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A CNN-Based Routing Scheme for Minimizing TCP Flow Completion Time in SD-DCNs

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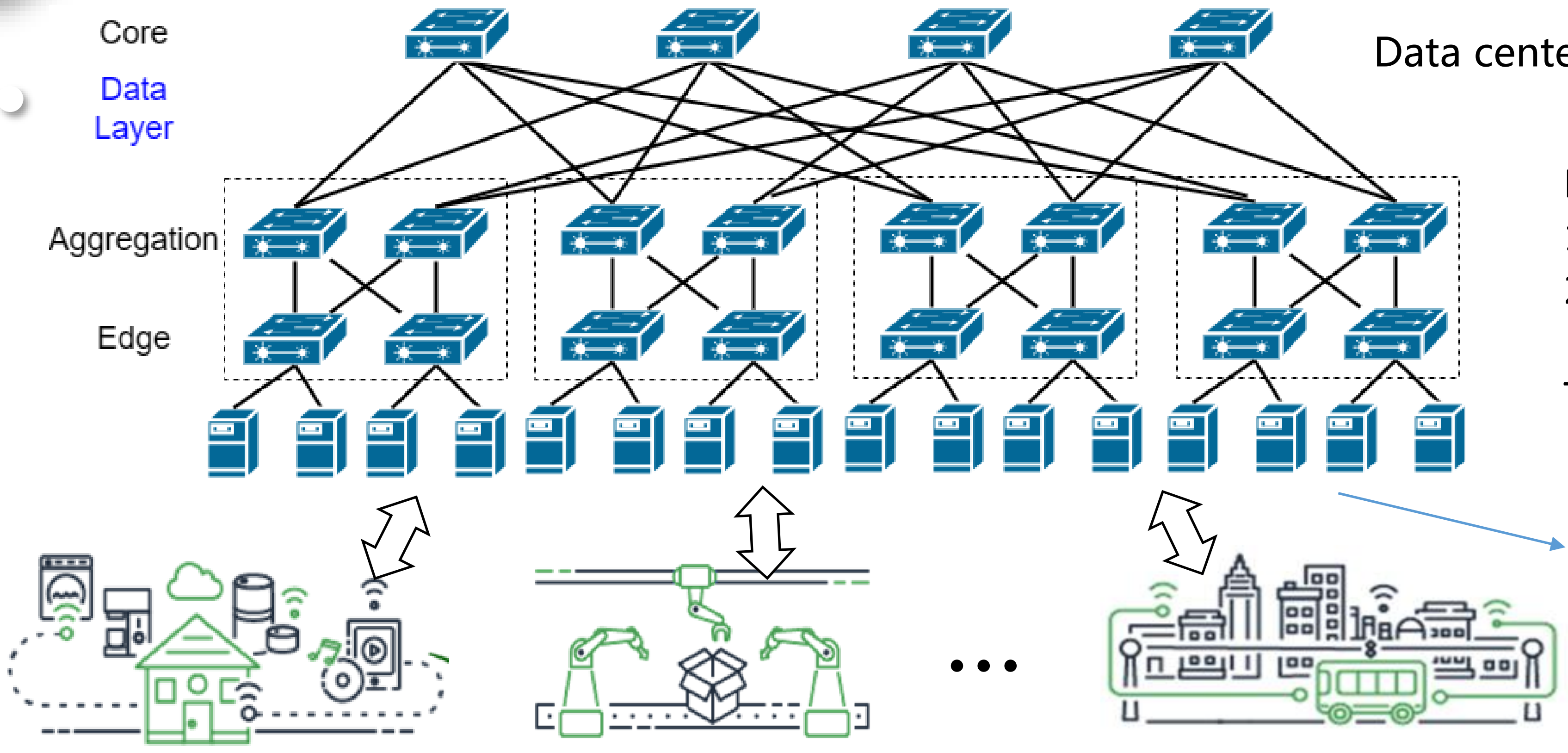
Introduction



IoT devices at home   Smart factory   Smart cities

Data centers:

Routing optimization：
1. traditional flow scheduling
2. SDN and AL technology

To improve QoS of IoT networks

QoS： delay, jitter, packet loss

We use an AI-based routing scheme to reduce the FCT in SD-DCNs. Our contribution is listed :

1) we proposed a flow-based routing algorithm using fixed point iterations;

2) for the first time, we apply the convolutional neural network (CNN) to routing optimization for TCP applications in SD-DCNs.

