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Simulation report on our selected paper entitled "A Scalable Approach for Service Chain Mapping With Multiple SC Instances in a Wide-Area Network"

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1 Introduction

Network Function Virtualization (NFV) aims to simplify service deployment using Virtual Network Functions (VNFs). Service deployment involves placement of VNFs and in-sequence routing of traffic flows through VNFs comprising a Service Chain (SC). The joint VNF placement and traffic routing is called SC mapping. In a Wide-Area Network (WAN), where several traffic flows, generated by many distributed node pairs, require the same SC; a single instance (or occurrence) of that SC might not be enough. SC mapping with multiple SC instances for same SC is a very complex problem, since sequential traversal of VNFs has to be maintained while accounting for traffic flows in various directions [1].

1.1 Network Function Virtualization

Traditionally, communication networks have deployed network services through proprietary hardware appliances (e.g., network functions such as firewalls, NAT, etc.) which are statically configured. With rapid evolution of applications, networks require agile and scalable service deployment.

Network Function Virtualization (NFV) [2] offers a solution for an agile service deployment. NFV envisions traditional hardware functionality as software modules called Virtual Network Functions (VNFs). VNFs can be run on commercial-off-the-shelf hardware such as servers and switches in datacenters (DCs), making service deployment agile and scalable.

1.2 Service Chain

When several network functions are configured to provide a service, we have a "Service Chain". The term "service chain" is used "to describe the deployment of such functions, and the network operator's process of specifying an ordered list of service functions that should be applied to a deterministic set of traffic flows". So, a "Service Chain" (SC) specifies a set of network functions configured in a specific order. With NFV, we can form SCs where VNFs are configured in a specific sequence that minimizes the bandwidth usage in the network [3].

In Table 1 we show some well-known Service Chains (SCs).

Service Chains	Chained VNFs
Web Service	NAT-FW-TM-WOC-IDPS
VoIP	NAT-FW-TM-FW-NAT
Video Streaming	NAT-FW-TM-VOC-IDPS
Online Gaming	NAT-FW-VOC-WOC-IDPS

Table 1: Service Chain Requirements; Network Address Translator (NAT), Firewall (FW), Traffic Shaper (TM), WAN Optimization Controller (WOC), Intrusion Detection and Prevention System (IDPS), Video Optimization Controller (VOC).

1.3 Service Chain Mapping Issues

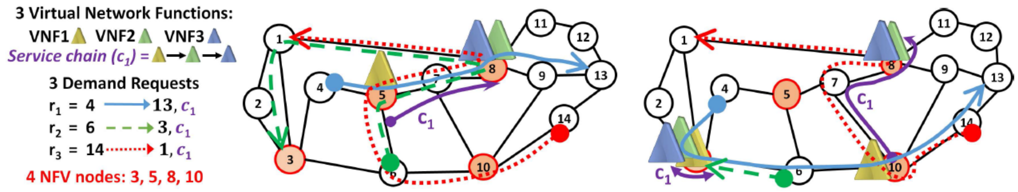
Unfortunately, since VNFs in a single SC may need to be traversed by several distinct traffic flows (i.e., flows requested by multiple geographically-distributed node pairs) in a specific sequence, it becomes difficult to improve network resource utilization.

For example, consider Figure 1(a) and 1(b), where three traffic requests r_1 (from node 4 to 13), r_2 (from node 6 to 3), and r_3 (from node 14 to 1) demand SC c_1 composed of VNF1, VNF2, and VNF3 (to be traversed in this order VNF1$\rightarrow$ VNF2 $\rightarrow$ VNF3).

In Figure 1(a), if we consider only one mapping occurrence (or instance) for SC c_1, then some traffic flows (in our example, r_3 and r_2) will be ineffectively routed over long paths. Instead, as shown in Figure 1(b), if we use two SC instances for the same SC, we can improve network resource utilization, at the expense of a larger number of VNFs to be deployed (or replicated) in the network to serve the same SC. This results in a more complex problem when, in a Wide-Area Network (WAN), a large number of distributed node pairs generate traffic flows, creating heavy traffic demands. Our objective in this work is to reduce the network resource consumption for a WAN with heavy traffic demands.

