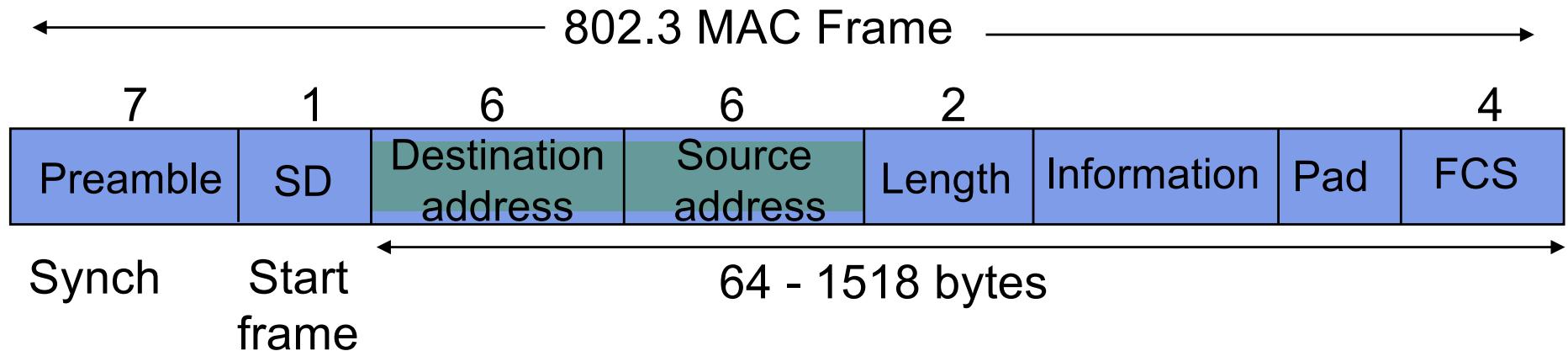
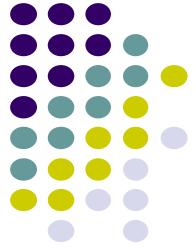


Byte-Stuffing in PPP

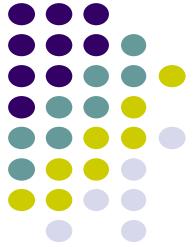
- PPP is character-oriented version of HDLC
- Flag is 7E (01111110)
- Control escape 7D (01111101)
- Any occurrence of flag or control escape inside of frame is replaced with 7D followed by original octet XORed with 20 (00100000)



IEEE 802.3 (Ethernet) MAC Frame

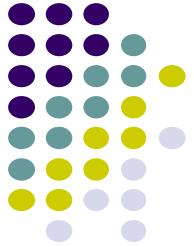


- Every frame transmission begins “from scratch”
- Preamble helps receivers synchronize their clocks to transmitter clock
 - 7 bytes of 10101010 generate a square wave
 - Start frame byte changes to 1010101**1**
 - Receivers look for change in 10 pattern



PPP: Point-to-Point Protocol

- Data link protocol for point-to-point lines in Internet
 - Router-router; dial-up to router
- 1. Provides *Framing and Error Detection*
 - Character-oriented HDLC-like frame structure
- 2. *Link Control Protocol*
 - Bringing up, testing, bringing down lines; negotiating options
 - **Authentication:** key capability in ISP access
- 3. A family of *Network Control Protocols* specific to different network layer protocols
 - IP, OSI network layer, IPX (Novell), Appletalk

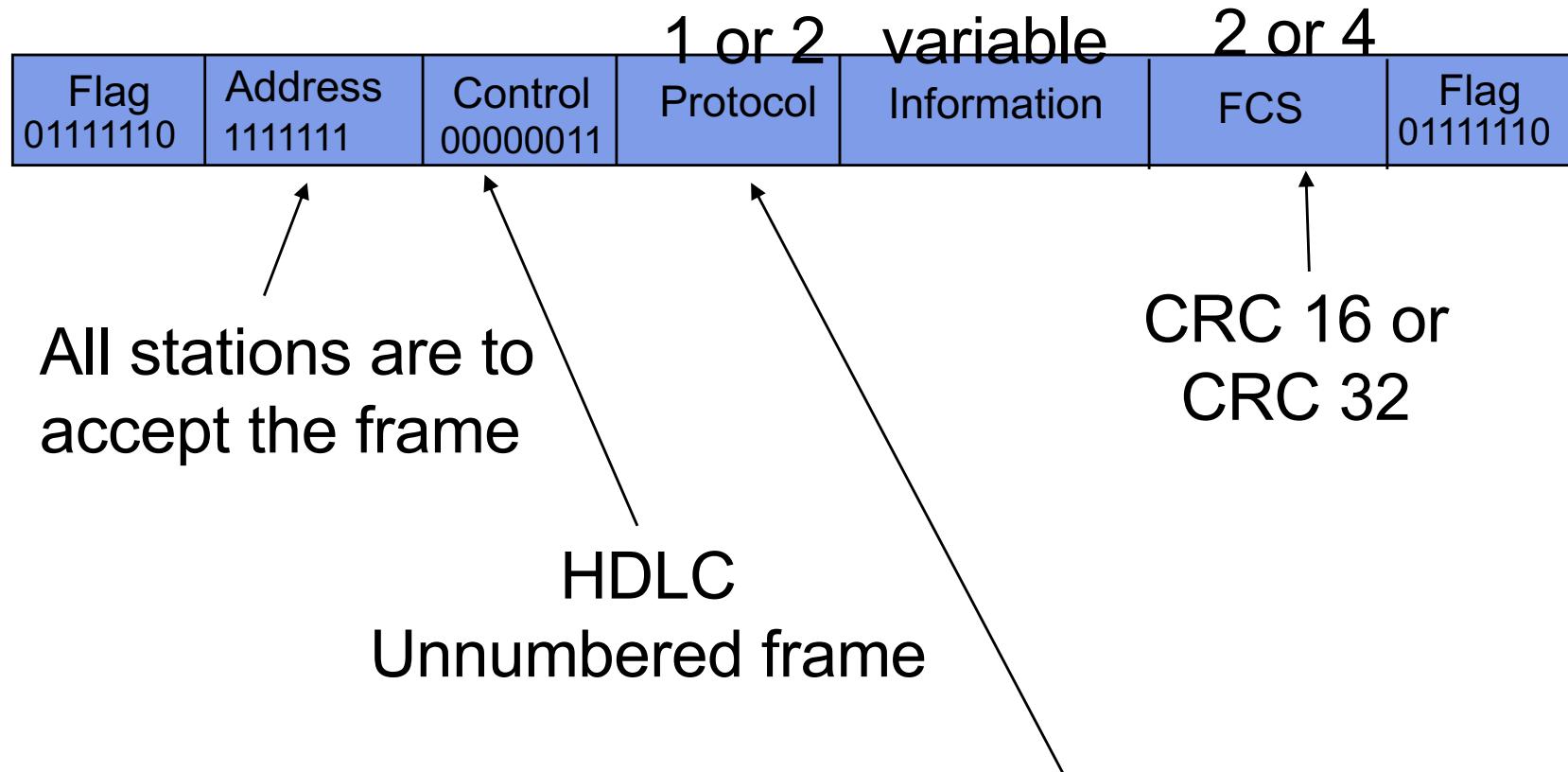
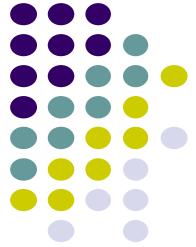


