

Lecture 1:

Basic switching concepts

circuit switching
message switching
packet switching

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Switching

→ Circuit Switching

- ⇒ Fixed and mobile telephone network
 - Frequency Division Multiplexing (FDM)
 - Time Division Multiplexing (TDM)
- ⇒ Optical rings (SDH)

→ Message Switching

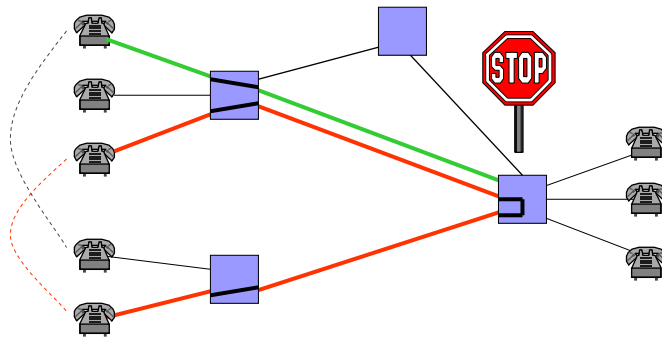
- ⇒ Not in core technology
- ⇒ Some application (e.g. SMTP)

→ Packet Switching

- ⇒ Internet
- ⇒ Some core networking technologies (e.g. ATM)

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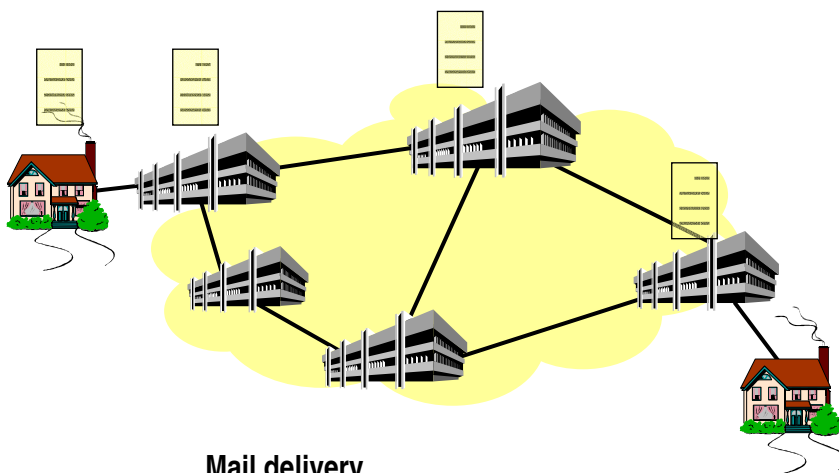
Circuit Switching



Phone Call routing

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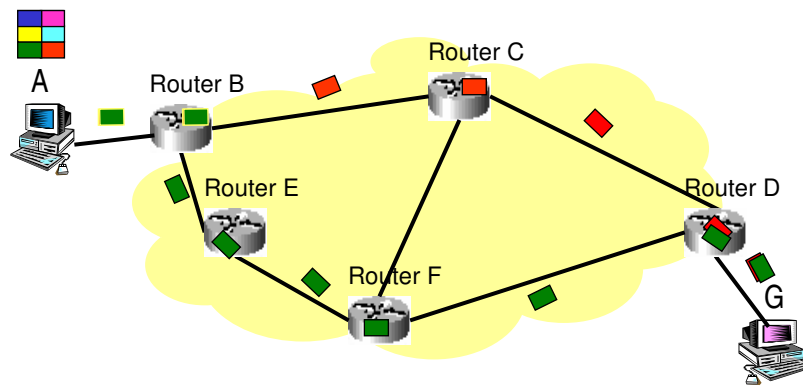
Message Switching



