# SCRA: A Hybrid Deterministic Routing Algorithm for Aging-Resilient Network-on-Chip

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***Abstract*—Network-on-Chip (NoC) has been proposed as a promising interconnection candidate solution for its high network bandwidth, low communication energy consumption and good parallel transmission capability. However, future many-cores processor will face aging problems such as negative bias temperature instability (NBTI), hot-carrier injection (HCI) and electro-migration (EM). These aging problems will cause switching delay and critical path depravation under imbalanced loads, which leads to bad system reliability. In this paper, a deterministic aging-resilient hybrid routing algorithm called SCRA (source-based configuration router algorithm) is proposed to evenly distribute packet flow over entire network and relieve the aging problems in NoC. In SCRA, a flow distribution model is used to achieve the best uniformity of network communications by combing the complementary characteristics of XY and YX routing algorithm. With the simulation and analysis results, SCRA can realize better uniformity and incremental longevity on the premise of ensuring accessibility and achieves acceptable network communication performance when compared with the single dimensional order routing algorithm.**

## I. INTRODUCTION

Network-on-chip (NoC) plays an important role in the future many-cores system due to its advantages on scalability, power-efficiency high-bandwidth, and parallel capability[1] [2]. With technology development, future many-cores processor will require high-performance and higher reliability on-chip networks to relieve the dominated aging problem. The gravest aging issues in nanoscale technology are Negative Bias Temperature Instability (NBTI), Hot-carrier Injection (HCI) and Electromigration (EM). Both HCI and NBTI can cause the threshold voltage shift, leading to switching delay and critical path depravation, and EM affects the metal wires of NoC [3]. These aging issues can lead to shorter lifetime of NoC, decreasing the reliability of processor [4][5].

By means of comprehensive aging model analysis, load imbalance is expected to account for asymmetric aging of routers and links over time [6] and the decrease of Mean Time to Failure (MTTF) of chips [7][8], leading to the failure of chip like bucket effect. A routing algorithm called LAXY is proposed to relieve the aging issue in NoC and manage the lifetime reliability of NoC components [9]. However, it only explored different Fishtail-like shapes for the regions W and E, which is not a mathematical optimal configuration.

In this paper, a hybrid deterministic routing algorithm called SCRA (source-based configuration router algorithm) is proposed to increase the lifetime of NoC. Routers in NoC have two properties and source nodes are used to select either XY or YX routing algorithm to route packets. The static configuration is optimized to offload the central nodes and balance traffic distribution over network. The situation of XY routers and YX routers on 8 × 8 network is determined to build a uniform flow distribution model. The simulation results show that SCRA can realize better uniformity and incremental longevity on the premise of ensuring accessibility and achieves acceptable network communication performance when compared with the single dimensional order routing algorithm.

## II. SCRA: AN AGING-RESILIENT HYBRID ROUTING ALGORITHM

The traffic distribution over network, regarded as the critical factors to bring about aging issue [9][10], is found to associate with routers workload, power density distribution and signal activity of interconnects. Therefore, if an algorithm distributes traffic over the network properly, it will obviously improve the lifetime of chip by more uniform aging rate.

### *A. XY and YX routing algorithm traffic distribution model*

In this subsection, a traffic distribution model is proposed to calculate the accumulated traffic of each router.

When a source node, using a kind of deterministic routing algorithms, transmits packets to a destination node, the flow of every node in the network will be a deterministic mapping relationship. Thus, when any node of the network is respectively source node (i, j), the influence to the network can be expressed by calculating the accumulation of each node (p, q) as T[(i, j),(p, q)]. For XY routing algorithm in n × n mesh, T[(i, j),(p, q)] can be expressed as:

$$T[(i,j),(p,q)] = \begin{cases} (n-i)\cdot n & p<i, j=q \\ (i+1)\cdot n & p<i, j=q \\ n^2-1 & p=i, j=q \end{cases} \begin{cases} j+1 & j<q \\ n-j & j>q \end{cases}$$

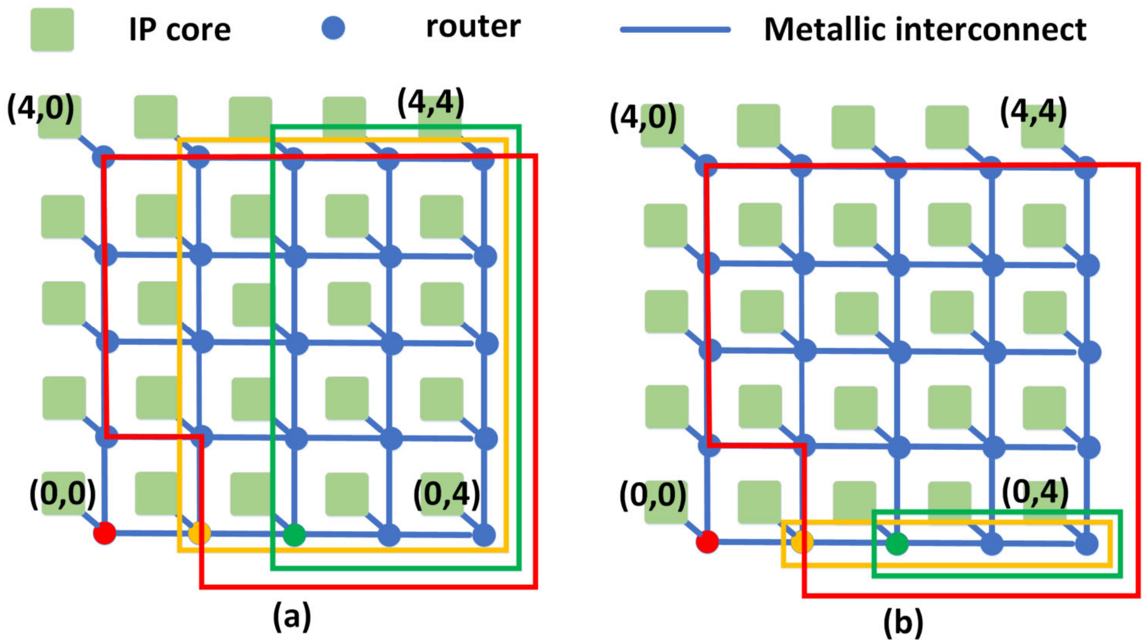



Fig. 1. Traffic distribution model in 5×5 2D mesh NoC: (a)for XY routing algorithm and (b) for YX.

For YX routing algorithm in n × n mesh, T[(i, j),(p, q)] can be expressed as:

$$T[(i,j),(p,q)] = \begin{cases} (n-j)\cdot n & q<j, i=p \\ (j+1)\cdot n & q<j, i=p \\ n^2-1 & q=j, i=p \end{cases} \begin{cases} i+1 & i<p \\ n-i & i>p \end{cases}$$

The proposed traffic distribution model is illustrated with several examples.

a) XY routing algorithm traffic distribution model

As shown in Fig. 1, the example depicts a 5 × 5 mesh architecture. Node (0, 0) is proposed as a source node and we assume that the probability of each routing in the network is uniform. When (0, 0) wants to communicate with the other 24 nodes, the path from (0, 0) to the destination will all pass (0, 0), causing the traffic accumulation of (0, 0) respectively. Thus, the source node (0, 0) has an influence on Node (0, 0), denoted as 24. In addition, when (0, 0) transmits to the other 24 nodes, the path from (0, 0) to the destination refrained by the yellow frame in Fig. 1, will cause the traffic accumulation of (1, 0). Thus, the source node (0, 0) has an influence on Node (1, 0), denoted as 20. Similarly, the influence of all nodes of the network by source node (0, 0) can be expressed as:

$$\begin{cases} T[(0,0),(0,0)]=24 \\ T[(1,0),(0,0)]=20 \\ T[(2,0),(0,0)]=15 \\ \ldots\ldots \\ \ldots\ldots \end{cases} \begin{cases} T[(0,2),(0,0)]=3 \\ T[(1,2),(0,0)]=3 \\ T[(2,2),(0,0)]=3 \\ \ldots\ldots \\ \ldots\ldots \end{cases} \begin{cases} \ldots\ldots \\ \ldots\ldots \\ T[(2,4),(0,0)]=1 \\ T[(3,4),(0,0)]=1 \\ T[(4,4),(0,0)]=1 \end{cases}$$

In above expressions, the second node is proposed as the source router, causing the traffic accumulation of the first node in equations.

What´s more, when all nodes of the network are proposed as the source node respectively, similarly as Node (0, 0), the influence of all nodes of the network by every source node can be expressed. By adding each nodes accumulation of total traffic, the traffic distribution of the network is obtained respectively.

b) YX routing algorithm traffic distribution model

The traffic distribution model by YX routing algorithm should also be considered. It is shown in Fig.1 (b). The traffic distribution of the network is proposed to obtain respectively with each nodes accumulation of total traffic similar to XY routing traffic model.

$$\begin{cases} T[(0,0),(0,0)]=24 \\ T[(1,0),(0,0)]=4 \\ T[(2,0),(0,0)]=3 \\ \ldots\ldots \\ \ldots\ldots \end{cases} \begin{cases} T[(0,2),(0,0)]=20 \\ T[(1,2),(0,0)]=4 \\ T[(2,2),(0,0)]=3 \\ \ldots\ldots \\ \ldots\ldots \end{cases} \begin{cases} \ldots\ldots \\ \ldots\ldots \\ T[(2,4),(0,0)]=3 \\ T[(3,4),(0,0)]=2 \\ T[(4,4),(0,0)]=1 \end{cases}$$

