THE BALANCE OF POWER IN SERVICE VALUE NETWORKS

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Abstract

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Keywords: Service value network, business web, modularization, complex service, balance of power, power ratio, cooperation, cooperating game theory

Introduction

Complete industries are moving from vertical integration to horizontal specialization. Hierarchically organized firms started to cooperate in firmly-coupled strategic networks with stable inter-organizational ties, recently exploring the benefits of moving to more loosely-coupled configurations of legally independent firms.

In theory, the complex products or services could be produced by a single vertically integrated company. But in this case the company cannot focus on its core competencies, having to cover the whole spectrum of the value chain. Also, it has to burden all the risks in a complex, changing and uncertain environment by itself. This is why companies tend to engage in networked value creation which allows participants to focus on their strengths. Partners in such ecosystems can leverage the know-how and capital assets of partners, at the same time spreading risk and sharing investment cost. Focusing on core competencies does not put constraints on the company or limit the reach of it. In contrary, by re-aggregating with partners a company can broaden its range of customer attractions. Especially in complex and highly dynamic industries, forming value networks – especially business webs with their open structure - is more than an attractive strategic alternative. Prominent advocates of this new paradigm are (Hagel III 1996, Tapscott et al. 2000, Zerdick et al. 2000, Steiner 2005). As (Tapscott et al. 2000, Steiner 2005) express it, business webs bring together mutually networked, permanently changing, legally independent actors in customer centric, mostly heterarchical organizational forms in order to create (joint) value for customers. Specialized firms co-opetitively contribute modules to an overall value proposition under the presence of network externalities.

Information and communication technology can be interpreted as fundamental drivers towards modularization and collaboration in business webs. Far-reaching progress in the field of ICT has significantly reduced transaction and coordination costs. Today, the benefit of integrating partners and customers in intra-company processes and communication networks has exceeded its costs many times over.

A prime example for such highly dynamic fields of application is the software industry, moving its service offerings towards an internet of services. Within this web, specialized service providers begin to leverage their core competencies in smaller, loosely-coupled service value networks in order to offer joint complex services. (Zerdick et al. 2000) summarize the advantages of such business webs related to modularization and specialization:

- Concentration on core competencies strengthens specialization (A1)
- Risk sharing (A2)
- High level of flexibility (A3)
- Modularization brings potential for innovation and allows for rapid market penetration (A4)
- Partners in the business web provide access and leverage extensive resources (A5)
- Fruitful interplay of competition and partnership (co-opetition) (A6)

In such highly decentralized environments, service intermediaries, linking together demand and supply, might play an important role. Such service brokers add value by acting as an infomediary or by assembling compatible, but modular services. Playing the intermediary, the service broker does not own all or even most necessary assets. Instead it acts as coordinator, integrator and interface, to bring together all partners accordingly.

Hence, in service ecosystems, a multitude of players are connected, whereas the configuration of collaboration does not result in a complete graph. We have to consider not only the identities of the players, but also their connection to other players in the network. If two players are connected basically depends on two factors - functional and strategic criteria. However, in this paper, we do not consider how such networks evolve, rather we assume that an initial topology already exists and is public knowledge.

Objective of this paper is to express the balance of power in such service networks. Therefore, we elaborate on and extend existing models from microeconomic theory introduced by (Shapley 1953) and extended by (Myerson 1977, Jackson 2005a). Thereby, important characteristics of service value networks, namely costs to links, paths through the network representing feasible complex services, and the flexible interchangeability of service providers are incorporated. We intend to make assumptions on the relationship between the relative power of service providers in a network and the costs incurring for the invocation of their service offering. Most importantly, the model shall include the whole network topology, not only those players contributing to the service offered.

Thus, the contribution of our work is two-fold. On the one hand, we extend above-mentioned concepts to the characteristics of service networks. On the other hand, we apply these theoretical considerations and findings to a real-world scenario by implementing the model as an information system and conducting a simulation illustrating how the loss of power of players in a network correlates with increasing cost to links.

This paper is organized as follows. The next section provides a literature overview on microeconomic concepts dealing with the allocation of value among players in coalitions and networks as well as their formation. Subsequently, we illustrate the idea of a service value network by introducing a business scenario "service request & order management". After formalizing the scenario, we proceed with extending existing approaches by (Shapley 1953, Myerson 1977, Jackson 2005a) in order to express the power ratio of individual players and the balance of power in the whole network. For the realization of our model, we describe its implementation as an information system, followed by a complexity consideration. A simulation shall then give an overview on the behavior of the power ratio subject to changing costs to links. The paper concludes with a summary and a survey of our further research agenda.

Literature Overview

In the area of cooperating game theory, there is a multitude of concepts dealing with the allocation of value among players. Considering coalition games (V,χ) with a finite set of players $V=\{v_1,...,v_N\}$ and a value function χ which maps a coalition of players $T \subseteq V$ into real numbers[1], well-known concepts are the core and stable sets introduced by (Von Neumann and Morgenstern 1944) as well as the bargaining solution by (Nash 1950).

The Shapley value (Shapley 1953) differs from above-mentioned approaches. It bases the payoff distribution on the average marginal contribution of a player to a coalition. Hence, it is somewhat of the average power or significance of a player $v_i \in T$. The Shapley value of player v_i expresses the average profit growth she yields to a coalition.

However, these concepts are based on a coalition structure and do not consider restrictions inherent to network topologies. The basic assumption in a coalition is that a player $v_i \in V$ is able to cooperate with any player $v_j \in V$. This holds not true for networked economies, where due to functional or strategic restrictions, not only the players itself, but also the links between them are of prime importance.

Bearing these characteristics in mind, Myerson provided an extension of the Shapley value to network structures (Myerson 1977). His major contribution was to transfer the Shapley value to cooperation graphs. Thus, the range of possibilities to form coalitions is reduced to a given topology and its links, resulting in the following allocation function for a player $v_i \in V$ as a direct extension to (Shapley 1953):

$$Y_i(g,\chi)=\sum_{T_j \subset V \setminus \{v_i\}} \left(\frac{|T_j|!(|V|-|T_j|-1)!}{|V|!} \right) \cdot (\chi(T_j \cup \{v_i\}) - \chi(T_j))$$

Myerson defines a graph g as a list of unordered pairs of linked players $\{v_i, v_j \mid v_i \in V, v_j \in V, v_i \neq v_j\}$.

