

A Low Latency Scalable 3D NoC Using BFT Topology with Table Based Uniform Routing

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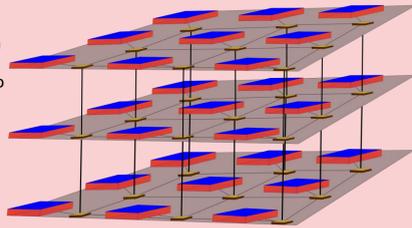
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PROBLEM DESCRIPTION

- Due to the close proximity of layers in 3D NoC structure the signals travelling in the vertical (inter-layer) direction is much faster than the horizontal (intra-layer) in their 2D counterpart.
- An inter-layer connection requires the addition of two more links (up and down) to each router that leads to an increase in complexity as well as the blocking probability inside the router.
- Being a multi-hop communication fabric, the traditional NoC routers can not be placed on the vertical path in a NoC as the multi-hop delay and the router delay would overshadow the ultra fast propagation time.

- Thus it is desirable to have single hop communication among the layers because of the short distance between them.
- Also, the number of vertical pillars should be kept low to reduce the manufacturing cost of a 3D NoC.
- It induces a new problem for the IP blocks with close vicinity to the pillar nodes on a layer giving more advantage in case of inter layer communication than those that are at relatively distant position from the pillar nodes.



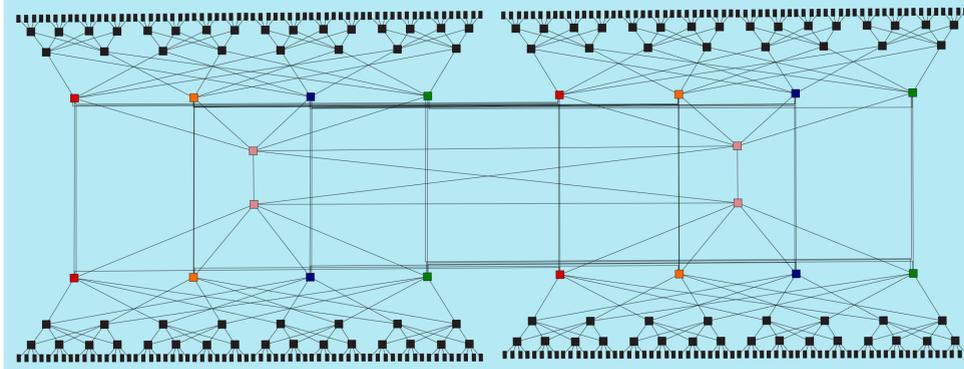
Connection Structure in a typical 3D Mesh topology.

Objective

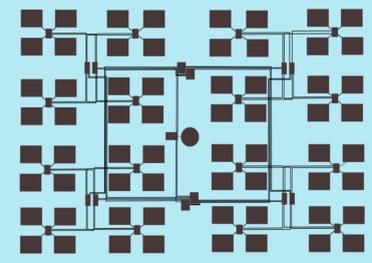
To propose a novel 3D NoC topology with proper routing method that can address all the above issues.

- Overall architecture of a layer in the proposed design of 3D NoC based on Butterfly Fat Tree topology. Four BFTs are connected together having four root nodes each (colored red, orange, blue, and green).
- Root nodes with same color are connected together to form complete graph. Reason behind connecting the root nodes in the above manner is to reduce the network latency in terms of hop count.
- For inter layer communication DTDMA pillars are used that eliminate transactional character commonly associated with buses [8], [9] by employing a dynamic bus arbitration (thus close to 100% bandwidth efficient). Single-hop communication and transaction-less arbitrations allow for low and predictable latencies. Furthermore, hybridization of NoC router with bus architectures requires only one additional link (in the place of two) on NoC router.
- The circular DTDMA pillar node is shown in the center of the floor plan picture of a single BFT. It is connected to a special router called as border router (responsible for regulating traffic across different layers of the chip). This router is the gateway for inter layer communication.

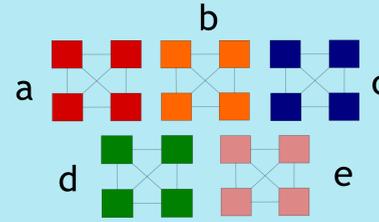
PROPOSED SOLUTION



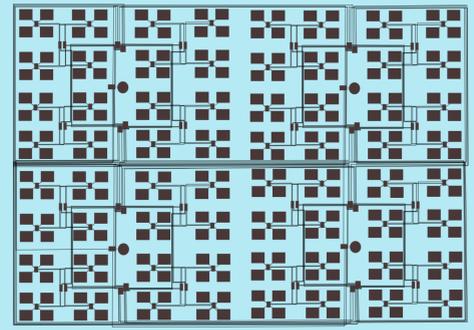
Logical diagram of four connected Butterfly Fat Trees.