So the question is: how many SC instances for the same SC are required for optimal network resource utilization?

A possible (trivial) solution to the problem of SC mapping in case of multiple node pairs requiring the same SC is to use one single instance that would most likely lead to host SCs at a single node (e.g., a DC) which is centrally located in the network. However, traffic flows may have to take



(a) One single SC instance mapping: requests r_3 and r_2 take longer paths. All traffic requests get mapped to the single instance.

(b) Two SC instances mapping: requests r_3 and r_2 take shorter paths. Here, each traffic request chooses to map to one of two given instances.

Figure 1: Deploying more SC occurrence mappings reduces network resource consumption.

long paths to reach the node hosting the SC, which will result in a high network resource consumption.

The other extreme case would be to use a distinct SC mapping per node pair (in other words, the number of SC instances is equal to the number of traffic node pairs). Now, we can achieve optimal network resource utilization as each node pair will use an SC effectively mapped along a shortest path in the network. However, this approach will increase the network orchestration overhead and increase capital expenditure, as there will be a large number of replicated VNF instances across nodes. To reduce excessive VNF replication, we bound the maximum number of nodes hosting VNFs.

Intuitively, the number of SC instances for a good solution will be a value between these two extremes. This solution will minimize the network resource utilization while not excessively increasing the number of nodes hosting VNFs [4].

2 System Model and Problem Formulation

An operator's network provides multiple services, and each service is realized by traversing a Service Chain (SC). To provide multiple services, the operator has to map corresponding SCs into network.

2.1 System Model

Given a network topology, capacity of links, a set of network nodes with NFV support (NFV nodes), compute resources at NFV nodes, maximum number of NFV nodes that can be used, traffic flows for source-destination pairs

Notations	Descriptions
G	Physical topology of backbone network $G = (V, L)$ with V: node set and L: link set
V^{NFV}	$\subseteq V$ Set of nodes that can host VNFs (NFV nodes)
I_c	Number of instances for SC c
K	Maximum number of NFV nodes to host VNFs
F	Set of VNFs, indexed by f
R_f	Maximum number of replicas of VNF f
n^{core}	Number of CPU cores present in a NFV node
n_f^{core}	Number of CPU cores per Gbps for function f
C	Set of chains, indexed by c
n_c	Number of VNFs in SC c
SD	Set of source-destination (v_s, v_d) pairs
SD_c	Set of source-destination (v_s, v_d) pairs for SC c
D_{sd}^c	Traffic demand between v_s and v_d for SC c
$\sigma_i(c)$	ID of ith VNF in SC c, where $f_{\sigma_i(c)} \in F$
T_{fi}^c	VNF ID (f) of the ith VNF in SC c

Table 2: Notations Descriptions

requiring a specific SC with a certain bandwidth demand, a set of VNFs, and a set of SCs, we determine the placement of VNFs and corresponding traffic routing to minimize network resource (bandwidth) consumption. Note that VNFs can be shared among different SCs.

Table 3 describes the input parameters used. To facilitate model formulation and discussion, we propose the concept of configuration ($\hat{\gamma}$). We use the following notation for SC representation. Each SC, denoted by c, is characterized by an ordered set of n_c functions:

$$[\text{SC } c] \quad f_{\sigma_1(c)} \prec f_{\sigma_2(c)} \prec \cdots \prec f_{\sigma_{n_c}(c)} \tag{1}$$

Each deployment of SC c is defined by a set of VNF locations, a set of paths, from location of first VNF to location of last VNF, and set of traffic flows traversing this deployment.

