

3D on-chip data center networks using circuit switches and packet switches

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Research background

- Many data centers have been built
 - Online services treating a large amount of data become popular
 - Example: Search engines, online shopping
 - Such online services are provided by data centers
- The energy consumed by data centers becomes an important problem
 - We should construct the energy efficient data center

The energy efficient data center :

An on-chip data center^[1]

- An on-chip data center is a chip performing a task of a data center with small energy consumption
- In an on-chip data center, many CPU cores are placed on a single chip, and network between the cores is constructed
 - CPU cores performs the tasks by cooperating with each other
 - This network plays an important role in this chip

[1] M. Kas, "Toward on-chip datacenters: a perspective on general trends and on-chip particulars," The Journal of Supercomputing, vol. 62, pp. 214-226, Oct. 2012. 2013/10/29

3D Network on Chip

- 3D Network on Chip(NoC) architecture
 - The 3D NoC^[2] is constructed by stacking multiple 2D chip layers vertically
 - The vertically stacked layers decrease the number of hops between switches
 - The vertical links are significantly shorter than the horizontal links
 - The vertical links consume less energy than the horizontal links
- 3D NoC reduces both the energy consumption and the delay
 - We believe that the 3D NoC is the network architecture suitable to on chip data centers

[2] F. Li, C. Nicopoulos, T. Richardson, and Y. Xie, "Design and management of 3D multiprocessors using network-in-memory," in Proceedings of ISCA, pp. 130-141, June 2006. 2013/10/29

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Comparison between circuit and packet switches

- Circuit switch

Consume less energy

Cannot relay flows from the same input ports to the different output port

- Packet switch

Consume more energy

Can relay flows from the same input ports to the different output port

Each type of switch has advantages and disadvantages
We should use effectively both types of switches

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The goal of this research

Clarify the network structure suitable to the on-chip data center

- We considered to use both of circuit and packet switches as approach for minimizing energy consumption
 - Circuit switch
 - Consume less energy
 - Can not relay flows from different input ports to the same output port
 - Packet switch
 - Consume more energy
 - Can relay flows from different input ports to the same output port

The key point of this research is how to use these two types of switches

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Our on-chip data center network

- Servers
 - Vertically stacked cores work as a single server
 - Each server is connected to one of packet switches
- Network
 - Network includes the packet and circuit switches
 - Switches are placed in 3D lattice
 - All switches without connection to servers are circuit switches

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Evaluation

- Parameters of the 3D network structures
 - Connection from servers
 - Inter layer connection
 - Placement of switches within each layer
- Metrics
 - Energy consumed by the network
 - The sum of energy consumed by switches and links
 - Delay
 - The time required to receive all traffic by the destination cores after generating the traffic demands

We investigate the impact of each parameter

Legend: Core (grey square), Packet switch (blue circle), Circuit switch (blue diamond)

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Environment

- Topology
 - The number of servers : 15*15
 - Length of intra layer link : 2mm
 - Length of inter layer link : 1um
- Traffic
 - Generated between randomly selected server pairs
 - The number of communicating server pairs: from 100 or 500
 - The amount of traffic between selected server pairs: 10,000 bit
- Routing
 - Set so as to minimize the energy consumed by the switches and links
- Energy consumption model
 - Model proposed in [3]

[3] P. T. Walkotte, G. J. M. Smit, N. Kavalidjiev, J. E. Becker, and J. Becker, "Energy model of networks-on-chip and a bus," in *Proceedings of IEEE International Symposium on System-on-Chip*, pp.82-85, Nov. 2005.

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Connection between servers and switches

All servers are connected to the switches in the same layer

Same layer connection

The servers neighboring with each other are connected to the switches in the different layers

Different layer connection

Legend: Core (grey square), Packet switch (blue circle), Circuit switch (blue diamond)

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Comparison of the connection between servers and switches

- Same layer connection achieves both of less energy consumption and less delay

Number of communicating server pairs	Same layer connection (Energy)	Different layer connection (Energy)	Same layer connection (Delay)	Different layer connection (Delay)
100	~80	~110	~40	~110
500	~90	~120	~40	~140

In different layer connection, packet switches prevent establishment of long circuit paths

Cannot construct the energy efficient long circuit paths

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Inter-layer connections

Switches in all layers are connected to the same packet switch

Packet switches have close connection between the nearest layer

Though these two types of connections has different connection patterns, the number of ports of each switch is the same

Packet switch centric connection

Nearest layer connection

Legend: Core (grey square), Packet switch (blue circle), Circuit switch (blue diamond)

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Comparison of Inter-layer connections

- The packet switch centric connection achieves both of a smaller energy consumption and a smaller delay

Any circuit switches can be used via direct connection from packet switch

Multiple hops are required

Each switch relaying the traffic consumes energy

Number of communicating server pairs	Packet switch centric connection (Energy)	Nearest layer connection (Energy)	Packet switch centric connection (Delay)	Nearest layer connection (Delay)
100	~70	~80	~40	~60
500	~70	~80	~40	~60

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Placement of switches within a layer

Each layer includes only one type of switches

There exists a layer including both types of switches

The numbers of switches passed by each flow between servers are small

The energy efficient routes may be found, because it has more candidates of routes of circuit paths

Single type placement

Multiple type placement

Legend: Core (grey square), Packet switch (blue circle), Circuit switch (blue diamond)

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Comparison of the placement of switches within a layer

- Multiple type placement does not reduce the energy consumption and delay
 - We conclude that the single type placement is sufficient

Energy consumption

Delay

Number of communicating server pairs

Legend: Single type placement (blue bar), Multiple type placement (red bar)

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Conclusion and future work

- Conclusion
 - We investigated the 3D on-chip data center network structures which use both of the circuit and packet switches
 - The servers should connect to the packet switches in the same layer
 - The packet switches should connect to the circuit switches in all layers
 - The layer including both of circuit and packet switches should be avoided
- Future work
 - The method to set the routes suitable to the on-chip networks

To achieve the smaller energy consumption and smaller delay

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Model

- Energy consumption model^[3]
 - Packet switch : 0.98μW/bit
 - Circuit switch : 0.37μW/bit
 - Link consumes : $(0.39 + 0.12L)\mu\text{W/bit}$ (L : length of link (mm))
- Delay model
 - The time required to receive all traffic by the destination cores after generating the traffic demands
 - Each flit can be relayed by a packet switch to the next packet switch in 1 clock cycle
 - The relay of the flits by the circuit switch takes no clock cycles
 - The delay between cores depends only on the number of packet switches passed by the flow

[3] P. T. Wolkotte, G. J. M. Smit, N. Kavalidjev, J. E. Becker, and J. Becker, "Energy model of networks-on-chip and a bus," in *Proceedings of IEEE International Symposium on System-on-Chip*, pp.82-85, Nov. 2005.

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