Floor plan of a single BFT as a locality of a pillar node.

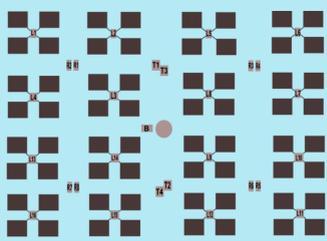


Connectivity between border and root routers. Each of (a),(b), and (d) is a four root level router, each pertaining to a particular BFT. (e) Border routers of a floor, each of which is dedicated to a particular BFT.



Floor plan of a complete NoC layer comprising four BFTs as the localities of their respective pillar nodes.

DIFFERENT ROUTING SCOPES



Distribution of routers across different scopes for a single BFT.

Layer Number	Tree Number	Region Number	Locality Number	Node Number
m bits	2 bits	2 bits	2 bits	2 bits

Address format of an IP block.

- First m bits specify the layer number.
- Next 2 bits specify the tree number out of four BFTs in a layer.
- Next 2 bits contain the region number out of four regions of a BFT.
- Next 2 bits denotes the locality number out of four localities of a region.
- Last 2 bits field contains the node number in that locality out of four IP blocks in that locality.

- Layer Scope:** A 3D NoC chip consists of several layers.
- Tree Scope:** Every layer is made up of four BFTs. (denoted by T)
- Region Scope:** In every BFT there are four regions. Each region is made up of two regional Routers (denoted by R) and their siblings.
- Local Scope:** Each region is made up of four localities, where each locality comprises of one local router (denoted by L) and four IP blocks connected to it

DIFFERENT ROUTING TABLES ACCORDING TO SCOPES

Local Routing Table	Table (Node Number, Link Number)
Regional Routing Table	Table (Locality Number, Link Number)
Root Routing Table	Table1 (Region Number, Link Number) Table2 (Tree Number, Link Number)
Border Routing Table	Table (Router Number, Link Number)

ROUTING ALGORITHMS FOR DIFFERENT SCOPES

```

Determine_Path()
Input : Source node index, Source node layer, Destination node index, and Destination node layer.
Output: Routing path.
begin
  Locate layer, tree, region, and locality for both source and destination.
  if Layer_s = Layer_d then
    if Tree_s = Tree_d then
      if Region_s = Region_d then
        if Locality_s = Locality_d then
          Place fit into respective physical channel.
        else
          Reach either of two R_L connected to L_s.
          Reach either of two T_L connected to R_L.
          Reach L_L connected to T_L.
          Place the fit into respective physical channel.
        end
      else
        Reach either of two R_T connected to L_s.
        Reach either of two T_T connected to R_T.
        Reach respective R_L connected to T_T.
        Reach L_L connected to R_T.
        Place the fit into respective physical channel.
      end
    else
      Reach either of two R_s connected to L_s.
      Reach either of two T_s connected to R_s.
      Reach pillar node connected to T_s.
      Jump to LAY E R_L through DTDMA pillar.
      Reach R_L from the pillar node, connected to R_L.
      Reach any of the four T_L.
      Reach respective R_L connected to T_L.
      Reach L_L connected to R_L.
      Place the fit into respective physical channel.
    end
  else
    Reach the Border router of LAY E R_L, where respective Tree number matches Tree number of destination node of LAY E R_L.
    Reach pillar node connected to that Border router.
    Jump to LAY E R_L through DTDMA pillar.
    Reach R_L from the pillar node, connected to R_L.
    Reach any of the four T_L.
    Reach respective R_L connected to T_L.
    Reach L_L connected to R_L.
    Place the fit into respective physical channel.
  end
end
    
```

The main routing methodology.

```

Forward_Local_Router()
Input : Fit address.
Output: Next hop.
begin
  if L_L = L then
    if T_L = T then
      if R_L = R then
        Search Table by n to find corresponding link number.
        Place fit into physical channel corresponding to that link found.
      end
    else
      Forward fit to either of two regional routers, connected to local router.
    end
  else
    Forward fit to either of two regional routers, connected to local router.
  end
end
    
```

Forwarding technique of a local router.

```

Forward_Root_Router()
Input : Fit address.
Output: Next hop.
begin
  if L_L = L then
    if T_L = T then
      Search Table1 by R_L to find corresponding link number.
      Forward fit to respective regional router connected through that link found.
    end
  else
    Search Table2 by T_L to find corresponding link number.
    Forward fit to respective root router connected through that link found and belongs to BFT of destination node.
  end
  Place fit into respective physical channel of corresponding border router connected to root router.
end
    
```

