On the Deployment and Operation of Correlated Data-Intensive vNF-SCs in Inter-DC EONs

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Outline

- Background
- Problem Description
- Proposed Scheme for vNF-SCs
- Evaluation
- Conclusions

Background of Network Function Virtualization

- Network function virtualization was proposed to improve the flexibility of network service provisioning and reduce the time to market of new services.
- NFV can also reduce the cost of offering the space and energy for a variety of middle-boxes, and make it easy for non-professional people to and maintain these services.

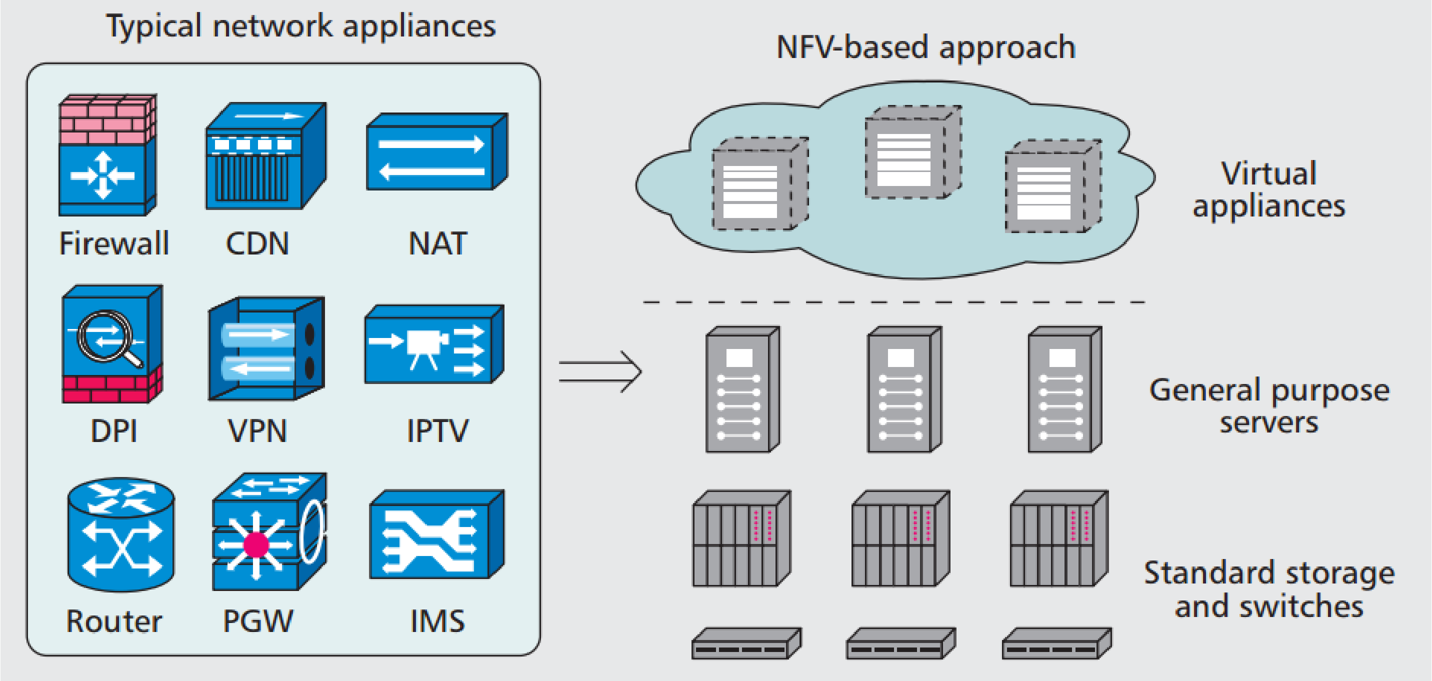

Figure A: Dedicated hardware-based appliances for network services to NFV [1]

[1] B. Han, V. Gopalakrishnan, L. Ji and S. Lee, "Network function virtualization: Challenges and opportunities for innovations," in *IEEE Communications Magazine*, vol. 53, no. 2, pp. 90-97, Feb. 2015.

NFV-related service function chains

- With NFV, we can represent a network service with a series of connected vNFs, i.e., formulating a service function chain (SFC).
- To operate a data-intensive vNF-SC, service providers need to accomplish two tasks:

1) scheduling the computing tasks in required vNFs

2) transferring application data between two adjacent vNFs in the vNF-SC.