Mail delivery

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Packet Switching



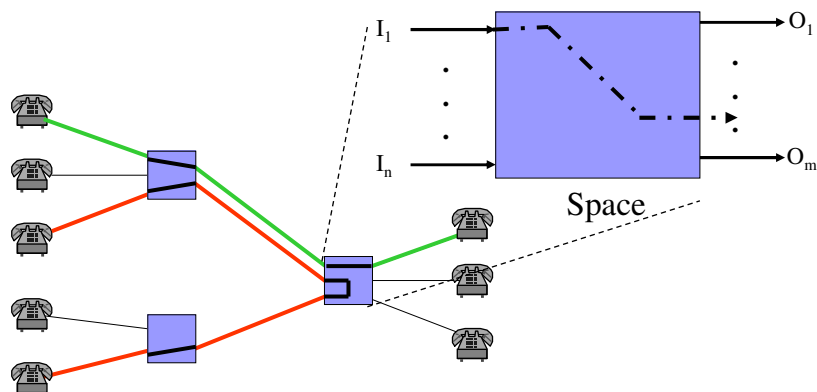
Internet routing

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Space Division Switching (for Circuit Switching)

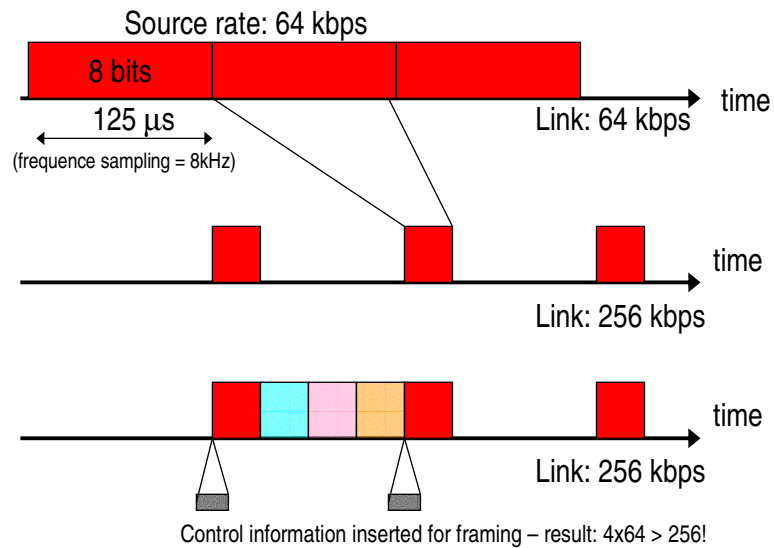
→ **Spatial mapping of inputs and outputs**

⇒ Used primarily in analog switching systems



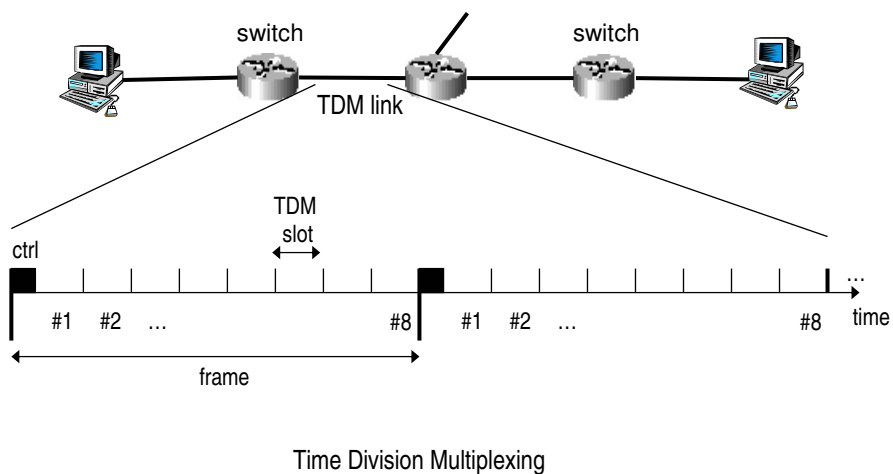
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Time Division Multiplexing