PPP Applications

PPP used in many point-to-point applications

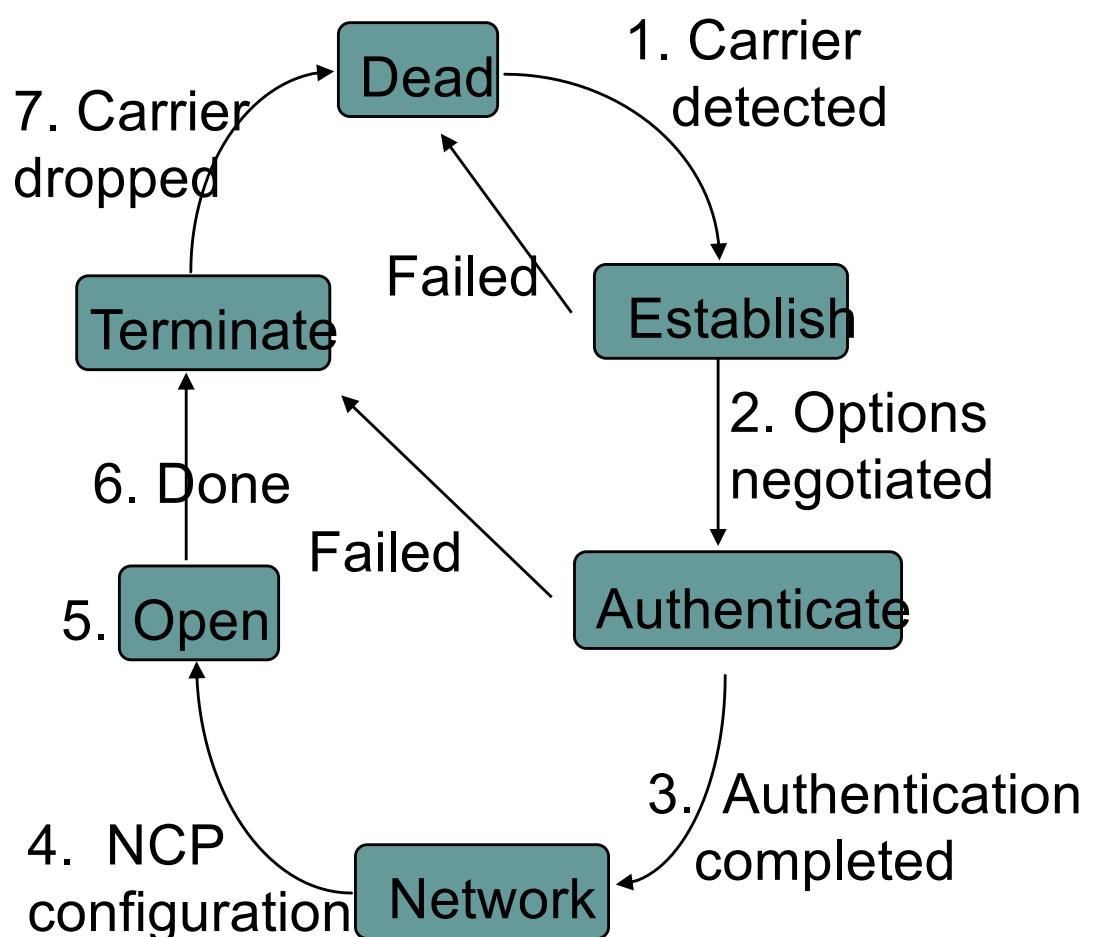
- Telephone Modem Links 30 kbps
- Packet over SONET 600 Mbps to 10 Gbps
 - Framing in SONET optical circuits
 - IP→PPP→SONET
- PPP also used over shared links such as Ethernet to provide LCP, NCP, authentication
 - PPP over Ethernet (RFC 2516)
 - Used over DSL

PPP Frame Format



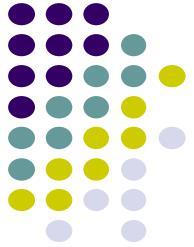
- PPP can support multiple network protocols simultaneously
- Protocol specifies packet type contained in the payload
 - e.g. LCP, NCP, IP,...

PPP Phases



Home PC to Internet Service Provider

1. PC calls router via modem
2. PC and router exchange LCP packets to negotiate PPP parameters
3. Check on identities
4. NCP packets exchanged to configure the network layer, e.g. TCP/IP (requires IP address assignment)
5. Data transport, e.g. send/receive IP packets
6. NCP used to tear down the network layer connection (free up IP address); LCP used to shut down data link layer connection
7. Modem hangs up



PPP Authentication

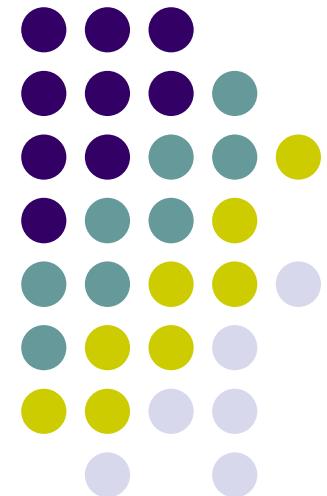
- Password Authentication Protocol (PAP)
 - Initiator must send ID & password
 - Authenticator replies with authentication success/fail
 - After several attempts, LCP closes link
 - Transmitted unencrypted, susceptible to eavesdropping
- Challenge-Handshake Authentication Protocol (CHAP)
 - Initiator & authenticator share a secret key
 - Authenticator sends a challenge (random # & ID)
 - Initiator computes cryptographic checksum of random # & ID using the shared secret key
 - Authenticator also calculates cryptographic checksum & compares to response
 - Authenticator can reissue challenge during session

