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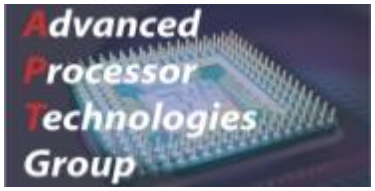

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An Asynchronous Routing Algorithm for Clos Networks

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Outline

- Introduction of Clos networks and asynchronous circuits
- Classic Synchronous dispatching algorithms
  - Random dispatching (RD)
  - Concurrent Round-Robin Dispatching (CRRD)
- Asynchronous Dispatching (AD) algorithm
- Implementation
- Outcome
  - 32-port Clos network. Setup 6.2 ns, release 3.9 ns.

Switching Networks

- Telephone networks
- Asynchronous transfer mode (ATM) and IP networks
  - ATLANTA chip (622Mb/s/port, 1997)
  - Petastar Optical Switch (160Gb/s/port, 2003)
- ***Intra/inter chip interconnect***
  - High-radix router with many narrow ports
  - SDM: delay guaranteed services

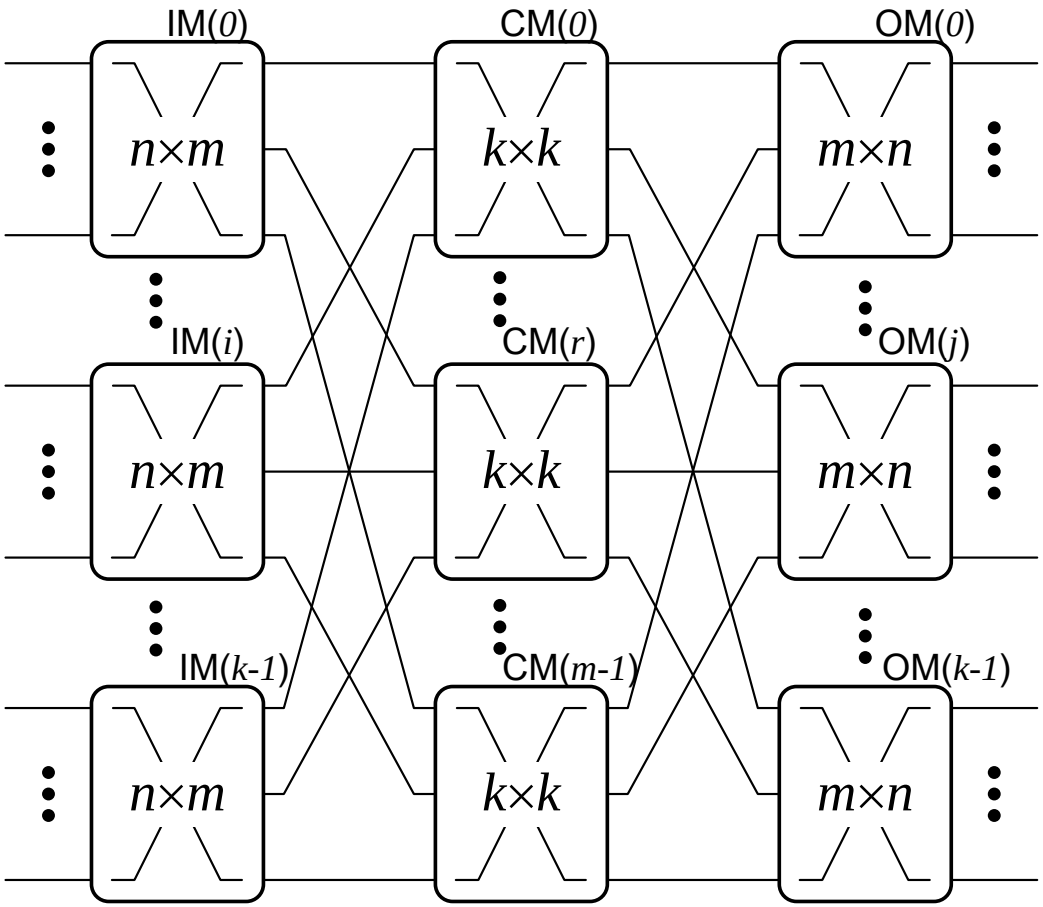
Asynchronous Circuit

- Asynchronous vs. synchronous
  - ***Low power (clockless)***
  - Possible performance boost (average latency)
  - ***Tolerance to process variation***
- Implementation style
  - 2-phase vs. 4-phase
  - Bundled-data vs. quasi-delay insensitive (QDI)
  - ***4-phase QDI***

Research Target

- An area-efficient and high-speed switching network for on-chip networks
  - High-radix router
  - Low-power consumption
  - Tolerance to process variation
  - Area efficient

Clos Switching Network



3 stages:
IMs, CMs and OMs

C(n, k, m):
k IM/OMs
n ports per IM/OM
m CMs

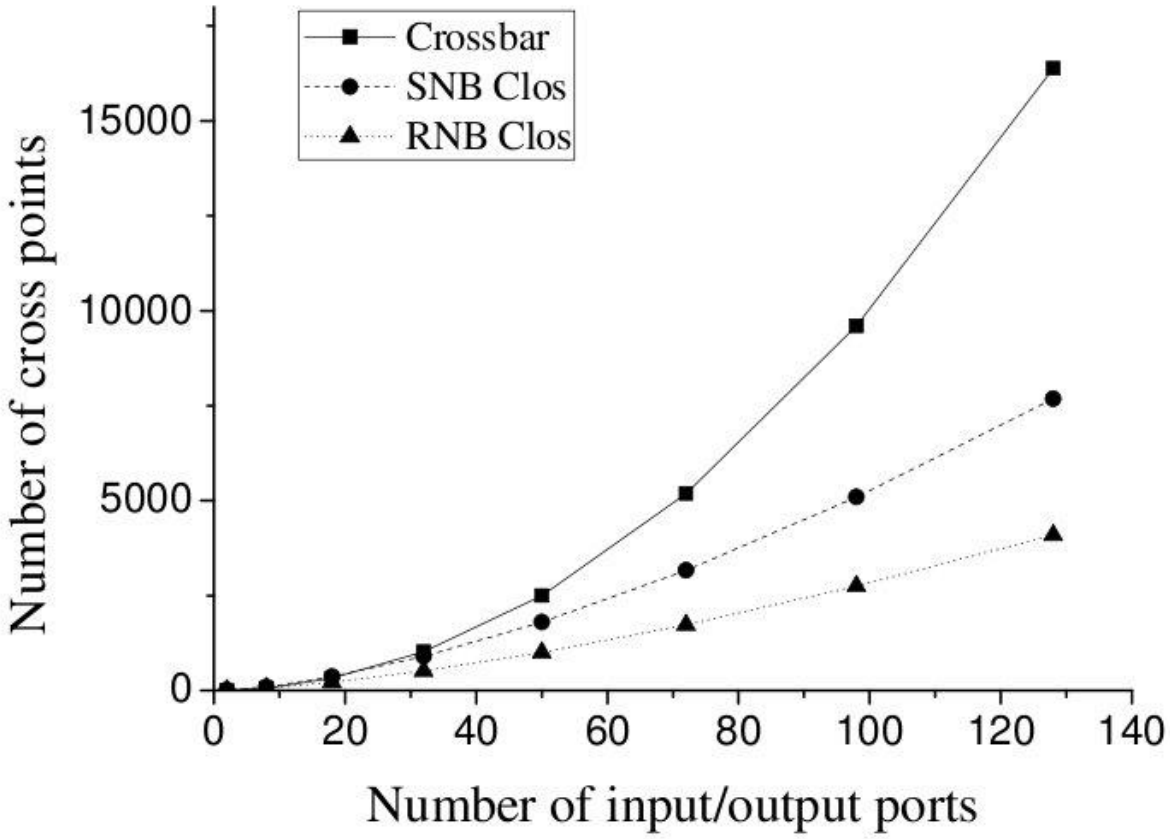
LI links between IM/CM
LO links between CM/OM

SMS: buffer CM
MSM: buffer IM/OM
S³: no buffer

Non-Blocking

- Blocking
  - An available input/output pairs may not be connected due to internal blocking.
- Strict Non-Blocking (SNB)
  - All available input/output pairs are connectable.
  - $m \geq 2n-1$
- Rearrangeable Non-Blocking (RNB)
  - Connecting available input/output pairs may require internal permutation.
  - $n \leq m < 2n-1$

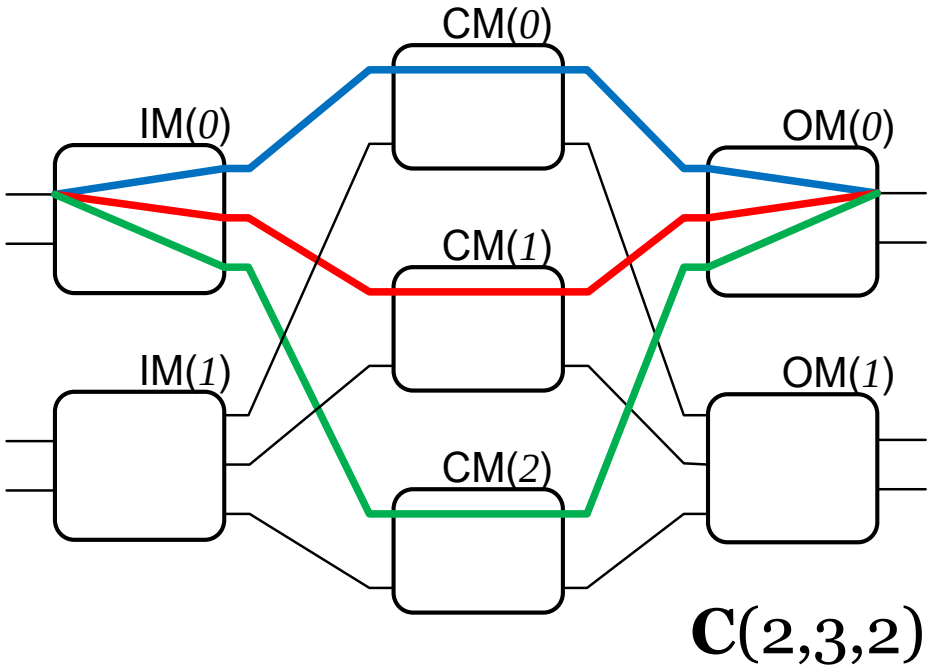
Area Consumption



Routing Algorithms

- Optimal algorithms
  - Algorithms provide guaranteed results for all matches but with a higher complexity in time and implementation.
- Heuristic algorithms
  - Algorithms provide all or partial connections in much lower time complexity.
- Most dynamically reconfigurable Clos networks use heuristic algorithms