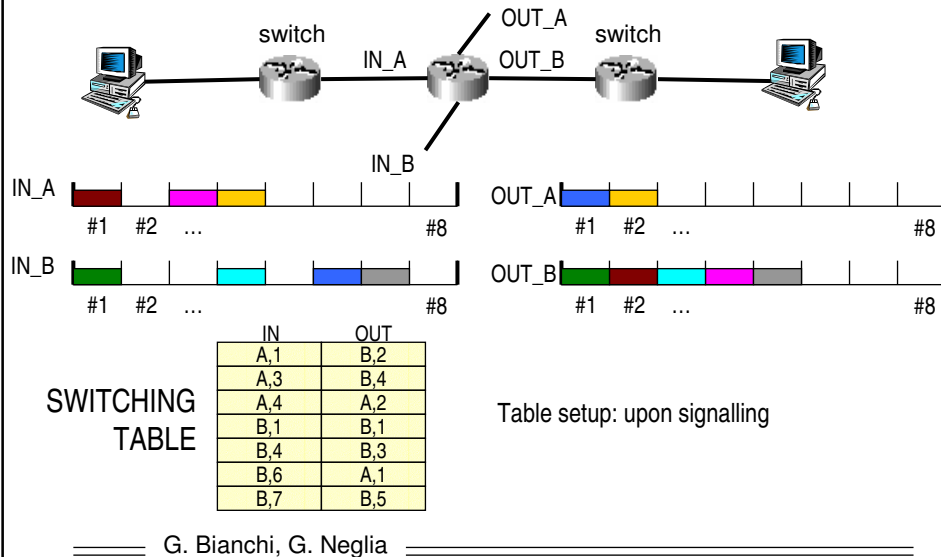
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Circuit Switching (i)



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Circuit Switching (ii)



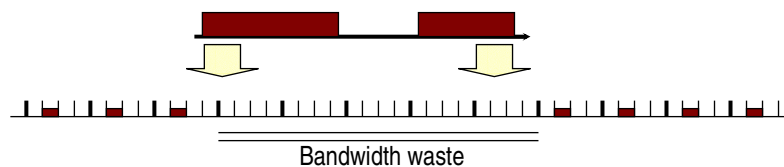
Circuit Switching Pros & Cons

→ Advantages

- ⇒ Limited overhead
- ⇒ Very efficient switching fabrics
 - Highly parallelized

→ Disadvantages

- ⇒ Requires signalling for switching tables set-up
- ⇒ Underutilization of resources in the presence of bursty traffic and variable rate traffic



Example of bursty traffic (ON/OFF voice flows)

On (activity) period



VOICE SOURCE MODEL for conversation (Brady):

average ON duration (talkspurt): 1 second

average OFF duration (silence): 1.35 seconds

$$activity = \frac{T_{ON}}{T_{ON} + T_{OFF}} = \frac{1}{1 + 1.35} = 42.55\% \quad (\text{before packetization})$$

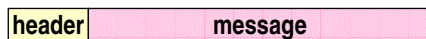
Efficiency = utilization % = source activity

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Message vs Packet Switching

→ Message Switching

⇒ One single datagram



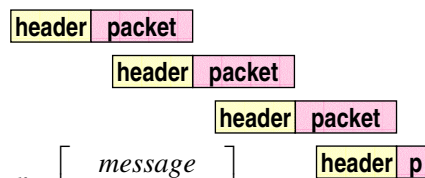
$$overhead = \frac{header}{header + message}$$

→ Packet Switching

⇒ Message chopped in small packets

⇒ Each packet includes header

→ like postal letters! Each must have a specified destination data



$$n = \left\lceil \frac{message}{packet_size} \right\rceil$$

$$overhead = \frac{n \cdot header}{n \cdot header + message}$$

Message switching overhead lower than packet switching

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Message vs Packet Switching

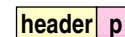
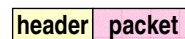
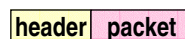
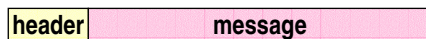
→ Message Switching

- ⇒ One single datagram
 - either received or lost
 - One single network path

→ Packet Switching

- ⇒ Many packets generated by a same node and belonging to a same destination
 - may take different paths (and packets received out of order – need sequence)
 - May lose/corrupt a subset (what happens on the message consistency?)

