Lecture 1:

Basic switching concepts

circuit switching
message switching
packet switching

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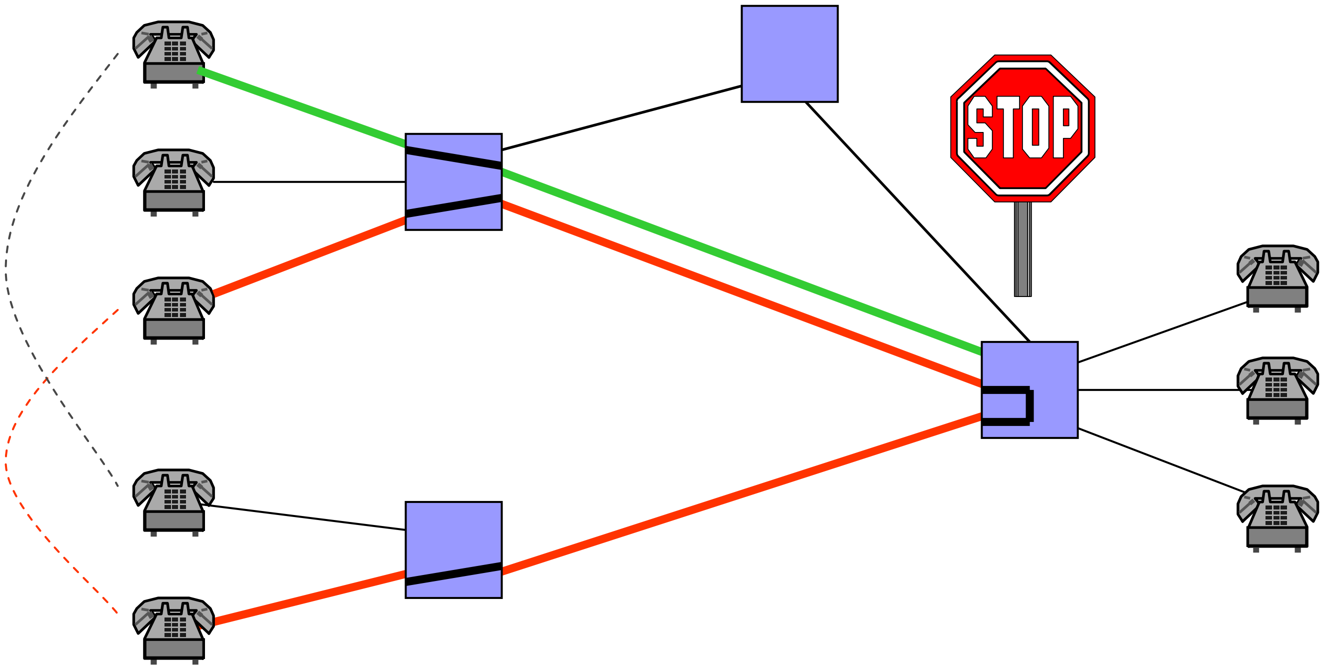
Switching

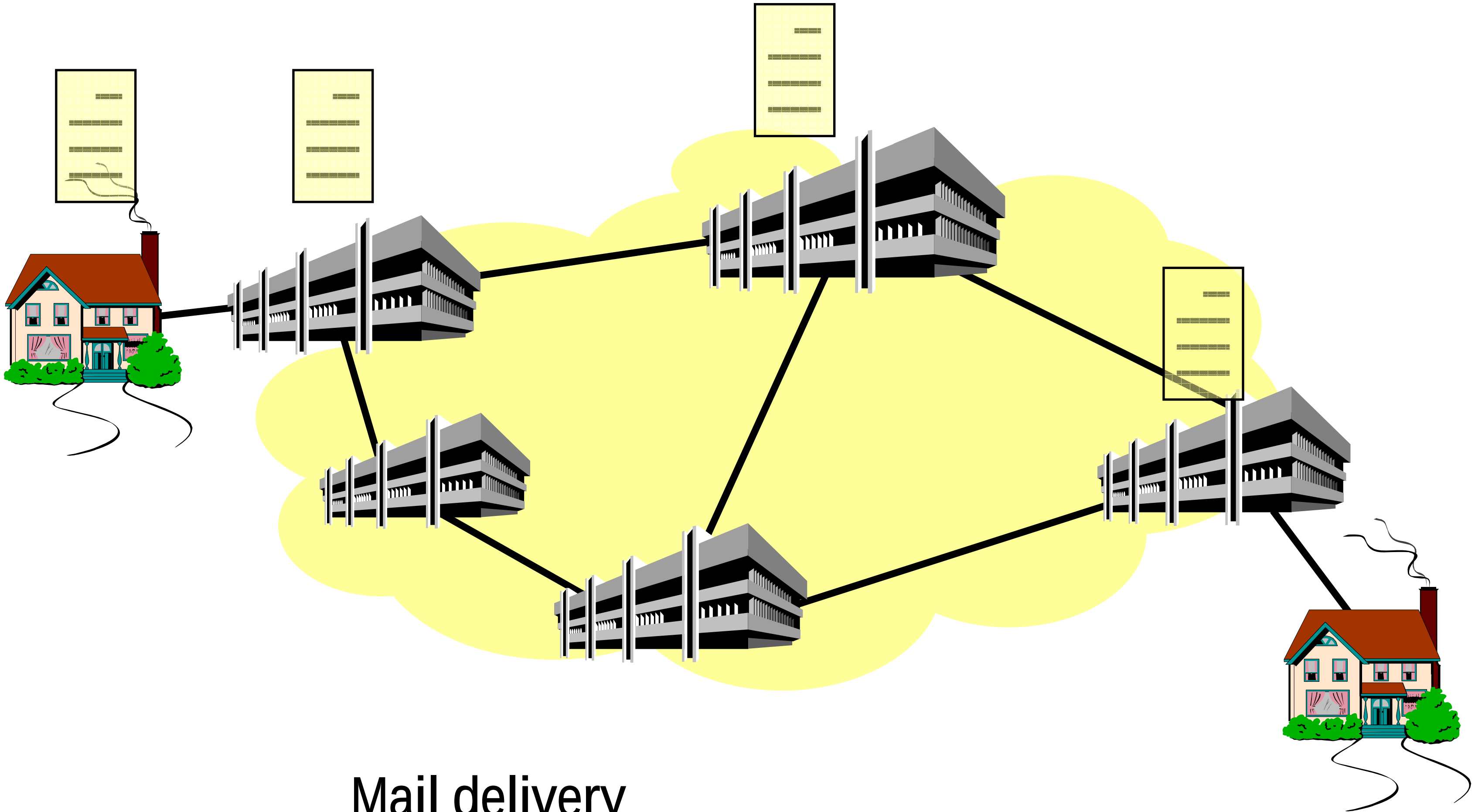
- ➔ **Circuit Switching**
  - ⇨ Fixed and mobile telephone network
    - → Frequency Division Multiplexing (FDM)
    - → Time Division Multiplexing (TDM)
  - ⇨ Optical rings (SDH)
- ➔ **Message Switching**
  - ⇨ Not in core technology
  - ⇨ Some application (e.g. SMTP)
- ➔ **Packet Switching**
  - ⇨ Internet
  - ⇨ Some core networking technologies (e.g. ATM)

