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# Using Clos Switches in Area Efficient Asynchronous SDM Routers

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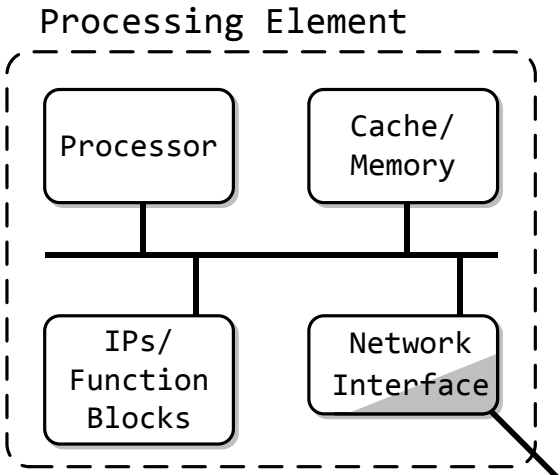
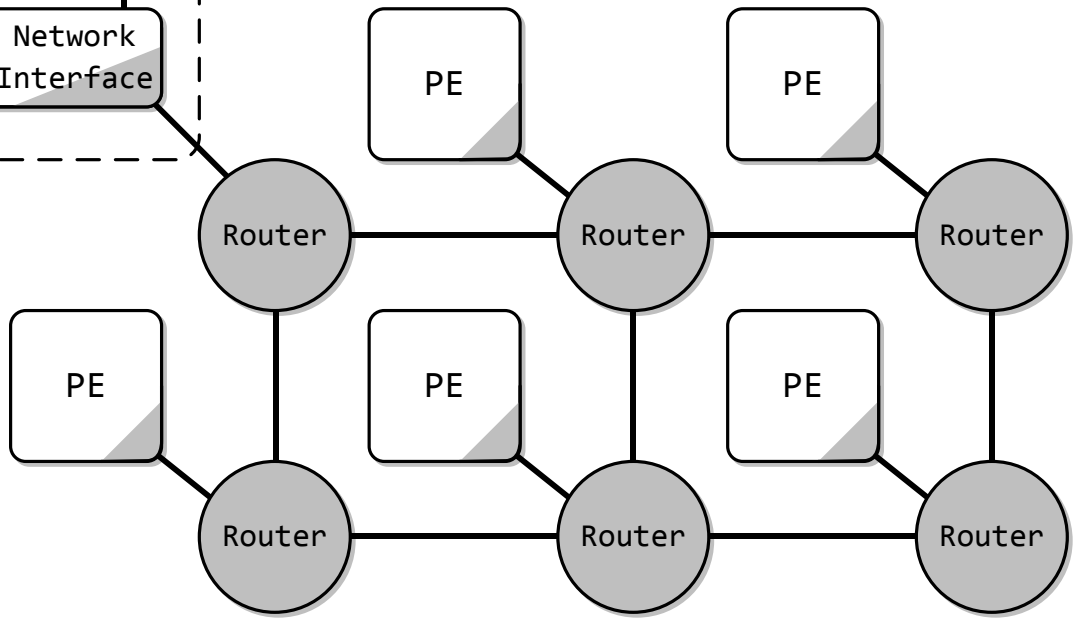
# Asynchronous Network-on-Chip

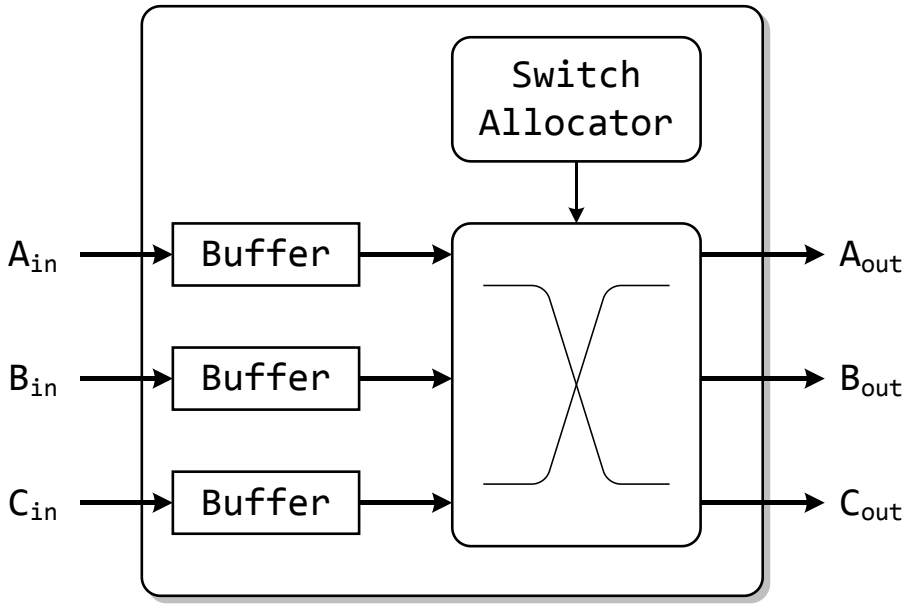



***Network-on-Chip (NoC)*** or ***on-chip network*** is the state-of-the-art on-chip communication structure for multiprocessor systems.



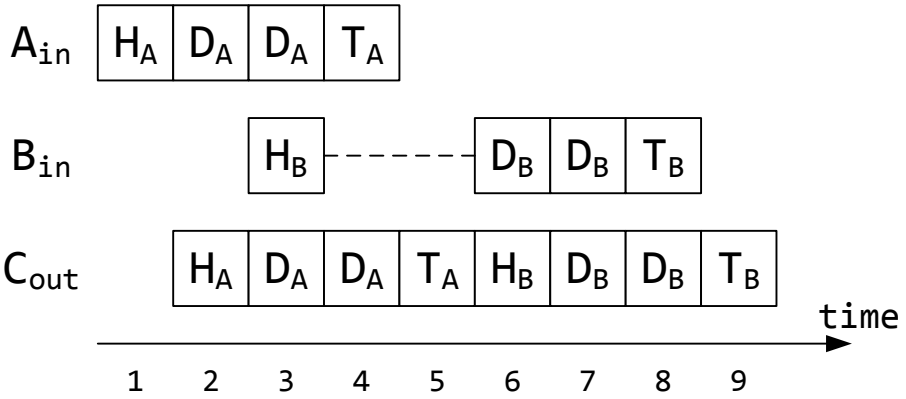

***GALS***: Globally asynchronous and locally synchronous

# Basic Router Structure

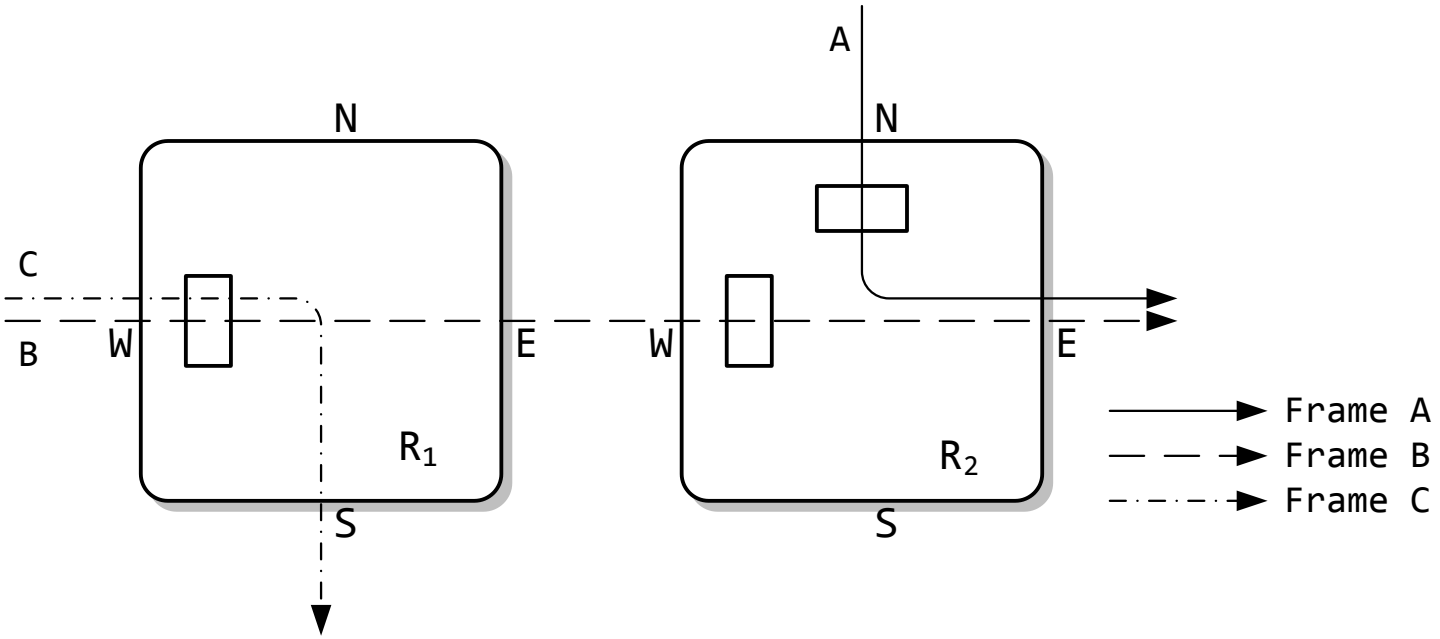



***Flow control***:
The algorithm used to allocate resources in a router to multiple frames.

***Wormhole***:
Frames are divided into flits. The header flit contains the target addr. and it is used to reserve a path. Other flits just follow the path.



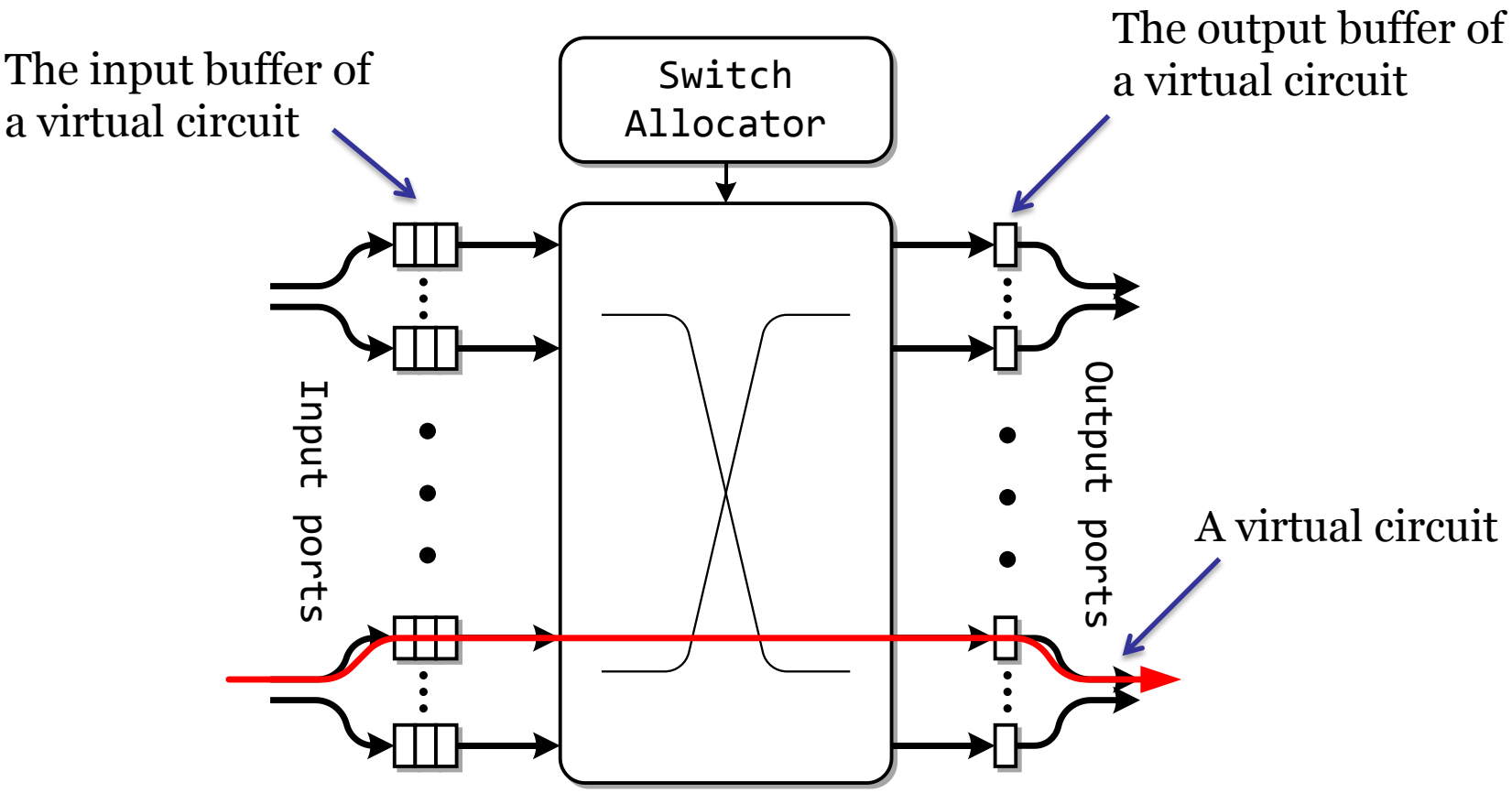
# Head-of-Line (HOL)



