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## Conference Paper

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21st European Regional Conference of the International Telecommunications Society (ITS):  
"Telecommunications at New Crossroads: Changing Value Configurations, User Roles, and  
Regulation", Copenhagen, Denmark, 13th-15th September 2010, No. 39

### **Provided in Cooperation with:**

International Telecommunications Society (ITS)

*Suggested Citation:* Wulf, Jochen; Limbach, Felix; Zarnekow, Rüdiger (2010) : Analysis of QoS  
Platform Cooperation Strategies, 21st European Regional Conference of the International  
Telecommunications Society (ITS): "Telecommunications at New Crossroads: Changing Value  
Configurations, User Roles, and Regulation", Copenhagen, Denmark, 13th-15th September 2010,  
No. 39, International Telecommunications Society (ITS), Calgary

This Version is available at:

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## **Analysis of QoS Platform Cooperation Strategies**

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### **Abstract**

In this paper we present a value-oriented modeling approach for the assessment of the QoS interconnection market. This approach is based on the economics of two-sided markets and takes cross-side market externalities between networks into account. The presented model comes along with strong limitations with regard to the complexity of the interconnection market. In order to cope with a realistic number of players and a higher level of complexity, we are proposing the use of a bottom-up, agent-based model. The novel micro-level modeling approach enables the analysis of QoS interconnection strategies. This model can be used to analyze macro-level simulation results and derive implications for the network type specific optimal interconnection strategies.

### **1. Introduction**

The growing demand for data intensive consumer and business services such as Video on Demand, HD TV over IP, or Video conferencing fosters the development of dedicated transport infrastructures. In contrast to the Internet, such infrastructures are capable of delivering content within guaranteed service levels. The most prominent examples are dedicated infrastructures for the delivery of IP TV, which are nowadays operated by many carriers. The profitability of such novel infrastructures relies primarily on the attraction of a sufficient number of consumers and content providers. We argue that the interconnection of platforms potentially represents a means to increase platform efficiency. The economic implications of the interconnection of multi-service QoS platforms are discussed in the course of NGN interconnection (Marcus 2006a, 2006b). We extend this debate by providing a framework, which bases on the theories of two-sided markets (Rochet and Tirole 2004, Cortade 2006) and game theory (Fudenberg and Tirole 1993, Shapley 1953, Winter 2002).

Under a set of assumptions explained below, QoS platform providers always achieve benefits from interconnection. Given that costly negotiations are required to reach interconnection agreements, platform providers require strategies to select cooperation partners taking into consideration the concentration of market power and opportunity costs associated with alternative strategies. The objective of this research is to analyze strategic decision making for QoS interconnection under the presence of interdependencies and conflicts of interests.

In analogy to the theory of two-sided markets we argue that operators of dedicated QoS infrastructures represent essential intermediaries which enable transactions between end-customers and content

providers. Operators can thus benefit from the internalization of positive externalities which are created by the two types of platform customers (Rochet and Tirole 2004). For simplicity reasons we assume, that a transaction on the platform provides constant benefits to both customer groups regardless of the transaction volume. If, for example, consumers strictly benefit from transactions on the platform, then additional content providers always exert a usage externality. In our model, platform providers internalize the added platform value, which is created by an increase of consumers for content providers and vice versa.

Furthermore, we assume that QoS platform providers can significantly extend their coverage only through interconnections. This is comparable to the mechanisms of today's Internet ecosystem (Faratin et al. 2007) where the ability to provide global end-to-end connectivity is a condition precedent to meet customer requirements. We focus our analysis on platform cooperation and explicitly exclude platform competition for customers by assuming single-homing and long-term contracts of content providers and consumers for platform connection.

Following Ma et al. (2008), we introduce the Shapley Value (Shapley 1953, Winter 2002) for distributing cooperative gains of QoS platform providers. The Shapley Value represents a mechanism for a fair allocation of gains in cooperative games. Ma et al. (2008) propose an application to cooperative settlement for IP network interconnection. In their model, the added value of an actor is determined by the revenues, a player generates in a cooperation. In two-sided markets, an actor will adjust prices according to the overall value a platform proposes to a customer. Hence, it will internalize the added value contributed by all cooperating platform providers. Therefore, a mechanism as presented by Ma et al. (2008) is not appropriate to model interconnection of two-sided market platforms. Instead, we propose to value an actor by the number of transactions its joining contributes to a platform.

