FlowBroker: Market-Driven Multi-Domain SDN
With Heterogeneous Brokers

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Abstract: We present an enhanced market-driven multi-broker architecture for multi-domain SDN forwarding, in which heterogeneous brokers compete for domain customers and can peer with one another to provide enhanced services if economically beneficial.

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1. Introduction
Recent advances in software defined networking (SDN) [1] has provided programmability and manageability using a centralized control plane but also encountered challenges in scaling it to multiple administrative domains. One solution based on hierarchical multi-domain SDNs (such as the SDN orchestrator [2, 3] and the Hierarchical Path Computation Element (H-PCE) architecture [4]) introduces another control plane at higher hierarchy to control lower hierarchy control planes in multiple domains, 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. Another solution such as 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. More recently, a new inter-networking paradigm has been proposed [5] using market-driven multiple broker services between networks of multiple administrative domains. In this paper, we discuss the market-driven FlowBroker architecture, which is a multi-domain and multi-controller SDN implementation in which controller agents, retaining autonomy over the forwarding decisions within their respective managed domains, purchase inter-domain forwarding services from broker agents with market currency. The currency each domain can spend on inter-domain forwarding services is directly proportional to the units of transit traffic that domain is willing to forward within its domain, on behalf of the broker. In previous works [6, 7] we introduced and analyzed the FlowBroker architecture as a multi-broker and multi-domain implementation, where homogeneous load-balancing brokers fully cooperate or compete with one another for distributed inter-domain forwarding, and domain controllers freely obtain forwarding services from any broker. In this work we introduce an enhanced FlowBroker architecture where heterogeneous market-driven brokers offer their inter-domain forwarding services to domain controllers in return for intra-domain transit for the flows coordinated by the brokers.

In the ensuing discussion we define an inter-domain forwarding broker as an agent which adheres to the following guidelines: (1) brokers will respect the autonomy of AS domain managers, (2) each AS will choose whether or not to negotiate with a broker based on their individual needs and interests, (3) each AS may negotiate a Service Level Agreement (SLA) and provide domain resources in exchange for an inter-domain forwarding services, (4) brokers will provide better end-to-end inter-domain performance with respect to overall throughput, latency and availability, (5) brokers can broker inter-domain forwarding deals but will not dictate the terms of the deal, and (6) market-driven competition drives brokers to innovate and provide better services. Brokers’ incentives (objectives) can be to increase revenues, reputation scores, customer base, throughput, etc, and ASes’ incentives can be to achieve inter-domain networking with better traffic engineering, throughput, security, resiliency, etc. To support variations of broker types and service offerings, we introduce broker heterogeneity by creating four classes of brokers, each with differing objectives, and investigate the scaling and performance of market-driven FlowBrokers.

2. Market-Driven Heterogeneous Broker Architecture
In the FlowBroker architecture, domain management agents, tasked with the management of the forwarding tables of switches within their respective domains, periodically send network state updates to the brokers with which they associate. These data include latency, utilization and capacity metrics of inter-domain links. This creates a clear incentive for broker agents to compete with other brokers to provide forwarding services to as many AS managers as possible, maximizing network state information collection and providing the best inter-domain forwarding services. Additionally, domain manager agents use Linear Discriminant Analysis (LDA) [7] to categorize the performance of the various broker services being offered, to inform their broker selections. As the level of service a domain manager receives for its flow(s) is proportional to the resources it provides to the broker for intra-domain transit, both agents must negotiate this agreement, and the steps involved are as follows [7]:
1. A domain manager becomes aware of a new flow which has a destination address external to its domain, and therefore examines it’s LDA-determined broker rankings to choose the best broker available.

2. Once a broker with an acceptable reputation level is chosen, the domain manager agent sends an AS_NEG_REQ message to the chosen broker to request an inter-domain forwarding path the destination address for the current flow.

3. The broker agent then sends a BR_NEG_RESP message which indicates whether it has a path and what the intra-domain data rate is for each inter-domain service level that it provides.

4. The domain manager selects the appropriate inter-domain service level (data rate) in exchange for a guarantee for the domain manager’s desired intra-domain transit forwarding data rate sending an AS_NEG_ACK to indicate acceptance or an AS_NEG_REJ to reject the offer and begin negotiations with another broker.

