Network Topology Monitoring Method of Large Scale Autonomous System Based on OSPF Protocol

Yue Dong¹, Lei Zhong²

¹ No.19, Yangguang New Road, Huaiyin, Jinan, Shandong, 250002, China
² Dangjia sub district office, Shizhong, Jinan, Shandong, 250002, China

*Corresponding author’s e-mail: dongyue126@126.com

Abstract. In order to monitor the OSPF (Open Shortest Path First) large-scale autonomous system in real time, for the shortcomings of current topology discovery methods based on OSPF protocol, firstly a hierarchical modelling method of OSPF large-scale autonomous system is proposed, which describes the autonomous system quantitatively. Secondly, a topology generation algorithm based on the link state database and an autonomous system model comparison algorithm are put forward in this paper. Finally, the experiment of monitoring the autonomous system in the actual network is carried out. The link state database is collected on any router in each OSPF area. The experiments show that the model and algorithm can be used to obtain the network topology map completely and accurately without the extra network burden, and to monitor the changes of network topology in real time. The model and algorithm proposed in this paper are helpful to realize the topology generation and monitoring of the large-scale autonomous system.

1. Introduction

OSPF (Open Shortest Path First) is an internal gateway protocol, which is used for route decision in a single autonomous system (AS). It is widely used in large-scale networks. In the operation of the actual network, the network topology is not static, it changes because of some software or hardware failures and configuration adjustment. At present, the network scale is relatively large and complex, it is difficult to monitor and understand the network topology in real time by handwork. Many scholars at home and abroad have studied this issue. Aman et al. proposed to establish network topology by detecting passively OSPF protocol packet[1-2]. A topology discovery algorithm in OSPF area for network topology was proposed, and a routing monitoring system based on passive monitoring technology was designed and implemented, but there was no research on the inter-area topology discovery in papers [3-4]. Wang H. proposed an algorithm which used database description packet and link state update packet of OSPF protocol[5], and the algorithm was realized by collecting LSU packets in the way of simulating router. Jiang Y.P. proposed a large-scale network topology discovery model based on OSPF protocol[6], but the OSPF packets needed to be acquired by spanning multiple OSPF areas, which resulted in incomplete message acquisition. In addition, none of the above-mentioned papers give a method of monitoring and comparison algorithm.

In this paper, for the shortcomings of current topology discovery methods based on OSPF protocol, a hierarchical modelling method of OSPF large-scale autonomous system is proposed. The model consists of an intra-area model and inter-area model. A topology generation algorithm based on link state database and a comparison algorithm of autonomous system model are proposed. Experiments
show that the model and algorithm proposed in this paper are helpful to realize the topology generation and monitoring of the large-scale autonomous system.

2. Topology model of autonomous system

Topology model of autonomous system based on OSPF protocol is represented by a two-tuple $T=\langle T_I, T_A \rangle$, where $T_I$ represents inter-area topology and $T_A$ represents intra-area topology.

2.1 Inter-area topology

Inter-area topology can be represented by the two-tuple $T_I=\langle A, ABR \rangle$, where $A$ represents the set of OSPF areas in autonomous system, $ABR$ represents the set of area boundary routers.

- $A=\{ \text{AreaID} \mid \text{AreaID} \in AS \}$. AreaID is the OSPF area number, which is used to identify an OSPF area. AS is an autonomous system, including many OSPF areas.
- $E=\{ e=\langle EA, ABR \rangle \}$. $e$ is a two-tuple, which represents a connection between areas. $EA$ is the set of interconnected areas, including at least two OSPF areas. $EA \subseteq A$, $EA$ is undirected. $ABR$ is the router ID of area border router, which is used to identify the area border router.

2.2 Intra-area topology

Intra-area topology can be represented by the three-tuple $T_A=\langle R, C, S \rangle$, where $R$ represents the set of routers in an OSPF area, $C$ represents the set of adjacencies in an OSPF area, $S$ represents the set of all subnets in an OSPF area.