Statistical Multiplexing in Routers & Switches

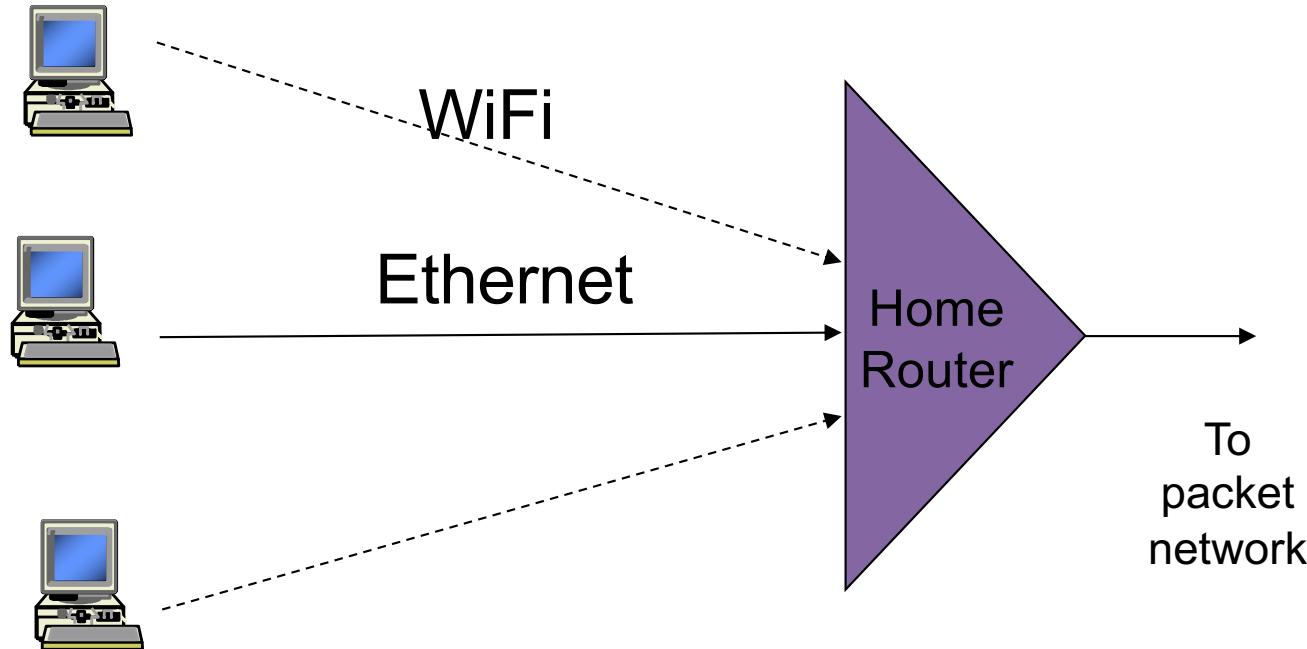
Multiplexing in Packet Networks

Delay & Loss Models

Chapter 5, p 313-322

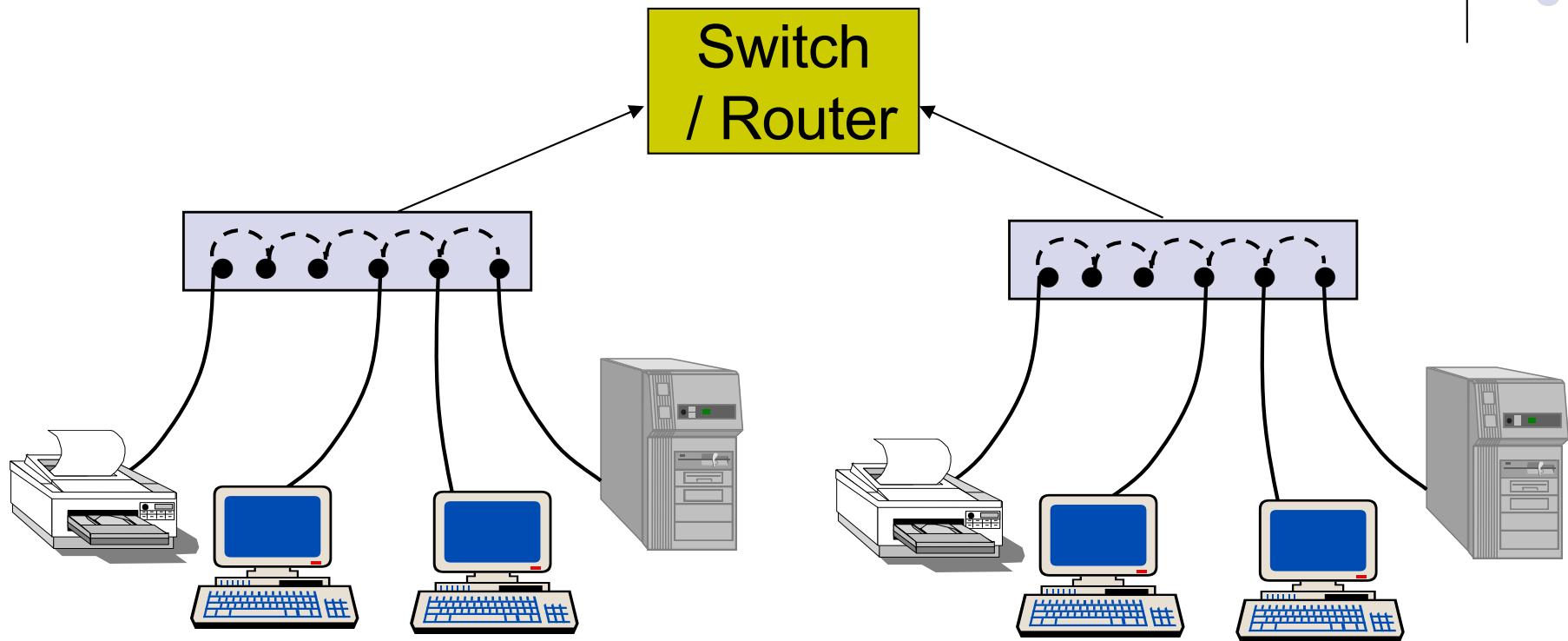
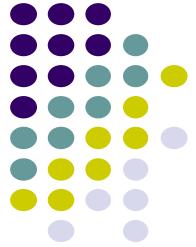


Home LANs



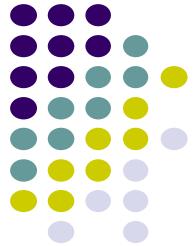
- **Home Router**
 - Local Area Network: Ethernet (GE) & WiFi (802.11a/b/g/n)
 - Private IP addresses in Home (192.168.0.x) using Network Address Translation (NAT)
 - 1 public IP address from ISP issued using DHCP
 - Packets/frames muxed at “home router” inbound to network

LAN Concentration in Campus

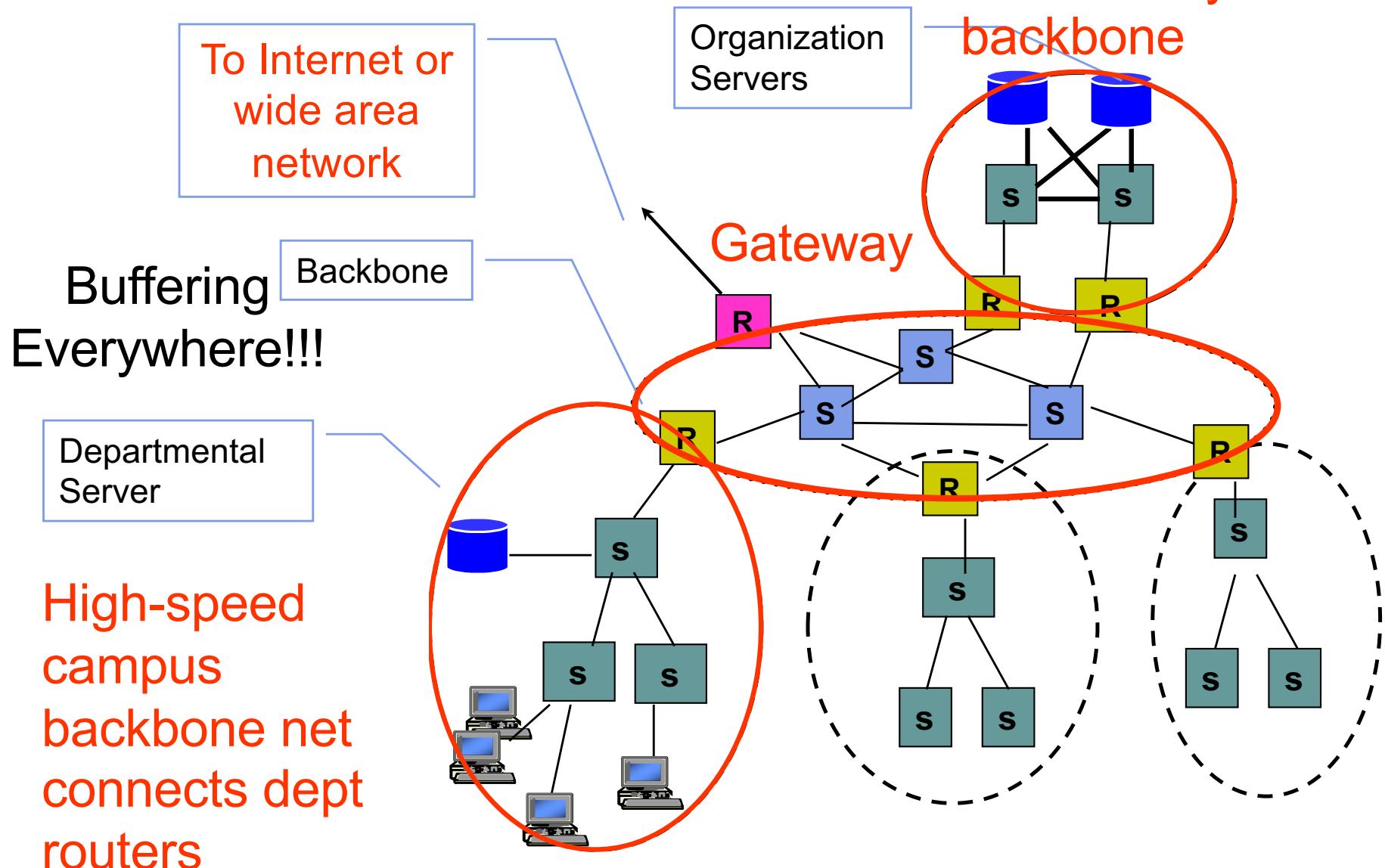


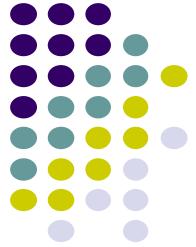
- LAN hubs/switches in access network aggregate packet/frame streams into network
- Frames and packets are buffered at switches & routers