We generate a set of *SC configurations* where each configuration ($\hat{\gamma}$) is associated with a potential provisioning of a SC c, i.e., with a potential node placement of its functions and a potential subset of traffic flows from SD_c. Let $\hat{\Gamma}$ be the set of configurations, and $\hat{\Gamma}_c$ be the subset of configurations

Notations	Descriptions
$z_{\hat{\gamma}}$	1 if configuration $\hat{\gamma}$ is selected; 0 otherwise
x_{vf}	1 if function f is located in v; 0 otherwise
$y_{\ell}^{f_1(c),sd}$	1 if ℓ is on path from v_s to location of first VNF in c; 0 otherwise
$y_{\ell}^{f_{n_c}(c),sd}$	1 if ℓ is on path from v_d to location of first VNF in c; 0 otherwise
h_v	1 if v is used as a location for a VNF; 0 otherwise

Table 3: Variables

associated with service chain $c \in C$: $\hat{\Gamma} = \bigcup_{c \in C} \hat{\Gamma}_c$

Potential set of configurations for a SC c is given by:

$$\hat{\Gamma}_c = \sum_{sd=1}^{N_{SD_c}} \binom{N_{SD_c}}{sd} \times \{N_{V^{NFV}}\}^{n_c} \times (P_{paths})^{n_c - 1} \tag{2}$$

where sd is the number of source-destination (v_s, v_d) pairs using a configuration, N_{SD_c} gives the number of source-destination (v_s, v_d) pairs for SC c, $N_{V^{NFV}}$ gives the number of NFV nodes and P_{paths} refers to the number of paths from the location of $f_{\sigma_i(c)}$ to the location of $f_{\sigma_{i+1}(c)}$.

A chain configuration $(\hat{\gamma})$ is characterized by the following parameters:

- Traffic flows: $\delta_{sd}^{\hat{\gamma}} = 1$ if (v_s, v_d) uses configuration $\hat{\gamma}$; 0 otherwise.
- Location of functions: $a_{vi}^{\hat{\gamma}} = 1$ if ith function $f_i \in c$ is located in v in configuration $\hat{\gamma}$; 0 otherwise.
- Connectivity of locations: path from location of current VNF to next VNF in SC c. If link ℓ is used in the path from location of $f_{\sigma_i(c)}$ to location of $f_{\sigma_{i+1}(c)}$, then $b_{il}^{\hat{\gamma}} = 1$; 0 otherwise.

2.2 Problem Formulation to an ILP

We precompute $\hat{\Gamma}$, which is an input for our ILP model. ILP selects the best configuration $(\hat{\gamma})$ based on other input parameters and constraints, and computes the route from v_s (source) to first VNF of c and from last VNF of c to v_d (destination) for each source-destination (v_s, v_d) pair.

Variables: See Table 2.

Objective: Minimize bandwidth consumed:

$$\sum_{c\in C}\sum_{\hat{\gamma}\in\hat{\Gamma}_c} \overbrace{(\sum_{(s,d)\in SD} D^c_{sd})}^{\text{Overall traffic using } c} \qquad \overbrace{(\sum_{\ell\in L}\sum_{i\in I}\delta^{\hat{\gamma}}_{sd} b^{\hat{\gamma}}_{i\ell})}^{\text{Number of links on the route of } c} \qquad z_{\hat{\gamma}} \\ +\sum_{c\in C}\sum_{\ell\in L}\sum_{(s,d)\in SD} D^c_{sd}(y^{f_1(c),sd}_{\ell} + y^{f_{n_c}(c),sd}_{\ell}) \tag{3}$$

Total bandwidth consumed in placing multiple SCs depends on configurations ($\hat{\gamma}$'s) selected for each SC c. Each $\hat{\gamma}$ for c locates VNFs of c and gives the route to traverse these VNF locations. So, bandwidth consumed when going from v_s to v_d and traversing the SC depends on selected $\hat{\gamma}$. Bandwidth consumed depends on the number of links, i.e., number of hops in path from v_s to v_d.

