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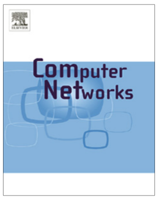

An adaptive multi-path computation framework for centrally controlled networks

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ABSTRACT

The Adaptive Dynamic Multi-Path Computation Framework (ADMPCF) is to provide an integrated resource control and management platform with an adequate set of management applications for better routing and resource allocation in centrally controlled or loosely coupled distributed software defined networking (SDN), especially for large network systems. As an open and extensible solution framework, it can provide the necessary infrastructure and integrates data collection and analytics, network performance evaluation, and various optimization algorithms. ADMPCF utilizes a set of complementary algorithms that work together in an adaptive and intelligent fashion that enable global routing and resource allocation optimization. It can also be easily extended to incorporate new algorithms through some open APIs. Such an approach would be able to efficiently and effectively adapt to the rapid changes in network topology, states, and most importantly application traffic, while it is often infeasible for a single optimization algorithm to get satisfactory solution for multiple nonlinear optimization objectives and constraints for a large and centrally controlled network. In addition, it could be costly for centrally controlled global optimization algorithms to calculate good routes dynamically with adequate response time, the proposed ADMPCF framework takes advantage of many hidden patterns of the network fragments in the combinations of network topology, states, and traffic flows. it utilizes much improved data structure for generating and utilizing various network analytics, and enables fast search and matching that that could avoid many expensive re-optimization whenever possible.

1. Introduction

Advances in information technologies, especially those related to data networking, have changed the business world and the social lives of people. It leads to new business opportunities, improved business agility and productivity, and at the same time, reduced operational cost. However, as data continue to grow significantly with more people and enterprises put their business and workloads on Internet and cloud computing, the underlying data network that supports these applications needs major improvements to avoid being the bottleneck for the changing business world.

To address these issues and challenges, software-defined networking (SDN) [1] is proposed and advanced rapidly to improve the existing data networking with various business benefits. With SDN, the network control plane is logically centralized and decoupled from the data forwarding plane. This separation of control and data

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forwarding allows more sophisticated data management and optimization to be applied through the logically centralized SDN controller to maximize the network performance. OpenFlow (OF) [2] is a standard protocol developed by Open Networking Foundation (ONF). It is used as the protocol for information (some data packets, control and status, etc.) exchange between SDN controller(s) and switches. In this model, application developers, enterprises, and carriers can gain unprecedented programmability to control the data flow in the underlying data networks to support their changing business needs with agility. The openness and the flexibility in SDN provide new capabilities that offer more satisfactory Quality of Service to users. Finally the intelligent utilization of network resources can result in much improved resource utilization, and at the same time, reduce the equipment and operational cost in addition to other benefits.

ONF published the OpenFlow 1.0 [2] in 2009. Following that, many large vendors and enterprises push out their new products for SDN, including Openflow enabled switches and controllers. Some enterprises, such as Google, re-invent their data centers utilizing SDN technologies, and they achieve much improved resource utilization and the reduction of management complexity and cost. Their successes in SDN further facilitate the development and enhancement to the standard Openflow protocol (especially, Openflow 1.2 and 1.3 [3] in 2011), and also the advances of the related networking technologies and products.

However, as SDN becomes more widely accepted, one critical challenge in its applicability is whether the centralized controller and the integrated applications for routing and resource allocations could provide promised decision making and distribute routing instructions for large scale networks in near real time. Despite many successful application scenarios, in-depth studies on their applicability to large scale data networks are critically needed.

This paper presents an adaptive multi-path computation framework that is aimed to provide a foundation to address the above mentioned issues. The rest of this paper is organized as follows: Section 2 will present an overview of the previous work on routing algorithms, from the basic Dijkstra/Bellman-Ford, to traffic engineering (TE), path computation element (PCE), and the more recent SDN-based TE works, including those developments at NEC and Google. Section 3 is on the proposed ADMPCF, including a brief overview of its component architecture, main procedures, adaptive and parameterized cost function, and path assessment criteria. Section 4 reviews the experimental studies, including the experimental setup, and the performance metrics that are used to compare ADMPCF with other approaches. Experimental studies are conducted over different topologies and traffic flow mixes to verify the efficacy of the proposed approach. Section 5 presents the experimental results, including some detailed analysis and observations. Finally in Section 6, we summarize the findings in this paper and discuss some future directions and related research issues to be addressed in centrally controlled large scale data networks.

2. Review of previous art

This section presents an overview of some previous work in routing and traffic engineering. We highlight the advances as well as the limitations that need to be addressed in these approaches, especially when applied to the centrally controlled data networking. We refer the reader to [4] for a more complete and in-depth survey and roadmap for SDN-TE.

2.1. Pre-SDN TE solutions

Shortest path routing algorithms, such as Dijkstra and Bellman-Ford algorithm, have been widely used in routing of todays data network. The complexities for Dijkstra and Bellman-Ford algorithms are $O(|E| + |V| \log |V|)$ and $O(|V||E|)$ respectively, where the number of edges is denoted by $|E|$, and the number of vertices is denoted by $|V|$. A shortest path is typically constructed based on the additive cost property, e.g. hop counts, link delay, etc. Shortest path first (SPF) based algorithms form the foundation for today's IP routing protocols, e.g. OSPF, ISIS, etc. Thus traditional routers and switches in the IP-dominant network world only consider some basic connection information from their neighbors, utilizing the famous 5-tuple (source/destination IPs, MAC addresses, and port numbers). They determine the best next hop for each destination node according to the result of the routing algorithm in a distributed manner.

However, in some networking environments, the cost property can be concave, and therefore, the additive cost property becomes not applicable, e.g. the dynamic call routing in the voice telephone network, the Quality of Service based routing, and some situations in Multiprotocol label switching (MPLS) networks [5]. To address this issue, widest path first routing algorithms [5] play an important role in such networks while end-to-end paths with the maximum possible bandwidth are found. One can get the widest path by extending some well-known shortest path algorithms such as Dijkstra or Bellman-Ford. The major difference is that the "width" of a path depends on the "narrowest" link (the one with least capacity) along the path, while the total distance/cost of the path depends on the sum of each link's distance or cost. Finally, the intrinsically distributed nature of the current network architecture and protocol stacks, coupled with the basic or enhanced shortest path algorithms that mostly consider only some basic information, such as the source and destination address, port numbers, and available bandwidths have made the network unnecessarily complex, have resulted in high network management cost, low resource utilization, and most importantly, incapable to dynamically match the needs of the ever changing traffic or application demands becoming unfriendly for network innovations to support future applications.

Traffic engineering (TE), the "control and optimization of routing to steer the traffic through the network in the most effective way" [6], is introduced around late 1980s [7]. It aims to provide a more centralized routing paradigm to increase network resource utilization by taking into

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