Campus Network



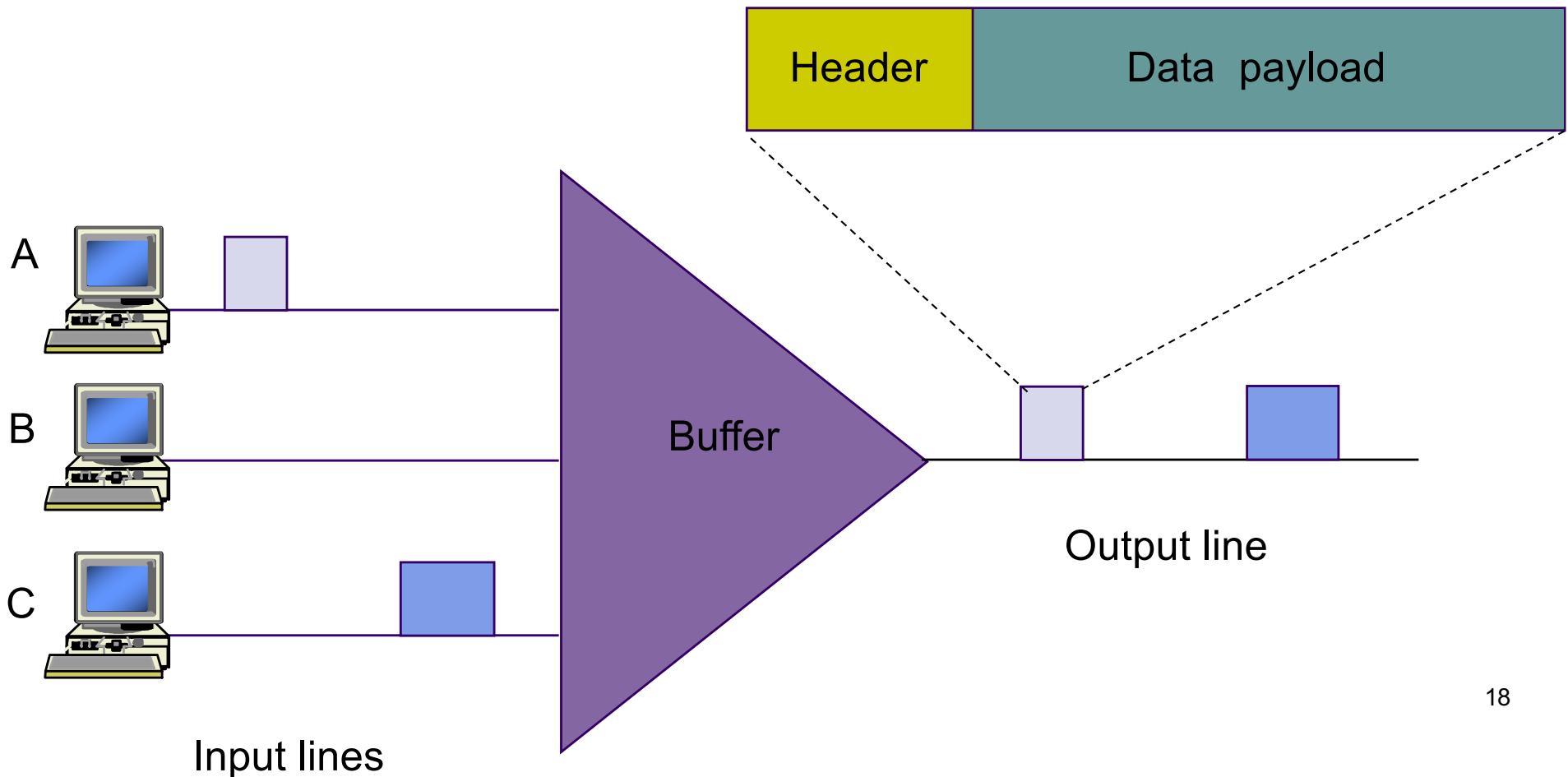
Servers have redundant connectivity to backbone



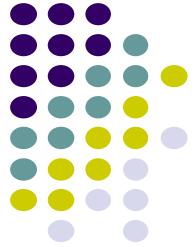


Statistical Multiplexing

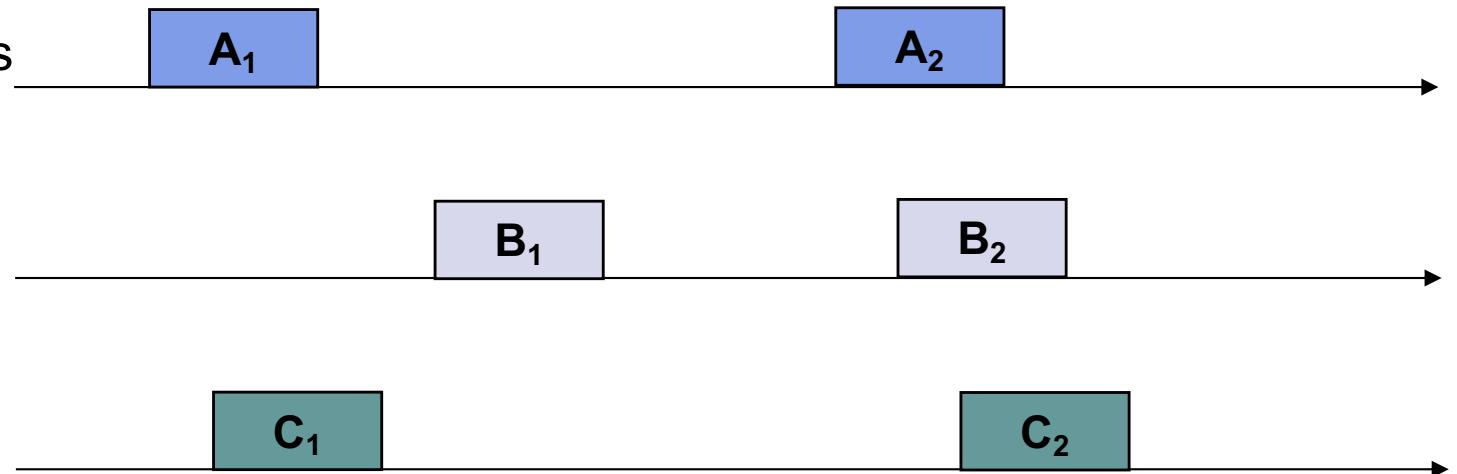
- Multiplexing concentrates bursty packet/frame traffic on shared line
- Greater efficiency and lower cost



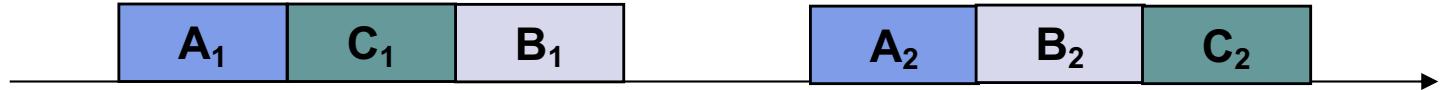
Tradeoff Delay for Efficiency



(a) Dedicated lines

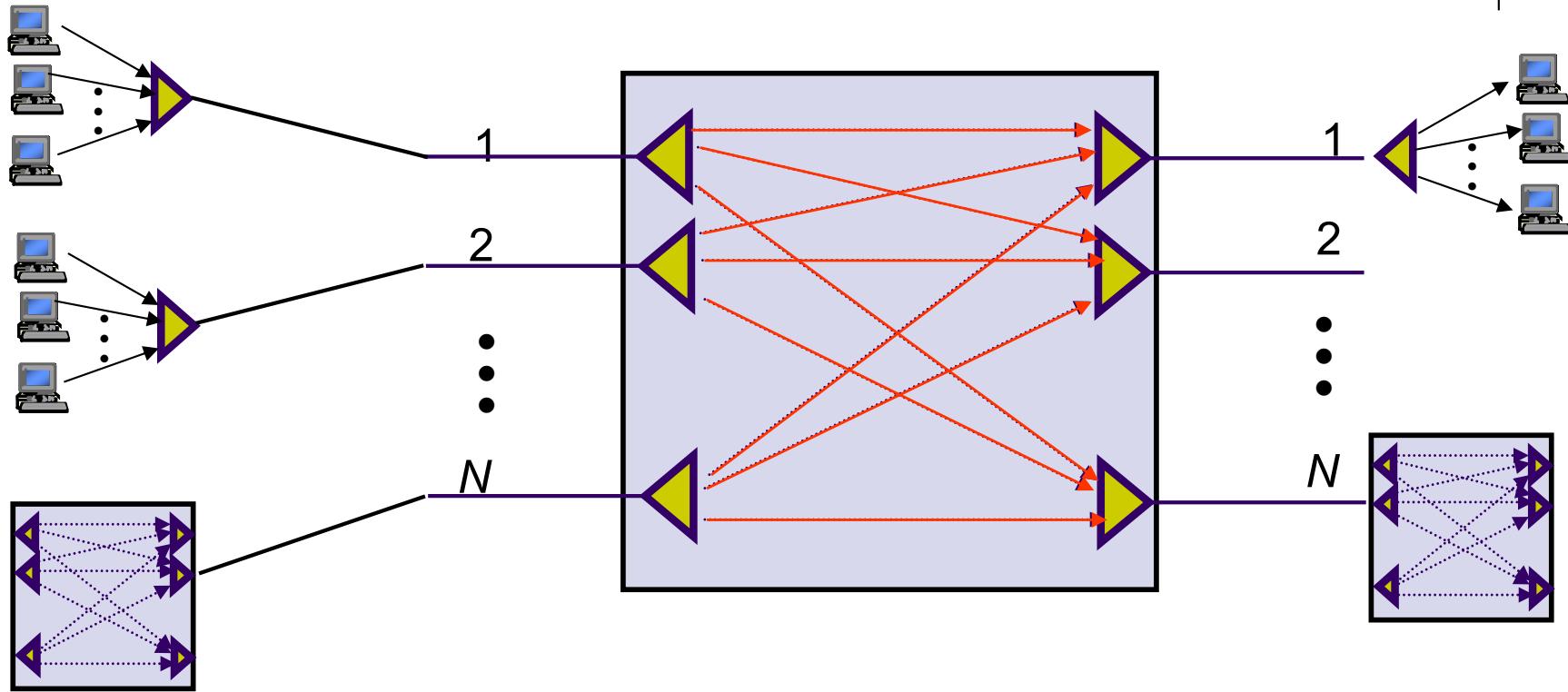
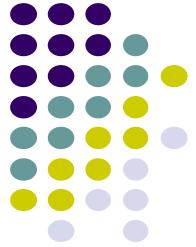