Due to the high costs associated with forming platform cooperations (Marcus 2006a, pg. 19), platform providers are forced to select partners. This is a non-trivial problem as cooperation platforms are formed in multi-stage processes and the identification of optimal cooperation strategies requires careful analyzes. We construct a game theoretic model as a one-stage game (Fudenberg and Tirole 1993) to analyze cooperation formation of QoS platform operators in a specific scenario. However, this game bases on the assumption that gains from a coalition can be defined independently of the coalitions which are formed by the remaining actors. Such approaches neglect the presence of externalities among coalitions and cannot be applied to endogenous coalitions (Bloch 1996). Bloch (1996) argues that if actors decide to form a coalition, they must take into account the reaction of external actors to the formation of a coalition. We introduce an alternative methodology of analysis by providing an outlook on how to apply agent-based economics in order to analyze strategies in such complex environments (North and Charles 2007, Tesfatsion and Judd 2006).

The paper is structured as follows: the subsequent section provides an overview on QoS interconnection. Thereafter, a game theoretic model for the analysis of QoS interconnection scenarios is presented and applied for an exemplary scenario. Afterwards, an outlook on the application of agent-based economics is given.

## **2. QoS Interconnection and the Market for Backbone Data Transport**

In the market for Backbone IP Data Transport, services for the transmission of data between different access networks are offered. The interconnection of independent IP networks is a necessary premise to assure a high degree of service coverage. The internet consists currently of more than 30,000 Internet Service Providers (ISPs) (Dhamdhere and Dovrolis 2008, Huston 1998 p. 13). ISPs can be subdivided into four classes which are distinguished by business goals and interconnection strategies: Large Transit Providers (LTPs), Small Transit Providers (STPs), Content Providers (CPs) and Enterprise Customers (ECs) (Norton 2003, Dhamdhere and Dovrolis 2008). LTPs operate global backbone networks and have numerous transit customers. Their business goal is to facilitate unrestricted reachability to their customers and thus gain a high market share in the IP transit market. STPs are limiting their activities to clearly defined regions and offer their internet connection and transit services to private and business customers. Their primary business goal is to achieve a significant market share while maximizing the profits of their private and business customer offerings. CPs are offering internet-based services and content or provide hosting and content distribution services. They strive to ensure the required quality of data transport at minimal cost rates. ECs comprise companies possessing autonomous systems and network operators limiting their activities to providing internet access to customers. Similar to CPs, their business goal regarding interconnections is to pay minimal access charges for the requested data transport quality. LTPs, STPs, CPs and ECs and their existing interconnections are forming a multi-layered system, which is denoted as tier system (Crémer et al. 2000). ISPs belonging to a certain layer receive transit services from the next superior layer. Among themselves ISPs of the same layer are exchanging data without payment due to the fact that symmetrical interests are assumed. To that effect, two fundamentally different types of interconnections must be distinguished: transit and peering (Norton 2002a, Faratin et al. 2007). IP transit is a business relationship where the provider guarantees the availability of data transport for the entire internet to his customer. The customer is assured a certain capacity (bandwidth) for incoming and outgoing data transport (committed data rate). If the effectively utilized data rate exceeds the acquired capacity, predetermined additional charges have to be paid. Determined by the overall capacity being available, this can create packet loss and errors in data transmission. To establish a transit connection, a one-time investment as well as a monthly capacity-dependent payment are necessary (Norton 2002a, DrPeering 2010).

Peering partners mutually guarantee the reachability of their respective customers without any payments. This principle is based on the assumption that different network providers are bearing symmetrical costs for the operation of the network and mutually benefit from the data exchange. To facilitate this kind of interconnection both network operators have to establish a connection to the peering point and must rent or buy an exchange port and collocation space at the exchange point (Norton 2002a, DrPeering 2010). The first-time investment and the monthly fees depend heavily on scale effects. Since peering arrangements can differ significantly in content and form, the quality of the data transport realized through peering varies as well. While some peering partners promise each other minimum capacities, the allocated peering capacities are subject of individual strategic considerations in other cases. This can result in capacity overflows of peerings and corresponding quality problems for the data transport.

