How to Coordinate Value Generation in Service Networks – A Mechanism Design Approach

The authors present a mathematical model for Service Value Networks (SVNs) describing the main components and their interdependencies. To coordinate distributed activities in SVNs, they present a scalable multidimensional auction mechanism that enables the allocation and pricing of complex services. The mechanism and its bidding language support the multidimensional description of QoS attributes, their (semantic) aggregation and enforcement. It is analytically shown that the mechanism is incentive compatible with respect to all dimensions of service providers' bids, i.e. truth-revelation of QoS attributes and private valuations is an equilibrium in weakly dominant strategies. Based on these results, the authors numerically analyze strategic behavior of participating service providers regarding possible collusion strategies.

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1 Introduction

The paradigm shift from a product- to a service-oriented economy fosters the movement of complete industries from vertical integration to horizontal specialization. Hierarchically organized firms start 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, complex products or services can be produced by a single vertically integrated company. But in this case the company is not able to focus on its core competencies, having to cover the whole spectrum of the value chain. Also, it has to burden all risks in a complex, changing and uncertain environment on its own. This is why companies tend to engage in network value creation which allows participants to focus on their strengths. At the same time rapid innovation in the ICT sector enables promising opportunities in B2B communication which also supports the current trend. However, 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 (1996), Tapscott et al. (2000), and Zerdick et al. (2004). As Tapscott et al. (2000) 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 in the presence of network externalities. We briefly outline the advantages of business webs related to modularization and specialization (Zerdick et al. 2000):

- C1. Concentration on core competencies strengthens specialization
- C2. Sharing the risk involved
- C3. High level of flexibility
- C4. Modularization brings potential for innovation and allows for rapid market penetration
- C5. Fruitful interplay of competition and partnership

A prime example for such highly dynamic fields of application is the Internet of services. Vendors turn into service providers, benefiting from the capabilities of Internet standards and interoperability. Today's software-as-a-service (SaaS) and Web service market already shows the way towards an Internet of services. While providers already offer both simple[1] and sophisticated[2] on-demand services

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[1] Cp. e.g. Amazon's Simple Storage Service S3 (http://aws.amazon.com/s3) or Google's map service Google Maps (http://maps.google.com).

[2] Cp. e.g. Salesforce CRM (http://www.salesforce.com/) or Netsuite (http://www.netsuite.com).

individually, they increasingly modularize their core competencies in *service value networks (SVNs)* in order to offer joint complex services which meet specific customer requests. As one of the pioneers, Salesforce.com's AppExchange[3] marketplace offers a range of pre-integrated complementary services provided by 3rd party providers grouped around the core service Salesforce CRM. However, there is still a research gap in respect to the joint provisioning of composite services that are independent from a core service. This gap is intended to be filled by TEXO[4] as a research project, within the THESEUS research program initiated by the Federal Ministry of Economy and Technology (BMWi). Within the THESEUS program, TEXO contributes to service economies by creating infrastructure components for SVNs in the Internet of Services. Via intuitive interfaces and technical systems TEXO addresses the full lifecycle of these services from innovation to productive usage. Addressing these demands requires an interdisciplinary approach to create an integrated platform for the internet of services which supports all phases of the lifecycle. For all stakeholders and participants in such a service value network, innovative business models which are as flexible as the network itself are required.

Auctions have proven to perform well under these conditions to coordinate value generation while addressing mentioned network characteristics. Nevertheless, traditional approaches in the area of multiattribute combinatorial auctions are not quite suitable to enable the trade of composite services. Auctions for composite services are much more complex than simple procuring auctions, where the suppliers themselves offer a full solution to the procurer. In composite services this is not the case, as a flawless service execution and therefore the requester's valuation highly depends on the accurate sequence of its functional parts, meaning that in contrary to service bundles, composite services only generate value through a valid order of their components.