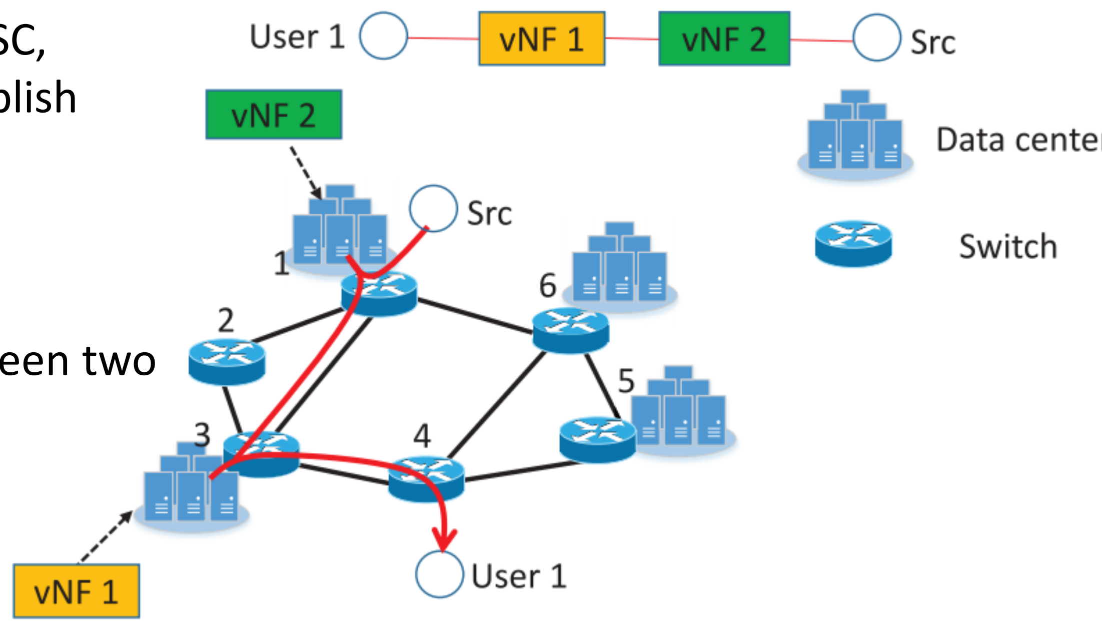

Figure B: A service example of NFV-related service function chains (SFC) [2].

[2] J. Liu, W. Lu, F. Zhou, P. Lu and Z. Zhu, "On Dynamic Service Function Chain Deployment and Readjustment," in *IEEE Transactions on Network and Service Management*, vol. 14, no. 3, pp. 543-553, Sept. 2017.

Elastic Optical Networks (EONs) vs WDM

- WDM: RWA problem
  (Routing, Wavelength Assignment)
- EON(O-OFDM): RSA problem
  (Routing, Spectrum Assignment)