Dispatching Algorithms

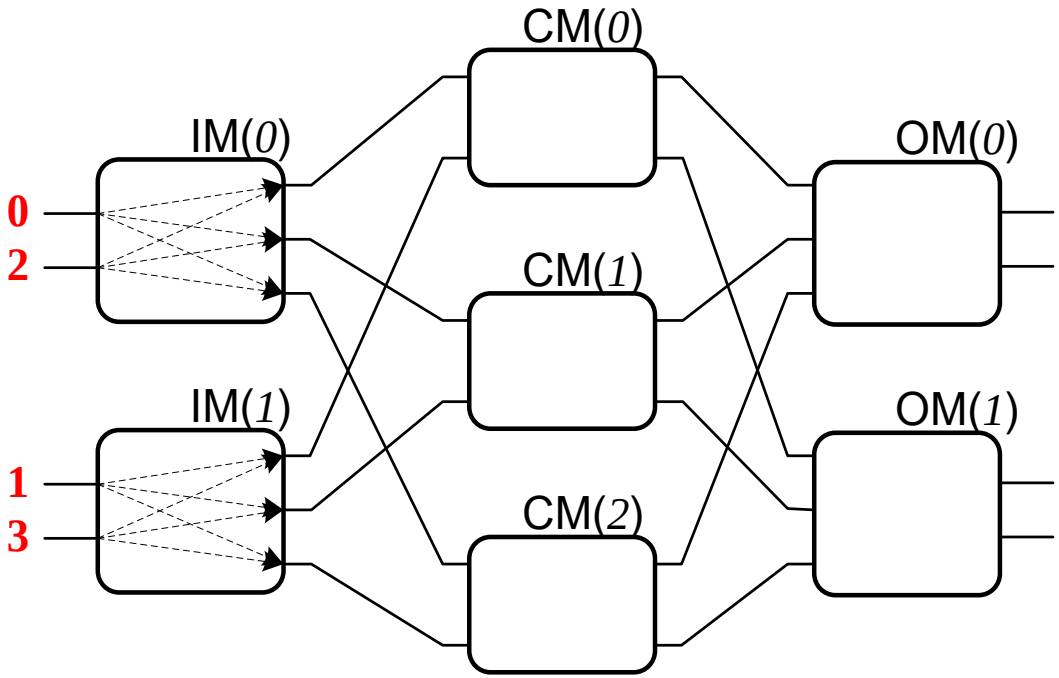


Every Input/output pair has *m* paths. Packets are dispatched evenly to all CMs.

Dispatching algorithm: the algorithm used in IM to CM packet dispatching.

Random Dispatching (RD)

- Phase 1
  - **IPs send requests to LIs**
  - LIs select IPs
- Phase 2
  - CMs select LIs
  - Configure granted IPs



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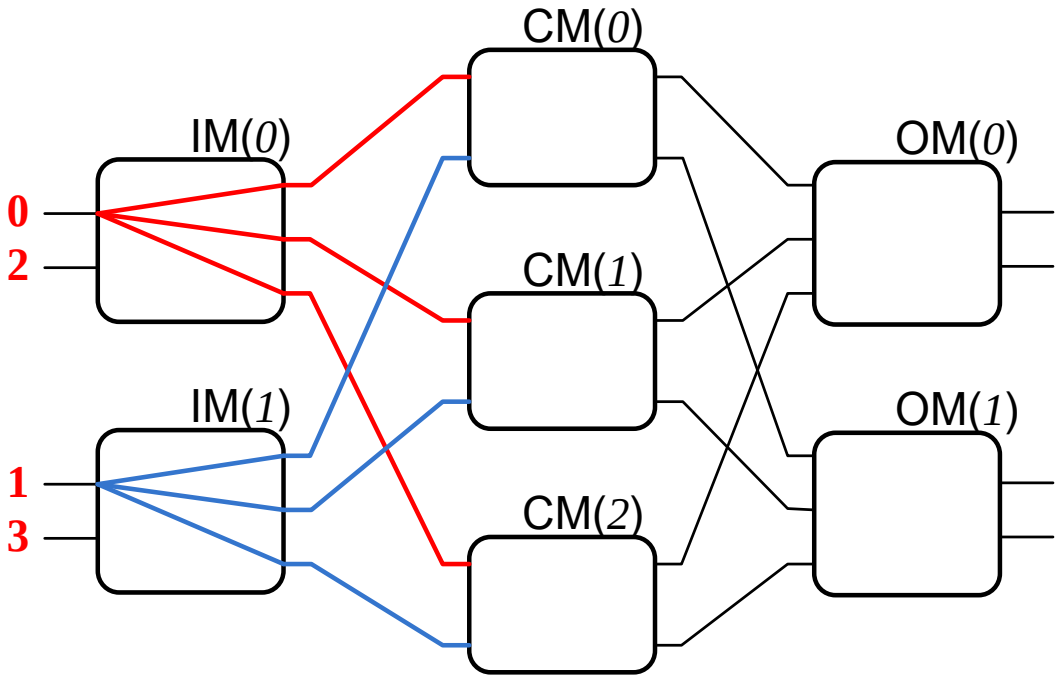

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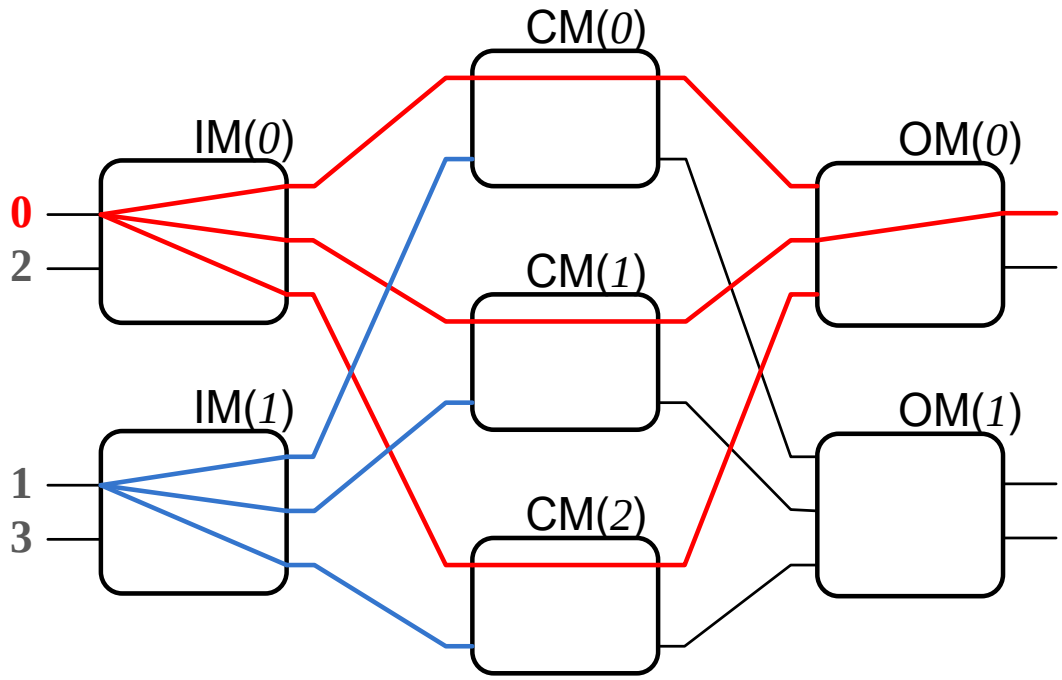
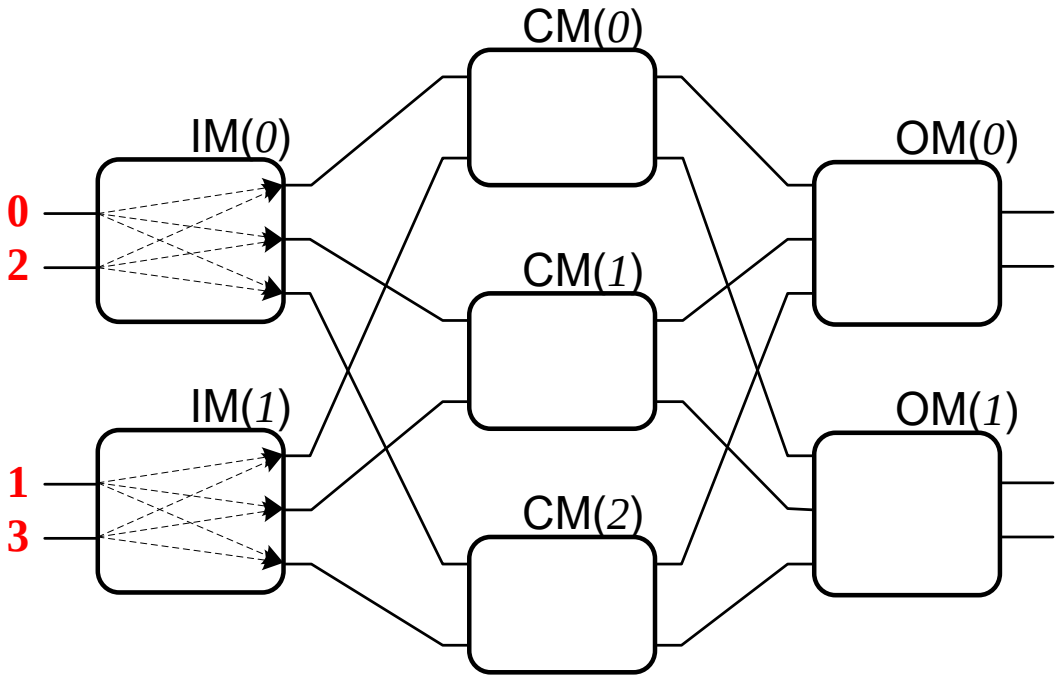


RD cannot resolve contention in IMs.