However, when applying the Myerson value, an implicit assumption inherited from the Shapley value is that a cooperation among more players must always be either more fruitful than a cooperation with less members or at least not less valuable[2]. But what if a smaller coalition of players is able to obtain a certain goal more efficient than a coalition of more players? In other words, considering real world scenarios, larger coalitions might be of lower value than smaller coalitions due to the overhead costs they generate. Yet, the Myerson value does not cover this issue.

Another shortcoming of the Myerson value is the general assumption that the network or the considered sub-network, respectively, is fixed at the time the network value is being allocated.

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[1] Formally, χ indicates how much value a given coalition can generate.

[2] The Myerson value requires superadditivity. Thus, $\forall T_1 \subseteq V$ and $\forall T_2 \subseteq V$, if $T_1 \cap T_2 = \varnothing$ then $\chi(T_1 \cup T_2) \geq \chi(T_1) + \chi(T_2)$.

Bearing in mind that larger networks oftentimes come along with higher costs and less efficiency than smaller networks, Jackson extended Myerson's approach (Jackson 2005a). His main concern was to consider alternative possible (sub-)networks of g that might have formed instead of the network at hand. Thus, Jackson interprets networks as a formation being flexible and subject to change over time.

In more detail, Jackson replaces value functions by monotonic covers $\hat{\chi}$ of the value function for all $g' \subseteq g$ with $\hat{\chi}(g) = \max_{g' \subseteq g} \chi(g')$ of value functions. Thereby, it is possible to assign higher value functions to g' than to g with $g' \subset g$. Furthermore, (Jackson 2005a) includes an extension term for inefficient networks, following the findings of (Jackson and Wolinsky 1996, Dutta and Mutuswami 1997, Jackson 2005b). They point out that the sets of stable networks and efficient networks do not always intersect. Consequently, inefficient networks in terms of created value must not be disregarded when allocating value among players of a network.

Let g^{T_j} be the complete network incorporating all possible relationships among players in $T_j \subseteq V$. For the allocation function primarily based on the vital players in a network (player-based flexible network rule, PBFN[3]), he introduces the following formula:

$$Y_i^{PBFN}(g,\chi) = \frac{\chi(g)}{\hat{\chi}(g)} \sum_{T_j \subset V \setminus \{v_i\}} (\hat{\chi}(g^{T_j \cup v_i}) - \hat{\chi}(g^{T_j})) \left(\frac{|T_j|!(|V| - |T_j| - 1)!}{|N|!} \right)$$

Another related scientific direction of impact studies the very formation of networks from various perspectives. Several game theoretic insights to network formation have been provided. (Jackson 2005b, Nouweland 2005) provide a far-reaching overview on cooperative game theoretic approaches to network formation, (Bala and Goyal 2000) base their approach upon non-cooperative game theory. However, their approaches act upon the assumption that a certain set of players is given with the basic design that notionally links can be formed between each and every player. A promising, non-game theoretic approach has been taken by (Axelrod and Bennett 1993) who used landscape theory to simulate the formation of coalitions. To this end, they initialized a handful of rather simple parameters adequately circumscribing the players involved. This approach was extended to standard setting coalitions by (Axelrod et al. 1995).

In this paper we will not elaborate on the formation of networks, taking the existing topology as given. However, prefacing our model to express the power balance in networks, we will identify and elaborate a suitable approach to investigate the formation process in service value networks in our further course of research.

Business Scenario

To illustrate the idea of a service value network we introduce a business scenario which is actually delivered to customers as part of an enterprise resource planning software. The software is developed by a major company for business solutions and focuses on the needs of small and medium enterprises.

Integration Scenario "Service Request & Order Management"

The integration scenario "service request & order management" describes operational processes in a customer service and support center based on service requests, service orders and service confirmations. From an end-to-end perspective the scenario includes the integration into related applications such as logistics planning and execution, invoicing and payment, as well as financial accounting (cp. Figure 1).

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[3] Jackson's studies also resulted in an allocation rule that emphasizes the importance of links between players, the link-based flexible network allocation rule (LBFN). However, we will not elaborate on the LBFN in this paper.

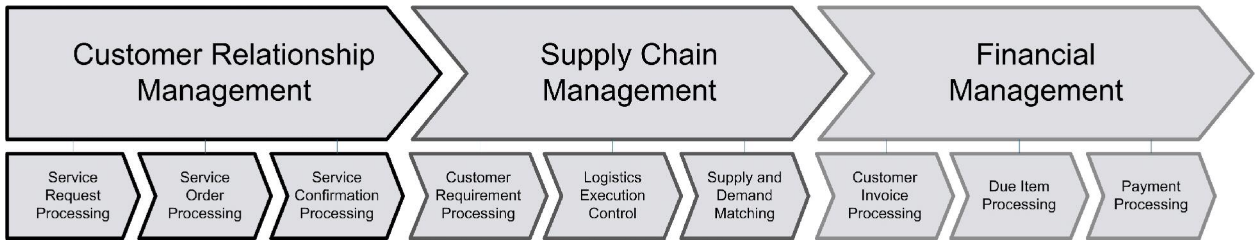

Figure 1. Business process "service request & order management"

The *customer relationship management* component comprehends functionality such as *service request processing, service order processing* and *service confirmation processing*. *Service request processing* is used in a service help desk to log and resolve customer issues reported to a service provider. Resolving a service request can include forwarding of the request between different processors depending on the required level of expertise. Work effort spent by a processor on resolving an issue can be captured in the service request. *Service order processing* includes performing availability check and triggering logistics planning and execution for required spare parts as well as date scheduling of service tasks to be assigned to service engineers for order execution. *Service confirmation processing* manages information objects that contain the actual amount of working times spent and parts consumed for service orders as reported back by service engineers after job execution. The data serves as a basis for customer invoicing and cost accounting for service orders.