As a coordination mechanism in network economies we propose a multidimensional procurement auction for trading composite services. We present a graph-based model that captures the main components and characteristics of service value networks. Based on this model we have introduced a mechanism design that enables allocation and pricing of service components that together form a requested complex service. The mechanism is capable of handling a wide range of aggregation operations for service attributes also supporting rich semantic approaches for dealing with complex non-functional service specifications. Due to the combinatorial restrictions imposed by the underlying graph topology the winner determination problem can be solved in polynomial time which is a crucial issue when it comes to implementing online systems. We furthermore show that the proposed mechanism is individually rational, allocation efficient and incentive compatible with respect to QoS characteristics and prices of service offers. Hence, reporting the true type regarding configuration and price is a weakly dominant strategy for all service providers. Since incentive compatibility only holds for a one shot game, we study strategic behavior that might improve the SP payoffs. The strategic behavior is studied by means of a simulation-based analysis of two different strategies for service providers within Service Value Networks. We analyze two environmental settings, a price competitive environment as well as competition on basis of service levels. Based on our results we discuss strategic recommendations for service providers depending on how they are situated within the network.

This paper is structured as follows: The next section gives a brief overview over related literature. Section 3 illustrates the idea of on-demand service procurement in network economies based on an integration scenario from industry. In Section 4, we propose a multidimensional procurement auction for trading composite services based on an abstract model to represent service value networks. The mechanism comprehends a multiattribute bidding language (Section 4.1) and the central allocation function (Section 4.2). Section 4.3 demonstrates the expressiveness of semantic aggregation of service attributes as well as the auction conduction by providing a numerical example. An extension regarding service level guarantees and penalties for non-performance is introduced in Section 4.4. In Section 5, we analytically show the providers' bidding strategies and valuable properties of the proposed mechanism. In Section 6, we investigate bidding strategies in repeated games using a simulation-based approach. Section **7** concludes with a summary, the proof-of-concept realization of our approach, and future work.

2 Literature review

Recently, an enormous body of work has been done that blurs the border between game theory and computer science (Papadimitriou 2001) and proposes the design of mechanisms and markets analogously to traditional engineering approaches (Weinhardt et al. 2003). This is especially true for the discipline of mechanism design that focuses on the problem to coordinate self-interested participants in pursuing an overall goal (Nisan and Ronen 2001). The authors design suitable mechanisms to standard optimization problems in the area of task scheduling and routing. In incentive compatible mechanisms agents are incentivized to choose the strategy of revealing their true type. Incentive compatible mechanisms such as the celebrated Vickrey-Clarke-Groves (VCG) mechanism are firstly introduced and extensively investigated by (Clarke 1971; Groves 1973; Vickrey 1961).

Most of the research has been done with respect to truth-telling of one-dimensional types. The field of designing incentive compatible mechanisms that induce truth-telling of multidimensional properties of goods or services, still lacks deeper research. A thorough analysis and investigation in the area of multidimensional auctions and the design of optimal scoring rules has been done in (Branco 1997, Che 1993). The suitability of multiattribute auctions in procurement scenarios and design related issues are investigated in Bichler et al. (2005). In Bichler and Kalagnanam (2005) the winner determination problem in configurable multiattribute auctions is investigated from an operational research perspective without accounting for mechanism design aspects such as incentive compatibility. In Parkes and Kalagnanam (2002; 2005) the authors introduce iterative multiattribute procurement auctions focusing on mechanism design issues and solving the multiattribute allocation problem.

Preferences for multidimensional goods and multidimensional types in scoring auctions are extensively investigated in Asker and Cantillon (2008) and extended to combinatorial auctions in Müller et al.

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[3] http://www.salesforce.com/appexchange

[4] http://theseus-programm.de/scenarios/en/texo

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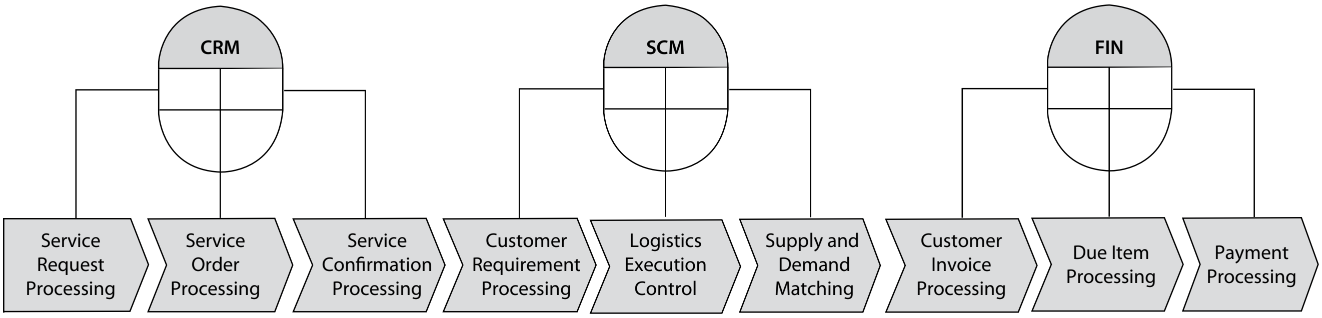

Fig. 1 Business process "Service Request and Order Management"

(2007). Nevertheless their work does not consider value chains and sequences of services as well as their technically feasible interrelations in order to coordinate value generation in service networks. All of these approaches assume bundles of goods in scenarios where the sequence and order does not matter and therefore cannot be applied to composite services that only fulfill their objectives in the right sequence of execution.

Nevertheless, combinatorial auctions yield major drawbacks regarding computational feasibility that result from an NP-complete complexity. Computational feasibility implies a trade-off between optimality and valuable mechanism properties such as incentive compatibility. Several authors propose approximate solutions for incentive compatible mechanisms to overcome issues of computational complexity (Nisan and Ronen 2007; Ronen 2001; Ronen and Lehmann 2005). Path auctions as a subset of combinatorial auctions reduce complexity through predefining all feasible service combinations in an underlying graph topology and are investigated in Archer and Tardos (2007), Feigenbaum et al. (2006), and Hershberger and Suri (2001). In their work, path auctions are utilized for pricing and routing in networks of resources such as computation or electricity. Application-related issues of auctions to optimal routing are examined by Feldman et al. (2005) and Maille and Tuffin (2007). All of these approaches deal with the utility services layer according to the service classification in Blau et al. (2008a) and hence do not cover the problems related to complex services.

3 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 SAP's BusinessByDesign[5]. The scenario consists of modular service components that can be provided by decentralized service providers. The integration scenario "Service Request and Order Management" (**Fig. 1**) describes operational processes in a customer service 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.

A *service value network* is formed by my 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 types of functionality within the network. In our scenario the functionality of each component can be modularized and therefore performed by different software-as-a-service providers as depicted in **Tab. 1**. The rapid upcoming of on-demand service providers shows the high degree of innovation and market penetration as a result of modularization (C4). Service providers offer specialized services and concentrate on their core competencies (C1). 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 (C2). Furthermore they partly grant access to their own resource supporting the realization of the overall business scenario (C5). The potential of substituting service providers on demand enables flexibility and rapid reaction to changing market requirements (C3).

4 Abstract model and mechanism implementation

A SVN is described by means of a simplified statechart model (Harel and Naamad 1996) and is aligned with the representation in Zeng et al. (2003). Statecharts have proven to be the preferred choice for specifying process models as they expose well-defined semantics and they provide flow constructs offered by prominent process modeling languages (e.g. WS-BPEL) and therefore allow for simple serialization in standardized formalisms.

Hence, a SVN is represented by an K-partite, directed and acyclic graph $G = (V, E)$. Each partition $Y_1, \ldots, Y_K$ of the graph represents a *candidate pool* that entails service offers that provide the same (business) functionality. The set of N nodes $V = \{v_1, \ldots, v_N\}$ represents the set of *service offers*[6] with u, v, i, j being arbitrary service offers. There are two designated nodes v_s and v_f that stand for source and sink in the network and are not part of any partition $Y \in \mathcal{Y}$, hence $V = \{Y_1 \cup \ldots \cup Y_K\} \cup \{V_s, V_f\}$. Services are offered by a set of Q *service providers* $S = \{s_1, \ldots, s_Q\}$ with s is an arbitrary service provider. The *ownership information* $\sigma : S \rightarrow \mathcal{P}(V \setminus \{v_s, v_f\})$ that reveals which service provider owns which services within the network is public knowledge[7]. The set of edges $E = \{e_{ij} | i, j \in V\}$ denotes technically feasible service composition such that e_{ij} represents an