Concurrent Round-Robin Dispatching (CRRD)

- Phase 1
  - **IPs request**
  - LIs select
  - IPs select
  - Go back (iteration)
- Phase 2
  - Same as RD



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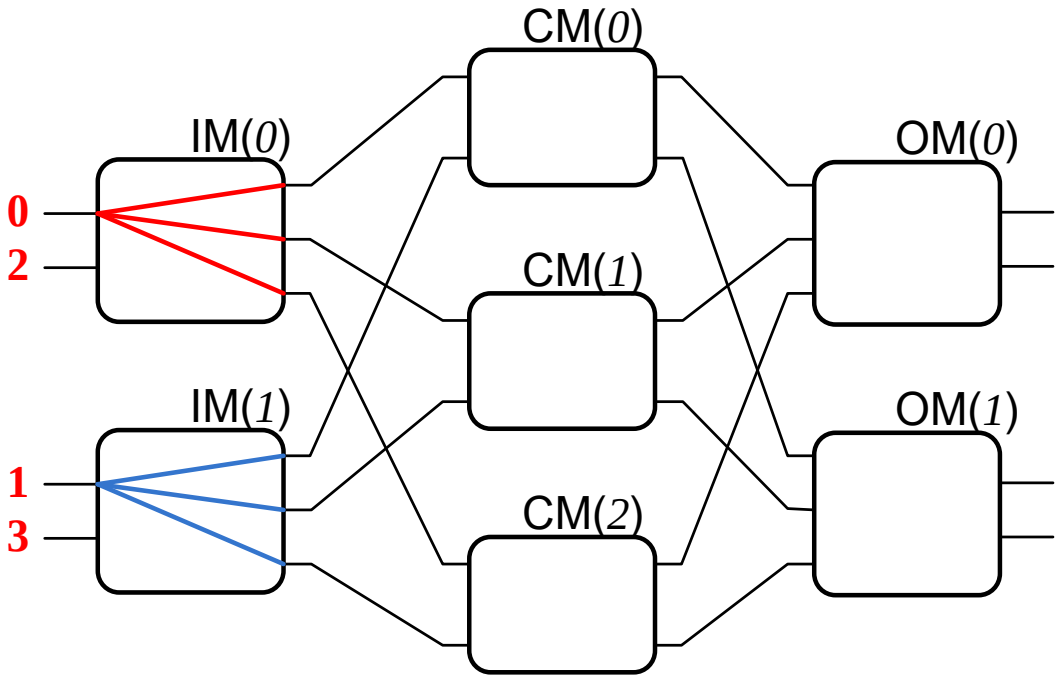

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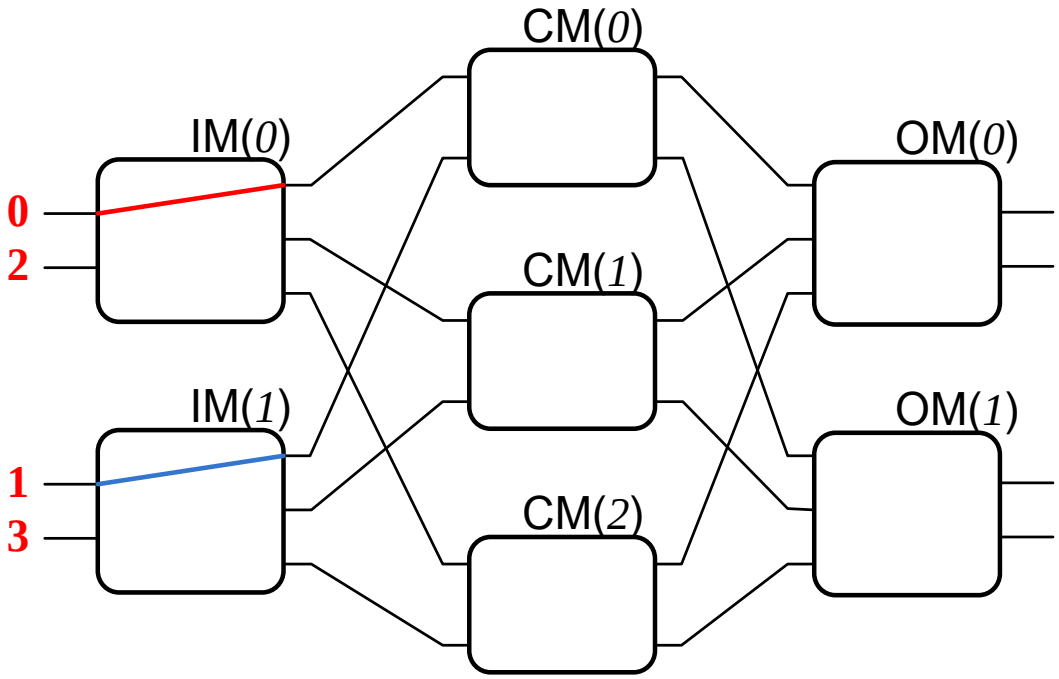

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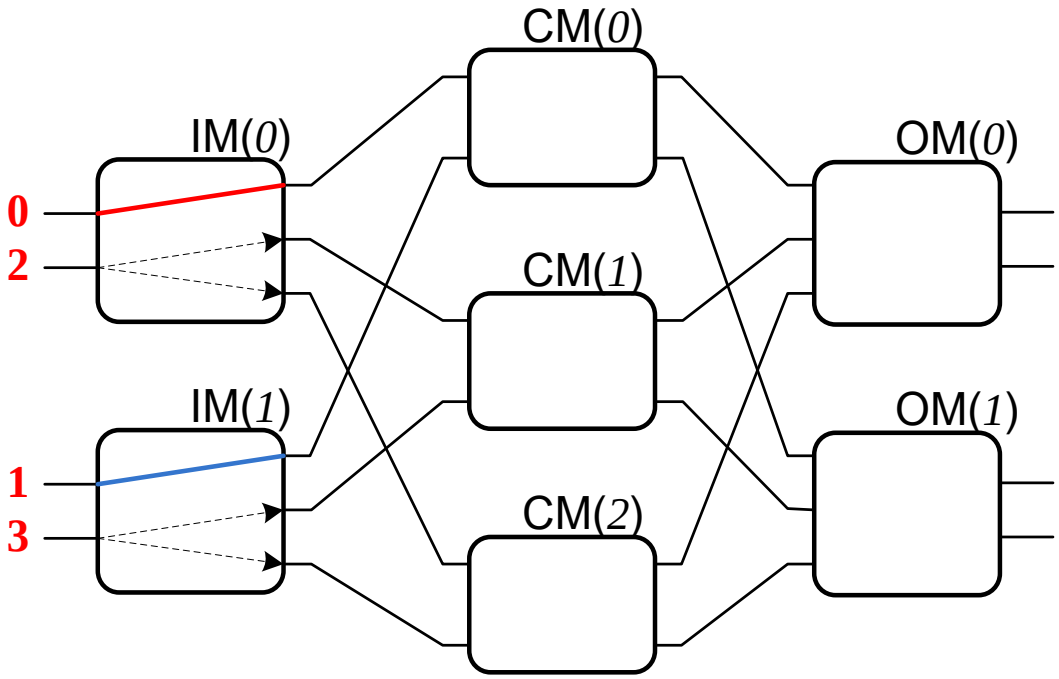

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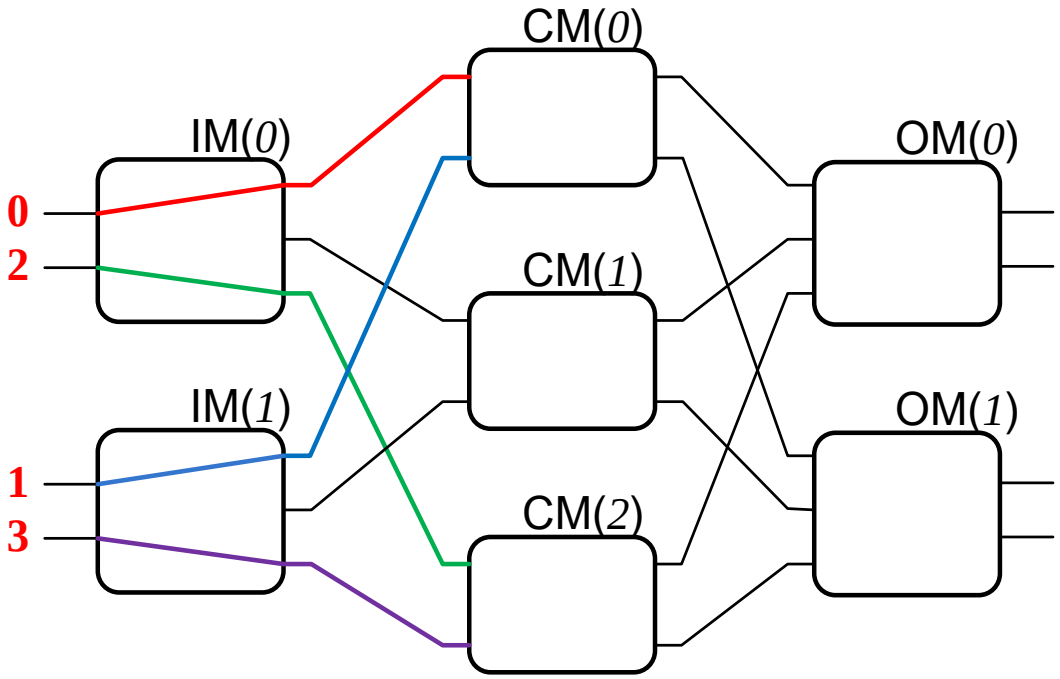

