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FAULT AND BALANCED RING FORMATION FOR FAULT TOLERANCE IN DMESH NETWORKS

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Abstract

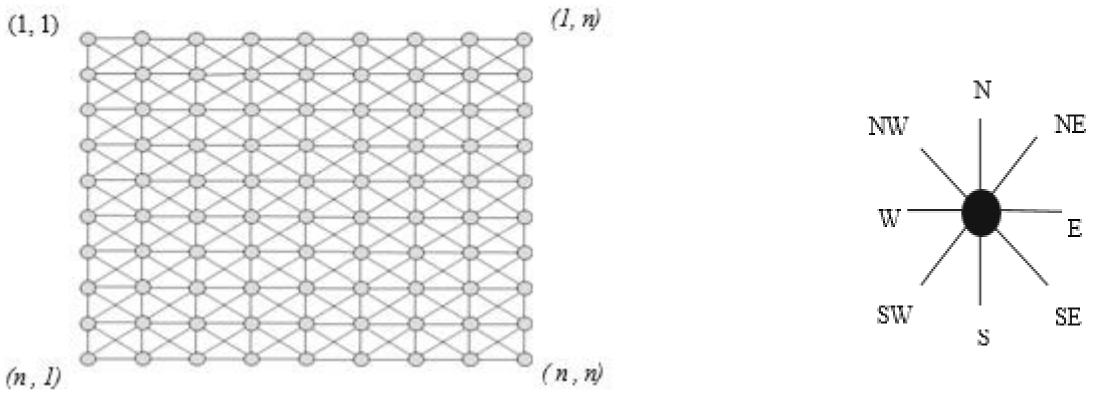
A key component of massively parallel processing systems (MPPs), which use thousands of processors working simultaneously to solve mission-critical engineering and scientific tasks, is fault tolerance. Failure of a single MPP component could result in system shutdown or performance reduction in fine-grained parallelism if an appropriate intelligent fault-tolerant routing mechanism is not used. As a result, an intelligent fault-tolerant routing strategy needs to enable a system to run an application in the event of a fault, at least partially. In order to increase the fault tolerance capability of the DMesh interconnection network, we introduce a unique method in this research that is based on the concepts of fault-ring and balanced-ring.

In order to offer a fault-free path for incoming routed packets, our suggested approach demonstrates that the system can avoid the fault by joining fault-free nodes encircled by a defective region. The accuracy of our method is demonstrated through mathematical proof and figurative demonstration.

Keywords: *DMesh network, Fault ring, Balanced ring, Fault tolerance, Interconnection network, Fault tolerant routing.*

Introduction

Because of its high scalability, straightforward structure, regularity, and minimal signal propagation delay between neighbouring processing elements, mesh is a popular interconnection network topology among researchers. However, its high diameter and average distance prevent development on a very large scale in MPP. In order to lower the overall communication delay by adding more communication channels among processing units, new types of interconnection networks, such as DMesh [1, 2], clos [3], Dragonfly [4], Cluster Mesh [5], Spidergon Doughnut [6], and Exchanged Crossed Cube [7], have been designed in response to the current scenario's massive data generation. A DMesh is a novel type of interconnection network that enhances overall network efficiency by reducing the width and average distance constraints of a standard 2D-mesh network while inheriting the superior qualities of mesh networks through the addition of diagonal linkages. As shown in Fig. 1a, a DMesh network is constructed by including diagonal linkages into a 2D mesh network. As seen in Fig. 1b, nodes are connected to neighbouring nodes in eight different orientations. Any network fault might result in an unneeded delay or interruption of the communication line, which could lead to a misrouted or stalled data packet. If a fault-free node in a fault-free network does not get an acknowledgement (ACK) from its neighbouring nodes during a normal neighbour status check, it may be regarded a node or link fault. An effective fault tolerance feature [8] guarantees the creation and validation of a system that functions well in the event of faults. The likelihood of a fault occurring increases exponentially with the scale of a network or its components, particularly in MPP. For this reason, research into intelligent, effective fault tolerance schemes has always been crucial to ensuring uninterrupted processing.



(a) Displaying the DMesh network's grid structure of size n×n

(b) Every node can connect to its neighbours in eight different ways.

Figure 1a displays the grid structure of a n × n b DMesh network. Each node can connect to its neighbours in eight different ways.

