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PT-BAR: Prioritized Thermo-Buffer based Adaptive Routing Protocol for Network-on-Chip

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Abstract

The Network-on-Chip (NoC) is an important technology that replaced the traditional bus-based architecture for the future of System-on-Chip (SoC). The NoC system provides better scalability, performance, reliability, etc. to the SoC networks by implementing the principles of interconnection networks and packet switching. One of the major problems in NoC is the increase in temperature of the nodes that leads to unbalanced thermal management within the network. This further leads to performance degradation due to damaged nodes. A novel thermal management scheme is proposed in this paper, which makes use of the thermal state and buffer state of the nodes for routing the packets. The proposed Prioritized Thermo-Buffer based Adaptive Routing (PT-BAR) protocol maintains a thermal region based on the thermal balance of the nodes within the region. Only high priority packets are transferred through the thermal region to preserve thermal balance throughout the network. During packet transfers the thermo-buffer model considers the energy consumption and thermal conductivity of nodes to calculate temperature and the current buffer state of the node. This factor is used to choose a path that will provide better performance in end-to-end delay and throughput while preserving the thermal balance of the network. Proposed PT-BAR reduces the temperature by $1.5^{o}C$ than the existing protocol by making use of the efficient thermal model and buffer models for the efficient routing strategy

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Keywords: Prioritization; Thermal balance; Network-on-Chip; Adaptive routing; Packet switching

1. Introduction

Highly integrated System-on-Chip (SoC) technology has been used recently where large numbers of transistors are being integrated into a single small chip [1]. The major cause for thermal glitches within the System-on-Chip networks are the continuous increase in consumption of power and the system cool down cost that leads to degradation in system performance and reliability. This further increases the delay incurred and the power leakage in

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the network [2]. Bottlenecks like these in the SoC network can be avoided by replacing the traditional bus-based architecture [3] of the on chip network with the Network-on-Chip (NoC) that is built using interconnection networks and packet switching. Issues such as end-to-end delay, low throughput, scalability and bandwidth are handled using the NoC network. The NoC architectural design still suffers from thermal glitches and problems even though the performance is high [4].

The major challenges in any NoC network are to provide the following: (1) an effective routing algorithm that obtains high performance and throughput with less delay, (2) enhanced thermal management scheme to provide balanced temperature throughout the network and (3) a reliable deadlock recovery mechanism to improve network reliability. The routing algorithm applied in the network should consider these aspects to provide a model that can obtain efficient packet delivery and can still preserve the thermal balance of the network. The most critical issue of the above is the thermal management of the network that affects the network performance completely.

Two cases of thermal issues have been noted in any given NoC system. The first is the regional temperature differential that occurs due to unbalanced distribution of temperature of the nodes in the network. The thermal unbalance within the system will eventually lead to system failure and performance degradation as it will affect network delay. The second is the occurrence of hotspot nodes due to a high temperature of any node that happens due to processing too much data or by consuming large amounts of energy. This may cause the hotspot node will stop working normally or get damaged with increate in temperature. Unique strategies should be used to obtain good thermal balance.

The routing algorithm implemented in the NoC system should also consider the thermal balance of the network before forwarding packets. The routing algorithm selects a path from source to destination based on a routing function and selection strategy to transfer the packets. The set of available output ports from the current nodes are obtained using the routing function and a suitable path is selected using the selection strategy using a weight factor.

Another dimension in efficient routing for managing thermal balance is by forwarding limited number of packets through high temperature nodes, and no packet at all, through hotspot nodes. The priorities of packets should be maintained in such a way that all high priority packets get delivered without delay. The next aim of routing algorithm is to effectively handle deadlocks [10] during packet transfer in the NoC system. Deadlocks can be prevented and avoided by implementing certain deadlock avoidance and deadlock recovery mechanisms [11]. Unwanted use of buffer space and traffic congestion can be avoided [11] by handling deadlocks. One such mechanism is to forward the deadlocked packets using a special deadlock recovery channel within the network.

A novel and dynamic routing protocol is proposed in this paper that works as an adaptive protocol in a given NoC system and aims to obtain thermal balance throughout the network and still provide good throughput and performance. The proposed PT-BAR routing protocol is designed using a priority based T-B(Thermo-Buffer) state model that considers both the thermal state and the buffer states of the nodes when forwarding packets. The thermal model is built by identifying node temperature and energy consumption based on energy transformation and thermal conductivity. The prioritizations of the packets are considered when forwarding them through high temperature regions. The proposed routing algorithm is implemented in a 3D mesh NoC system.

The key contributions of the proposed routing algorithm are as follows: (1) the T-B state model can achieve good performance in end-to-end delay and throughput while conserving node temperature, (2) by using prioritization of nodes in packet transfer hotspot nodes and unbalanced thermal distribution can be avoided and finally (3) deadlocks can be avoided and especially in case of high priority nodes the delivery ratio obtained will be high.

The remainder of the paper is organized as follows. Section 2 talks about existing methods in thermal management and routing protocols. Section 3 explores the working principle of the proposed PT-BAR protocol using the T-B state model and the prioritization principle. Section 4 shows the simulation of proposed routing strategy using a 3D NoC system and results are compared with existing methods. Section 5 provides the conclusion of the paper.

2. Existing Methods and Motivation of Work

2.1 Network-on-Chip

The Network-on-Chip is a network architecture that provides a detailed structure of various elements of the network. The various processing elements of NoC network can be classified as: