Plane-Balanced and Deadlock-Free Adaptive Routing for 3D Networks-on-Chip

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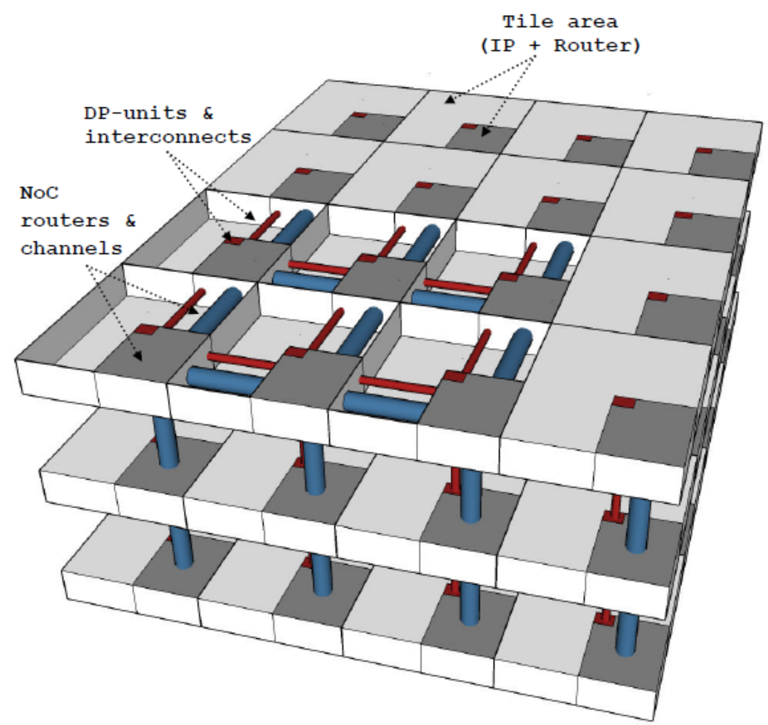
Outlines

- Background
  - 3D NoCs
  - Dynamic Programming Routing in 3D NoCs.
  - Deadlocks
  - Turn model for adaptive routing
- Motivations and Contributions
- Plane-Balanced 3D Routing
  - 3D Odd-Even routing
  - Balanced OE routing
  - Degree of Adaptiveness
- Results
- Conclusion