(b) Shared lines

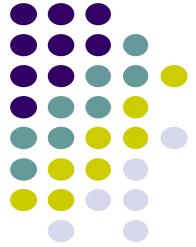


- Dedicated lines involve no waiting, but lines are used inefficiently when user traffic is bursty
- Shared lines concentrate packets into shared line; packets buffered (delayed) when line is not immediately available

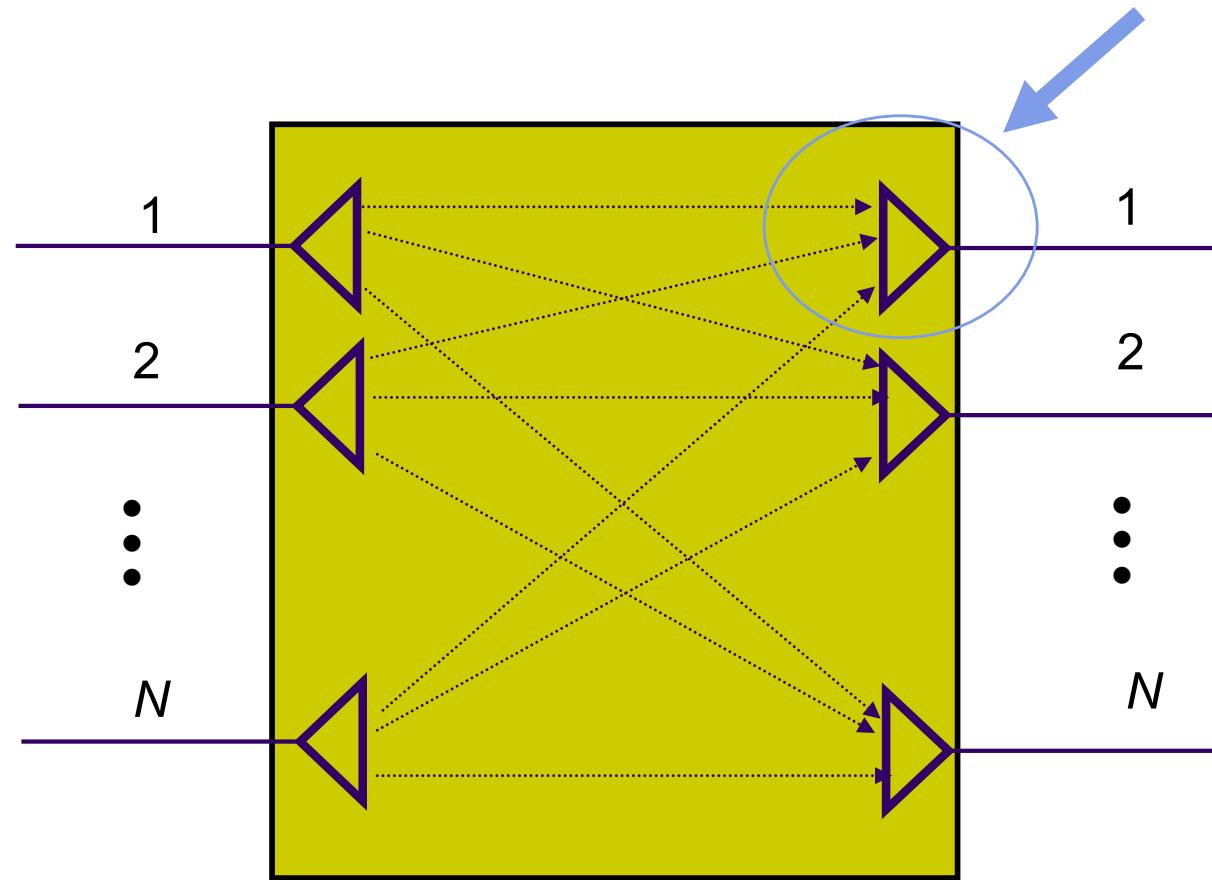
Switch: Where Traffic Flows Meet



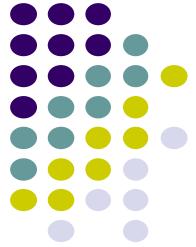
- Inputs carry multiplexed flows from access muxs & other switches
- Flows demultiplexed at input, routed/forwarded to output ports
- Packets buffered, prioritized, and multiplexed on output (and possibly on input) lines
- End-to-End **delay** is sum of transmission & waiting times
- End-to-End **packet loss** is fraction of packets lost along path



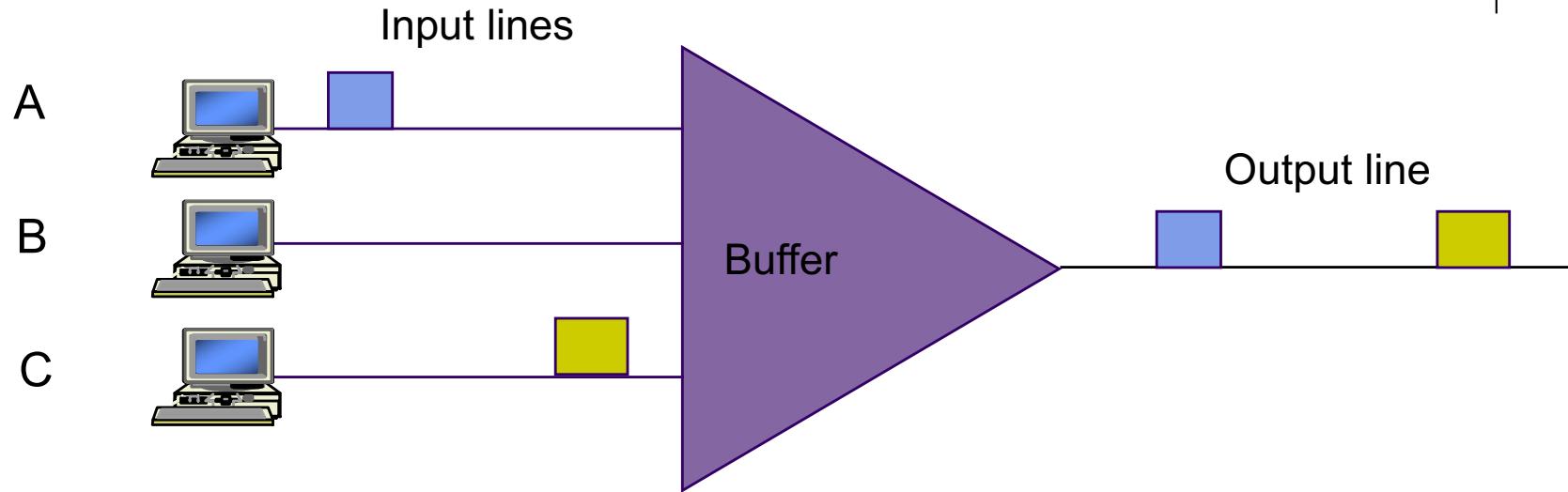
Multiplexers Built into Packet Switches



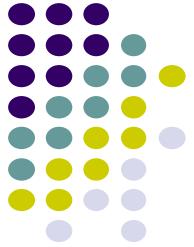
- Packets/frames forwarded to an output buffer prior to transmission from switch
- Multiplexing occurs in these buffers