Circuit Switching



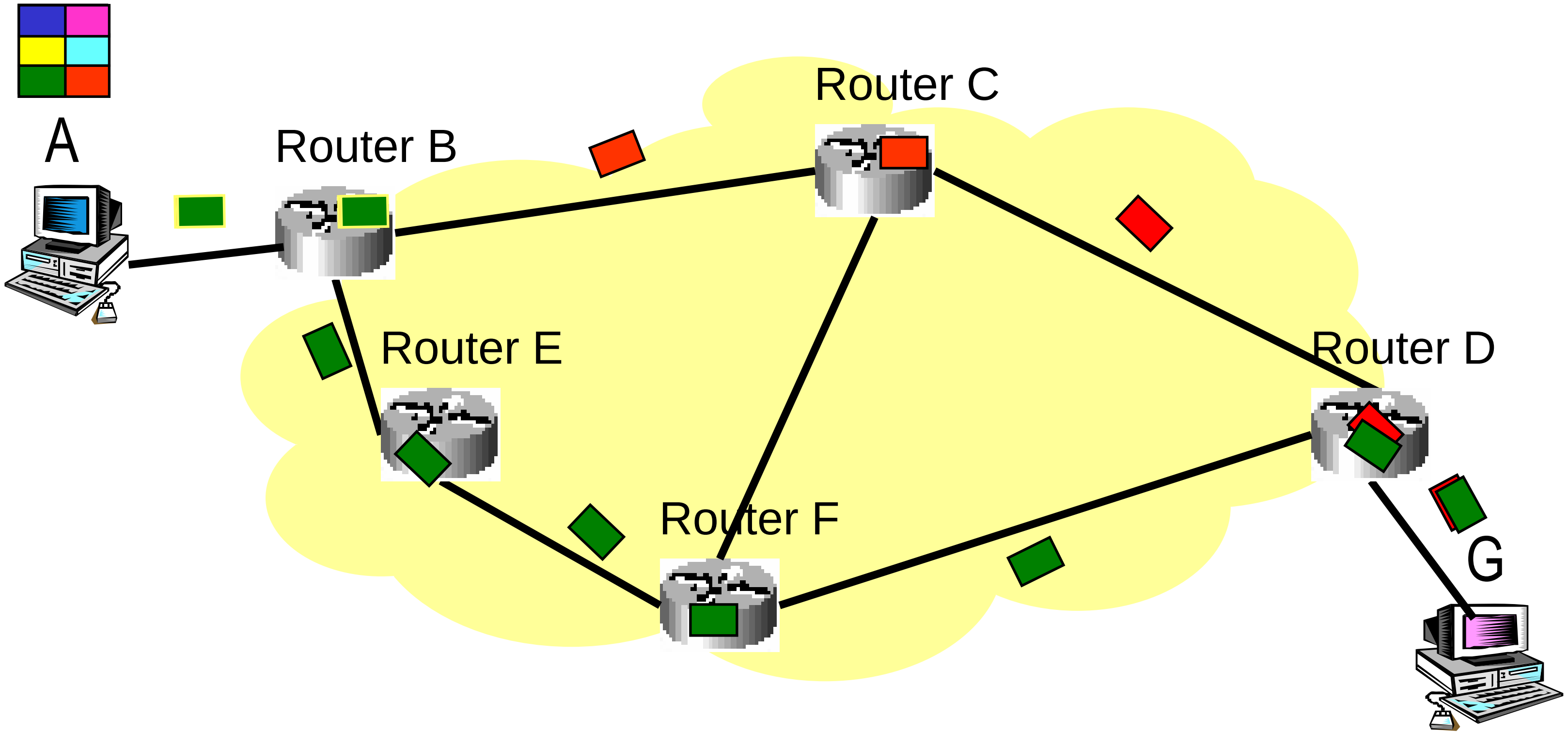
Phone Call routing

Message Switching



Mail delivery

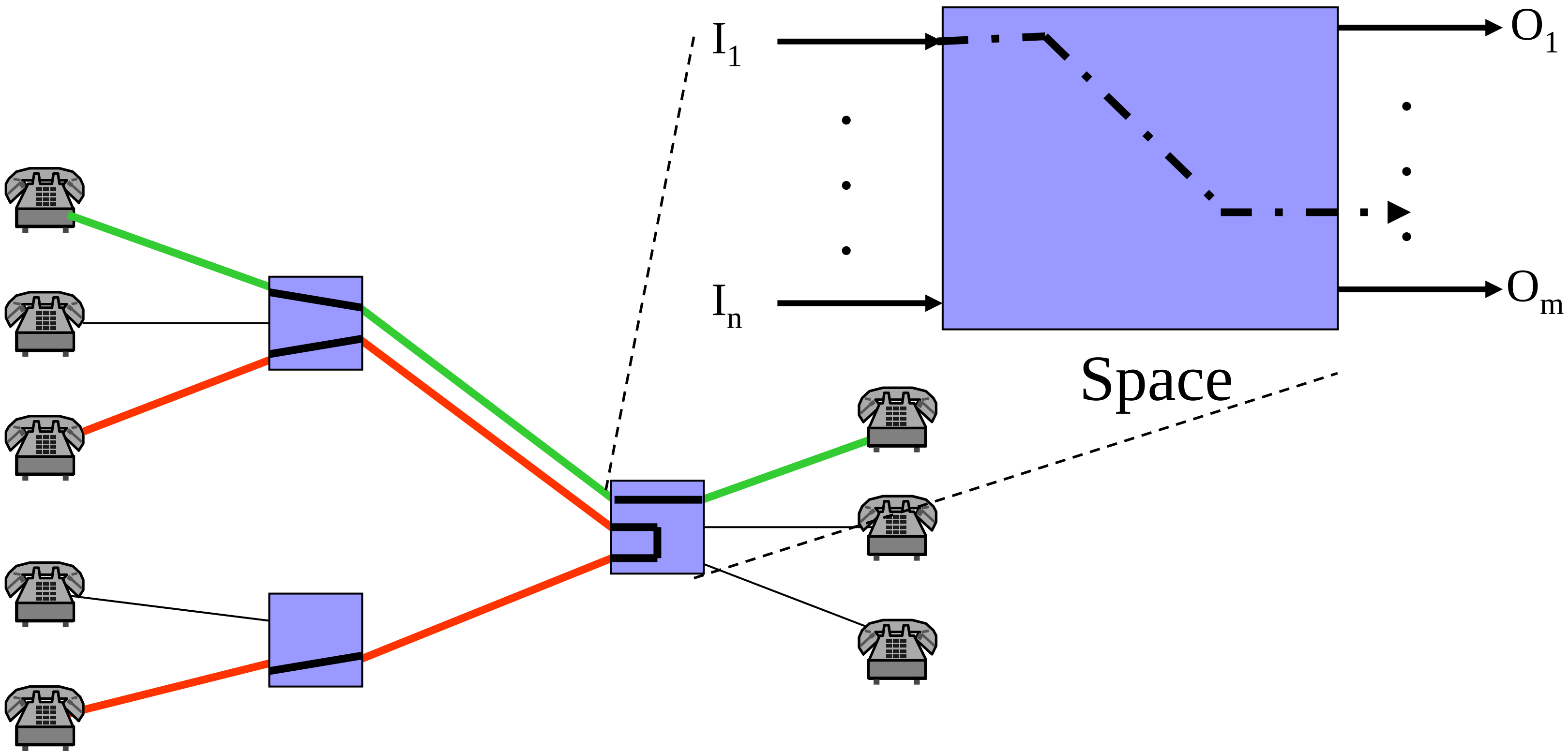
Packet Switching



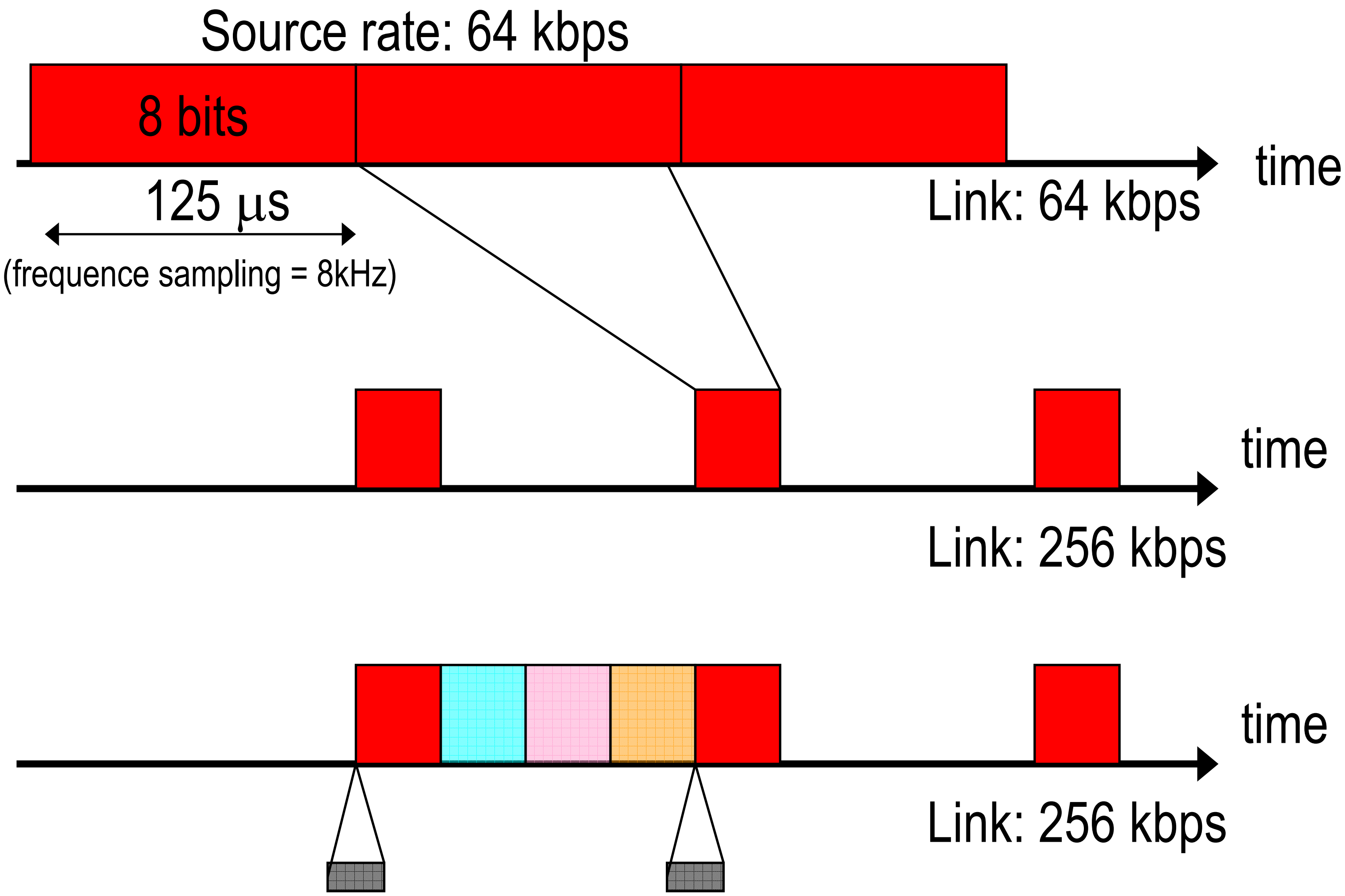
Internet routing

Space Division Switching
(for Circuit Switching)