### B. *Network-wide homogeneous flow distribution*

In this subsection, the network-wide uniform flow model is built by optimizing the configuration of XY and YX routing algorithm. In the example of 5×5 mesh architecture, the traffic load of Node (i, j) can be expressed as:

$$T(i,j) = \sum_{p,q=0}^{p,q=4} T[(i,j),(p,q)]$$

Separately getting i = 1 ~ 4, j = 1 ~ 4, the traffic distribution of the network is obtained as previous analysis. The variance of all nodes in the network is used to measure

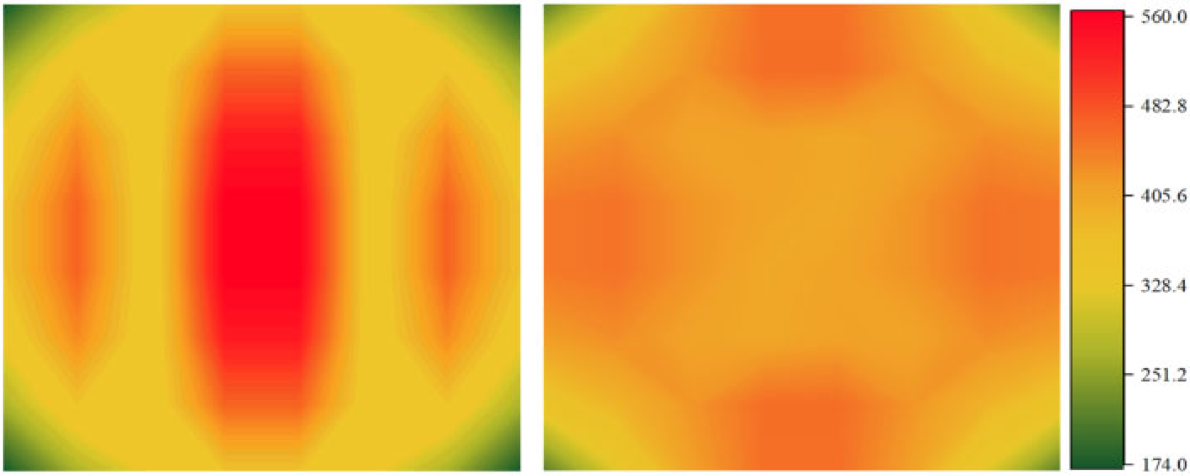



Fig. 2. The heat diagram of XY (left) and SCRA (right)

the uniformity of traffic distribution. Thus, the optimal objective function can be expressed as:

$$min \sum_{i,j=1}^{i,j=5} [T(i,j) - \overline{T}]^2$$

where $\overline{T}$ is the average traffic of each node.

In accordance with the 25 expressions, each nodes traffic load by any communication from Node (0, 0) is represented by a matrix as M(0, 0, 0) in XY, and represented by M(0, 0, 1) in YX. The first two zero of M(0, 0, 0) represent the source node (0, 0), while the third "0" represents XY routing algorithm, while "1" represents YX.

$$M(0,0,0) = \begin{Bmatrix} 1 & 1 & 1 & 1 & 1 \\ 2 & 2 & 2 & 2 & 2 \\ 3 & 3 & 3 & 3 & 3 \\ 4 & 4 & 4 & 4 & 4 \\ 24 & 20 & 15 & 10 & 5 \end{Bmatrix} \quad M(0,0,1) = \begin{Bmatrix} 5 & 4 & 3 & 2 & 1 \\ 10 & 4 & 3 & 2 & 1 \\ 15 & 4 & 3 & 2 & 1 \\ 20 & 4 & 3 & 2 & 1 \\ 25 & 4 & 3 & 2 & 1 \end{Bmatrix}$$

Each node´s traffic load by any communication from the node set $\{(p, q)|p \in 0 \sim 4, q \in 0 \sim 4\}$ is obtained similarly. Then the optimal static router configuration can be derived by the objective function to achieve uniform traffic distribution of the whole network.

### *C. Computation of traffic distribution model*

To achieve the best complementary characteristics of XY and YX routing algorithms, the static router configuration is optimized. Through the same modeling method as the 5 × 5 mesh, the best configuration on 8 × 8 mesh can be represented by the matrix:

$$Opt\ Config_{8\times 8} = \begin{Bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \\ 1 & 1 & 0 & 0 & 0 & 0 & 1 & 1 \\ 1 & 1 & 1 & 0 & 0 & 0 & 1 & 1 \\ 1 & 1 & 0 & 0 & 0 & 1 & 1 & 1 \\ 1 & 1 & 0 & 0 & 0 & 0 & 1 & 1 \\ 1 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{Bmatrix}$$

The numbers in the matrix represent the type of routers corresponding to the node of 8 × 8 mesh. The flits from the nodes, expressed by 0, will be transferred by XY routing algorithm, while 1 means YX. With this configuration, the variance of traffic distribution step down from $1.0923 \times 10^4$ to $3.5026 \times 10^3$, meaning more uniform and aging-resilient. The heat diagrams of the two routing algorithms is shown in Fig.2, representing the traffic distribution.