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[5] http://www.sap.com/solutions/sme/businessbydesign/

[6] For the reader's convenience the terms *service offer*, *service* and *node* are used interchangeably

[7] The reverse ownership information $\sigma^{-1}: V \setminus \{v_s, v_f\} \rightarrow S$ maps service offers to single service providers that own that particular service

interoperable connection of service $i \in V$ with service $j \in V$[8]. If two services are not interoperable at all, they are not connected within the network.

A *servicekonfiguration* A_j of service $j \in V$ is fully characterized by a vector of attributes $A_j = (a_j^1, \ldots, a_j^L)$ where a_j^l is an attribute value of attribute type $l \in \mathcal{L}$ of service j's configuration. Attribute types can be either functional attribute types or non-functional attribute types (e.g. availability or privacy). A service's configuration represents the quality level provided and differentiates its offering from other services. According to Lamparter et al. (2007), a service configuration can be defined as follows:

Definition 1. Service configuration.
A service configuration A_j of a service $j \in V$ selects a value a_j^l for each attribute type $l \in \mathcal{L}$ of a service and thereby unambiguously defines all relevant service characteristics. The choice of configuration might affect the functional and non-functional aspects of a service and is a major determinant of the price.

Value is created through the network by performing a sequence of services that form a connected path from source to sink. We call such created value a complex service. Let F denote the set of all feasible paths from source to sink. Every $f \in F$ with $f \subset E$ represents a possible instantiation of the complex service[9].

In our model we focus on the core process of realizing the 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 goal can be achieved maximizing the systems welfare and to dynamically determine prices (**Fig. 2**).

4.1 Bidding language

As a formalization of information objects which are exchanged during auction conduction we introduce a bidding language based on bidding languages for products with multiple attributes as discussed in (Engel et al. 2006).

Tab. 1 SaaS providers for CRM, SCM and FIN components and their functional coverage

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/)		

A service requester wants to purchase a complex service f which is characterized by a configuration $\mathcal{A}_f$. The importance of certain attributes and prices of a requested complex service is idiosyncratic and depends on the preferences of the requester. The requester's preferences are represented by a utility function u^R of the form:

$$\mathcal{U}_f^R(\alpha, \Lambda, \mathcal{A}, \mathcal{P}) = \alpha S(\mathcal{A}_f) - \mathcal{T}_f$$

$\mathcal{T}_f$ denotes the sum of all transfer payments the requester has to transact to service providers that contribute to the complex service such that $\mathcal{T}_f = \sum_{s \in S} t^s$. The configuration $\mathcal{A}_f$ of the complex service is the aggregation of all attribute values of contributing services on the path f such that $\mathcal{A}_f = \left(\mathcal{A}_f^1, \ldots, \mathcal{A}_f^L\right)$ with $\mathcal{A}_f^l = \oplus_{e_{ij} \in f} a_j^l$. The aggregation of attributes values depends on their type (i.e. encryption can be aggregated by an AND operator whereas response time is aggregated by a sum operator). Different methods for aggregating service attributes are presented in detail in Section 4.3.

The scoring rule $S(\mathcal{A}_f) = \left(\sum_{l=1}^{L} \lambda_1 \left\|\mathcal{A}_f^l\right\|\right)$ represents the requester's valuation for a configuration $\mathcal{A}_f$ of the complex service represented by path f. The scoring rule is specified by a set of weights $\Lambda = \{\lambda_1, \ldots, \lambda_L\}$ with $\sum_{l=1}^{L} \lambda_l = 1$ that defines the requester's preferences of each attribute type analog to the definition of scoring rules in Asker and Cantillon (2008). To assure comparability of attribute values from different attribute types the aggregated attribute values $\mathcal{A}_f^l$ are mapped on an interval [0;1]. $\mathcal{T}_f$ represents the overall price of the complex service. α can be interpreted as the willingness to pay for a optimal configuration $S(\mathcal{A}_f) = 1$ based on the requester's score. In other words α defines the substitution rate between configuration and price based on the requester's preferences.

