

# Modeling a Circuit Switched Multiprocessor Interconnect

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$n$	Number of network stages
$k$	Switch size ( $k \times k$ )
$s$	Packet size (flits)
$T_M$	Memory latency (cycles)
$m$	Cache miss rate
$U$	Processor utilization

Table 1: Parameter Terminology

## 1 Introduction

For the ALEWIFE Multiprocessor project at MIT, we considered a low-latency circuit-switched network as one possible medium for the processor-memory interconnect. Models that approximate network behavior were used to gain intuition about the network and to reduce the need for computer-cycle-intensive simulations. The same models were used to verify the correctness of the simulations.

A circuit-switched network was analyzed by Patel [1]. Patel's model, although quite good over a large range of parameters, employs one principal simplification, the unit-request approximation, which hurts its accuracy. In this paper, we discuss Patel's analysis and develop our own model for comparison. Like Patel, we explicitly model network depth and switch size, but unlike Patel, we explicitly take into account the effects of packet size and memory latency.

## 2 Network Description

We considered the standard architecture of a multi-stage unbuffered circuit-switched Omega[2] network for connecting processors to memory modules. Table 1 contains a summary of the network parameters. On any given cycle, a processor node issues a network request with probability  $U/m$ . Each request travels through the

network stages toward the memory, establishing a path between the processor and the memory module to transfer the packet.

A collision occurs at network stage  $i$  when two or more inputs to this stage need to use the same switch output or when the requested output is already part of a previously established path. In such a case, the request path is turned around and a one-flit collision response packet is sent back to the point where the request originated. A switch input is thus occupied for  $s+1$  cycles when handling a packet that collides in that switch.

When a processor receives a collision response packet, it reissues the request. Eventually the packet head successfully reaches the last stage of the network. At that point, the link to the requested memory module remains busy for  $T_M + 2s$  cycles. The total time between a (successful) memory request and positive acknowledgment is therefore  $T_M + 2s + 2n$  cycles.

The analysis presented in this paper is based upon the following two assumptions:

- (1) Cache requests to main memory are random, independent, and uniformly distributed over all memory modules and requests at the inputs of any switch are uniformly distributed over all outputs.
- (2) The probability that a given packet head has a collision at a given switch is independent of the packet's history.

## 3 Patel's Model

Patel's model estimates the network delay using the unit-request approximation. Let the transaction time be  $t$ , where  $t = T_M + 2s + 2n$ . The unit-request approximation views this as equivalent to a situation in which the cache miss rate is  $mt$  and the transaction time is one. In other words, the processor splits up a memory request that would require  $t$  cycles to service into  $t$  independent and uniformly distributed unit-time sub-requests.

This approximation greatly simplifies the analysis. Define  $r_i$  to be the probability that any link at level  $i$

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