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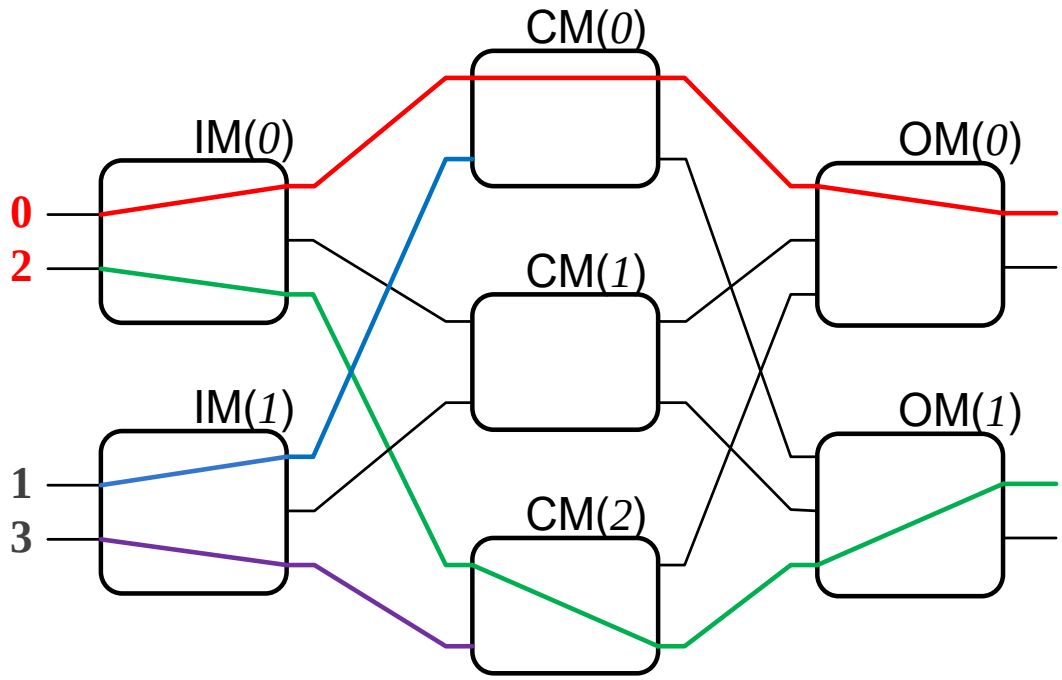


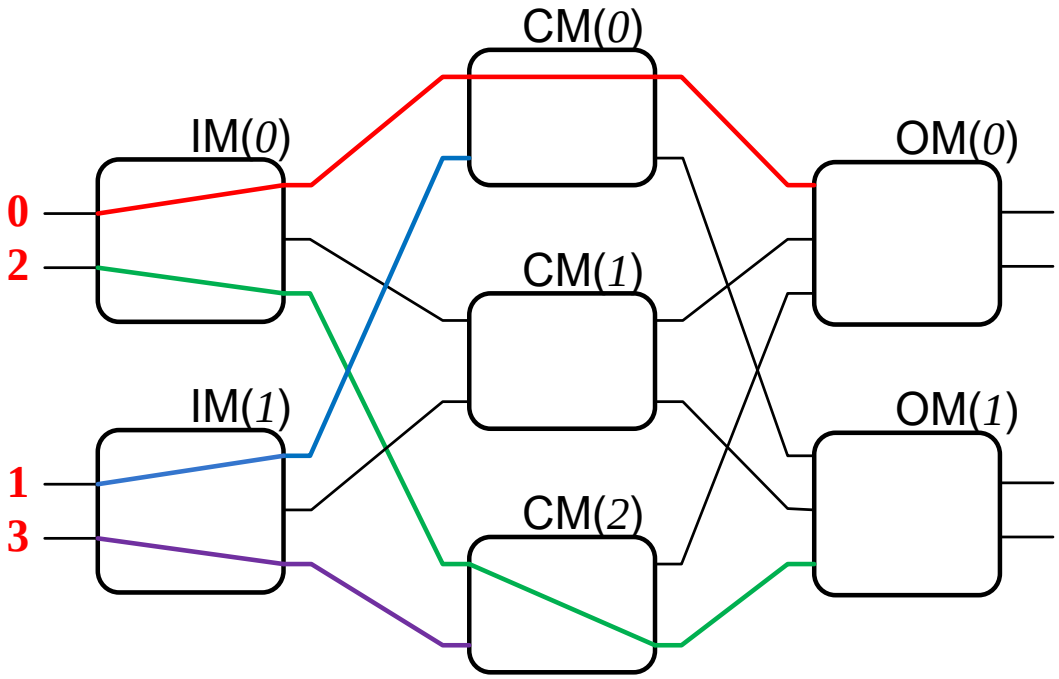
CRRD cannot resolve contention in CMs.

Asynchronous Dispatching (AD)

- Difficulties
  - Packets arrive asynchronously
  - Modules are event-driven
  - Orphans are generated by failed requests
- Solution
  - Independent algorithms (allocators) run in IMs and CMs
  - Failed requests use status feedback from CMs as acknowledge.

Asynchronous Dispatching (AD)

- IM alg.
  - **IPs request**
  - **LIs select**
  - OK? Send data
  - Fail? Go back
- CM alg.
  - **CMs grant LIs**
  - Update status feedback



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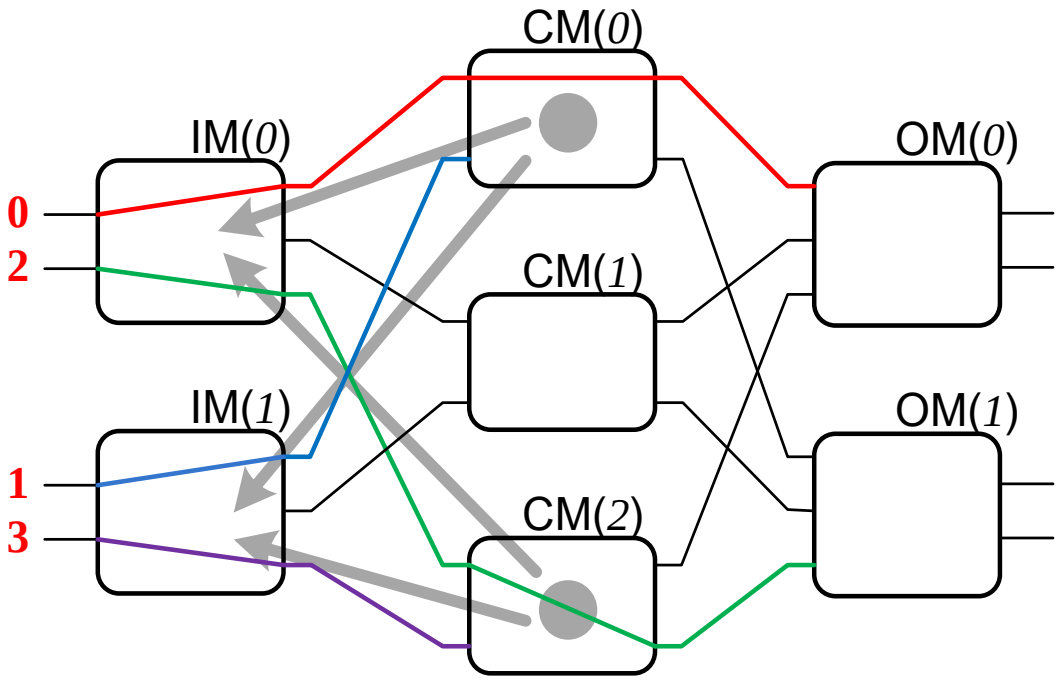

