Shahrouz YASREBI, Akram REZA, Mohammad NIKRAVAN, Seena VAZIFEDAN, 2021. A fuzzy integrated congestion-aware routing algorithm for network on chip. *Frontiers of Information Technology & Electronic Engineering*, 22(5):741-755. https://doi.org/10.1631/FITEE.2000069

A fuzzy integrated congestion-aware routing algorithm for network on chip

Key words: Network on chip; Routing algorithm; Congestion control; Fuzzy logic

Corresponding author: Akram REZA
Email: a.reza@qodsiau.ac.ir; a.ak.reza@gmail.com
ORCID: https://orcid.org/0000-0003-3853-2734

Motivation

- Network on chip (NoC) is an infrastructure providing a communication platform to multiprocessor chips.
- The wormhole-switching method, which shares resources, is used to increase its efficiency; however, this can lead to congestion.
- One of the main challenges in NoC is congestion, which consumes more energy and will lead to increase in power consumption, heat, and thermal fluctuations that lessen the life span of the infrastructures and, more importantly, reduce the network performance.
- So, for performance, power consumption, and thermal fluctuation management in chip, we need a congestion control method; however, providing a method that controls congestion is a significant design challenge.
- One of the main classes of congestion control method is congestion-aware routing. In adaptive routing, the path with the minimum congestion is selected.
- Path selection can be done based on local, reginal, or global information. The local information has low overhead, but it is not efficient enough; the global information has high overhead.

Main idea

We propose congestion-aware routing based on:

- defining congestion based on local information (the occupied input buffer and the total occupied buffers of the neighboring nodes),
- the maximum possible path diversity with the minimum path length from instant neighbors to the destination, and
- using the uncertainty of the fuzzy logic algorithm to enhance the path selection function.