Supply chain management is involved in the integration scenario in order to manage service order spare part logistics. This encompasses planning functions such as *customer requirement processing*, *Logistics execution control* and *supply and demand matching* for spare part items. *Customer requirement processing* analyzes customers' requirements to guarantee their satisfaction from a *supply and demand matching* perspective. *Logistic execution* triggers the supply of required spare parts if necessary.

Receivables and payables from invoices are processed by the *customer invoice processing* component. Furthermore the *financial management* controls receivables and payables from goods and services, as well as from corresponding sales and withholding tax. It is responsible for paying, clearing, and reporting open receivables and payables, for example, for tax declaration or customer statement. In addition the component *due item processing* provides services for collecting and dunning outstanding receivables. The actual liquidity flows are triggered by *payment processing*.

Decentralized Service Providers

A *service value network* is formed by decentralized service providers that contribute to the achievement of an overall goal. In our scenario this goal is the flawless execution of a business scenario in order to provide defined functionality to the customer. From now on we call this overall goal a *complex service*. Recalling the main characteristics of service value networks there are many service providers that offer differentiated and specialized services covering various functionality within the network. In our scenario the functionality of each component can be modularized and consequently performed by different software-as-a-service providers as depicted in Table 1.

The rapid upcoming of on-demand service providers shows the high degree of innovation and market penetration as a result of modularization (A4). Service providers offer specialized services and concentrate on their core competencies (A1). Each service provider is responsible for a certain part of the overall functionality which consequently spreads the risk of an erroneous business process over all contributing service providers (A2). Furthermore they partly grant access to their own resource supporting the realization of the overall business scenario (A5). The potential of an on-demand substitution of service providers enables high flexibility and rapid reaction to changing market requirements (A3). The nature of Service Value Networks implies competition and cooperation of service providers depending on the overall goal they contribute to (A6).

Table 1. SaaS providers for CRM, SCM and FIN components		
CRM	**SCM**	**FIN**
Salesforce (http://www.salesforce.com/)	*GXS* (http://www.gxs.com/)	*Cashview* (http://www.cashview.com/)
Rightnow (http://www.rightnow.com/)	*7Hills* (http://www.7hillsbiz.com/)	*Opsource* (http://www.opsource.net/)
Oracle (http://www.oracle.com/crmondemand/)	*Intacct* (http://www.intact.com/)	
SAP (http://www.sap.com/solutions/sme/businessbydesign/)		

Formalization of the Scenario

The abstract model is a formalization of a Service Value Network containing a *service requester* and *service provider*. It captures the network's characteristics as defined in the introduction using a formal notation. A service value network is represented by a directed and acyclic graph $G = (V, v_S, v_f, E, e_{i,f})$

In real world scenarios, a service provider can own more than one service. For simplicity we assume that each service is owned by a different service provider. Thus, the set of nodes $V = \{v_1, \ldots, v_N\}$ with $|V| = n$ represents the service providers acting in network G. Additionally, there are two designated nodes v_s and v_f that represent the source and the sink of the network. These two nodes are not considered players in the network, hence they are not included in V. Let v_i be an arbitrary player in the service network. The set of edges $E = \{ e_1, \ldots, e_M \}$ denotes the functional possibility of orchestrating two linked nodes. An arbitrary link in the set of edges is denoted as $e_{i,j}$, indicating the possibility of connecting players v_i and v_j. These links are annotated with costs $c_{i,j}$ symbolizing the costs for provider v_j when invoking player v_i's service. There are no costs to the incoming edges of the sink since v_f is not considered a service or player and thus does not invoke any other service offers. Consequently, the links $e_{i,f}$ $\forall v_i \in V$ are not included in E.

Let $\hat{F} \subseteq G$ denote the set of minimally instantiable composite services, i.e. all feasible paths from source to sink. Thus, every $\hat{F}_i \in \hat{F}$ represents a possible instantiation of the complex service. Let $F_i := \hat{F}_i \setminus \{v_s, v_f, e_{i,f}\}\ \forall \hat{F}_i \in \hat{F}$ and $F := \{F_1, \ldots, F_L\}$ with $F \neq \emptyset$

Figure 2 shows a formalization of a service value network. Every feasible path from source to sink represents a possible realization of a complex service. Hence, we can describe the graph shown in figure 2 as $G = (\{v_1, v_2, v_3, v_4, v_5, v_6, v_7\}, \{v_s, v_f\}, \{e_{s,1}, e_{s,2}, e_{s,3}, e_{1,4}, e_{1,5}, e_{2,5}, e_{3,5}, e_{3,6}, e_{4,7}, e_{5,7}\}, \{e_{6,f}, e_{7,f}\})$. This graph shows the network of providers and their connections which are able to meet the requirements of the inquiry posted by the service requester. The model is kept rather simple, we deliberately ignore additional attributes besides the price of the services offered. Moreover, we did not investigate mechanisms for (internal) pricing, as the costs $c_{i,j}$ might not be the price offered by a service provider v_j.

In our model we focus on the core process of realizing an overall goal without going into process-related details such as parallel or cyclic components. We apply a business and management-oriented view addressing the question of how an overall consideration of the balance of power in service value network can be achieved.