The scope of action in the wholesale market for data transport is strictly limited since a differentiation can solely be achieved through the price and the quality of data transport (Huston 1999, p.3). Offerings concerning inter-provider IP data transport with distinct quality features are regarded as an opportunity to support new and innovative internet service offerings (Crémer et al. 2000, Faratin et al. 2007, Huston 1998, p. 574). Moreover, the preferential handling of critical applications in cases of serious failures of parts of the internet infrastructure is seen as a positive macro-economic effect (Kruse, 2010). In consequence of commercial routing practices, data packets are frequently transmitted over the cheapest route instead of using the shortest path, resulting in a significantly higher delay of data packets (Huston 1998, p. 544). In addition, the end-to-end quality is not guaranteed by the ISP to the content provider because of the fact that the internet data transport is traditionally paid partly by the sender and partly by the receiver (Huston 1998, p. 574). An ISP cannot assure a high quality data transport due to the fact that usually another ISP, which could negatively influence the quality, is involved in data transmission (Crémer and Huston 1998, p. 540). For this reason content providers cooperate with content distributors that operate a global network of caching servers and are capable of delivering great amounts of data traffic directly to the termination network. Nonetheless, the ability of content delivery network providers to support services with strict real time requirements, which are not cacheable, is limited. Numerous authors argue that such services cannot be realized under the prevalent conditions (Kruse 2010, Faratin et al. 2007, Crémer et al. 2000). To deal with these challenges, ISPs are establishing quality-oriented interconnection mechanisms on the application layer, e.g. for VoIP and for VPN services. Furthermore, there are approaches to enable the IP data transport of quality-sensitive internet applications by the introduction of "inter-provider QoS" (Briscoe and Rudkin 2005, Constantiou and Courcoubetis 2001, Shenker et al. 1996). Apart from the network neutrality debate (Musacchio et al. 2009, Lee and Wu 2009, Ganley and Allgrove 2006) the question of the interconnection regime is a central point of discussion at the implementation of "inter-provider QoS". Kruse (2008) and Steingroever (2008) argue for the introduction of a Sending (network) Party Pays (SPP) regime, in which the data originator is paying for the end-to-end transport. Every ISP is submitting the traffic just to those ISPs that match the quality criteria and rewards them correspondingly. By doing so, the QoS transport charges are cascadingly distributed congruent with the data flow. With the alternative regimes, Receiving Party Pays and Bill and Keep, the incentives to transmit the data with the requested quality are not argued to be sufficient since the receiver's willingness to pay is not assured and because there are only suboptimal investment stimuli in asymmetric networks (Brenner et al. S. 51 ff). Nonetheless, "inter-provider QoS" has not been realized on a broad scale so far, among other things because of the difficult predictability of the demand and associated revenues. Besides the end-user demand, the cooperation schemes of "inter-provider QoS" and the impact of competitive strategies on the entire wholesale market are difficult to predict. Global cooperations are necessary to realize a high coverage of QoS-based IP transport services. Moreover, it is uncertain which kind of competitive behavior, e.g. by the adjustment of routing strategies, would occur, and which interaction effects a co-existence of QoS and the current best effort systems would evoke. These issues are being addressed in detail in the following analysis.

### **3. Game Theoretic Perspective on QoS Interconnection**

In this section, a value oriented model on QoS interconnection is presented. Thereafter, the application of this model in a simple scenario as a two player game is illustrated.

### 3.1 Value Oriented Model on QoS Interconnection

A core contribution of two-sided markets economics addresses the setting of prices in platforms with two customer groups and cross-sided markets externalities. The optimal prices depend on the price elasticities of demand and the marginal costs for output changes on both sides (Rochet and Tirole 2004, Schmalensee and Evans 2007).

Researchers have shown, that platform cooperations yield competitive advantages in certain circumstances (Rochet and Tirole 2002). A key assumption for pricing is the free flow of customers. Nevertheless, in many cases, customers are bound due to long-term contracts or fixed investments. In the following model, the cooperation increases the value of a platform for the customer groups. In such case, the cooperating partners could skim additional customer rents by setting prices according to the value increase. According to Rochet and Tirole (2004), a customer  $i$  joins a platform if and only if

$$b^i + \frac{B^i}{N^j} \geq a^i + \frac{A^i}{N^j} \quad (1)$$

The benefits per transaction on this platform  $b^i$  and the fixed benefits of platform access  $B^i$  per transaction must be greater or equal to the transaction fees imposed by the platform  $a^i$  and platform access fees  $A^i$  per transaction.  $N^j$  refers to the number of transactions carried out by a customer  $i$  on the platform. Given that the number of transactions is known, the above equation represents the optimal pricing policy for a platform provider.