Constraints:

$$\sum_{\hat{\gamma}\in\hat{\Gamma}_c} z_{\hat{\gamma}} \leq I_c \qquad c\in C \tag{4}$$

$$\sum_{c\in C}\sum_{\hat{\gamma}\in\hat{\Gamma}_c}\sum_{i=1}^{n_c} T^c_{fi} a^{\hat{\gamma}}_{vi} z_{\hat{\gamma}} \leq M x_{vf} \qquad f\in F, v\in V^{NFV} \tag{5}$$

$$\sum_{c\in C}\sum_{\hat{\gamma}\in\hat{\Gamma}_c}\sum_{i=1}^{n_c} T^c_{fi} a^{\hat{\gamma}}_{vi} z_{\hat{\gamma}} \geq x_{vf} \qquad f\in F, v\in V^{NFV} \tag{6}$$

$$\sum_{v\in V^{NFV}} x_{vf} \leq R_f \qquad f\in F \tag{7}$$

$$M h_v \geq \sum_{f\in F} x_{vf} \geq h_v \qquad v\in V^{NFV} \tag{8}$$

$$\sum_{v\in V^{NFV}} h_v \leq K \tag{9}$$

$$\sum_{c\in C}\sum_{\hat{\gamma}\in\hat{\Gamma}_c}\sum_{(v_s,v_d)\in SD} D^c_{sd}\delta^{\hat{\gamma}}_{sd} \times (\sum_{f\in F}\sum_{i=1}^{n_c} T^c_{fi} n^{CORE}_f a^{\hat{\gamma}}_{vi}) z_{\hat{\gamma}} \leq N^{CORE} \qquad v\in V_{NFV} \tag{10}$$

$$\sum_{c\in C}\sum_{(v_s,v_d)\in SD} D^c_{sd} \times (y^{f_1(c),sd}_{\ell} + y^{f_{n_c}(c),sd}_{\ell} + \sum_{\hat{\gamma}\in\hat{\Gamma}_c}\delta^{\hat{\gamma}}_{sd} z_{\hat{\gamma}} \sum_{i=1}^{n_c-1} b^{\hat{\gamma}}_{i\ell}) \leq CAP_{\ell} \qquad \ell\in L \tag{11}$$

$$\sum_{\hat{\gamma} \in \hat{\Gamma}_c} \delta_{sd}^{\hat{\gamma}} z_{\hat{\gamma}} = 1 \qquad c \in C, (v_s, v_d) \in SD : D_{sd}^c > 0 \tag{12}$$

Constraints (4) guarantee that we select exactly I_c configurations for SC c and force c to have I_c instances. Each $\hat{\gamma}$ is associated with a set of $a_{vi}^{\hat{\gamma}}$ required to be consistent with $x_v f$, which is resolved by Eqs. (4), (5) where T_c^{fi} is to find the VNF f at sequence i in SC c. Eq. (6) is used to limit the number of VNF replicas. Eq. (7) is used to keep track of NFV nodes used for hosting VNFs while Eq. (8) limits the number of NFV nodes allowed to host VNFs. Constraints (9) ensure that each NFV node has a sufficient number of CPU cores for hosting f. Eq. (10) constrains link capacity. Eq. (11) enforces that, for each source-destination pair (v_s, v_d) requesting SC c, there is exactly one configuration $\hat{\gamma}$.

Route from v_s to first function location:

$$\sum_{\hat{\gamma} \in \hat{\Gamma}_c} \delta_{sd}^{\hat{\gamma}} a_{v_s,1}^{\hat{\gamma}} z_{\hat{\gamma}} + \sum_{\ell \in \omega^+(v_s)} y_\ell^{f_1(c),sd} = 1 \qquad c \in C, (v_s, v_d) \in SD : D_{sd}^c > 0 \tag{13}$$

