Performance Evaluation of Unicast and Multicast Communication in Three-Dimensional Mesh Architectures

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***Abstract*— As the multicast communication is utilized commonly in various parallel applications, the performance can be significantly improved by supporting multicast operations at the hardware level. In this paper, we define several factors of efficiency for unicast/multicast communication such as average of unicast latency, average of maximum multicast latency and level of parallelism in 3D mesh NoCs. Then, we propose analytical models for measuring the efficiency factors of a method in unicast/multicast communication called vertical block partitioning.**

I. INTRODUCTION

The routing protocols in NoCs and MPSoCs can be unicast or multicast [1][2]. In the unicast communication a message is sent from a source node to a single destination, while in the multicast communication a message is delivered from one source node to an arbitrary number of destinations nodes. The tree-based and path-based methods [2][3] are two famous hardware-based schemes employed in the multicast communication. In the tree-based method, a destination set is partitioned at the source node and separate copies are sent on one or more outgoing channels [2]. In the path-based method, a source node prepares a message for delivery to a set of destinations by sorting the addresses of destinations in the order in which they are delivered. Some researches show that path-based routing is more beneficial in the wormhole switched network [3]. For preventing deadlock in path-based routing, the Hamiltonian path strategy was introduced [3][4].

Multicast latency consists of two parts: startup latency and network latency. The startup latency is the time required to break a message into several packets and deliver them to the network. The network latency is defined as the time between the first flit is injected to the network until the tail flits of all messages has reached corresponding destinations. The performance of multicast communication is measured in terms of its latency in delivering a message to all destinations.

II. RELATED WORK

There have been several attempts to improve the performance of multicast communication in 3D NoCs. An adaptive multicast communication in 3D mesh networks is discussed in [5]. The algorithm is based on an extension of a theory defined in [6] from 2D to 3D mesh network. The algorithm utilizes the Hamiltonian path and prevents deadlocks by using virtual channels. Two another methods of unicast/multicast communication in 3D meshes are presented in [7]. The proposed methods are guaranteed to be deadlock free because of using the Hamiltonian path. However, the presented algorithms are suffering from inability to partition the network efficiently. In [4], several partitioning methods for unicast/multicast traffic are introduced: Two-Block Partitioning (TBP), Vertical-Block Partitioning (VBP) and Hybrid Partitioning (HP). In order to improve the performance of multicast communication, the idea of balanced partitioning in 3D mesh network is discussed. However, the results are obtained for a fixed network size and therefore, the work suffers from a lack of generality. In this paper, we defined several factors of efficiency such as average of unicast latency, average of maximum multicast latency and level of parallelism for unicast/multicast communication in 3D mesh NoCs. Then, we proposed analytical models for VBP method that can be extended to other methods.

III. VERTICAL-BLOCK PARTITIONING (VBP)

In this scheme by utilizing the Hamiltonian path [3][4], the network is partitioned into high and low channel subnetworks. The high channel subnetwork contains all directional channels with nodes labeled in ascending order, and the low channel subnetwork contains all directional channels with nodes labeled in descending order (Fig. 1). Destinations in the high group should be sorted in ascending order and other destinations in descending order. The created messages are routed via high and low channel subnetworks. In the next step, each subnetwork should be vertically partitioned in which the nodes with the same *x* value will be put in the same group. This scheme avoids the creation of long paths and reduces the network latency. Fig. 1(a) and Fig. 1(b) are two examples of dividing the network into several partitions by utilizing VBP method, where the source node is located at 25 and 6, respectively. In both examples the network is divided into eight partitions. In Fig. 1(a), all partitions contain comparable number of nodes while in Fig. 1(b) four partitions cover more number of nodes than others. Now, suppose a multicast message is generated and sent to destinations {2,4,8,10,16,28,31,40,43} in both examples. The longest path in Fig. 1(a) is belonged to set4 with maximum 6 hops and with the following path {**25**,26,27,28,35,36,43}. Similarly, the longest path in Fig. 1(b) is {**6**,7,8,15,16,23,24,31,32,39,40}.

