Multi-domain Cognitive Optical Software Defined Networks with Market-Driven Brokers

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Abstract We propose a new multi-domain networking paradigm where multiple broker agents compete to provide desirable inter-networking services to autonomous systems (ASes) through market-driven incentives. Broker agents with cognitive intelligence can adaptively offer end-to-end performance on a distributed platform involving ASes.

Introduction

Software defined networking (SDN) has brought a centralized control plane to improve manageability of networks, however, it faces difficulties in scalability in extending it to multiple administrative domains. Hierarchical multi-domain SDNs assume another control plane at higher hierarchy to control lower hierarchy control planes in multiple SDNs. Examples are the SDN orchestrator and the Hierarchical Path Computation Element (H-PCE) architecture, but they unduly limit the autonomy of Autonomous Systems (ASes). Having a single control plane at the highest level of the Internet is not a plausible notion. On the other hand, the recently adopted IETF’s Path Computation Element Computation Protocol (PCEP) with PCE can support multi-domain networks, but it fails to achieve coordinated resource management and end-to-end QoS across multi-domain networks.

The challenges we face today are to support:
- Scalability in multi-domain, multi-AS networking,
- Assurance for end-to-end QoS performance across multi-domain heterogeneous networks,
- Assurance for autonomy and security across multi-domain heterogeneous networks, and
- Service protection and restoration across multi-domains.

New Approach: Market-Driven Multiple Broker-Assisted Multidomain SDN

We propose a new inter-networking paradigm that maintains today’s heterogeneous Internet with autonomous systems, but that also incorporates market-driven multiple broker services between networks of multiple administrative domains. The proposed method supports the autonomy of the AS and offers a combination of centralized and distributed control planes for better scalability and manageability. The dynamic nature of the market-driven-broker vs. AS interactions will likely drive evolutions and improvements during the contracting and renewal processes. The broker agents compete freely with each other to provide attractive inter-networking services to ASes while ASes choose service plans from one or multiple brokers valuable for their inter-networking needs. The relationship between broker services and the ASes are through market-driven incentives. The broker agents have incentives to attract and serve many ASes so that they can offer even better and diverse inter-networking services in return for possible rewards or revenues through advertisements, direct payments, or improved reputations. The ASes can also benefit from signing up for one or multiple broker services depending on their inter-networking needs and the offered service plans. Signing up for many service plans from multiple brokers can give ASes a variety of tools to design a rich set of services for their clients at the expense of in-kind or cash payments. For instance, some broker services may require ASes to provide link state or other intra-AS information that is typically considered proprietary to the ASes. While providing such information will expose more internal information and compromise security, ASes can receive improved services (e.g. better end-to-end routing) in return. Broker agents are driven towards offering various security features and improved inter-domain services through incentivizing such information to be provided from ASes.

Figure 1 illustrates the concept behind the multi-broker service multi-AS heterogeneous networking, and Figure 2 shows the market interactions of multiple brokers (B1, B2, B3) with ASes’ source and destination (D1_s, D2_s,...D6_s, D1_d, ...D6_d). The track record and the level of mutual satisfaction can improve or degrade the level of trust between the broker agents and the ASes. As a result, upgrading/downgrading of service plans, increasing/reducing of information exchanges can take place as part of evolutionary process.
Due to the typical distance and bandwidth needs of inter-AS networking, optical networking with flexible capacity will be viable. **Optical-label-switched Elastic Optical Networking** can be offered to combined the benefit of optical label switching with optical-label-switching networking and EON scaling to multiple terabit per second capacity while supporting end-to-end QoS and optimal consumption of network resources. The brokers may offer to use optical labels that include requirements of applications (quality of service, class of service, type of service, etc) so that ASes can use the labels to achieve application-aware or attribute-based networking between the ASes.

Depending on the service plan negotiated with the broker service, different level of information can be exchanged between the domain manager and the broker service. Intra-domain network monitoring and inter-domain network monitoring information can be exchanged and fused into a large database that can be useful for all ASes participating in the broker services. A circle of client ASes may exchange information through social networks, and even a circle of broker services can exchange information if deemed to be advantageous and to be meeting the security policy. In some cases, a number of broker services may decide to form an alliance to be more competitive against other brokers, in a way similar to the way multiple competing airlines form alliances.

Available resources seen by the brokers and the ASes will be the constraints in the proposed market-driven, multi-broker, and multi-domain networking. The ASes will select broker services using the limited resources (funds and in-kind resources) and the broker services will have limited amount of network resources (e.g. bandwidths and paths) available to support the client ASes. On the other hand, ASes can possibly increase their revenues by providing better services to their subscribers by paying for more advanced broker services, while the broker services can offer better services if they invest more on the network resources procured or chartered from other infrastructures. Market-driven game theory as well as reputation-driven social networking will play a role.

**Cognitive Brokers with Machine Learning**

The minimum roles of the brokers are to discover, advertise, and monitor resources, to provide routing and resource allocations, to provide quality-of-service and security, and to bill for the services consistent with the service level agreement (SLA) with the ASes for inter-domain networking. Some or many broker services are likely to adopt various machine learning or cognitive intelligence mechanisms with advanced monitoring techniques to improve their services better suited for each specific AS they serve, and to adapt to and to predict changes of their needs. In particular, attribute-based networking can be significantly improved by such intelligent broker agents fortified by machine learning. The key architectural components for supporting cognitive intelligence in the multi-domain networking should include: (1) network measurement system, (2) knowledge discovery mechanism, (3) network management system, (4) knowledge transfer/propagation mechanism, and (5) network elements capable of adapting their functionalities. Using these components, the sensing, observations, reasoning, explanations, and actuation cycle will be simplified into an “observe-analyze-act” loop in the networking system.

The following two simulation results illustrate (a) the effectiveness of the broker agent, and (b) the effectiveness of multiple brokers in the multi-
domain networks. Figure 3 (a-c) illustrates the first simulation which compares the cases with and without broker services inter-domain networking of six ASes. The broker cooperates with the six ASes to obtain global view of the multi-domain network (Figure 3 (a)). Without the broker, the six ASes utilize BGP to achieve multi-domain networking. In our simulation, we study the performance of the flow from MAN 1 to MAN 2. Heavy bursts of traffic from MAN 4 and MAN 3 are introduced during the intervals from 50 to 80 seconds and 120 to 150 seconds, respectively. The bursty traffic will congest Router 5 (from MAN 4) and Router 1 (from MAN 3), causing very high end-to-end delays and packet loss (shown in Figure 3 (b) and (c)) if Router 0 does not become aware of these changing traffic patterns and continue routing along the shortest path (via AS 2 and AS 3). With the broker’s help, Router 0 will dynamically divert the flow to an alternative path through AS 6 and AS 5 during the bursty periods even if it is not the shortest path. By using the alternative path, end-to-end delay increases a small amount, but the performance will not degrade as significantly as previously.

Figure 4 illustrates multi-broker networking simulation results of the same topology Figure 3 (a) but utilizing two brokers. AS1, AS3, AS4, and AS5 subscribe to the service of broker 1; AS1 and AS2 subscribe to the service of broker 2; and AS6 does not subscribe to any service (relies on conventional BGP). If the broker 1 and broker 2 are specializing in disjoint regions (e.g. West coast vs. East coast), neither broker 1 or broker 2 can observe the entire network, the information provided by any single broker alone is inadequate for Router 1 to make the optimal routing decision. However, AS 1 subscribes to both broker services, so it can combine information provided by both brokers to find an optimal decision, achieving a level of performance identical to that in the case of the single (global) broker simulation. Figure 4 shows the performance by utilizing only information provided from broker 1 and by broker 2, as well as the performance after combining the information from both broker 1 and broker 2. For the flow from MAN 5 to MAN 6, Router 6 is unaware that it should adjust its routing decision according to the change in traffic dynamics along the path since AS 6 has no subscription to broker services. Instead, Router 6 will simply continue to forward traffic along the shortest path. Then when Router 5 is congested due to a heavy burst of traffic, the performance of the flow suffers (Figure 4).

Conclusions
The above simulations indicate that the broker has the incentive to attract more ASes so that it may obtain a more comprehensive view of the network dynamics to provide better services to the ASes. From the AS’s perspective, they may seek additional brokers and base their routing decisions upon an aggregate of the individual brokers’ services. The result of all this will provide more intelligent inter-domain routing, and consequently, better QoS for end users based on market-driven incentives in a distributed platform.

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References