Many fault-tolerant routing methods have been developed to avoid failures on various interconnection networks. Adaptive routing algorithms are adequate to provide fault tolerance qualities in a system, as demonstrated by Reddy and Freitas [9]. Three communication models were employed: (1) asynchronous communication with a random destination (2) synchronous communication with a random destination and (3) synchronous communication where all processors synthesise at each step and destinations are localised require global knowledge of any faults, which is challenging to maintain in an MPP and the routing tables to examine the performance constraints. A somewhat adaptive technique for resolving faults in a mesh network with three virtual channels was proposed by Chein and Kim [10], however it was unable to manage faults that were located on the network's boundaries. Boppana and Chalasani [11] used the worm-hole technique to overcome the issue by employing four virtual channels for fault-tolerant routing algorithms in mesh networks. They employed just local knowledge of defects and took into account problematic blocks that were arbitrarily located. Bypassing messages via a fault ring surrounding a defective region—that is, linking faulty free nodes—was the fundamental idea behind message routing when faults occurred.

In the subsequent study, they presented a fault-tolerant routing algorithm based on the e-cube routing scheme. They also demonstrated that the method was free of deadlocks and live-locks by employing a rectangular-shaped fault model that included both f-rings and f-chains. A solid fault model-based fault-tolerant wormhole routing algorithm for an overlapping fault region with four virtual channels was introduced by Kim and Han [12]. Deadlock and live-lock were absent from the algorithm. Wu [13] proposed an extended XY-routing protocol that is fault-tolerant and can handle both orthogonal and rectangular faulty blocks. It is based on the odd-even turn model and dimension ordering routing technique. Additionally, Boppana and Chalansani [14] proposed a fault-tolerant routing algorithm to handle solid faults, which include all convex and non-convex faults, as well as convex faults shaped like L, T, or + with four virtual channels in meshes and rectangular-shaped fault regions in toruses with six virtual channels. Two wormhole routing methods, F3 and F4, were proposed by Seungjin Park, Jong-Hoon Youn, and Bella Bose [15]. These algorithms handled more relaxed (zigzag) fault ring geometries, which in some cases reduced the number of disabled components. Additionally, Jipeng Zhou and Francis C.M. Lau published an adaptive fault-tolerant routing technique in 2D meshes [16] that can withstand convex faults with just three virtual channels per physical channel despite the f-polygons of several fault locations overlapping. The majority of fault tolerance strategies (summarised in Table 1) rely on fault rings, which facilitate communication while guaranteeing the correct delivery of packets in a network.

The position information of the malfunctioning blocks is distributed in the respective columns by the ZoneDefence [17] routing method, which is used to a 2D-Mesh interconnection network suggested by Binzhang Fu et al. Because the nodes that are aware of the location of faulty blocks create the defence zones, packets are able to locate the faulty blocks and avoid them beforehand. The impact of node failure on network nodes' capacity to retain connectivity is examined by Xiang [18]. A strict upper constraint on the node failure probabilities needed to preserve complete network connectivity was provided by the author. Two methods, flow controlled clue and wormhole clue, were suggested by W. Luo and D. Xiang [19]. These algorithms outperformed the bubble flow control technique for a number of common traffic patterns in 3D-torus.
Only two virtual channels were needed. A scalable and energy-efficient ZMesh Network was designed and evaluated by Prasad [20] et al. He mapped applications onto the ZMesh topology using a heuristic technique. The probabilistic study of mesh interconnection networks was produced by Jianer Chen et al. [21]. He also developed a method to formally calculate lower bounds on the connectivity probability for 2D and 3D mesh networks. In order to avoid agents from becoming lost at irrational nodes (maliciously behaving nodes), Munshi [22] and colleagues devised a strategy to tolerate errors induced by malicious node behaviour and link failure using agent cloning. [23] For fault-tolerant NoCs, D. Fick, A. DeOrio, G. Chen, V. Bertacco, D. Sylvester, and D. Blauw developed a robust routing algorithm. Segment-based routing: An effective fault-tolerant routing technique for meshes was proposed by Mejia et al. [24].

Table 1: A comparison of a few fault-tolerant routing algorithms that are aware of local network issues

	Fault model	Virtual channels	Fault tolerated in meshes	Routing techniques
Duato [27, 28]	Arbitrary	4	Up to n-1 in n meshes	Adaptive
Chein and Kim [10]	Rectangles (non-overlapping f-ring only)	3	Multiple faulty rectangles	Planar-adaptive
Su and Shin [29]	Disconnected rectangles	2	Multiple faulty rectangles	Adaptive
Shil [30]	Rectangles	2	Faulty rectangles	Adaptive
Chalasini and Boppana [11, 14]	Special Convex(L,T, + shape) *f- ring*	4	Multiple convex regions(*f-rings*)	Adaptive
Jipeng Zhau and	Convex faults	3	Multiple fault regions	Adaptive

Francis Lau[16]				
Our Result	Concave and Convex faults (*frings* and *brings*)	3	Multiple faults of different shape and regions in DMesh network	Adaptive

Stockmeyer [25] introduced a novel method for mesh-connected parallel computers using fault-tolerant wormhole routing.

