3. Time Switching, Multi-Queue Memories, Shared Buffers, Output Queueing Family

3.1 TDM, Time Switching, Cut-Through

3.2 Wide Memories for High Thruput, Segm'tn Ovrhd

3.3 Multiple Queues within a Buffer Memory

3.4 Queueing for Multicast Traffic

3.5 Shared Buffering and the Output Q'ing Family

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3.5 Output Queueing & Shared Buffer Family

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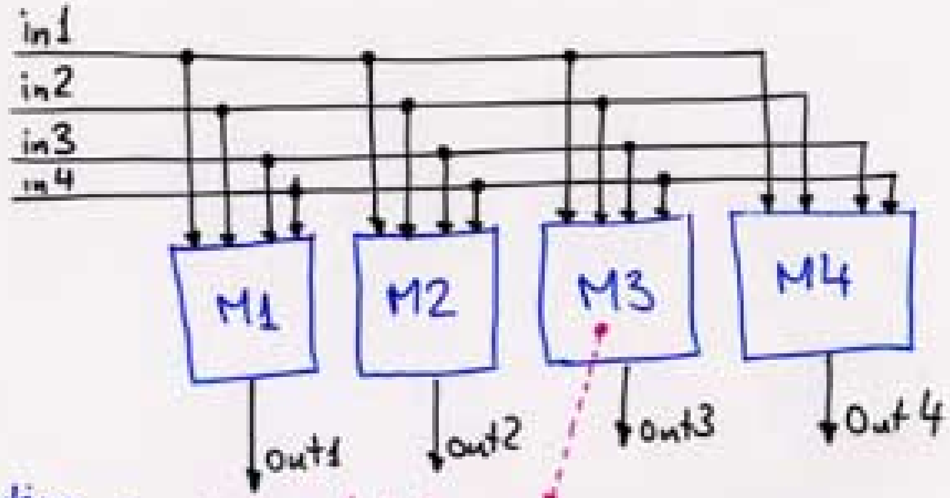
Output Queueing:

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

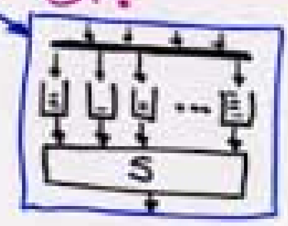
inside each buf memory:

- one FIFO queue per output

or:

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

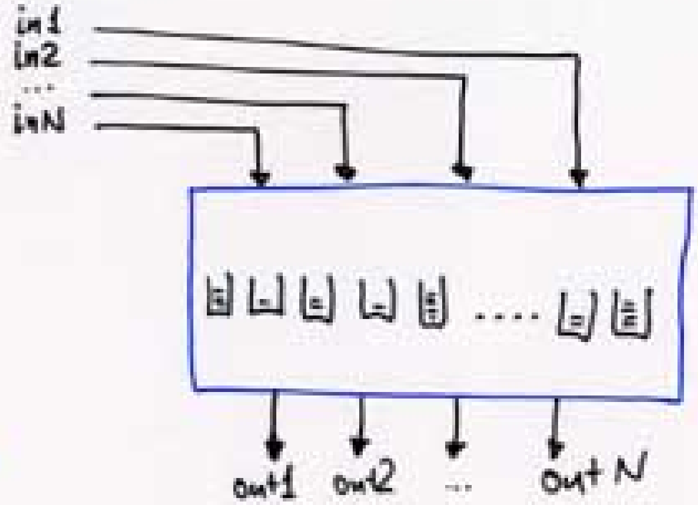
or:



⇒ 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:

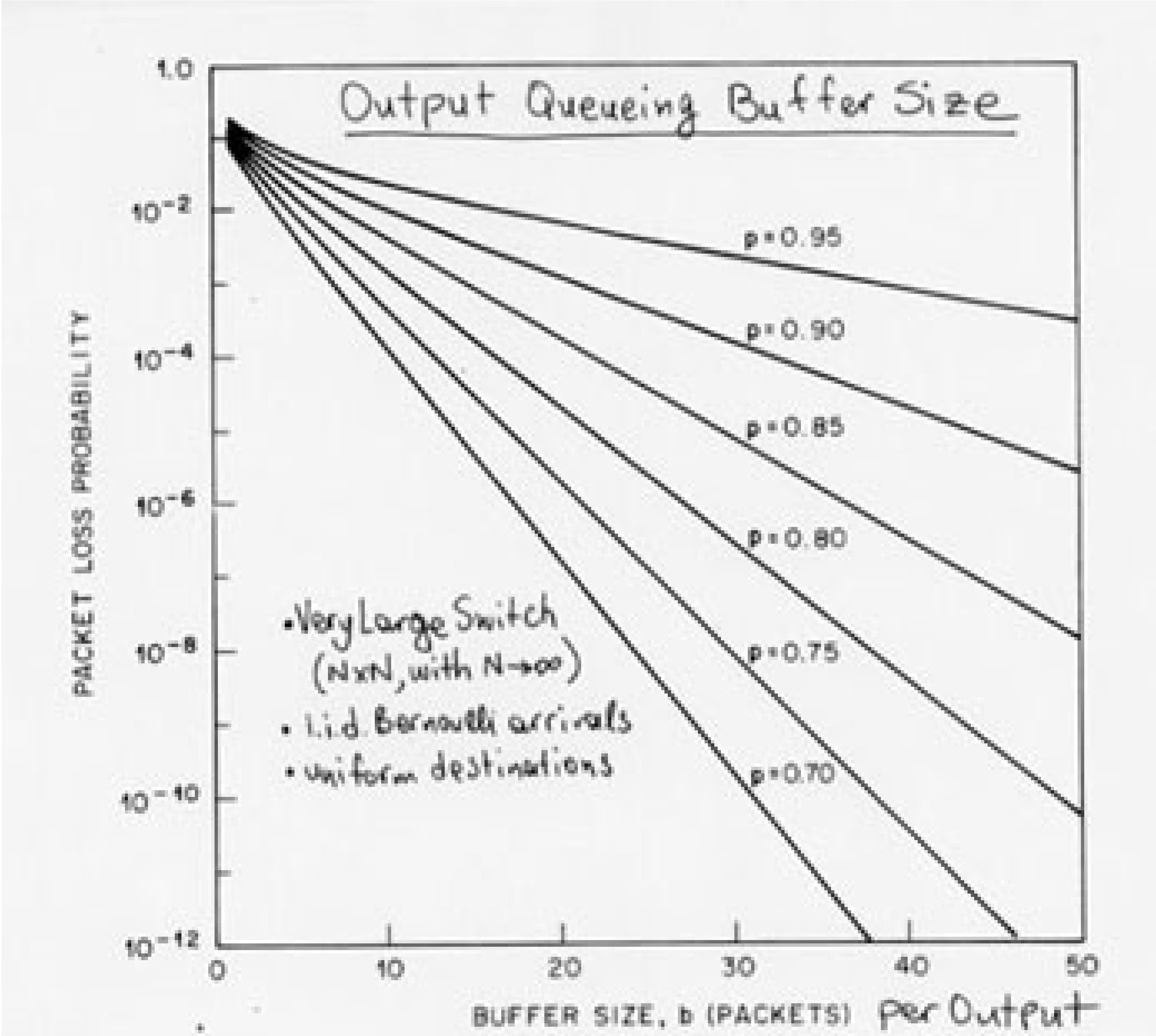


Top Performance at Low Cost for small N

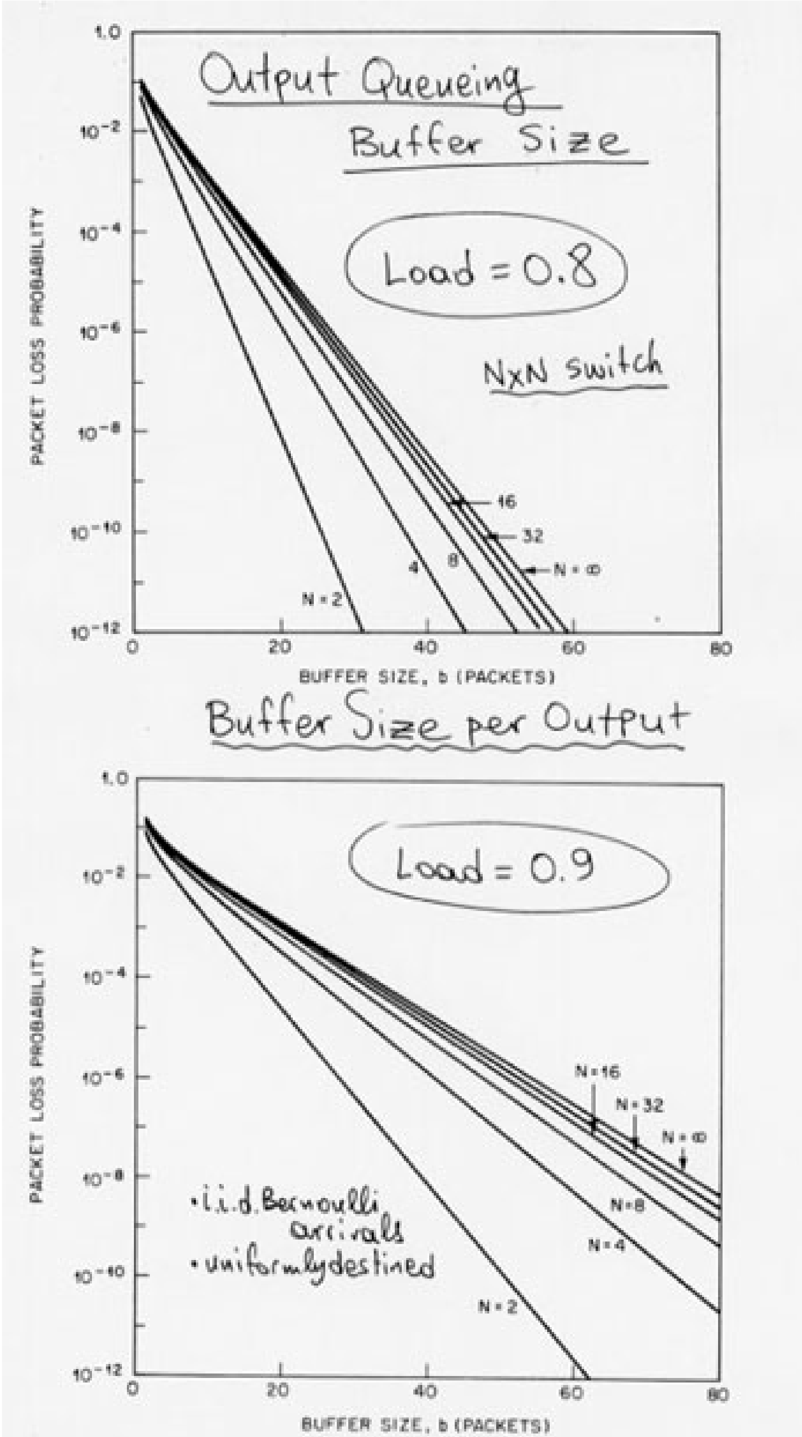
- total buffer memory throughput = 2N
  (versus N×(N+1) for output queueing)
- memory space is shared ⇒ better utilization
- same performance as output queueing for unicast traffic
  - multiple logical queues in a single memory, at least per output, possibly also per priority/flow)...
- for multicast 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