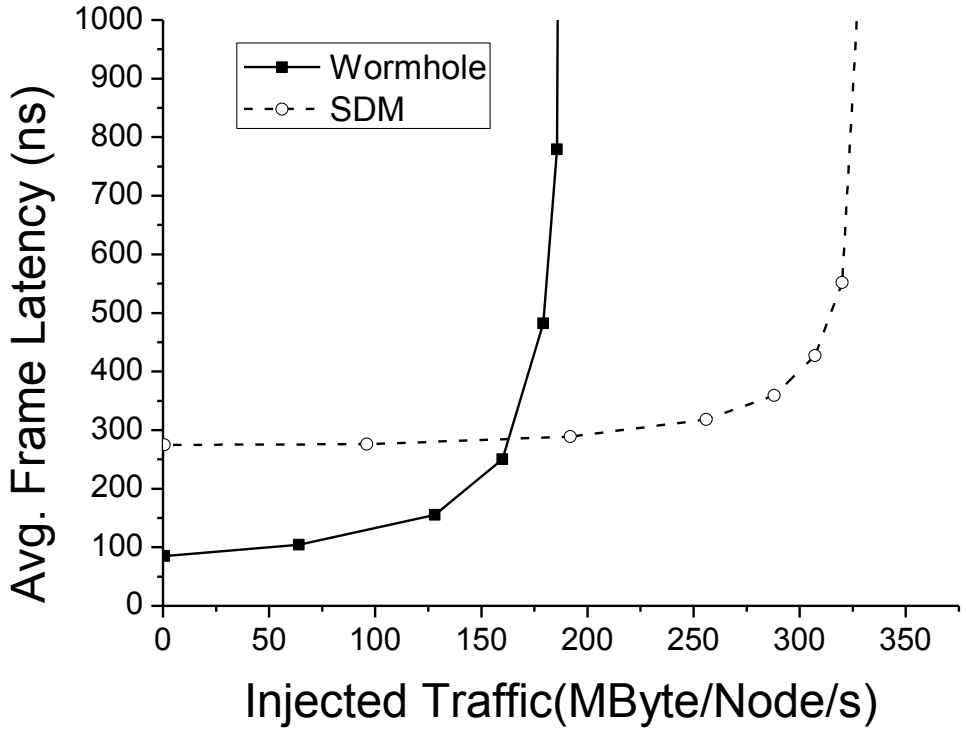

***The spread of blocking:***

Assuming frame B is blocked by frame A, frame B may also block frame C; however, C is not directly related to A.

# Spatial Division Multiplexing



# SDM vs. Wormhole




| | WH | SDM |
|---|---|---|
| Input Buf. | 14,303 | 21,995 |
| Output Buf. | 5,935 | 6,000 |
| Crossbar | 4,356 | 21,744 |
| Arbiters | 772 | 22,208 |
| Overall | 25,366 | 71,956 |

***The area of crossbars***

***WH:***

P*P*W

***SDM***:

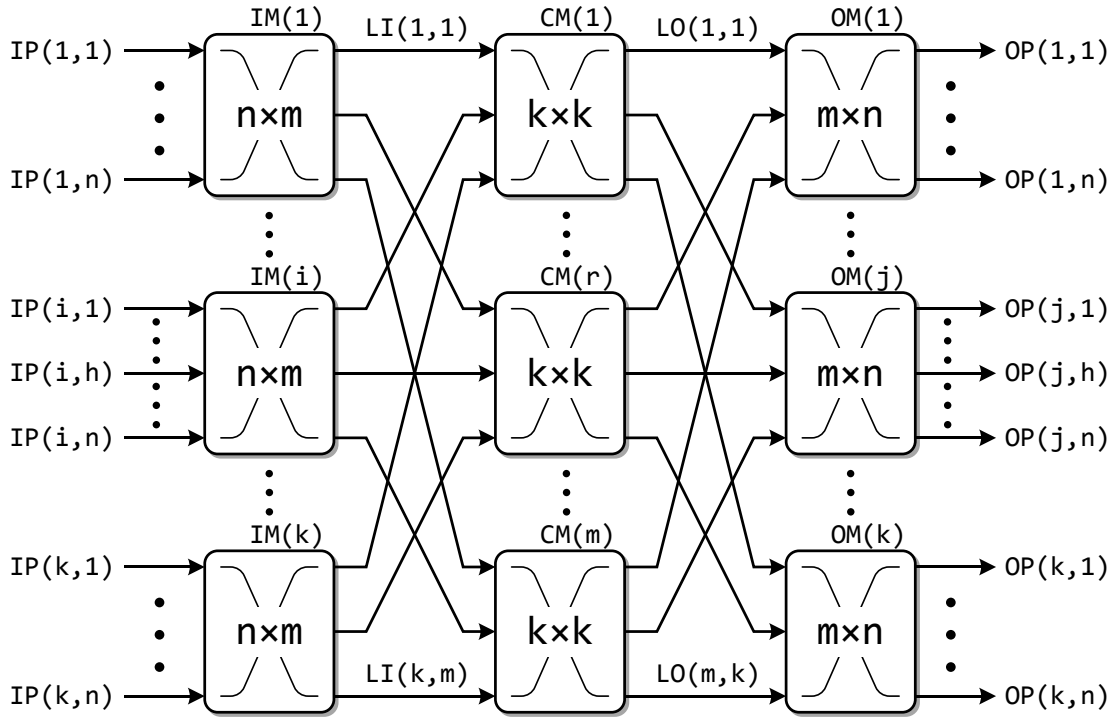
MP*MP*W/M = MP*P*W

[7] W. Song and D. Edwards. "Asynchronous spatial division multiplexing router," *Microprocessors and Microsystems*, 35(2), 85-97, 2011

# Clos Switch - Motivation

- The problems of SDM
  - High-radix crossbars
  - Large crossbar and switch allocator
- Clos networks are the optimal switch structure
- Problems to solve
  - Dynamic configuration [11]
  - Optimal structure for SDM router (this paper)