In order to take advantage of routing adaptivity and go around any network failures, this paper presents the creation of fault-ring and balanced rings. By creating a fault-ring or fault-chain around a defective region, the proposed approach can effectively handle both convex and concave faults.

The following is a description of the remainder of the paper: The DMesh network's architectural characteristics and routing method are covered in Section 2. In Sect. 3, we introduce the fault-ring formation technique. In Section 4, the balanced-ring formula is presented to offer additional options in the event that a substantially congested fault-ring is used.

DMesh Network Architectural Features

DMesh Network Architecture

A DMesh network of size $n \times n$ nodes shown in Fig. 1 is made up by introducing new diagonal links among the nodes in a 2D-Mesh Network. A processor(or node) placed in row x and column y is denoted by $p(x, y)$, $1 \leq x \leq n$; $1 \leq y \leq n$ has three dimension links for communication say, Dim_0, Dim_1 and Dim_2 to provide an efficient routing decision during communication among the nodes in a network. We assume that all links are bi-directional, thus, the flow of information can be done in both directions. A node $N(x_j, y_i)$ is to be considered as a neighbor (or adja- cent) of a node $N(x_i, y_i)$, *iff* $x_i - x_j + (y_i - y_j) \leq i; \forall 1 \leq i \leq 2$. Table 2, shows all possible neighbor nodes of a given node $N(x, y)$.

Lemma 1 At any intermediate node say $\diagdown x , y \lbrack$, adjacent neighbor node (x_j, y_i) towards the destination node can be visited by dim_0 link if and only if, $(x_i - x_j) = 0$ similarly neighbor node can be visited by dim_1 link if and only if $(y_i - y_j) = 0$ while dim_2 link is used if $(x_i - x_j) + (y_i - y_j) = \{0; 2\}$

DMesh Network Routing

Here, we provide a ZXY-routing technique (an extension of the XY-routing technique applicable in 2D-Mesh Network) for the sake of user readability and simplicity. When a flit travels over a fault-free network, an intermediate node S(x, y) may make the appropriate routing decisions according to Lemma-1 for destination node D(xj, yj), preferring dim2 link only until S(xi) = D(xj) or S(xi,yi)-= D(xj,yj). Dim0 can be used when S(xi) = D(xi), and dim1 can be used in the same way if S(yi) = D(yi).

As seen in Fig. 2, we assume that a node S (6, 1) is the source node and a node D (4, 5) is the destination node. Therefore, according to the universal ZXY-routing method, the general path for communicating flits might be N(6; 1) → N(5; 2) → N(4; 3) → N(4; 4) → N(4; 5).

Table 2: Using Lemma 1, all eight potential neighbours of node N (x, y) with their coordinate positions and eight directions

Neighbor of a node $N_{(x,\ y)}$in direction:	Coordinate of a neighbor w. r. t $N_{(x,\ y)}$:	Alias Name	Neighbor node can be visited by link
East	$x{,}y + 1$	E	Dim_1
West	$x, y - 1$	W	Dim_1
North	$x - 1{,}y$	N	Dim_0
South	$x + 1{,}y$	S	Dim_0
North East	$x\text{-}1{,}y + 1$	NE	Dim_2
South East	$x + 1{,}y + 1$	SE	Dim_2
South West	$x + 1{,}y - 1$	SW	Dim_2
North West	$x - 1{,}j - 1$	NW	Dim_2

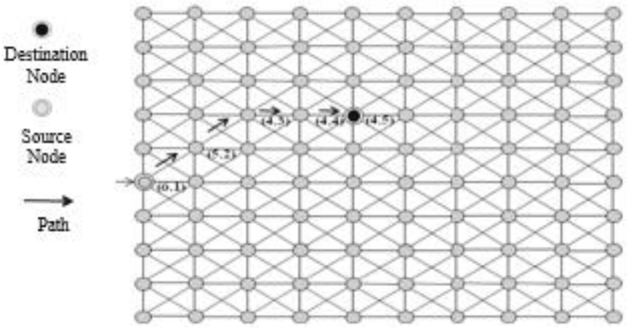


Figure 2: Using the generic ZXY-routing approach for DMesh routing

The Formation of Fault Rings

The creation of a f_ring is presented in this section. First, we go over how f_ring forms in a 2D-mesh network, as explained in [12, 14, and 15].