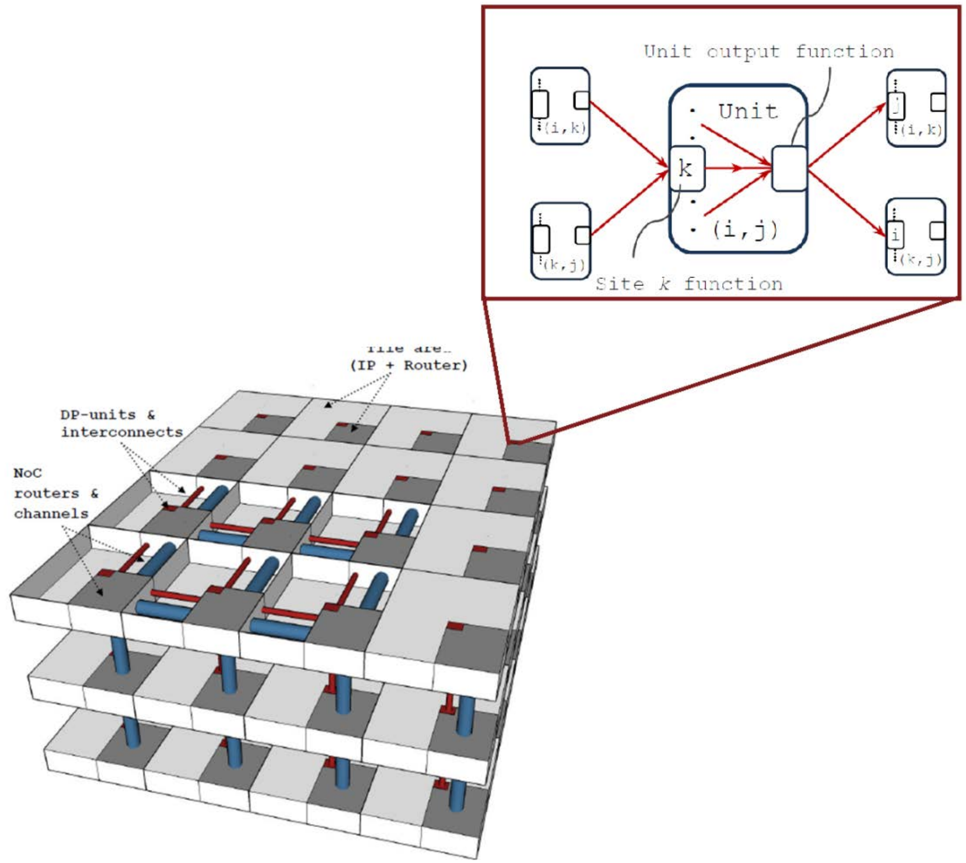
Background

- 3D NoCs
- Die stacking 3D IC technology and NoC leads to 3D NoC
- Advantages:
  - Smaller form factor
  - Lower latency
  - Higher throughput
- 3D adaptive routing must be:
  - Deadlock free
  - Balanced adaptiveness



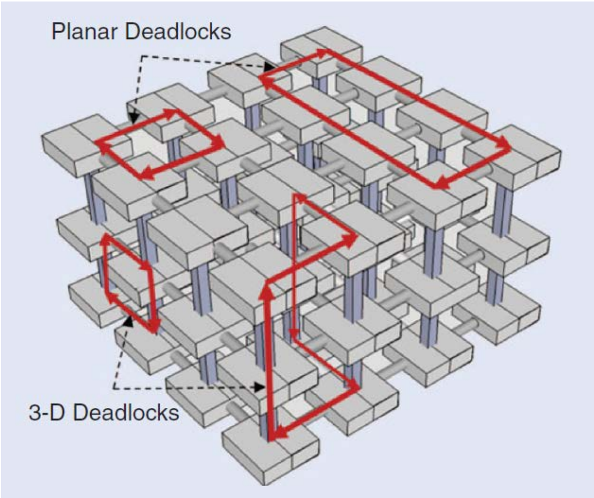
Dynamic Programming Network in 3D NoCs

- For runtime shortest path computation.
- A net of dynamic programming units (DPU's).
  - multi-source single destination
  - hard coupled with the router
  - each unit:
    - gets the costs of the neighbouring units,
    - propagate the minimum cost after adding its local cost,
    - cost is defined in terms of the local router congestion (performance counter).



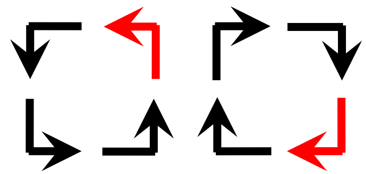
Deadlocks

- A situation in which two or more packets are unable to make progress to their destination because they are waiting for each other to release channels. Thus, neither ever does!
- Can paralyze network communications.
- Strategies to deal with deadlocks are;
  - Detection and recovery.
  - Avoidance (the turn model or virtual channels).
  - Prevention (circuit switching).

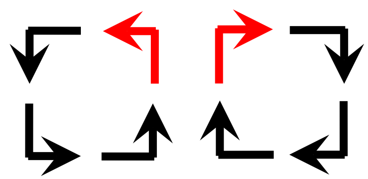


Turn Model for Adaptive Routing

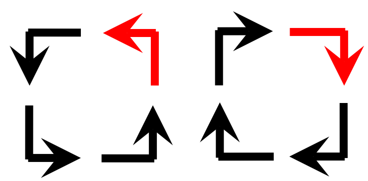
- Deadlock avoidance using the *Turn Model*:
  - West First



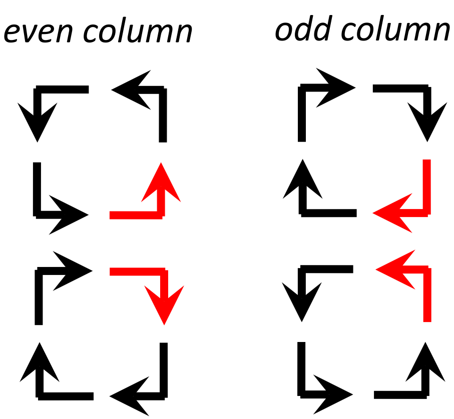
  - North Last



  - Negative First



- Odd-Even routing gives higher and more balances degree of adaptiveness compared to other deadlock free routing algorithms.
  - Restricts ***locations*** where certain turns can occur.
  - Offer more ***balanced*** degree of adaptiveness.