As shown in (1) access and transaction fees for a customer group are positively correlated with the size of the opposite customer group in two-sided markets. In our model, delivery platforms only impose access charges ( $A$ ) and no transaction charges to consumers. Moreover, consumers neither have to make investments nor receive fixed benefits from platform access. This corresponds to the widespread practice that consumers solely have to pay flat charges to access Internet or voice platforms. Hence, we can calculate consumer access charges as follows:

$$A = b_{cs} \sum_{q=1}^z k_q \quad (2)$$

The overall number of content providers on a platform is represented by  $z$  and  $k_q$  describes the number of transactions per consumer of a content provider  $q$ . In contrast to consumers, content providers are only obliged to pay transaction fees ( $a$ ) to delivery platforms in our model. Additionally, content providers have to make investments (~~the negative term  $B_{CP}$~~ ) to establish a platform connection. Therefore, the transaction fees are calculated as follows:

$$a_q = b_{CP} + \frac{B_{CP}}{k_q x} \quad (3)$$

The number of consumers on a platform is represented by the term  $x$ . As a consequence, the value of carriers in a delivery network is positively correlated with the aggregated popularity of the content providers and the number of consumers connected to a platform.

The overall revenues  $R$  generated by a platform can now be calculated with the equations (2) and (3) as follows:

$$R(x, k_1, \dots, k_z) = Ax + \sum_{q=1}^z k_q a_q = (b_{cs}x + b_{cp}) \sum_{q=1}^z k_q + z \frac{B_{CP}}{x} \quad (4)$$

The Shapley Value represents a mechanism for a fair allocation of gains in cooperative games (Shapley 1953, Winter 2002). Ma et al. propose an application to cooperative settlement for IP network interconnection (Ma et al. 2008, Ma et al. 2007). In their model, the added value of an actor is determined by the revenues, a player generates in a cooperation. As explained above, in two-sided markets, an actor will adjust prices according to the overall value, which a platform proposes to a customer. Hence, it will price in the added value of all other actors to its customers. Therefore, a mechanism as presented by Ma et al. (2007) is not appropriate to settle the interconnection of two-sided market platforms. Instead, we propose to value an actor  $c$  by the number of transactions it contributes to a platform:

$$\varphi_c = \frac{x_c \sum_{i \in R} \sum_{z \in Q_i} k_z + (\sum_{i \in R} x_i) (\sum_{v \in Q_c} k_v)}{2 \sum_{i \in R} x_i \sum_{j \in R} \sum_{z \in Q_j} k_z} \quad (5)$$

The set of actors on a platform is referred to by  $R$ . The number of consumers connected to an actor  $i \in R$  is denoted by  $x_i$ . Each actor  $i$  connects a set of content providers  $Q_i$ . Each content provider  $z$  is allocated a popularity  $k_z$ , which quantifies the number of transactions carried out by this content provider per consumer.

### 3.2 Application of Game Theory for the Analysis of Platform Cooperation Strategies

With the method to calculate overall platform revenues and to allocate the revenues to the cooperation partners one can now design and analyze strategic behavior in the establishment of platform cooperations. An analysis of such strategies is presented in the following for a scenario with three platform operators. A core assumption in the following game theoretic analysis regards the nature of cooperations and strategic behaviour: The agreement to cooperate determines the allocation of joint revenues in the future: at the time an operator A enters a cooperation with operator B, its revenue share ( $\varphi_{A/B}$ ) is determined with the shapley value according to equation (5) and remains constant thereafter. It is then applied to split the joint revenues ( $\varphi_{AUB}$ ) of cooperations with third parties:

$$\varphi_A = \varphi_{A/B} * \varphi_{AUB} \quad (6)$$

In this section, a QoS platform cooperation scenario is analyzed for a scenario with three platform operators A, B and C. While operators A and B have equal characteristics and host little content but a considerable number of consumers, operator C is a content-heavy network with a small number of consumers. Table 1 provides an overview on the operator characteristics.

QoS Platform Operator	A	B	C
Aggregated Popularity of Content Providers	$\sum_{z \in Q_A} k_z = 1$	$\sum_{z \in Q_B} k_z = 1$	$\sum_{z \in Q_C} k_z = 12$
Number of Consumers	$x_A = 4$	$x_B = 4$	$x_C = 1$

Table 1. Platform Cooperation Scenario with three Operators

With these three operators, we design a one stage two player game, in which the operators A and B both have a set of two strategies: cooperation and no cooperation. If both operators decide to cooperate ( $s_{12}$ ,  $s_{22}$ ), they form a platform cooperation prior to interconnecting with operator C. If one operator opts for cooperation and the other one against it ( $(s_{12}, s_{21})$  or  $(s_{11}, s_{22})$ ), the cooperating operator enters into a cooperation with operator C prior to interconnecting with the other operator. If both operators decide not to cooperate ( $s_{11}, s_{21}$ ), all three operators interconnect at once. Table 2 depicts all four possible constellations.