Network Model

We consider a basic SD-DCN architecture including three layers: the data layer, the control layer and the application layer.

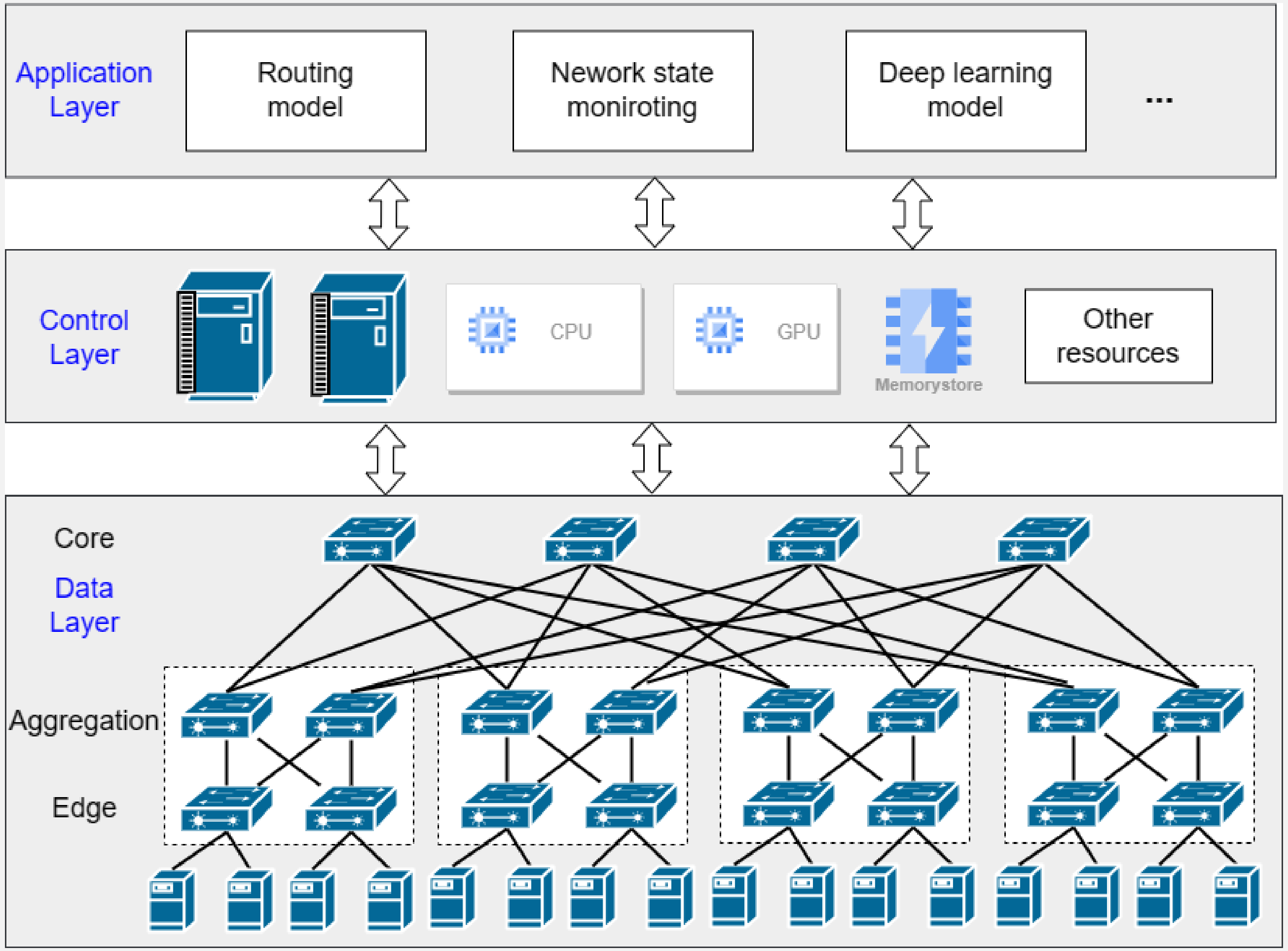


Fig. 1： the architecture of SD-DCN

	Key Information
V	The set of SDN switches
E	The set of possible links between switches
(v_i, v_j)	The link from v_i to v_j
c_{ij}	The capacity of (v_i, v_j)
F	The set of flows $\{f_1, f_2, \ldots f_k\}$
P	The set of routes $\{p_{f1}, p_{f2}, \ldots p_{fk}\}$
FCT	Flow completion time

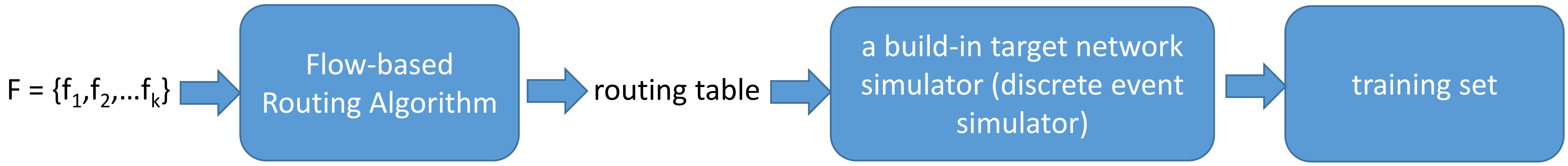
P ={pf1, pf2, ..., pfK } → $F = \{f_1, f_2, \ldots f_k\}$

