High Performance and Connection-retaining Fault-Tolerant Routing Algorithm for NoC-based many core Systems

Muhammad Abo Bakar Aslam, Naveed Khan Baloch, Jawad Ali Khan, Muhammad Iram Baig

***Abstract* – Communication prerequisites in multi-core systems are highly convoked by egressing the network-on-chip (NoC) architecture. NoC should cover communication reliability issues that are essential factor in communication between multiple cores embedded on a chip. Mostly, fault tolerance routing algorithms are based on rerouting data packets around the faults for reliable communication in presence of faults. But this rerouting packets might bring on non-minimal path causing increase in latency and congestion around the faults that further affect the performance. Proposed algorithm is able to tolerate both faulty links and routers by utilizing one and two virtual channels along X and Y dimensions. To bypass the faults, it always furnishes a shortest route for packets as long as the route exists. Packets are routed to shortest path even if faulty router is located on the route directly between current and destination router by utilizing the non-faulty links connected to the faulty router. This technique optimally reduces the congestion due to rerouting packets around the faults. Moreover the network congestion is balanced by adaptively selection of output channel whenever current and destination routers are located at distance of greater than two hop counts along both dimensions. Experimental results, in presence of six faults for 6x6 mesh network, manifest capability of up to 99.3% reliability for a system under functionality of proposed technique.**

***Index Terms* – Congestion aware, fault tolerant routing algorithm, fully adaptive routing scheme, minimal route, network-on-chip.**

I. INTRODUCTION

According to Moore's prognostication, billions of transistors could be merged on a single chip in the nearly future [1]. This prediction allows for placing together hundreds of functional intellectual property (IP) cores (Like processing components and memory modules) forming Multiple-Processors System-on-Chips (MPSoCs) to attain higher performance [1].

But bus architecture used in MPSoCs became a bottleneck to provide an optimal performance communication between processing elements with increasing number of processing elements on a single chip, so a new communication infrastructure is needed. Network-on-Chip (NoC) proposed in 1999, provided an effective solution that solved interconnection problems faced in MPSoCs due to its reliability, scalability and reusability characteristics. NoC used a router-based architecture for interconnection between cores providing more reliable and efficient communication infrastructure than bus architecture [2] [3] [4].

On-chip interlinks are implemented through deep submicron technologies that are running at clock frequency of GHz causing prostate to failures. Probability of failures increases due to uttermost device scaling. Mainly there are two types of faults that can fall in NoC. One is transient faults that are temporary, due to unpredictable cases (like power grid variations, particles collisions) and are hard to be discovered and corrected. Other is permanent faults that are due to physical damages like manufacturing faults and device wear off [2] [5]. This paper is centered on the permanent faults only.

Routing technique allows for tolerating permanent faults classified into deterministic and adaptive routing algorithms [3] [6]. In deterministic algorithms, data packets follow a fixed rout when they move from source to destination node. Dimension-order (XY or YX) routing algorithms are simplest examples of deterministic algorithms. In these methods, data packets follow one direction until its offset becomes zero before adapting the next direction. While using adaptive routing, data packets can adapt multiple routs from source to destination instead of a fixed rout causing that caused to decrease in latency and improve the performance as compared to deterministic routing. Thus adaptive routing scheme allows more beneficial fault tolerance than deterministic approach by using its alternative route selection scheme. One major weakness of deterministic scheme is its higher probability of creating deadlock situation than adaptive routing scheme. Deadlock is the state in which network resources remain in waiting queue to be relinquished. Routing scheme should be deadlock-free. One solution is to use virtual channels to avoid deadlock situation [7] [8] [9] [17], increase performance and tolerate faults but virtual channels charge high prices. There are some fault tolerant scheme that don't use virtual channels [10] [11] [12] but they used partial adaptive scheme and are very limited to tolerate faults. Moreover these algorithms are more complicated because of usage of dissimilar fault model to find an appropriate path for data packets in presence of faults.

In this paper, a method named as HPCoF (**H**igh **P**erformance **Co**nnection-retaining **F**ault tolerant approach) is proposed that furnish optimal performance in presence of faults. The major differences of HPCoF from previous work are:

Muhammad Abo Bakar Aslam, Naveed Khan Baloch, Jawad Ali Khan, Muhammad Iram Baig, Department of Computer Engineering, University of Engineering and Technology (UET) Taxila, Taxila, Pakistan. Email: naveed.khan@uettaxila.edu.pk. Manuscript received July 23, 2015; revised on November 24, 2015; accepted on December 18, 2015.

i) In It can tolerate a group of both faulty routers and faulty links by utilizing one and two virtual channels along X and Y dimension respectively, to ensure deadlock freeness.
ii) Each router would have some fault-information related to its neighboring routers to ensure that there are still some available substitute routes for packets to attain their destination through the selected direction.
iii) Most crucial feature of the proposed research that it is able to direct the packets to shortest route even if faulty router is located directly between source and destination router. This feature is implemented by utilizing non-faulty links connected to faulty router in such a manner that they also became active component of the network.
iv) The research shows the two different reliability methods to prove the research.
v) It always furnishes a shortest route among each pair of source and destination router regardless of positions of the faulty routers. But, in presence of faulty links, it allows non-minimal route only if source and destination router are at either same row or column, and faulty link exists between them.
vi) To stave off congestion around the faulty component, a shortest route could be adaptively preferred whenever relative distance between current and destination routers is more than one along both dimensions.

The remaining portion of the paper contains: Section-II recaps the related work, Section-III addresses the proposed fault-tolerant approach, Section-IV demonstrates reliability analysis for the proposed research under multiple faults, Section-V points the results, Section-VI summarize the research and last section traces some future work for the research to get more optimal performance.

II. RELATED WORK

This segment provides a review about some fault tolerant techniques and architectures in addition to HiPFaR and RR-2D routing schemes that are compared with the proposed scheme.

There are primarily two subdivision of fault-tolerant approaches covering the permanent faults. One is dealing with convex shapes in which a fault ring/chain is specified for a faulty region. But, in this approach, sometimes some healthy nodes become disable to form the shapes [14] [15]. Other is based on contour strategies for tolerating the faults that is further categories into two groups: One is using the virtual channels and other is without employing virtual channels.

A. *HiPFaR (**H**igh **P**erformance and **F**ault-**T**olerant **R**outing)*

This approach [16] is a fully adaptive routing approach and used one and two virtual channels for X and Y directions respectively. But this approach provides non-minimal route as shown in Fig.1 to tolerate faults in the network. When current and destination routers are located in a same row or column, and faulty routers lies between them, then data packets would have to follow non-minimal route to achieve their destination. Model 1 and 2 of Fig.1 show such routers location in which destination router is located at east side of current router. In this cases, there are two possible routes furnished by HiPFaR, either through north direction (Model 1) or through south direction (Model 2). Both routes are non-minimal route as compared to the proposed routing scheme. Moreover these non-minimal routes caused to increase in latency and congestion around the faulty region that further affects the overall network performance. Similarly non-minimal routes are adapted by packets when routers are located such as shown in Model 3 and 4. In these cases, packets have to traverse either through west direction (Model 3) or through east direction (Model 4).

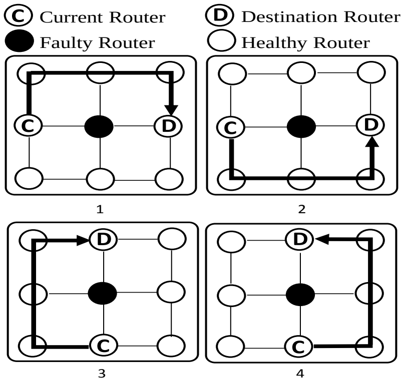

Fig. 1. Network behavior in presence of faults recommended by HiPFaR

B. *Reliable and adaptive Routing for 2D network-on-chip (RR-2D)*

RR-2D [18] is also a fully adaptive routing approach and used same number of virtual channels as that of HiPFaR. It is able to tolerate a group of both faulty routers and faulty links, and furnish a possible minimal route for packets in presence of faulty links and routers except for those positions in which source and destination routers are at either at same row or column and faulty links/routers are located directly between them.

Experimental results of the proposed research are compared with both HiPFaR and RR-2D. The results shows that overall performance of the network is better by using the proposed research as compare to both HiPFaR and RR-2D in presence of multiple faults and the proposed research furnishes a minimal router as compared to them as long as possible.

III. HPCoF: THE PROPOSED APPROACH

The chief goal of HPCoF is to endure the permanent faults occur in the NoC architectures. It is capable for tolerating a group of both faulty routers and faulty links in a 2D mesh NoC architecture providing reliable and high performance fault tolerant routing scheme.

A. *Turn Model and Deadlock Exemption*

The proposed research is fully adaptive fault-tolerant routing algorithm on behalf of one and two virtual channels along X and Y dimension respectively. Usually fault tolerant routing algorithms are very complicated and they should be free from deadlock situation. Deadlock situation is erected because cyclic dependencies in the channels during packets transmissions. Fig. 2(a) points the four basic cycles that can be occurred in a network causing deadlock state, utilizing one and two virtual channel. To break these cyclic dependencies, proposed technique prohibited some turns as shown in Fig. 2(b) with dash-lines and allowed some ones expressed through solid-lines.

If destination router is located at right or left side of source router, data packets would be routed through eastward or westward sub-network and, propagating through virtual channel 1 (vChannel1) and virtual channel 2 (vChannel2), respectively. Eastward packets can adapt turns N1-E, E-S1, S1-E, E-N1 turns using vChannel1, and turns N2-E, S2-E using vc2. While westward packets can adapt turns W-N1, W-S1 using vChannel1, and W-N2, S2-W, W-S2, N2-W using vChannel2.

B. Fault Distribution Mechanism

It is assume that permanent faults are specified by fault detection mechanisms. In the proposed research, each router distributes faulty status of its some links to its directly connected neighboring routers that is further utilized by them to avoid unnecessary non-minimal routes.

HPCoF requires that each router should have to know faulty status of maximum of eight links connected to its four directed neighboring routers Fig. 3. On behalf of this information, each router is capable for such routing decision that always directs packets to available minimal route. Faulty status of east and west links of north- and south-neighboring router is transfer to current router via 2-bit wire. Similarly, faulty status of north and south links of east- and west-neighboring router is delivered to current router via 2-bit wire.

C. The HPCoF Router Architecture

Faults can exist in the IP cores, routers or communication channels. When an IP core becomes faulty, healthy routers and links can operate normally without experience the core faults. Similarly, when links face permanent faults, routers and core can communicate with each other through subsisting channels by using their dynamic sharing [2]. But when a router becomes faulty, functionality of both core and link will interrupt by the faulty router. In this situation, the core connected to the faulty router cannot communicate with other healthy components in the network. Moreover other healthy routers cannot directly communicate through this faulty router even though links connected to the faulty router are healthy.

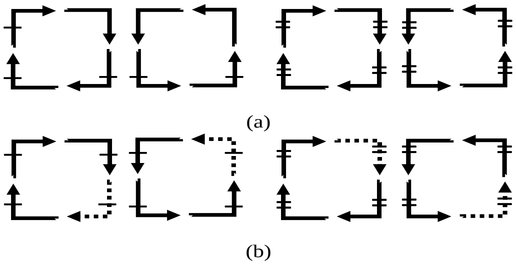

Fig. 2. (a) Four possible complete cycles that formed whenever use one and two virtual channels along X and Y dimensions respectively (b) Prohibited (dash lines) turns and allowable (solid lines) turns in the proposed approach

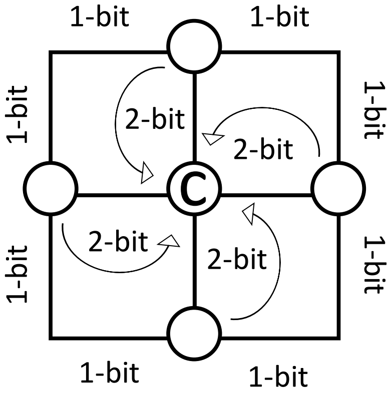

Fig. 3. Faulty status for eight links needed by proposed approach

When router becomes faulty, both non-faulty links and cores connected to a faulty router can be able to associate with other non-faulty components of the network by using MiCoF [13] and CoreRescuer [19] techniques, respectively. By using router architecture proposed in MiCoF approach, the proposed HPCoF technique utilizes the non-faulty links connected to a faulty router.

D. Tolerating Faulty Links and Router by HPCoF

1) *Tolerating Faulty Router:* This section demonstrates how the faulty routers are tolerated in the network. It targets the tolerating faulty routers, and forbidding packets to be rerouted around the faulty region. In other words, packets don’t need to due to faulty router in the route even if faulty router is located directly between source and destination router. Fig. 4(c, d) exposes some routes adapted by packets in presence of one or more faulty routers directly between source and destination routers.

2) *Tolerating Combination of Faulty Routers and Links:* Fig. 5 depicts the some possible location of both faulty router and link in a network for packets traversing towards north-east direction. Fig. 5(a) displays such situations in which **H**op **C**ount (HC) between source and destination router is one (xHC = 1 and yHC = 1) along both dimensions. In accordance with HPCoF, selection priority of both east and north is same if there is no alternative route through next hop to destination. However, according to fault distribution process (Fig. 3), if east directed link is faulty or next hop faces some faults through east direction then packets are routed towards north direction (models A2 and A3 of Fig. 5(a)) and vice versa (models A4 and A5 of Fig. 5(a)). While if both east and north directions are safe for routing and at equally distance from destination, packets are routed on basis of congestion value (models A1 of Fig. 5(a)). Model A6 demonstrates a situation

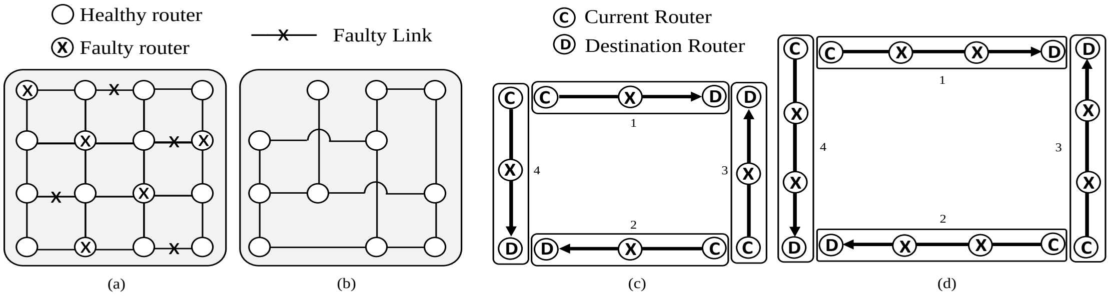

Fig. 4. (a) 4x4 mesh network with 5 faulty routers 4 faulty links (b) Resultant network according to the proposed approach (c, d) Bypass faulty router located directly between current and destination routers

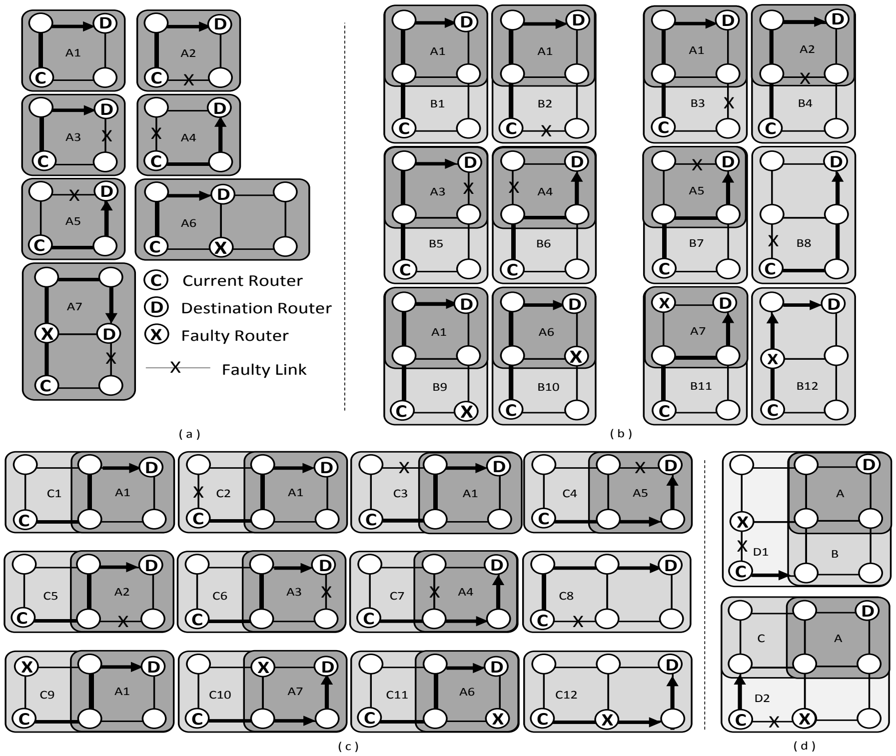

Fig. 5 Tolerating faulty links and router by using the proposed approach

in which both links are healthy but one connected neighbor (east directed neighbor) is far away related to destination router as compare to other connected neighbor (north directed neighbor). So, packets are routed towards north direction. Model A7 depicts a situation in which east directed link is not safe, while north directed neighbor is safe but its relative distance with destination router is less than two. So packets are routed towards north direction.

In Fig. 5(b), there are some routers positions in which xHC = 1 and yHC = 2. Notice that hop count is greater along Y direction as compare to X direction. So, before examine X direction, Y directed neighbor and Y directed link are analyzed first. Model B1, B2, B3, B4, B5, B6, B7, B9, B10 and B11 show that packets are directed towards Y directions as both Y directed link and neighbor are non-faulty, while at Y directed neighbor the packets face the situation similar to model A1 to A6.

Fig. 5(c) demonstrates router positions in which xHC = 2 and yHC = 1. In this case, availability of X directed route is examine earlier than Y direction because of greater hop count along X direction. In other situations, when hop count is either equal or greater than two along both directions (xHC => 2 and yHC => 2), packets are routed towards non-faulty direction as shown in Fig. 5(d). This proposed routing scheme for east-, west-, south-, and north-ward packets is demonstrated in Fig. 6 while Fig. 7 expresses the procedure for northwest-, southeast- and southwest-ward packets.

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Definitions: Xc, Yc, Xd, Yd: X and Y coordinates of current
             and destination routers
**------------------------------------------------**
dir_x < = W when Xc > Xd else E;
dir_y < = S when Yc > Yd else N;
xHC < = Xc - Xd when Xc > Xd else Xd - Xc;
yHC < = Yc - Yd when Yc > Yd else Yd - Yc;
vChannel < = vChannel1 when position={ NE, E, SE} else
             vChannel2 when position={W,N,S,NW,SW};
if position={W or E} then
  if yHC=0 then
    if link(dir_x)=faulty then
    select <= N(vChannel) or S(vChannel);
    else select <= dir_x; end if;
  else    if neighbor(dir_y)=dest or link(dir_y)=faulty then
            select <= dir_y(vChannel);
          else select <= dir_x; end if;
  end if;
else position={S or N} then
   if xHC=0 then
            if link(dir_y)=faulty then
                if Xc/= 0 = then
                    select <= W; else select <= E; end if;
            else select <= dir_y(vChannel); end if;
   else
            if inputPort /= {W or E} and link(dir_x)=faulty then
                    select <= dir_x;
            else select <= dir_y(vChannel); end if;
   end if;
end if;
```

Fig. 6. Proposed routing algorithm for North-, south-, east- and west-ward packets

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if position={SW, SE, NE or NW} then
   if (xHC>=1 and yHC=0) then select <= dir_x;
   elsif (xHC=0 and yHC>=1) then select <= dir_y(vChannel);
   elsif (xHC=1 and yHC>=1) then
         if (|Ny-Yd|>1) or link(dir_y)=faulty then
            if (|Ny-Yd|=1) and link(dir_x)=healthy then
               select <= dir_x;
            else select <= dir_y(vChannel); end if; end if;
   elsif (xHC>1 and yHC=1) then
         if (|Nx-Xd|>1) or link(dir_x)=faulty then
            if (|Nx-Xd|=1 and link(dir_y)=healthy) then
               select <= dir_y(vChannel);
            else select <= dir_x; end if; end if;
   else
         if (|Nx-Xd|>1) or link(dir_x)=faulty then
            if (|Nx-Xd|=1 and link(dir_y)=healthy) then
               select <= dir_y(vChannel);
            elsif (|Ny-Yd|>1) or link(dir_x)=faulty then
               if (|Ny-Yd|=1) and link(dir_x)=healthy then
                     select <= dir_x;
               else select <= dir_x or dir_y(vChannel);end if;
            end if;
     end if;
end if;
```

Fig. 7. Proposed routing algorithm for Northeast-, northwest-, southeast- and Southwest-ward Packets

IV. RELIABILITY UNDER MULTIPLE FAULTS

By the HPCoF approach, all locations of multiple faults can be endured by utilizing available shortest route. The algorithm is not needed to be changed to tolerate multiple faults. There are some positions in presence of two faults in which packets are not directed to shortest path because of unavailability of the shortest path. These are the cases in which distance along both dimensions is one between source and destination routers while neighboring channel in both dimensions are not possible (Fig. 8(a)). These positions are named as diagonal positions. Source router can still communicate with all other routers in network excluding the destination router. While for all other positions, all packets are able to reach their destinations through shortest possible route. If source and destination routers are far away from each other, the data packets never face such unsupported positions because packets already adapt other possible routes prior reaching these positions. All possible diagonal positions for 4x4 mesh network are shown in Fig. 8(b).

In this paper, reliability1 and reliability2 are two different reliability metrics that are used in presence of faulty routers. Reiability1 indicates the probability under the presence of faults that network can deliver the packets successfully. Reliability2 shows the probability in which a packet can be delivered successfully under the fault. These metrics measurements can be estimated as follows:

A. *Reliability*

According to HPCoF, when two faults occur at diagonal positions, the network might be fail to deliver data packets. First of all, total number of combinations of the two faulty routers are calculated in a network. Then, measure the total number of combinations of the two such faulty routers that are located at diagonal positions. By fractioning these two values, reliability1 measurements are obtained. Total number of combinations for two faulty routers in a nxn mesh network is measured as:

$$\mathrm{N}_{\text{total\_combinations}} = \binom{n^2}{2} = \frac{n^2(n^2-1)}{2} \qquad (1)$$

Now the total diagonal combinations are calculated as:

$$\mathrm{N}_{\text{diagonal\_combinations}} = 2(n-1)^2 \qquad (2)$$

Ultimately, reliability1 (R1) is calculated as:

$$R1 = 1 - \frac{\mathrm{N}_{\text{diagonal\_combinations}}}{\mathrm{N}_{\text{total\_combinations}}} = 1 - 4\,\frac{(n-1)^2}{n^2(n^2-1)} \qquad (3)$$

By using this reliability formula, there is 92.06% probability that two faults cannot occur in diagonal positions for 6x6 mesh network. This probability will be increased when more number of routers are added in mesh network. For example, this probability would become 95.14% for 8x8 mesh network. Thus it can be stated that the network will function normally without any loss of data packets in presence of two faults.

B. *Reliability*

This second definition is usually employed in literature to evaluate the reliability. Presume that a network is analyzed for all possible combinations of two faulty routers. Thereby, total count of examinations will be equal to $\mathrm{N}_{\text{total\_combinations}}$. For each examination, every healthy router sends one data packet to other healthy router in the mesh network (i.e. total packets count, ejected from a router, would be $n^2 - 3$. Here 3 is because of excluding the source router itself and two faulty routers). These packets are traversing towards their specified destination routers. While total number of routers, which are able to send or receive packets, would be equal to n^2–2. Here 2 is due to presence of two faulty routers because they are able to neither send nor receive data packets. So, per combination, total count for delivered packets is:

$$\mathrm{N}_{\text{delivered\_packets}} = (n^2-2)(n^2-3) \tag{4}$$

While for a whole examination, total count for delivered packets is:

$$\mathrm{N}_{\text{total\_delivered\_packets}} = \mathrm{N}_{\text{delivered\_packets}} \times \mathrm{N}_{\text{total\_combinations}} \tag{5}$$

As two data packets have to be dropped for one diagonal position (those traversing from source to destination router or vice versa), so total count for defeated packets can be calculated by:

$$\mathrm{N}_{\text{defeated\_packets}} = 2 \times \mathrm{N}_{\text{diagonal\_combinations}} = 4(n-1)^2 \tag{6}$$

Therefore, reliability2 could be calculated by:

$$R2 = 1 - \frac{\mathrm{N}_{\text{defeated\_packets}}}{\mathrm{N}_{\text{total\_delivered\_packets}}} \tag{7}$$

By using this reliability formula, for a 6x6 mesh network, 99.98% of packets are able to attain their destination successfully regarding all possible combination for two faulty routers.

V. EXPERIMENTAL RESULTS

To evaluate the performance efficiency of proposed routing algorithm, major components of on-chip-network are developed by using VHDL language to form a 2D NoC simulator by utilizing ModelSim SE PLUS 6.2c. Features of the simulator include hot-potato (buffer-less) router architecture, packet switching, delay model with no flit loss, and relative addressing schemes with no memory unit. Each input/output of a router has 145 parallel links forming a flit represented by router port width bits. Each flit is split up into header and payload rows. The header information would be utilized to address the flit to its destination based on switching policy and routing algorithm. While the payload contains the literal information having message to be send from to source to destination router. On basis of performance matric, latency is used that is defined by the number of cycles among the introduction of message emerged by the Processing Element (PE) and completely delivered message to destination PE. Simulator is warmed-over for 9000 cycles and after then average latency is evaluated over 16000 cycles.

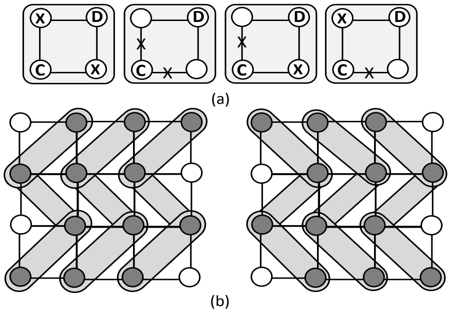


Fig. 8. (a) Multiple intimately faults creating diagonal positions (b) All diagonal positions are indicated by a couple (i.e. each figure contains nine diagonal positions)

For performance comparison between HPCoF and other routing algorithms discussed in the literature, two more routing algorithms (RR-2D [18] and HiPFaR [16]) are also implemented in the simulator. Like HPCoF, both RR-2D and HiPFaR utilize same number of virtual channels. For a fair comparison, average performance is measured and analyzed on 6x6 mesh network and same number of clock cycles for all routing algorithms. Experimental results expressed that overall performance of HPCoF is at least 7.22% higher than both RR-2D and HiPFaR.

A. *Reliability Analysis under Uniform Traffic Profile*

In case of uniform traffic profile, every PE introduces data packets that are send towards others PE in accordance with uniform distribution [20]. For reliability evaluation for HPCoF, count for faulty routers is vary from one to six. Random function is used for selection of these faulty routers. For uniform traffic, results are derived by employing 10,000 different iterations.

Reliability evaluation values on basis of first metric are shown in Fig. 9(a) and for the second metric is shown in Fig. 9(b). By observing the results, it is started that network is 100% reliable in presence of one faulty router. While in case of two faulty routers, reliability is a little bit decreased. And with the gradual increase in further faults from third to sixth the reliability also increases gradually.

B. *Performance Analysis under Uniform Traffic Profile*

In Fig. 10(a), average latency for HPCoF, RR-2D and HiPFaR is explicit for fault free cases and under different injection rates. Results observation expressed that both RR-2D and HPCoF acquire almost same average latency and have better average performance than HiPFaR. While in case of different number of faults, HPCoF conducted a more optimal average performance as compare to both RR-2D and