- ➔ **Spatial mapping of inputs and outputs**
  - ⇨ Used primarily in analog switching systems

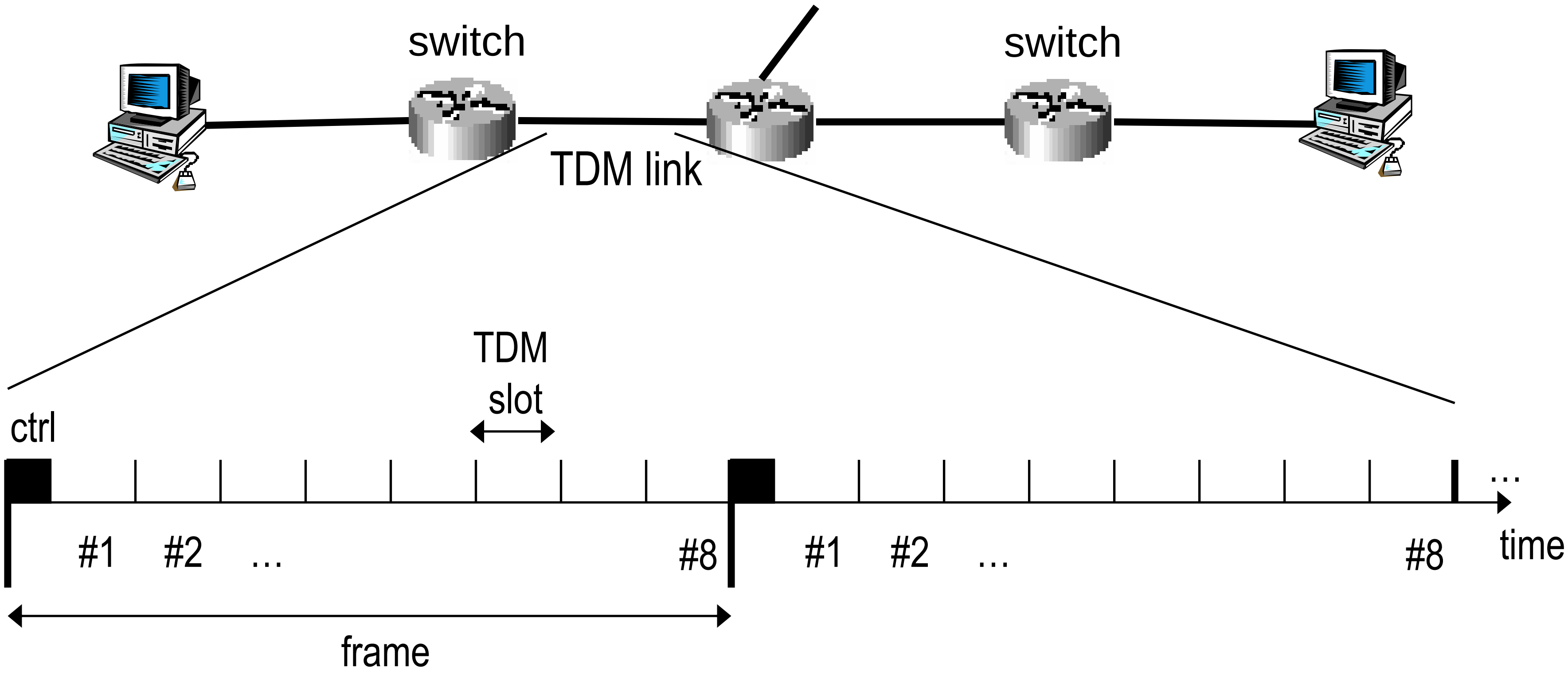


Time Division Multiplexing



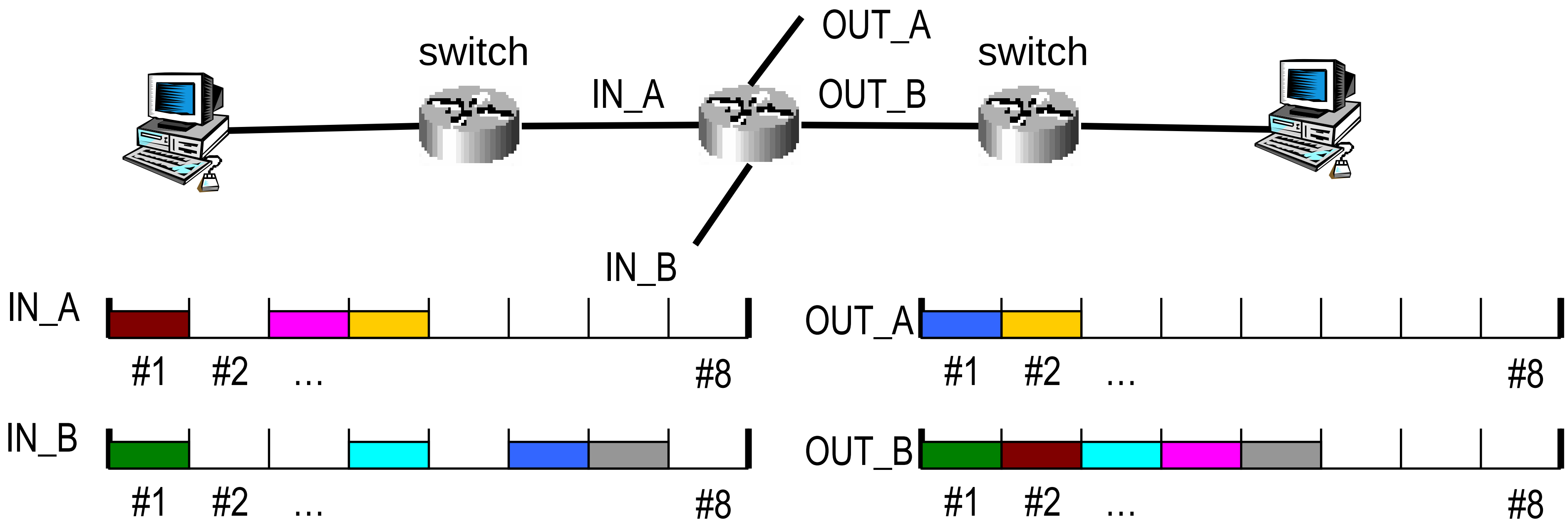
Control information inserted for framing – result: 4x64 > 256!