Minimize the FCT of all flows

np-hard

The dynamic variation of traffic → **A CNN-based routing scheme**

CNN-based routing scheme



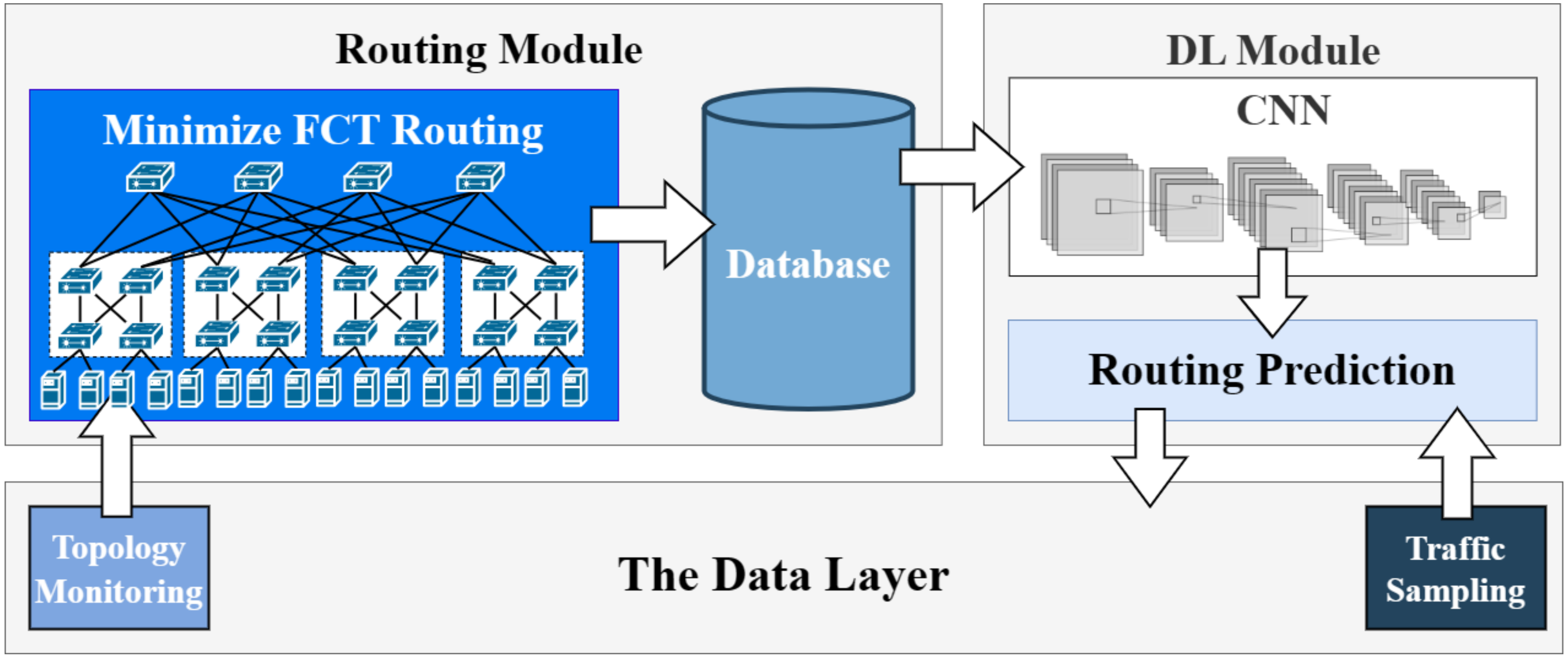
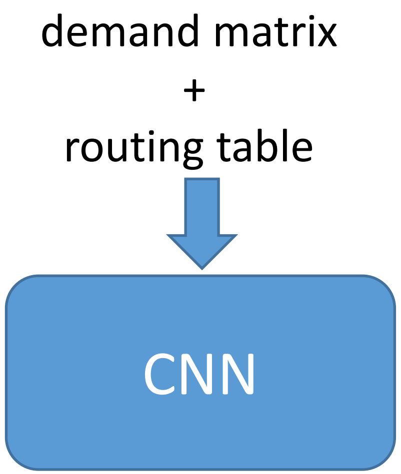


Fig. 2: CNN-based routing scheme



The resultant model is implemented in the application layer for routing computation.

Routing model : Minimizing the FCT in SD-DCNs

The flow completion T is :

$$T = \sum_{i=1}^{m} T_i \qquad T_i = \sum_{k \in p} (s_k + q_k)$$

Based on [4], the arrival of packets follows the Poisson distribution, then each queue of the target network can be modeled as an M/D/1/FIFO system.

The average delay of an M/D/1/FIFO system is:

$$D = \frac{1}{\mu} + \frac{\rho}{2\mu(1-\rho)} \text{ ,so} \qquad T_i = \sum_{k \in p} \left(\frac{1}{\mu_k} + \frac{\rho_k}{2\mu_k(1-\rho_k)} \right)$$

To minimize the FCT, we need to minimize the delay T_i of the flow . Using d_k to represent the delay of packets in the k^{th} flow . Multi-objective(flows) optimization:

$$\min\left(d_1(A\gamma), d_2(A\gamma), \ldots, d_k(A\gamma)\right)$$

path-edge matrix A (aij ∈ {0, 1})

s.t. $\lambda = A\gamma$

$$\sum_{(u,v)\in E} \lambda_{uv} = \sum_{(v,z)\in E} \lambda_{vz}$$

$$\lambda_{uv} L < c_{uv}$$

$$\begin{cases} a_{ij} = 1, \text{flow j chooses link i} \\ a_{ij} = 0, \text{otherwise} \end{cases}$$