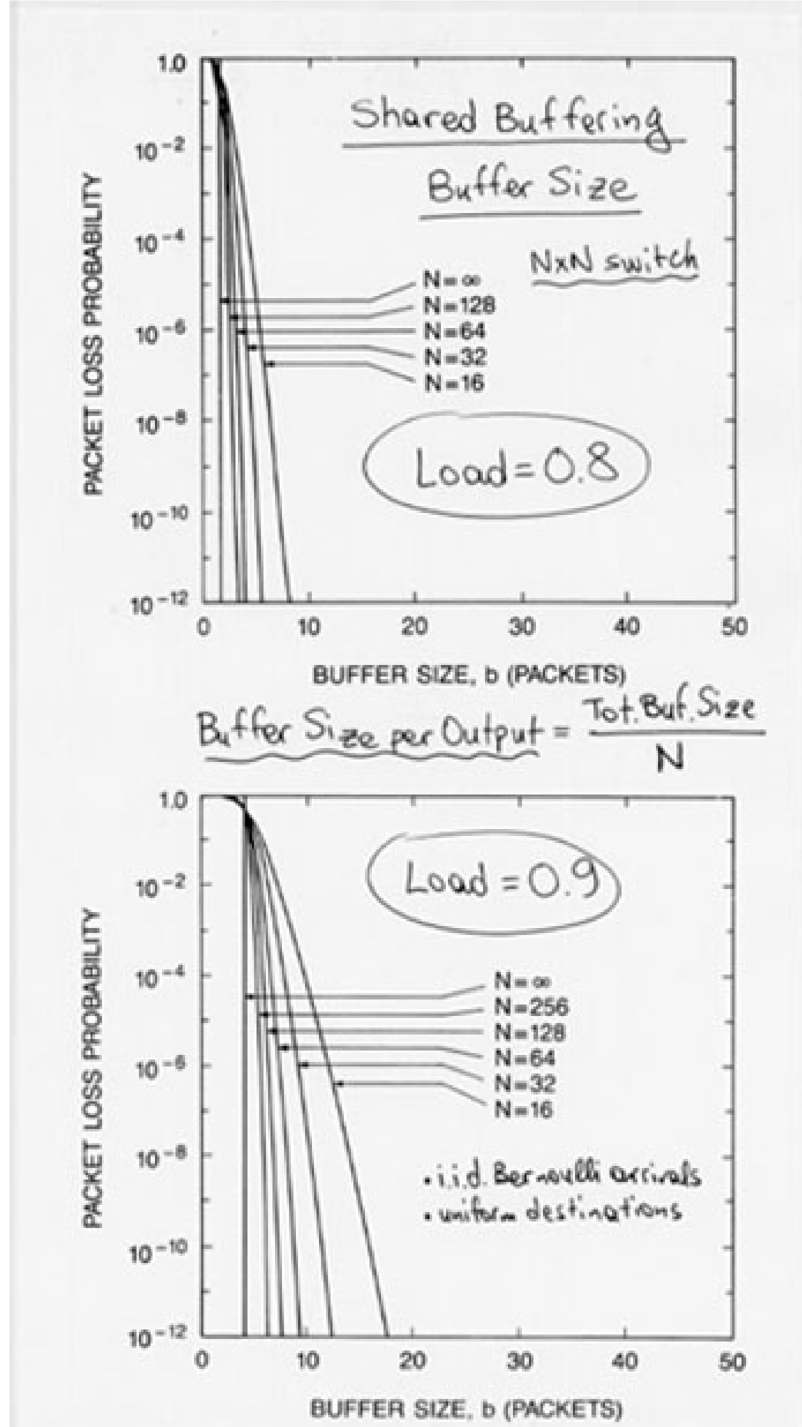
3.5.2 Buffer Space Requirements: Analysis Results