Circuit Switching (i)



Time Division Multiplexing

Circuit Switching (ii)



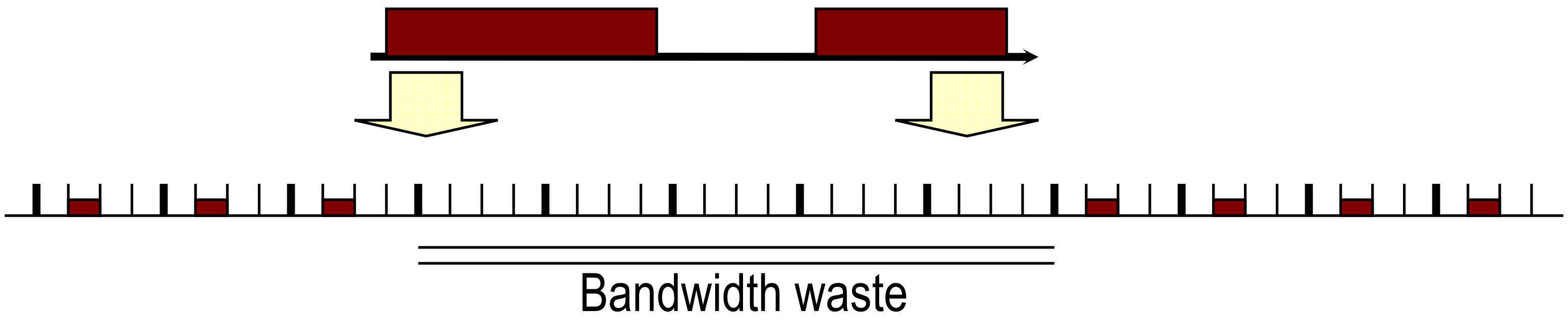
SWITCHING TABLE

IN	OUT
A,1	B,2
A,3	B,4
A,4	A,2
B,1	B,1
B,4	B,3
B,6	A,1
B,7	B,5

Table setup: upon signalling

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)

VOICE SOURCE MODEL for conversation (Brady):

average ON duration (talkspurt): 1 second

average OFF duration (silence): 1.35 seconds

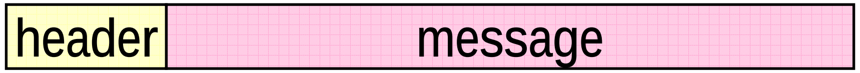
$$activity = \frac{T_{ON}}{T_{ON} + T_{OFF}} = \frac{1}{1+1.35} = 42.55\% \quad \text{(before packetization)}$$

Efficiency = utilization % = source activity

Message vs Packet Switching

➔ Message Switching

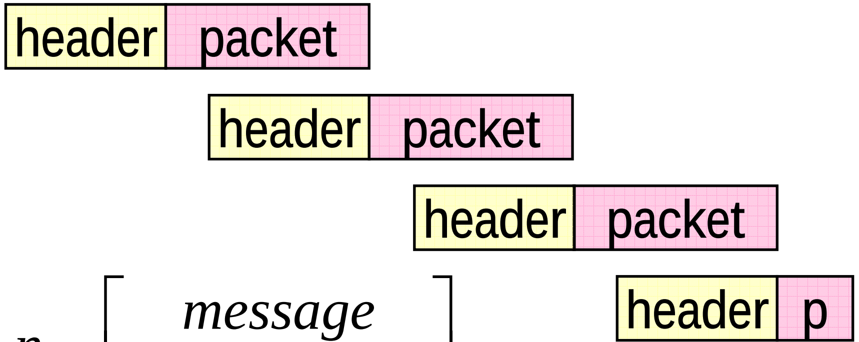
- ⇨ One single datagram



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

➔ 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

Message vs Packet Switching

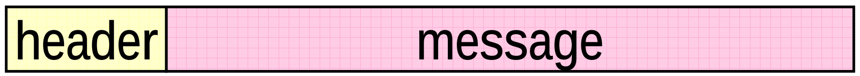
➔ Message Switching

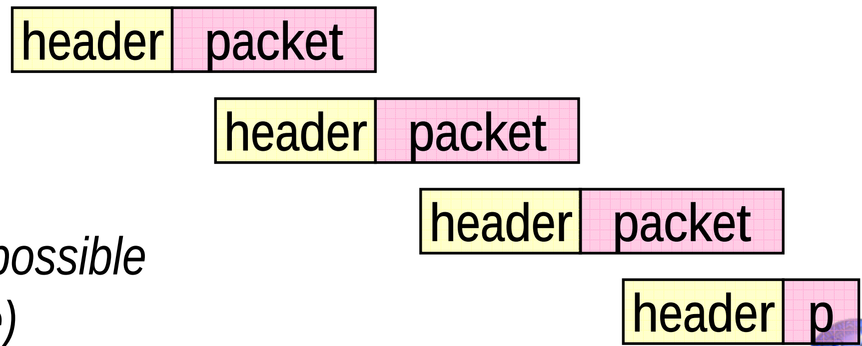
- ⇨ One single datagram
  - → either received or lost
  - → One single network path

➔ 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?)

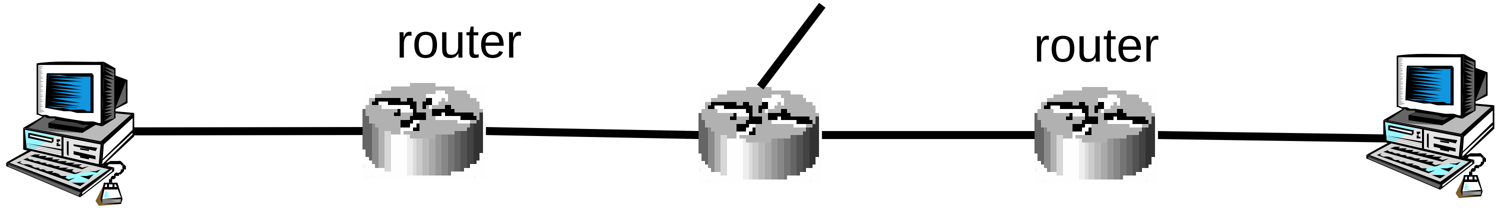
Message switching: higher reliability, lower complexity





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

Message/packet Switching vs circuit switching



header	mesg/pack

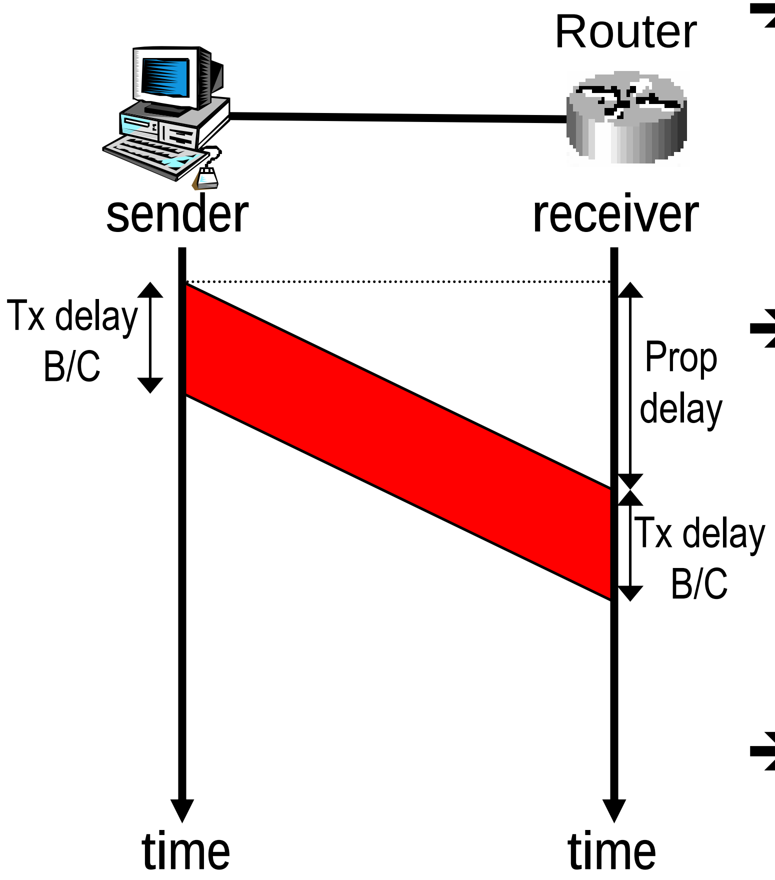
Router:

- 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

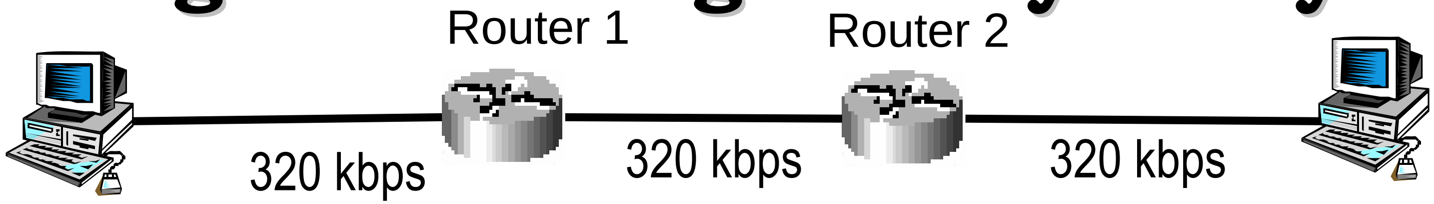
Link delay computation

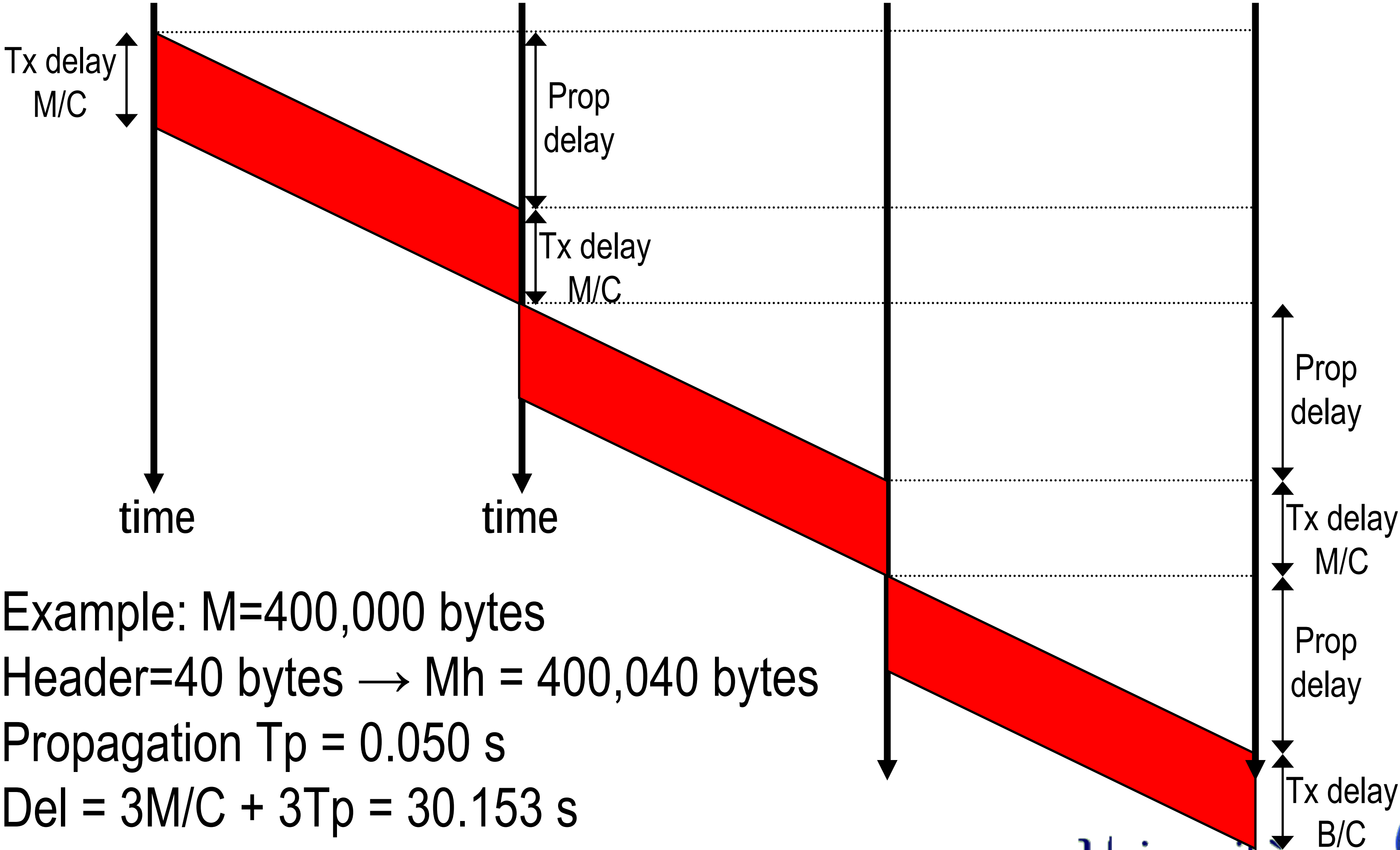
- ➔ **Delay components:**
  - → Processing delay
  - → Transmission delay
  - → Queueing delay
  - → Propagation delay



- ➔ 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*8/64000 = 64ms
- ➔ Propagation delay – constant depending on
  - ➔ Link length
  - ➔ Electromagnetig waves propagation speed in considered media
    - ➔ 200 km/s for copper links
    - ➔ 300 km/s in air
- ➔ other delays neglected
  - ➔ Queueing delay
  - ➔ Processing delay