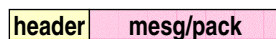
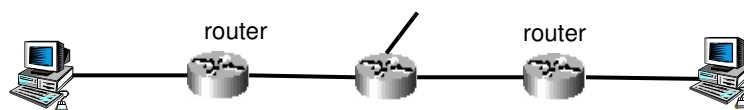
Message switching: higher reliability, lower complexity



*But sometimes message switching not possible
(e.g. for real time sources such as voice)*

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Message/packet Switching vs circuit switching



Router:

- reads header (destination address)
- selects output path

→ Advantages

- ⇒ Transmission resources used only when needed (data available)
- ⇒ No signalling needed

→ Disadvantages

- ⇒ Overhead
- ⇒ Inefficient routing fabrics (needs to select output per each packet)
- ⇒ Processing time at routers (routing table lookup)
- ⇒ Queueing at routers

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Link delay computation

→ Delay components:

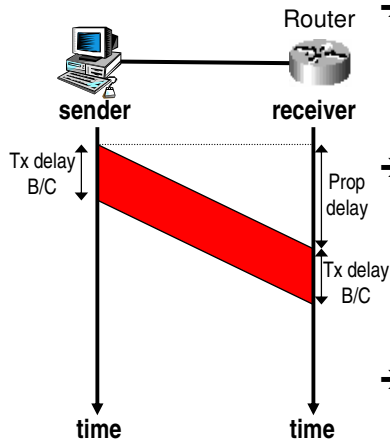
- Processing delay
- Transmission delay
- Queueing delay
- Propagation delay

→ Transmission delay:

- C [bit/s] = link rate
- B [bit] = packet size
- transmission delay = B/C [sec]

→ Example:

- 512 bytes packet
- 64 kbps link
- transmission delay = $512 \cdot 8 / 64000 = 64 \text{ ms}$



→ Propagation delay - constant depending on

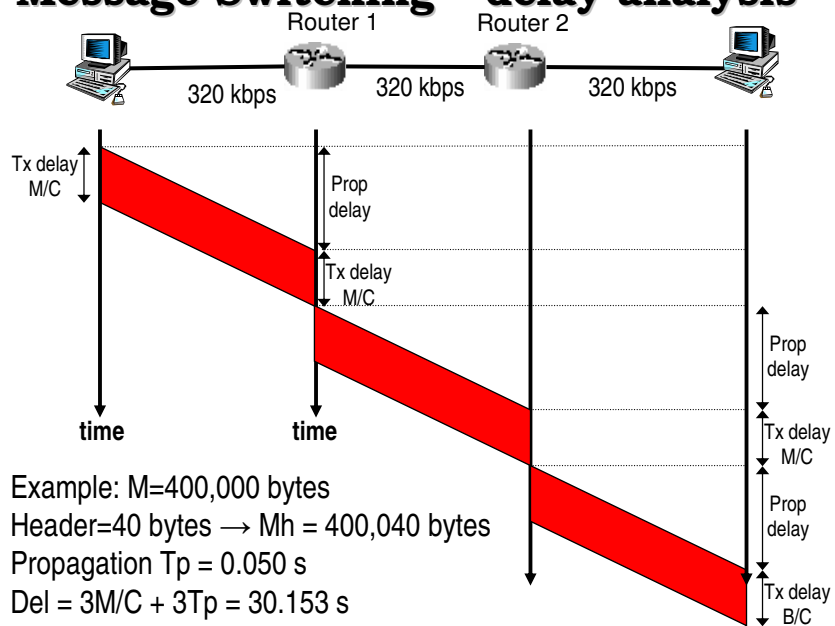
- Link length
- Electromagnetic waves propagation speed in considered media
- 200 km/s for copper links
- 300 km/s in air