Definition 2.Multiattribute service request.
A request for a complex service is a vector of the form
$R := (G, F, \alpha, \Lambda, \Gamma)$
with G represents a complex service network, F represents all feasible paths from source to sink that form a possible instantiation of a complex service, Λthe requester's preferences and αthe willingness to pay. Γ denotes the set of lower and upper boundaries for each attribute type.

A service offer consists of an announced service configuration A_j and a corresponding price bid p_{ij} that a service provider wants to charge for service j being invoked depending on the predecessor service i such that $b_{ij}(e_{ij}) = (A_j, p_{ij})$ is a service offer bid for invocation of service j which is interoperable with a predecessor service i with $b: E \to A \times R$. A service provider s bids for all incoming edges to every service it owns.

Definition 3. Multiattribute service offer.
A multiattribute service offer is a bid matrix of the form

$$B^s := \begin{cases} b_{ij}(e_{ij}) = (A_j, p_{ij}), & i \in \tau(j),\ j \in \sigma(s) \\ (\bar{A}, -\infty) & \text{otherwise} \end{cases}$$

with τ(v) denotes the set of all predecessor services to service v with τ: V → V and σ(s) the set of all services owned by service provider s. $\bar{A}$ is an arbitrary configuration.

4.2 Mechanism implementation

The mechanism maximizes welfare by allocating a path f^* within the service value network that yields the highest overall utility. Let $\mathcal{U}_f$ denote welfare induced by path f with $\mathcal{U}_f = \alpha S(\mathcal{A}_f) - P_f$.

$o := \arg\max_{f \in F} \mathcal{U}_f$

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[8] For the reader's convenience the notion e_{ij} is equivalent to $e_{v_i v_j}$ representing an interoperable connection of service $i \in V$ with service $j \in V$.

[9] Focusing on the presence or absence of a particular service $i \in V$, F_{-i} represents the set of all feasible paths from source to sink in the reduced graph G_{-i} without node i and without all its incoming and outgoing edges. In contrary, let F_i be the subset of all feasible paths from source to sink that explicitly entail node i.