Broker agents have incentives to maximize their rewards. Brokers still compete with each other for resources, rewards, and client ASes, but will measure their success based on differing objective metrics. Specifically, our model enhances the FlowBroker architecture by introducing four distinct broker classes, each of which is labeled by their respective strategy, as shown in Table 1.

<table>
<thead>
<tr>
<th>Broker Type</th>
<th>Strategy Description</th>
<th>Strategy Implementation</th>
</tr>
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<tbody>
<tr>
<td>Client Maximization</td>
<td>Achieve maximal number of AS clients with decreased emphasis on revenue</td>
<td>Multiply the cost of all routes by a discount factor of 0.5.</td>
</tr>
<tr>
<td>Revenue Maximization</td>
<td>Capture maximal revenue from clients, with decreased emphasis on number of clients</td>
<td>All routes provided at full cost, no discount.</td>
</tr>
<tr>
<td>Packet Loss Minimization</td>
<td>Increase market share by minimizing packet loss, thereby improving performance reputation.</td>
<td>Set peering probability to 0.9 to encourage broker path diversity</td>
</tr>
<tr>
<td>Packet Latency Minimization</td>
<td>Increase share of clients by minimizing latency for flows and improve performance reputation.</td>
<td>Favor paths with minimum hop counts and per hop latency</td>
</tr>
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3. Results for Stability, Scale and Heterogeneous Brokers

The following simulation studies are conducted using the Mininet SDN emulation software [8], leveraging the Floodlight [9] SDN controller software to create FlowBroker compliant controllers. Our simulated topology consists of 13 domains, each containing 4 switches, 2 to 20 brokers, and max concurrent flow counts ranging from 100 to 500 flows. We examine the performance and scalability of the heterogeneous market-driven FlowBroker model in terms of flow vs. broker count, and Fig. 1 illustrates these results.

![Figure 1](image)

Figure 1. Simulation results addressing the network performance and scalability of market-driven FlowBroker relative to broker count with respect to (a) Route Establishment Latency, (b) Overhead Traffic, and (c) Network Availability.

From the perspective of scalability, Fig. 1(a) conveys that as number of brokers increases, the route convergence latency will decrease until about the point where the number of brokers roughly exceeds the number of domains, at which point the growth in route establishment latency increases and is more pronounced for higher flow counts. We observed a 22% decrease in route est. latency when utilizing from 2 brokers up to 12 brokers, and only a 16% decrease when utilizing from 2 to 20 brokers. We conclude that broker diversity improves performance, to a certain point, at which too many brokers can actually increase the inter-domain route establishment latency, and traffic
overhead increases at an increasing rate. Specifically, traffic overhead from 2 to 12 brokers only increases by ~25%, whereas increasing from 2 to 20 brokers increases overhead traffic by ~60%.

We examined the effects of broker heterogeneity in the market-driven architecture by examining three key performance metrics; market share per broker type, network availability per broker type, and route establishment latency per broker type. With respect to market share, Fig. 2(a) conveys our studying the share of both overall revenues and client flow forwarding requests for all domain controllers and broker types in the network. Client maximization and revenue maximization have an inverse relationship when discounting is used. Specifically, client maximization brokers had the highest client share (31%) and lowest revenue share (18%), whereas revenue maximization brokers had the highest revenue share (29%) but lowest client share (21%).

From the perspective of the network availability, the Loss Minimization Brokers had the highest network availability under heavy load (98.8%) due to the increase path diversity resulting from a higher peering affinity, while the Client Maximization Brokers yielded the lowest network availability under heavy load (96.8%) resulting from the increase client count but decreased revenue, which resulted in decreased network resources for forwarding transit flows over client ASes. In regards to route establishment latency, the Revenue Maximization Brokers had the lowest route establishment latency (0.0982 s) due to the fact that fewer clients purchase non-discounted services, thereby increasing the availability of that broker’s existing resources for customers paying full price. Loss minimization brokers had the highest average route establishment latency (0.13 s) due to the increased likelihood that these broker types will peer with others, and therefore need to exchange network state information prior to route establishment.

Future work will integrate the market-driven multi-broker architecture with the OpenFlow based software-defined elastic optical networking testbed, as well as to investigate the social networking aspects of broker-controller and broker-broker interactions.

5. Acknowledgement
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6. References