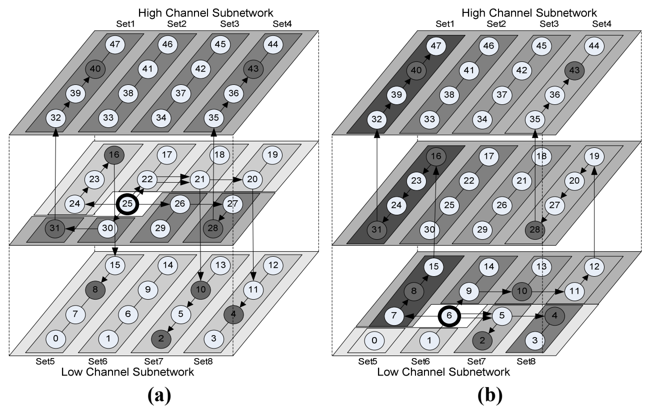

Fig. 1. VBP method (a) balanced (b) unbalanced partitions.

A. Level of Parallelism

Breaking the network into unbalanced partitions (Fig. 1(b)) might create long paths in some partitions. In contrast, balanced partitions can help to distribute the traffic inside the network. It results to avoid the creation of long paths and thus decrease message arrival time to all destinations.

The "Level of Parallelism (LoP)" is a factor indicating how efficiently the network is divided into balanced partitions. The greater LoP, the better distribution of traffic through the network. When the network is divided into several partitions by source node *s*, LoP can be calculated by:

$$LoP(s) = \frac{\sum_{i=1}^{Num.of\ partitions} Num.of\ nodes in\ partition i}{(Num.of\ partitions) \times (Num.of\ nodes in bigest partition)}$$

As an instance, the LoP is equal to 0,86 and 0,54 in Fig. 1(a) and Fig. 1(b), respectively. In a case the network is divided into equal sized partitions, LoP will be equal to 1.

The LoP can be calculated for the whole network as:

$$LoP = \frac{1}{n}\sum_{s=0}^{s=n-1} LoP(s) \qquad where\ n = a \times b \times c$$

B. Network Latency for unicast messages

The performance of VBP can be measured by the number of hops required for delivering the message from the source node to any destination [2]. Assuming the dimension-order routing, the Average number of Hops for Unicast messages (AHU) in 3D mesh is [8][9]:

$$AHU_{VBP} = \frac{abc(a+b+c) - c(a+b) - ab}{3(abc)} \qquad (1)$$

For a 2D mesh, this equation has changed by assigning the value of 1 to *c*, as follow:

$$AvgUnicast_{2D} = \frac{ab(a+b+1) - (a+b) - ab}{3(ab)} \qquad (2)$$

C. Network Latency for multicast messages

Each multicast message contains several destinations, and the message path between the source node and the last destination necessarily is not a minimal path. On the other hand, the number of hops taken by a multicast message depends on the number of destinations and their locations. Therefore, calculating the average number of hops for multicast messages cannot be easily analyzed and modeled analytically. In order to find an analytical formula to calculate the latency of the multicast messages, we assume that the messages travel within the longest path to reach the last destination without considering intermediate destinations. As a result, the factor is determined as an Average of Maximum Hop counts for Multicast messages (AMHM) between each source node and destination. Considering the example in Fig. 1(a), if messages are sent through the longest paths, the paths in Fig. 2 are obtained. As can be observed from the example, in order to calculate AMHM for the VBP method, the network can be imagined as 2D a×b′ mesh network where b′ dimension is equal to b×c. Now, dimension-order routing can be utilized for each message and AMHM can be formulated by (2). As a result, an average of maximum hop counts for multicast messages in VBP method is:

$$AMHM_{VBP} = \frac{ab'(a+b'+1) - (a+b') - ab'}{3(ab')} = \frac{(abc-1)(a+bc)}{3(abc)}$$

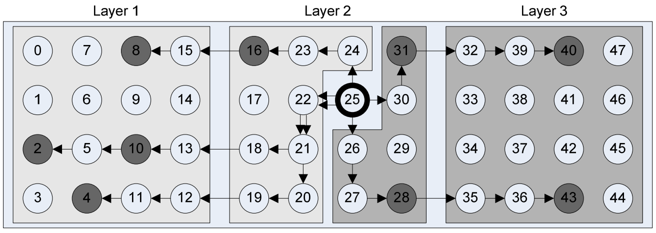

Fig. 2. Traveling the messages through longest paths in VBP method

IV. Summary and Conclusion

In order to analyze the performance of unicast and multicast communication, we introduced several factors of efficiency such as average of unicast latency, average of maximum multicast latency and level of parallelism in 3D mesh NoCs. Then, we presented analytical models that describe the efficiency factor of the vertical-block partitioning method which has been proposed for unicast and multicast communication.

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