Message Switching – delay analysis





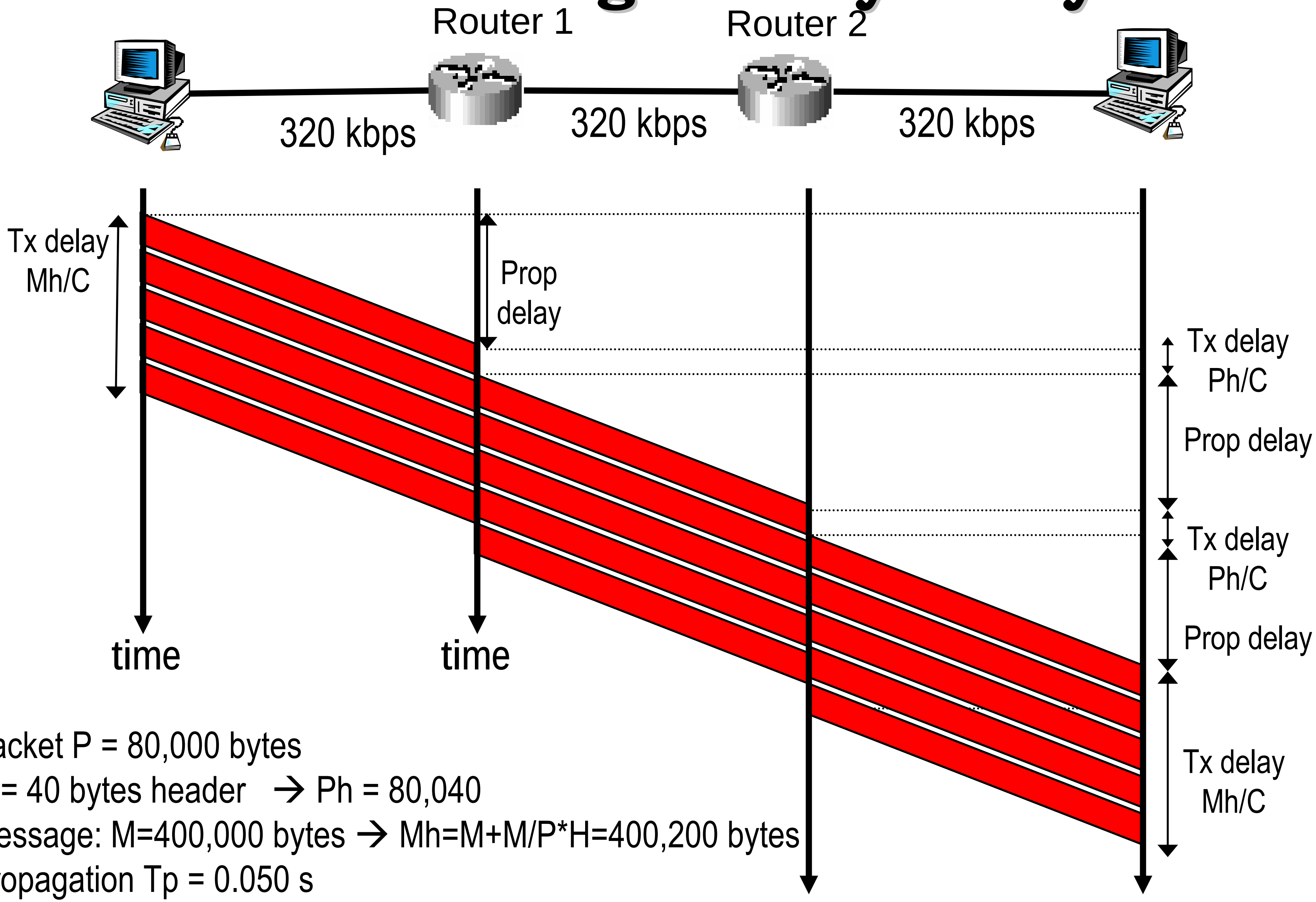
Example: M=400,000 bytes

Header=40 bytes → Mh = 400,040 bytes

Propagation Tp = 0.050 s

Del = 3M/C + 3Tp = 30.153 s

Packet Switching – delay analysis



Packet P = 80,000 bytes

H = 40 bytes header → Ph = 80,040

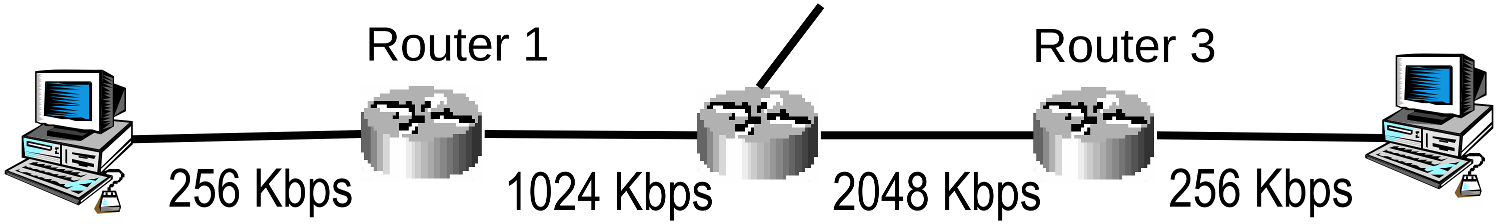
Message: M=400,000 bytes → Mh=M+M/P*H=400,200 bytes

Propagation Tp = 0.050 s

Del = Mh/C + 3Tp + 2Ph/C = 14.157 s

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

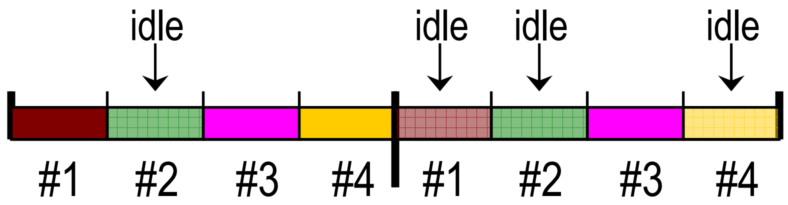
Other example
(different link speed)



- ➔ **Time to transmit 1 MB file**
- ➔ **Message switching (assume 40 bytes header)**
  - ⇨ 1MB = 1024*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 = 77.83s
- ➔ **Packet switching (40 bytes header, 1460 bytes packet)**
  - ⇨ 718.2 → 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 =33.73s
- ➔ **Key advantage: pipelining reduces end to end delay versus message switching!**

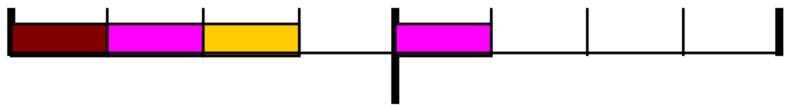
Statistical Multiplexing
the advantage of packet switching

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!!

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 ⟷ 62.5 packets/s

Assumption: 40 bytes header

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

$$(\text{versus } 64000 \text{ nominal rate} = 31.25\% \text{ overhead})$$

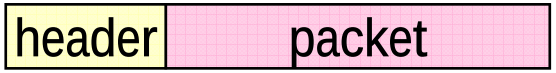
PACKETIZATION for voice sources (Brady model, activity=42.55%):

Assumptions: neglect last packet effect

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

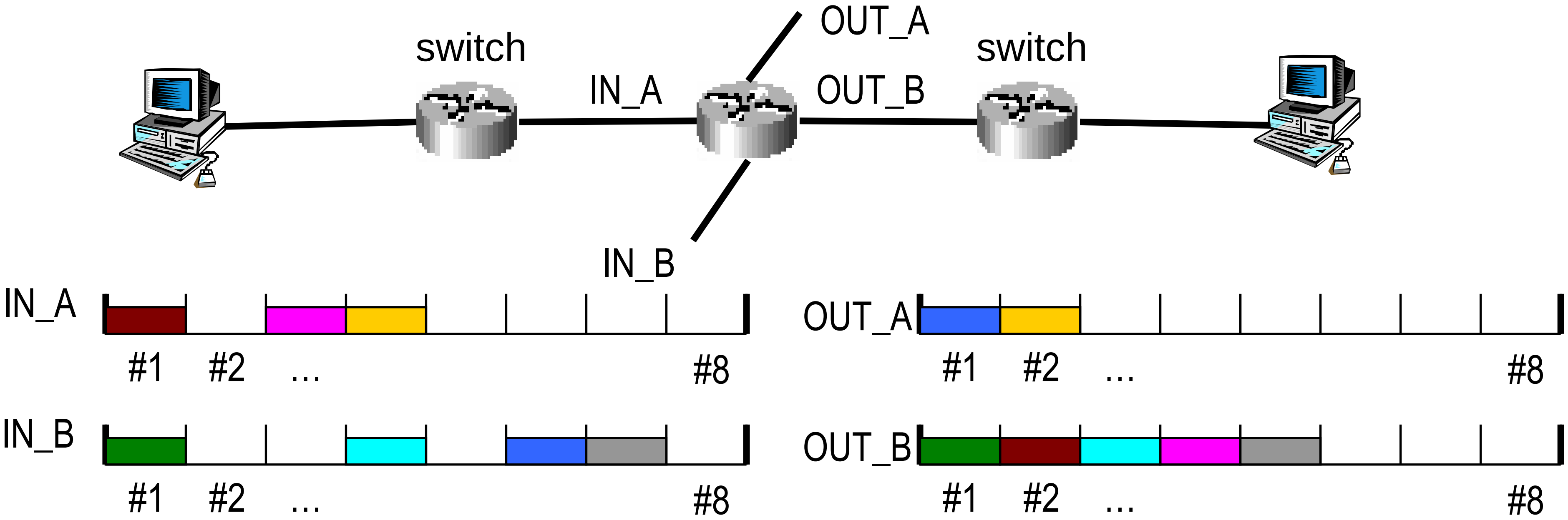
$$(\text{versus } 64000 \text{ nominal rate} = 55.85\%)$$

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

Circuit Switching (again)



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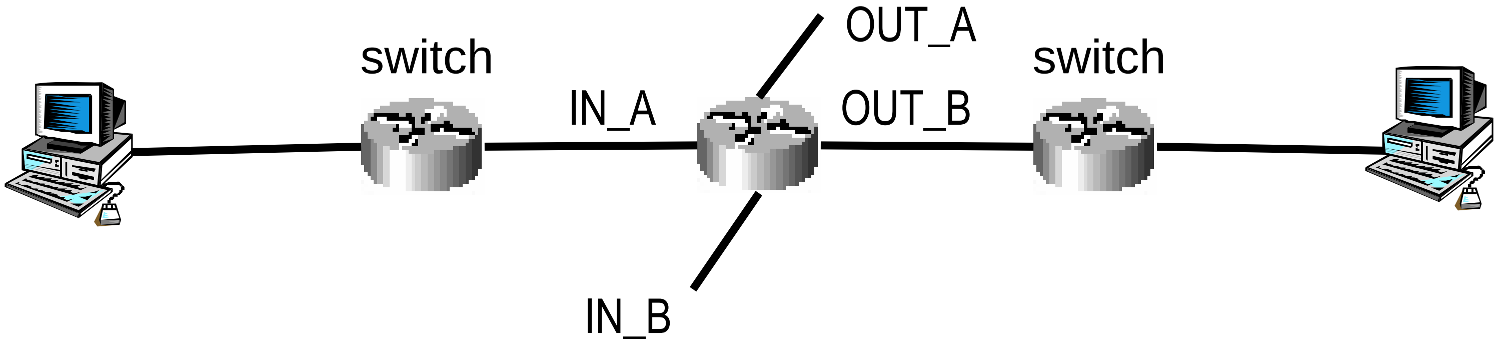
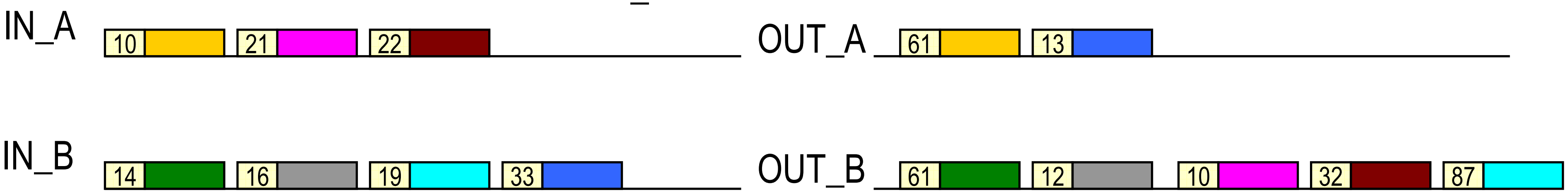
B,6	A,1
B,7	B,5

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!)