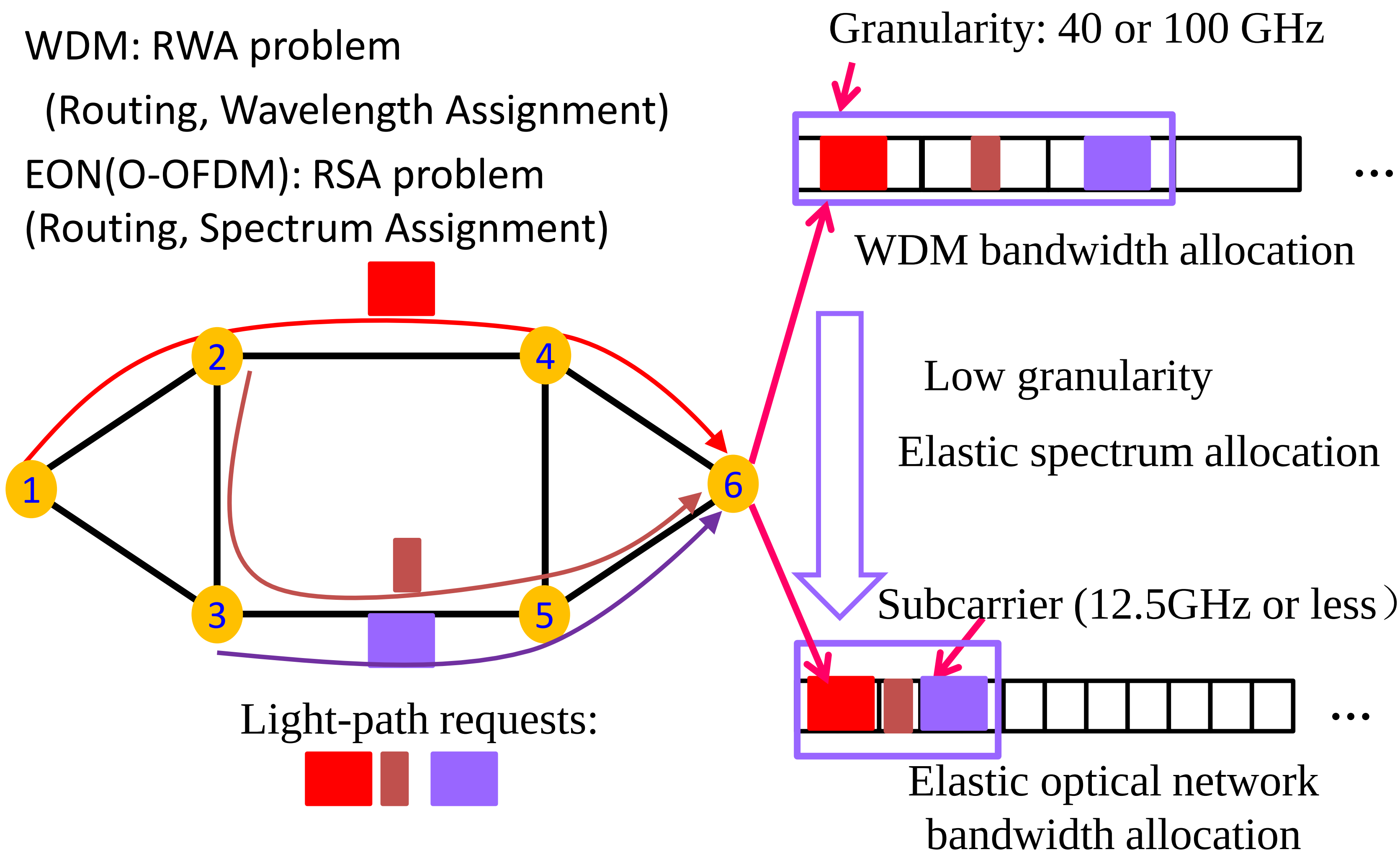

Figure C: Elastic optical networks and WDM

Contributions

- In this work, we study the problem of deploying and operating the correlated data-intensive vNF-SCs in inter-DC EONs, and our target is to minimize the average SCT of the deployed correlated data-intensive vNF-SC.

- We propose two correlation-aware algorithms to minimize the average SCT of such services. In a practical inter-DC EON, the dynamic background traffic and the vNF-SCs are co-exisiting, which would generate two-dimensional (2D) spectrum fragments on the fiber links. Since these 2D fragments can be leveraged to accomplish spectrum-efficient data transfers in EONs, our algorithms schedule the bulk-data transfers with them.

- Simulation results show that the proposed algorithms can reduce the average SCT effectively.

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Problem Descriptions

- The inter-DC EON is denoted as G(V, L), where V is the DC set and L is the set of established lightpaths to interconnect the DCs.
- Each DC $v \in V$ has certain vNF(s) deployed on it already, and there are F types of vNFs supported by the inter-DC EON in total.
- We assume that the inter-DC EON operates in a discrete-time system, i.e., the network operation status changes every time slot (TS).
- 2D spectrum fragments is generated on the lightpaths due to the dynamics of background traffic, which can be utilized for bulk data transfers between the vNFs.
- Our target is to minimize the average SCT of the deployed correlated data-intensive vNF-SC. The SCT of a service is defined as the time when all the data from the source are processed by the designated vNF-SCs and delivered to the destination.

Deploying and Operating Correlated Data-intensive vNFSCs in the Inter-DC EON

- Fig. 1(a) shows an intuitive example on the inter-DC EON, which consists of 6 DCs and has 8 lightpaths. Fig. 1(b) shows a network service that consists of three correlated data-intensive vNF-SCs. The scheme in Fig. 1(c) makes the network service in Fig. 1(b) have an SCT of 13 TS'.

