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Revenue distribution in a quality-centric internet interconnection market

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ABSTRACT

The economic principals of today's internet have facilitated the rapid development of the digital economy. However, content providers with business models that are based on Voice over IP, internet-based TV or Software-as-a-Service have higher quality requirements than other internet companies. Thus, network operators are discussing the introduction of quality differentiated transport classes (QoS). This article uses the methodology of agent-based computational economics (ACE) to assess the economics of a QoS interconnection market. Based on real-world market data we choose a representative set of networks for simulating the value distribution among different network types in three market phases. Moreover, we analyze which network properties correlate with market success. The results suggest that content providers have strong incentives to establish direct interconnections with access providers. Thus, transit providers will be bypassed and face falling revenues. Access network providers will be able to collect most transport revenues and refinance infrastructure investments.

Keywords

Network Operator value creation and distribution, Wholesale Business Models, Inter-Provider QoS, Sending Party Pays, agent-based computational economics.

INTRODUCTION

The increasing popularity of services such as Internet based TV, Voice over IP, Software-as-a-Service or online gaming results in rising infrastructure requirements with respect to network properties like latency, reliability or bandwidth. This development constitutes a structural challenge for telecommunications and broadband Internet industries as quality-centric data transport has to be negotiated and assured across network boundaries (Inter-Provider QoS) (Briscoe and Rudkin, 2005; Constantiou and Courcoubetis, 2001; Hwang and Weiss, 2000; Shenker, Clark, Estrin and Herzog, 1996). In order to enable Inter-Provider QoS network operators propose to assign quality parameters to services (QoS) (Gozdecki, Jajszczyk and Stankiewicz, 2003; Zarnekow, Brenner and Dous, 2007). However, network operators do not only have to resolve technical issues in order to setup Inter-Provider QoS but they are also discussing the introduction of a new QoS specific interconnection regime which could fundamentally change value creation and distribution in the Internet interconnection market. The aim of this paper is the introduction of an agent-based computational model for the simulation and assessment of value distribution in a QoS interconnection market with a QoS specific interconnection regime.

A quality-centric interconnection regime

The proposal of a QoS-specific interconnection regime is causing controversial debates among network operators, scientists and politicians which are dominated by economic and political interests. Advocates of the traditional interconnection regime of the Best-Effort Internet (Bill and Keep) argue that it should be applied to any Internet service (FCC, 2010). In this interconnection regime Transit Provider (TP) are paid by enterprise customers (EC) and content providers (CP) for received and transmitted data. However, some scientists point out that the introduction of Inter-Provider QoS should go along with the introduction of a Sending-(Network)-Party-Pays (SPP) regime (Kruse, 2008; Steingröver, 2008). In the SSP regime payments are cascading along the data stream. Inter-Provider QoS has not been implemented on a large scale, yet. Thus, economic consequences of competitive strategic behavior under the SSP regime are not sufficiently understood and of interest for advocates and opponents (FCC, 2010). We are therefore proposing a model for the assessment of value creation under the SSP regime.

Related work

During the last ten years many authors have proposed models for the assessment of value creation processes within the Internet. Several authors assess coordination between internet services providers with game theoretic approaches (Cao, Shen, Milito and Wirth, 2002;Ma, Chiu, Lui, Misra and Rubenstein, 2007). However, as indicated in (Wulf, Limbach and Zarnekow, 2010) these approaches can be too static in order to analyze the dynamics in a QoS interconnection market. Other authors have used Agent-based Computational Economics (ACE) in order to assess techno-economic issues within the Best-Effort interconnection market (Chang, Jamin and Willinger, 2006; Dhamdhere and Dovrolis, 2009; LeBaron and Tesfatsion, 2008; Li, Alderson, Willinger and Doyle, 2004). Our paper uses the same quantitative research method but assesses a QoS interconnection market which is based on the SSP regime. Previous publications on the SSP regime have been qualitative and conceptual in nature (Kruse, 2008; Steingröver, 2008).