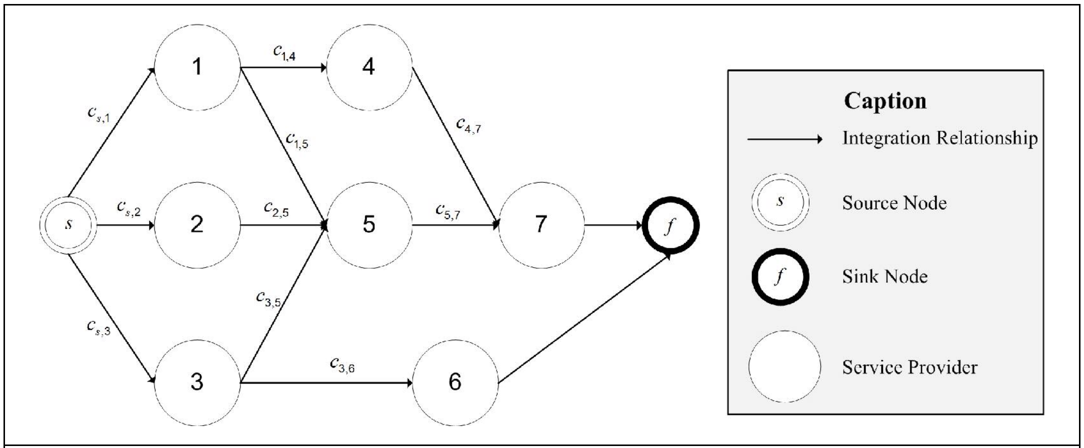

Figure 2. Formalization of a service value network

An Approach to Express the Balance of Power in Service Networks

In this section, we will present our approach to incorporate the requirements of service networks. Costs to links, paths through the network representing feasible complex services, and the flexible interchangeability of service providers are incorporated. We will then compare this approach to Jackson's player-based flexible network rule (Jackson 2005a).

Power Ratio and Balance of Power in Service Value Networks

As above-mentioned, we need to include costs to links $c_{i,j}$, that is our model is to yield the possibility to assign lower value functions to configurations incorporating more players. Since paths from source to sink stand for feasible services, only those are being considered when assigning a value to a set of players and their corresponding links $S_i = (V_i^S, E_i^S) \in S$ with S being the set of all cooperations possible in G. That is, a cooperation S_j with $F_j \not\subseteq S_i \; \forall F_j \in F$ is assigned a value $\chi(S_i) = 0$. For cooperations $S_k \in S$ with $\exists F_j \subseteq S_k$ we need a valuation that is directly dependent on the costs incurred. Consequently, we introduce a value function that reciprocally accounts for the costs of services included into the complex service, adding a correction term $\lambda > 0$ to enforce a solution even if the costs of a path $F_j \in F$ from source to link equals zero.

Thus, we define the value function for cooperations $S_k \in S$ as a function $\chi : S \to \mathrm{R}$ as follows:

$$\chi(S_k) := \begin{cases} \dfrac{1}{\sum_{S_k} c_{i,j} + \lambda}, & \text{if } \exists F_l \subseteq S_k, F_l \in F, S_k \in S \\ 0, & \text{otherwise} \end{cases}$$

We define X as the set of all possible value functions. Without loss of generality we assume that $\lambda = 1$.
Note that we do not interpret the value function allocated to a cooperation S_k as the value this liaison of players and relationships can generate which is then distributed among the player via an allocation function. We rather perceive the value functions as the contribution of S_k to the overall worth or productivity of the network. Remember that we just incorporate the costs incurred by the inclusion of a player (i.e. the service she offers) into the value function. Hence, we do not distribute the value created via Shapley-style calculations, but the influence of a single player relative to the topology of the whole network.

Let S_G be the cooperation of all players and links included in network G. In order to determine the balance of power in a service network, we define an allocation rule as a function $Y : S \times \mathrm{X} \rightarrow \mathrm{R}^n$ such that $\sum_i Y_i(S_G, \chi) = \chi(S_G)$.

Basis for our consideration is always the full given graph G incorporating all possibly involved players V and links E. However, we need to make sure that decreasing value functions with $\chi(S_1 \cup S_2) < \chi(S_1) + \chi(S_2)$, $S_1 \in S$, $S_2 \in S$, $S_1 \cap S_2 = \varnothing$, do not cause any issues like negative allocations as possible when using the standard Myerson value. In order to rectify such problems, we suggest to incorporate merely those players in our calculation that provide additional value. That is, as soon as there is cooperation that yields a path through G, the path providing the highest value is incorporated into the calculation. For example, consider a player v_i that enters an existing cooperation $S_k \supseteq F_j \in F$. Assume that v_i does not provide an additional path through G. Conversely, by entering the complex service offering, player v_i only causes costs without providing additional value for the service consumer. On the other hand, if player v_i joins a cooperation $S_1 \supset F_1$, thereby accounting for a cooperation S_2 with additional path F_2 with $\chi(F_1) < \chi(F_2)$, then $\chi_{\max}(S_2) = \max\{\chi(F_1), \chi(F_2)\} = \chi(F_2)$.

Thus, we define the maximum value of a cooperation $S_k \in S$ as follows:

$$\chi_{\max}(S_k) := \begin{cases} \max_i \chi(F_i), & \text{if } \exists F_i \subseteq S, F_i \in F, S_k \in S \\ 0, & \text{otherwise} \end{cases}$$

Incorporating these maximum value functions into Myerson's allocation function, we get:

$$Y_i(S_G, \chi) = \sum_{S_k \text{ with } V_k^S \subset V \setminus \{v_i\}} \left(\frac{\left|V_k^S\right|!(\left|V\right| - \left|V_k^S\right| - 1)!}{\left|V\right|!} \right) \cdot (\chi_{\max}(S_k \cup \{v_i, E_{S_k,i}\}) - \chi_{\max}(S_k))$$

The set of all incoming and outgoing edges of a node v_i within a cooperation S_k is denoted $E_{S_k,i}$. As soon as a player v_i enters a cooperation S_k, $E_{S_k,i}$ is also added. Thus, formally we distribute the value function assigned to the cheapest path through G. From above-mentioned allocation function, we can calculate a player's relative share in the overall productivity of the network which we interpret as her power ratio (PR) φ_i relative to the overall network:

$$\varphi_i(S_G, \chi) = \frac{Y_i(S_G, \chi)}{\sum_{j \in V} Y_j(S_G, \chi)} = \frac{Y_i(S_G, \chi)}{\chi_{\max}(S_G)}$$

$\Gamma_G = (\varphi_1, ..., \varphi_N)$ shall be the balance of power (BOP) in the network G and does not depend upon the actual value that is distributed.