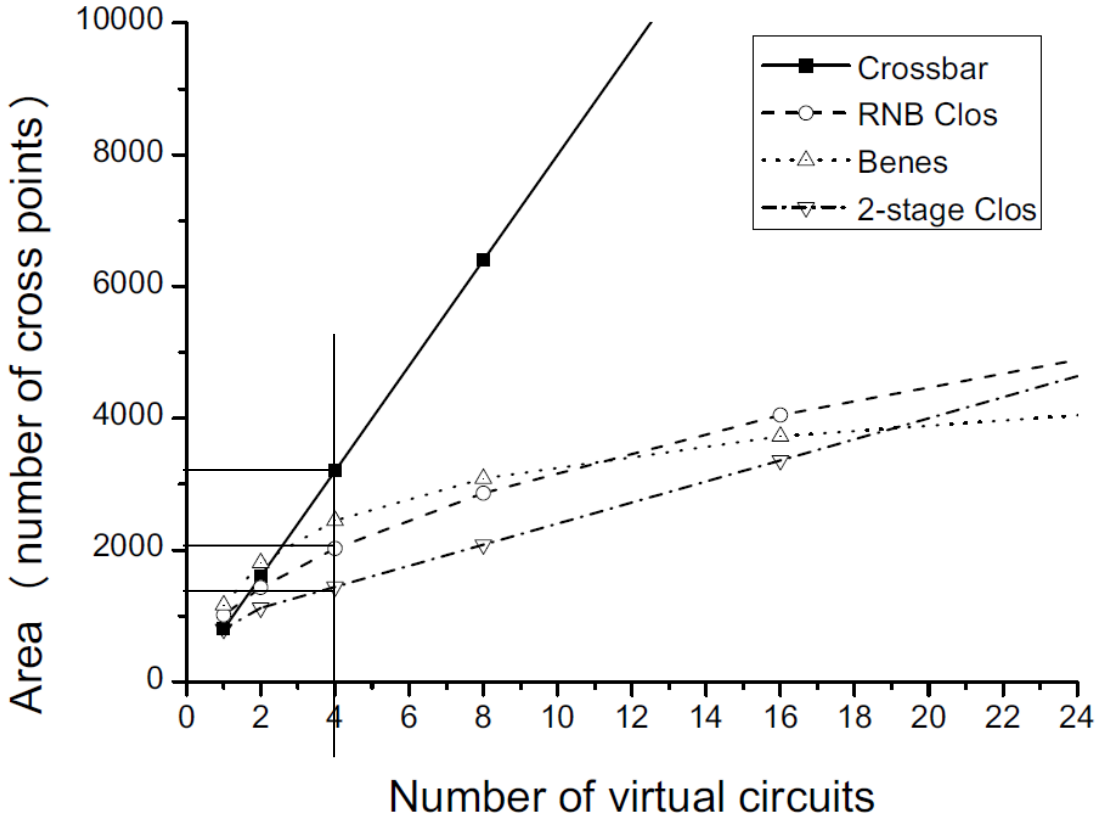
# Clos Networks



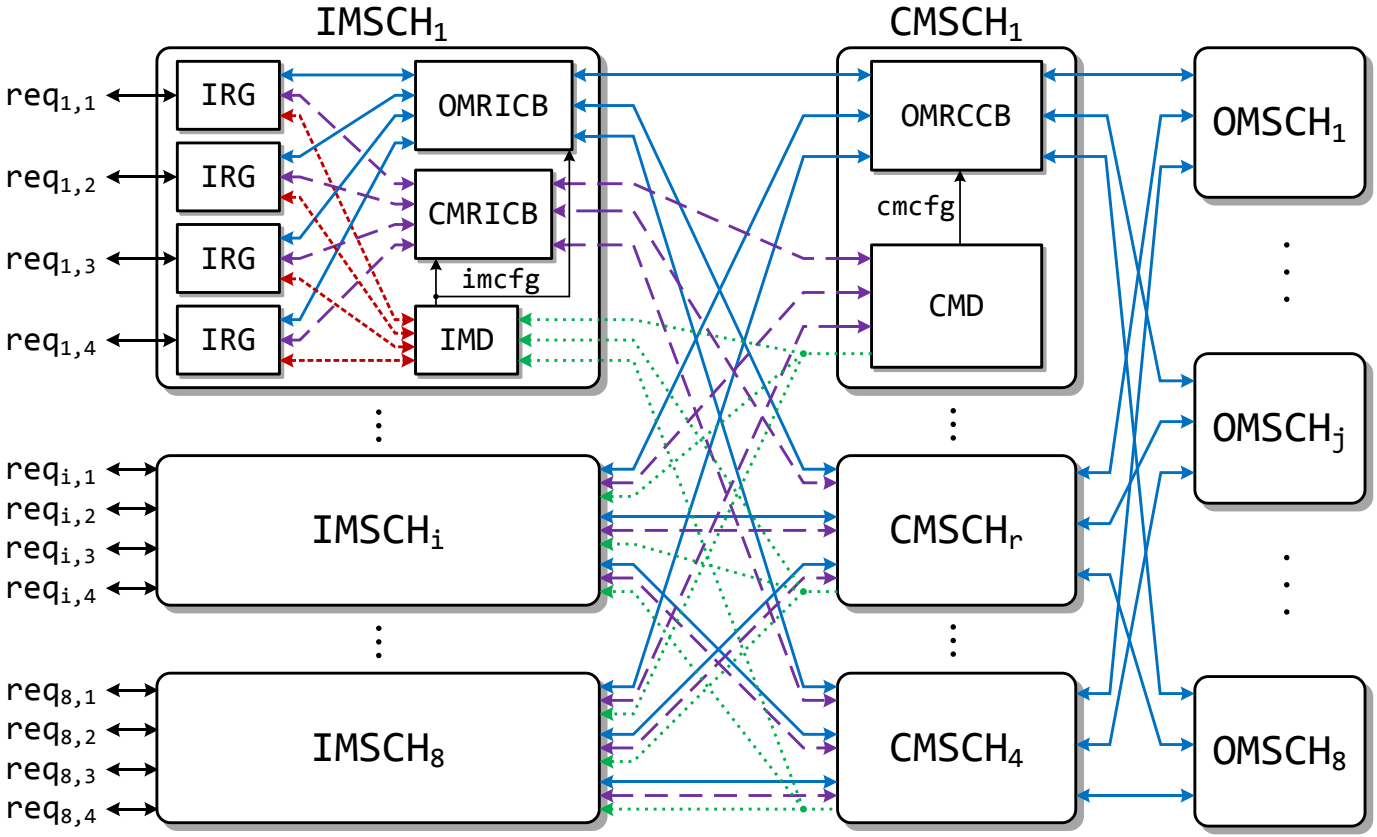

**IP/OP:** input/output port
**IM:** input module
**CM:** central module
**OM:** output module
***n*:** number of IPs in IM
***k*:** number of IMs
***m*:** number of CMs
***N* = *kn*:** the total number of IPs