AGENT-BASED SIMULATION MODEL

ACE is the computational study of economic processes which are modeled as dynamic systems of interacting heterogeneous agents (Tesfatsion and Judd, 2006). North and Macal (2007) advocate the use of ACE if agents engage in dynamic relationships with other agents, structural changes in the macro level are not simulation input but simulation result and the decision behavior of agents is mutually dependent.

Simulation validity and data

Any model which aims to facilitate the understanding of a real-world economy needs to be validated (LeBaron and Tesfatsion, 2008). The validity of ACE models can be proved with empirical data or based on scenarios proposed by experts (Moss, 2008). Since a QoS interconnection market does not exist, empirical validation with historic data is currently impossible. This implies that the model must be validated based on scenarios created by experts. Our modeling assumptions are therefore derived from industry databases and published expert opinions. Furthermore, agents should be subject to real-world grounded taxonomic classification (LeBaron and Tesfatsion, 2008). Thus, we assign agent properties from publicly available databases which comprise information about the network operators of today's interconnection market. PeeringDB (2010) is an Internet-based database which contains network operator information for the initiation of interconnection agreements. This database provides information about peering locations, traffic levels and traffic ratios. CAIDA (2010) is a data-record which contains interconnection agreements between network operators in the Best-Effort Internet and enables network type classification. This data is particularly suited for the analysis of customer-provider transit relationships (Dimitropoulos, Krioukov, Fomenkov, Huffaker, Hyun, Claffy and Riley, 2007). Based on a third data source we infer transit prices and a quality premium for QoS-transit (TeleGeography, 2010a, 2010b).

Agent model

Network operators differ in their network operator class, geographical presence, interconnection strategy and their traffic ratio. These characteristics will be described in detail below.

Network operator classification

In the current Internet network operators can be subdivided into four network classes which differ in terms of their business objectives and interconnection strategies: large transit provider (LTPs), small transit providers (STPs), content provider (CPs) and enterprise customers (ECs) (Dhamdhere and Dovrolis, 2008; Norton, 2003). LTPs have many transit customers and possess a global backbone network. STPs are customers of LTPs as they have a limited geographic scope and provide service to CPs and ECs. CPs provide Internet services and content to other networks. ECs are companies which provide internet access to end-customers. Based on industry database information networks are assigned to network classes. Networks without transit customers are classified as CPs, if they offer more data than they request. All other networks without transit customers are classified as ECs. Networks which have at least one transit customer are classified as STPs, if more than 10% of the purchased and sold transit are purchased. Other networks with transit customers are classified as LTPs.

Geographical Presence

In or model we assume that only those networks negotiate about Inter-Provider QoS which are jointly present in one or more cities of today's Internet. We argue that the similarity of two networks increases with the number of cities where both networks are present. The degree of similarity of a network j to a network i is quantified with the directed SimilarityIndex:

$$SimilarityIndex_{ij} = \frac{G_{ij}}{A_i}$$

A_i denotes the overall number of cities were network i is present. G_{ij} denotes the number of cities were a network i and a network j have common peering points.

Interconnection strategies

A key strategic objective of LTPs and STPs is the maximization of the realized transport data volume (Dhamdhere and Dovrolis, 2008; Norton, 2002). Thus, transit providers will try to increase their scope with the number of directly and indirectly connected CPs and ECs. In the SPP regime data transmitters pay for the termination of content. Since ECs are primarily receiving traffic they will increase their scope just like transit providers in order to satisfy their customer's QoS demand. Under the SPP regime CPs are faced with a tradeoff. On the one hand they must ensure that they can satisfy the demand for QoS content on the other hand CPs must try to minimize content termination costs. We assume that CPs will switch from a scope to a cost minimization strategy once a critical QoS market saturation degree is reached. Based on information about broadband penetration in the USA and Germany, which provides a benchmark for the percentage of economically reachable consumers, a threshold of 66% will be used for the model (OECD, 2010).