(γ) is the arrival rate of the flows

Algorithm 1 Flow-based Routing Algorithm Using Fixed Point Argument Method

Input: network topology $G(\mathbb{V}, \mathbb{E})$, flow vector $\mathbf{f}$;
Output: the minimum FCT path vector $\mathbf{p}$;

```
p^(0) = []
n = 0
for f_i ∈ f do
    use the algorithm in [12] to get the initial path p_i for flow f_i
    p^(n).append(p_i)
    for each link (u, v) ⊂ p_i^(n) do
        (u, v).pps = (u, v).pps + f_i.pps
        pps means packets per second
    end for
end for
repeat
    n = n + 1
    for f_i ∈ f do
        for each link (u, v) ⊂ p_i^(n-1) do
            (u, v).pps = (u, v).pps - f_i.pps
        end for
        for each link (u, v) ⊂ E do
            (u, v).pps = (u, v).pps + f_i.pps
        end for
        use (6) to calculate the delay as link's weight
        use the algorithm in [12] to get the path p_i for flow f_i
        for each link (u, v) ⊄ p_i do
            (u, v).pps = (u, v).pps - f_i.pps
        end for
        p_i^(n) = p_i
    end for
until p^(n) == p^(n-1)
p = p^(n)
```

Initialization

Iteration

Update weights

Termination condition

CNN Module: CNN-Based Routing Table Prediction

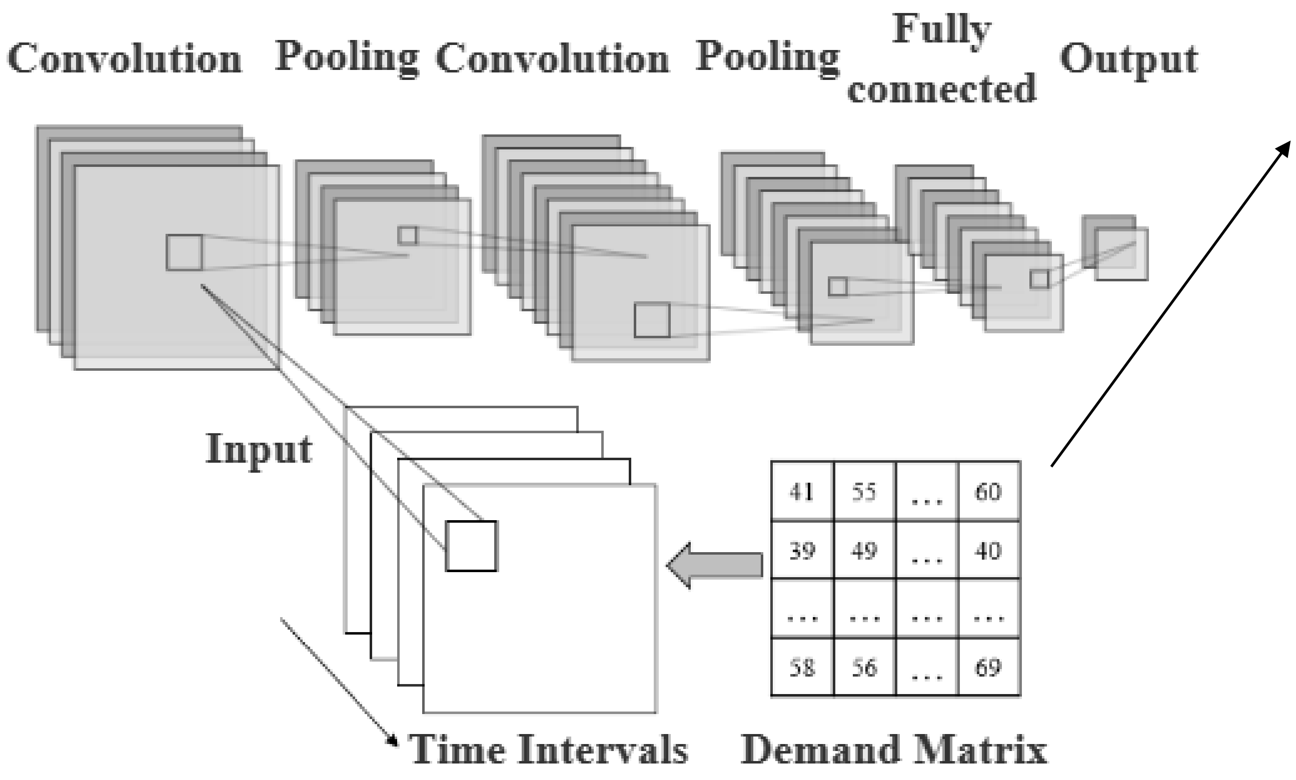


Fig. 3: The structure of CNN model

1) Matrix Input: demand matrix can be obtained in SDN controller, including flows between all hosts.

2) Convolution Layers: extract the distinguished features of the input.

$$x_{i,j}^l = (X^{l-1} * W_l)(i,j) + b^l = \sum_{m=1}^{M}\sum_{n=1}^{N} W_{m,n} a_{i+m,j+n}^{l-1} + b^l,$$

$$a_{i,j}^l = f(x_{i,j}^l),$$

3) Softmax Output: adopts Softmax as the classifition function to realize routing selection in DCNs