→ other delays neglected

- Queueing delay
- Processing delay

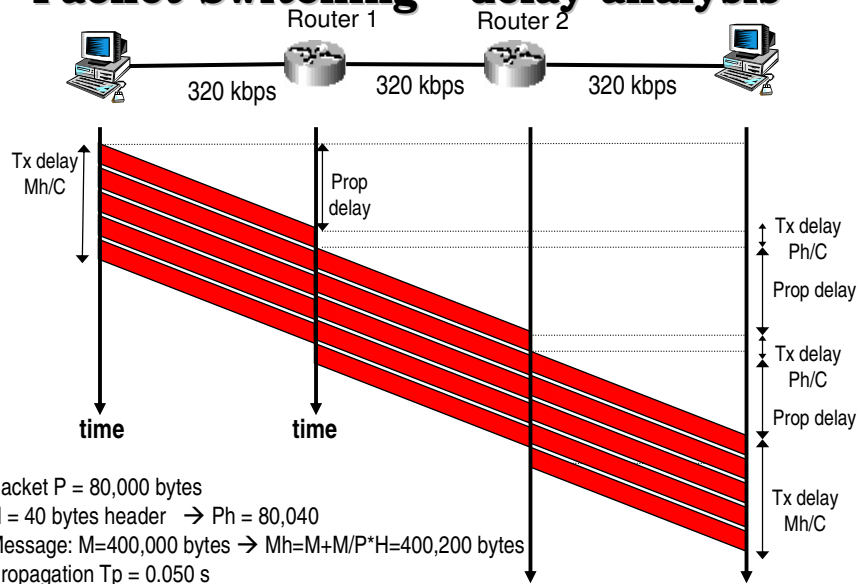
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Message Switching – delay analysis



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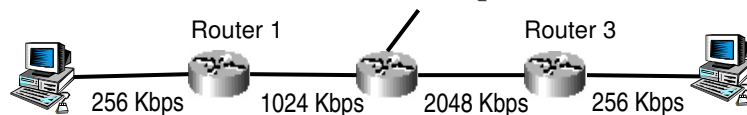
Packet Switching – delay analysis



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But if packet size = 40 bytes, Del = 20.154s!

Other example (different link speed)



→ Time to transmit 1 MB file

→ Message switching (assume 40 bytes header)

⇒ $1\text{MB} = 1024 \cdot 1024$ bytes = 1,048,576 bytes = 8,388,608 bits

⇒ Including 40 bytes (320 bits) header: 8,388,928

⇒ Neglecting processing, propagation & queueing delays:

→ $D = 32.76 + 8.19 + 4.10 + 32.77 = 77.83\text{s}$

→ Packet switching (40 bytes header, 1460 bytes packet)

⇒ $718.2 \rightarrow 719$ packets

⇒ total message size including overhead = 8,618,688 bits

⇒ Just considering transmission delays (slowest link = last – try with intermediate, too)

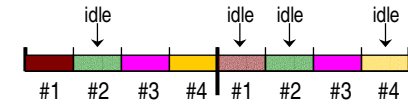
→ $D = 0.06 + 33.67 = 33.73\text{s}$

→ Key advantage: **pipelining reduces end to end delay versus message switching!**

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Statistical Multiplexing the advantage of packet switching

Circuit switching:
Each slot uniquely
Assigned to a flow



Full capacity does not imply full utilization!!

Packet switching:
Each packet grabs
The first slot available



More flows than nominal capacity may be admitted!!

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Packet Switching overhead vs burstiness

Overhead for voice sources at 64 kbps

Source rate: 64 kbps

during 16 ms 128 voice samples = 1024 bit every 16 ms $\longleftrightarrow$ 62.5 packets/s

Assumption: 40 bytes header

emission rate = $62.5 \cdot (1024 + 40 \cdot 8) = 84000$

(versus 64000 nominal rate = 31.25% overhead)

On (activity) period



PACKETIZATION for voice sources (Brady model, activity=42.55%):

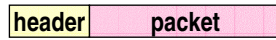
Assumptions: neglect last packet effect

average emission rate = $62.5 \cdot (1024 + 40 \cdot 8) \cdot 0.4255 = 35745$

(versus 64000 nominal rate = 55.85%)

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Packet switching overhead



→ Header: contains lots of information

⇒ Routing, protocol-specific info, etc

⇒ Minimum: 28 bytes; in practice much more than 40 bytes

→ Overhead for every considered protocol: (for voice: 20 bytes IP, 8 bytes UDP, 12 bytes RTP)

→ Question: how to minimize header while maintaining packet switching?