Method

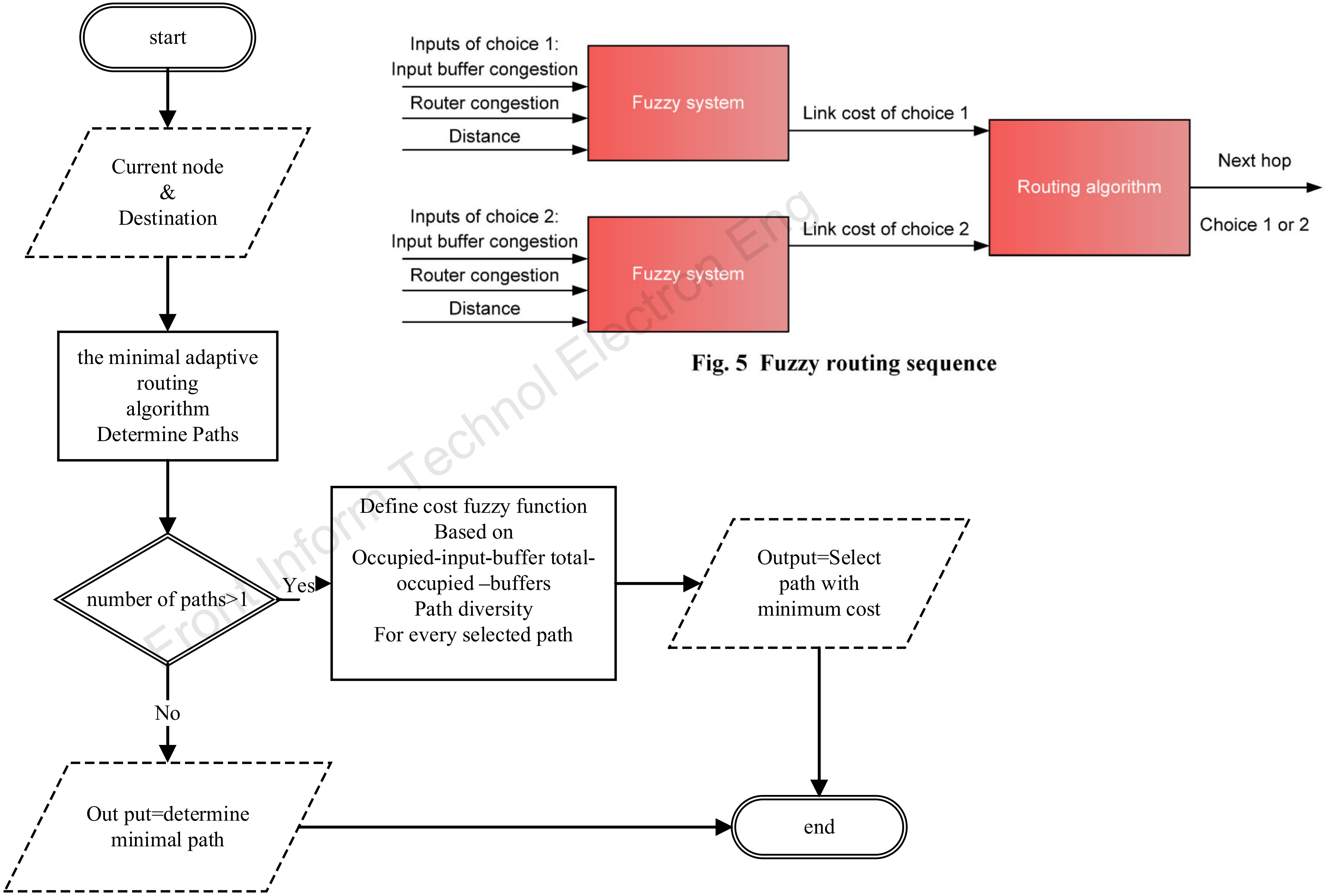

Fig. 5 Fuzzy routing sequence

Method

Fuzzification

- Occupiedslot_input
- Occupiedslot_Router
- Path diversity
- Cost function

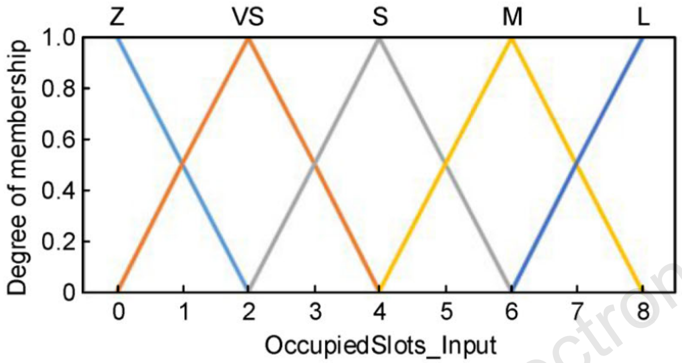

Fig. 6 Allocating the OccupiedSlots_Input membership function to five fuzzy collections

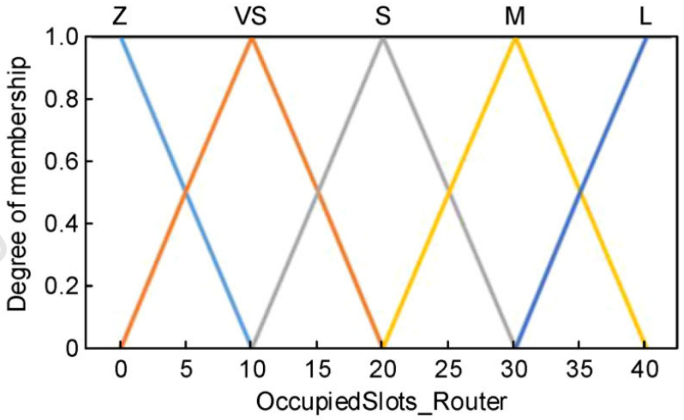

Fig. 7 Dividing the OccupiedSlots_Router membership function into five fuzzy collections