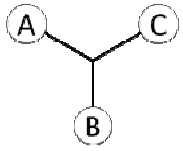

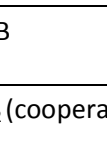

		Operator B	
		$s_{21}$ (no cooperation)	$s_{22}$ (cooperation)
Operator A	$s_{11}$ (no cooperation)		
	$s_{12}$ (cooperation)		

Table 2: Cooperation Strategies and Outcomes

If both operators A and B follow a no cooperation strategy ( $s_{11}, s_{21}$ ), the three platform operators enter the cooperation simultaneously. The share of the overall platform revenues received by operators A and B according to equation (5) are the following:

$$\varphi_A = \varphi_B = \frac{x_A \sum_{z \in \{Q_A, Q_B, Q_C\}} k_z + (x_A + x_B + x_C) (\sum_{v \in Q_A} k_v)}{2(x_A + x_B + x_C) \sum_{z \in \{Q_A, Q_B, Q_C\}} k_z} = \frac{4 * 14 + 9 * 1}{2 * 9 * 14} = \frac{65}{252}$$



If both operators A and B both follow the cooperation strategy ( $s_{12}, s_{22}$ ), they enter a cooperation before confronting operator C. In the initial cooperation between A and B, the share  $\varphi_{A/B}$  determines the future share received by A of the joint proportion of the revenues generated by the cooperation of A and B with C ( $\varphi_{AUB}$ ). It is determined the following way:

$$\varphi_{A/B} = \varphi_{B/A} = \frac{x_A \sum_{z \in \{Q_A, Q_B\}} k_z + (x_A + x_B) (\sum_{v \in Q_A} k_v)}{2 (x_A + x_B) (\sum_{v \in \{Q_A, Q_B\}} k_v)} = \frac{4 * 2 + 8 * 1}{2 * 8 * 2} = \frac{1}{2}$$

Operator A's share of the revenues generated by the joint cooperation with C is represented according to equation (6) by the following term:

$$\begin{aligned} \varphi_A &= \varphi_{A/B} * \varphi_{AUB} = \frac{1}{2} * \frac{(x_A + x_B) \sum_{z \in \{Q_A, Q_B, Q_C\}} k_z + (x_A + x_B + x_C) (\sum_{v \in \{Q_A, Q_B\}} k_v)}{2 (x_A + x_B + x_C) \sum_{z \in \{Q_A, Q_B, Q_C\}} k_z} \\ &= \frac{1}{2} * \frac{8 * 14 + 9 * 2}{2 * 9 * 14} = \frac{65}{252} \end{aligned}$$

If operator A decides to cooperate and operator B opts against a cooperation ( $s_{12}, s_{21}$ ), A enters a cooperation with C prior to interconnecting with B. The share  $\varphi_{A/C}$  has to be calculated prior to  $\varphi_A$ :

$$\varphi_{A/C} = \frac{x_A \sum_{z \in \{Q_A, Q_C\}} k_z + (x_A + x_C) (\sum_{v \in Q_A} k_v)}{2 (x_A + x_C) (\sum_{v \in \{Q_A, Q_C\}} k_v)} = \frac{4 * 13 + 5 * 1}{2 * 5 * 13} = \frac{57}{130}$$

Operator A's share of the revenues generated by the joint cooperation with B is calculated as follows:

$$\begin{aligned} \varphi_A &= \varphi_{A/C} * \varphi_{AUC} = \frac{57}{130} * \frac{(x_A + x_C) \sum_{z \in \{Q_A, Q_B, Q_C\}} k_z + (x_A + x_B + x_C) (\sum_{v \in \{Q_A, Q_C\}} k_v)}{2 (x_A + x_B + x_C) \sum_{z \in \{Q_A, Q_B, Q_C\}} k_z} \\ &= \frac{57}{130} * \frac{5 * 14 + 9 * 13}{2 * 9 * 14} = \frac{3553}{9100} \end{aligned}$$

The proportion of revenues allocated to operator B in this scenario equals operator B's share in ( $s_{11}, s_{21}$ ). One can now gather the respective revenue shares as the utilities in a two-player game (Fudenberg and Tirole 1991) in the strategic form (Table 3).

For both players the cooperation strategy weakly dominates the no cooperation strategy. Hence, the strategy pair ( $s_{12}, s_{22}$ ) represents a dominant strategy equilibrium. This equilibrium is not pareto efficient, because the strategy pairs ( $s_{12}, s_{21}$ ) and ( $s_{11}, s_{22}$ ) yield better payoffs for one operator without subjecting the other partner to worse conditions.