When $m >= n$, the switch is no-blocking

# Clos vs. Crossbar

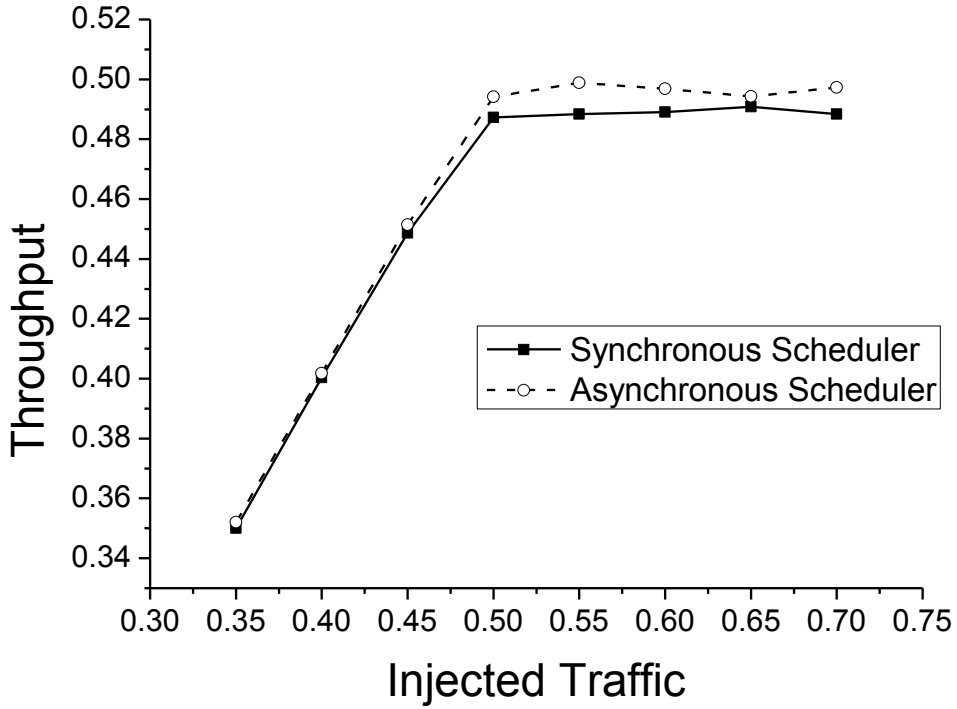


# Asynchronous Clos Scheduler



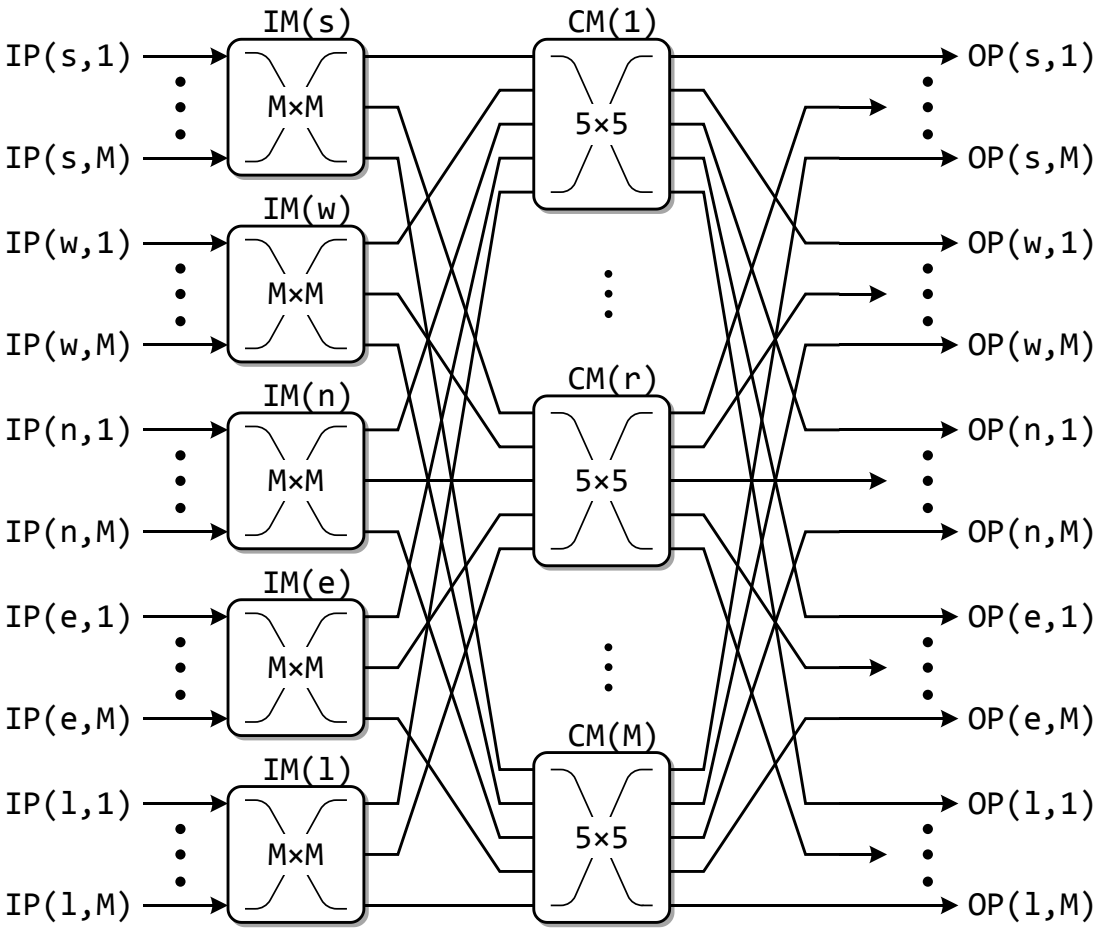

[11] W. Song and D. Edwards. "An asynchronous routing algorithm for Clos networks," In *Proc. of International Conference on Application of Concurrency to System Design*, 2010, 67-76

# Async vs. Sync Algorithm




[11] W. Song and D. Edwards. "An asynchronous routing algorithm for Clos networks," In *Proc. of International Conference on Application of Concurrency to System Design*, 2010, 67-76