$$\begin{gathered} \sum_{\hat{\gamma} \in \hat{\Gamma}_c} \delta_{sd}^{\hat{\gamma}} a_1^{\hat{\gamma}} z_{\hat{\gamma}} - \sum_{\ell \in \omega^-(v)} y_\ell^{f_1(c),sd} \leq 0 \\ c \in C, (v_s, v_d) \in SD : D_{sd}^c > 0 \quad v \in V^{NFV} \setminus \{v_s\} \end{gathered} \tag{14}$$

$$\begin{gathered} \sum_{\hat{\gamma} \in \hat{\Gamma}_c} \delta_{sd}^{\hat{\gamma}} a_1^{\hat{\gamma}} z_{\hat{\gamma}} + \sum_{\ell \in \omega^+(v)} y_\ell^{f_1(c),sd} - \sum_{\ell \in \omega^-(v)} y_\ell^{f_1(c),sd} = 0 \\ c \in C, (v_s, v_d) \in SD : D_{sd}^c > 0, \quad v \in V^{NFV} \setminus \{v_s\} \end{gathered} \tag{15}$$

$$\begin{gathered} \sum_{\ell \in \omega^+(v)} y_\ell^{f_1(c),sd} - \sum_{\ell \in \omega^-(v)} y_\ell^{f_1(c),sd} = 0 \\ c \in C, (v_s, v_d) \in SD : D_{sd}^c > 0, \quad v \in V \setminus (V^{NFV} \cup \{v_s\}) \end{gathered} \tag{16}$$

We assume that a unique route exists from v_s to first VNF location. This is imposed by selecting exactly one outgoing link from v_s unless first VNF is located at v_s. We account for these scenarios using Eq. (13). To find the route from v_s to first VNF, flow conservation needs to be enforced at the intermediate nodes which may or may not have NFV support. Eqs. (14) and (15) enforce flow-conservation constraints at nodes with and without NFV support, respectively.

Route from last function location to v_d:

$$\sum_{\hat{\gamma} \in \hat{\Gamma}_c} \delta_{sd}^{\hat{\gamma}} a_{v_d,n_c}^{\hat{\gamma}} z_{\hat{\gamma}} + \sum_{\ell \in \omega^-(v_d)} y_\ell^{f_{n_c}(c),sd} = 1 c \in C, (v_s, v_d) \in SD : D_{sd}^c > 0 \tag{17}$$

$$\sum_{\hat{\gamma} \in \hat{\Gamma}_c} \delta_{sd}^{\hat{\gamma}} a_{v_d,n_c}^{\hat{\gamma}} z_{\hat{\gamma}} - \sum_{\ell \in \omega^+(v)} y_\ell^{f_{n_c}(c),sd} \leq 0$$
$$c \in C, (v_s, v_d) \in SD : D_{sd}^c > 0, v \in V^{NFV} \backslash \{v_d\} \tag{18}$$

$$\sum_{\hat{\gamma} \in \hat{\Gamma}_c} \delta_{sd}^{\hat{\gamma}} a_{v_d,n_c}^{\hat{\gamma}} z_{\hat{\gamma}} - \sum_{\ell \in \omega^+(v)} y_\ell^{f_{n_c}(c),sd} + \sum_{\ell \in \omega^-(v)} y_\ell^{f_{n_c}(c),sd} = 0$$
$$c \in C, (v_s, v_d) \in SD : D_{sd}^c > 0, v \in V^{NFV} \backslash \{v_d\} \tag{19}$$

$$\sum_{\ell \in \omega^+(v)} y_\ell^{f_{n_c}(c),sd} + \sum_{\ell \in \omega^-(v)} y_\ell^{f_{n_c}(c),sd} = 0$$
$$c \in C, (v_s, v_d) \in SD : D_{sd}^c > 0, v \in V^{NFV} \backslash \{v_d\} \tag{20}$$

Eq. (17) selects one incoming link to v_d to ensure a route to v_d. For cases where last VNF is placed at destination node, we use Eq. (18). Eqs. (19) and (20) enforce flow conservation at nodes with and without NFV support, respectively.