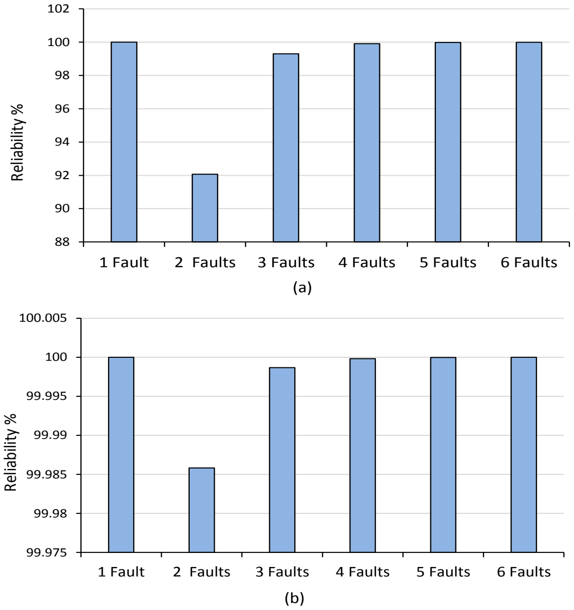
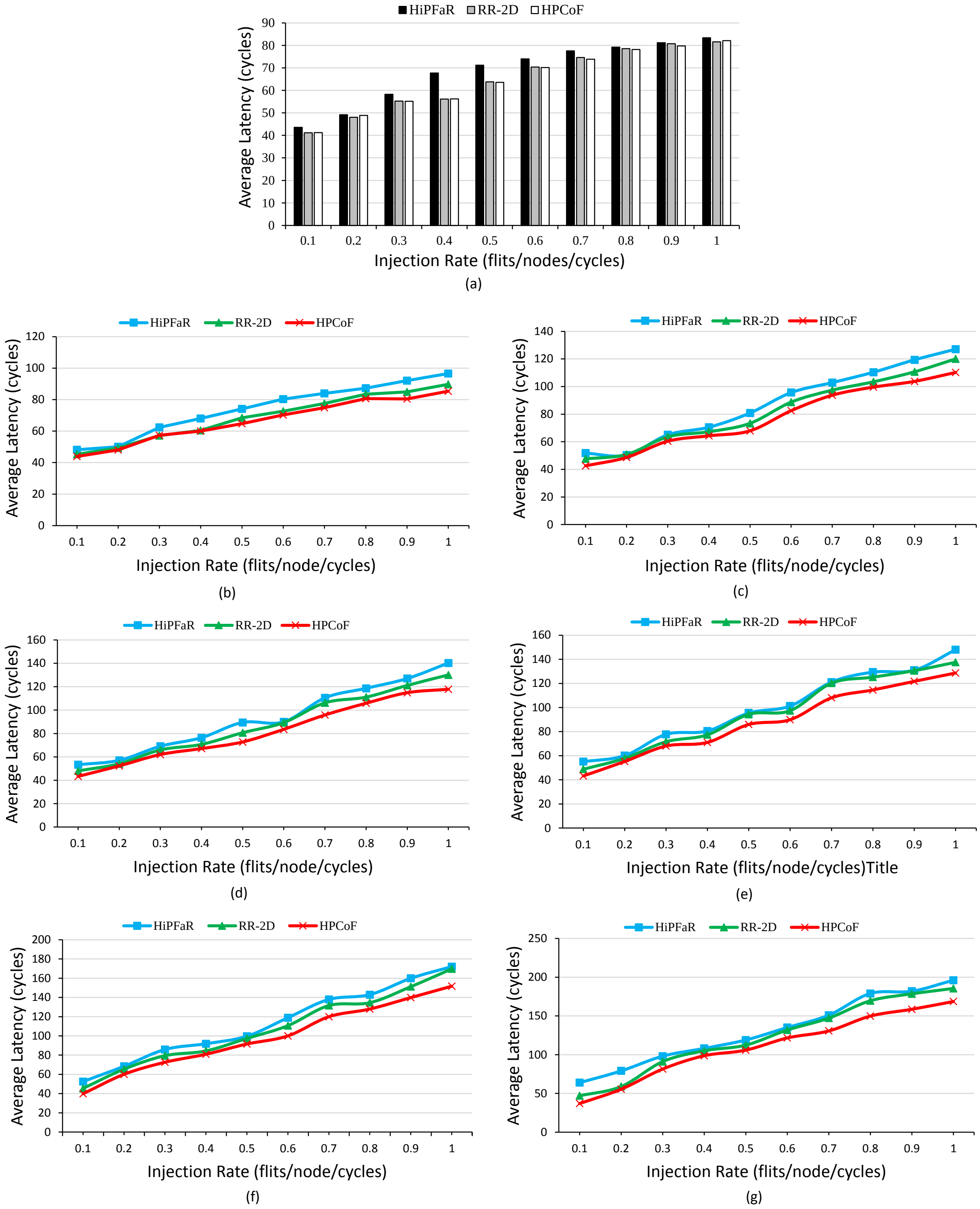


Fig. 9. Reliability measurements on basis of (a) first definition (b) second definition

HiPFaR. This achievement is because of the proposed alternative shortest route in presence of faults and depicted in Fig. 10(b-g) by using performance analysis curves under different number of faults. The curves shows HPCoF, RR-2D and HiPFaR independently, and proves that the average latency performance with increase in the injection rate has lower latency for HPCoF than RR-2D and HiPFar. With the increase in the fault injection rate the latency also increases is shown in Fig10(b-g).



(a)

(b)

(c)

(d)

(e)

(f)

(g)

Fig. 10. Performance analysis under uniform traffic in presence of (a) no fault (b) 1 fault
(c) 2 faults (d) 3 faults (e) 4 faults (f) 5 faults (g) 6 faults

C. Performance Analysis under Hotspot Traffic Profile

In case of hotspot traffic profile, one or more than one routers are selected as hotspots that receive surplus portion of traffic along with uniform traffic. Two routers (14, 14) and (22, 27) are chosen as hotspot routers in a 6x6 mesh network. In Fig. 11(a), average latency for HPCoF, RR-2D and HiPFaR is illustrated for fault free cases and under various injected rates. HPCoF renders more optimal performance than both RR-2D and HiPFaR as shown in Fig. 11(b-g). These results also proves that the average latency performance with increase in the injection rate has lower latency for HPCoF than RR-2D and HiPFar. With the increase in the fault injection rate the latency also increases is shown in Fig11(b-g).