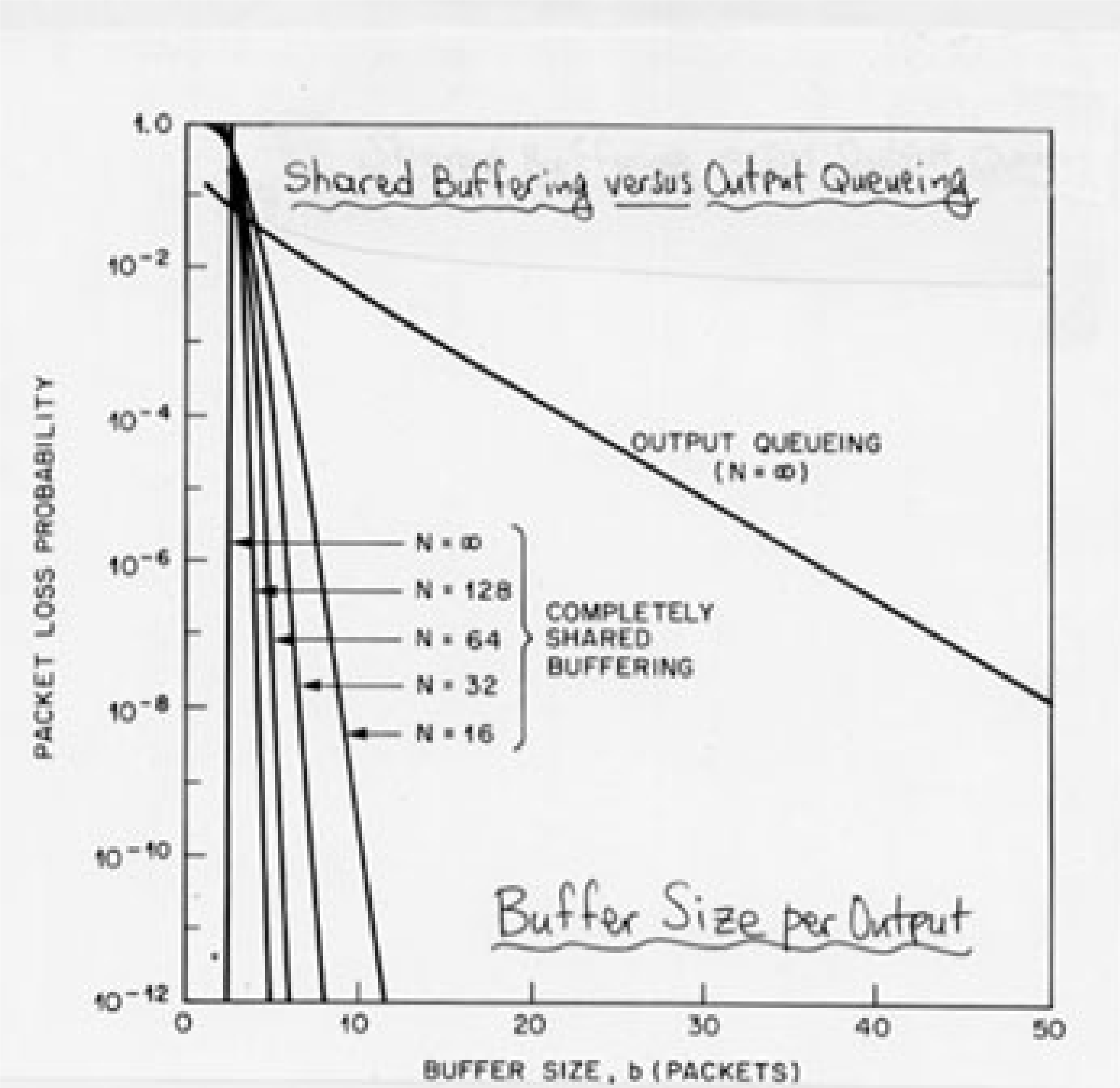
- Analysis & simulation have yielded the results plotted below
  - *Reference:* M. Hluchyj, M. Karol: "Queueing in High-Performance Packet Switching", IEEE Journal on Sel. Areas in Communications (JSAC), vol. 6, no. 9, Dec. 1988, pp. 1587-1597
- **Assuming** that the input traffic consists of packets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



Output Queueing Buffer Size
1.0
10⁻²
10⁻⁴
10⁻⁶
10⁻⁸
10⁻¹⁰
10⁻¹²
PACKET LOSS PROBABILITY
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