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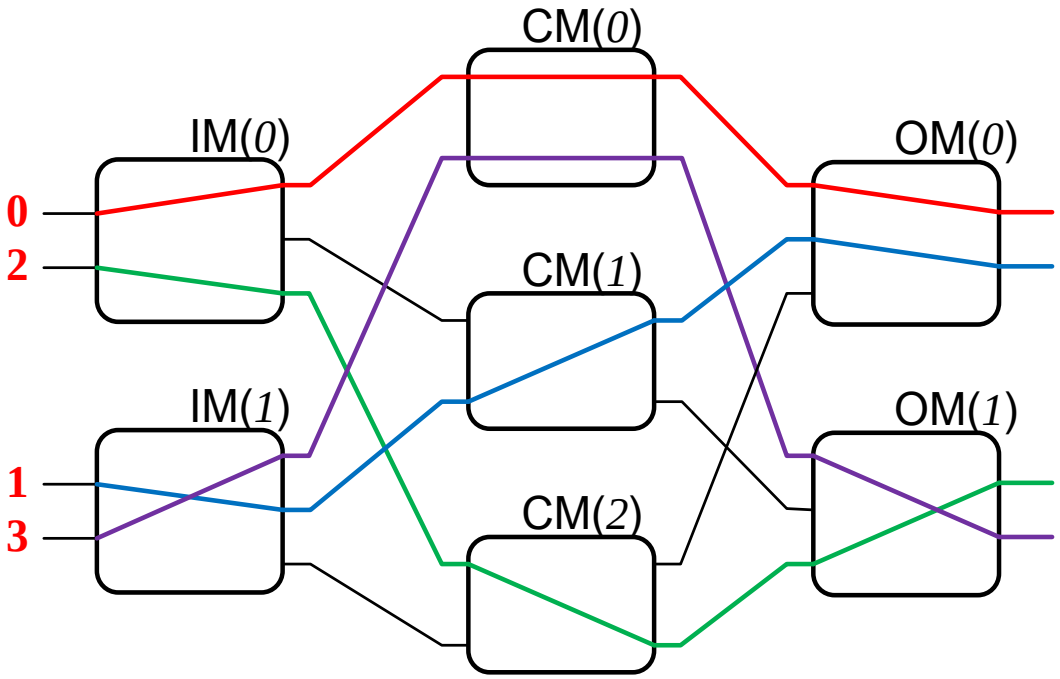
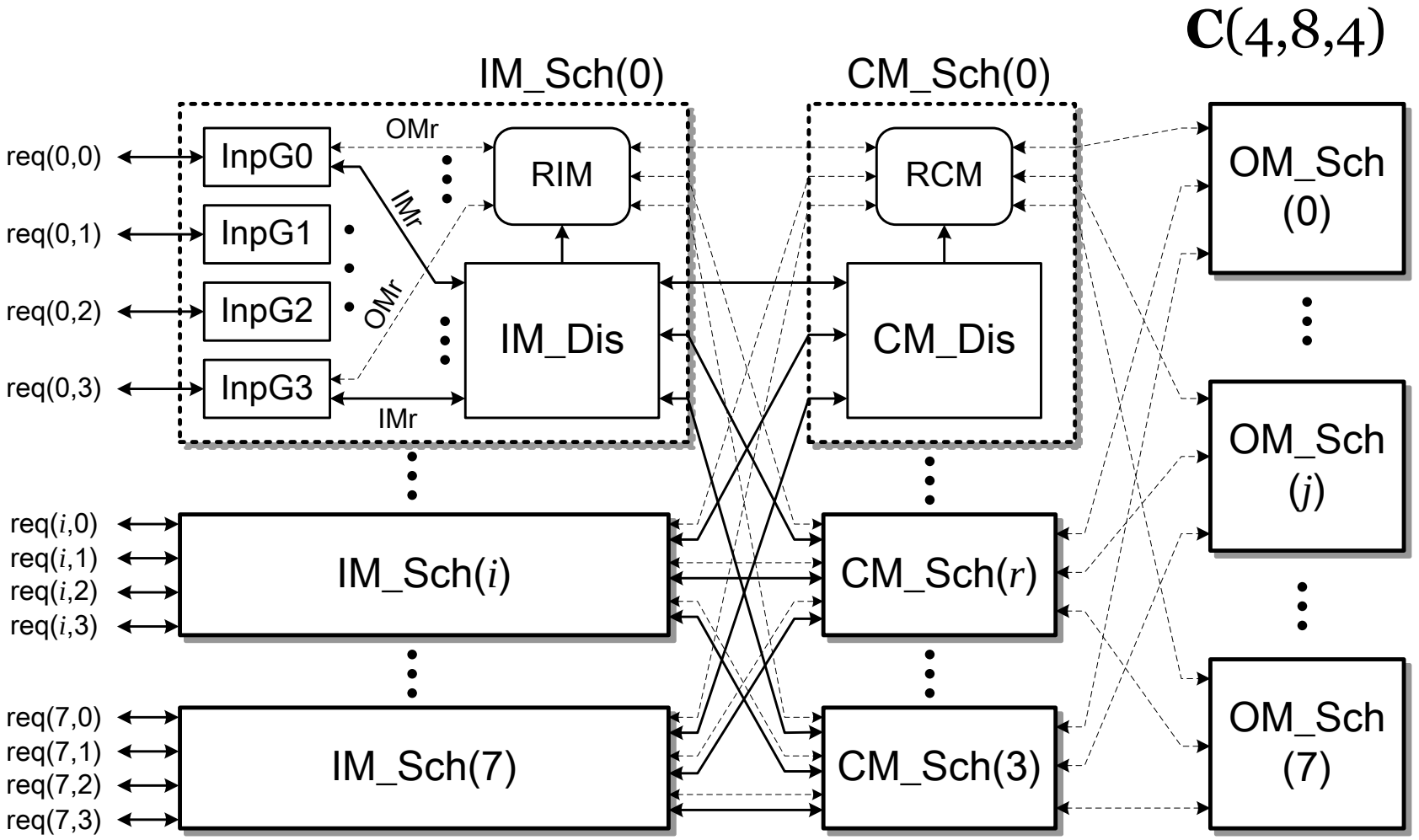


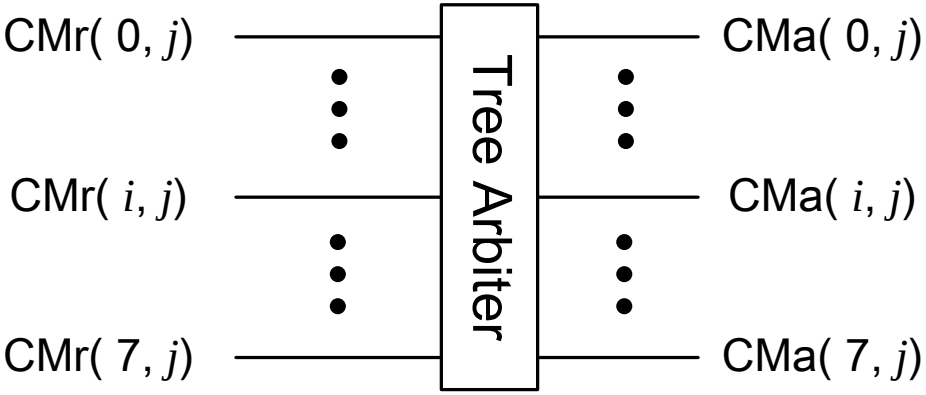
Comparison of Algorithms

- Random Dispatching (AD)
  - Cannot resolve contention in IMs or CMs.
- Concurrent Round-Robin Dispatching (CRRD)
  - Handle contention in IMs using iterations.
  - Cannot resolve contention in CMs.
- Asynchronous Dispatching (AD)
  - Contention in IMs is handled by asynchronous arbiter naturally.
  - Handle contention in CMs using status feedback.

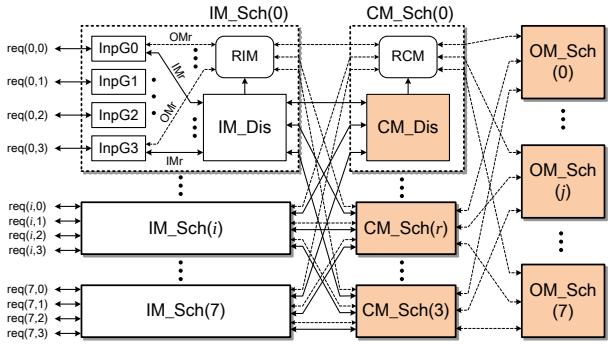
Scheduler Architecture

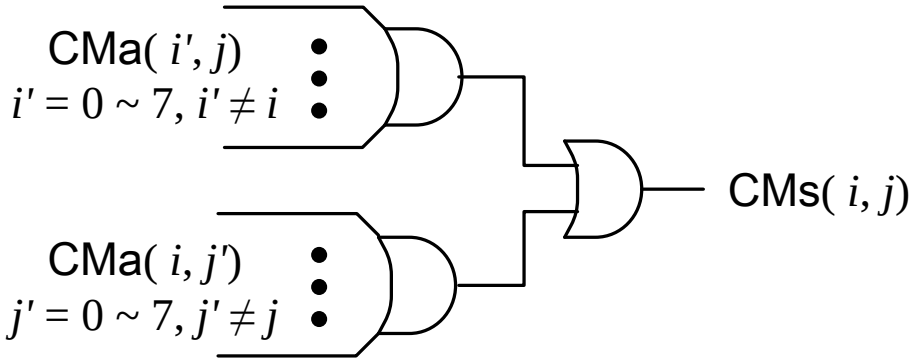


CM Dispatcher/OM Scheduler



C(4,8,4)