Forwarding technique of a root router.

```

procedure forward()
begin
  if L_L = L then
    if T_L = T then
      if R_L = R then
        Search Table by L_L to find the corresponding link number.
        Forward the fit to the respective local router, connected through that link found.
      end
    else
      Forward the fit to either of the two root routers, with which the regional router is connected to.
    end
  end
end
    
```

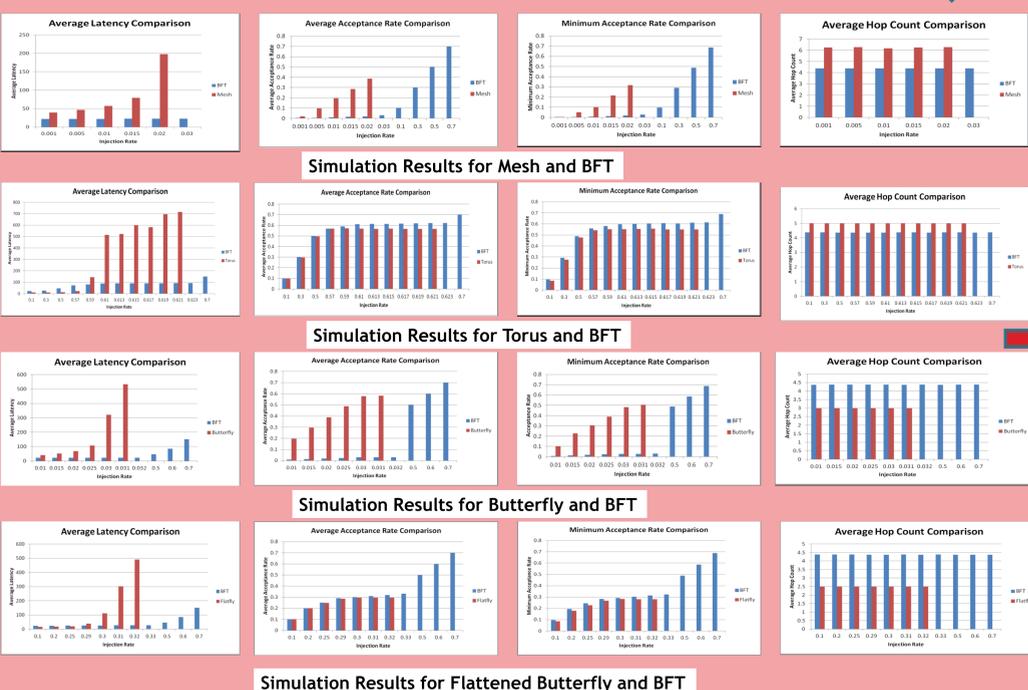
Forwarding technique of a regional router.

```

Forward_Border_Router()
Input : Fit address.
Output: Next hop.
begin
  if fit comes from any of three other border routers then
    Place fit into respective physical channel the pillar node is connected to.
  end
  if fit comes from pillar node the border router is connected to then
    Forward fit to any of four root routers of BFT the border router is connected to.
  end
  if fit comes from any of four root routers the border router is connected to then
    if T_L = T then
      Place fit into respective physical channel the pillar node is connected to.
    else
      Search Table by T_L to find corresponding link number.
      Forward fit to respective border router of the BFT connected through that link found and Tree number matches to Tree number of destination node of L_L.
    end
  end
end
    
```

Forwarding technique of a border router.

EXPERIMENTAL RESULTS



SUMMARY OF COMPARATIVE IMPROVEMENTS (%) FOR DIFFERENT PERFORMANCE METRICS

Performance metrics Topologies	Avg Hop Count	Avg Acceptance Rate	Avg Latency	Min Acceptance Rate
Mesh	30	NIL	43-89	NIL
Torus	13	6-9	83-88	6-13
Butterfly	NIL	NIL	46-96	NIL
Flattened Butterfly	NIL	1-8	31-95	5-14

CONCLUSION AND FUTURE WORK

- Proposed BFT topology can withstand heavy workload while still maintaining low latency, and the acceptance rate also increases with increasing injection rate. This is because of the uniform and load balancing connectivity of BFT where we have more than one path between a pair of source and destination but with same hop count. On the other hand, all other topological designs have failed to balance the load and sometimes crash.
- If routers can be designed in such a way that they can have the capability to balance load and control congestion efficiently, then with this design we can achieve a really effective NoC system for interactive applications with threading capability.
- Future works may be in the direction of investigating the thermal effects and optimizing it accordingly with a suitable core placement strategy, investigating and improving performance using real time application mapping and so on.

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