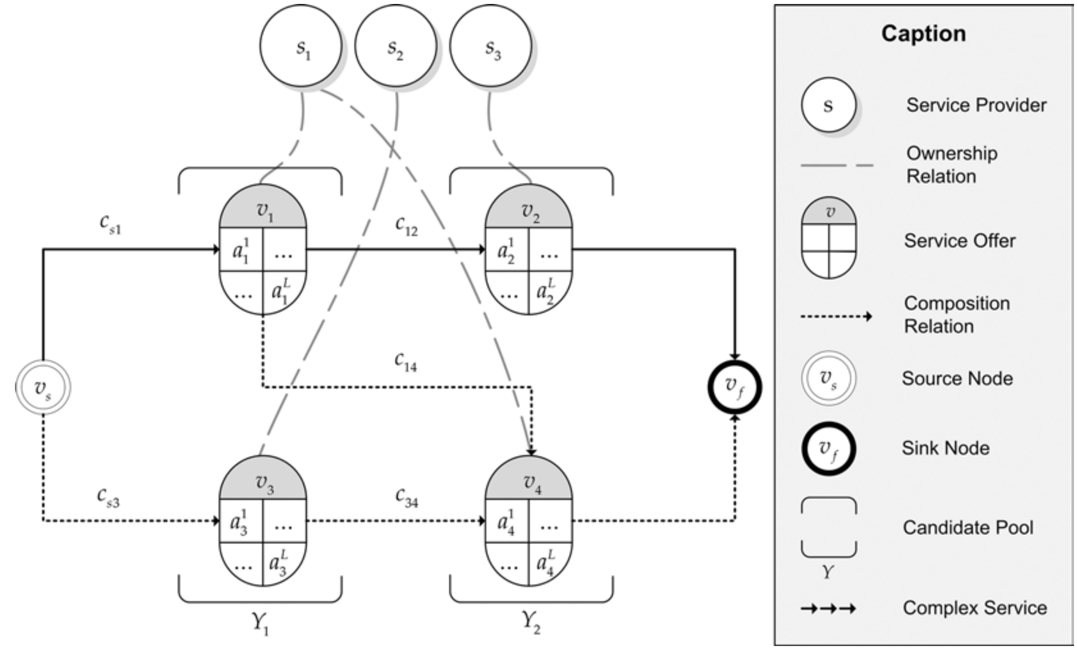

Fig. 2 Service value network model

Let $\mathcal{U}^*$ denote the utility of the winning path meaning the utility of a path f^* that maximizes welfare[10]. Let $\mathcal{U}^*_{-s}$ denote the utility of a path f_{-s}^* that yields a maximum overall utility in the reduced graph without every service owned by service provider *s* and its incoming and outgoing edges.

Every service provider *s* receives a payment or transfer t^s if *s* is allocated[11] i.e. it owns service offers which have incoming edges that are on the winning path. A payment t^s for service provider *s* corresponds to the monetary equivalent of the utility gap between the "winning path" and "second best path". In other words, a monetary equivalent to the utility service provider *s* contributes to the system's welfare. This monetary equivalent represents the price that service provider *s* could have charged without losing its participation in the allocation.

Definition 4. Critical value.
Thecritical value Δtcrit, sof a service provider s represents its contribution to the system as the difference between the overall utility $\mathcal{U}^*$ in the complete graph and the overall utility in the reduced graph $\mathcal{U}^*_{-s}$ without service offers owned by service provider s and incoming and outgoing edges of these services such that
$\Delta t^{crit,s} = \mathcal{U}^* - \mathcal{U}^*_{-s}$

Let $\bar{E}^s = \{e_{ij} | e_{ij} \in o,\, j \in \sigma(s),\, i \in \tau(j)\}$ be the set of allocated edges that belong to service provider *s*. Consequently the transfer function t^s for service provider *s* is defined as

$$t^s := \begin{cases} \sum\limits_{j\in\sigma(s)} \sum\limits_{i\in\tau(j)} p_{ij} + \left(\mathcal{U}^* - \mathcal{U}^*_{-s}\right) \\ 0, \end{cases}$$

if $e_{ij} \in o$

otherwise

Under the assumption of additive and monotone aggregation operations, the solution to the allocation problem in Equation (4) can be computed in polynomial time using well-known graph algorithms to determine the "shortest" path within a network such as the Dijkstra algorithm. The time complexity for an extended Dijkstra variant that solves the allocation problem is $\mathcal{O}(|V| + |E|)$ with $|E|$ is the number of edges and $|V|$ the number of nodes within the graph. According to the payment scheme in Equation (6), the allocation must be computed twice: Based on the graph with the service offerings of the service provider receiving the payment and without its participation. In the second case the graph can be pre-processed and reduced by all service offerings owned by the service provider that receives the payment. After the reduction the shortest path can be computed accordingly which yields the same time complexity. In contrary to the $\mathcal{NP}$ -complete complexity in general combinatorial auctions, this is a valuable achievement that enables to conduct our auction in online systems.

4.3 Aggregation and preference mapping of service quality

In order to determine the overall score for a provider based on its scoring function, the attribute values of the complex service have to be computed. Recall that the type of function for aggregating attribute value highly depends on the attribute type. Traditional quality of service attributes such as *response time* for example can be aggregated with basic mathematic operations such a sum operator. **Tab. 2** shows different types of aggregation functions for multiple attribute types exemplarily. For example, the overall *throughput* of a complex service that consists of multiple service components is determined by the lowest throughput rate within the allocation and can therefore be computed using a minimum operator.

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[10] For the reader's convenience, the notion $\mathcal{U}^*$ is short for $\mathcal{U}_{o(B)}$ which denotes the overall utility of the path f^* allocated by *o*(*B*) based on service providers' bids.

[11] For the sake of simplicity, the expression *allocated service offer* means that this service offer has an incoming edge that is entailed in the allocated set of edges f^*. Analogously, the expression *allocated service provider* means that a service provider owns at least one *allocated service offer*.