Agent interaction

In order to simulate QoS interconnection negotiations we use the following procedure. If an agent is in turn of establishing an interconnection, it creates a ranked list of the preferred interconnection partners. The order of the ranked list is determined by the network specific interconnection strategy and the expected costs and revenues which are calculated based on traffic supply and demand. An interconnection will only be established if it is congruent with the interconnection strategy of both networks. That is, every established interconnection either increases a network's scope or reduces the data transport costs. An imminent premise of the SPP regime is the assumption that network operators receive sufficient compensation for the use of their infrastructure. Thus, de-peering will not be considered as a strategy which can improve a network's market share and will not be part of the model.

Data demand and supply

Interconnections enable traffic streams that generate revenues for network operators. We are therefore modeling the data demand and supply of a network and subsequently derive the revenues. In a first step we determine a network's data demand (I_i):

$$I_i = TrafficLevel_i * On\text{-}Net\text{-}TrafficRate_i * TerminationRate_i$$

The parameters TrafficLevel and TerminationRate are derived from traffic level and traffic ratio information available at PeeringDB (2010). We quantify the parameter TerminationRate as follows: Heavy outbound = 0.9; Mostly outbound=0.7; Balanced= 0.5; Mostly inbound = 0.3; Heavy inbound = 0.1. Based on information from Renesys (2010) we set the On-Net-TrafficRate of LTPs to 30% and assume 50% for STPs. ECs and CPs have an On-Net-TrafficRate of 100% as these networks do not offer transit. Following Chang, Jamin, Mao and Willinger (2005) we model the data that is requested from CPs as a Zipf-distribution. For this purpose we assume that a network operator's data demand increases with the similarity of its data sink network i to the source network j ($SimilarityIndex_{ij}$). Furthermore, we define that OriginationRate and TerminationRate add up to 1. These premises enable the data popularity calculation for network i (p_{ij}):

$$p_{ij} = TrafficLevel_j * On\text{-}Net\text{-}TrafficRate_j * OriginationRate_j * SimilarityIndex_{ij}$$

Based on an ordered list of all data source popularities p_{ij} a rank r_{ij} is being assigned to each traffic data source. That is, the network operator with the highest data popularity will be assigned to rank one and so on. As proposed by Chang et al. (2005) and Dhamdhere and Dovrolis (2009), we determine the traffic stream of the traffic source j to the traffic sink i with the Zipf distribution:

$$T_{ji} = \frac{\frac{1}{r_{ij}^{0.8}}}{\sum_{k=1\ldots n} \frac{1}{k^{0.8}}} I_i$$

In the next step a network operator's data supply C_i can be determined:

$$C_i = \sum_j T_{ij}$$

Based on the information on data demand and supply and on the existing interconnection in the next step, the traffic flows are calculated. For this purpose the data is routed through various interconnections from the source to the sink, based on a routing model of Gao and Wang (2002). In the next step, we calculate the costs and revenues based on the transferred data volume (v) with the cost function $K_i(v)$ formula:

$$K_i(v)=v^{0.857}*m_i$$

m_i denotes a company specific price component which was determined to be $23.28 with a variance of $2.9. The cost function is the result of a non-linear regression which was carried out on DECIX transit prices in Frankfurt, Germany which are available in a transit price database (TeleGeography, 2010a). The scaling effect and the price component were confirmed with a coefficient of determination of R^2=0.989. Furthermore, we assume a 20% markup for QoS traffic as an analysis of different VPN classes showed a markup of 19.9% between the cheapest and the most expensive offer (TeleGeography, 2010b).

Market model

The establishment of network interconnections is implemented as an iterative procedure. In the first step of each period the data demand and suppy is calculated for each agent. In the next step a random agent interaction order is assigned by the market. Every agent will approximatly be selected once per period. If an agent is in turn of negotiating with other agents it will establish an interconnection according to the procedure which is described in the agent model. Each period ends with the calculation of a routing schedule which is determined based on the updated network topology. Finally, the revenues and costs are calculated for each agent based on the transported traffic.

MARKET SIMULATION ANALYSES

The model described above was implemented using the Java-based development and simulation environment Repast in version 1.2.0 (Repast Simphony, 2010). The simulation implementation, setup and results are presented in this section.