Label Switching (virtual circuit)





LABEL SWITCHING TABLE

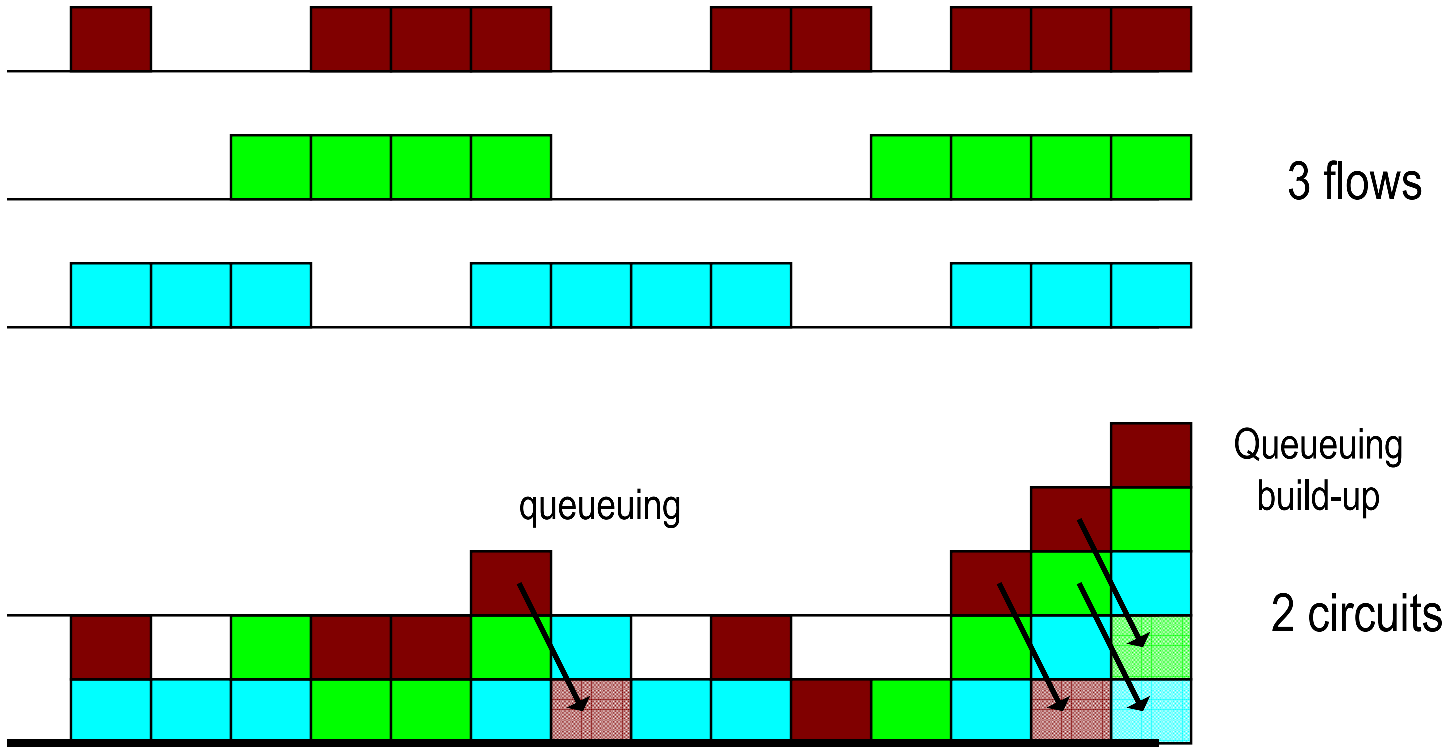
Label-IN	OUT	Label-OUT
10	A	61
14	B	61
16	B	12
19	B	87
21	B	10
22	B	32
33	A	13

Condition: labels unique @ input

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

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

Statistical mux efficiency
(for simplicity, fixed-size packets)



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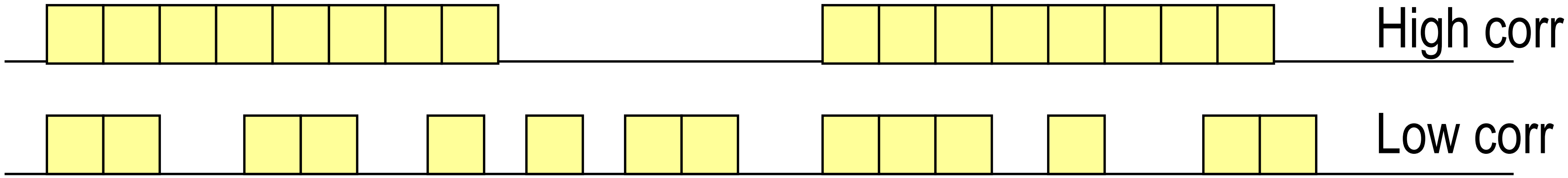
Statistical mux analysis

- ➔**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**

Statistical mux analysis (i)
unbuffered model

N traffic sources;
Source rate = 1;
TDM: N must be <= C

Homogeneous, same activity factor ρ
Link capacity = C
Packet: N may be > C

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

Example: N=5; each having 20% activity

number of active sources	probability
0	32.77%
1	40.96%
2	20.48%
3	5.12%
4	0.64%
5	0.03%

Average load = 5*0.2 = 1
But C=1 appears insufficient…

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

$$P_{overflow} = \sum_{k=C+1}^{N} \binom{N}{k} \rho^k (1-\rho)^{N-k} =$$

$$= 1 - \sum_{k=0}^{C} \binom{N}{k} \rho^k (1-\rho)^{N-k}$$

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%

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**

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%**

$$P_{loss} = \frac{\sum_{k=C+1}^{N} (k-C) \binom{N}{k} \rho^k (1-\rho)^{N-k}}{N\rho} =$$

$$= \frac{1}{N\rho} \sum_{k=C+1}^{N} k \binom{N}{k} \rho^k (1-\rho)^{N-k} - \frac{C}{N\rho} P_{(overflow)}$$

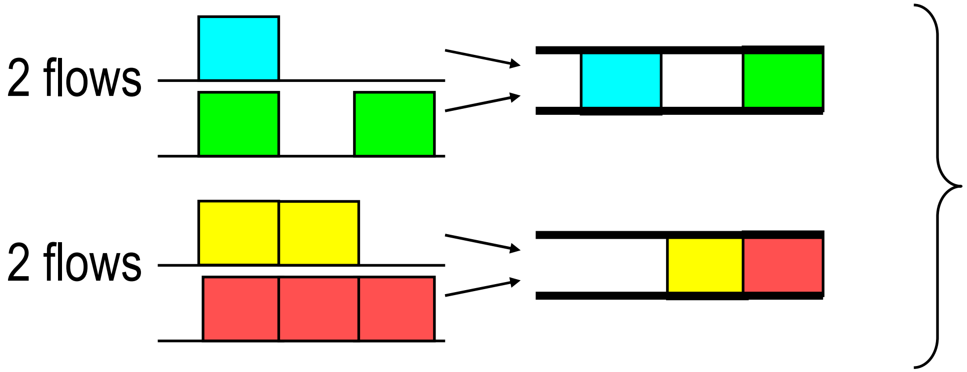
Loss vs overflow

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;
$N \rho = 6$

for $C >> N\rho$:
Overflow=good approx for loss.