A flit requires an intelligent routing system, such as a fault ring (f_ring), to avoid a faulty area in a 2D mesh network. As illustrated in Fig. 3a for a 2D-Mesh network of size n × n as reported in [12, 14, and 15], a defective region consists of either one component failure or a sequence of components/adjacent nodes failure. Fault-free nodes and links surrounding a defective region can be connected to create a f_ring. For the sake of simplicity, we simply took into account physical component failure, such as a node or link fault, which could result in a deadlock or live-lock scenario for Flit in the absence of a fault-tolerant routing mechanism.

When a flit encounters a f_ring, it wanders around it until the generalised routing algorithm, also known as the XY-routing algorithm, is unable to be applied to it. An f_ring could be shaped differently. Depending on the defective region's initial shape, it may be convex or concave. If two or more fault rings share one or more links, they are said to be overlapped fault rings. If a malfunctioning node or link (channel) is located on the network's edge, a fault-chain rather than a fault-ring is created.

In a DMesh network, f_ring can also be created by connecting components that are free of faults around an area that is problematic. It is made up of fault-free nodes and links that are next to one or more parts of the problematic region, either diagonally, rowwise, or columnwise. In a network, multiple fault rings may exist. If a flit comes into contact with f_ring, it can move both clockwise and anticlockwise. If a fault ring shares nodes or links with another fault ring, it may overlap, as Fig. 3b illustrates. The fault regions F1, F2, F3, F4, F5, F6, and F7 are made up of malfunctioning nodes or links.

When a fault arises on the network's boundaries, a fault-chain is created rather than a f_ring, as seen in Fig. 3b for faulty regions F6 and F7.

A Suggested Algorithm for DMesh Network Fault Ring Formation

This section introduces a new method for fault ring formation in a DMesh network. Although it is somewhat similar to how f_ring forms in 2D mesh networks, a different f_ring technique must be created for DMesh networks because of their distinct topological characteristics. The fundamental concept of f_ring formation in a DMesh network is elaborated in the next two sections.

1) In the first stage, every node in a network delivers a hello packet along the dim0, dim1, and dim2 dimensions to each of its eight neighbours.

2) Every time a node receives an ACK from a neighbour node, it changes status_neighbor = TRUE; otherwise, it sets fring_member = TRUE for the node that is now executing and invokes a function called nodesOn_fring() to identify neighbouring nodes that can help form fring.

3) In order to establish a fring or fchain around the faults, each node whose fring_member is TRUE executes a different function called formation_ of_fring().

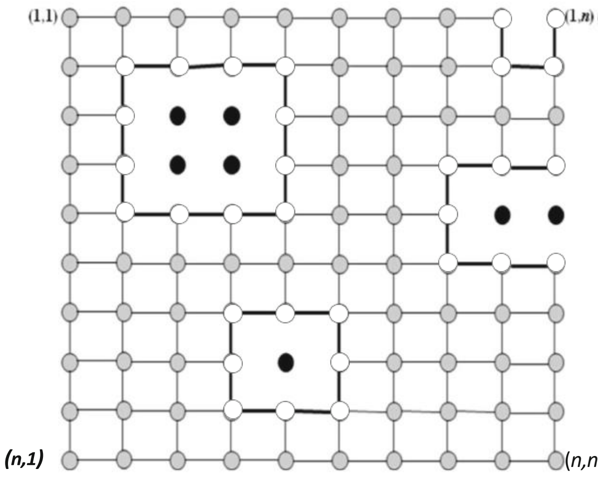
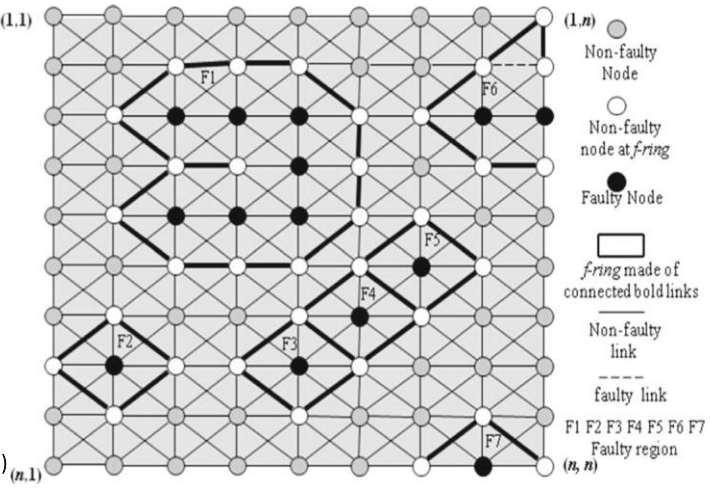