Applicability of Jackson's Player-Based Flexible Network Rule

We identify two major differences between Jackson's PBFN and our power ratio. The first difference between Jackson's PBFN and our suggestion to express the balance of power in service networks is the scope of consideration. Jackson only puts those players to the test that are directly connected with the value creation and then incorporates all alternative links which are theoretically possible between those players. In contrary, we always consider the whole set of players and links to express the power balance in a network, regardless of which cooperation eventually takes hold. Most importantly, in doing so, we do not consider all theoretically possible alternative links between players, but only the links given through the network topology. That is, we merely incorporate the links that are existent due to functional or strategic dependencies. Secondly, we adapted the value function of a cooperation to the requirements of service value networks by introducing costs to links and a path-dependent valuation of cooperations. That is, we merely assign a value to those cooperations which incorporate a path $F_i \in F$.

Realization

Research on balance of power in coalitions and networks provided by above-mentioned authors is merely theoretical. Implementation of Shapley-like calculations to complex real-world problems with the help of information systems has been provided very scarcely, an application to service value networks has not been provided yet.

In order to process the PR, we implemented our abstract model as an information system as described in the following. Algorithms 1 and 2 are fundamental auxiliary routines. *ComputeSubgraphSet* outputs the set of possible sub-graphs, i.e. cooperations possible in a given graph G. *ComputePathsDFS* calculates the set of paths $\hat{F}$ from source to sink and afterwards prunes source and sink node as well as all incoming links of the sink. Both calculations are pre-requisites for the calculation of the value function for each possible cooperation done in *ComputeValueFunction*. This algorithm assigns the value of the best possible path incorporated in each $S_k \in S$. Algorithms 4 and 5 represent the two major parts of the BOP calculation:

$$\varphi_i = \frac{1}{\chi_{\max}(S_G)} \cdot \sum_{S_k \text{ with } V_k^S \subset V \setminus \{v_i\}} \left(\frac{\left|V_k^S\right|!(\left|V\right| - \left|V_k^S\right| - 1)!}{\left|V\right|!} \right) \cdot (\chi_{\max}(S_k \cup \{v_i, E_{S_k,i}\}) - \chi_{\max}(S_k))$$

ComputeMarginalContribution invokes *ComputeValueFunction* to calculate the value growth if player v_i enters an existing cooperation $S_k^{-i} := \{S_k \mid S_k \in S, v_i \notin S_k, v_h \in S_k, v_j \in S_k, e_{h,i} \notin S_k, e_{i,j} \notin S_k\}$. *ComputeCombinatorics* calculates the number of combinations how the members of S_k^{-i} can enter the cooperation prior to player v_i, divided by the number of all possible permutations of V. *ComputePR* finally determines the allocation function which is then returned as a (relative) power ratio value.

Algorithm 1 *ComputeSubgraphSet*

Require: G
  return S

Algorithm 3 *ComputeValueFunction*

Require: S_k, F
  $U_k = S_k \cap F$
  if $U_k \not\subset F$
    return 0
  else
    for all $F_h \in U_k$
      for all $e_{i,j} \in F_h$
        $\text{out} = \text{out} + c_{i,j}$
      $\text{output} \leftarrow 1/(\text{out}+1)$
  return $\max\{\text{output}\}$

Algorithm 5 *ComputeCombinatorics*

Require: V_k^S, V
  return $\frac{|V_k^S|!(|V| - |V_k^S| - 1)!}{|V|!}$

Algorithm 2 *ComputePathsDFS*

Require: G
  return F

Algorithm 4 *ComputeMarginalContribution*

Require: $S_k, F, v_i, E_{S_k,i}$
  Return
    $\mathit{ComputeValueFunction}(S_k^{-i} \cup \{v_i, E_{S_k,i}\}, F) -$
    $\mathit{ComputeValueFunction}(S_k^{-i}, F)$

Algorithm 6 *ComputePR*

Require: G, v_i
  $F = \mathit{ComputeSubgraphSet}(G)$
  $S = \mathit{ComputePathsDFS}(G)$
  For all S_k^{-i}
    $\text{out} = \text{out} + \mathit{ComputeCombinatorics}(V_k^S, V) \cdot$
    $\mathit{ComputeMarginalContribution}(S_k^{-i}, F, v_i, E_{S_k,i})$
  return $\text{out} / \mathit{ComputeValueFunction}(S_G)$

Above-described algorithms calculate the power ratio which serves as a basis for continuative examinations on the relationship between costs of invocation and strength of single players. Therefore, a simulation setting is to be determined for which we also provide a preparative survey on the complexity of our algorithms.

Simulation

In this section, we apply a simulation approach to study the behavior of the power ratio with increasing costs to links. In particular, we examine the relative changes in the power ratio of a player before and after a player drops of the cheapest path[4].

Simulation Model

As a first simplification to the formal model presented in the Formalization of the Scenario, we deliberately disregard service providers that offer a bundled service as player v_6 does shown in Figure 2. Consequently, a service value network is represented by a k-partite, directed and acyclic graph. Each cluster or part represents a specific class of functionality. We assume that each of the k sub-service classes is required to offer the complex service demanded by a service requester. Let player v_i^α denote that player v_i belongs to cluster $\alpha \in \{1,...,k\}$ and V^α the set of nodes allocated to cluster α. Edges are only possible between nodes of consecutive clusters. Source and sink are not considered a cluster. In case of v_s, there are no incoming edges and one outgoing edge to each node of the first cluster. Analogously, the sink has no outgoing edges, but one incoming edge from each of the nodes of the last cluster. Generally, each v_i with $i \neq s$ and $i \neq f$ must at least have one incoming and one outgoing edge. A valid graph G_1 is depicted in Figure 5.

Complexity

To determine the overall complexity of calculating φ we focus on the computing intense functions such as *ComputePathsDFS* and *ComputeSubgraphSet*. Less computing intense functions result in a linear complexity and are therefore ignored.