$$p_i(z) = \frac{e^{z_i}}{\sum_{j=1}^{m} e^{z_j}}, \qquad z_i = w_i x + b$$

network loads (from ρ = 0.1 to ρ = 0.9)

dataset
$D = \{(X^k, y^k), k = 1, 2, ..., n\}$,
$X^k \in R^{n\times n}$,
$y^k \in R^{1\times 9}$

The resultant CNN will be placed in the application layer. SDN controller will sample the network traffic as the input and utilize the CNN to deliver the flow table for packet forwarding.

Results and discussion: A. CNN Model Analysis

TABLE Ⅰ:The detailed CNN Structure information.

No.	Input Layer	Convolution Layer (Kernel)	Pooling Layer	Convolution Layer	Pooling Layer	Fully Connected Layer	Output Layer
S1	16×16	$3 \times 3 \times 5$	2×2	$3 \times 3 \times 5$	2×2	$16 \times 16 \times 5 \times 9$	1×9
S2	16×16	$3 \times 3 \times 10$	2×2	$3 \times 3 \times 10$	2×2	$16 \times 16 \times 10 \times 9$	1×9
S3	16×16	$3 \times 3 \times 15$	2×2	$3 \times 3 \times 15$	2×2	$16 \times 16 \times 15 \times 9$	1×9
S4	16×16	$5 \times 5 \times 5$	2×2	$5 \times 5 \times 5$	2×2	$16 \times 16 \times 5 \times 9$	1×9
S5	16×16	$5 \times 5 \times 10$	2×2	$5 \times 5 \times 10$	2×2	$16 \times 16 \times 10 \times 9$	1×9
S6	16×16	$5 \times 5 \times 15$	2×2	$5 \times 5 \times 15$	2×2	$16 \times 16 \times 15 \times 9$	1×9
S7	16×16	$7 \times 7 \times 5$	2×2	$7 \times 7 \times 5$	2×2	$16 \times 16 \times 5 \times 9$	1×9
S8	16×16	$7 \times 7 \times 10$	2×2	$7 \times 7 \times 10$	2×2	$16 \times 16 \times 10 \times 9$	1×9
S9	16×16	$7 \times 7 \times 15$	2×2	$7 \times 7 \times 15$	2×2	$16 \times 16 \times 15 \times 9$	1×9

TABLE II : The accuracy of different CNN structures.