3 Simulation

3.1 Simulation Parameters Declaration

We tested our optimization process on a 14-node NSFNET WAN topology as shown in Figure 2. To simplify the simulation, we considered a traffic matrix which consists of 5 demands with just one type of Service Chain (Refer to Table 4). Just 4 nodes can be made NFV nodes. The link capacities are 1Tbps. Each traffic flow demand is 1 Gbps. Compute resource (CPU) at each NFV node is 100 cores per node. All other simulation parameters are shown in Table 5.

3.1.1 Precompution Step

As we have stated in previous Section we should precompute $\hat{\Gamma}$, which is an input for our ILP model. Then ILP selects the best configuration ($\hat{\gamma}$) based on other input parameters and constraints. We map all network nodes which are the name of States in USA (Refer to Figure 2) to a number which is shown in Table 6. Table 7 shows 10 different configurations ($\hat{\gamma}$) which we have computed manually.

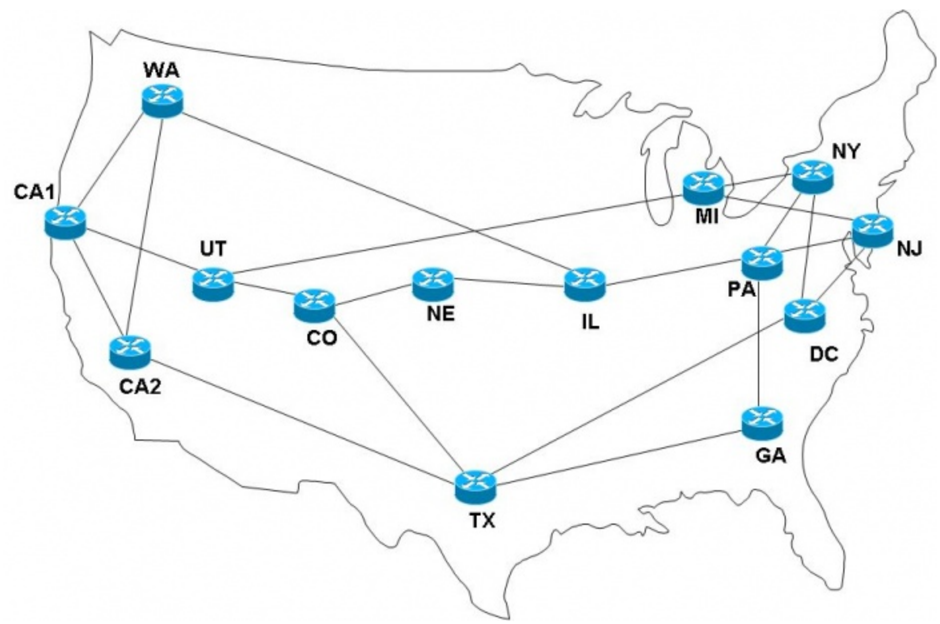


Figure 2: 14-node NSFNET WAN topology.

Number	Source	Destination	Demanded SC	Bandwidth
1	Washington	NewJersey	Web Service	$1Gbps$
2	Texas	Michigan	Web Service	$1Gbps$
3	WashingtonDC	Washington	Web Service	$1Gbps$
4	California2	Michigan	Web Service	$1Gbps$
5	California1	NewYork	Web Service	$1Gbps$

Table 4: Traffic demands (D^c_{sd})

3.2 Rewriting the ILP

In this subsection we put the parameters into the optimization problem as follows:

$$\begin{aligned} 60z_{\gamma_1} + 60z_{\gamma_2} + 70z_{\gamma_3} + 35z_{\gamma_4} + 70z_{\gamma_5} + 140z_{\gamma_6} + 120z_{\gamma_7} + 140z_{\gamma_8} \\ +150z_{\gamma_9} + 140z_{\gamma_{10}} \end{aligned} \tag{21}$$

$$z_{\gamma_1} + z_{\gamma_2} + z_{\gamma_3} + z_{\gamma_4} + z_{\gamma_5} + z_{\gamma_6} + z_{\gamma_7} + z_{\gamma_8} + z_{\gamma_9} + z_{\gamma_{10}} \leq 4 \tag{22}$$