Even though the model presented above allows to analyze cooperation strategies in a specific simple scenario, it does not allow analyzing QoS interconnection at a sufficient level of complexity. This is due to the underlying assumptions as well as to the game design. Regarding the model assumptions, it is not realistic, that content providers follow a single-homing strategy. Moreover, consumers will change their access providers according to criteria such as price and quality. Hence, it is a severe limitation to ignore the competition of platform operators for consumers. Furthermore, the model assumes that all possible transactions are carried out on the platform. In reality, consumer demand varies among customers and

over time. In addition, contrary to the model, the benefits of consumers and content providers per transaction is not equal.

		Operator B	
		$s_{21}$ (no cooperation)	$s_{22}$ (cooperation)
Operator A	$s_{11}$ (no cooperation)	$(\frac{65}{252}, \frac{65}{252})$	$(\frac{65}{252}, \frac{3553}{9100})$
	$s_{12}$ (cooperation)	$(\frac{3553}{9100}, \frac{65}{252})$	$(\frac{65}{252}, \frac{65}{252})$

Table 3: Strategic Form of the Two Player Game

A dynamic game with incomplete information (Fudenberg and Tirole 1993, pp. 319-434) could possibly take into account a higher level of complexity. Nevertheless, the identification of Bayesian Nash Equilibriums for this type of games with a large number of participating players is computationally highly complex and solutions are only proposed for a small number of special cases (Singh 2004).

## 4. Outlook on the Agent based Simulation of the QoS Interconnection Market

The QoS interconnection market encompasses global interaction patterns, player specific strategies, local interactions and market wide regularities. In order to assess the market complexity in a quantitative manner, we pursue a bottom-up modeling approach by using agent-based computational economics (ACE).

### 4.1 Theory of ACE

ACE is the study of economic processes that are being modeled as dynamic system of interacting agents which do not necessarily have perfect information and rationality (Tsfatsion and Judd 2006, xi). In contrast to standard economic models, ACE does not require equilibrium conditions which are common

in macroscopic models because modeling is done on the microscopic-level. Thus, ACE is particularly suited for the analysis of constantly evolving systems which comprise agents adapting to their surrounding and engaging in dynamic relationships. Furthermore, ACE is an opportune modeling technique if structural changes in the macro-level are the result of the simulation and not its input (North and Macal 2007, 93).

The flexibility of ACE models is gained at the expense of the obligation to model all relevant aspects that influence agent interactions. This can be a difficult process as empirical studies and data do often not include all necessary information to model individual decision behavior and derive a realistic level of agent heterogeneity. This implies that modelers have to work with hypotheses and stochastic distributions in order to compensate the missing data. Given that the mechanisms of individual network interaction are sufficiently understood, modelers can assign initial agent properties and strategies which constitute the basis for the agent interaction model.

The interaction of agents can be described as a two-step procedure. In the first step agents perceive their environment and global simulation parameters. The agent environment consists of other agents which pursue certain strategies and have existing relations. In a second step the agent reacts with a specific interaction which changes the simulation and variable agent properties (Deckert and Klein 2010). The repeated interaction of heterogeneous agents produces emergent properties which in turn influence the interaction patterns of the agents and can serve as the basis for the analysis of the macro system (Tsfatsion and Judd 2006, 837).

## ***4.2 Applicability of ACE for the analysis of QoS Interconnection***

In section 3.2 we established a simple model in which cooperative QoS Interconnections increase the payoffs of two players. However, today's internet ecosystem is much more complex as it consist of over 30,000 autonomous systems (Damdhare und Dovrolis 2008, Huston 1998, 13). The interaction between networks of this market is characterized by emergent effects and network effects between heterogeneous market participants.

The previous section stated that ACE is particularly suited for the analysis of heterogeneous agent environments. It is our preferred method for modeling the QoS Interconnection market as agents in this environment can be characterized as heterogeneous for a number of reasons. Publicly available data shows that CP, LTP and STP differ largely in the number of peering points, network scope, traffic levels and peering policies (PeeringDB 2010). Furthermore, it is obvious that networks differ with regard to the number of traffic consuming customers, transit providers and peering partners.

Section 4.1 stated that ACE is the preferred method for micro-level modeling of ecosystems. This is particularly true if network effects between agents produce emergent effects on the macro-level which are the subject of analysis. In reality a strategic decision of one network will

usually influence the decisions of other networks in the neighborhood. For the purpose of modeling the interconnection market we will assume that an agent belongs to the neighborhood if and only if the agents have at least one peering point in common. The combination of network heterogeneity and network effects results in agent specific thresholds for the execution of actions. This results in situations where agents of the same type will choose different interconnection partners because their properties are marginally different (Deckert and Klein 2010).