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Motivations and Contributions

- Motivations
  - The original turn model for partial adaptive routing initial proposed to 2D and results in uneven degree of adaptiveness.
  - No turn model is proposed to utilize 3rd dimension for 3D NoCs.
- Contributions
  - Introducing a new approach for extending 2D mesh partially adaptive routing algorithms to 3D.
  - Plane-balanced degree of adaptiveness is achieved by applying different rules for different layers.
  - Evaluation of the proposed method under different traffic scenarios

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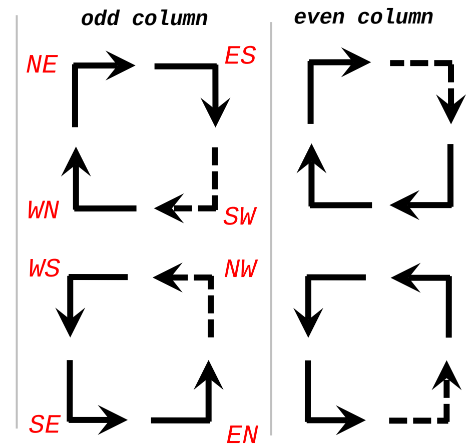
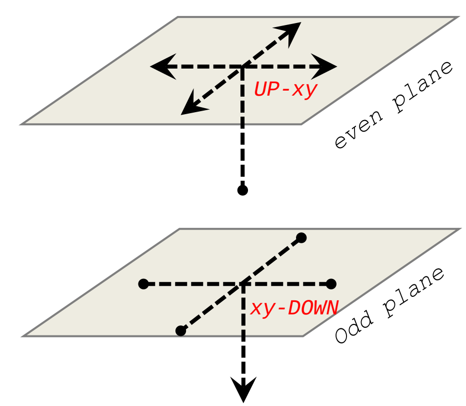
The 3D Odd-Even routing

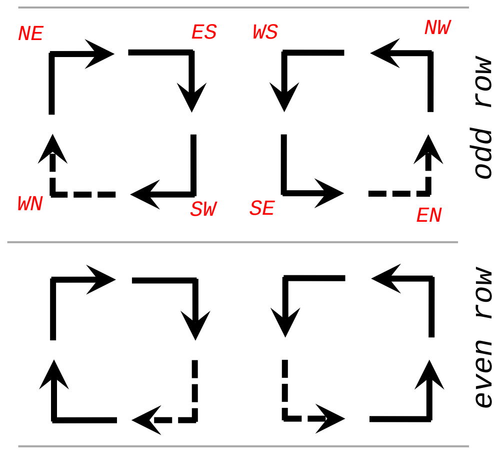
- For the 3D Conventional OE, the following rules are applied :
  - **Rule 1:odd column**: *Packets are not allowed to take **North-West** turns nor **South-West** turns.*
  - **Rule 2: even column**: *Packets are not allowed to take **East-North** turns nor **East-South** turns.*
  - **Rule 3:** *Up–xy turns are not allowed in an even xy-plane, and xy-Down turns are not allowed in an odd xy-plane.*