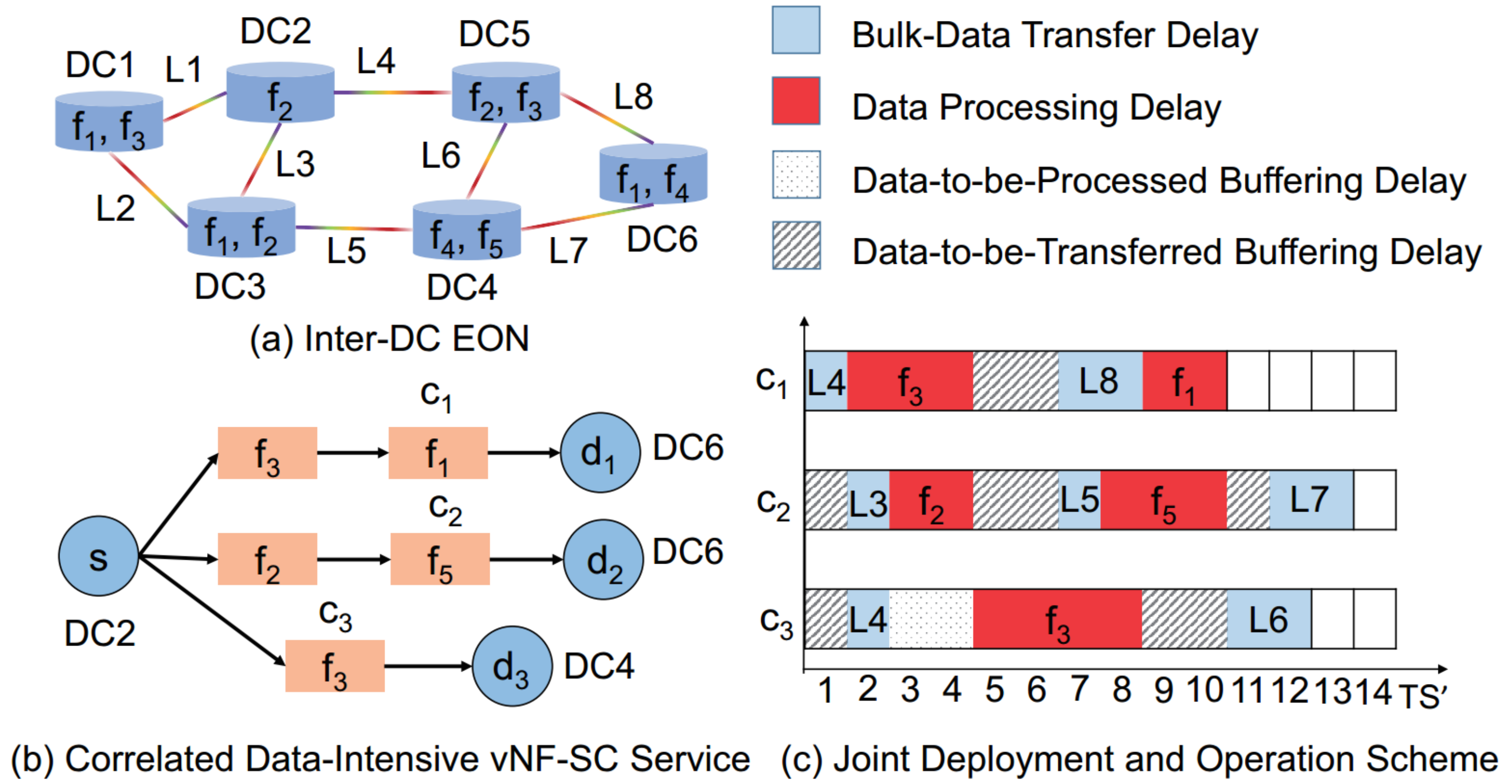

Figure 1: An example of deploying and operating correlated data-intensive vNFSCs in an inter-DC EON.

Latency Definitions

- The SCT of a vNF-SC includes four parts:

1) the total data processing latency in all of its vNFs,
2) the total data transmission latency on all of its lightpaths,
3) the total “data-to-be-processed” buffering delay, and
4) The total “data-to-be-transferred” buffering delay.

Apparently, the first part is constant and cannot be reduced, and hence we should focus on minimizing the remaining three parts.