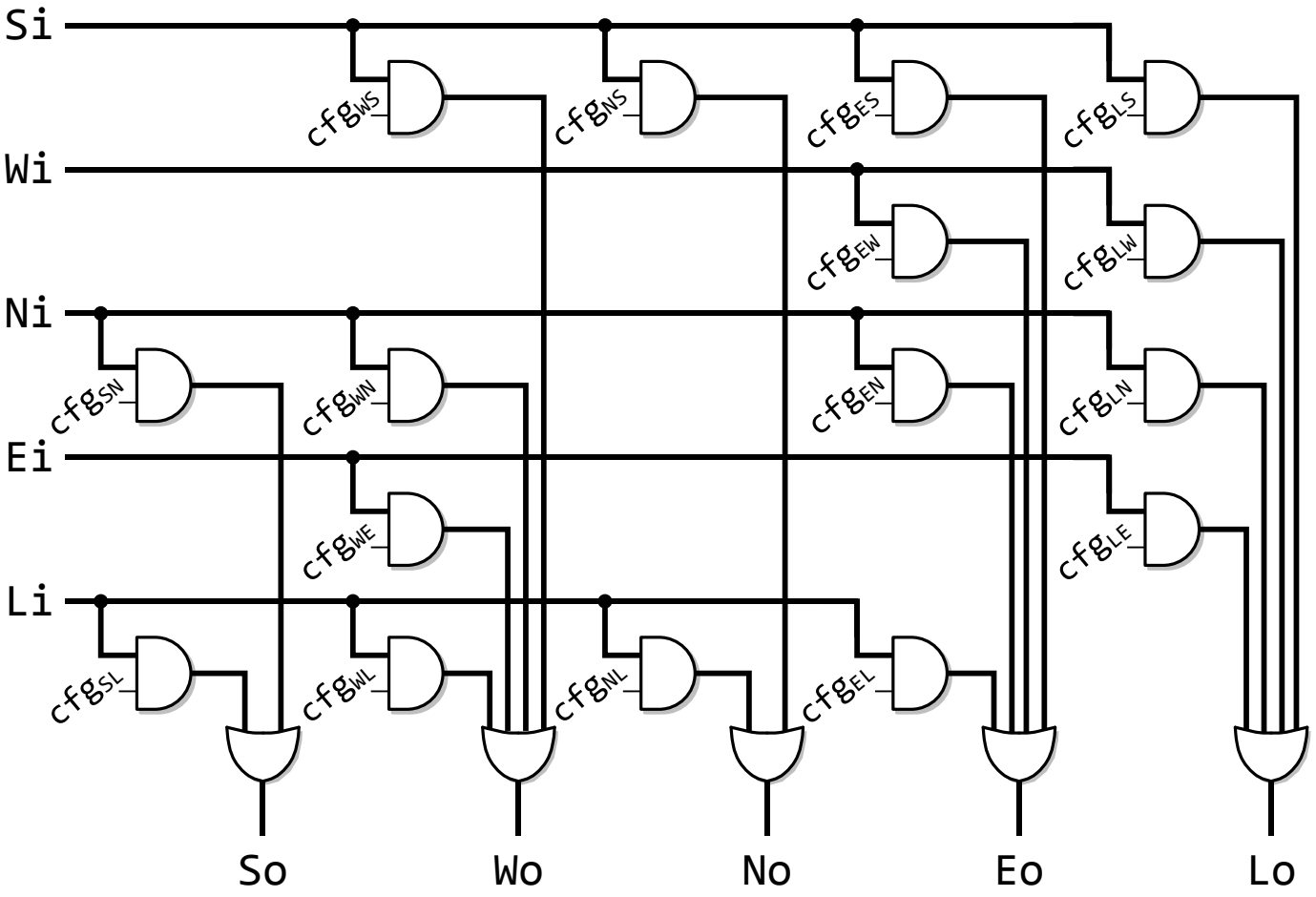
# 2-stage Clos Switch



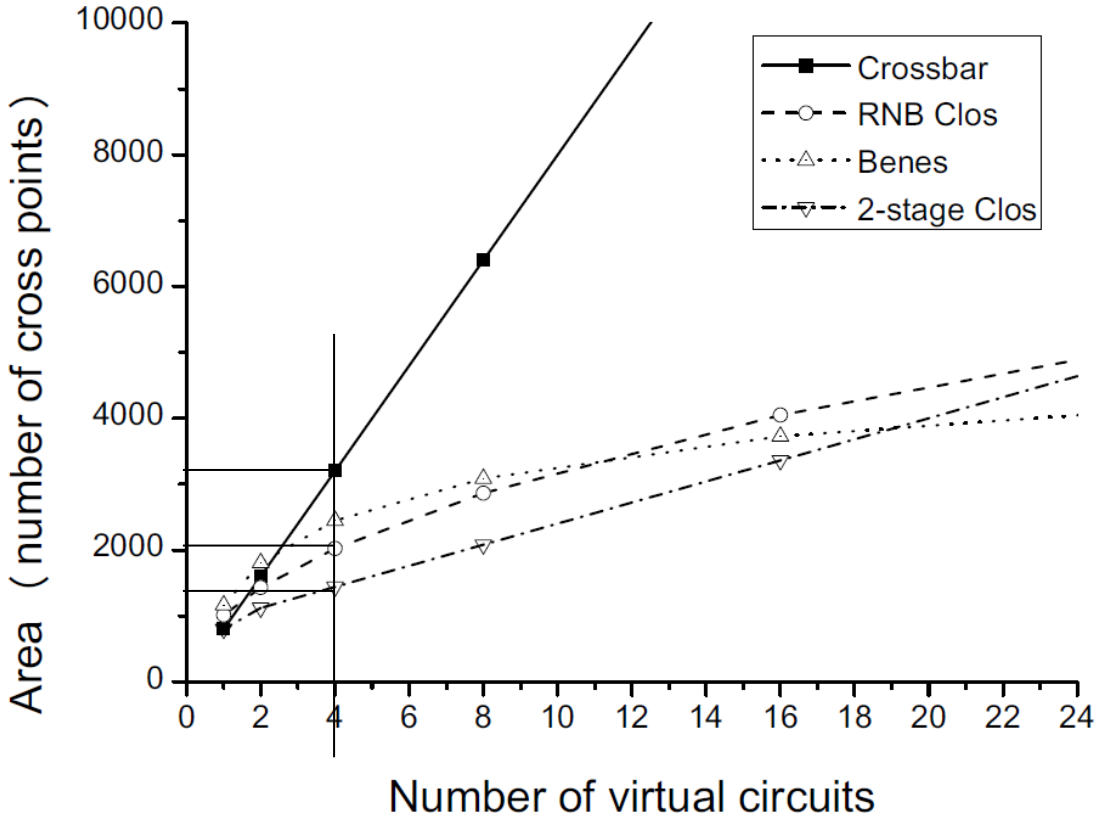

**Benefits:**

1. 2-stage
   1.a less latency
   1.b smaller
   1.c simpler scheduler
2. CMs can be further simplified