Assuming a graph meeting above-mentioned requirements with N nodes and k clusters, the maximum number of edges evolves as follows:

$$|E| = |V^1| + |V^k| + \sum_{l=1}^{k-1} (V^l \cdot V^{l+1}) \in O(N)$$

Consequently, the complexity of the depth-first-search applied to identify all feasible paths through G is $O(|V| \cdot |E|) = O(N \cdot N) = O(N^2)$.

The complexity of the calculation of the set of sub-graphs as a requirement for our allocation rule is exponentially, there are 2^N sub-graphs in a graph G with $|V| = N$ nodes. Therefore, the complexity of *ComputeSubgraphSet* yields $O(2^N)$.

In summary, the calculation of the PR exhibits exponential complexity.

Simulation Setting

We conduct simulations with $N = 9$ nodes plus source and sink in 100 arbitrary chosen topologies G_l. These topologies meet above-mentioned characteristics. We choose $k = 3$ and $|V^\alpha| = 3$. Due to the essence of Shapley-style calculations, the computational complexity increases exponentially with increasing number of nodes.

[4] The *cheapest path* shall also be denoted as the *best path* in the following.

Therefore, we limited the number of players to $N = 9$. Out of maximally $|E| = 24$ edges, we randomly draw links with a density of 0.8 in each simulation run. The costs to links are drawn from a uniform distribution in the interval $[0.1,1]$ with increments of 0.1. Each simulation run has $Z = 10$ sub runs. For a sub run, an edge $e_{i,j} \in \overline{E} \setminus \{e_{h,f} \mid v_h \in G_l\}$ is drawn randomly and reset. Its cost $c_{i,j}$ is then incrementally set to $c_{i,j} \in [0.1,1]$, meaning that in the first sub run $c_{i,j} = 0.1$, in the second $c_{i,j} = 0.2$ and so on ending with $c_{i,j} = 1.0$ in the tenth sub run. For each of these sub runs, we calculate the power ratio φ_j of player v_j the chosen edge $e_{i,j}$ is an incoming link for.

We choose 100 arbitrary topologies each with 10 sub runs, drawing a random link the graph in order to eliminate stochastic dependencies.

Discussion

We are aware of the fact that, if the randomly drawn link $e_{i,j}$ is not part of the best path through G_l, yet the corresponding and considered player v_j can be on the best path via another link $e_{h,j}$ (with $v_h \in G_l$). However, by choosing 100 random topologies, we claim that we can diminish such effects. This argument is supported by a first analysis of the simulation data (cp. Figure 3). The diagram shows the power ratio of a player v_j (PR_j) and the probability of her being situated on the best path $(p\_j(BestPath))$ dependent on the cost $c_{i,j} \in [0.1,1]$ aggregated over all 100 topologies. One sees that with $c_{i,j} = 0.1$, v_j is situated on the best path with $p = 0.52$, continuously decreasing to $p = 0$ for $c_{i,j} = 1.0$. Thus, we argue that there is a clear dependency between the costs $c_{i,j}$ of the randomly drawn edge and both player v_j's power ratio and her being on the best path or not. Our sample seems to sufficiently rule out alternative links of v_j being situated on the best path.

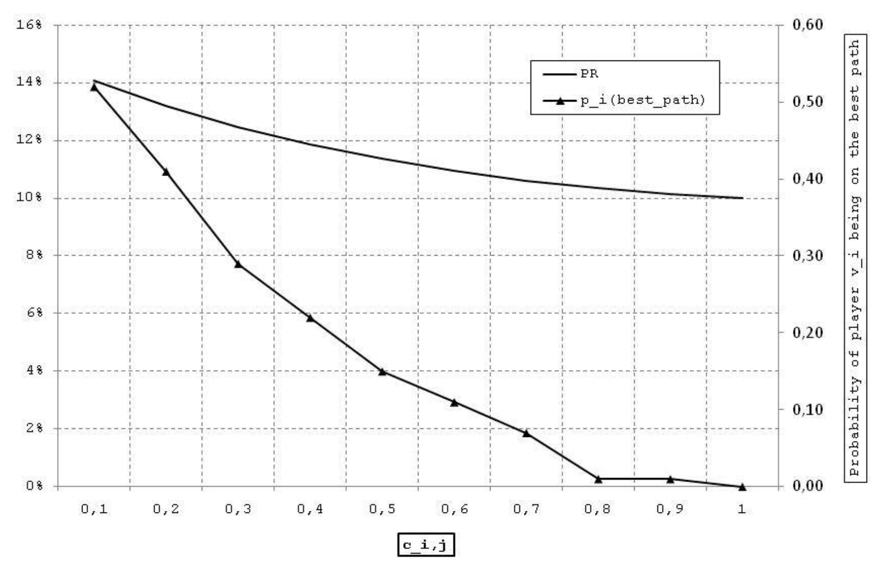

Figure 3. Analysis of average values of power ratio and probability of player v_j to be situated on the best path dependent on varying costs $c_{i,j}$

Effects on the Power Ratio if a Corresponding Link Drops Off the Best Path

Now we turn our attention to how the randomly drawn edge $e_{i,j}$ with varying costs $c_{i,j}$ impacts on player v_j's power ratio. In order to examine the behavior of the power ratio of player v_j at the moment the link drifts off the best path due to increasing costs, we deleted all topologies where $e_{i,j}$ is never on the best path. This leaves us with 52 out of 100 arbitrary topologies. Out of these 52 topologies, we aggregate all topologies where the cut from $e_{i,j}$ being on the best past to being off the best past occurs after the same increment. Based on this categorization, we are able to study the change in the power ratio for player v_j for a certain $c_{i,j}$ over all aggregated topologies. $\Delta\varphi_j^c$ expresses the relative change of φ_j with the costs associated to $e_{i,j}$ rising from $c_{i,j}-0.1$ to $c_{i,j}$:

$$\Delta\varphi_j^c = \frac{\varphi_j^c - \varphi_j^{c-0.1}}{\varphi_j^{c-0.1}}$$

In Table 2, we outline the cut c_{off} (meaning that the cut occurs after $c_{i,j} = c_{off}$) in two different ways. In columns 3 and 4 we merely compare the single values $\Delta\varphi_j^{c_{off}}$ and $\Delta\varphi_j^{c_{off}+0.1}$ whereas we compare the average of all values before the cut $\frac{1}{|l \le c_{off}|}\sum_{l \le c_{off}} \Delta\varphi_j^l$ and the values afterwards $\frac{1}{|l > c_{off}|}\sum_{l > c_{off}} \Delta\varphi_j^l$ in columns 5 and 6.