Multiplexer Modeling



- Arrivals: What is the packet interarrival pattern?
- Service Time: How long are the packets?
- Service Discipline: What is order of transmission?
- Buffer Discipline: If buffer is full, which packet is dropped?
- Performance Measures:
- *Delay Distribution; Packet Loss Probability; Line Utilization*

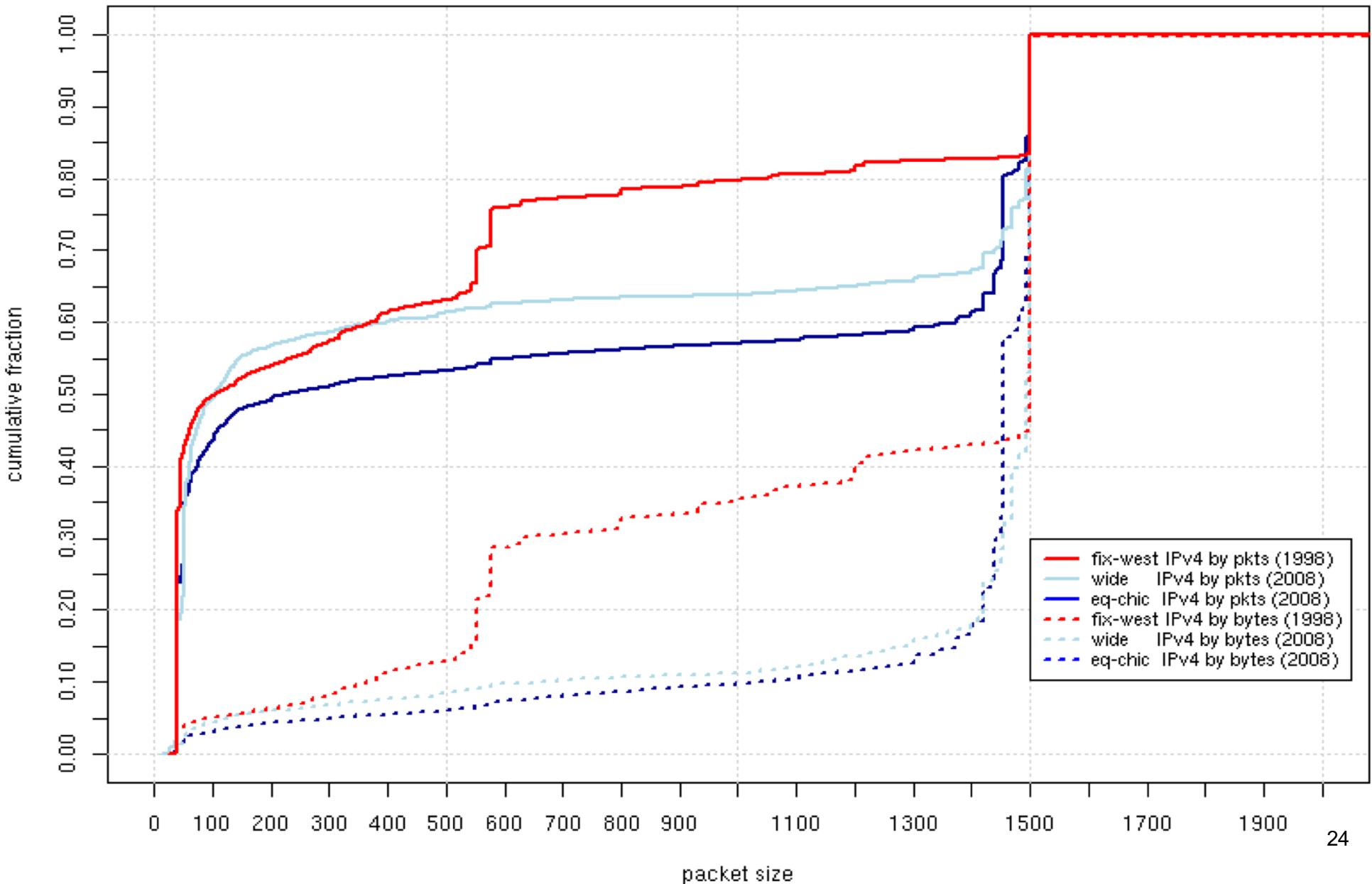


Packet Lengths & Service Times

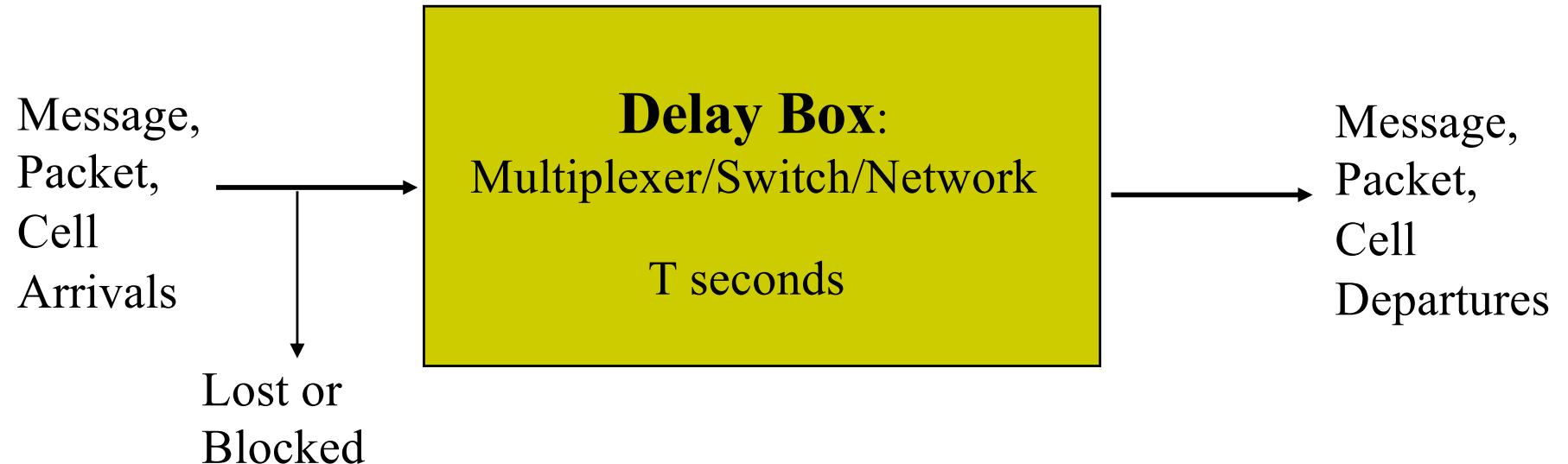
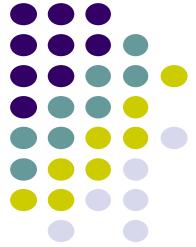
- R bits per second transmission rate
- L = # bits in a packet
- $X = L/R$ = time to transmit (“service”) a packet
- Packet lengths are usually variable
 - Distribution of lengths → Dist. of service times
 - Common models:
 - Constant packet length (all the same)
 - Exponential distribution
 - Internet Measured Distributions for packet length
 - See next chart



