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LAPGN: Accomplishing information consistency under OSPF in General Networks (an extension)

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ABSTRACT

Open Shortest Path First (OSPF) protocol is a link-state routing protocol which requires the link-state information to be synchronous, and it needs to achieve a fast convergence when the network topology changes. In this paper, we extend the Limitation Arrangement Principle (LAP) algorithm to General Networks (GN) and design an LAP-based routing algorithm in GN (LAPGN) to solve the information consistency problem of the full network under OSPF with the following operations: (i) decomposing GN into one or more Single-link Networks (SNs) with the approach of depth-first walk; (ii) re-composting the SNs to a network with regular topology structure by connecting networks and adding links; (iii) searching the undirected complete graph of three nodes round by round until it converges to a simple network topology based on region binding; and (iv) processing different converged network topologies with different LAP-based routing algorithms. We compare the proposed algorithm with the well-known OSPF algorithm over some random network topologies and six backbone topologies. The simulation results reveal that LAPGN can solve the information consistency problem and has better performance than OSPF algorithm.

1. Introduction

The routing protocol plays an important role in Internet, and it can be usually classified into Interior Gateway Protocol (IGP) and Exterior Gateway Protocol (EGP) according to the working domain (Tanenbaum and Wetherall, 2012). The purpose of IGP is to find and compute route within an Autonomous System (AS), and it mainly includes Routing Information Protocol (RIP) and Open Shortest Path First (OSPF). EGP is used for exchanging routing information among ASes, and its representative is Border Gateway Protocol (BGP). According to Internet Engineering Task Force (IETF) RFC 2328 (Moy, 1998), OSPF is an IGP and it is designed to be used internal to a single AS. Compared to the distance-vector or Bellman-Ford technology found in routing protocols, *e.g.*, RIP, OSPF uses link-state or Shortest Path First (SPF)-based technology. RIP usually shows poor performance in the large-scale network and it probably needs a few minutes to accomplish information convergence (Nikolaidis, 2000). In contrast, OSPF is adaptive to the large-scale network and shows good performance. In OSPF, an AS is divided into multiple sub-ASes. In this way, information convergence can be accomplished at a relatively fast speed. Moreover, RIP is a distance-vector routing protocol of which routing metric is hop count. OSPF is a link-state routing protocol of which routing metrics are bandwidth and delay, being easily used to express the user's QoS requirements. Based on this, OSPF has strong suitability to different networks. For example, Information-Centric Networking (ICN) (Xylomenos et al., 2014) which is a promising future network paradigm that aims to shift the network focus on IP address to name content. In (Wang et al., 2012), OSPF is adopted by ICN to announce name prefixes.

As analyzed in IETF RFC 1245 (Moy, 1991), individual Link State Advertisements (LSAs) describe pieces of the OSPF AS. These LSAs are flooded throughout the AS, forming the link-state database. Each router maintains an identical link-state database. In this paper, we describe it as an information consistency of the full network (*e.g.*, an AS). A simple example for explaining information consistency is presented as follows. Assume that there are four persons, of which their names (information) are Jack, Tom, David and Sue respectively. At the beginning, they do not know each other (i.e., Jack does not know Tom, David and Sue). After information consistency is accomplished, they become acquainted with each other (i.e., Jack knows Tom, David, and Sue). In an AS, accomplishing information consistency means that the information is synchronous (consistency) and can be provided for other nodes (availability and effectiveness), and that each node has copies of

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information (integrity). In summary, it has three remarkable advantages.

· Consistent information database provides the network operator with a consistent view and ease the management of the network.
· When the given routing nodes are crashed, the rest of the routing nodes can provide the same information quickly. In this way, rerouting problem in the network layer can be addressed effectively.
· Even when some links or routing nodes are crashed, the information will not lose as long as one routing node is available. Thus, the integrity of network information can be guaranteed.

The key issues are (i) how to accomplish information consistency and (ii) how fast to accomplish information consistency. Inconsistent information database or slow convergence will decrease the efficiency of routing process. However, in OSPF, the synchronization of the link-state databases is simply maintained via the flooding algorithm, which has three limitations. (i) The prime concern of OSPF is to limit the processing/bandwidth requirements of the protocol and the speed of convergence is of secondary importance (Goyal et al., 2012). Once a node fails in the network, OSPF requires several tens of seconds to accomplish a new consistent state. This is obviously intolerant with the emerging of real-time applications (*e.g.*, VoIP) on the Internet. (ii) In OSPF, a router may receive multiple copies of a new LSA from its neighbors during the flooding process. However, as the network becomes larger in size, the overhead of processing these redundant packets can have a significant impact on network stability and utility of bandwidth. (iii) OSPF ignores the complexity of network topologies, which implies the relationships among different structure of graphs and such relationships are critical to optimize the information consistency problem.