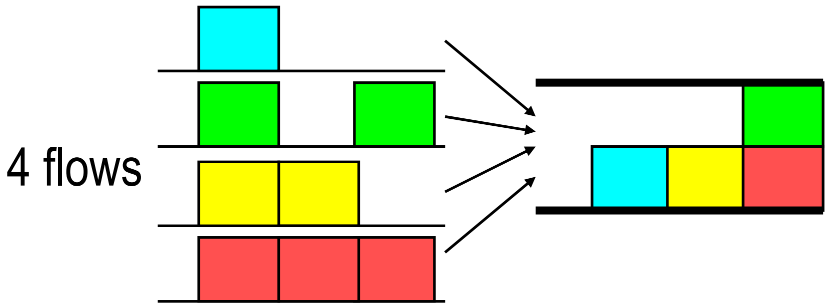
Statistical Mux Gain (i)



Average load = 4 ρ

C = 2

$$Ploss_1 = \frac{1 \times 1 \times \rho^2}{2\rho} = \frac{\rho}{2}$$



Average load = 4 ρ

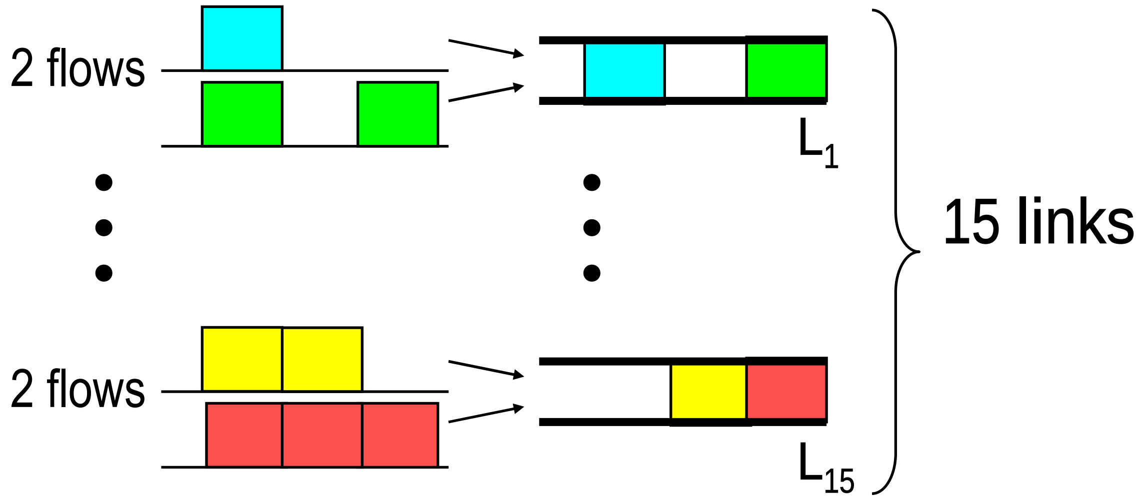
C = 2

$$Ploss_2 = \frac{1 \times 4 \times \rho^3 (1-\rho) + 2 \times 1 \times \rho^4}{4\rho}$$

$$= \frac{\rho^2 (2-\rho)}{2} < Ploss_1$$

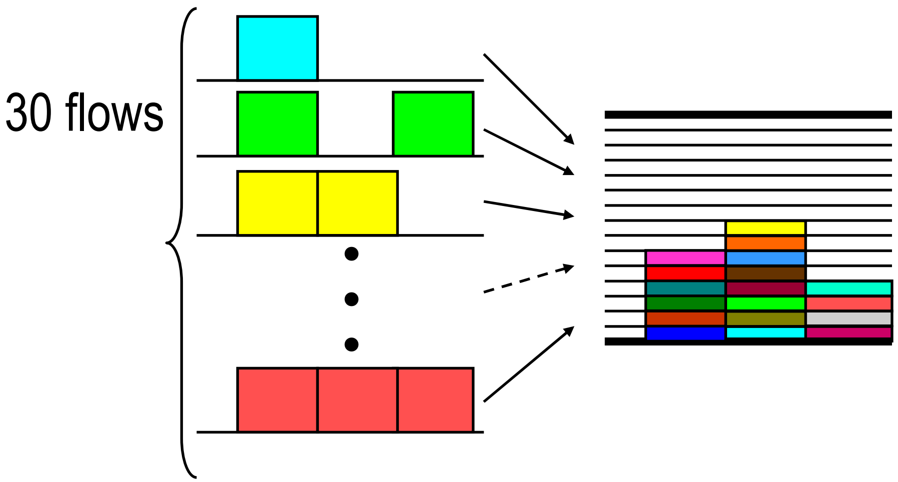
A sample-path argument is faster!

Statistical Mux Gain (ii)



ρ = 20%
Average load = 6
C = 15

$$Ploss_1 = 0.1$$



ρ = 20%
Average load = 6
C = 15

$$Ploss_2 = 1.08 \times 10^{-5}$$

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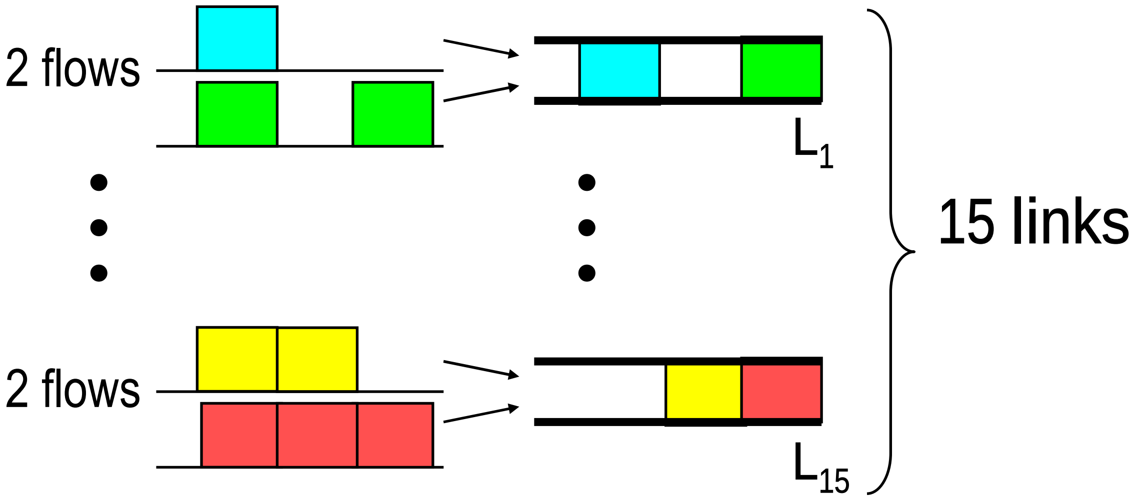
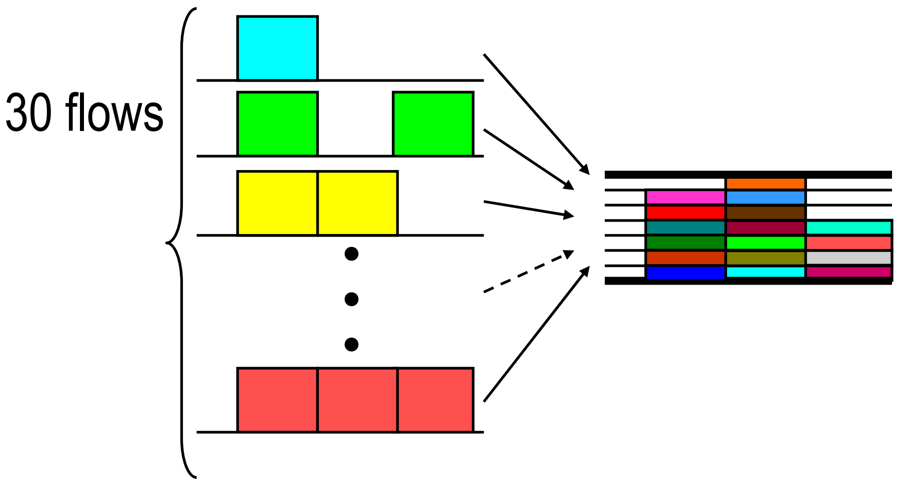
Statistical Mux Gain (iii)



$\rho = 20\%$
Average load = 6
C = 15
$$Ploss_1 = 0.1$$



$\rho = 20\%$
Average load = 6
C = 7
$$Ploss_2 = 0.0781$$

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