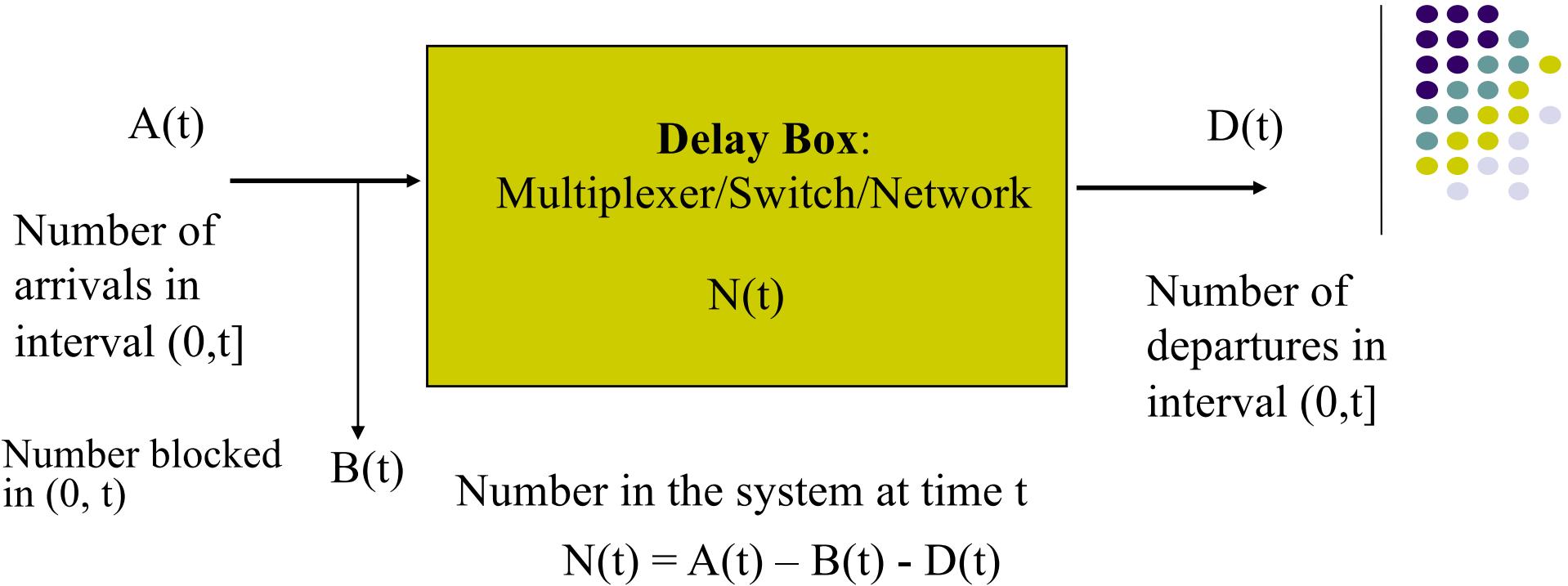
Packet Size: 1998 vs 2008



Delay Analysis in Networks



- Mean, variance, and distribution of *time spent in the system*
- Mean, variance, and distribution of *number in the system*
- *Fraction* of arrivals that are *lost or blocked*
- *Throughput* = average number of messages/sec through system

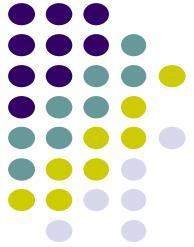


$$\text{Arrival Rate} = \lim_{t \rightarrow \infty} \frac{1}{t} A(t)$$

$$\text{Throughput} = \lim_{t \rightarrow \infty} \frac{1}{t} D(t)$$

$$\text{Average Number in the System} = \lim_{t \rightarrow \infty} \frac{1}{t} \int_0^t N(t') dt'$$

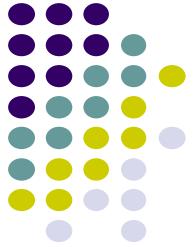
$$\text{Packet Loss Rate} = \lim_{t \rightarrow \infty} \frac{B(t)}{A(t)}$$



Little's Formula

$$E[N] = \lambda_{net} E[T]$$

- λ_{net} is the net arrival rate into system: $\lambda_{net} = \lambda(1 - P_b)$
- Valid for general “delay box”
- Intuition (assuming FIFO queue):
 - When a typical customer arrives, it finds approximately $E[N]$ customers in system
 - When it leaves system (after approximately $E[T]$ delay), $\lambda_{net}E[T]$ other customers should have arrived
 - In steady state, the number of customers left behind should equal the number of customers found on arrival

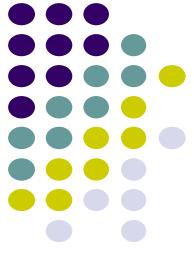


Example

- Suppose a multiplexer has an average occupancy of 100 packets. Suppose packets arrive to the mux at a rate of 2 per microsecond. What is the average packet delay in the multiplexer?

$$100 = 2(10^{-6})^{-1} E[T]$$

$$E[T] = 100/2(10^{-6})^{-1} = 50 \text{ microseconds}$$



Poisson Arrival Process

- Interarrival times α_i are independent random variables with identical exponential distribution:

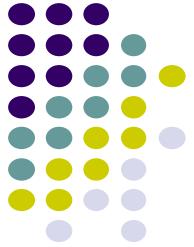
$$P[\alpha_i > x] = e^{-\lambda x} \quad , x > 0$$

- Mean time between events:

$$E[\alpha_i] = \frac{1}{\lambda}$$

- Long-term arrival rate:

$$\text{Arrival Rate} = \frac{1}{E[\alpha_i]} = \lambda \quad \text{events/second}$$

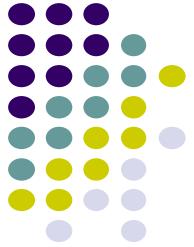


- Memoryless Property of Exponential random variable:

$$P[\alpha_i > x_0 + x \mid \alpha_i > x_0] = e^{-\lambda x}, x > 0$$

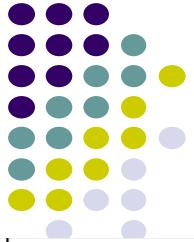
- For the Poisson process, $A(t)$ has a Poisson distribution with mean λt

$$P[A(t) = k] = \frac{(\lambda t)^k}{k!} e^{-\lambda t} \quad k = 0, 1, 2, \dots$$

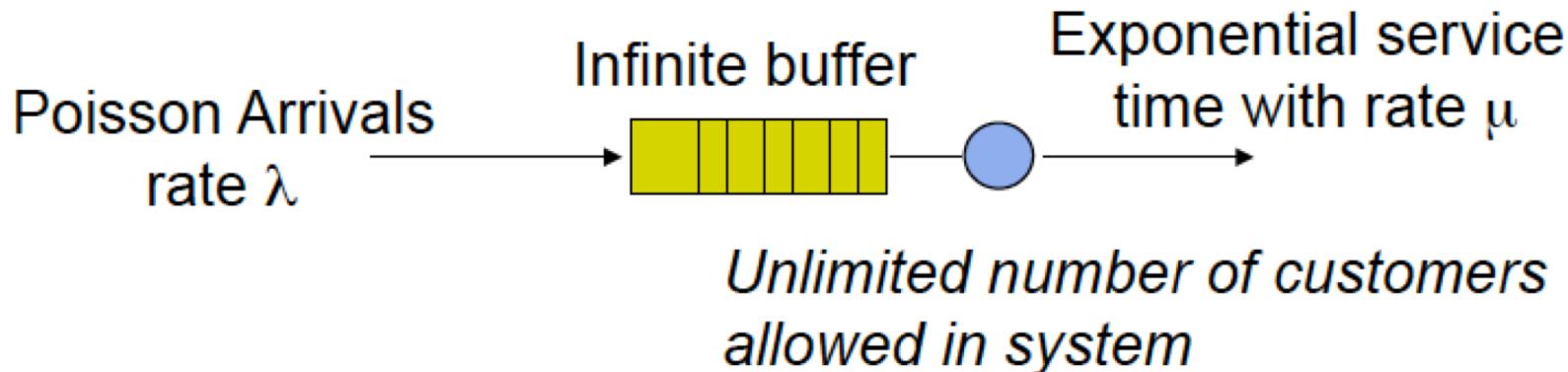


Examples

- M/M/1: Simplest model for packet multiplexers
 - Large (infinite) buffer
- M/M/1/K: Multiplexer with finite buffer
- M/G/1: Multiplexer with general service time,
e.g. mixture of constants
- M/D/1: Multiplexer with constant service time
- M/M/c: Multiplexer with c transmission lines



M/M/1 Queue



- $P_b=0$ since customers are never blocked
- Average Time in system $E[T] = E[W] + E[X]$
- When $\lambda \ll \mu$, customers arrive infrequently and delays are low
- As λ approaches μ , customers start bunching up and average delays increase
- When $\lambda > \mu$, customers arrive faster than they can be processed and queue grows without bound (unstable)