The emerging Software-Defined Networking (SDN) (Kreutz et al., 2015) aims to separate the forwarding plane and the control plane which is aware of the network status in real-time and maintains a centralized view of underlying network status. Besides, the control of the network resources is done out-of-band in SDN which reduces the control overhead. For example, the centralized SDN controller can directly query the state of the nodes and links via the southbound APIs (*e.g.*, OpenFlow (McKeown et al., 2008)) and keeps these information consistent. With this benefit, SDN helps solving the dynamic deployment and orchestration of virtualized network function (Yi et al., 2017). However, SDN faces a critical problem of single point of failure (Kreutz et al., 2015). When the SDN controller goes wrong, the underlying network breaks down immediately. Moreover, in large-scale networks, it is not possible to assume that the network snapshot, at any point, is consistent, due to the frequent changes in routing status and the performance of a centralized SDN controller is limited to the scale of the network. Thus, distributed information consistent mechanism is still needed.

Based on the above analysis, we propose a Limitation Arrangement Principle (LAP)-based routing algorithm in General Networks (GN) (LAPGN) to accomplish information consistency. LAPGN is oriented to distributed network systems. Each network topology can be abstracted into a graph and such graph has its unique features. In LAPGN, we exploit the relationships in structure of graph and find the optimized connectivity solution through decomposing, re-composing, searching process to make the link-state database consistent. LAPGN abandons the flooding algorithm used by OSPF. The major contributions are summarized as follows.

· We propose a system framework of LAPGN to accomplish information consistency.
· We propose an equivalent transformation of GN, i.e., at first decomposing a GN into one or more Single-link Networks (SNs, i.e., linear network), and then re-composing the SNs to a Regular Network (RN).
· To search the Undirected Complete Graph (UCG, i.e., full-mesh network) of the three nodes from RN round by round, an algorithm based on domain binding of three nodes is proposed. Then, RN will converge to SN, Single-link Network with Multi-loops (SNM), Intersecting Network with Single-links (INS), or Hybrid Network of SNM and INS (HNSI).
· We propose an approach to transform INS into SN or SNM, and further present a hybrid algorithm to process GN.

The rest of this paper is organized as follows. The related work is reviewed in Section 2. Section 3 proposes a system framework of LAPGN. The detail of LAPGN is introduced in Section 4. Section 5 shows the simulation results. The challenges of LAPGN are presented in Section 6. Finally, Section 7 concludes this paper.

2. Related work

2.1. Information consistency

Some information consistency-related research has recently been studied. In (Ding and He, 2004), a K-nearest neighbor consistency in data clustering was proposed to incorporate the local information into the global optimization. In (Donald and Harold, 2003), the tradeoff between completeness and consistency in information decision contexts was studied. In (Zhang et al., 2009), an information framework for consistency maintenance in the distributed interactive applications was proposed, which explored the use of the information metric to analyze the effect of network latency on remote consistency. In (Silva and Narayanan, 2010), a strongly consistent estimate for mutual information was proposed. In (Hoellrigl et al., 2010), a consistency model was proposed for identity information in a distributed system. In (Beltran and Paradells, 2012), a control mechanism based on presence update was proposed, which was a tradeoff between traffic optimization and information consistency. In (Takasago et al., 2005), a synchronization method was proposed to solve the problem of inconsistency and maintain the latest information. In (Linnell et al., 2011), a scheme was proposed to check information consistency in an encrypted data storage system. In (Pan and Yang, 2015), an approach was proposed to provide information consistency in a distributed computing environment. Although (Ding and He, 2004)- (Pan and Yang, 2015) considered information consistency, they were not for OSPF.

2.2. OSPF

Some research is proposed for OSPF. In (Shaikh et al., 2002), an OSPF topology server was devised, which tracked the intra-domain topology, by listening into OSPF reliable flooding mechanism, or by pushing and pulling information from routers via the simple network management protocol. In (Merindol et al., 2009), a multi-path computation algorithm was proposed to calculate at least two paths with a different first hop between all pairs of nodes if the next hops existed. In (Srivastava et al., 2005), a Lagrangian relaxation-based approach was proposed to determine the link weight system under various objectives for OSPF. In (Rastogi et al., 2003), the important practical problem of configuring OSPF aggregation was addressed to minimize the error in OSPF shortest path computation due to subnet aggregation. In (Arai and Oki, 2012), a scheme was proposed to update metrics without loops while minimizing routing instability time. In (Kamrul and Oki, 2010), a preventive start-time optimization scheme was proposed to determine a suitable set of OSPF link weights at the start time which could handle any link failure scenario preventively. In (Vallet and Brun, 2014), an online approach was proposed to optimize OSPF weights in IP networks. It is worth noting that the recent research conducted by IETF focuses on OSPF extensions on (i) advertising node administrative tags which allows tagging and grouping of the nodes in an OSPF domain (Hegde et al., 2016), (ii) encoding the existing OSPF LSA information in