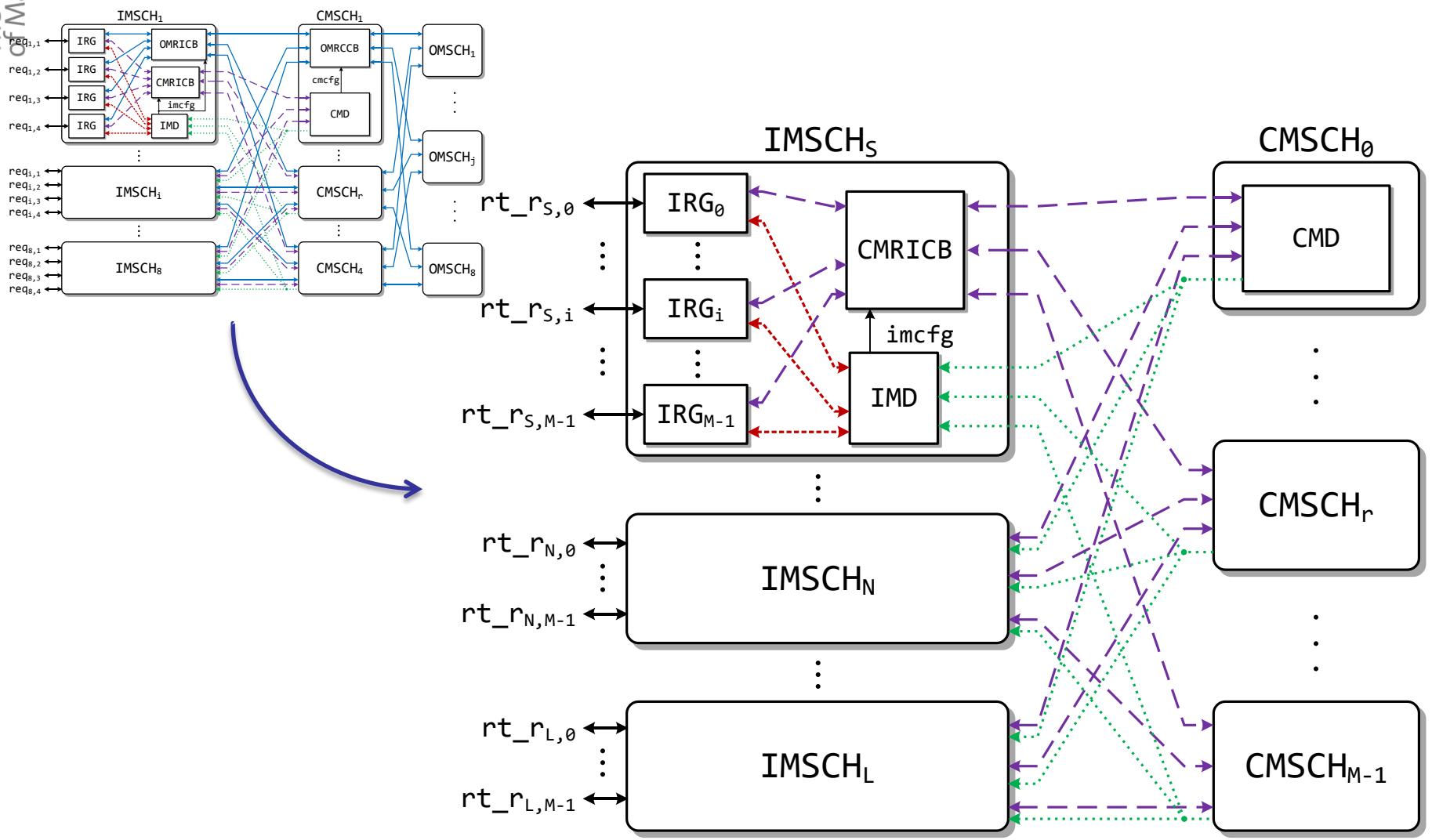
# Simplified CM



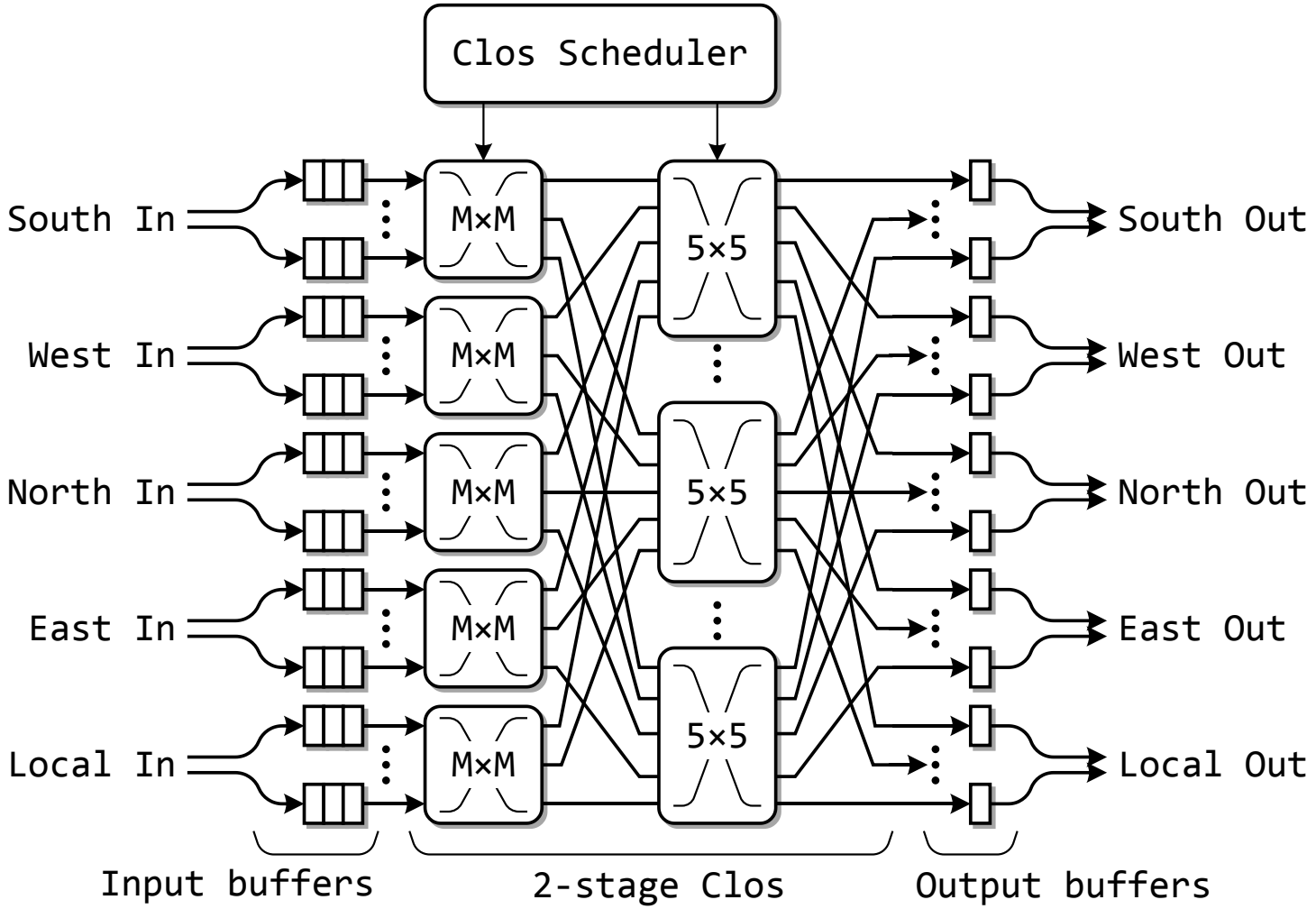
# Clos vs. Crossbar



# 2-stage Clos Scheduler



# A New SDM-Clos Router



# Area Breakdown

| | WH | SDM | SDM-Clos |
|---|---|---|---|
| **IP Buf.** | 17,147 | 23,356 | 19,995 |
| **OP Buf.** | 11,034 | 9,016 | 8,893 |
| **Switch** | 17,754 | 69,701 | 33,417 |
| **Alloc.** | 909 | 83,485 | 19,884 |
| **Overall** | 48,170 | 187,872 | 84,054 |