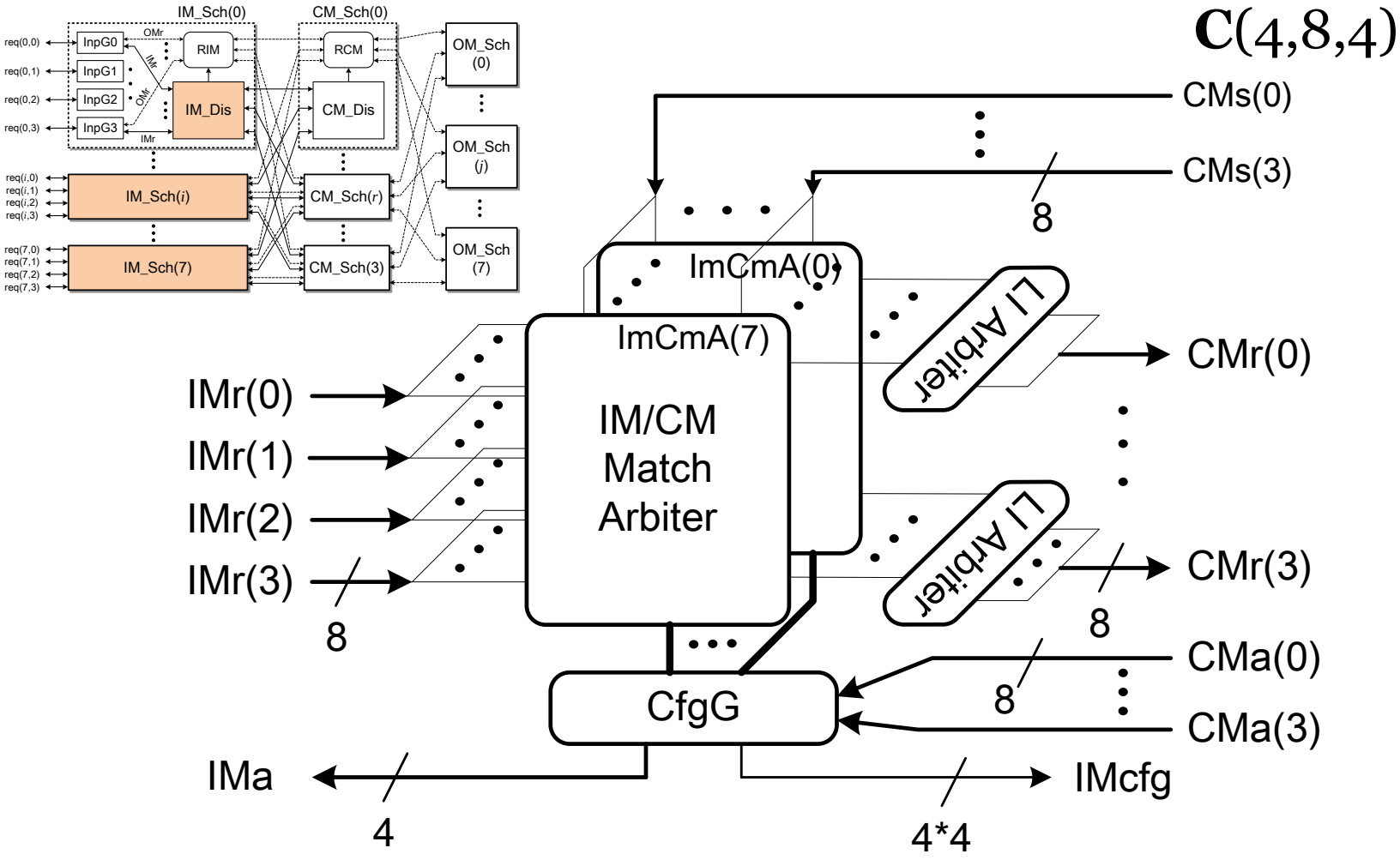


CMa: CM ack

CMs: CM status feedback

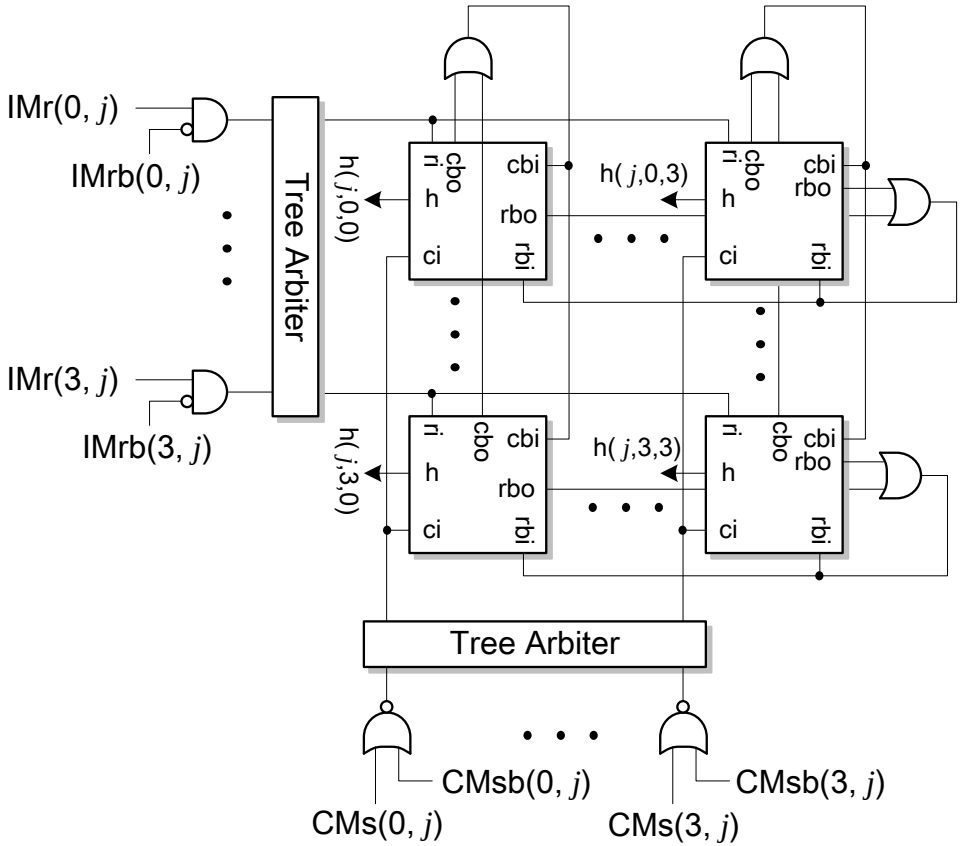
CMa and CMs are mutually exclusive

IM Dispatcher



IM/CM Match Arbiter (Multi-resource Arbiter)

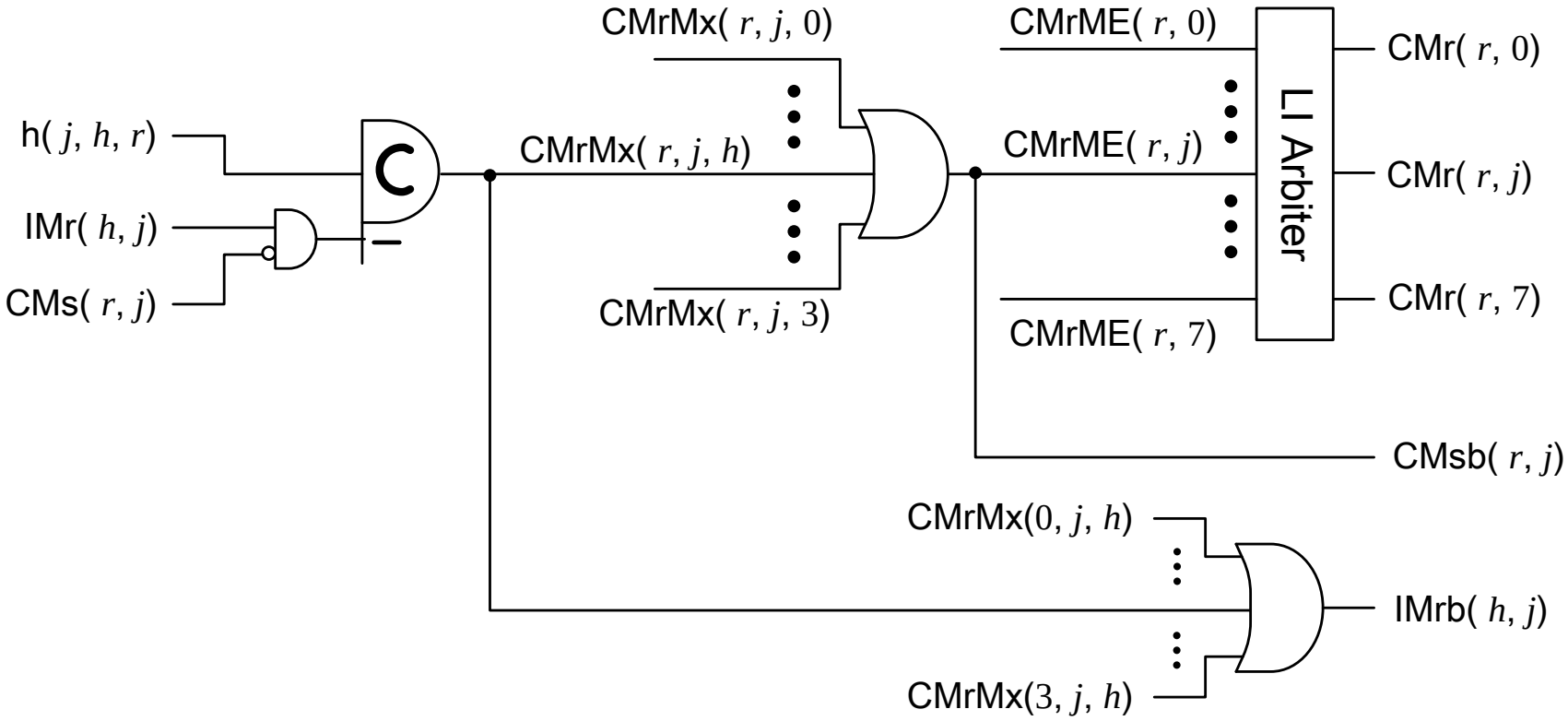
C(4,8,4)



- S. Golubcovs, D. Shang, F. Xia, A. Mokhov, and A. Yakovlev, “Modular approach to multi-resource arbiter design,” ASYNC 2009.

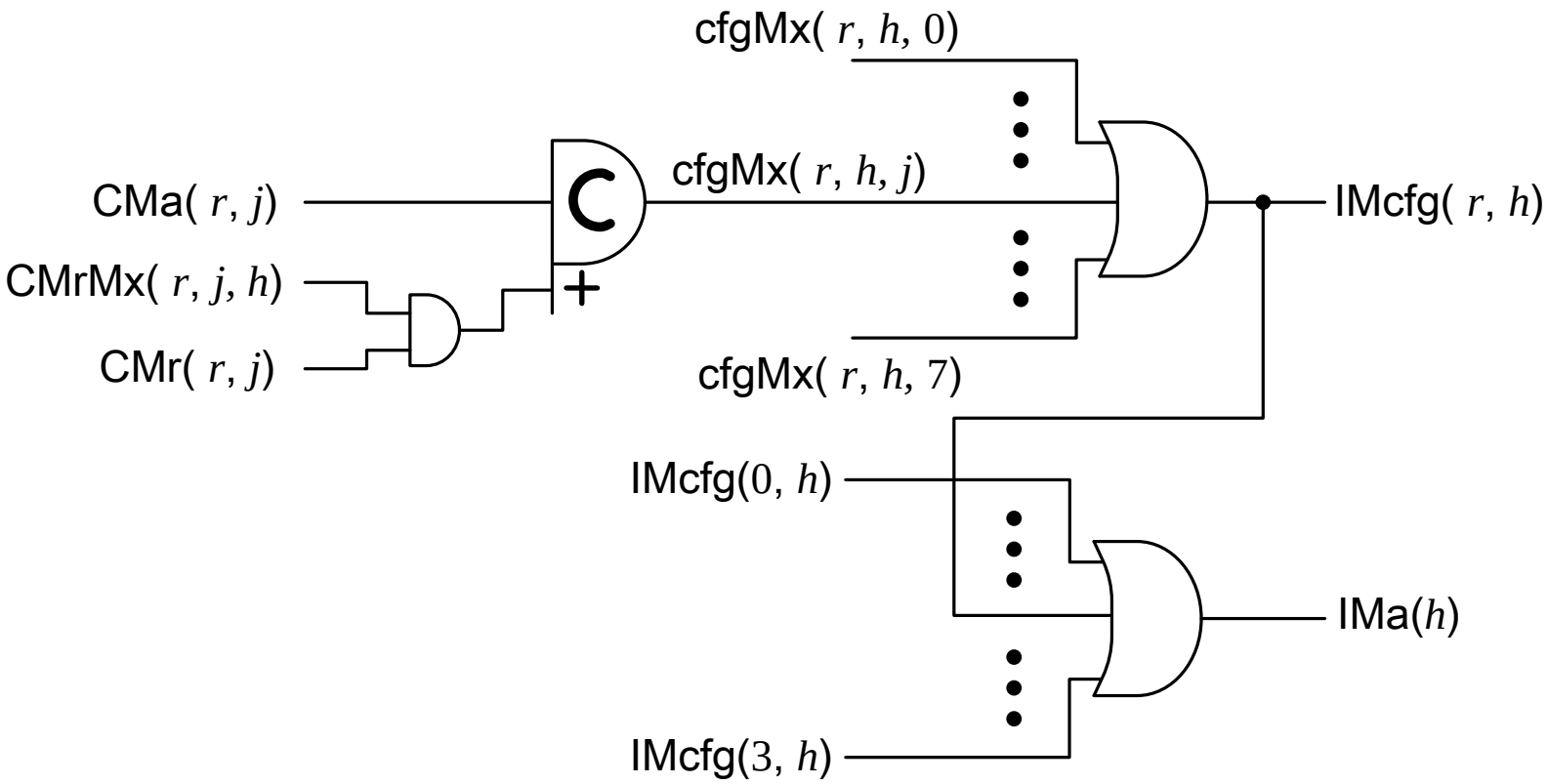
Request Generation

C(4,8,4)



Configuration Generation

C(4,8,4)

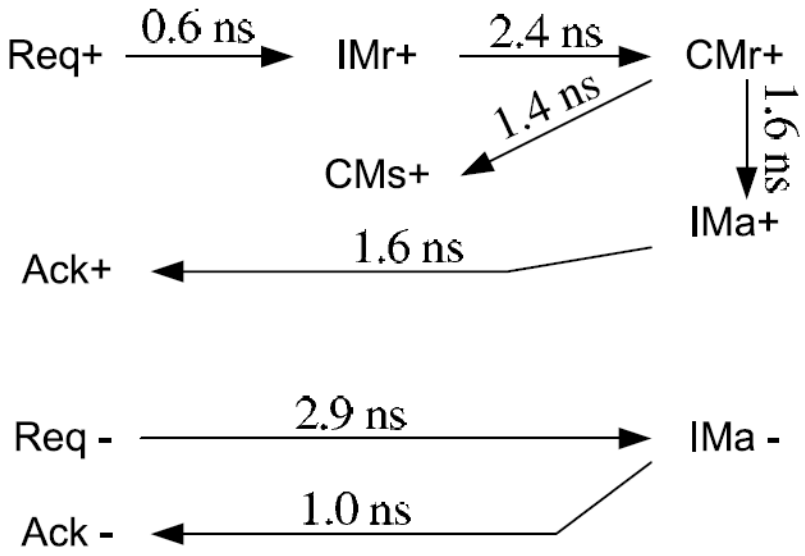


Area and Speed

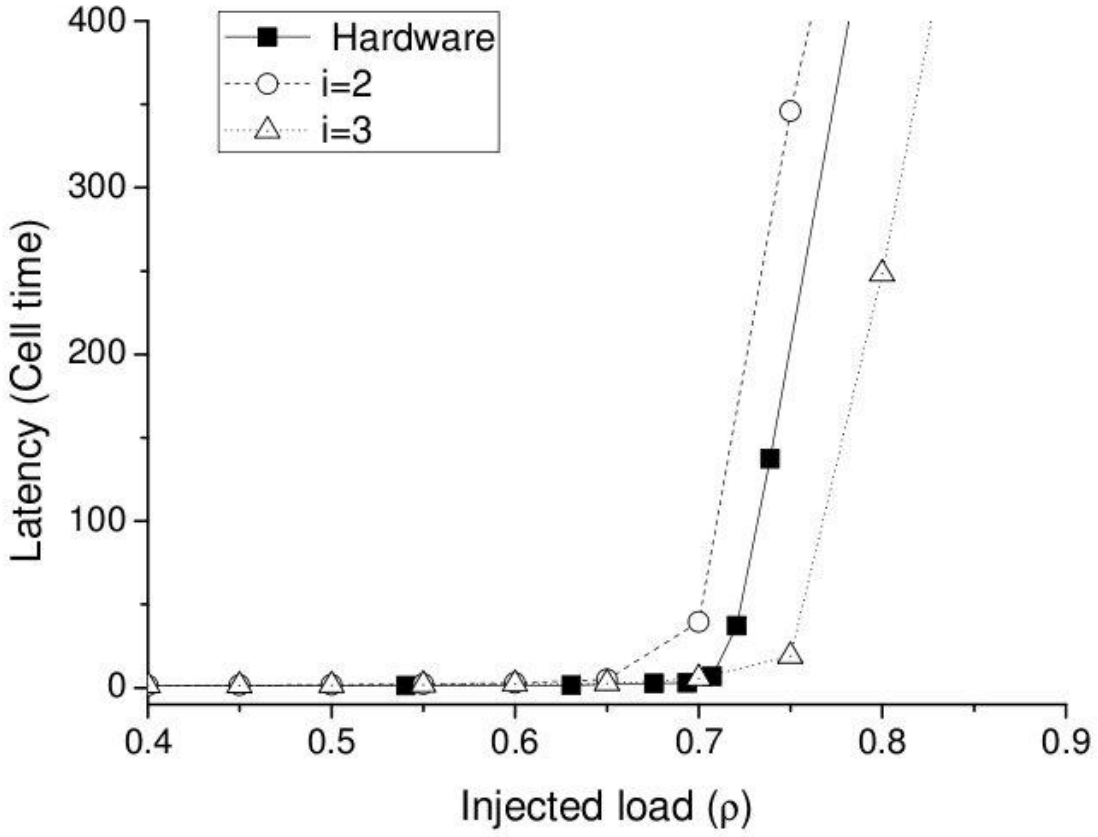
	area (um^2)	gate count (NAND2X1)	percent
InpG	6.26K	1.6K	2.5%
IM_Dis	175.06K	43.8K	67.2%
CM_Dis	33.75K	8.4K	12.9%
OM_Sch	10.06K	2.5K	3.8%
RIM & RCM	13.46K	3.4K	5.2%
other	22.15K	5.5K	8.4%
Total	260.74K	65.2K	

C(4,8,4)

Dispatching:
setup 4.6 ns release 2.9 ns
OM Scheduler:
setup 1.6 ns release 1.0 ns
Total:
setup 6.2 ns release 3.9 ns



MATLAB Simulation Model



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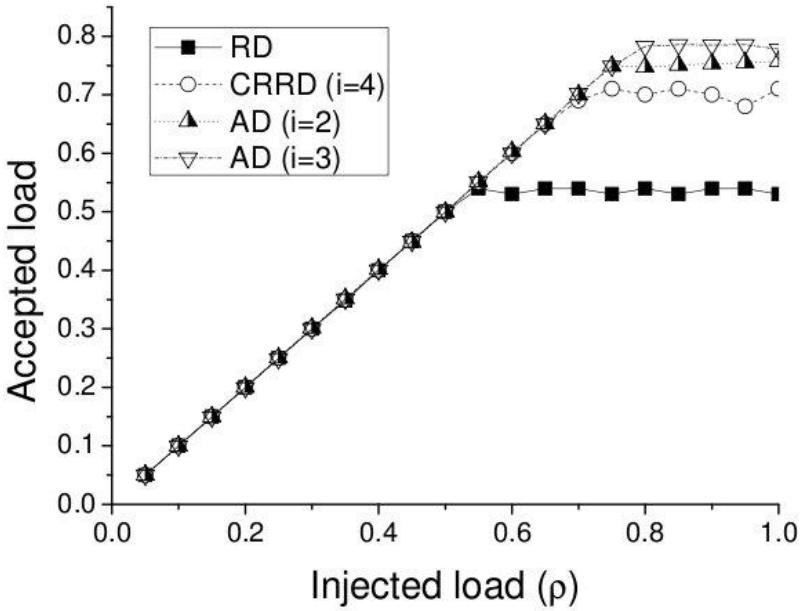
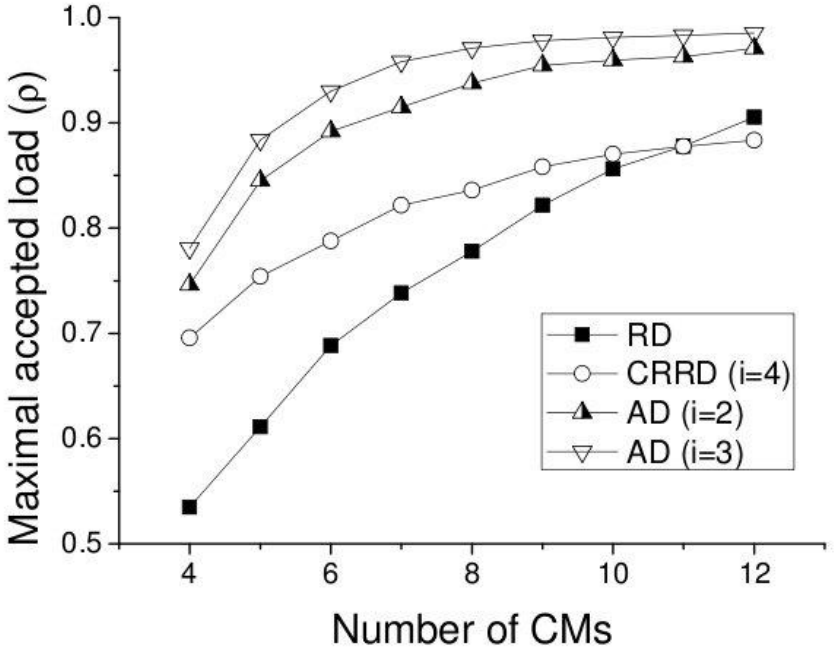
Throughput Analysis