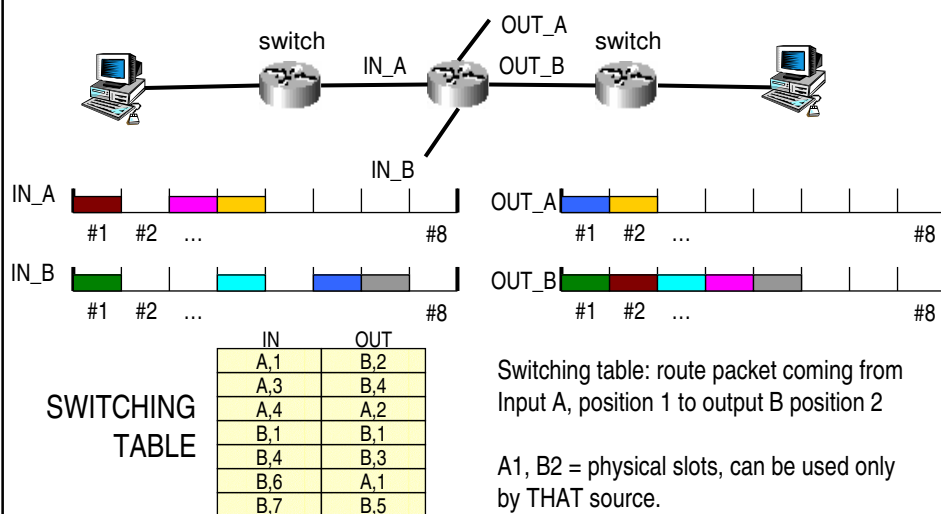
→ Solution: label switching (virtual circuit)

⇒ ATM

⇒ MPLS

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Circuit Switching (again)



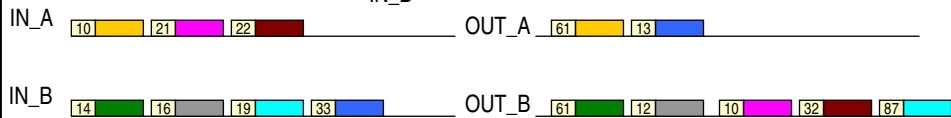
Switching table: route packet coming from Input A, position 1 to output B position 2

A1, B2 = physical slots, can be used only by THAT source.

Let them be "virtual" (labels on packet!)

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The diagram illustrates a network topology for a multi-processor system. A central router is shown with four ports: IN_A, IN_B, OUT_A, and OUT_B. IN_A and IN_B are connected to a switch, which is then connected to a computer. OUT_A and OUT_B are connected to another switch, which is then connected to another computer.

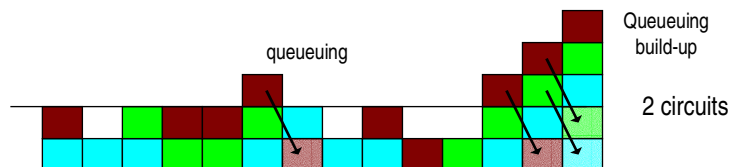


LABEL SWITCHING TABLE	Label-IN	OUT	Label-OUT
	10	A	61
	14	B	61
	16	B	12
	19	B	87
	21	B	10
	22	B	32
	33	A	13

Advantage: labels very small!!
(ATM technology overhead:
only 5 bytes for all info!)

KEY advantage: no reserved phy slots!
(asynchronous transfer mode vs synchronous)

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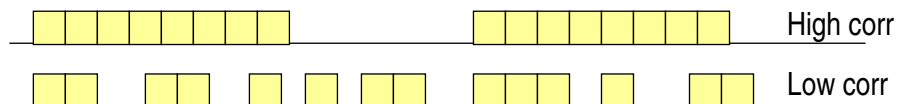


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Statistical mux analysis

→ Very complex, when queueing considered

- ⇒ Involves queueing theory
- ⇒ Involves traffic time correlation statistics



→ Very easy, in the (worst case = conservative) assumption of unbuffered system

- ⇒ In practice, burst size long with respect to buffer size

→ Depends only on activity factor ρ

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Statistical mux analysis (i) unbuffered model