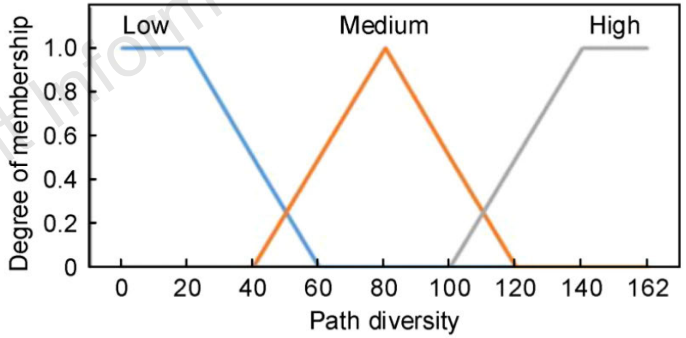

Fig. 8 Allocating the path diversity membership function to three fuzzy sets

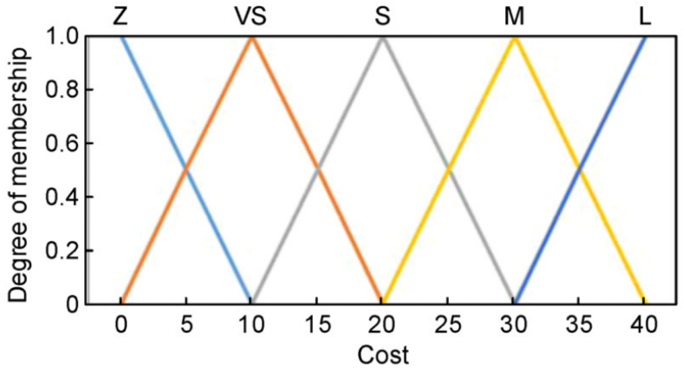

Fig. 9 Allocating the cost function to five fuzzy sets

Method

- Fuzzy inference system

- Defuzzification

$$X^* = \sum_{i=1}^{n} x_i \mu(x_i) \Big/ \sum_{i=1}^{n} \mu(x_i),$$

Table 1 Fuzzy table in the first step

OccupiedSlots_Input	Cost in the first stage				
	OccupiedSlots_Router				
	Z	VS	S	M	L
Z	Z	Z	VS	S	M
VS	Z	VS	VS	S	M
S	VS	VS	S	M	M
M	S	S	M	L	L
L	M	M	L	L	L

Table 2 Fuzzy table in the second step

Cost in the first stage	Final cost		
	PathDiversity		
	Low	Medium	High
Z	Z	Z	VS
VS	Z	VS	VS
S	VS	VS	S
M	S	S	M
L	M	M	L

Major results

- The Noxim simulator is used to evaluate the proposed method.

Table 3 Number of gates of the selection function using fuzzy implementation and their signal sizes

Step	Main function	Number of gates	Signal size (bit)
Fuzzification step	OccupiedSlots_Input	8*	5×2=10
	OccupiedSlots_Router	40*	5×4=20
	PathDiversity	8*	5×4=20
	Cost	–	5×4=20
Rule step	Cost-first	25** 12***	5
	Cost-final	15** 12***	5
Defuzzification step	Multiplier/Adder/Divider	604****	6
Total count		724	86
Hardware redundancy in the selection function		$3.2\times gate\_count_{\text{Buffer level}}$	$1.6\times signal\_count_{\text{Buffer level}}$

* For the membership function/set defined; ** for the cost set; *** for the cost membership function; **** parallel

Table 4 Simulation parameters

Topology	Mesh
Network size	8×8
Packet size	8 flits
Buffer depth	4 flits
Simulation time	100 000 cycles
Reset time (warm-up time)	1000 cycles
Traffic patterns	Hotspot, transpose, realistic benchmarks: TVOPD (treble VOPD), TMPEG-4 (treble MPEG-4), and QPIP (quadruplicate PIP)
Packet injection rate	0.001–1

Major results

Table 5 Methods of fuzzy algorithms along with their routing and selection functions

Method	Routing and selection functions
FA_BL	Fuzzy logic + Minimal full adaptive routing buffer (input buffer) level selection
FA_CBL (Ebrahimi et al., 2013)	Fuzzy logic + Minimal full adaptive routing + Buffer level & Router level (total router buffer) selection
FA-MPD_BL	Fuzzy logic + Minimal full adaptive routing + Buffer level & Maximum path diversity selection
FA-MPD_CBL	Fuzzy logic + Minimal full adaptive routing + Buffer level & Router level & Maximum path diversity selection
DyXY (Li et al., 2006)	Minimal full adaptive routing + Buffer level & Router level
NOP (neighbors-on-path) (Ascia et al., 2008)	Minimal full adaptive routing + Buffer level + Channel available
DOR	XY routing + No selection function