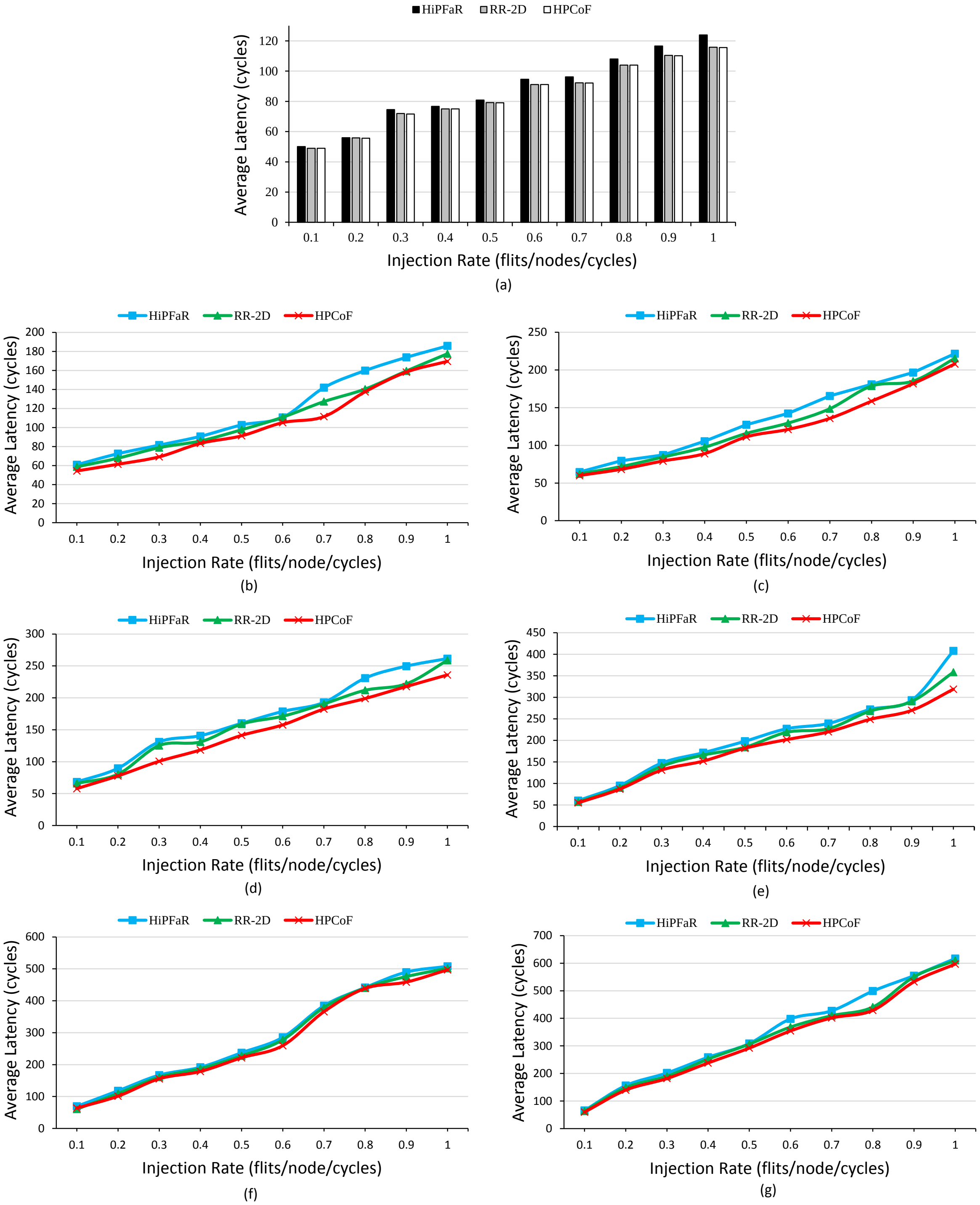


Fig. 11. Performance analysis under hotspot traffic in presence of (a) no fault (b) 1 fault (c) 2 faults (d) 3 faults (e) 4 faults (f) 5 faults (g) 6 faults

VI. CONCLUSION

This research contributes to render high performance, reliable and fault tolerant approach for 2D mesh network-on-chip. By utilizing the proposed technique, a group of both faulty links and routers can be tolerated with an optimal performance and reliability of the system. The technique is based on fully adaptive selection of output channel throughout the packets traversing from one router to another. So it is congestion aware routing scheme as well that optimize the throughput overall in the network. Moreover it always furnishes a shortest route between each pair of source and destination router in presence of any location of fault as long as the path exists in the network. It employed one and two virtual channels along both X and Y dimensions that is the minimum number of virtual channel that can be used for tolerating faults and avoiding the deadlock situation in a network. Most crucial feature of the proposed research that it is able to direct the packets to shortest route even if faulty router is located directly between source and destination router. This feature is implemented by utilizing non-faulty links connected to faulty router in such a manner that they also became active component of the network.

VII. FUTURE WORK

The reliability and performance of the proposed technique can be increase more. One solution to attain this achievement is to employ more efficient fault distribution mechanism so that packets remain far away from faulty region as long as possible if source and destination routers are located at longer distance. We intent to enforce this feature to supply worldwide routing scheme for network-on-chip, in the future as soon as possible.

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