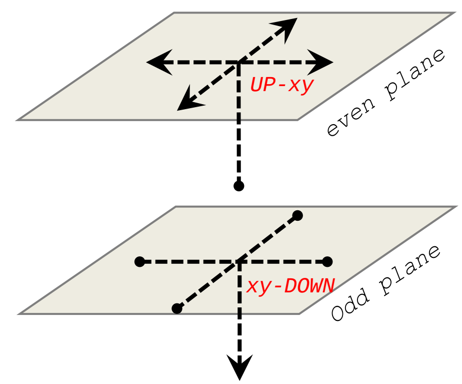




Balanced OE Routing

- Let us define the Modified OE routing which applies the following rules:
  - **For even xy-plane,**
  - **Rule 4:** in **odd row**: *Packets are not allowed to take **West-North** turns nor **East-North** turns,*
  - **Rule 5:** in **even row**: *Packets are not allowed to take **South-West** turns nor **South-East** turns.*
  - **Rule 3** is also applied to constrain entering an leaving xy-planes.
- **Balanced OE uses rules 1 and 2 in even plane and rules 4 and 5 for odd plane.**

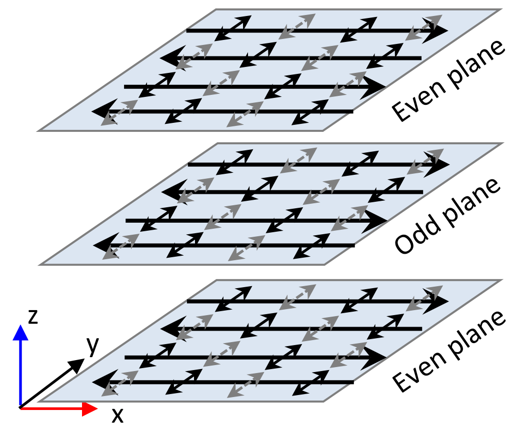




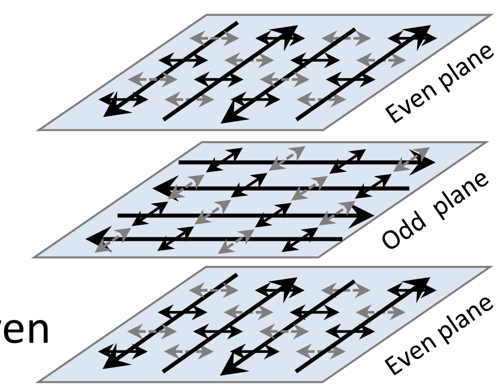
Degree of Adaptiveness

- For 3D mesh let:
  - source node (x_s, y_s, z_s)
  - destination node (x_d, y_d, z_d)
  - $d_x = |x_d - x_s|$, $d_y = |y_d - y_s|$ and $d_z = |z_d - z_s|$
- Degree of adaptiveness for:
  - Conventional 3D OE
    - $$P_{ConventionalOE} = \frac{(h + d_y + k)!}{h!d_y!k!}$$
    - Where h is equal to (d_x/2) or (d_x-1/2) depending on x_s and d_x
  - Modified 3D OE
    - $$P_{ModifiedOE} = \frac{(d_x + q + k)!}{d_x!q!k!}$$
    - Where q is equal to (d_y/2) or (d_y-1)/2 depending on y_s and dy.
- In the proposed Balanced odd-even routing, applying Conventional OE for for odd layers and Modified OE for even layers will result balanced adaptiveness among the planes

