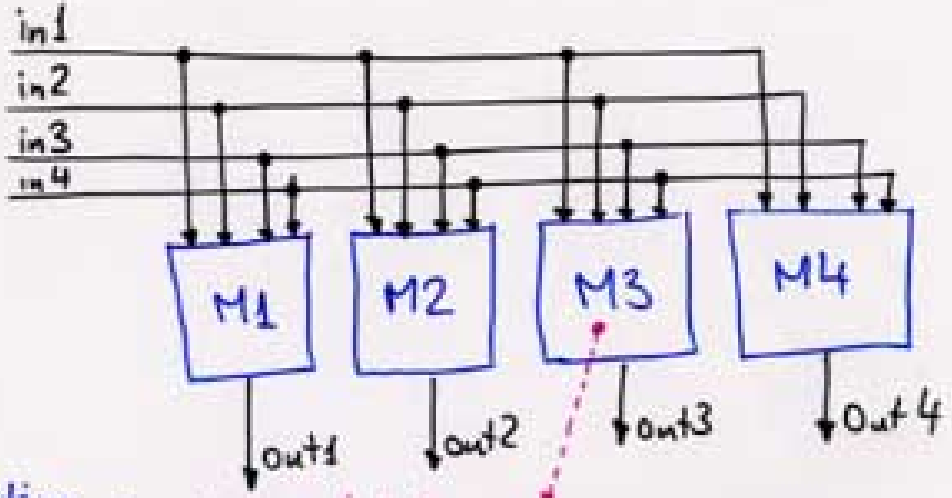
3.2 The Output Queueing / Shared Buffer family of Switch Queueing Architectures

- Time Switching (this chapter):
  - Output Queueing (needlessly expensive): the reference architecture
  - Shared Buffer (improve space utilization): the best, when feasible
  - Crosspoint Queueing: high throughput, low space utilization
  - Block-Crosspoint Queueing: hybrid between shared-buffer & crossp.
- Space Switching (next chapter):
  - Input Queueing, HOL blocking, Virtual-Output Queues (VOQ)
- Combinations (next two chapters):
  - Internal Speedup
  - Switching Fabrics with Internal Buffering

Output Queueing:

The "Reference" Architecture



⇒ "Top" Performance:

- no head-of-line blocking
- full outgoing throughput utilization (no internal blocking)
- "minimum" delay
- adaptable to any QoS policy ⟹
- multicast traffic handled cleanly, at top performance

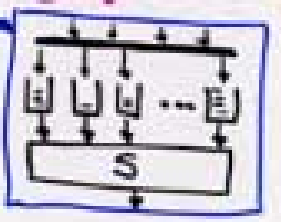
inside each but memory:

- one FIFO queue per output

or:

- multiple queues + scheduler
  - per connection, or
  - per flow, or
  - per group of flows, or
  - per priority, or...

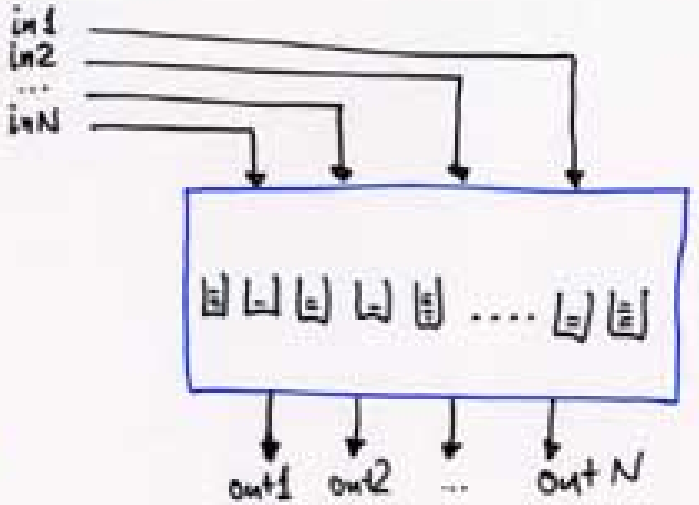
or:



⇒ Unnecessarily High Cost:

- wasteful in memory throughput (but interesting for use with multicast packet pointers)
- partitioned buffer space is less efficient than shared

Shared Buffer:

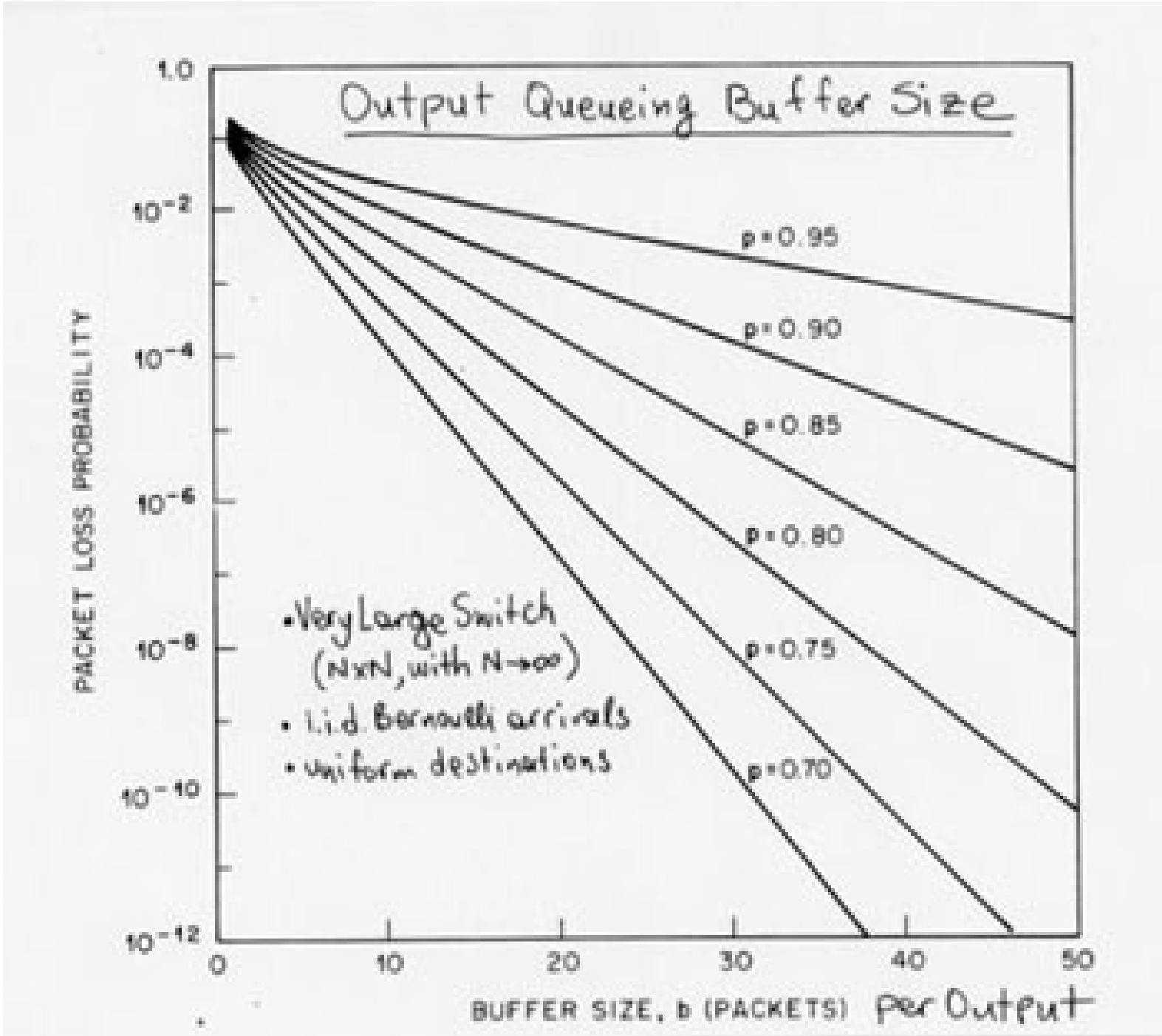


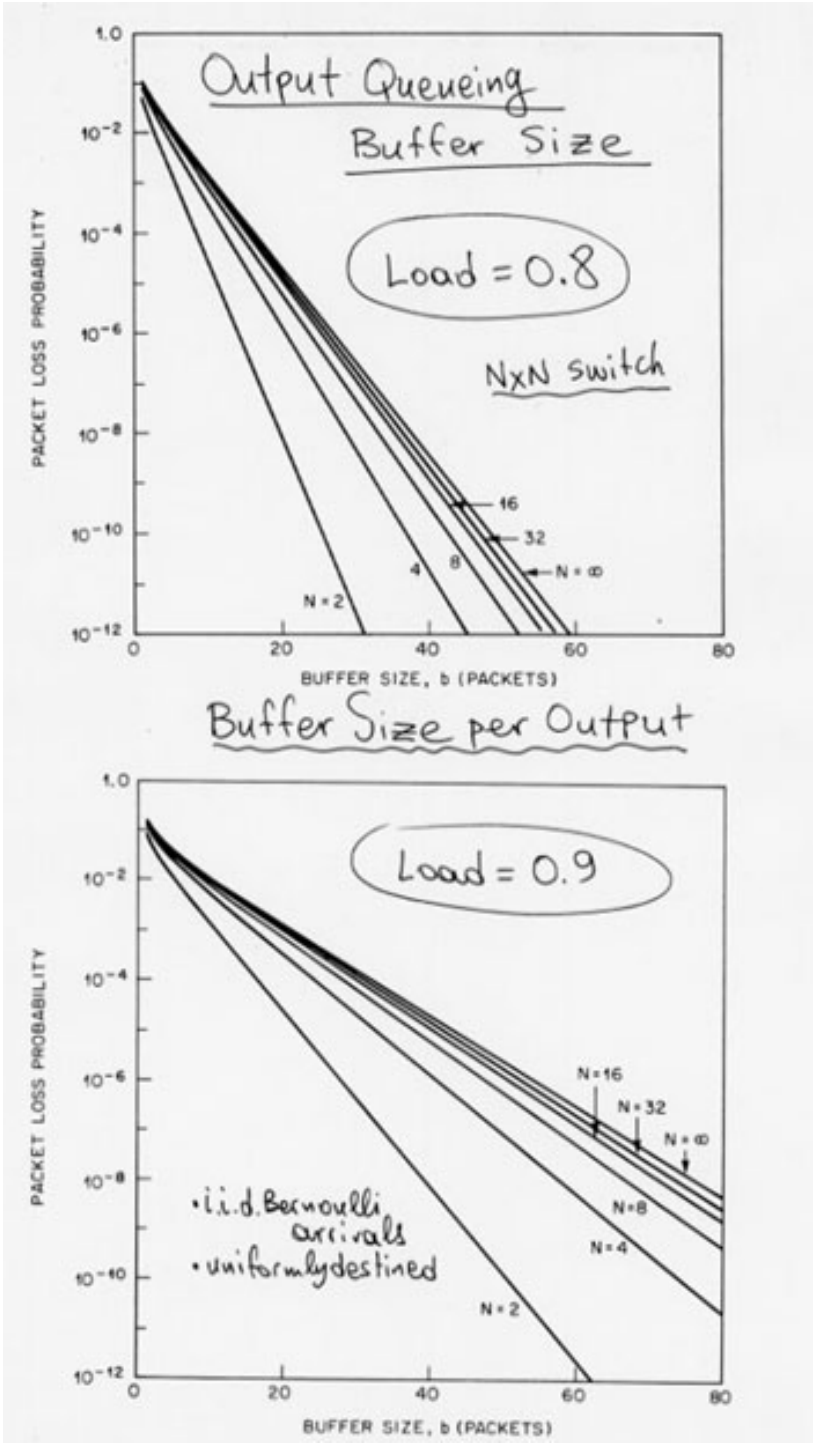
Top Performance at Low Cost for small N

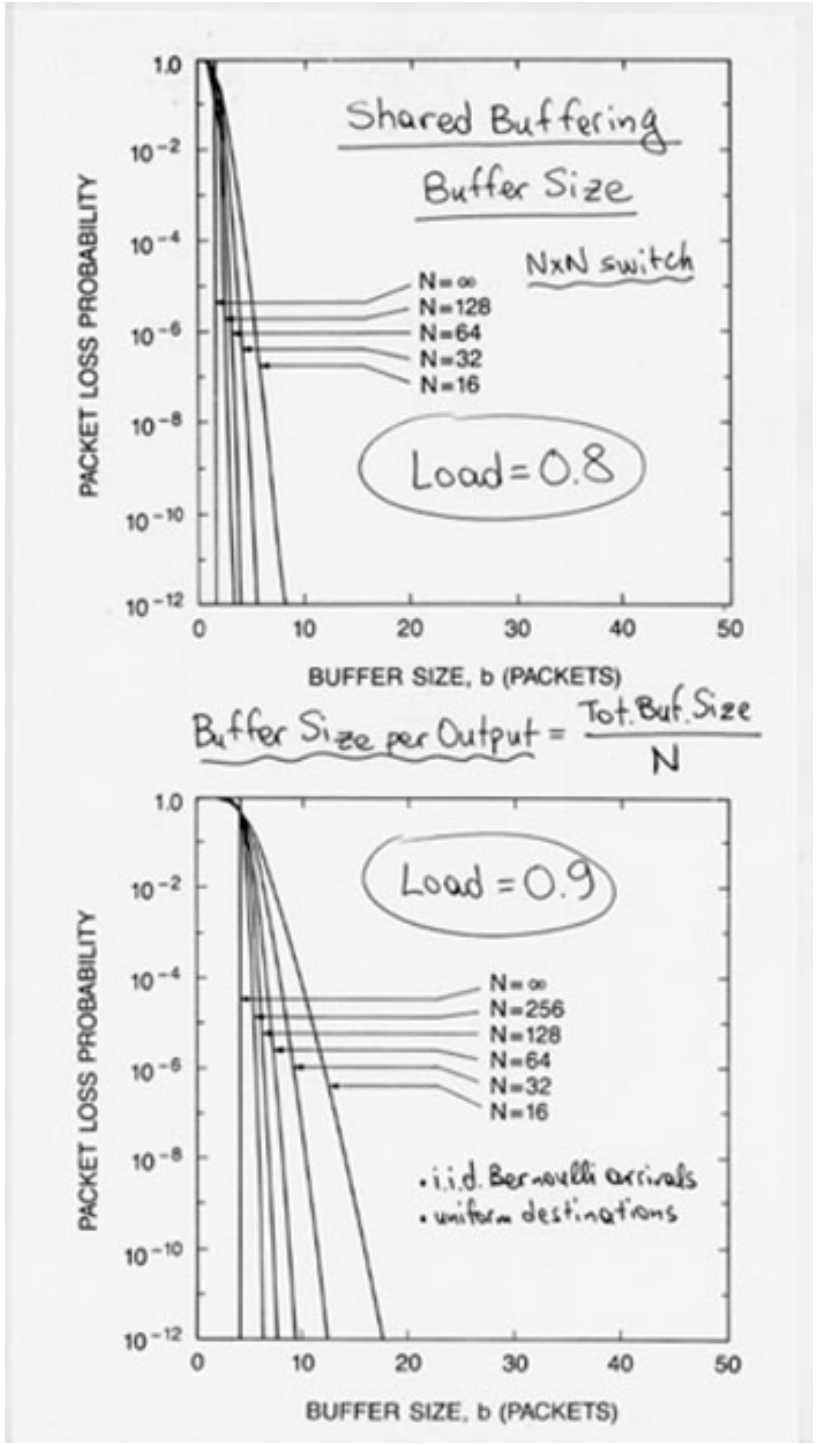
- total buffer memory throughput = 2N
  (versus N×(N+1) for output queueing)
- memory space is shared ⇒ better utilization
- same performance as output queueing for unicast traffic
  - multiple logical queues in a single memory,
    at least per output, possibly also per priority/flow) ...
- for multicast packets: not enough throughput to enqueue each arriving packet into multiple (per output) queues. Hence, if fewer than 2^N multicast queues exist, some head-of-line blocking will occur in them. Interesting combination:
  - shared buffer for packet bodies
  - output queueing for queue pointers