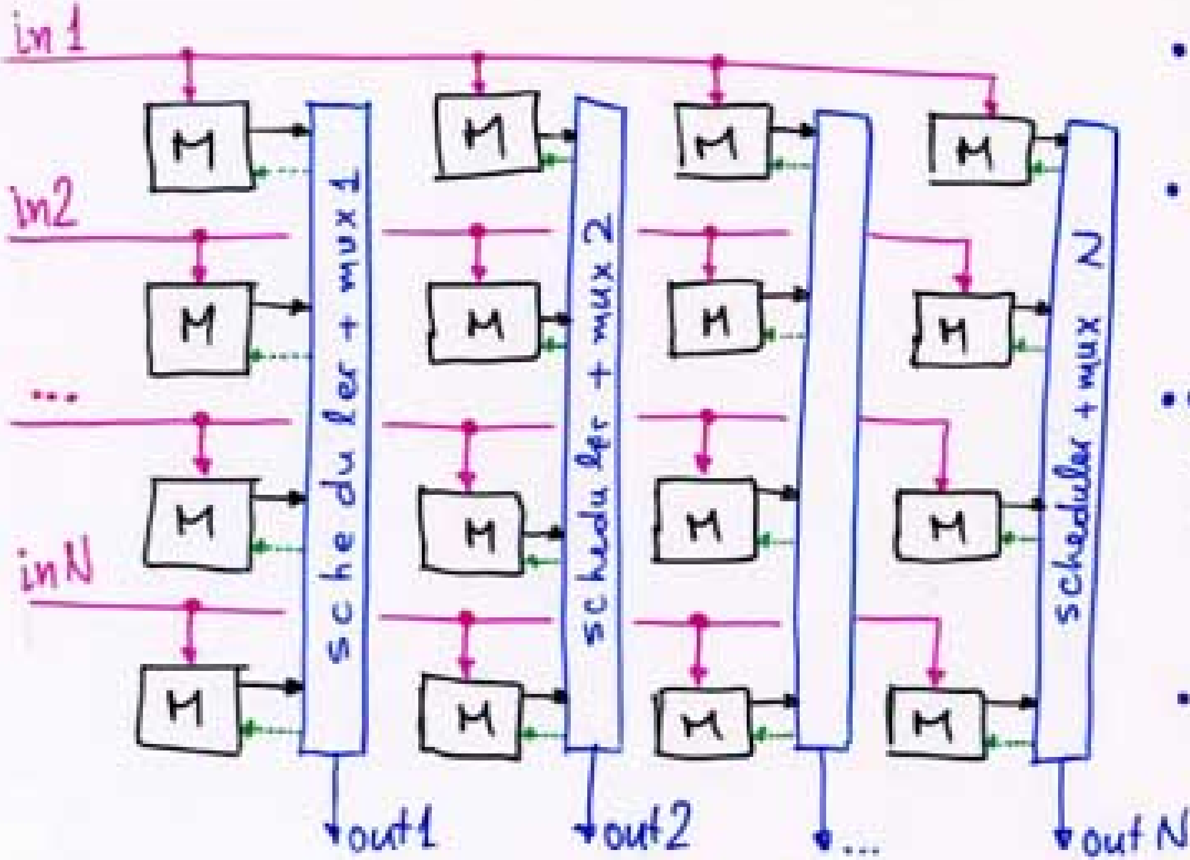

Output Queueing
Buffer Size
Load = 0.8
NxN switch
PACKET LOSS PROBABILITY
1.0
10⁻²
10⁻⁴
10⁻⁶
10⁻⁸
10⁻¹⁰
10⁻¹²
N = 2
4
8
16
32
N = ∞
0
20
40
60
80
BUFFER SIZE, b (PACKETS)
Buffer Size per Output
Load = 0.9
N = 16
N = 32
N = ∞
N = 8
N = 4
N = 2
• i.i.d. Bernoulli arrivals
• uniformly destined


Shared Buffering
Buffer Size
NxN switch
Load = 0.8
PACKET LOSS PROBABILITY
1.0
10⁻²
10⁻⁴
10⁻⁶
10⁻⁸
10⁻¹⁰
10⁻¹²
N = ∞
N = 128
N = 64
N = 32
N = 16
0
10
20
30
40
50
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


Shared Buffering versus Output Queueing
1.0
10^{-2}
10^{-4}
10^{-6}
10^{-8}
10^{-10}
10^{-12}
PACKET LOSS PROBABILITY
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:

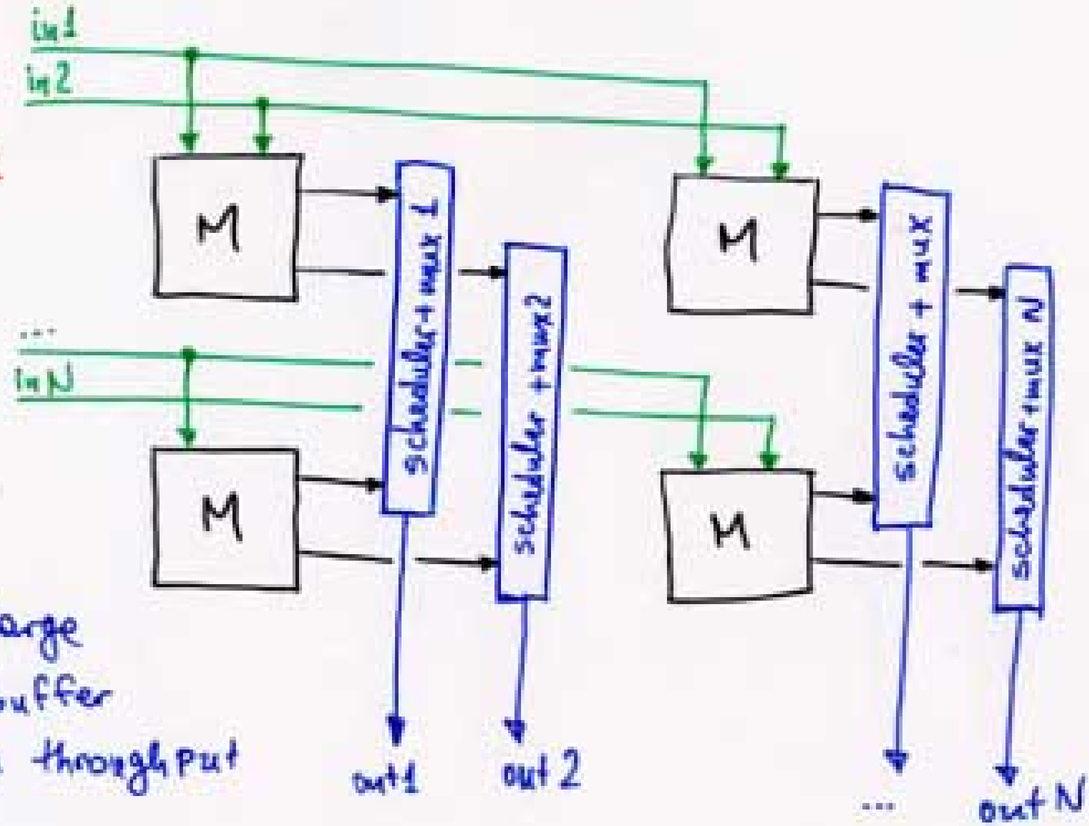


- top performance, like output queueing
- even more wasteful in memory throughput, and even more partitioned space
- existence proof of top performance switches: indiv. mem. block throughput = = Constant = 2, indep. of N
- <u>very</u> expensive ($\sim N^2$) for large N

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

Block-Crosspoint Queueing:

Distributed Shared Buffers

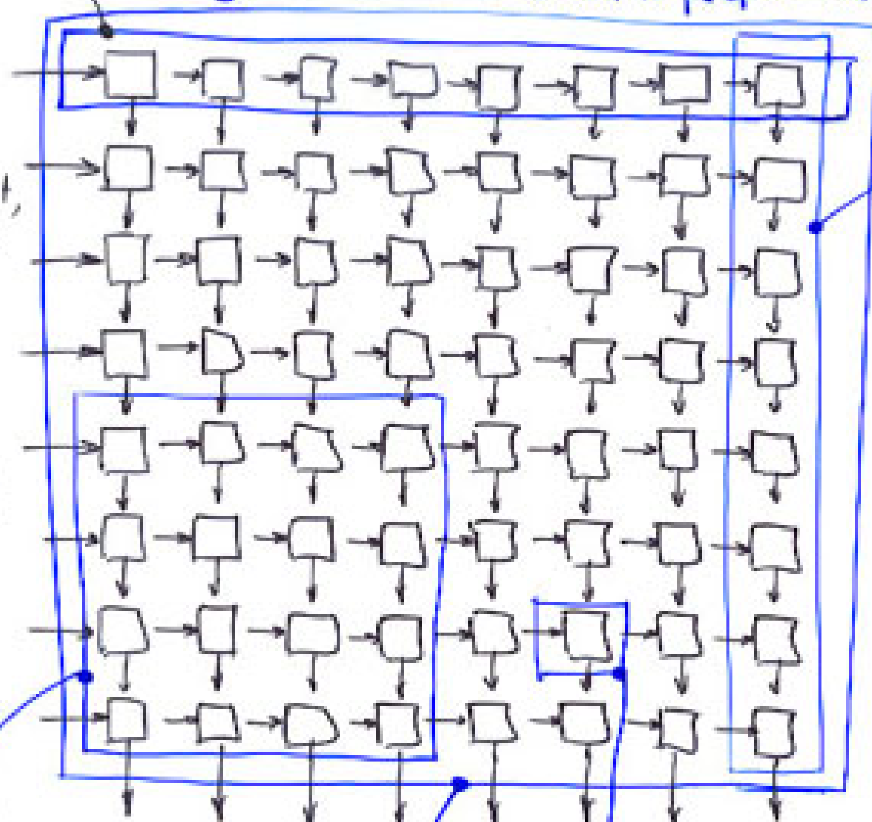


- Combination of:
  - crosspoint queueing
  - shared buffer
- Interesting when N is so large that a single shared buffer would need too high a throughput
- Applicable for arbitrarily large N, but cost grows with $\left(\frac{N}{c}\right)^2$.

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.

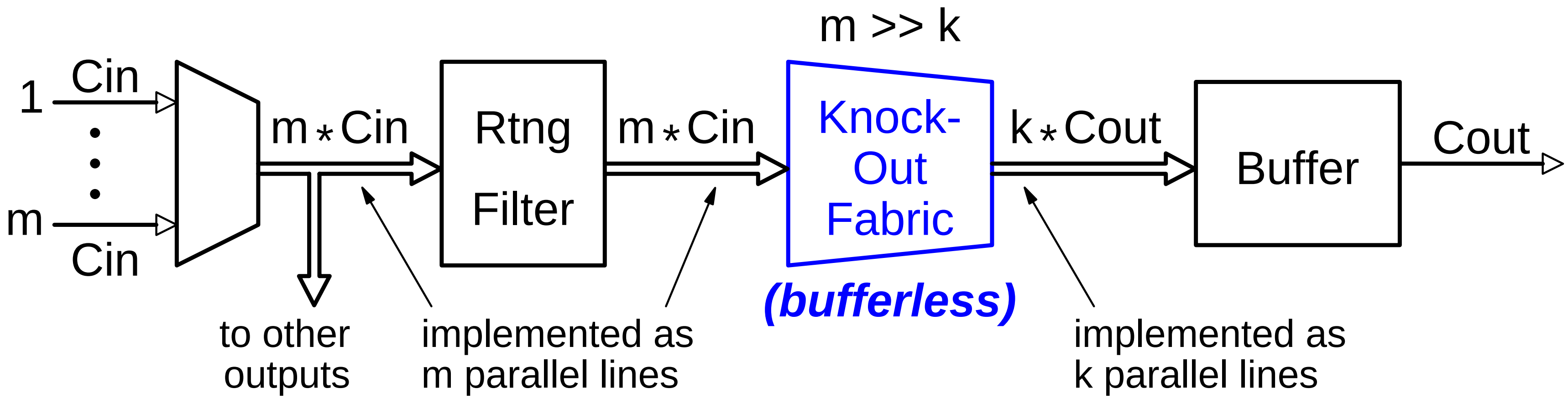
Unnamed, wasteful version of input queueing (noone uses it...): very large outgoing throughput, so as to allow the (rare) case where all outputs simultaneously decide to forward packets that arrived through the same input. By using a more complicated scheduler, that look at all outputs – not just each 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")



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.