N traffic sources; Homogeneous, same activity factor ρ
 Source rate = 1; Link capacity = C
 TDM: N must be $\leq C$ Packet: N may be $> C$

$$\text{Prob}(k \text{ sources simultaneously active}) = \binom{N}{k} \rho^k (1 - \rho)^{N-k}$$

Example: N=5; each having 20% activity

0	32.77%
1	40.96%
2	20.48%
3	5.12%
4	0.64%
5	0.03%

Average load = $5 \cdot 0.2 = 1$
 But $C=1$ appears insufficient...

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Statistical mux analysis (ii) unbuffered model

→ Overflow probability

- ⇒ Probability that, at a given instant of time (random), the link load is greater than the link capacity
- ⇒ Implies packet loss if buffer=0

$$\begin{aligned} \text{overflow_prob} &= \sum_{k=C+1}^N \binom{N}{k} \rho^k (1-\rho)^{N-k} = \\ &= 1 - \sum_{k=0}^C \binom{N}{k} \rho^k (1-\rho)^{N-k} \end{aligned}$$

Example: N=5;
each having 20% activity;

link capacity	overflow prob
0	67.23%
1	26.27%
2	5.79%
3	0.67%
4	0.03%
5	0.00%

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Statistical mux analysis (iii) unbuffered model

→ Packet loss probability

- ⇒ Number of lost packets over number of offered packets

→ Offered packets

- ⇒ N * average number of offered packets per source = N * ρ

→ Lost packets:

- ⇒ If k ≤ C active sources, no packet loss
- ⇒ If k > C, k-C lost packets

→ hence

$$\begin{aligned} P_{\text{loss}} &= \frac{\sum_{k=C+1}^N (k-C) \binom{N}{k} \rho^k (1-\rho)^{N-k}}{N\rho} = \\ &= \frac{1}{N\rho} \sum_{k=C+1}^N k \binom{N}{k} \rho^k (1-\rho)^{N-k} - \frac{C}{N\rho} P(\text{overflow}) \end{aligned}$$

Example: N=5; each having 20% activity;
N ρ = 1

k or C	p(k)	k*p(k)	overflow(C)	loss(C)
0	32.77%	0	67.23%	100.00%
1	40.96%	0.4096	26.27%	32.77%
2	20.48%	0.4096	5.79%	6.50%
3	5.12%	0.1536	0.67%	0.70%
4	0.64%	0.0256	0.03%	0.03%
5	0.03%	0.0016	0.00%	0.00%

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Loss vs overflow

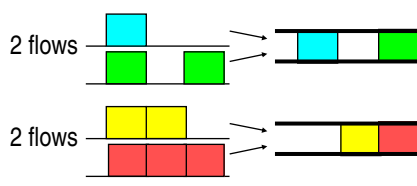
k or C	binom	p(k)	k * p(k)	overflow(C)	loss(C)
0	1	1,2E-03	0,0E+00	9,99E-01	1,00E+00
1	30	9,3E-03	9,3E-03	9,89E-01	8,34E-01
2	435	3,4E-02	6,7E-02	9,56E-01	6,69E-01
3	4060	7,9E-02	2,4E-01	8,77E-01	5,09E-01
4	27405	1,3E-01	5,3E-01	7,45E-01	3,63E-01
5	142506	1,7E-01	8,6E-01	5,72E-01	2,39E-01
6	593775	1,8E-01	1,1E+00	3,93E-01	1,44E-01
7	2035800	1,5E-01	1,1E+00	2,39E-01	7,81E-02
8	5852925	1,1E-01	8,8E-01	1,29E-01	3,82E-02
9	14307150	6,8E-02	6,1E-01	6,11E-02	1,68E-02
10	30045015	3,5E-02	3,5E-01	2,56E-02	6,57E-03
11	54627300	1,6E-02	1,8E-01	9,49E-03	2,30E-03
12	86493225	6,4E-03	7,7E-02	3,11E-03	7,18E-04
13	119759850	2,2E-03	2,9E-02	9,02E-04	2,00E-04
14	145422675	6,7E-04	9,4E-03	2,31E-04	4,94E-05
15	155117520	1,8E-04	2,7E-03	5,24E-05	1,08E-05
16	145422675	4,2E-05	6,7E-04	1,05E-05	2,11E-06
17	119759850	8,6E-06	1,5E-04	1,84E-06	3,62E-07
18	86493225	1,6E-06	2,8E-05	2,84E-07	5,46E-08
19	54627300	2,5E-07	4,7E-06	3,83E-08	7,21E-09
20	30045015	3,4E-08	6,8E-07	4,48E-09	8,28E-10
21	14307150	4,0E-09	8,5E-08	4,50E-10	8,20E-11
22	5852925	4,1E-10	9,1E-09	3,86E-11	6,92E-12
23	2035800	3,6E-11	8,2E-10	2,78E-12	4,91E-13
24	593775	2,6E-12	6,3E-11	1,65E-13	2,88E-14
25	142506	1,6E-13	3,9E-12	7,82E-15	1,35E-15
26	27405	7,5E-15	2,0E-13	2,87E-16	4,91E-17
27	4060	2,8E-16	7,5E-15	7,60E-18	1,29E-18
28	435	7,5E-18	2,1E-16	1,30E-19	2,18E-20
29	30	1,3E-19	3,7E-18	1,07E-21	1,79E-22
30	1	1,1E-21	3,2E-20	0,00E+00	0,00E+00