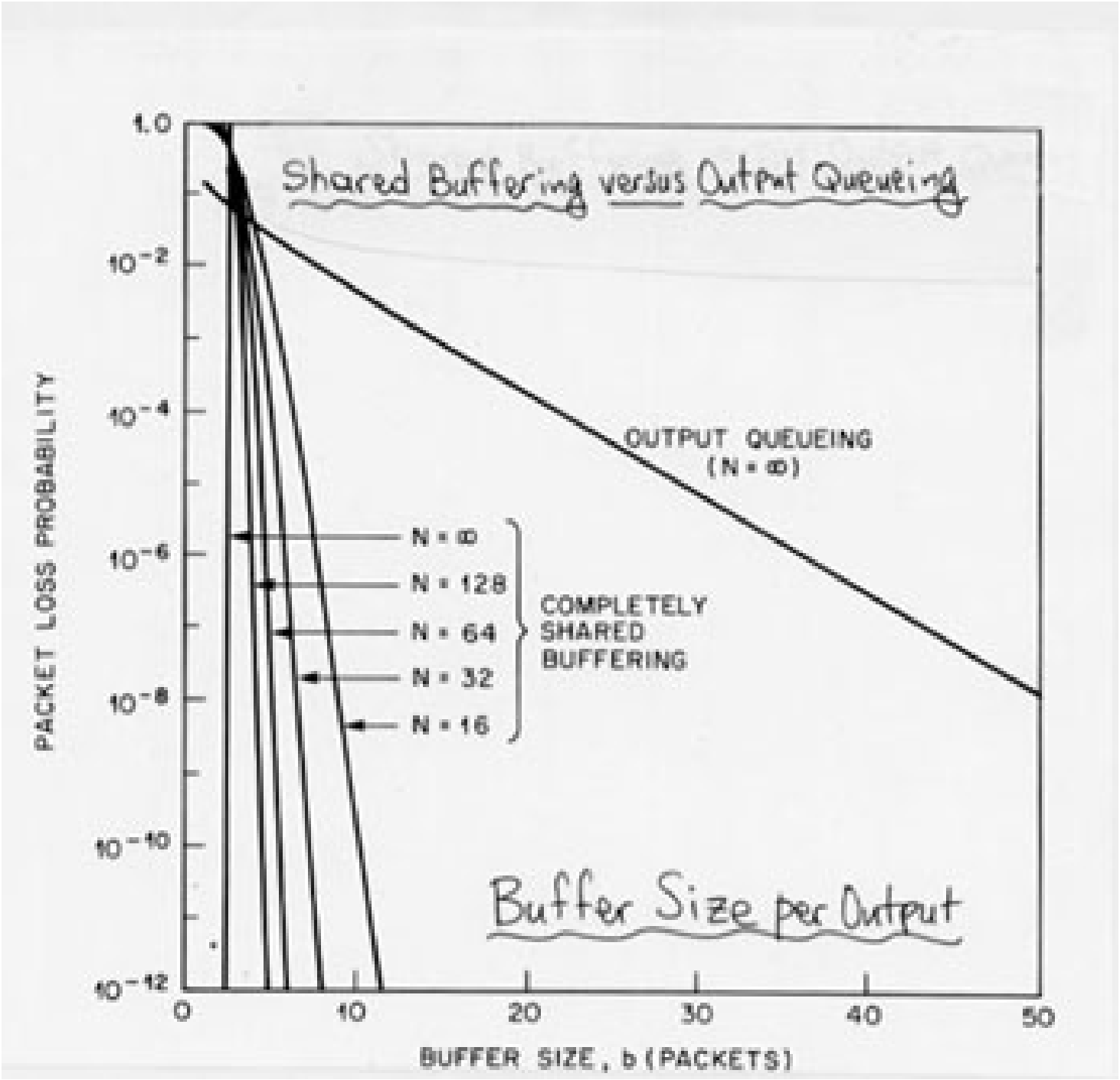
Buffer Space Requirements

- When the incoming traffic consists of fixed-size packets from independent, identically distributed (i.i.d.) Bernoulli processes, with uniformly-distributed destination (output) ports, analysis and simulation have yielded the results plotted below.
- *Reference:* M. Hluchyj, M. Karol: "Queueing in High-Performance Packet Switching", IEEE Journal on Sel. Areas in Commun. (JSAC), vol. 6, no. 9, Dec. 1988, pp. 1587-1597
- *Attention:* results derived for i.i.d. Bernoulli (non-bursty) arrivals, with uniformly-distributed destinations (no overloaded hot-spots), are only useful for gaining a rough, first insight into the behavior of systems, but are often not representative of the real behavior of systems under real traffic!...


Output Queueing Buffer Size
PACKET LOSS PROBABILITY
1.0
10^{-2}
10^{-4}
10^{-6}
10^{-8}
10^{-10}
10^{-12}
p = 0.95
p = 0.90
p = 0.85
p = 0.80
p = 0.75
p = 0.70
• Very Large Switch (NxN, with N→∞)
• i.i.d. Bernoulli arrivals
• uniform destinations
0
10
20
30
40
50
BUFFER SIZE, b (PACKETS) per Output