Table 2. Relative change of aggregated power ratio

Position of cut c_{off}	Number of topologies in sample	$\Delta\varphi_j^{c_{off}}$	$\Delta\varphi_j^{c_{off}+0.1}$	$\frac{\sum_{l \le c_{off}} \Delta\varphi_j^l}{\lvert l \le c_{off}\rvert}$	$\frac{\sum_{l > c_{off}} \Delta\varphi_j^l}{\lvert l \le c_{off}\rvert}$
$c_{off} = 0.2$	12	-0.1096	-0.0519	-0.1096	-0.0322
$c_{off} = 0.3$	7	-0.0852	-0.0470	-0.0825	-0.0291
$c_{off} = 0.4$	7	-0.1009	-0.0663	-0.0959	-0.0457
$c_{off} = 0.5$	4	-0.0948	-0.0673	-0.0874	-0.0405
$c_{off} = 0.6$	4	-0.0875	-0.0572	-0.0775	-0.0381
$c_{off} = 0.7$	6	-0.0668	-0.0425	-0.0630	-0.0371
$c_{off} = 0.9$	1	-0.1443	-0.0718	-0.1039	-0.0718
Weighted average		**-0.0949**	**-0.0547**	**-0.0909**	**-0.0370**

A striking insight seems to be the finding that φ_j decreases severely (in average 9.49% or 9.09%, respectively, per increment) as long as $e_{i,j}$ is part of the best path. This phenomenon changes abruptly as soon as $e_{i,j}$ glides off the best path with the decreases in the power ratio becoming much more moderate (in average 5.47% or 3.70%, respectively, per increment). This typical behavior is shown in Figure 4 for the aggregated data of $c_{off} = 0.5$. Note, that the interval in between two data points is interpolated to a straight line.

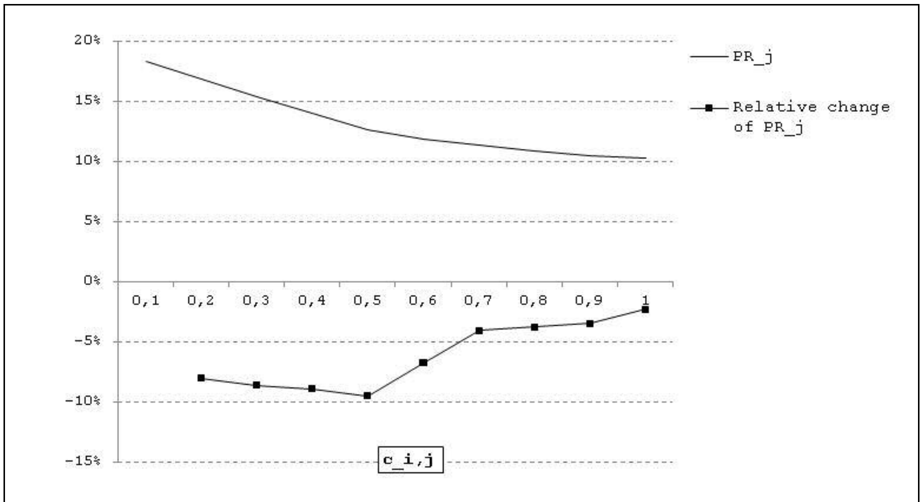

Figure 4. Behavior of power ratio

Starting from $c_{i,j} = 0.1$, the delta of the power ratio of v_j gets larger, i.e. the relative losses in power increase exactly up to the moment the player falls off the best path. With this event happening, we can observe a crease in the interpolated power ratio function which is more distinctly visualized in the steep increase of the lower function plotting the relative change of player v_j's PR. From this point on, the relative change in her power ratio carries less and less weight. The same trend is observable in all other aggregated samples as well.

Based on these insights we suggest that the delta of PR prior to the cut is larger than the post-cut delta of PR.

In order to back up our proposition, we perform a single-sided paired t-test. The underlying data groups are (i) $\Delta\varphi_j^c$ and (ii) $\Delta\varphi_j^{c+0.1}$ of each topology with $c_{off} > 0.1$. We can conclude that above-described behavior occurs systematically since the t-test shows significance with p<<0.02.

This effect is induced by the construction of the PR. As long as a player's link is part of the cheapest path through the network, it influences the value function of the whole network since $\chi(S_G) = \max\{\chi(F_1),...,\chi(F_L)\} = \chi(F^*)$. We chose the power ratio such that $\chi(F^*)$ is incorporated disproportionally. Assume that the complex service offered at lowest price is allocated by the service requester. The effect fosters a higher degree of cost pressure for services that are on the lowest cost path than for those which are not allocated. The cost pressure is induced by a greater loss of power due to increasing costs compared to the loss for services that are not part of the complex service. This is reasonable from an economic perspective as these services embody the actual contributors to the overall goal. On the other hand, services that are not on the lowest cost path face a lower cost pressure because they are not responsible for the realization of the complex service.

Further Observations Regarding the Balance of Power

An interesting observation is that a player v_j may have a rather high power ratio φ_i even if he is not situated on the best path, neither via any value $c_{i,j} \in I$ of the randomly chosen edge nor via an alternative path. Player v_5 in the topology shown in Figure 5 is a suitable example. In this case, the player has a strategically important role in the network. The BOP in this network G_1 is $\Gamma_{G_1} = (0.035, 0.180, 0.111, 0.392, 0.142, 0.185, 0.108, 0.788, 0.121)$. Note that player v_5 does not contribute to best path, however has three incoming and two outgoing links and a power ratio of $\varphi_5 = 0.142$. Player v_6 has two incoming and two outgoing links, additionally contributing to the best and the second-best link in the network, resulting in the highest PR of $\varphi_6 = 0.185$.

