On Private Peering Agreements between Content and Access Providers: A Contractual Equilibrium Analysis

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ABSTRACT

Driven by the rapid growth of content traffic and the demand for service quality, Internet content providers (CPs) have started to bypass transit providers and connect with access providers directly via private peering agreements. This peering relationship often raises disputes, e.g., Netflix vs. Comcast, and is not well understood. In this paper, we build a peering contract model and propose the concept of *contractual equilibrium*, based on which we study the formation and evolution of peering contracts. By using market data, we emulate the strategic peering behavior of providers and shed light on the understanding of private peering agreements.

We reveal that the *superiority* and *market dominance* of providers primarily determine their peering strategies. We show that 1) superior providers tend to engage in peering more aggressively, and 2) non-dominant CPs' optimal peering strategies are negatively correlated due to market cannibalism, while the dominant CP often behaves oppositely. Our findings help explain phenomena such as why Netflix and Comcast signed the first peering contract, and reason whether private peering contracts will strengthen in future.

CCS CONCEPTS

• **Networks** → **Network economics**; *Network performance modeling*; *Public Internet*.

KEYWORDS

Internet; private peering; superiority; market dominance

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1 BACKGROUND AND PROBLEM

Today's Internet is dominated by content traffic, especially video streaming. According to Sandvine 2018 Internet Phenomena Report [8], video is almost 58% of the total downstream Internet traffic, while Netflix solely contributes 15% of the downstream traffic across the entire Internet. To accommodate the increasing traffic demand

from users, large content providers (CPs) have been deploying wide-area infrastructures so as to bring content closer to users and bypass transit providers on many paths [3]. For example, Netflix uses third-party content delivery networks, e.g., Akamai and Limelight, and builds its own [6]. This causes the *flattening phenomenon* [1, 3] of the Internet topology, which transitioned from a transit hierarchy to a peering mesh.

However, regardless how flat the Internet could be, end-users still rely on the last-mile access providers (APs) for accessing the Internet. Thus, the limited capacity of APs may constrain users' download speed due to network congestion. For example, the average throughput of Netflix users behind Comcast, the largest U.S. broadband provider, degraded 25% from over 2 Mbps in Oct 2013 to 1.5 Mbps in Jan 2014 [7]. Only after Netflix purchased a direct connection from Comcast to its network via a private peering agreement in Feb 2014 [10], did the average user throughput rebounded almost doubly. Due to similar reasons, Netflix also signed another peering contract with Verizon two months later [4].

As a content service market, the entire Internet can be regarded as a two-sided platform, where CPs and APs may establish private peering agreements that affect the performance of content applications. Although from a service perspective, this peering relationship seems to be a collaborative effort between CPs and APs to improve service quality, the actual implementation is driven by the autonomous objectives and decisions of the contracting entities. In contrast to the traditional customer-provider relationship under which APs pay upstream entities transit fees, this type of peering often involves an AP imposing termination fees on a counterparty that specializes in content distribution and therefore, often causes peering disputes, e.g., Netflix-Comcast and Netflix-Verizon [5], in the bargaining process of contract negotiation. In the Netflix-Comcast dispute, for example, Netflix claimed that congestion was made intentionally by Comcast to force it to pay for direct connectivity; while Comcast claimed that Netflix was sending more traffic to transit providers than what they could accommodate and caused congestion. These peering disputes also raise policy concerns such as net neutrality [9], and therefore, the U.S. Federal Communication Commission (FCC) has requested the peering agreements Netflix signed with Comcast and Verizon [5] for investigations.

Nevertheless, private peering is not well understood and has not been explored much in the research community, partially due to the lack of public data sources of peering agreements, which are often confidential business contracts. The difficulty also lies in the fact that any CP's peering decision is driven by the competition in the content market, as well as the bilateral bargaining with an AP, during which financial transfers are involved and potential disputes could happen. Ultimately, any bilateral contract depends on not

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only the two trading parties but also all other possible contracts engaged by other pairs of providers in the entire service market.

In this paper, we build an analytical peering contract model and propose the concept of *contractual equilibrium*, based on which we study the formation and evolution of peering contracts. In particular, we try to answer the questions: What kind of CP-AP pairs has strong incentives to sign the first peering contract? What is the best-response strategy of a peering pair if others sign peering contracts? How does a contractual equilibrium look like? How should a CP adapt its contracts with varying characteristics of itself and others? How does the equilibrium evolve when conditions of market environment change?