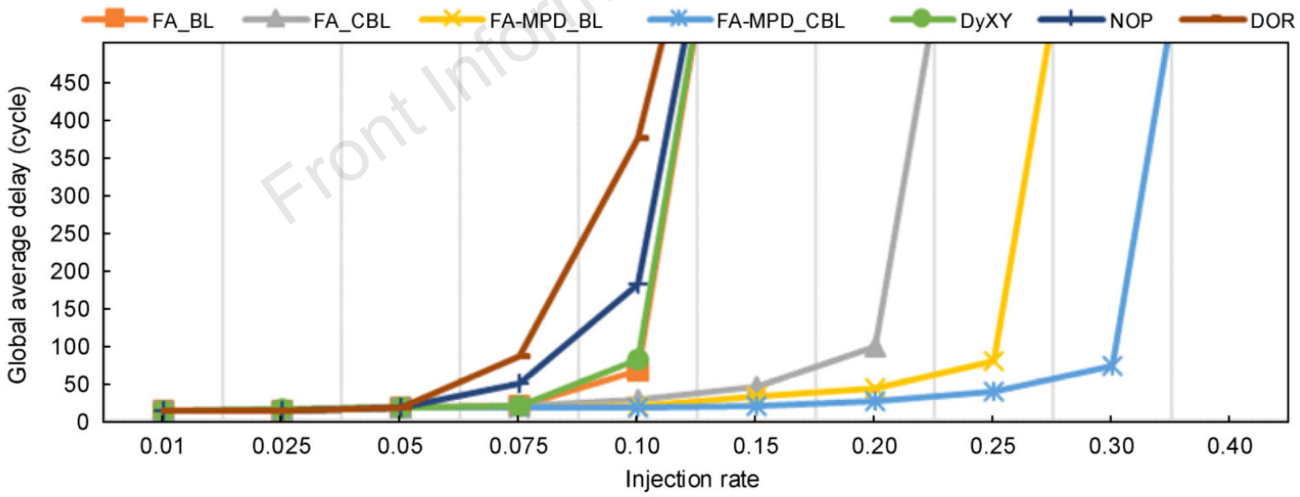

Fig. 10 Average delay using the hotspot traffic pattern

Major results

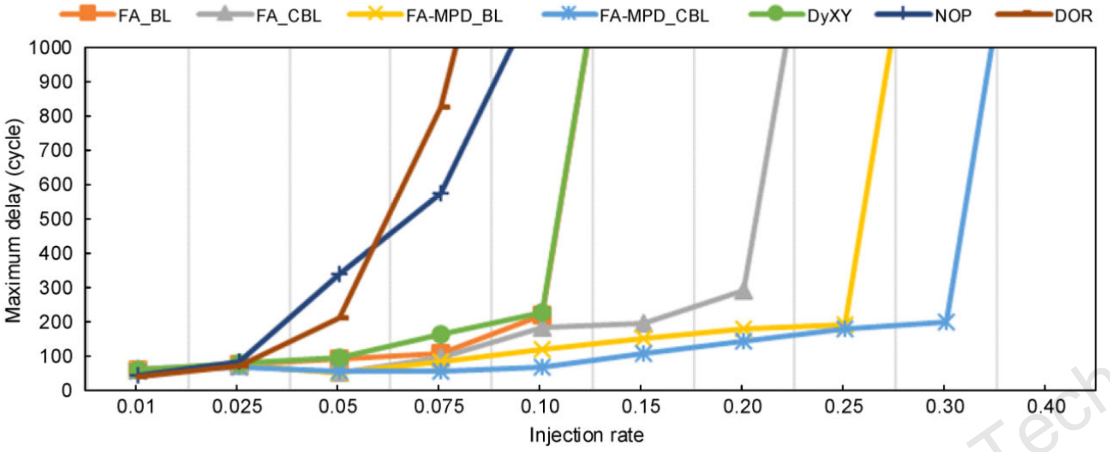

Fig. 11 Maximum delay using the hotspot traffic pattern

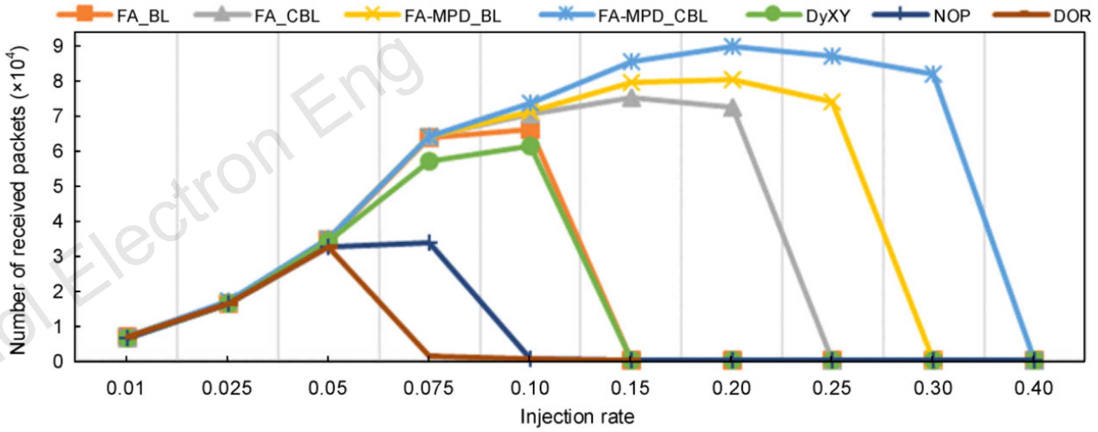

Fig. 12 Total number of received packets using the hotspot traffic pattern

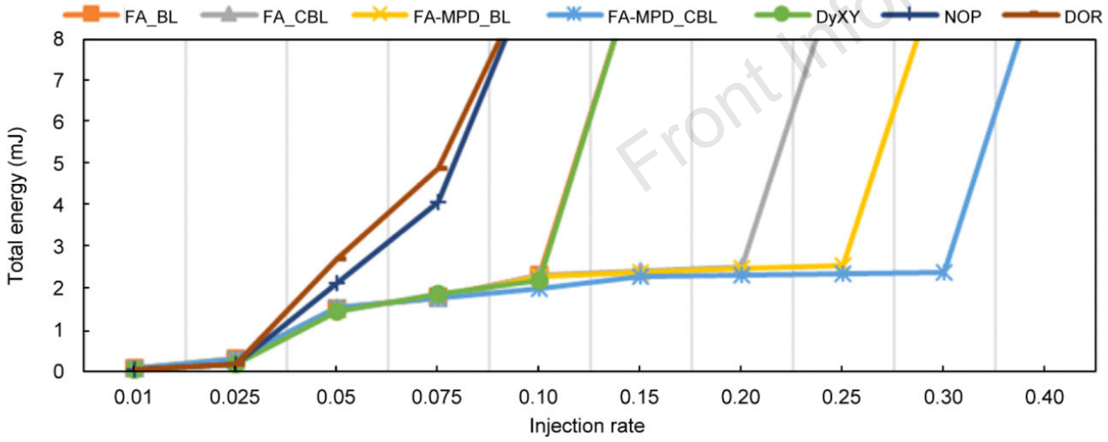

Fig. 13 Energy consumption using the hotspot traffic pattern

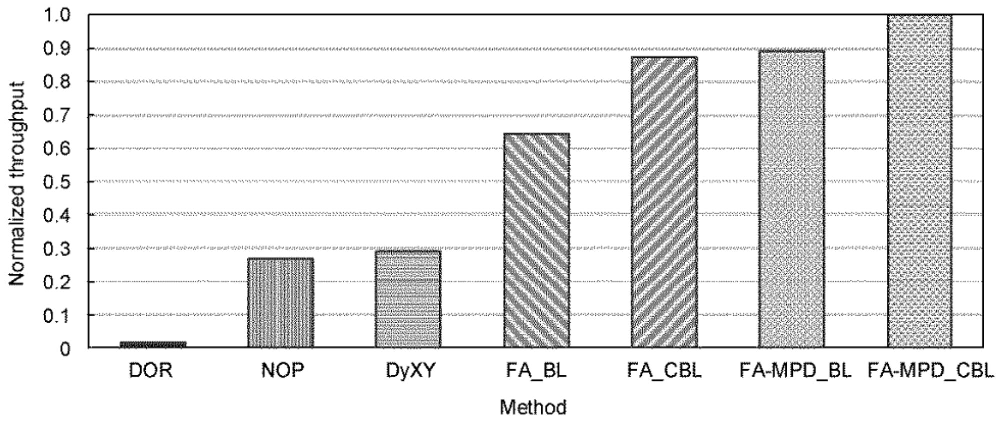

Fig. 14 Average throughput using the hotspot traffic pattern

Major results

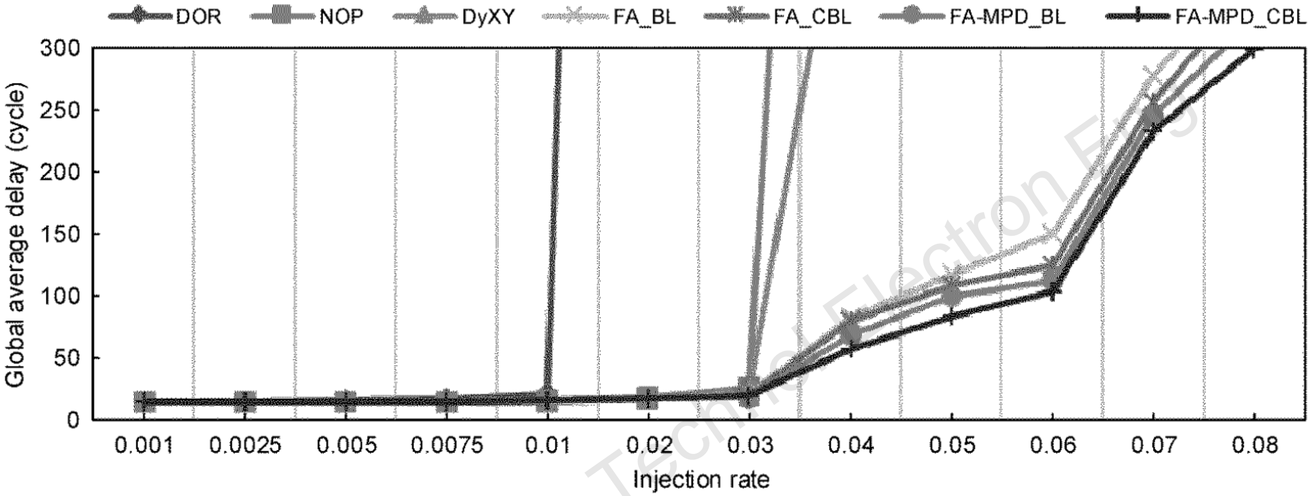

Fig. 15 Average delay using the transpose traffic pattern

