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Performance analysis of adaptive wormhole routing in a two-dimensional torus

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Abstract

This paper presents an analytical evaluation of the performance of adaptive wormhole routing in a two-dimensional torus. Our analysis focuses on minimal and fully adaptive wormhole routing that allows a message to use any shortest path between source and destination. A validation of the analysis through simulation is presented to demonstrate the accuracy of the obtained results. Finally, we remark that no theoretical limitation prevents the extension of our analytical approach to the evaluation of the performance of adaptive wormhole routing in hypercubes or other symmetric topologies with wrap-around connections.

Keywords: Message passing; Multicomputers; Performance analysis; Torus topology; Wormhole

1. Introduction

Wormhole routing is the most adopted and efficient technique for communications in parallel machines [28]. This policy makes the latency insensitive to the diameter of the interconnection network in case of light traffic and allows the reduction of the channel buffer size. Even if commercial multicomputers employ wormhole combined with *deterministic* routing, several studies have demonstrated the usefulness of *adaptive* strategies [5,6,13,15,22]. Deterministic routing does not have the ability to

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cope with dynamic network conditions such as faults and congestion because the path between source and destination is determined statically. These drawbacks are avoided by adaptive routing that, in case of channel unavailability, looks for alternative paths.

In this paper we propose an analytical approach to evaluate performance of minimal and fully adaptive wormhole. We present the model for a two-dimensional torus with bi-directional links. However, our analysis can be extended to other symmetric k-ary n-cubes with wrap-around connections (especially with low dimensional topologies which were demonstrated to achieve best performance [2,10]).

In the literature, most of the results about adaptive wormhole have been obtained through simulation studies (e.g., [6,15,16,20,22]), whereas analytical models are usually restricted to deterministic wormhole [1,7,8,10,12,19] or to different techniques such as *circuit-switching* [9] and *virtual-cut-through* [21,24]. To the best of our knowledge there are two papers related to our work [23,26], which present analytical evaluations for the case of adaptive wormhole routing.

Finally, we note that the dynamic choice of paths proper of adaptive routing makes an analytical treatment of the wormhole technique very difficult. Many equations of our performance model show mutual dependencies that prevent a closed form solution and motivate the recursive form equation for the mean latency time.

The remainder of the paper is organized as follows. In Section 2 we describe the operational features of minimal and fully adaptive wormhole routing in a two-dimensional torus. In Section 3 we present the model. In Section 4 we propose a solution for the estimation of the mean latency time. In Section 5 we validate the analytical results against time values obtained from simulations.

2. Routing techniques

Three main techniques transmit packets while building the path from the source to the destination processor: *store-and-forward*, *virtual-cut-through*, and *wormhole*. The store-and-forward technique gathers the entire message at each intermediate node before asking for another channel. Virtual-cut-through, proposed by Kermani and Kleinrock [18], aims at reducing the transmission time. It partitions a message in *flits* and implements a pipeline technique for the transmission: upon getting a channel, the *header flit* tries to get another channel while the *data flits* are transmitted through the already obtained channels. This strategy requires message buffering only in the case of channel unavailability.

Latest generation multicomputers adopt *wormhole* routing [3,25] which, in the absence of channel contention, behaves like virtual-cut-through. However, when contention occurs, wormhole does not gather all the flits into the buffer of the last reached node, but stores them in the flit buffers of the nodes along the already established path. A channel is released only after the last flit (*tail flit*) of the message is transmitted through it.

Unlike deterministic routing that, in the case of channel contention, blocks the message transmission, adaptive wormhole routing looks for alternative paths with-