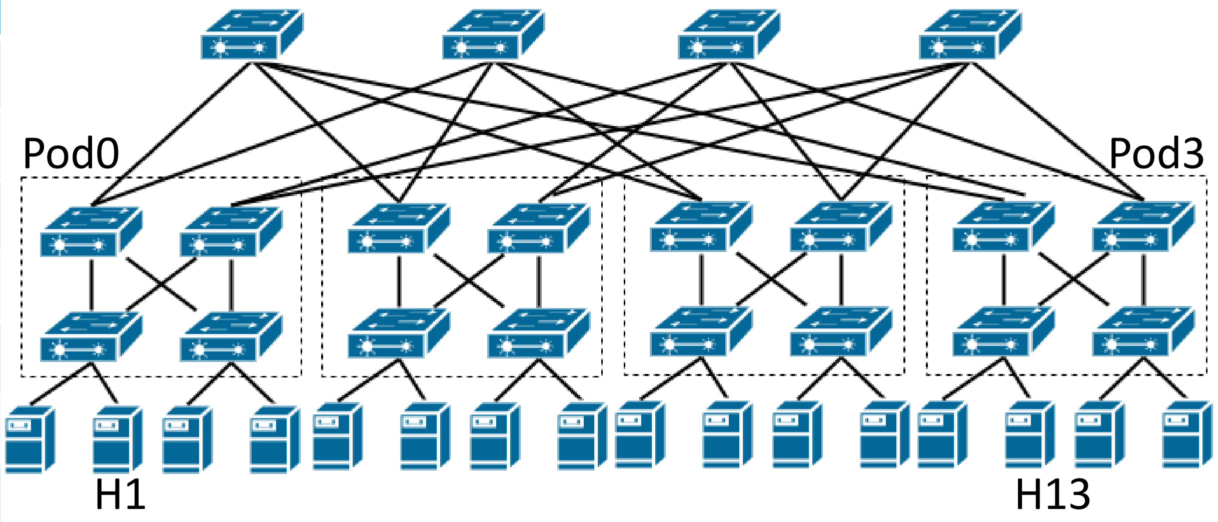
No.	S1	S2	S3	S4	S5	S6	S7	S8	S9
The Accuracy	0.9327	0.9956	0.9978	0.9674	1	1	0.9913	1	1
The Convergence Time (s)	8.54	6.93	7.20	6.48	5.12	6.64	7.49	6.21	7.36

S5 √

Results and discussion: B. Flow Completion Time Analysis in SD-DCNs

Simulation parameters

Parameter	Value
Data Center Networks	
Topology	Fat-tree(k = 4)
Link bandwidth	1Gbps-10Gbps
TCP Flows	
File size	1 MB
TCP algorithm	Tahoe
MSS	1460 bytes
Sstresh	16 MSS
Advertised window	65535 bytes
CNN	
Number of layers	10
Input layer	16 × 16
Convolution layer	5 × 5
Max pooling layer	2 × 2
Activation function	ReLu
Optimizer	Adam



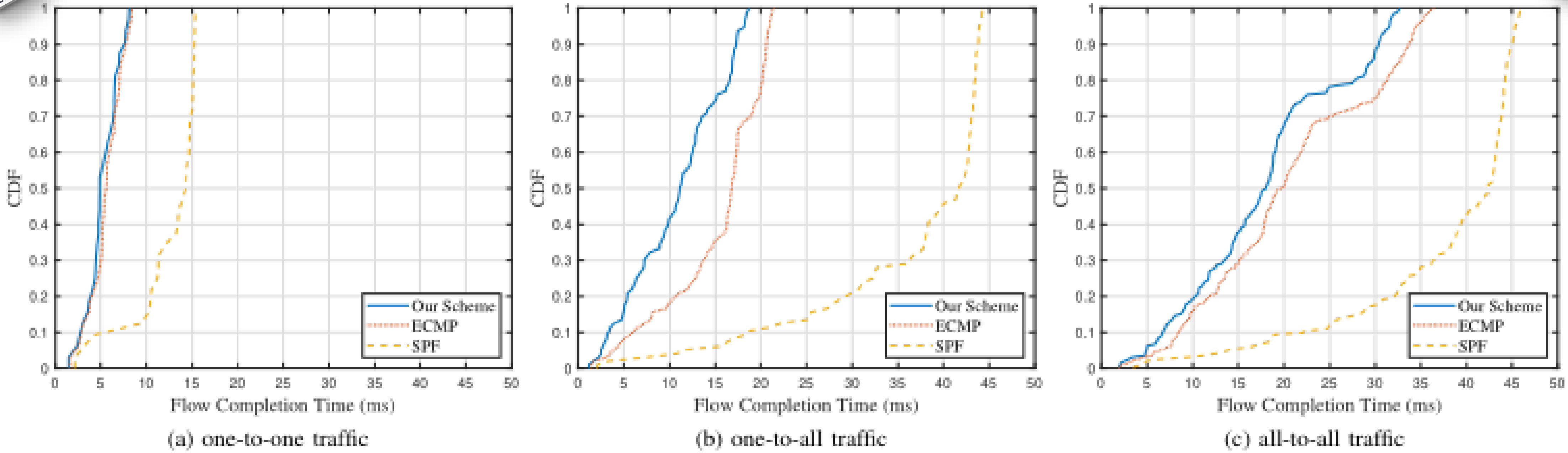
Three traffic patterns:

1) One-to-one traffic: TCP flows between two Pods.

2) One-to-all traffic: TCP flows from one Pod to all other Pods.

3) All-to-all traffic: TCP flows between all Pods.

Results and discussion: B. Flow Completion Time Analysis in SD-DCNs



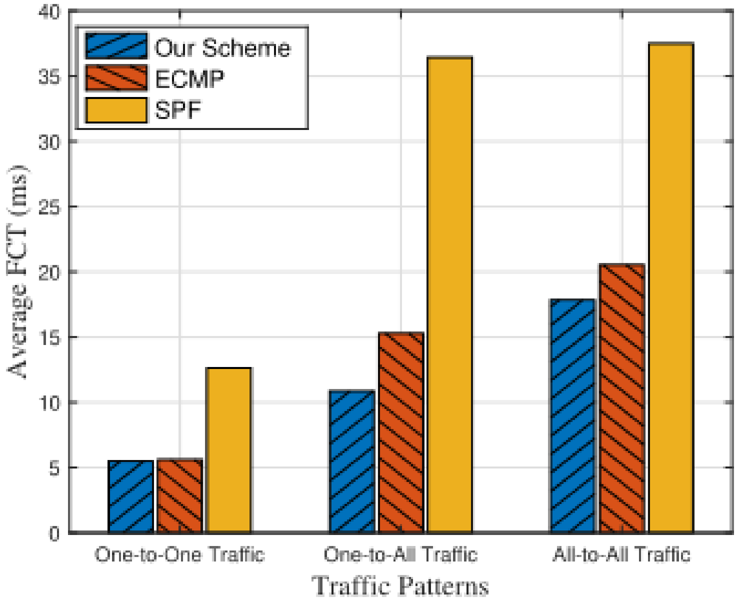


Fig. 5: Performance comparison results

Fig. 4: The CDF of FCT under different traffic patterns.

Conclusions:

1. It can be seen that with our scheme, the CDF of FCT is closer to the Y - axis than SPF and ECMP . This implies that more TCP flows have shorter flow completion time.
2. the performance of our scheme is better than the SPF algorithm and reduces the FCT by up to 50% shorter than the SPF algorithm. For the ECMP , as the load of the network increases, the effect of our scheme is also apparent and reduces FCT by up to 21%.

Conclusions

A CNN-based routing scheme for minimizing TCP flow completion time in SD-DCNs is proposed which consists of routing module and CNN model. Our contribution is listed as below:

- we proposed a flow-based routing algorithm using fixed point iterations;.
- we apply the CNN to routing optimization for TCP applications in SD-DCNs.

A simulation platform was implemented based on the three-layer architecture of SD-DCNs with the scheme. The simulation results show that our proposed scheme outperforms the SPF algorithm and ECMP in terms of the flow completion time (FCT).

More importantly, the scheme predicts the path without prior knowledge of traffic input and provides a practical solution to routing problems in real complex SD-DCNs.

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