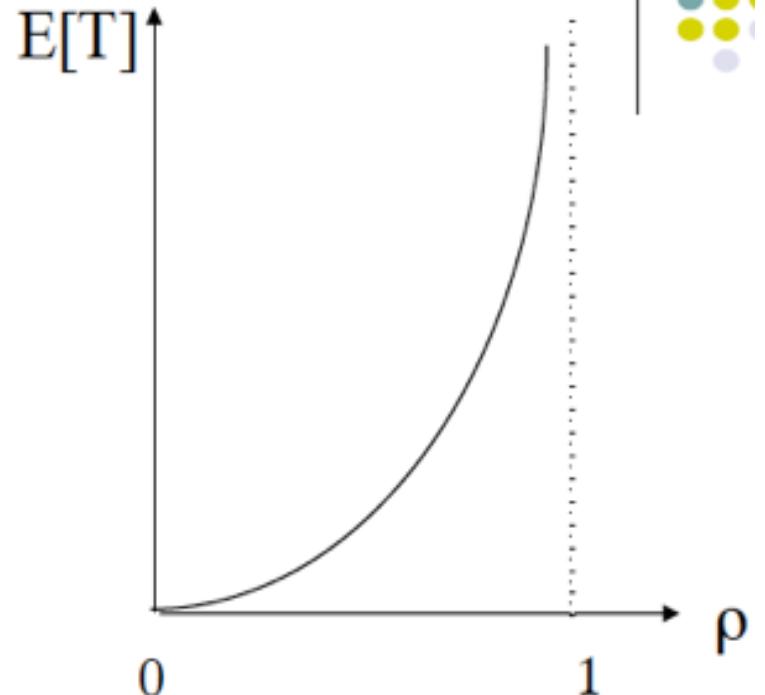
M/M/1 Queue Results

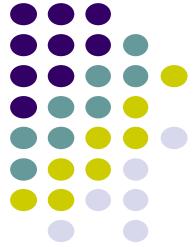
$$P[N = n] = (1 - \rho)\rho^n \quad n = 0, 1, 2, \dots$$

$$E[N] = \sum_{n=0}^{\infty} n(1 - \rho)\rho^n = \frac{\rho}{1 - \rho}$$

$$E[T] = \frac{1}{\lambda} E[N] = \frac{1/\mu}{1 - \rho}$$

$$E[W] = E[T] - E[X] = \frac{1}{\mu} \frac{\rho}{1 - \rho}$$





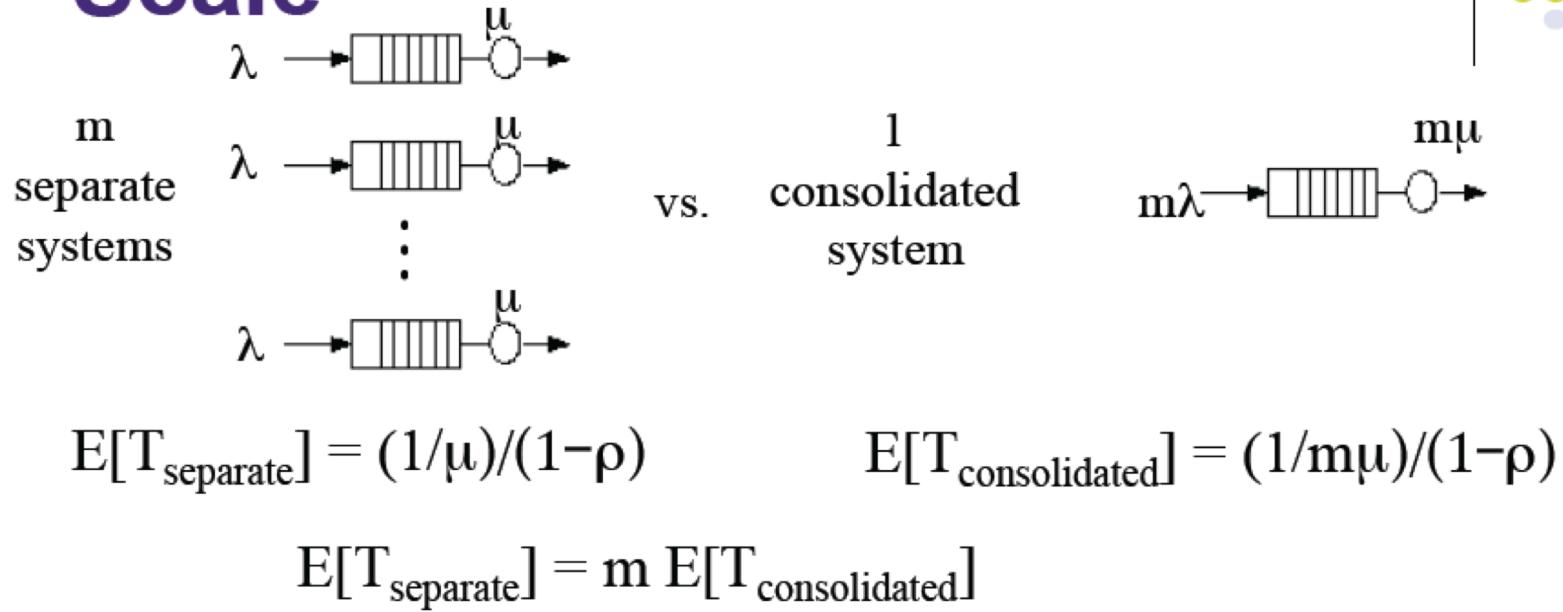
Effect of Scale

- $C = 100,000 \text{ bps}$
- Exp. Dist. with Avg. Packet Length: 10,000 bits
- Service Time: $X=0.1 \text{ second}$
- Arrival Rate: 7.5 pkts/sec
- Load: $\rho=0.75$
- Mean Delay:
 $E[T] = 0.1/(1-.75) = 0.4 \text{ sec}$
- $C = 10,000,000 \text{ bps}$
- Exp. Dist. with Avg. Packet Length: 10,000 bits
- Service Time: $X=0.001 \text{ second}$
- Arrival Rate: 750 pkts/sec
- Load: $\rho=0.75$
- Mean Delay:
- $E[T] = 0.001/(1-.75) = 0.004 \text{ sec}$

Reduction by factor of 100

Aggregation of flows can improve Delay & Loss Performance

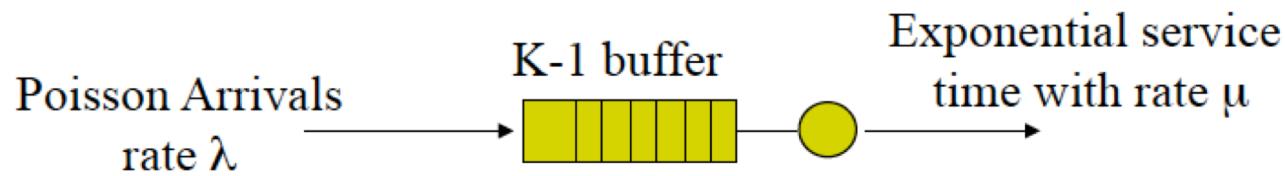
Multiplexing Gain & Effect of Scale



- Consolidated system works at maximum capacity as long as there is work to be done; Separate system does not.
- $E[N]$ equal in both cases, but packets move faster in consolidated system
- *Multiplexing multiple streams into one server with consolidated capacity improves performance*



M/M/1/K Queue



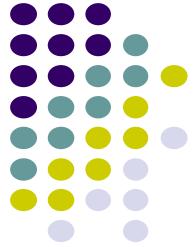
M/M/1/K Steady State Probabilities

$$P[N(t) = n] = p_n = \frac{1 - \rho}{1 - \rho^{K+1}} \rho^n \quad n = 1, 2, \dots, K$$

- p_n is the proportion of time n customers are in the system

$$E[N] = \sum_{n=0}^K np_n = \frac{\rho}{1 - \rho} - \frac{(K + 1)\rho^{K+1}}{1 - \rho^{K+1}}$$

$$P_{blocking} = P[N(t) = K] \quad E[T] = \frac{E[N]}{\lambda(1 - P_{blocking})}$$



Effect of Scale on Loss

Aggregation of 100 multiplexers. Assume individual buffer size = 10.

- $R = 100,000$ bps
- Arrival Rate: 7.5 pkts/sec
- Exp. Dist. with Avg. Packet Length: 10,000 bits
- Service Time: 0.1 second
- Load: $\rho = 0.75$
- $K = 10$
- Packet loss prob = 0.015
- $R = 10,000,000$ bps
- Arrival Rate: 750 pkts/sec
- Exp. Dist. with Avg. Packet Length: 10,000 bits
- Service Time: 0.001 second
- Load: $\rho = 0.75$
- $K = 1000$
- Packet loss prob = 2.9×10^{-126}

$$P_{loss} = \frac{(1-\rho)\rho^K}{1-\rho^{K+1}}$$