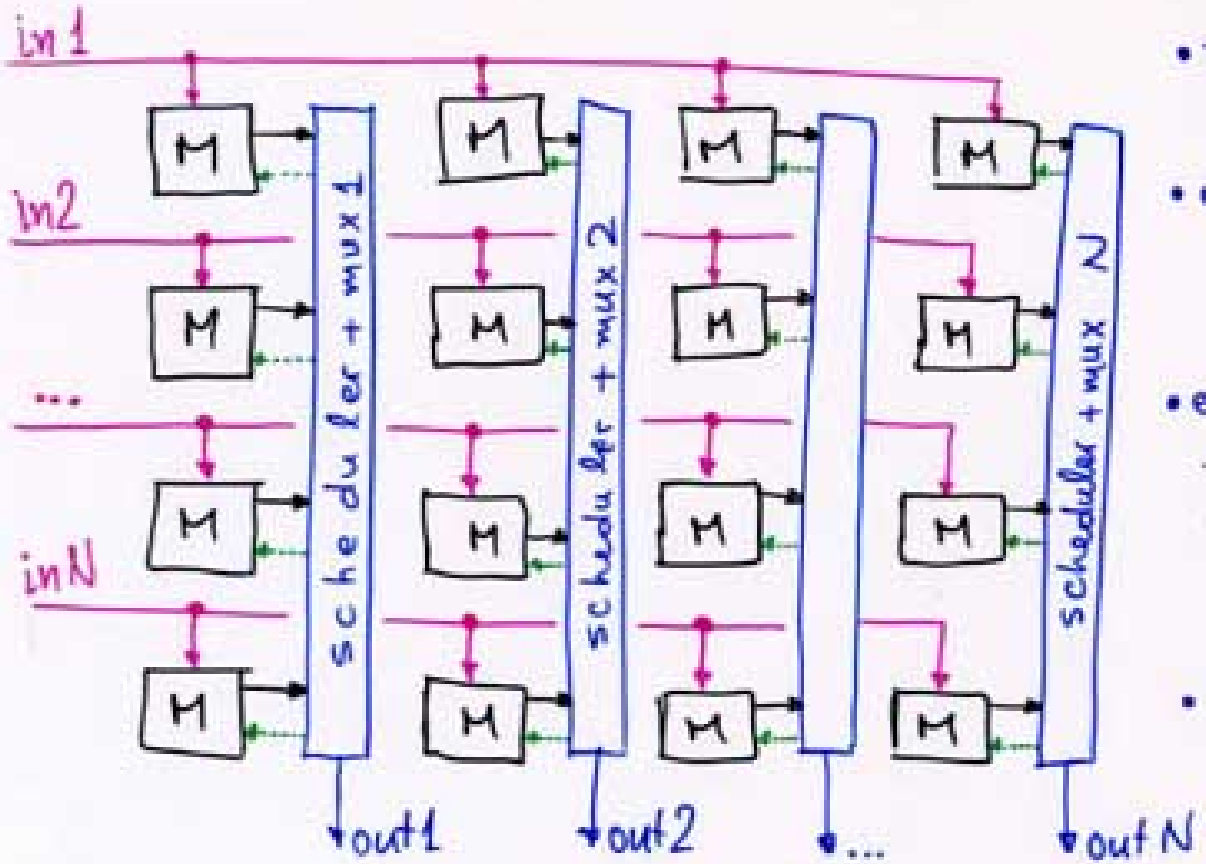

Output Queueing
Buffer Size
Load = 0.8
NxN switch
PACKET LOSS PROBABILITY
BUFFER SIZE, b (PACKETS)
N = 2
4
8
16
32
N = ∞
Buffer Size per Output
Load = 0.9
• i.i.d. Bernoulli arrivals
• uniformly destined
N = 16
N = 32
N = ∞
N = 8
N = 4
N = 2
PACKET LOSS PROBABILITY
BUFFER SIZE, b (PACKETS)


Shared Buffering
Buffer Size
NxN switch
N = ∞
N = 128
N = 64
N = 32
N = 16
Load = 0.8
PACKET LOSS PROBABILITY
BUFFER SIZE, b (PACKETS)
Buffer Size per Output = Tot. Buf. Size / N
Load = 0.9
N = ∞
N = 256
N = 128
N = 64
N = 32
N = 16
• i.i.d. Bernoulli arrivals
• uniform destinations
PACKET LOSS PROBABILITY
BUFFER SIZE, b (PACKETS)


Shared Buffering versus Output Queueing
PACKET LOSS PROBABILITY
1.0
10^{-2}
10^{-4}
10^{-6}
10^{-8}
10^{-10}
10^{-12}
OUTPUT QUEUEING
(N = ∞)
N = ∞
N = 128
N = 64
N = 32
N = 16
COMPLETELY
SHARED
BUFFERING
Buffer Size per Output
0
10
20
30
40
50
BUFFER SIZE, b (PACKETS)

Load =
85 %

Crosspoint (Distributed) Queueing:



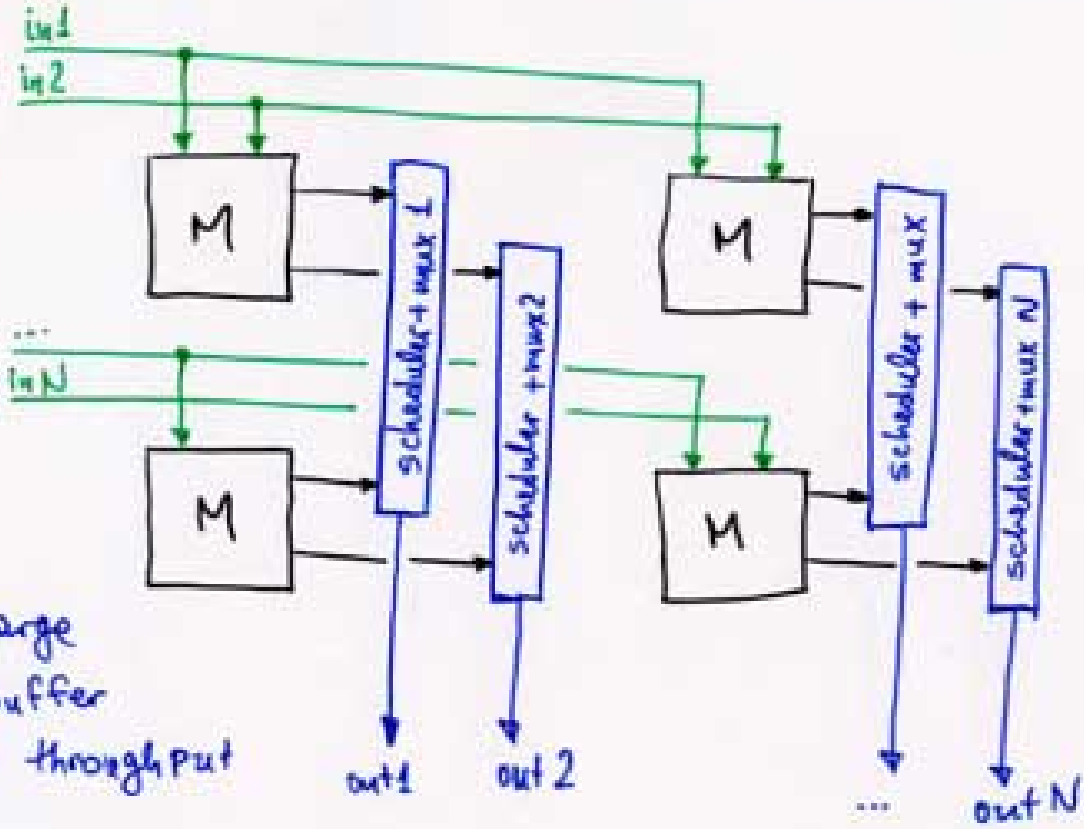
- top performance, like output queueing
- even more wasteful in memory throughput, and even more partitioned space
- existence proof of top performance switches: indiv. mem. block throughput = = Constant = 2, indep. of N
- very expensive ($\sim N^2$) for large N

Note: "←----" is notification that this buffer was selected, in order for it to perform a dequeue; it is the most primitive form of backpressure!

Block-Crosspoint Queueing:

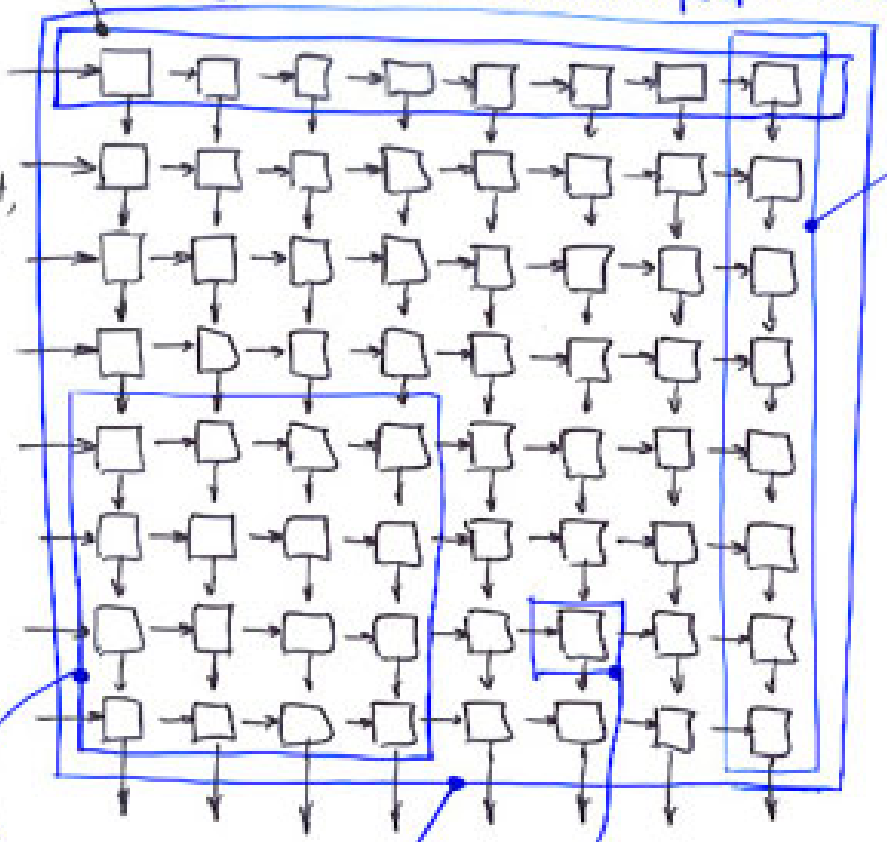
Distributed Shared Buffers

- Combination of:
  - crosspoint queueing
  - shared buffer
- Interesting when N is so large that a single shared buffer would need too high a throughput
- Applicable for arbitrarily large N, but cost grows with $\left(\frac{N}{c}\right)^2$.



Conceptual Derivation/Taxonomy of Queueing Architectures

- Buffer memory throughput is proportional to the periphery of the rectangle; memory space utilization is proportional to its area.



Unnamed, wasteful version of input queueing (noone uses it ...): very large outgoing throughput, so as to allow the (rare) case where all outputs simultaneously decide to forward packets that arrived through the same input. By using a more complicated scheduler, that look at all outputs - not just each output in isolation - we can arrange that only a single output reads from here every time ("input queueing"), or a few of them read from here at a time ("internal speedup" or "Combined Input/output Queueing").

Block Crosspoint Queueing

Shared Buffer

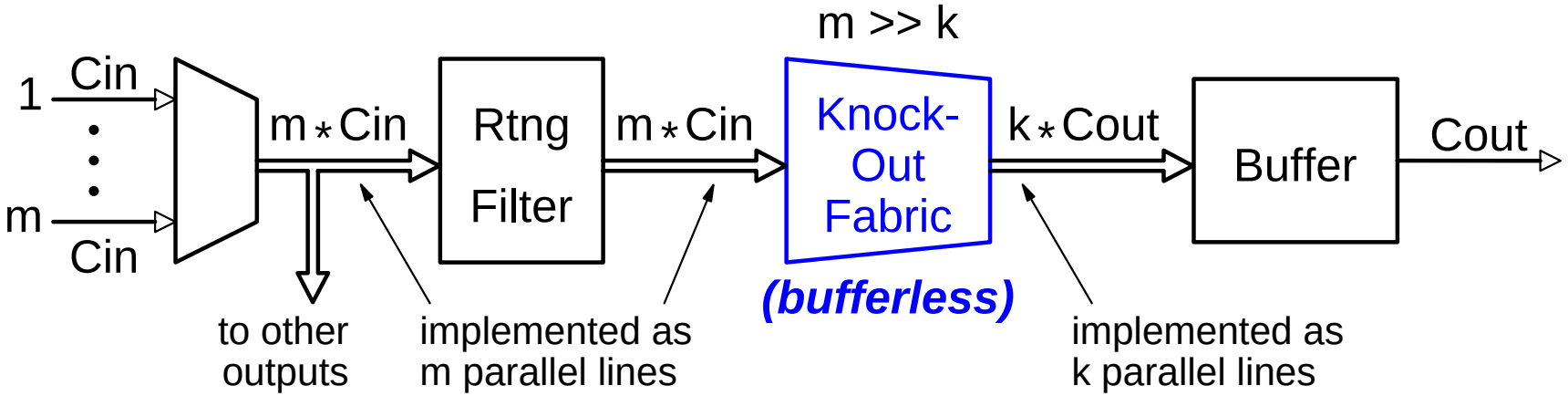
Crosspoint Queueing (Buffered Crossbar)

Output Queueing

Very large incoming throughput, because it may happen that all incoming packets are destined to a same output, at some worst-case time.

If we economize on write throughput, like "Knock-out" architecture does, then we risk to have to drop some incoming packets on some (rare?) situations

Other Variations of Output Queueing: **Knock-Out Switch**



Knock-Out Fabric:

- has m inputs and k outputs, k << m
- passes on up to k non-idle packets to its outputs
- when more than k packets arrive in the same time slot, all destined to the same output, k of them are passed and the rest are dropped
- if the traffic is uniformly destined, and k is on the order of 8 to 12, packets will rarely be dropped

See: Yeh, Hluchyj, Acampora: IEEE JSAC, October 1987, pp. 1274-1283.