Several authors showed in recent publications that modeling the network interaction process with ACE can evolve emergent network properties like global interaction patterns and market wide regularities (Li et al. 2004, Chang and Jamin 2006, Dhamdhere and Dovrolis, 2009). These papers improved the understanding of network interactions in the current existing internet which are focused on peering and transit negotiations between networks. However, these research approaches have not yet been applied to the question of how the internet topology and profits will change when QoS interconnection strategies will be introduced to the internet ecosystem.

We aim to close this research gap by proposing an agent interaction framework which enables the analysis of QoS interconnection dynamics and the evolving emergent properties for the internet ecosystem.

### ***4.3 Short Description of the ACE Model***

In this section we propose a novel agent interaction model for the assessment of QoS interconnection strategies and its interaction with the current Best Effort internet. In a first step we are therefore modeling the current Best Effort Internet based on real world observations of the current interconnection market and analyses of publicly available interconnections data (CAIDA 2010).

Data analyses confirm an internet topology as described in section 2. We can affirm that the internet topology has a hierarchical structure and consists of largely different network types which can be categorized in LTPs, STPs, ECs and CPs based on their level in the hierarchy. We are modeling this hierarchy for the Best Effort Internet based on CAIDA (2010) interconnection data and calculate traffic flows for existing interconnections based on a mechanism proposed by Gao and Wang (2002).

In order to calculate the revenue streams and financial fitness of an ISP it is necessary to model the income and the costs of the interconnections which are determined by transit prices and peering costs. For this purpose we will use a transit price function that considers economies of scale for bit-price costs and exhibits a network specific multiplier as proposed by Dhamdhere

and Dovrolis (2008). We determine the parameters of the transit price function based on an analysis of Telegeography data and identify a price spread between low- and high-quality VPN products (Telegeography 2010). Further calculations are based on the assumption that the determined price-spread of 20 percent is a representative surcharge customers are willing to pay for a QoS-service as opposed to BE transit.

Peering costs comprise collocation costs, peering point membership fees, IX port costs, equipment- and circuit costs (Norten 2002, DrPeering 2010). We assume that expenses for ports, circuits and equipment are variable and account for 75 percent of the overall peering costs. The remaining 25 percent are assumed to be fixed monthly membership fees and collocation costs. Based on a regression analysis of publicly available pricing information we propose a function for the determination of the monthly peering costs. For simplicity reasons we will not consider changes in the Best Effort internet topology. Hence, a network's financial fitness will primarily be determined by its ability to establish and maintain QoS interconnections.

The main contribution of our framework is the analysis auf QoS interconnections which are being introduced to the current BE internet ecosystem. We are therefore proposing potential QoS interconnection strategies for the SPP regime. The concept of cascading payments allows us to make two key assumptions about reasonable QoS interconnections strategies for the different network types within the internet topology. First, we make the obvious proposition that CP networks are price sensitive as they will have to pay for their originated QoS traffic. However, CP also have to extend their coverage in order to reach their potential customers who are willing to pay for QoS-content. For simplicity reasons we assume that CPs accept every proposed QoS interconnection price until a coverage threshold is reached. The residual QoS demand is covered by QoS transit providers with the lowest price. Our second assumption embraces that LTPs and STPs are pursuing pure QoS coverage strategies.

Based on these key assumptions we propose a QoS interconnection mechanism which will be designed as follows.

1. Every network determines a ranking of different QoS interconnection options based on an analysis of the agent- and the model-environment. This ranking incorporates coverage optimization and cost reduction criteria.
2. An QoS interconnection will be established with the highest ranked network, given that this interconnection will increase this network's coverage or reduce this network's interconnection costs.

After a new QoS interconnection is established, spare interconnections will be removed as every interconnection is associated with fixed costs.

Based on our key assumptions we are able to calculate traffic and revenue streams for the BE and the QoS model. Subsequently we can calculate the aggregated network revenues and

identify optimal QoS interconnection strategies for different network types. The complete simulation cycle is depicted in Figure 1.