Parameter	Value
G	It is shown in Figure 2
V^{NFV}	All nodes can be NFV node
I_c	4
K	4
F	{NAT, FW, TM, WOC, IDPS}
R_f	2
n^{core}	100
n_f^{core}	[1 1 1 1 1]
C	{Web Service }
n_c	5
SD	It is shown in Table 4
SD_c	It is shown in Table 4
D_{sd}^c	It is shown in Table 4
$\sigma_i(c)$	ID of ith VNF in SC c, where $f_{\sigma_i(c)} \in F$
T_{fi}^c	VNF ID (f) of the ith VNF in SC c

Table 5: Simulation Parameters

State	Number
Washington	1
California1	2
California2	3
Utah	4
Colorado	5
Utah	6
Texas	7
Nebraska	8
Illinois	9
Pennsylvania	10
Georgia	11
NewYork	12
NewJersey	13
WashingtonDC	14

Table 6: Each USA State and its corresponding number

Number	Configuration
1st	$3(f_1, f_2) \to 6 \to 5(f_3) \to 7 \to 8(f_4) \to 9 \to 10(f_5)$
2nd	$3(f_1) \to 6 \to 10(f_2, f_3) \to 9 \to 8(f_4) \to 7 \to 5(f_5)$
3rd	$3(f_1) \to 2 \to 4 \to 5(f_2, f_3) \to 7 \to 8(f_4) \to 9 \to 10(f_5)$
4th	$8(f_1) \to 7 \to 5(f_2) \to 4 \to 2 \to 3(f_3, f_4) \to 6 \to 10(f_5)$
5th	$10(f_1) \to 9 \to 8(f_2) \to 7 \to 5(f_3) \to 4 \to 2 \to 3(f_4, f_5)$
6th	$5(f_1, f_2) \to 4 \to 2 \to 3(f_3) \to 6 \to 10(f_4) \to 9 \to 8(f_5)$
7th	$5(f_1, f_2) \to 6 \to 10(f_3) \to 9 \to \underline{8}(f_4) \to 1 \to 3(f_5)$
8th	$10(f_1) \to 6 \to 3(f_2) \to 2 \to 4 \to 5(f_3, f_4) \to 7 \to 8(f_5)$
9th	$8(f_1) \to 1 \to 2 \to 3(f_2, f_3) \to 6 \to 10(f_4) \to 9 \to 12 \to 11 \to 4 \to 5(f_5)$
10th	$3(f_1, f_2) \to 2 \to 1 \to 8(f_3) \to 7 \to 5(f_4) \to 6 \to 10(f_5)$

Table 7: 10 different configurations

$$z_{\gamma_1} + z_{\gamma_2} + z_{\gamma_3} - 5x_{v_3 f_1} \leq 0 \tag{23}$$

$$z_{\gamma_1} + z_{\gamma_8} + z_{\gamma_9} + z_{\gamma_{10}} - 5x_{v_3 f_2} \leq 0 \tag{24}$$

$$z_{\gamma_4} + z_{\gamma_6} + z_{\gamma_9} + z_{\gamma_{10}} - 5x_{v_3 f_3} \leq 0 \tag{25}$$

$$z_{\gamma_4} + z_{\gamma_5} - 5x_{v_3 f_3} \leq 0 \tag{26}$$

$$z_{\gamma_5} + z_{\gamma_7} - 5x_{v_3 f_4} \leq 0 \tag{27}$$

$$z_{\gamma_6} + z_{\gamma_7} - 5x_{v_5 f_2} \leq 0 \tag{28}$$

$$z_{\gamma_3} + z_{\gamma_4} + z_{\gamma_6} + z_{\gamma_7} - 5x_{v_5 f_3} \leq 0 \tag{29}$$