2 CONTRACT MODEL

We consider an Internet content market consisting of a set of CPs and APs which compete with each other for end-users. To provide content to users, CPs need to deliver content data via APs that users subscribe to. CPs and APs may wish to establish private peering through which users can obtain better service quality. We denote the set of CP-AP pairs that could potentially establish private peering and jointly serve end-users by $\mathcal{L}$. As a key to understanding the private peering between CPs and APs lies in the contracts they sign, we model the contract terms of a CP-AP pair $l \in \mathcal{L}$ by a tuple (ϕ_l, ψ_l) of contractual level and monetary transfer. The level ϕ_l models the amount of resource the AP deploys under the contract and reflects the data delivery quality provided by the AP. The transfer ψ_l denotes the corresponding contractual payment from the CP to the AP. We define ϕ and ψ to be the vectors of all contractual levels and transfers. We denote the entire *contract profile* by (ϕ, ψ) and the profile except pair l 's contract by (ϕ_{-l}, ψ_{-l}) .

Because any contractual level ϕ_l affects the service quality for users who choose the pair l of providers, it influences the choices of users among alternative providers and therefore affects the market share and profits of providers. We defined the profits of any CP m and AP n by $P_m(\phi, \psi) \triangleq U_m(\phi) - \sum_{k \in \mathcal{L}^m} \psi_k$ and $Q_n(\phi, \psi) \triangleq \sum_{k \in \mathcal{L}^n} \psi_k - V_n(\phi)$, where $\mathcal{L}^m$ and $\mathcal{L}^n$ define the set of CP-AP pairs involving CP m and AP n , respectively, and $U_m(\phi)$ and $V_n(\phi)$ denote the CP's revenue and AP's cost, respectively. Here, the profit of a CP is defined as its revenue (from users or advertisers) minus the payments to APs, while the profit of an AP is defined as its received payments from CPs minus its cost for fulfilling the peering.

To understand what peering contracts would be signed between CPs and APs, we define an *optimal contract* that is ideally desirable for a pair of CP and AP to reach. A contract (ϕ_l, ψ_l) of any CP-AP pair l is optimal if the contractual level ϕ_l maximizes the aggregate profit of the CP and AP and the contractual payment ψ_l equalizes the profit gain, i.e., the difference in profit derived from signing a contract, for both providers. Based on the characterization of optimal contract, we define *contractual equilibrium* that specifies what contract profile will be formed between all CP-AP pairs.

Definition 2.1 (Contractual Equilibrium). A contract profile (ϕ, ψ) is a *contractual equilibrium* if for any CP-AP pair $l \in \mathcal{L}$, (ϕ_l, ψ_l) is an optimal contract given the contracts (ϕ_{-l}, ψ_{-l}) of others.

Similar to Nash equilibrium, a contractual equilibrium is defined for any bilateral contract (ϕ_l, ψ_l) , which specifies the conditions under which the parties $l = (m, n)$ reach to their optimal contract and

thus will not have incentives to “unilaterally” change the contract. This ensures the stability of contracts specified under equilibrium.

3 MAIN RESULTS

By using market data as inputs to the contract model, we emulate the strategic peering behavior of providers. Combining with theoretical analysis, we reveal that the *superiority* and *market dominance* of providers play key roles in determining their optimal peering strategies. The former is defined by two intrinsic properties of providers, while the latter is determined by whether a CP obtains more than half of the entire user market. In particular, our main findings are as follows: 1) A CP-AP pair is more likely to sign the first peering contract if they are superior to their competitors. In general, superior providers also tend to maintain contracts at high levels and obtain high market shares; 2) In response to enhanced peering relationship between other providers, non-dominant CPs will weaken their peering contracts due to market cannibalism. However, a dominant CP will behave oppositely; 3) As a CP becomes superior and dominant, most peering contracts, even its own, will weaken; 4) As the market penetration and quality requirements increase for the Internet content, non-dominant CPs will strengthen their peering contracts, while a CP will behave oppositely after it dominates the market. We believe that the findings shed light upon the understanding of private peering agreements between content and access providers.

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