- $R=\{ \text{RouterID} \mid \text{RouterID} \in AS \}$. RouterID is the ID of router, which represents a router.
- $C=\{ c=\langle CR, CS, LinkType \rangle \}$. $c$ is a four-tuple, which represents a adjacency among routers. $CR$ is the set of routers which are adjacent to each other, including at least two routers. $CR \subseteq R$, $CR$ is undirected. $CS=\langle \text{SubnetIP}, \text{Netmask}, \text{AreaID} \rangle$, indicates the adjacent interconnection subnet, which consists of network address, subnet mask and area number, $CS \subseteq S$. LinkType represents the type of connection.
- $S=\{ s=\langle \text{SubnetIP}, \text{Netmask}, \text{AreaID} \rangle \}$. Subnet indicates the IP address of a subnet in the autonomous system, Netmask indicates the subnet mask, and AreaID indicates the area number.

3. Topology generation algorithm of OSPF large scale autonomous system

3.1 Topology generation algorithm of inter-area

The basic principle of topology generation algorithm of inter-area is as follows: The area boundary router floods the summary network LSA (Link State Acknowledgement) to transmit the routing information. The summary network LSA includes OSPF area number, advertising router, link ID and net mask fields. These fields can be used to analyze how the areas are connected through the boundary router. The basic idea is to obtain the summary LSA set of each OSPF area, establish the inter-area topology model related to this area, and then merge the inter-area topology models of all areas to get the topology model of the autonomous system. The specific algorithm is as follows:

**step 1** Read the link state database in any router in OSPF area AreaID, obtain Summary-LSA.

**step 2** Read the area ID and advertising router fields in order to establish the area set $A=\{ \text{AreaID}_1, \text{AreaID}_2, \ldots, \text{AreaID}_n \}$ and the area boundary router set $ABR=\{ \text{ABR}_1, \text{ABR}_2, \ldots, \text{ABR}_n \}$, $n$ is the number of areas in the set $A$, $ABR$ represents the area boundary router in the area AreaID.

**step 3** Calculate $E$ among areas, the specific steps are as follows:

1. Take $k=2$, $z=C^k_n = \frac{n!}{k!(n-k)!}$, which represents the number of combinations that $k$ elements are taken out of from $n$ different elements. The sign $!$ represents factorial.

2. Take $k$ elements out of $ABR$ as a combination, record the combination as $\{ \text{ABR}_1, \text{ABR}_2, \ldots, \text{ABR}_k \}$. The area set corresponding to the $k$-element combination is $EA=\langle \text{AreaID}_1, \text{AreaID}_2, \ldots, \text{AreaID}_k \rangle$, calculate the intersection $ISABR= \bigcap_{i=1}^{k} \text{ABR}_i = \{ \text{ABR}_1, \text{ABR}_2, \ldots, \text{ABR}_m \}$. If
ISABR≠∅, <EA, ABR₁>,..., <EA, ABRₘ> records are merged into E, duplicate items need to be removed when merged.

(3) For the other z–1 combinations, calculate the set E according to step (2).

(4) Taking k=3, ..., n, repeat steps (1) and (3) respectively to get the set E of inter-area connections related to this area.

step 4 Repeat steps 2 and 3 above for other OSPF areas in the autonomous system, get the inter-area topology model T_{AreaID} related to other areas. The data of all areas should be merged, and the duplicates should be removed. The inter-area topology model of the autonomous system is got, T_A = \bigcup T_{AreaID} . Finished.

3.2 Topology generation algorithm of intra-area

Basic principle of the topology generation algorithm of intra-area is as follows: each router running OSPF protocol in the area can learn exactly the same topological structure when the network is stable. These topological structures are stored in each router in the area in the form of link state database. When the network topology changes, the related router will flood link state information in order to advertise to other routers in the same area. After receiving the new link state, other routers update its own link state database, and recalculate the routing table. If the network topology does not change, the router will also flood the link state acknowledgement every specific time (default 30 minutes).