Simulation setup and realization

The basis for the simulation setup is a representative selection of agents from the PeeringDB (2010), which consecutively will be referred to as test case and was created on the basis of PeeringDB and CAIDA data analyses (CAIDA, 2010;

PeeringDB, 2010). Analyses show that network operators are very heterogeneous with respect to properties such as traffic level, traffic ratio, degree of cross-linking and similarity. Furthermore, computation costs limit the size of a random test case sample. Therefore, estimates which would be derived from a random selection of agents can be subject to large fluctuations. We address this fact with a stratified sample which reduces the variance of the analyzed network properties within the strata and subsequently allows a more precise estimation (Raj, 1968). The test cases sample size and the number of simulations were chosen based on considerations of computational complexity. Following LeBaron and Tesfatsion (2008) we argue that a small-scaled agent model can be well suited to facilitate the understanding of macroeconomic questions. Thus, under the same conditions seven simulation runs were accomplished for a set of 22 agents. Thereafter, the simulation results undergo statistical analysis.

Market share analysis

The aim of the market share analysis is to assess the distribution of the total market revenues among network operator classes. For the determination of a period's market share we are dividing the total revenue of a network operator class by the aggregated revenue of all network classes. Subsequently the average of all simulation runs is calculated and shown in Figure 1. In addition, the average transport costs per unit of data and period are determined for each simulation run. Figure 1 shows the change of the average transport costs compared to the previous period.

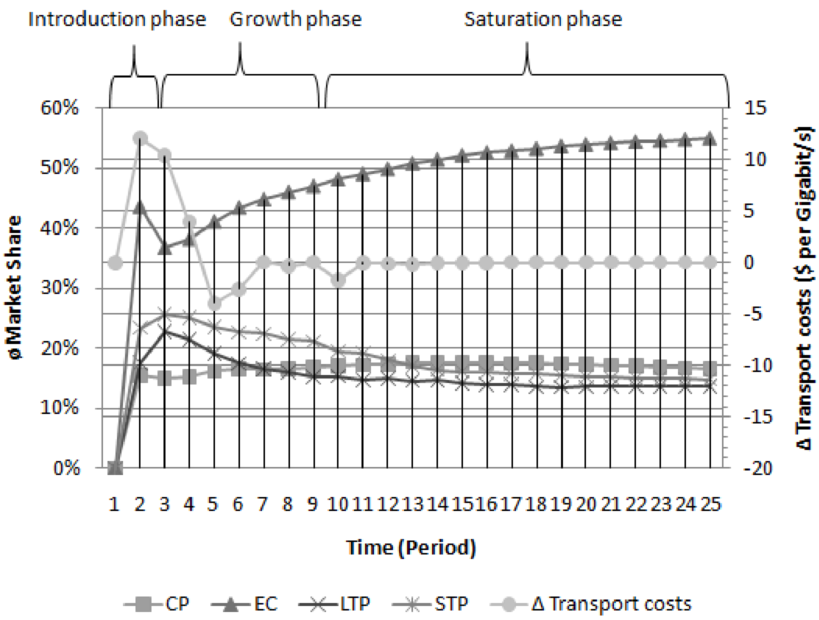

Figure 1. Average revenue shares of network operator classes

According to product life cycle theory the development of the market for QoS data transport can be divided into the introduction, growth and saturation phases (Hooley, 1995). In the introduction phase, the first interconnections are established. It is characterized by a strong growth of consumer demand saturation degree. In contrast to the introduction phase, some CPs already behave price-sensitively in the growth phase. At the end of the growth phase a complete demand saturation is reached. In the saturation phase, all CPs try to reduce their transport costs. The saturation phase is completed if no further interconnections can be established. A potential degeneration phase is not considered in this analysis because of the limited analysis time frame and the assumption of a steadily growing demand for QoS. All three market phases are characterized by a clear dominance of the ECs (Figure 1). The market share of ECs and CPs decreases in the introduction phase until the end of the introduction phase, whereas in particular the market share of LTPs increases strongly. To achieve a high level of demand saturation, CPs are willing to accept high costs for data transport at this phase. This can be observed in the curve of the average transport costs per unit of data. The growth phase is characterized by an increase in market share of ECs, and a decrease in the shares of STPs and particularly of LTPs. CPs behave cost-sensitive in covering the remaining unsatisfied demand. ECs benefit disproportionately high from the new transportation revenues which are generated by the increasing saturation of consumer demand. Furthermore, the cost sensitivity of CPs leads to a reduction in average transport costs. In the saturation phase, a slight decline in the average transport cost can be observed. While the market share of ECs further increases, the shares of STPs drops. CPs show a relatively steady market share in all market phases.

