Buffer Organization Trade-offs in On-Chip Networks

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Introduction

Router input buffers allow blocked packets to be temporarily queued up during periods of network congestion. The size and organization of these buffers directly affect network performance and cost. We investigate the key design trade-offs that determine the optimal buffer organization for a given set of constraints. Furthermore, we explore the performance and cost benefits of employing dynamic buffer management, and we quantify how buffer sharing can degrade quality-of-service by causing interference between different workloads. Finally, we propose a low-overhead mechanism which mitigates this effect by dynamically varying the degree of buffer sharing based on network load.

Slicing and Sizing the Input Buffer

Buffer size
- Limits number of in-flight flits at a router
- Determines propagation rate for tree saturation

VC Depth
- Must be sufficient to cover credit round-trip delay
- Determines flow control backpressure stiffness (adaptive routing!)

Number of VCs
- Can enable deadlock avoidance
- Additional VCs reduce head-of-line blocking
- Determine load on VC and switch allocator
- Diminishing returns due to correlation between requests (e.g. DOR)

Buffer Management

- Static can derive part of pointer from VC identifier
- Self-compacting requires expensive shifting to keep flits contiguous
- Table-based requires complex table structure, many pointers
- Linked list requires most complex management

Deadlock Avoidance

- Unrestricted buffer sharing is prone to interleaving deadlock
- Solutions:
  - Disallow packet interleaving \rightarrow increases HoL blocking
  - Assign 1+ private slots to each VC \rightarrow risk of under-utilization
  - Only allow VC to give up its last buffer slot when sending tail
  - Avoid protocol & routing deadlock via single private slot per class

Variable Buffer Sharing

- Downstream congestion causes arriving flits to acquire buffers
- Backpressure via unreturned credits \rightarrow only throttle once buffer full
- With shared buffers, this facilitates monopolization of buffer space
- If congestion is severe, buffer slots are held for long periods of time
  - Reduces effective buffer size for other, unrelated packets
  - Congestion spreads across traffic classes
- To avoid this pathology, restrict sharing based on number of currently active VCs
  - Prevent VCs from acquiring buffer slots when they hold more than their fair share (# of slots / # of active VCs)
  - Under low load, behaves like unrestricted sharing
  - Under high load, strives to emulate static partitioning
  - Implement via additional checks in credit tracking logic

Simulation Results

- Statically partitioned input buffers lead to under-utilization of the most expensive resources in on-chip networks
- Dynamic buffer management can improve performance for a given buffer size or reduce buffer size for given performance constraints
- Buffer sharing introduces additional coupling between traffic flows, allowing misbehaving flows to degrade the performance of others
- Variable buffer sharing can be used to mitigate this effect in exchange for a modest increase in router complexity

Conclusions

- Finally, we propose a low-overhead mechanism which mitigates this effect by dynamically varying the degree of buffer sharing based on network load.

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