- The studied problem is NP-hard by reducing any instance of the task scheduling problem into our problem [3].

[3] J. Riera et al., “Virtual network function scheduling: Concept and challenges,” in Proc. of SaCoNeT 2014, pp. 1–5, Jun. 2014.

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DP-based Optimization for Single vNF-SC Branch

- In order to deploy and operate a data-intensive vNF-SC branch, we need

1) select DCs to deploy requested vNFs,
2) schedule computing tasks with available TS' for being processed by the vNFs in selected DCs
3) Schedule bulk-data transfers with 2D fragments on lightpaths to transmit data between adjacent vNFs.

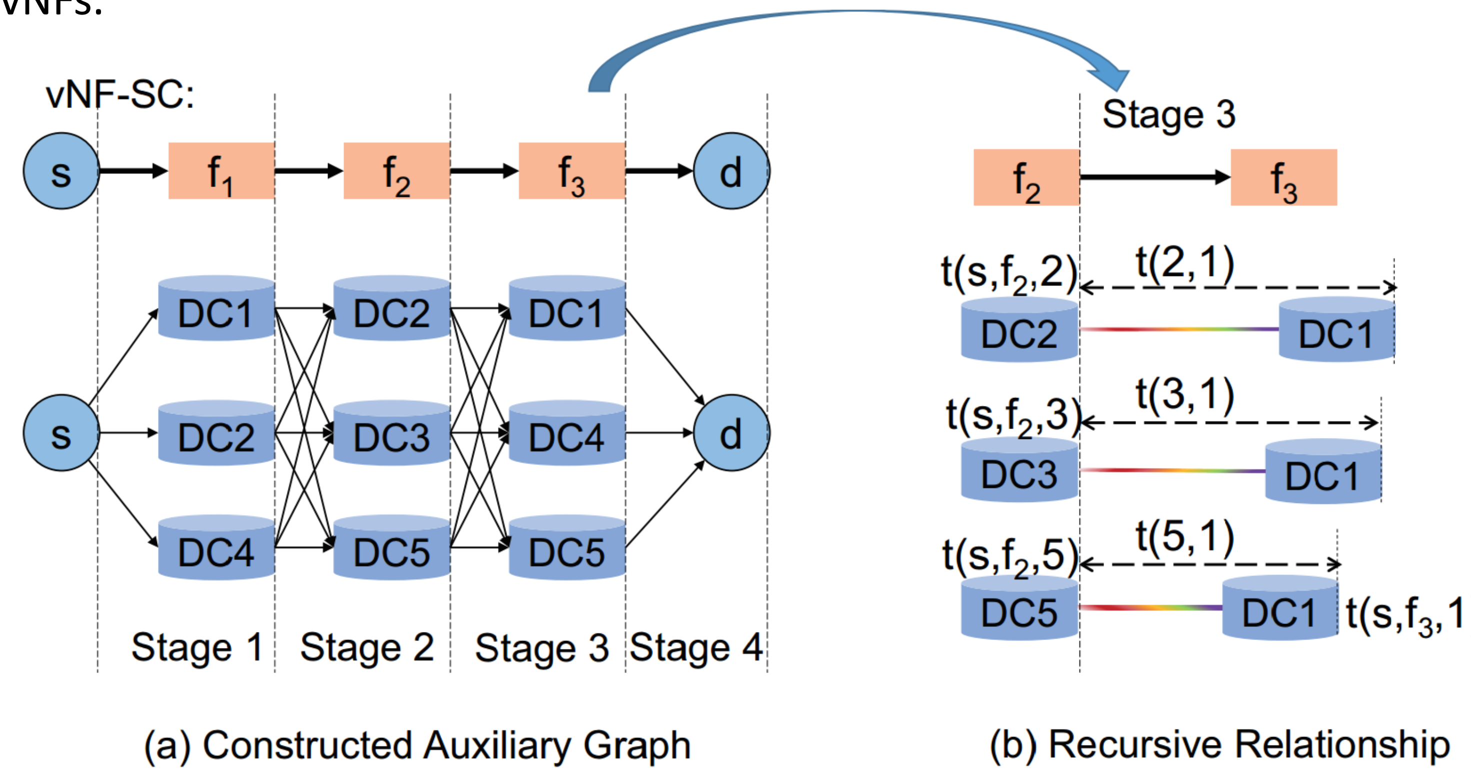

Figure 2: An example of optimizing the deployment and operation of single dataintensive vNF-SC branch with an AG and a DP-based scheme.