Tab. 2 Aggregation functions for different types of attributes

Attribute type	Aggregation operation
l	$\oplus^{l}_{e_{ij}\in f\setminus\{v_f\}} a^{l}_{j}$
Response time (rt)	$\sum_{e_{ij}\in f\setminus\{v_f\}} a^{rt}_{j}$
Encryption type (et)	$\wedge_{e_{ij}\in f\setminus\{v_f\}} a^{et}_{j}$
Error rate (er)	$\max_{e_{ij}\in f\setminus\{v_f\}} a^{er}_{j}$
Throughput (tp)	$\min_{e_{ij}\in f\setminus\{v_f\}} a^{tp}_{j}$
Probability of default (pd)	$1-\prod_{e_{ij}\in f\setminus\{v_f\}} \left(1-a^{pd}_{j}\right)$
Probability of success (ps)	$\prod_{e_{ij}\in f\setminus\{v_f\}} a^{ps}_{j}$

Nevertheless, only considering basic quality of service attributes is not sufficient for dealing with complex non-functional service characteristics that express rich semantic information. The auction mechanism must be capable of aggregating a broad range of descriptive service attributes that express multiple quality aspects. Recalling the business scenario in Section **3** an auction mechanism must be capable of supporting a huge variety of service descriptions and attribute types describing highly complex semantic states. For the reader's convenience we reduce the scenario to a minimal setting that is sufficient to illustrate the strength of semantic service description and attribute aggregation. For detailed information on the design of suitable ontologies and semantic techniques to describe services and enable their trade the interested reader should refer to Blau et al. (2008b). The following example depicted in **Fig. 3** shows a service value network with four service offers and three possible paths from source to sink (f^{top}, f^{middle}, f^{bottom}).

For simplicity and without loss of generality we assume that each service provider owns only a single service. Price values on the edges represent price bids announced by service providers. Each service configuration consists of attribute values for the *encryption types* (a^{et}) and *probability of success* (a^{ps}). Attribute values are aggregated according to the aggregation operations in **Table 2**. Encryption types are derived from the concepts in the *security algorithm ontology* as illustrated in **Fig. 4**.

The service requester specifies an *individual encryption* attribute type (a^{ie}) in first order logic:

$$\begin{aligned}
&\text{Individual Encryption(x)} \leftarrow (\text{Block Ciper(x)}\\
&\wedge \text{ has Key Length}(x,k)\\
&\wedge \text{is GreaterOrEqual}(k,\text{‘128’}))\\
&\vee\ (\text{Asymmetric Algorithm(x)}\\
&\wedge \text{has key Length}(x,k)\\
&\wedge \text{ is Greater Or Equal}(k,\text{‘256’}))
\end{aligned}$$

The service requester furthermore announces its willingness to pay and weights for each attribute type representing its scoring function such that $\lambda_{ie} = 0.2$, $\lambda_{ps} = 0.8$ and $\alpha = 100$.

The mechanism allocates service offers on a path from source to sink based on the service request and announced multi-attribute offers according to Equation (4). The welfare generated by each allocation evolves as follows:

$$\mathcal{U}^{top}_{f} = 100\,(0.2\,(1\wedge 0) + 0.8\,(0.9\times 0.7)) - (13+16) = 21.4$$

$$\mathcal{U}^{middle}_{f} = 100\,(0.2\,(1\wedge 1) + 0.8\,(0.9\times 0.8)) - (13+17) = 47.6$$

$$\mathcal{U}^{bottom}_{f} = 100\,(0.2\,(0\wedge 1) + 0.8\,(0.9\times 0.8)) - (10+20) = 27.6$$

Therefore f^{middle} is allocated as it yields the highest welfare and each service provider that owns a service on it receives a payment according to Equation (6) such that $t^{s_1} = 13 + (47.6 - 27.6) = 33$ and $t^{s_4} = 17 + (47.6 - 21.4) = 43.2.$ The transfer is designed to compensate service providers for their contribution to the system's welfare which implies that e.g. provider s_1 could have bid a price of 33 without having lost its participation in the allocation.