Analysis of market power determinants

In the next step, the market share distribution of LTPs and STPs is to be explored. For this part of the analysis a characteristic period is selected for every market phase and the influence of specific network characteristics on the market share is quantified. The assessed characteristics include the volume of data supply (C), the volume of data demand (I), the company-specific price component (m_i), the market's random allocation order of the first decision (1stDec), the number of potential interconnection partners (#Part) and the number of pre-existing network interconnections (# Con). The influence of the network characteristics on the market share is examined by using linear regression analyses. In these regression analyses the specific network characteristic represents the independent and the period-revenue of network operators the dependent variable. Non-linear relationships were assessed as well, but did not reveal new findings.

			Market share (TP)			Beta					
	Pa)	Period	Avg	Max	SD	C	I	m	1stDec	#Con	#Part
S 1	P1	2	0.10	0.32	0.12	0.647	0.563	-0.067	-0.853*	0.062	0.519
	P2	18	0.06	0.13	0.05	0.188	0.972**	0.099	-0.486	0.714	0.649
	P3	22	0.06	0.13	0.05	0.132	0.978**	0.122	-0.433	0.636	0.636
S 2	P1	3	0.09	0.47	0.19	0.465	0.343	0.820*	-0.596	0.948**	0.315
	P2	9	0.05	0.11	0.04	-0.112	-0.001	0.750	0.162	0.714	-0.155
	P3	26	0.03	0.10	0.04	0.407	0.609	0.709	-0.669	0.458	0.458
S 3	P1	3	0.07	0.15	0.06	-0.547	0.406	0.071	0.323	0.712	-0.321
	P2	17	0.04	0.12	0.04	0.635	0.629	0.657	0.639	0.676	0.561
	P3	22	0.04	0.13	0.05	0.507	0.658	0.706	0.658	0.530	0.530
S 4	P1	3	0.09	0.24	0.10	-0.030	0.880*	0.285	0.113	0.919**	0.642
	P2	5	0.07	0.16	0.06	0.131	0.820*	0.078	-0.064	0.968**	0.749
	P3	28	0.05	0.18	0.07	-0.097	0.887*	0.730	0.391	0.405	0.405
S 5	P1	2	0.09	0.23	0.12	-0.561	0.327	0.018	0.047	0.701	-0.496
	P2	4	0.07	0.26	0.10	-0.113	0.919**	-0.584	-0.394	0.907*	0.426
	P3	25	0.03	0.07	0.03	0.306	0.881*	-0.197	-0.150	0.730	0.730
S 6	P1	2	0.09	0.32	0.14	0.354	0.782	-0.261	-0.052	0.948**	0.452
	P2	5	0.08	0.24	0.09	0.630	0.498	-0.143	-0.476	0.775	0.510
	P3	23	0.04	0.10	0.03	0.086	0.941**	0.221	-0.418	0.687	0.687
S 7	P1	2	0.11	0.52	0.20	-0.127	-0.138	-0.773	-0.272	0.985**	0.356
	P2	4	0.12	0.36	0.13	-0.338	-0.033	-0.690	-0.547	0.961**	0.192
	P3	20	0.08	0.20	0.07	0.063	0.967**	0.516	0.472	0.669	0.669
a) P1: Introduction phase, P2: Growth phase, P3: Saturation phase											
* significant [Level of significance α = 5%]											
** very significant [Level of significance α = 1%]											

Table 1. Market share values and standardized regression coefficients

Table 1 presents standardized regression coefficients (Beta) for the seven simulation runs (S1-7). For each analyzed period and each simulation run the average (Avg), standard deviation (SD) and maximum (Max) of the market share is calculated. For the analysis of the introduction phase we select the characteristic period, in which CPs change their strategy and the consumer demand saturation degree is closest to 66%. Similarly the growth phase shall be characterized by the period in which the market reaches the complete saturation of consumer demand for the first time. For the analysis of the saturation phase we select the first period that is characterized by the fact that no further interconnections can be established.