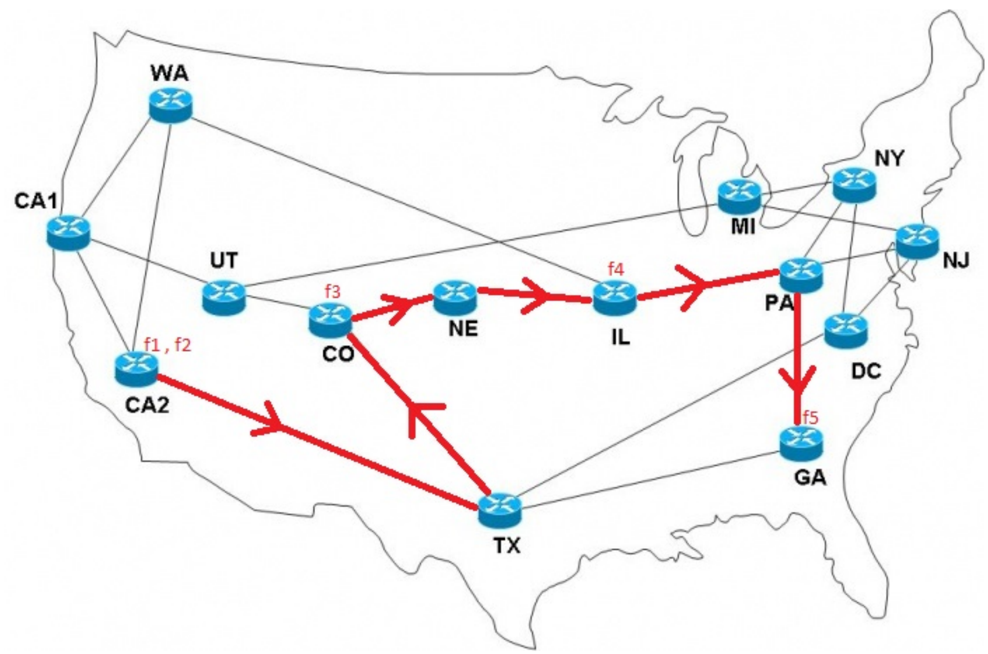


Figure 3: One of the route and placement.

$$z_{\gamma_1} + z_{\gamma_3} + z_{\gamma_4} + z_{\gamma_7} - 5x_{v_5 f_4} \leq 0 \tag{30}$$

We have 180 inequality, and we have stated some of them as above. Now we write some of the equality constraints:

$$z_{\gamma_1} + z_{\gamma_2} + z_{\gamma_6} + z_{\gamma_7} + z_{\gamma_8} + z_{\gamma_{10}} = 1 \tag{31}$$

$$z_{\gamma_2} + z_{\gamma_3} + z_{\gamma_4} + z_{\gamma_5} + z_{\gamma_6} + z_{\gamma_7} + z_{\gamma_9} + z_{\gamma_{10}} = 1 \tag{32}$$

$$z_{\gamma_3} + z_{\gamma_6} + z_{\gamma_7} + z_{\gamma_8} + z_{\gamma_9} + z_{\gamma_{10}} = 1 \tag{33}$$

$$z_{\gamma_3} + z_{\gamma_5} + z_{\gamma_6} + z_{\gamma_7} + z_{\gamma_8} + z_{\gamma_9} = 1 \tag{34}$$

Solving this ILP optimization problem with the help of *intlinprog* command in MATLAB, gives the route and placement of each demand. Figure 3 visualizes one of the optimal topology of the demands.

4 Conclusion

We have solved the ILP problem with help of Matlab.We choose ten topologies and found optimal route and placement among of them by means of ILP solver in MATLAB. The MATLAB code is available in *MATLAB* folder.

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