C(4,8,4) non-blocking load
RD 55%
CRRD (i=4) 70%
AD (i=3) 76%

C(4,8,*m*) non-blocking load
RD (*m*=7) 74%
CRRD (*m*=7) 82%
AD (*m*=7) 96%

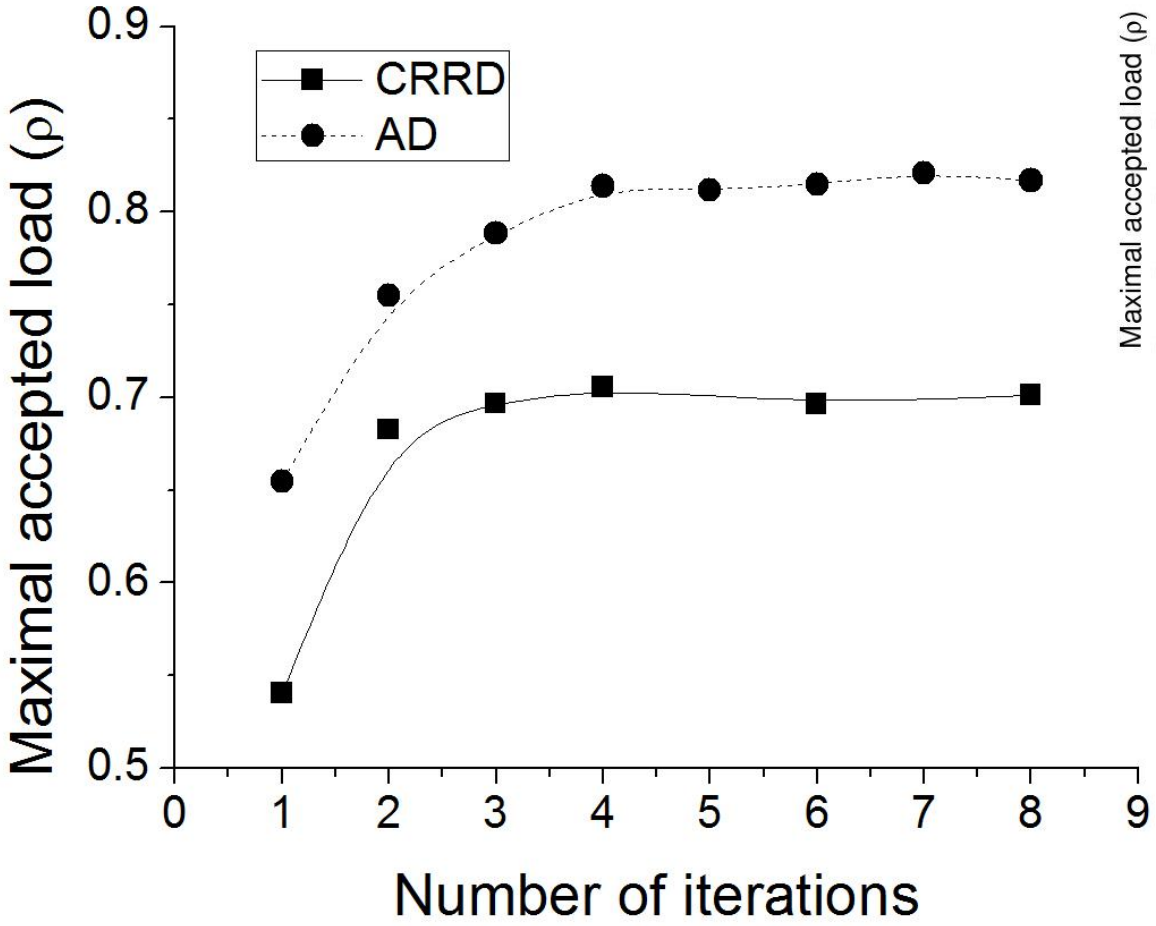
Conclusions

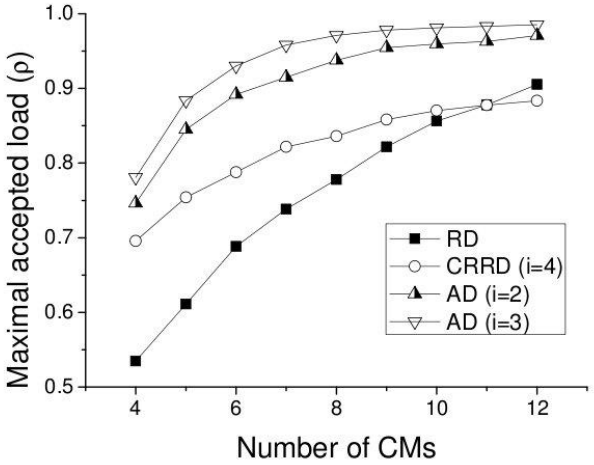
- The first asynchronous routing algorithm for general 3-stage Clos networks.
- Better throughput performance than RD and CRRD
- Future works
  - Optimize the Clos structure
  - Reduce area and latency

Thank you!

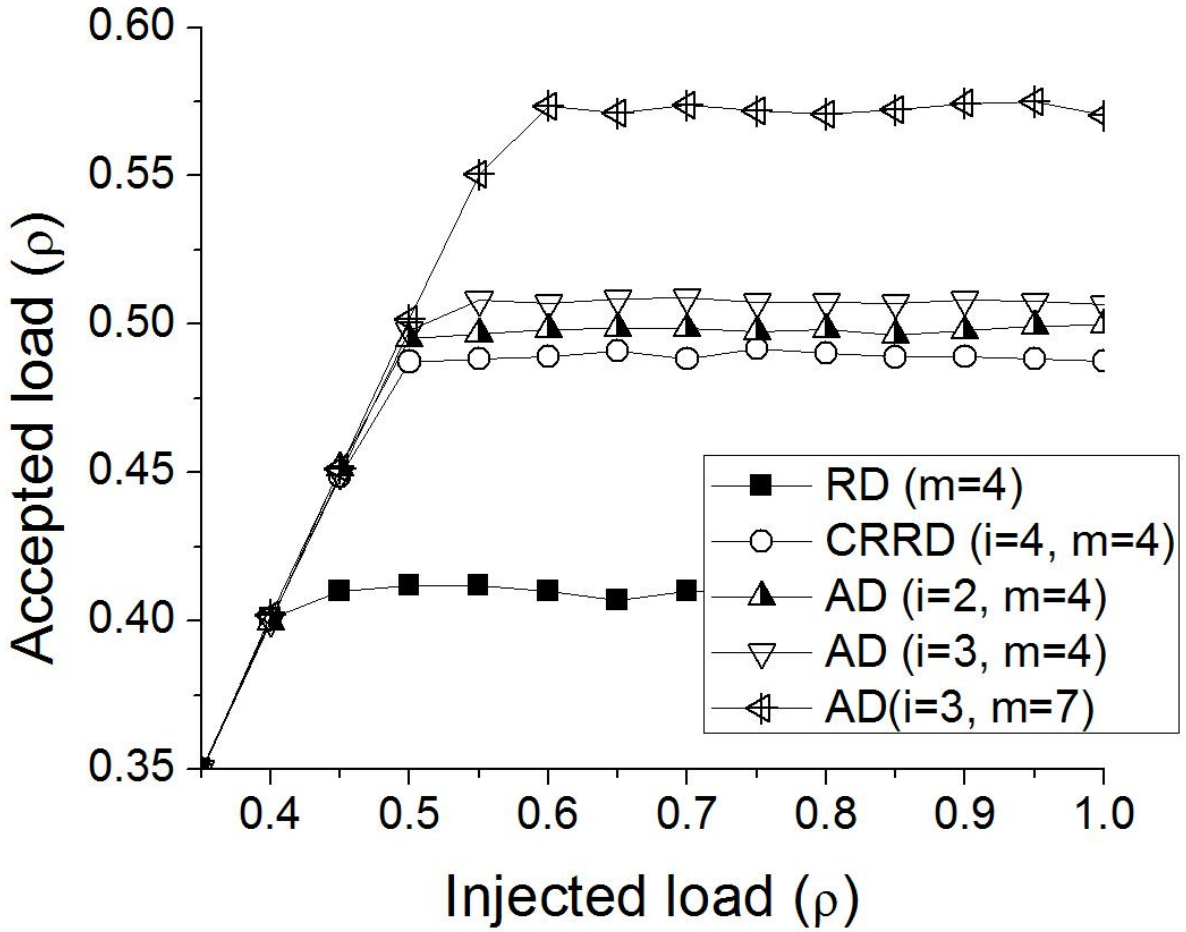
Questions?

Iterations


CRRD
AD
Maximal accepted load (ρ)
Number of iterations
0.5
0.6
0.7
0.8
0.9
0
1
2
3
4
5
6
7
8
9


RD
CRRD (i=4)
AD (i=2)
AD (i=3)
Maximal accepted load (ρ)
Number of CMs
0.5
0.6
0.7
0.8
0.9
1.0
4
6
8
10
12

Uniform Traffic



Results after Optimization

- Async
  - Setup 3.7 ns
  - Reset 3.2 ns
  - Period ~ 7 ns (140M)
  - 28K Gates
- Sync
  - 350 MHz
  - Cell time = Iter+1 =5 (70M)
  - 22K Gates
- Optimization
  - Replace multi-resource arbiter
  - Eager request (InpG)
  - MUTEX arbiter
  - Optimized tree arbiter