INTERPRETATION

The market share analysis indicates that STPs and particularly LTPs act as procurer for data transport during the introduction phase. They transport high traffic volumes and thus increase their market share. However, the market share of LTPs decreases rapidly during growth phase. This finding suggests a disintermediation in the data transport chain: in order to ensure a cost-effective transport, more direct links are established and LTPs are bypassed. As indicated by the cost change curve, CPs realize the strongest transport cost savings in this step. The decreasing market share of STPs suggests a trend towards the establishment of direct connections during growth phase. A similar development can be observed in the Best-Effort internet, where interconnections are increasingly established at lower hierarchical levels in order to bypass Tier 1 network operators (McPherson, 2009).

The regression analysis provides an insight into the determinants of market success. During introduction phase the number of existing interconnections is the most important success factor for transit providers. Other determinants hardly influence the market share in this phase. A high maximum market share and a large market share distribution have been observed. These observations indicate the occurrence of network effects during the introduction phase. At an interconnection market network effects increase the benefit that a network operator gains from an interconnection with a partner along with the number of interconnections which this partner has already established (Katz and Shapiro, 1985). In network effect markets positive feedback can lead to a strong dominance of a market actor. Thus, the existing interconnections of a network operator can be considered a core resource for the development of further interconnections and an increase in market share. During growth phase, the number of existing interconnections remains the most significant determinant for explaining the market share. Furthermore, a decreasing variance of market shares and smaller maximum market shares can be observed. This suggests a decreasing importance of network effects. At the same time the volume of data demand gains importance. During saturation phase network effects can no longer be observed. In this phase the only significant determinant is the volume of data demand.

The company-specific price component does not influence interconnection revenues. This result can be traced back to the fact that the proposed model is based on the SPP regime. In this regime the establishment of a direct connections between source and sink network always has a cost minimizing effect. Consequently a disintermediation of LTPs and STPs occurs for any QoS transit price. The lack of correlation between the amount of possible interconnection partners and revenues implies that presence at interconnection points does not constitute a competitive advantage. However, our model does not consider this aspect to the full extent as local competitive differentiation is not part of our research. The analysis also does not reveal first mover advantages because the random agent interaction order has no significant effect on the market success. However, the observed time differences of the active market entry are small. An analysis of greater time periods could result in different conclusions at least for the introduction and growth phase.

CONCLUSION

In order to facilitate the development of future content provider business models, which require Inter-Provider QoS, network operators are discussing the introduction of a SPP interconnection regime. By analyzing the economic consequences of competitive strategic behavior under the SSP regime we aim to contribute to the consolidation of a controversial debate between advocates and opponents of a QoS interconnection market. For this purpose we conduct a market analysis for a set of 22 network operators in order to assess a scenario for revenue distribution in a SPP interconnection market. The results of our analyses indicate that content providers have incentives to bypass transit providers and establish direct interconnections with access providers. A similar trend can be observed in today’s internet where paid-peering is becoming common between content and access providers (Faratin et al., 2007). According to the simulation results access providers collect a large share of the overall market revenues. Therefore, our results support the argumentation in Kruse (2008) that an SPP regime offers incentives to invest in an infrastructure that meets higher quality requirements. Thus, content provider business models which require Inter-Provider QoS would be facilitated by the new interconnection regime.

The proposed model has several limitations. Thus, caution is advised in generalizing the results. The current version of the model considers only two interconnection strategies that are assigned to network operators of discrete network classes. In a real QoS interconnection market more differentiated strategies may consider decision parameters that are currently not part of the model. Due to the high computational complexity simulations were carried out with a limited number of network operators and simulation runs. Thus, a set of agents with properties which differ from the representative test case might not reproduce the observed results. Further research efforts will focus on improving the model's ability to produce results which are valid beyond the scope of a representative test case.

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