(unit: $\mu m^2$)

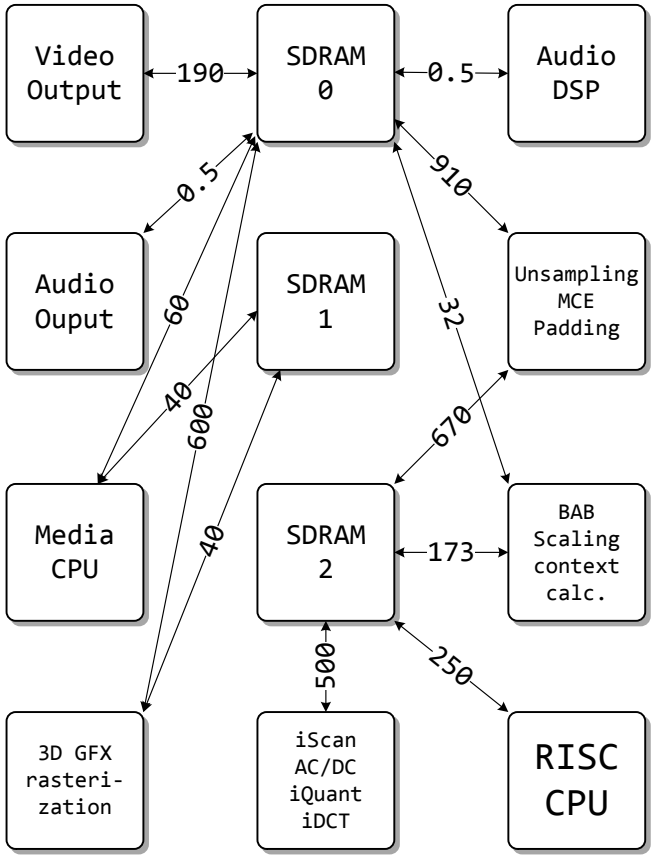
WH: 1 SDM: 3.9 SDM-Clos: 1.7

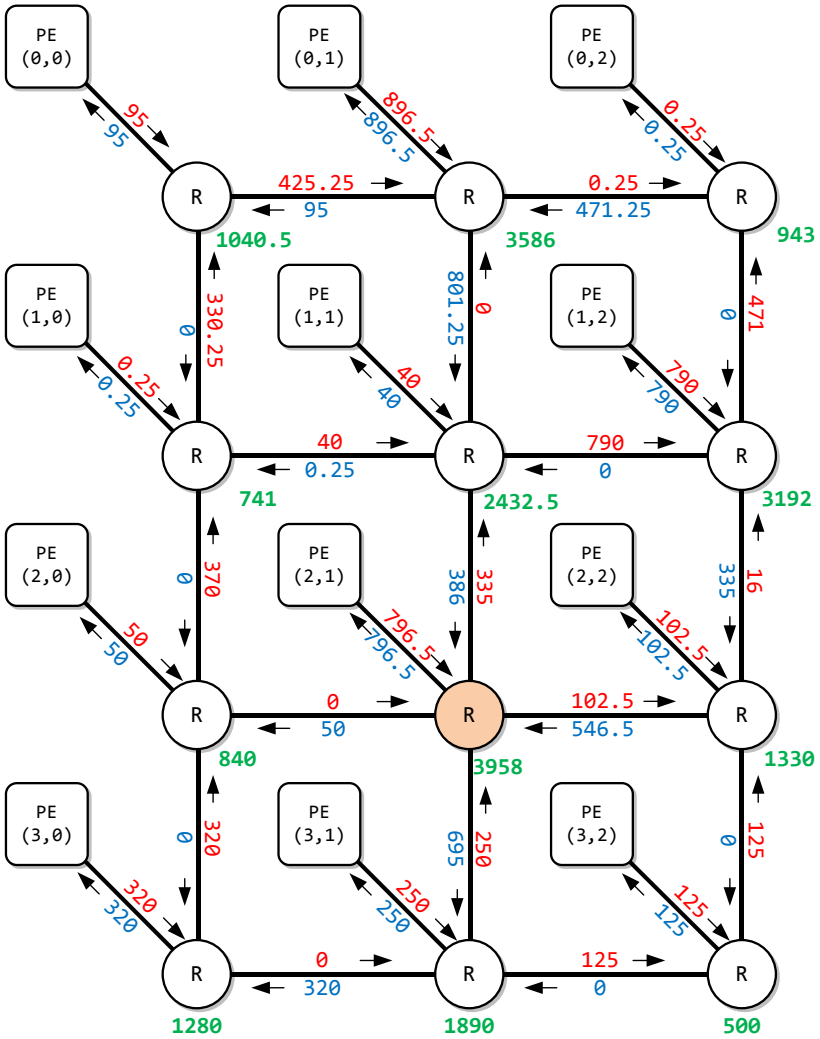
# Speed Performance

| | WH | SDM | SDM-Clos |
|---|---|---|---|
| **Cycle period** | 2.24 | 2.86 | 2.67 |
| **Router latency** | 0.92 | 1.18 | 1.29 |
| **XY router** | 0.64 | 0.68 | 0.63 |
| **Allocation** | 1.24 | 2.01 | 2.13 |

(unit: ns)

# Evaluation: MPEG-4



# Network Performance

| | WH | SDM | SDM-Clos |
|---|---|---|---|
| **Throughput (MByte/s)** | 3414.6 | 3458.1 | 3458.1 |
| **Avg. latency (ns)** | 108.6 | 239.4 | 248.5 |
| **Power (mW)** | 15.6 | 15.2 | 13.6 |

Throughput requirement: ~3,400 Mbyte/s

SDM-Clos:
small latency overhead; low energy consumption; half of the area

# Conclusion

- SDM improves throughput
- Clos switch can reduce the area overhead
- A new 2-stage Clos switch
  - Half area (4 virtual circuits)
  - Small latency overhead
  - Less energy consumption

# Thanks

http://opencores.org/project,async_sdm_noc