Correlation awareness on the optimization

- Based on the proposed DP-based optimization scheme, we propose a correlation-aware service provisioning algorithm to minimize the average SCT of correlated data-intensive vNFSC services.

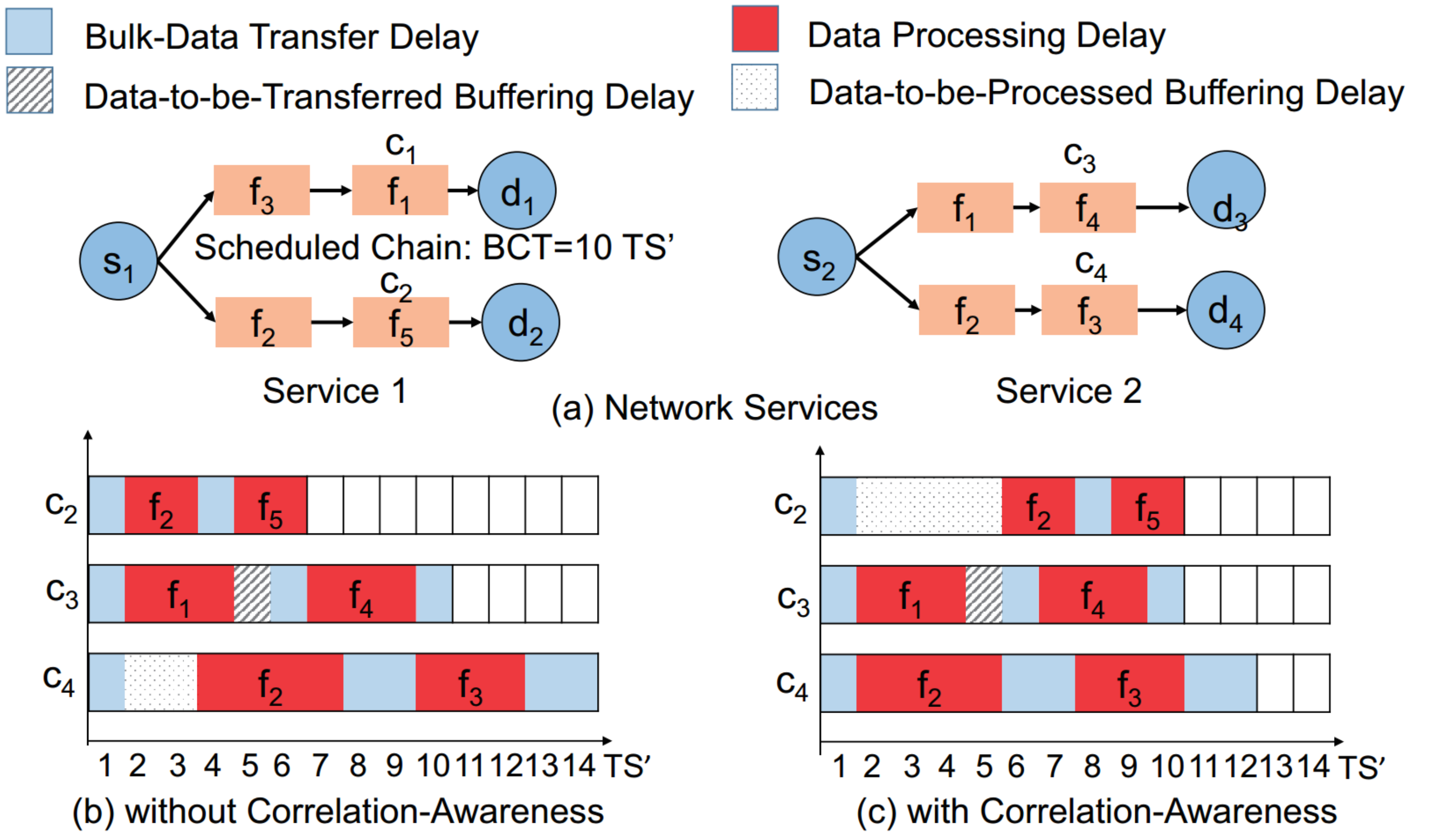

Figure 3: An example of the importance of correlation awareness.