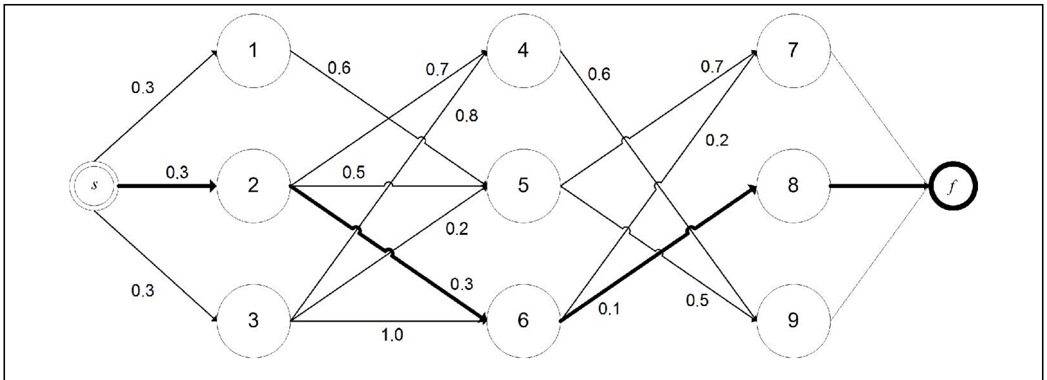

Figure 5. Exemplary 3-partite network with N=9

Generally, it seems that it is important for a player to be linked with as many as possible nodes which lets her be part of a path more often. Transferred to our scenario, this means that a service offering is compatible to more precedent or subsequent service offers, thus reflecting a player's degree of compatibility. Consequently, having more connections a service provider is also more often a vital player when it comes to cooperation formation. Our power ratio factors the contribution to each and every path through the network, losing significance with increasing costs. However, sub optimal paths that are merely marginally worse than the best path are included quite weightily into the PR. This is an effect explicitly desired by the design of our PR calculation since actually the whole network is subject to examination, regardless of the best path is being chosen or not. Applied to the service value network scenario this is of striking practical importance: As a response to a service requester's inquiry, the best suitable complex service is being composed ad hoc. Such customer centricity is fostered by the high degree of flexibility attained by the modularity of the providers. Now, if a link or player falls out of business, others can dynamically replace this certain producer of substitutes, potentially only slightly more expensive.

However, the other way round, if player v_i was monopolist for a certain functionality, her power ratio would be disproportionally high. Let's assume that a k-partite graph is given[5]. With player v_i controlling one of the (functionality) clusters, a naïve approach is to assign a power ratio of $\frac{1}{k}$. But with player v_i being the linchpin of the network, she contributes to each and every path through the network such that φ_i should be larger than $\frac{1}{k}$.

Conclusion

Summary and Review

In this paper we presented a model to express the balance of power in service value networks. Thereby, we incorporate important characteristics of service value networks, namely internal costs, paths through the network representing feasible complex services, and the flexible interchangeability of service providers. The model is based on work by (Shapley 1953, Myerson 1977, Jackson 2005a). However, our model allows for expressing the power ratio of each partner in the network, regardless of the complex service eventually allocated. The model was then implemented as information system. To study selected characteristics of our model, we applied a simulation approach. The main focus was put upon the behavior of a player's power if corresponding costs to links increase. We've shown that a player's loss of power is significantly larger as long as she is situated on the best path than when have dropped off the best path. Assuming that the cheapest complex service is allocated, the effect fosters a

[5] Mapped to our simulation setting, it would be the only node in a cluster having both incoming and outgoing edges. We are aware that this type of topology cannot result from our simulations. However, we consider this case for analytic reasons.

higher degree of cost pressure for service providers that are on the lowest cost path than for those which are not allocated.

A further observation of our simulation is the PR's favor of players with a high degree of incoming and outgoing links. We will evaluate this behavior in our further course of research. Transferred to service value networks, having more links to other players indicates a higher degree of compatibility which does in fact increase a player's power ratio. However, being compatible with more network partners yields higher overall costs due increasing adaptation and transaction costs. In our model, we do not explicitly factor such rising costs. Particularly, when turning to researching the very formation process of service value networks, we need to envisage a penalty term added to the value function. That way we may be able to control the trade-off between compatibility and rising adaptation and transaction costs.

Future Work and Open Issues

The field of network formation has been disregarded in this paper. We take the initial network topology as given. However, we intend to preface the calculation of the power ratio and balance of power in service value networks with a simulation of the very formation of such networks. For that purpose, we intend to not only consider functional, but also strategic dependencies. For instance, a premium quality provider might not want to contribute to the same complex service offering as a discounter. Inspired by (Axelrod and Bennett 1993, Axelrod et al. 1995) who simulated the formation of coalitions and alliances using a handful of simple parameters, we intend to introduce a setting which maps real-world strategic considerations to parameters. Most importantly, we do not want to come up with a setting that leaves us with a somehow optimal – howsoever optimality is defined – network structure. Rather we want to generate overall topologies depicting all possible dependencies upon which we then base our balance of power considerations.

Depending on the topology emerging from above-mentioned simulation, we are up to cognize patterns in the power balance scheme of such a network, allowing for a classification of the players according to their actual power. Such classifications are likely to allow for giving strategy recommendations for new entrants willing to join the network as well as incumbents willing to assert or develop their position.

In addition, several extensions to our power ratio model are foreseen. Currently, we extend the model with an additional factor "quality". That is, not only costs are being included, but also quality. Due to this extension, we are able to introduce utility functions for the service requester. Incorporating these extensions, we want to combine our BOP consideration with research that examines incentive schemes for the pricing of services in service value networks (Blau et al. 2008). Furthermore, we will include that a service provider might offer more than one service in the network.

These extensions will be substantiated by several simulation settings, for instance investigating the interrelation of power ratio and degree of incoming and outgoing links. Besides, modifications to our simulation have to be introduced that allow for the inclusion of bundling, i.e. loosening of the k-partite graphs we currently enforce.

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