## III. NETWORK EVALUATION AND ANALYSIS

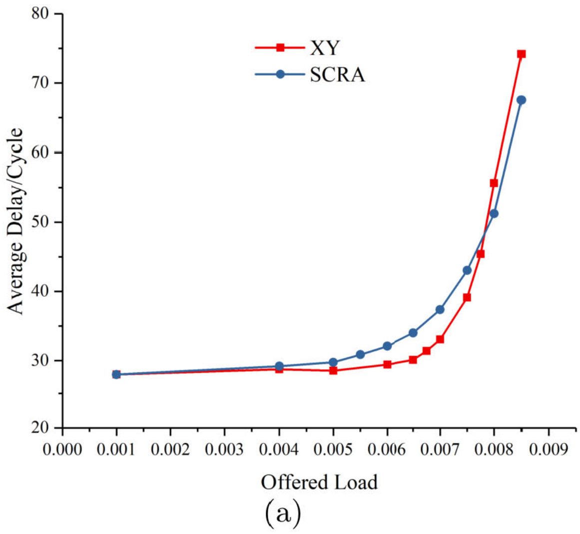
In this section, an 8 × 8 mesh for this proposed aging-resilient algorithm is evaluated with a network simulator. By modeling NoC in system level, configuring simulation parameters in Table 1, SCRA is compared to the XY only routing algorithm.

**Table I.** Simulation parameters configuration

| Parameter | Value |
|---|---|
| Clock Frequency(MHz) | 100 |
| Packet Length(bit) | 96 |
| Network Size(cores) | 64 (8 × 8) |
| Switching Mechanism | Virtual Cut-through Switching |

Fig.3 (a) shows the average delay vs. offered load in 8×8 mesh of SCRA and XY routing algorithm. For the same network load, XY routing algorithm and SCRA nearly achieve the same performance at saturation point with the rising of offered load. Corresponding to the saturation point of delay, the throughput of this point is obtained and shown in Fig.3 (b). The throughput saturation point of SCRA is 6.5 Gbps, while XY routing algorithm is 7.84 Gbps.

According to the simulation results, XY routing algorithm imposes the highest traffic load on central nodes in mesh topologies and SCRA realizes much uniformity and incremental longevity on the premise of ensuring accessibility. Compensated with YX routing algorithm, the side of routers relay the packet transmission to offload the central nodes. The



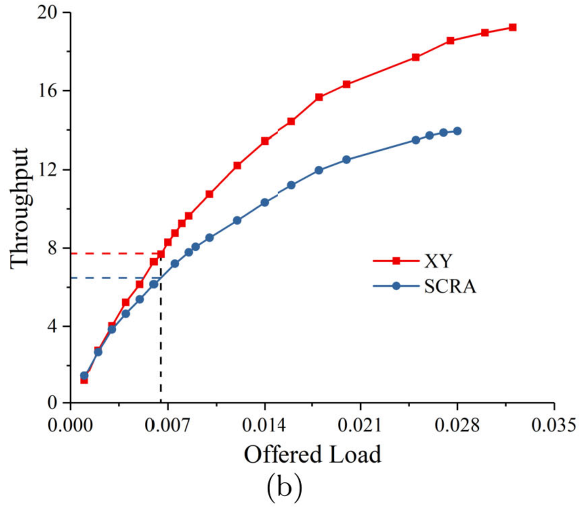




Fig. 3. Network simulation and comparison: (a) average delay vs. offered load in 8×8 mesh; (b) saturation throughput of XY and SCRA

accumulative number of packets transmitted through the congested central area of the network are worn-out with higher rate under higher load. On the other hand, deadlock situation in SCRA should be managed by virtual channels.

## IV. Conclusions

In this paper, a hybrid deterministic aging-resilient hybrid routing algorithm called SCRA is proposed to relieve the aging issue. We build a network-wide uniform flow distribution model, achieving the best complementary characteristics of XY and YX routing algorithm. According to the simulation results, SCRA achieves admirable uniformity in the whole network and eliminates the aging problems. Our future work is to extend to the dynamic reconfiguration with the run-time traffic distribution.

## Acknowledgment

This work was supported by the National Science Foundation of China under Grants 61634004, and Grant 61472300, the Fundamental Research Funds for the Central Universities Grant No. JB170107 and No. JB180309, china post-doctor science foundation No. 2018M633465, the key research and development plan of Shaanxi province No. 2017ZDCXL-GY-05-01, and the short-term overseas study program for doctoral students at Xidian University.

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