Correlation-aware service Provisioning Algorithm

Algorithm 1: Correlation-Aware Service Provisioning Algorithm with DP-Based Optimization (CASP w/ DP)

$$O(|\widehat{C_p}|^2 \cdot O(DP))$$

while $C_p \neq \emptyset$ **do**
  obtain the latest network status;
  for *each vNF-SC branch in* C_p **do**
    calculate its BCT with the DP-based scheme;
  end
  if $C_p^{dd} \neq \emptyset$ **then**
    select the vNF-SC branch with minimum gap between its BCT and deadline in C_p^{dd};
    if *the minimum gap is smaller than* t_h **then**
      deploy/schedule selected branch in C_p^{dd} with DP;
      update C_p, C_p^{dd} and deadline of branches in C_p^{dd};
    else
      select the branch with the smallest BCT among all the longest branches in C_p^{∞};
      deploy/schedule selected branch in C_p^{∞} with DP;
      update C_p, C_p^{dd}, C_p^{∞}, deadline of branches in C_p^{dd};
    end
  else
    select the branch with the smallest BCT among all the longest branches in C_p^{∞};
    deploy/schedule selected branch in C_p^{∞} with DP;
    update C_p, C_p^{dd}, C_p^{∞}, deadline of branches in C_p^{dd};
  end
end

calculate the BCT for all pending branches

obtains the most urgent branch

Continue to find the urgent branch

Update network

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Simulation Settings

- We evaluate the proposed algorithms with the 14-node NSFNET topology [11]. Here, each node in the topology is a DC node, and between each DC pair, there are [1,2] established lightpaths, each of which has 11 FS'.

- The background traffic occupies the lightpaths' bandwidth dynamically along the time axis and leaves 12.02% and 2.65% on average in the low and high traffic scenarios, respectively. The number of deployed vNFs on each DC is within [2,4] and there are 10 types of vNFs in total.

- In each simulation, the network services are generated dynamically according to the Poisson traffic model. Each of them asks for 3 correlated vNF-SC branches on average, the average number of vNFs in a vNF-SC is 5, and its initial data volume is uniformly distributed within [1,3] FS·TS. The vNFs' processing rates are within [0.56,1.12], and their output-to-input data volume ratios are within [0.7,1.3].

- The threshold t_h in Algorithm 1 is set to 5 TS'. For comparison, we adopt the service provisioning algorithm without correlation awareness (abbreviated as "CISP") as the benchmark.

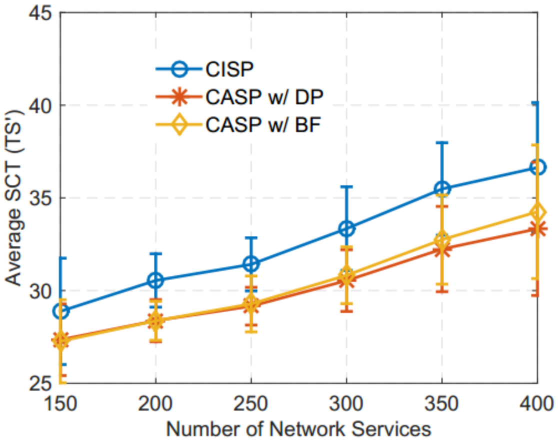
Running Time Results

- **CASP w/ DP**: correlation-aware service provisioning algorithm with DP-based optimization
- **CASP w/ BF**: correlation-aware service provisioning algorithm with feature-based Optimization
- **CISP**: the service provisioning algorithm without correlation awareness

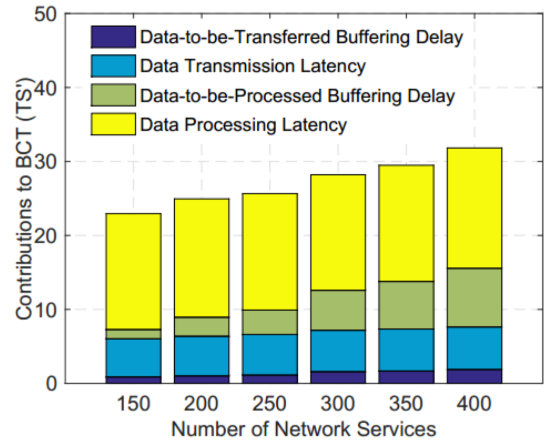
Table I. Running Time per Network Service in low Traffic (Seconds).