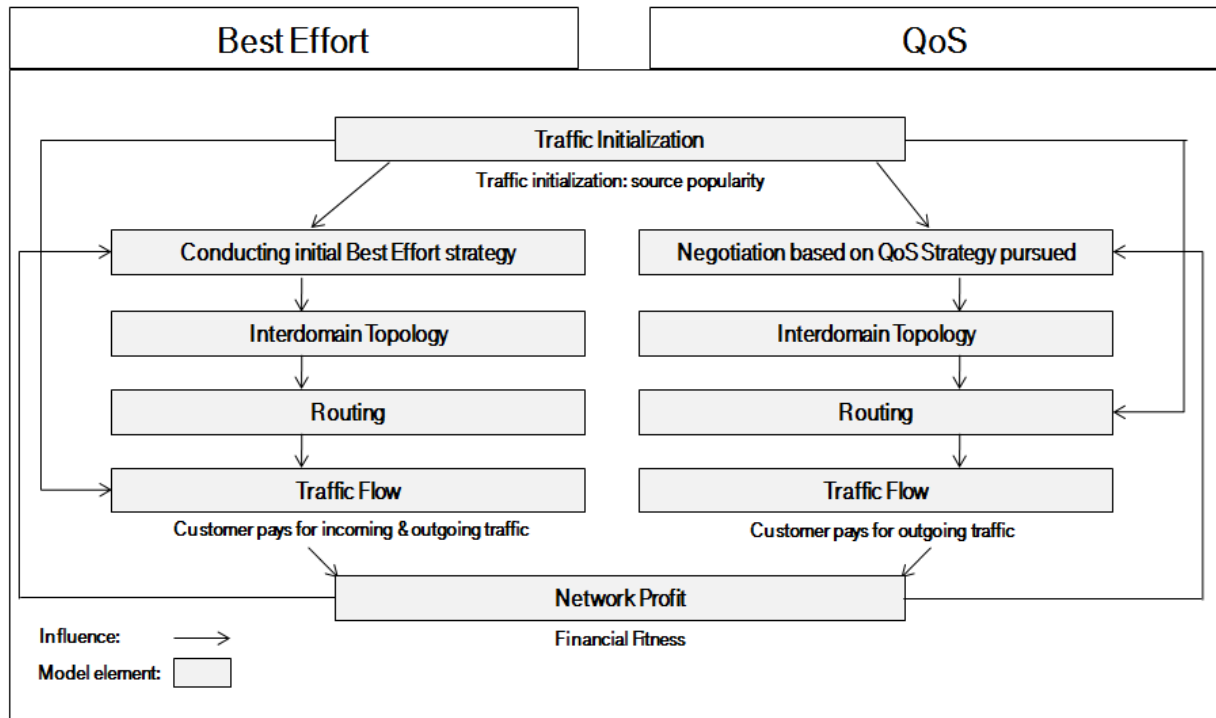


Figure 1: ACE Simulation cycle

## 5. Conclusion

Today's internet carriers are faced with the continuous diffusion of data intensive services and the prospect that IP data transit with differentiated quality levels potentially represents the means to support innovative internet offerings. Furthermore, some experts argue that carriers need to have quality differentiating mechanisms on hand in order to guarantee agreed service levels in case of severe internet failures. Carriers are therefore interested in the establishment of QoS interconnections. While on the technology layer, approaches for the implementation of QoS mechanisms have been extensively discussed, on the economic layer, carriers have difficulties to predict possible profits.

In this paper we present a value-oriented modeling approach for the assessment of the QoS interconnection market. This approach is based on the economics of two-sided markets and takes cross-side market externalities between networks into account. It enables the calculation of the overall platform revenues and uses the Shapley-value for distributing the cooperative gains. We apply this game theoretic approach in a simple model showing that cooperation can constitute a dominant strategy equilibrium. However, a revisal of our model puts its applicability to the complex QoS interconnection market into question as real world influences such as multi-homing strategies, competition for

customers and demand variations are not taken into account. The utilization of more sophisticated game theoretic modeling approaches is limited due to the computational complexity that goes along with a realistic number of players.

In order to cope with a realistic number of players and a higher level of complexity, we are proposing the use of a bottom-up, agent-based model. We account for the heterogeneity of networks by incorporating real-world data from CIADA (2010) and peeringDB (2010) in our model. Furthermore, we propose network type specific agent strategies for the establishment of QoS interconnections and impose an agent interaction mechanism. We suggest to calculate the financial carrier fitness based on routing information, peering costs and transit prices. Subsequently we are able to analyze QoS interconnection strategies in a quantitative manner.

Our novel micro-level modeling approach enables the analysis of QoS interconnection strategies. We aim to analyze macro-level simulation results and derive implications for the network type specific optimal interconnection strategies. Furthermore, we will use our model in order to analyze transient, none-equilibrium conditions. That is, we will focus on the introduction process of QoS interconnections to the BE internet ecosystem.

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