Conventional OE



Balanced OE



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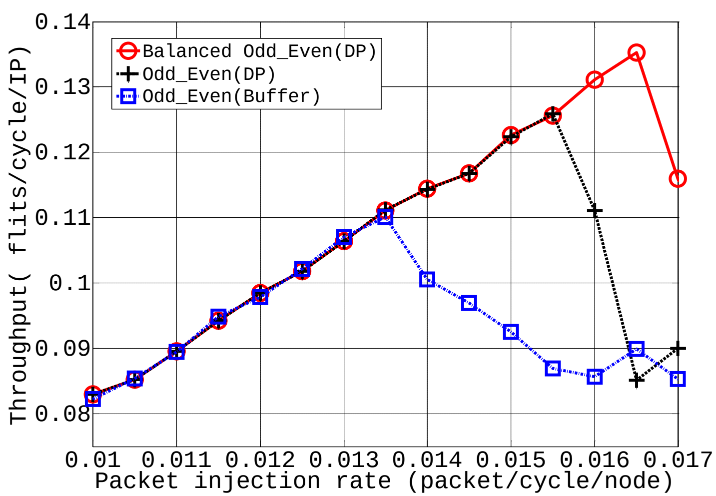
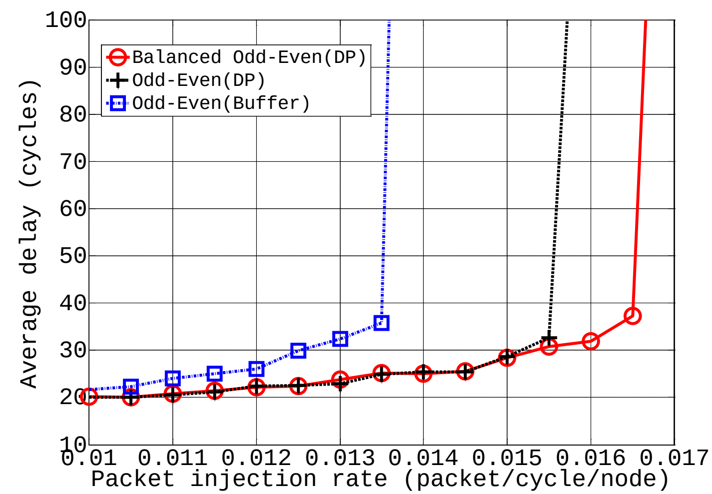
Experimental Setup

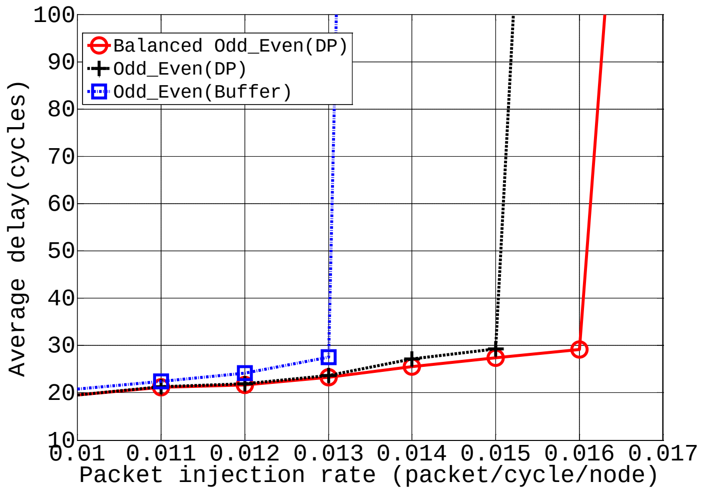
- 3D mesh NoC with size of 6×6x4
- Traffic simulation is performed using a modified version of Noxim.
  - The router architecture is modified to support 3D NoCs.
  - The 2D NoC routing algorithms and traffics are modified to support the 3D NoC routings and traffics.
- The traffics used in our experiments are; *Uniform*, *Transpose*, and *Hotspot*.
- The following routing strategies are compared:
  - **Odd-Even(buffer):** Conventional OE rules are ap-plied (Rule 1,2 and Rule 3 are applied for all planes)with buffer level selection strategy.
  - **Odd-Even(DP):** Conventional OE with dynamic programming guided selection strategy to guide packets to the least congested path among the available paths between a source and a destination.
  - **Balanced Odd-Even(DP):** The proposed Balanced OE routing in which, in addition to rule 3, rules 1 and 2 are applied in an odd xy-plane and rules 4 and 5 are applied in an even xy-plane. Dynamic programming guided selection strategy is also used in this case.