# of Network Services	Average Running Time per Network Service		
	CISP	CASP w/ DP	CASP w/ BF
200	0.68	4.64	0.92
300	0.89	7.64	1.23
400	0.98	9.77	1.39

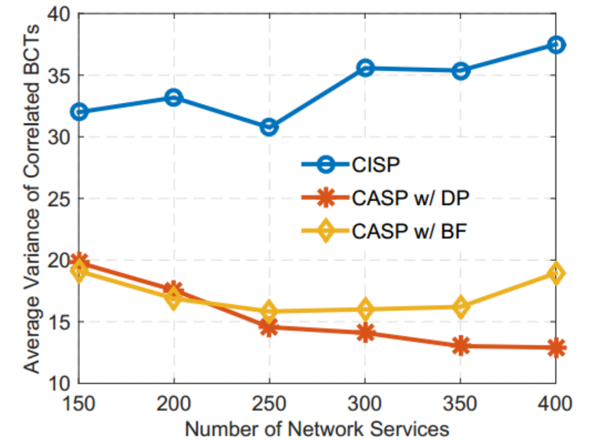
Evaluation Results



(a) Average SCT of network services

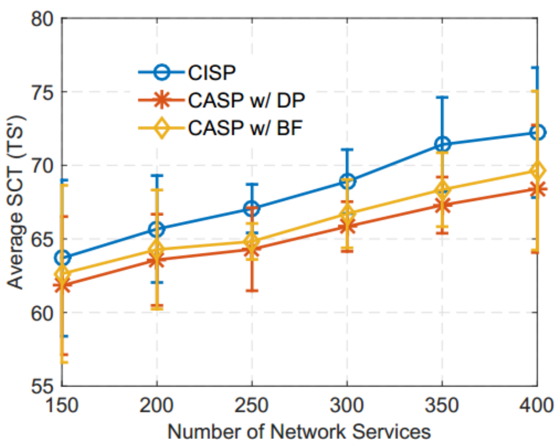


(b) Average BCT of vNF-SC branches

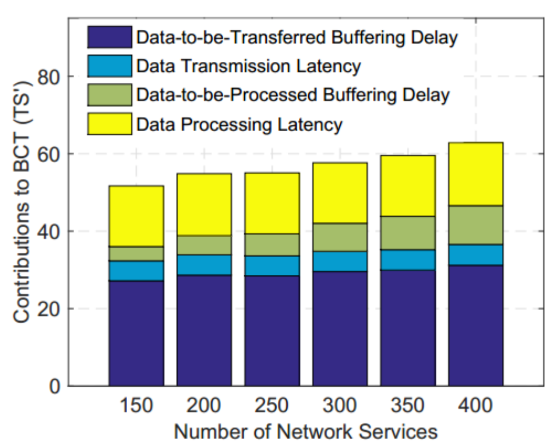


(c) Average variance of correlated BCTs

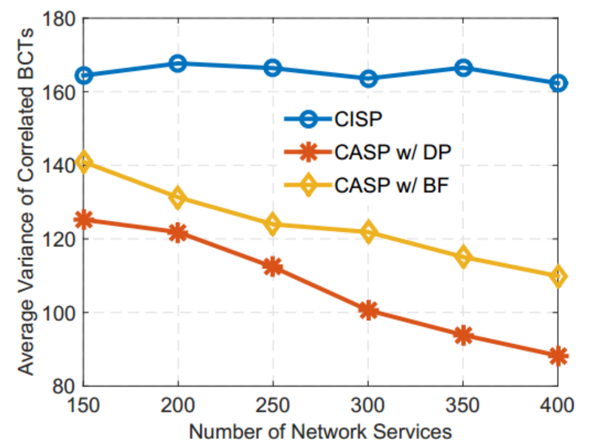
Fig. 4: Results in low background traffic scenario.



(a) Average SCT of network services



(b) Average BCT of vNF-SC branches



(c) Average variance of correlated BCTs

Fig. 5: Results in high background traffic scenario.

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Conclusions

- In this work, we studied how to deploy and operate correlated data-intensive virtual network function-service chain (vNF-SCs) to minimize their average service completion time (SCT).
- We proposed a dynamic programming based optimization scheme and two correlation-aware service provisioning algorithms to minimize the average SCT of network services.
- Simulation results verified that the proposed algorithms can effectively reduce the average SCT of network services.