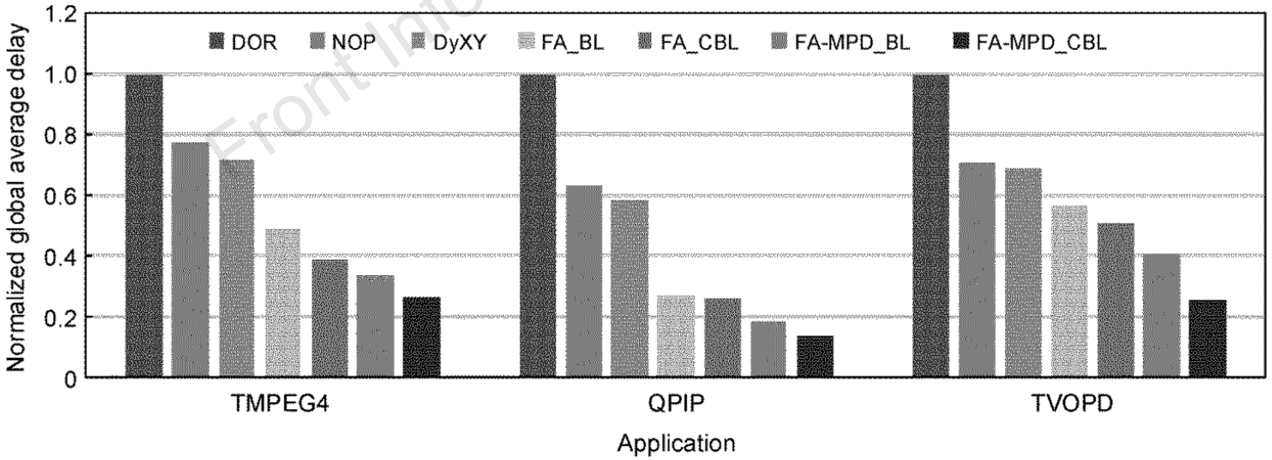

Fig. 16 Average delay using the three applications (References to color refer to the online version of this figure)

Summary of major results

- The average delay is improved by 14.88%, the energy consumption is enhanced by 7.98%, the maximum delay is reduced by 19.39%, and the throughput is improved by 14.9%.
- To show the significance, the proposed algorithm is examined using the transpose traffic patterns, and the average delay is improved by 15.3%.
- The average delay is reduced by 3.8% in TMPEG-4, 36.6% in QPIP, and 20.9% in TVOPD.

Conclusions

- One of the main challenges in NoC is congestion, which can lead to thermal fluctuation.
- Providing methods to control congestion is a leading design challenge.
- Congestion-aware routing is one of the main solutions to congestion control.
- This paper presents a fuzzy logic based congestion control routing algorithm, which uses local congestion information to select a path that benefits from fuzzy logic uncertainty.
- Due to the overhead of the proposed method, the delay increases at a low traffic injection rate. However, as it increases, the proposed algorithm chooses an optimal route to reach the ideal traffic distribution, which benefits from the uncertainty of fuzzy logic.