Figure 3a displays f_ring in a 2D mesh with n × n nodes.



b Displaying f_ring and f_chain in a n × n node DMesh Network

Balanced Ring Formation in the DMesh Network

A balanced ring is made up of nodes and connections that are free of faults and surround the fault ring to create a larger, similarly shaped concentric ring. In a DMesh network, nodes on the balanced ring are next to nodes on the fring (row-wise (dim0), column-wise (dim1), and diagonally (dim2). Compared to the 2D-mesh network depicted in Table 2, the DMesh network's diagonal link availability makes it simpler and requires fewer nodes to produce a balanced ring and fault ring. A vast network may have multiple balanced rings of various kinds, such as partially balanced rings and overlapped-balanced rings.

Definition 1 (balanced chain): A fault chain [26] is created in place of a fault ring if any defective region contains faulty components in the network border.

Definition 2 (partially balanced ring): A balanced ring is referred to be a partially balanced ring if it must share links with its fault rings [17].

Definition 3 (overlapping balanced ring): A balanced ring is referred to be an overlapped balanced ring if it shares any components with another balanced ring. Figure 4. Sections B1, B2, and B3 display a balanced ring in which B1 and B2 overlap.

Conclusion

We looked at an interconnection network's fault-tolerant routing characteristics. The formation of balanced rings (bring) and fault rings (fring) in DMesh interconnection networks is explained in this study. With diagonal links as an added benefit, DMesh is a network that inherits the fundamental characteristics of the most widely used 2D-Mesh interconnection network. As a result, nodes can communicate directly with the diagonal node, greatly reducing communication latency and increasing the network's bisection width. It is dependable for a variety of scientific applications when the bisection width is larger. In order to help the flits avoid the problematic area and lessen the likelihood of a live-lock or deadlock situation, we have first provided a method for the formation of a fault ring, which is a concentric ring around a faulty component or region, in this work. The communication time between nodes may significantly increase in the fine-grained parallelism scenario because several flits for different source and destination pairs are likely to overload the fault ring. Another concept for creating a balanced ring—a larger concentric ring surrounding the fault ring—has been put forth to address this problem. As a result, when a large number of flits encounter the fault ring on their routed path, the fault ring's flit control capability greatly increases. At this point, the balanced ring activates and load balancing occurs, which lowers the likelihood of congestion on the fault ring. The suggested approach manages several faults simultaneously and is independent of network size. Several mathematical proofs and figurative illustrations have been used to illustrate the suggested algorithm.

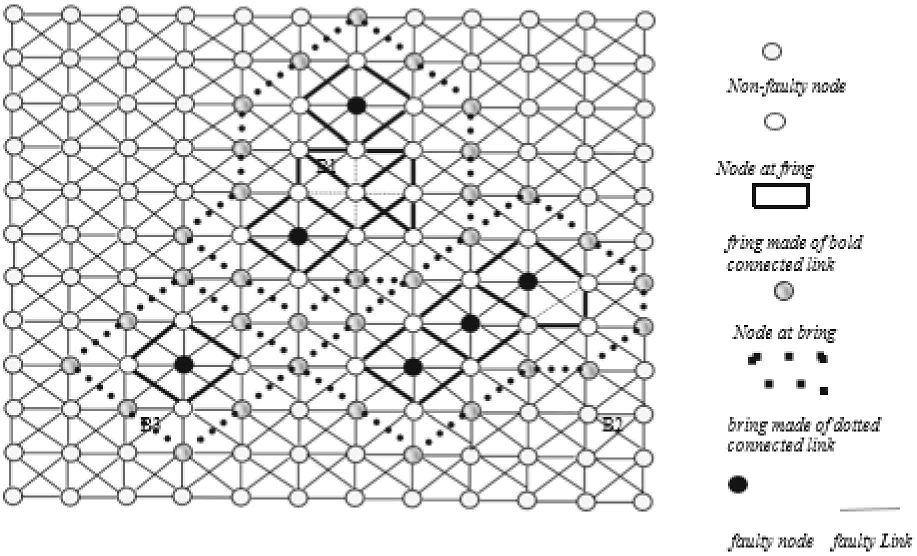


Figure 4: A fring and bring-in DMesh network with n × n nodes

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