Example: N=30;
each 20% activity;
N ρ = 6

for C >> Nρ:
Overflow=good approx for loss.

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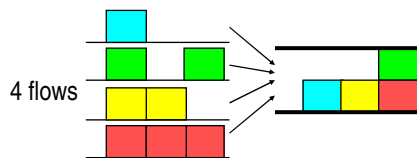
Statistical Mux Gain (i)



Average load = 4ρ

$C = 2$

$$P_{loss_1} = \frac{1 \times 1 \times \rho^2}{2\rho} = \frac{\rho}{2}$$



Average load = 4ρ

$C = 2$

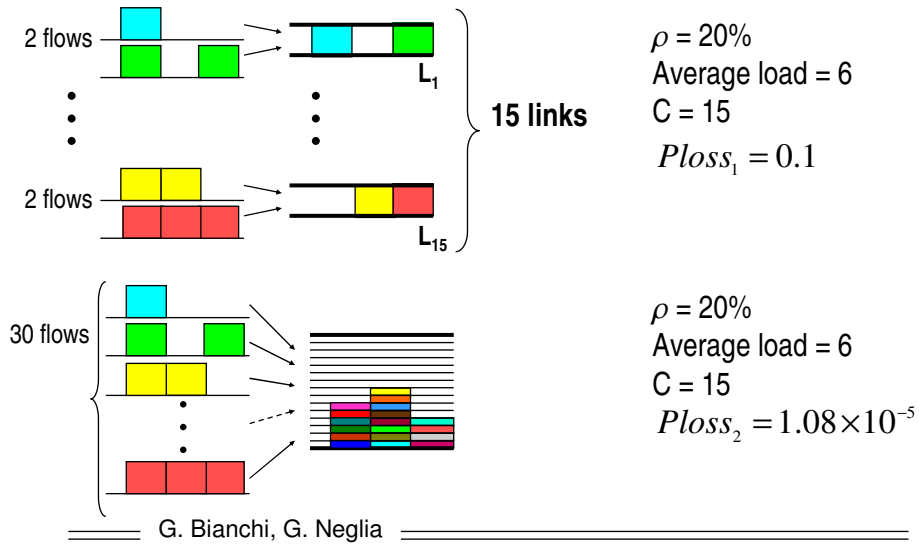
$$P_{loss_2} = \frac{1 \times 4 \times \rho^3 (1 - \rho) + 2 \times 1 \times \rho^4}{4\rho}$$

$$= \frac{\rho^2 (2 - \rho)}{2} < P_{loss_1}$$

A sample-path argument is faster!

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Statistical Mux Gain (ii)



Statistical Mux Gain (iii)