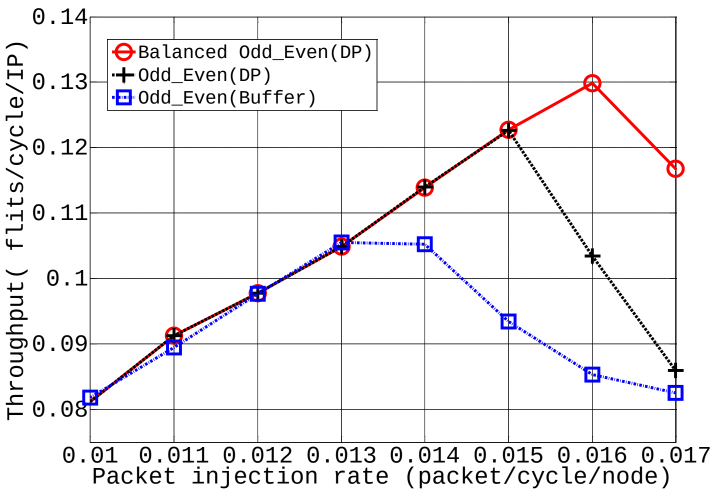
Performance: Random Traffic



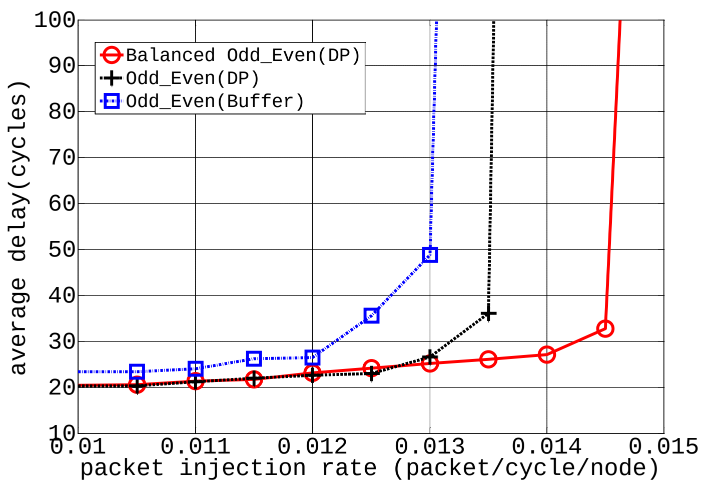


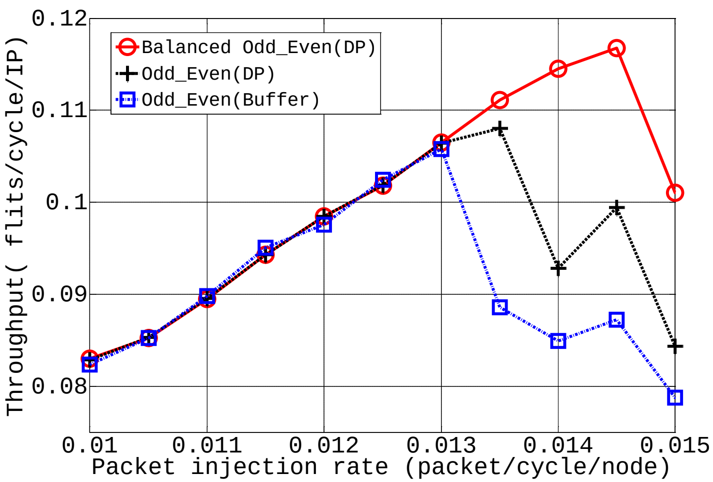
Performance: Transpose Traffic





Performance: Hotspot Traffic





Results Summary

Traffic	Saturation point throughput (flit/cycle/IP)			Balance OE(DP) improvement	
	Odd-Even(Buffer)	Odd-Even(DP)	Balanced OE(DP)	vs. Odd-Even(Buffer)	vs. Odd-Even(DP)
Random	0.11	0.125	0.1352	22.91%	8.16%
Transpose	0.105	0.122	0.13	23.81%	6.56%
Hotspot	0.105	0.108	0.117	11.43%	8.33%

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- A novel method for extending turn model adaptive routing algorithms from 2D to 3D NoCs is proposed.
- The method applies different rules for different layers which results in different restriction on traffic flow for different layers to achieve 3-D plane-balanced approach with higher degree of adaptiveness is achieved.
- Path diversity analysis and deadlock freeness of the proposed method are discussed and compared to the conventional 3D odd-even method.
- Experimental results show that the proposed balanced odd-even with DPN can achieve improvement of up to 23.8% compared odd-even with buffer level and 8.3% compared to odd-even with DPN and the improvement is consistent for all the considered traffic types.

Thank you for listening …