According to the OSPF protocol, the topology information of OSPF area is mainly stored in router LSA and network LSA. The basic idea of this algorithm is firstly to obtain the router LSA set Router-LSA and network LSA set Network-LSA in each OSPF area, to establish the topology TA_{AreaID} of a single area, and secondly to combine the topology of all OSPF areas into the topology of autonomous system. The process is proposed as follows:

step 1 Read the link state database in any router in OSPF area AreaID, obtain Router-LSA and Network-LSA.

step 2 Read a Router-LSA ∈ Router-LSA, obtain advertising router and link list in the head of packet Router-LSA, separately marked as AdvRouterID and Link.

step 3 Traverse Link in order. According to the four link types defined in OSPF protocol, there are four cases for discussion. Mark the current link as CurrentLink, mark the link ID and link data in current link as CurrentLink.LinkID and CurrentLink.LinkData.

(1) If CurrentLink is P2P type, read the next link next to the current link, marked as NextLink. Make r = AdvRouterID, c = <AdvRouterID, CurrentLink.LinkID>, <NextLink.LinkID, NextLink.LinkData >, P2P, AreaID>, combine r and c into the set R and C respectively, remove duplicates in R at the same time.

(2) If CurrentLink is transit type, search the network-LSA in the set Network-LSA whose link state ID is equal to CurrentLink.LinkID. Mark the found network-LSA as CurrentNetwork-LSA, read LS ID, net mask, attached router list, marked separately as LSID, NetMask, AttachedRouterID. Make c = <AttachedRouterID, <LSID & NetMask, NetMask >, transit, AreaID>, the sign & represents bitwise logic and operation, combine c into set C.

(3) If CurrentLink is virtual type, the processing method is the same as P2P type.

(4) If CurrentLink is stub type, make s = <CurrentLink.LinkID, CurrentLink.LinkData, AreaID>, combine s into the set S.

step 4 Repeat steps 2 and 3 above, until Router-LSA is traversed, the topology model T_{AreaID} of the area is got.

step 5 Repeat steps 1-4 for other OSPF areas in the autonomous system, the topology model of other areas will be got. The topology models of all areas are merged, the duplicates need to be removed when merging. Finally, the topological models in the region are obtained T_A = \bigcup T_{AreaID} . Finished.
3.3 Topology comparison algorithm of large scale autonomous system based on OSPF

The basic idea of the comparison algorithm is to firstly establish the standard topology model \( T_B \) of autonomous system, and then compare the collected real-time topology \( T \) of autonomous system with \( T_B \), finally to get the difference result \( D \). Since the topology model of autonomous system can be represented by five-tuple, comparing \( T \) with \( T_B \) can be equivalent to comparing five tuples, that is, comparing \( A, ABR, R, C, S \). Next, take the comparison of \( R \) and \( R_B \) as an example to illustrate the specific way.

**step 1** Check whether any element in \( R \) belongs to \( R_B \), namely, \( \forall \text{RouterID} \in R \), if \( \text{RouterID} \not\in R_B \), \( \text{RouterID} \) is incorporated into the set \( D_1 \), which is the set of \( \text{RouterID} \) more elements of real-time topology than standard topology.

**step 2** According to the same method above, check whether every element in \( R_B \) belongs to \( R \), and merge the elements not belonging to \( R \) into \( D_2 \), which is the set of \( \text{RouterID} \) less elements of real-time topology than standard topology.

**step 3** After the above comparison, the difference data set is obtained. \( D = D_1 \cup D_2 \). If \( D = \emptyset \), \( R \) is the same as \( R_B \), if \( D \neq \emptyset \), \( D \) is difference data.

4. Example

The experiment of OSPF route monitoring is carried out in an autonomous system. The autonomous system consists of two areas. The link state database is read from a router in each OSPF area. According to the above model and algorithm, the topology of the autonomous system is obtained and recorded as the standard structure. When the topological structure changes, the real-time obtained topological structure is compared with the standard topological structure to get the difference data. Figure 1 shows the topology of inter-area, figure 2 shows the topology of area 16.35.0.1.

![Figure 1. Topology of inter-area](image1.png)

![Figure 2. Topology of area 16.35.0.1](image2.png)

5. Conclusion

In this paper, a hierarchical mathematical model of OSPF autonomous system is proposed, which can easily describe the topological structure of intra-area and inter-area. A topology generation algorithm based on router link state database and a comparison algorithm of autonomous system model are proposed. The experiment shows that the model and algorithm can monitor the real-time monitoring of routing changes without the extra network burden. The next step of this paper is to study the monitor of autonomous systems of other protocol types.

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