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Study of OSPF Routing Optimization among Forwarding Elements in the ForCES Router

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Abstract: The router based on ForCES (Forwarding and Control Elements Separation) architecture could satisfy the requirements of openness, scalability and programmability for the next generation routers, so it attracted much attention. The router is composed by Control Elements (CEs) and Forwarding Elements (FEs). This study focuses on the Smart-OSPF (Open Shortest Path First) routing among FEs. Smart-OSPF contains two steps. In the first step, the source FE forwards the traffic to the neighbor FEs. In the second step, the neighbor FEs use the OSPF protocol to forward the traffic to the destination FE. The OSPF protocol in the second step only forwards traffic using the shortest path, even if the path is congested, the traffic will not be switched to other paths. For improving Smart-OSPF, firstly, the study proposes an improved scheme called W-S-OSPF, in which, there will be multiple paths from the neighbor FEs to the destination FE. Secondly, the study builds the optimization model, which optimizes the maximum link utilization between FEs, so that, the congestion will also be reduced. Finally, according to experiment results, W-S-OSPF could improve 20-55% in the maximum utilization of the link. The study provides a foundation for ForCES router performance research.

Key words: Forwarding and control elements separation, open shortest path first, smart-OSPF, weight-smart-OSPF, model

INTRODUCTION

With the increasing and changing of internet traffic, it needs a new network architecture which is flexible enough to respond quickly to new business and demands. The technology of Forwarding and Control Elements Separation (ForCES) can meet the above requirements, so it has been extensively studied currently. IETF has established specifically ForCES Working Group (Droz, 2012) for manipulation. Figure 1 shows the typical structure of ForCES (Wang *et al*., 2010), which complies with the ForCES Framework defined in RFC 3746. In ForCES architecture, there were one primary CE and some redundant CEs for system high availability purpose. There are multiple FEs (may be up to hundreds of FEs for core routers), which are separated from CEs. The interface between CE and FE is standardized and the CE is responsible for the management of FEs by using the ForCES protocol (Doria *et al*., 2010). There are probably various topologies among FEs and OSPF (Open Shortest Path First) (Moy, 1998) can be used to routing among FEs, as the OSPF protocol is popular and simple.

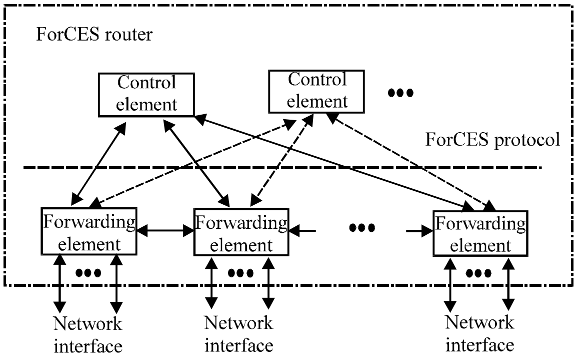

Fig. 1: Typical architecture of a ForCES router

There are a lot of research for improving OSPF. Smart-OSPF (Mishra and Sahoo, 2007) is one of important improvements on OSPF, there are two steps in Smart-OSPF. In the first step, the source FE forwards the traffic to the neighbor Fes. In the second step, the neighbor FEs uses the OSPF protocol to forward the traffic to the destination FE, but the OSPF protocol in the second step only forwards traffic using a single shortest path, even if other paths are also free. In order to avoid this situation, this study used link weight optimization method based on Equal-Cost Multipath

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Routing (ECMP) (Thaler and Hopps, 2000) to improve the OSPF protocol in the second step.

The OSPF protocol has been recognized as one of the most important routing protocols in TCP/IP networks. Generally, the shortest path in OSPF is measured by routing metrics, which are the criterion to choose the optimal path. The routing metrics in OSPF are the link capacity (i.e., the link bandwidth) and the actual flow in the link, it refers to the literature (Cisco Systems Inc., 2000).

Traditional OSPF protocol forwards flow only by calculating the shortest path. In fact, if non-shortest path can share the load with the shortest path, the network congestion can be probably avoided. In recent years, some researchers have been trying to develop non-shortest path routing protocols in order to increase the routing flexibility (Wang *et al*., 2001). Two-phase routing (Altin *et al*., 2010) and ECMP are two typical improvement methods of OSPF:

- In the two-phase routing, when a packet arrives at the source router and intermediate routers is determined, the packet is forwarded from the source router to the intermediate routers. Next it is forwarded from the intermediate routers to the destination router, load balanced is made by intermediate routers. A combination of the shortest path and non-shortest path overcomes the shortcomings of the OSPF protocol. Smart-OSPF (S-OSPF) is a special two-phase routing, in which the packet is forwarded only from the source router to the neighbor routers in the first phase
- In ECMP, the traffic must be evenly distributed by all paths to the destination node. Figure 2 shows that two black spots denote the source router and destination router respectively. Symbol (c,w,l) on the link represents the link capacity, weights and traffic load. $U^{max} = max_{a\in E}$ (la/ca) represents the network maximum congestion ratio (or called the maximum link utilization ratio). Figure 2a shows that there is the unique shortest path (dash line) from the source router to the destination router. There are four units of flow in the network, so the four units of flow only could be transported on the unique shortest path, although, the other paths are idle. In this case, the maximum link utilization ratio is 4/5 = 80%. Figure 2b shows the link weight has nothing to do with the link capacity, all link weight values are set to 1, so there are three equivalent paths (dash line) from the source router to destination router. In this case, all links in the network have traffic load and the maximum link utilization rate is smaller than (a), it is 60% = 3/5. So, the suitable link weight coupled with ECMP can effectively improve the load balance in the network

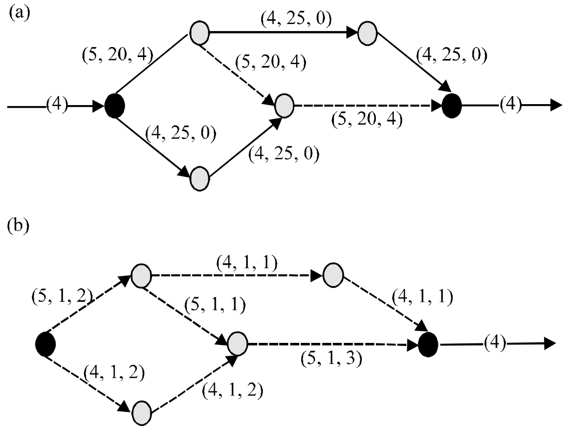

Fig. 2(a-b): Brief description of ECMP, (a) Unique shortest path and (b) Three equivalent paths

The load balance in the network can be improved using routing optimization method. OSPF routing optimization problems in FEs are discussed often under a given requirements and network topology. Literatures (Kodialam *et al*., 2007, 2011a, b; Belotti and Pinar, 2008) studied generally oblivious routing problem, in which, an iterative path-based algorithm is used. Literature (Pioro *et al*., 2002) dealt with flow allocation problems in IP networks using OSPF routing, its main purpose discussed methods for finding settlements of OSPF link weight system realizing the assumed demand pattern for the given network resources (links capacities). Xu *et al*. (2011) and Oki and Iwaki (2010) studied the weight management of OSPF routing. The following will introduce OSPF routing optimization scheme among FEs in the ForCES router.

OSPF ROUTING OPTIMIZATION SCHEME

Choice of objective function: The objective function choice of the optimization model is important. To minimize the average delay function can be used as the objective function, the fairness, the throughput, the balance and the network utilization also can be used as the objective function. Fairness and throughput are flow-oriented objectives, while balance and network utilization are resource-oriented objectives. Fortz and Thorup (2000) proposed a linear cost function as the objective function and the cost is convex function of network utilization.

The study chose to minimize the maximum link utilization as the objective function, rather than select the cost function. Because the goal of this study is to maximum link utilization and reduces congestion, the objective function is appropriate. If our goal is to ensure the delay, we should choose the average delay as the objective function.

Optimization model of S-OSPF: In S-OSPF, only source edge nodes distribute traffic to the neighbor nodes, where optimum traffic distribution ratios are obtained by solving a Linear Programming (LP) problem. After the traffic reaches the neighbor nodes, it is routed according the OSPF protocol. The study used a directed graph G = (V, E) to represent a network, where V represents the set of nodes, E is the set of the links. $Q \subseteq V$ represents the set of the edge nodes. Traffic flows into the network through these nodes. $(i, j) \in E$ represents the link from node i to node j. These following are the variables and parameters used in the S-OSPF model:

r = The maximum link utilization

d_{st} = The traffic demand of from node $s \in Q$ to node $t \in Q$

C_{ij} = The capacity of link $(i, j) \in E$

f_{ij}^{st} = The flow variable denoting the total amount of flow through the link $(i, j) \in E$ for traffic demand d_{st}

θ_{ij} = The weight of the link $(i, j) \in E$, which are integer and vary between 1 and Θ_{max}, which equals 65535

y_{ij}^{st} = A binary variable, which has the value "1" if the link $(i, j) \in E$ is on the shortest path from the node s to the node t

ρ_j^t = The shortest path distance from node j to node t according to the metric defined by the variable θ_{ij}.

$OSPF_{nexthop}{}^{st}_{y}$ = The next node of node y on the shortest path from node s to node t

$OSPF_{ancestor}{}^{st}_{y}$ = The ancestor node of node y on the shortest path from node s to node t

$TM = [d_{st}]_{(s,t) \in Q}$ = The traffic matrix

The traffic matrix $TM = [d_{st}]_{(s,t) \in Q}$ is given and each link capacity is also given. The maximum link utilization will be obtained by solving the following S-OSPF model:

$$\sum_{z:(y,z) \in E, z \neq OSPF_{ancestor}{}^{st}_{y}} f_{yz}^{st} = 1, \forall s, t \in Q, y = s \tag{1}$$

$$\begin{cases} \sum_{x:(x,y) \in E} f_{xy}^{st} - f_{yz}^{st} = 0, \forall s, t \in Q, y \in V, y \neq s \neq t \\ z = OSPF_{nexthop}{}^{yt}_{y} \end{cases} \tag{2}$$

$$\sum_{x:(x,y) \in E} f_{xy}^{st} = 1, \forall s, t \in Q, y = t \tag{3}$$

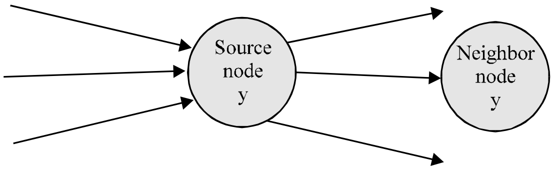

Fig. 3: Flow conservation of the source node

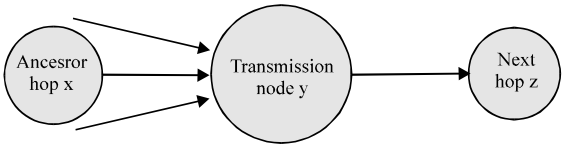

Fig. 4: Flow conservation of transmission node

$$\sum_{s,t \in Q} d_{st} f_{xy}^{st} \leq c_{ij} r, \forall s, t \in Q, (i, j) \in E \tag{4}$$

$$0 \leq f_{ij}^{st} \leq 1, \forall s, t \in Q, (i, j) \in E \tag{5}$$

The objective function is r for minimizing the maximum link utilization. Equation 1-3 are the constraints of flow conservation.

Figure 3 shows that the total output traffic ratio from the source node y (= s) is 1 and the traffic will flow into the neighbor nodes z ($\neq OSPF_{ancestor}{}^{st}_{y}$). It does not include the ancestor node, otherwise it will form a loop. This idea is shown in Eq. 1.

Figure 4 shows that the transmission node y ($\neq$s, t) (which is neither the source node nor the destination node) has a single output link. The next hop node is z (= $OSPF_{nexthop}{}^{st}_{y}$) according to the OSPF protocol. Equation 2 represents the network flow to the transmission node y zero according to flow conservation.

Weight-smart-OSPF (W-S-OSPF): S-OSPF is a special Two-Phase Routing (TPR). Because there are usually fewer neighbor nodes than intermediate nodes in the network, the implementation of S-OSPF is simpler than other TPRs. The study will improve S-OSPF by changing the second phase of S-OSPF. The improved S-OSPF is called W-S-OSPF (Weight-smart-OSPF), in which each link sets a reasonable weight value and there will be multiple paths from the neighbor to the destination node. In W-S-OSPF, more than one path can undertake traffic load, so load balancing can be achieved to some extent. The following is the W-S-OSPF algorithm and its mathematical model.

Algorithm W-S-OSPF:

Step 1: Source edge nodes distribute traffic to the neighbor nodes

Step 2: This study will get suitable link weigh value by solving the linear programming model of W-S-OSPF, there will be many paths between the neighbor nodes and the destination nodes to reduce congestion. If this study don't get the suitable link weigh value, then stop

Step 3: According to the link weigh value, the neighbor nodes distribute traffic to the destination nodes

Step 4: It will get the maximum link utilization

Min r:

$$\sum_{z(y,z)\in E,\, z\neq OSPF_{ancestor}{}^{st}{}_{y}} f^{st}_{yz}=1,\forall s,t\in Q, y=s \tag{6}$$

$$\sum_{x(x,y)\in E} f^{st}_{xy}-\sum_{y(y,z)\in E} f^{st}_{yz})=0,\forall s,t\in Q, y\in V, y\neq s, y\neq t \tag{7}$$

$$\sum_{x(x,y)\in E} f^{st}_{xy}=1,\forall s,t\in Q, y=t \tag{8}$$

$$\sum_{s,t\in Q} d_{st} f^{st}_{ij}\leq c_{ij} r,\ \forall s,t\in Q,(i,j)\in E \tag{9}$$

$$0\leq f^{st}_{ij}\leq 1,\forall s,t\in Q,(i,j)\in E \tag{10}$$

$$f^{st}_{ij}\leq y^{st}_{ij},\forall s,t\in Q,(i,j)\in E, i\neq s \tag{11}$$

$$y^{st}_{ij}+\rho^{t}_{j}-\rho^{t}_{i}+\theta\geq 1,\forall (i,j)\in E,(s,t)\in Q, i\neq s \tag{12}$$

$$-y^{st}_{ij}-\frac{\rho^{t}_{j}-\rho^{t}_{j}+\theta_{ij}}{2\Theta_{max}}\geq -1,\forall (i,j)\in E,(s,t)\in Q, i\neq s \tag{13}$$

$$f^{st}_{ij}\leq \varphi^{st}_{i},\forall (i,j)\in E,(s,t)\in Q, i\neq s \tag{14}$$

$$1+f^{st}_{ij}-\varphi^{st}_{i},\geq y^{st}_{ij},\ \forall (i,j)\in E,(s,t)\in Q, i\neq s \tag{15}$$

$$1\leq \theta_{ij}\leq \Theta_{max,}\ \text{integer}\forall (i,j)\in E \tag{16}$$

$$y^{st}_{ij}\in\{0,1\},\forall (i,j)\in E, s,t\in Q \tag{17}$$

$$0\leq \varphi^{st}_{i}\leq 1,\forall (i,j)\in E, s,t\in Q \tag{18}$$

Similarly, it assumes that traffic matrix TM = $[d_{st}]_{(s,\,t)\in Q}$ is known and each link capacity is also given. Equation 6, 7 and 8 are also the constraints of flow conservation.

Equation 7 shows that the neighbor node x may have many output paths (next node z is uncertain), the shortest path is not the only one, the routing is determined by an unknown link weight.

Constrain (9) is the link capacity bounds. In OSPF routing, constrain (11) makes sure all of flows to occur only on the shortest path.

OSPF mathematical formulas are described as constraints (12) and (13). ρ^{t}_{j}-ρ^{t}_{j}+$\theta_{ij}\geq$ 0 can be obtained from (12), if the link (i, j) is the shortest path, which means y^{st}_{ij} = 1. Constrain (13) is used to ensure ρ^{t}_{i}+θ_{ij}-ρ^{t}_{j} = 0, which means when the link (i, j) is the shortest path from the node s to the node t.

ECMP rules are described by the following constraints (14) and (15). f^{st}_{ij}-$\varphi^{st}_{i}\leq 0$ can be obtained from (14), if the link (i, j) is on the shortest path from the node s to the node t, which means y^{st}_{ij} = 1. Constraint (15) is used to ensure f^{st}_{ij}-φ^{st}_{i} = 0, which means that the total output flow of node i is shared evenly by all shortest paths from node i to t.

The values of other variables constraints are 16- 18. The study mainly improve the second phase link weight of the S-OSPF, the first phase link weight needn't be set, so several constraints have the additional restriction i≠s (the node i is not the source node s). Under this mathematical model there will be multiple paths from neighbor nodes to the destination node.

NUMERICAL ANALYSIS AND RESULTS

Experimental environment: In this study, Fig. 5 shows five typical network topologies which cited from the literature (Oki and Iwaki, 2010) are adopted in the numerical experiment. Attributes of these five networks are shown in Table 1. The study refers the literature to set the traffic matrix and link capacity. For example, each link capacity is uniformly distributed in (80,130). Without loss of generality, we randomly selected the source node s and the destination node t. The study sets traffic demand d_{st} = 50, which is the link capacity (i.e., the link bandwidth). The traffic matrix is expressed as TM = $[d_{st}]_{(s,\,t)\in Q}$. For OSPF, S-OSPF and W-S-OSPF routing, their link weight settings are the link capacity.

In this study, the LP solver in the LINGO (Linear Interactive and General Optimizer) software is used for linear and nonlinear problems. LINGO is a good tool to

Table 1: Network attributes

Type of network	No. of nodes	No. of links
1	6	24
2	12	36
3	12	48
4	15	56
5	20	68

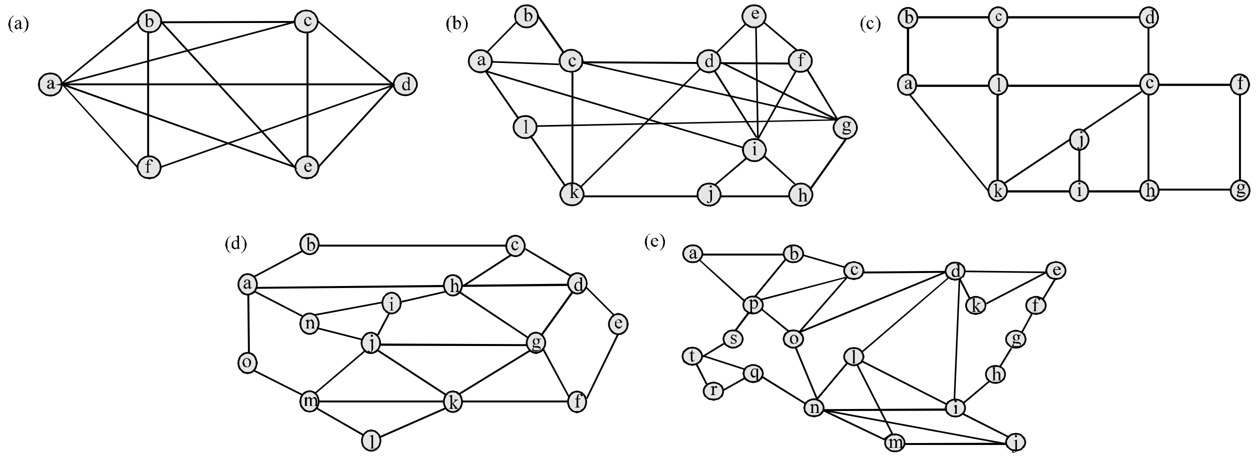

Fig. 5(a-e): Typical network (a) 1, (b) 2, (c) 3, (d) 4 and (e) 5 topologies used in experiments

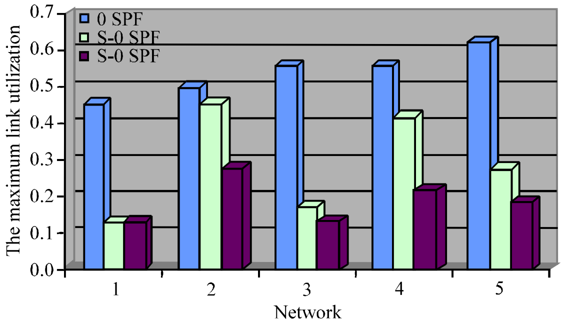

Fig. 6: Comparison three schemes in five networks

Table 2: Average computation time of five networks

Network type	S-OSPF time (sec)	W-S-OSPF time (sec)
1	<1	1
2	<1	4
3	<1	5
4	<1	2
5	<1	35

solve the optimization model, it can provide more than a dozen internal functions and allows the decision variable to be an integer (integer programming, including 0-1 Integer Programming). LINGO is also convenient and flexible and can easily exchange with other software such as EXCEL.

Comparison of techniques: Comparing traditional OSPF, S-OSPF and W-S-OSPF Fig. 6 shows the numerical experiment results of the three routing schemes. The maximum link utilization is compared as follows: OSPF>S-OSPF>W-S-OSPF. It means that the result of the experiment is consistent with theoretical analysis. According to our experiment results, W-S-OSPF could improve 20-55% in the maximum utilization of the link.

The computation of solving the routing problems is executed in a Windows-based computer with 2.83 GHz Intel®Core™2 Quad CPU Q9500 and 2.96 GB of memory. The results (Table 2) indicate that the computation time and complexity depends on network topologies. The results also show that the optimization time is less than 5 sec for the topology whose nodes is less than twenty and links is less than sixty. It means that the complexity of W-S-OSPF is acceptable for small-medium-size networks. In fact, the number of FEs in a ForCES router is actually not large, therefore W-S-OSPF is appropriate for the ForCES router.

CONCLUSIONS

The study mainly studied OSPF routing optimization scheme between ForCES FEs. First, this study introduced the concepts and issues related to the OSPF protocol, including the shortest path metric and ECMP concepts, as well as some issues related route optimization modeling, these provide a good theoretical basis for the later study. Then, the study shows S-OSPF routing and W-S-OSPF. It builds a mathematical model, which can be resolved using the linear programming. Finally, numerical experiments are carried out on a few typical network topologies, which are from related literatures. The results show that W-S-OSPF is feasible for small-medium-size networks. W-S-OSPF could improve 20-55% in the maximum utilization of the link. This study provides a foundation for ForCES router performance research.

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