4.4 Verification and service level enforcement

As introduced in Section 4.1 service providers' bids contain a configuration and a price component. The allocation function maximizes welfare based on the achieved quality for the service requester and the costs that occur on the producer's side. This shows that the announced quality also determines the likelihood of being allocated which might induce an incentive for service providers to lie about their configuration. Therefore, the proposed mechanism is extended with a compensation function which is explained in detail in this section.

Let a_j^l be the *announced attribute value* for attribute type l of service j's configuration. Furthermore let $\tilde{a}^l_j$ be the *verified attribute value* for attribute type l realized by service j and monitored during execution. Analogously, A_j and $\tilde{A}_j$ denote announced and verified configurations of service j. In distinguishing between announced and verified attribute values, the overall utility may also differ. Recall that $\mathcal{U}^*$ denotes the *ex-ante overall utility* of the allocated path f^* based on the information available in the declaration phase. Furthermore, $\tilde{\mathcal{U}}^{*s}$ denotes the *ex-post overall utility* that results from the complex service instance formed by allocated service offers on a path f^* and based on the verified attribute values $\tilde{a}^1_j,\ldots,\tilde{a}^l_j$ of all service offers $j \in \sigma(s)$.

Auctioning services based on a platform approach opens up the possibility of ex-post verification. This means that the actually delivered quality of participating services can be measured and monitored after execution. Therefore we can ex-ante enforce a true announcement of quality to be delivered by verifying it ex-post. According to the *Compensation and Bonus Mechanism* introduced in Nisan and Ronen (2001) a compensation function is constructed as follows

$$\Delta t^{comp,s} := \left(\mathcal{U}^* - \tilde{\mathcal{U}}^{*s}\right)$$

The compensation function represents the utility gap that results from the utility difference of the announced attribute values and the actually performed ones from the service requester's perspective. In other words the gap that results from the utility loss the systems incurs because of the service provider's untruthful announcement. The monetary equivalent to this utility gap according to the requester's preferences represents the penalty payment the service provider has to bear for deviating from the announced attribute values. This *negative consequence* can be interpreted as a contractual penalty for not realizing

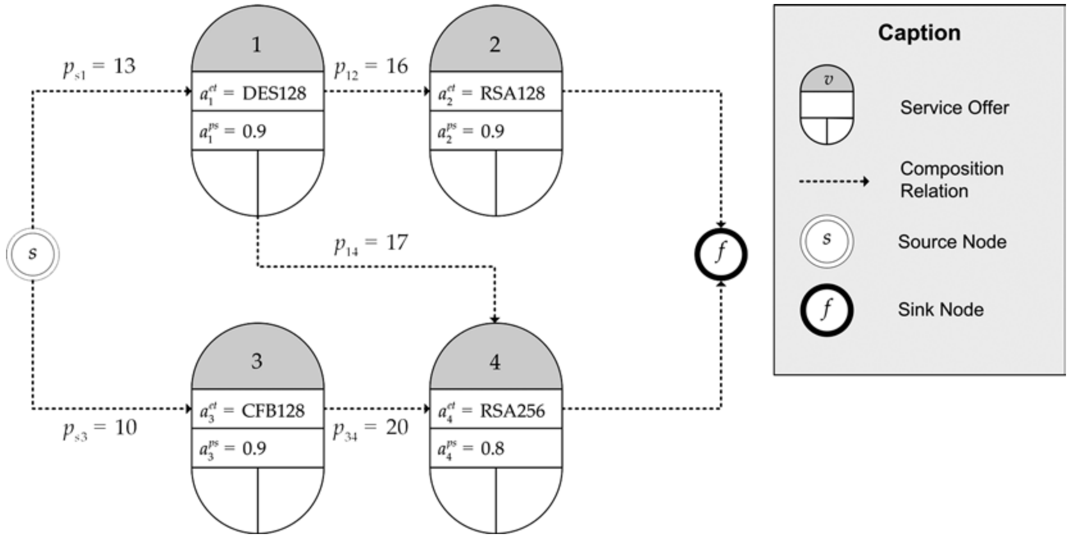

Fig. 3 Service value network with semantic QoS characteristics

specified service-level-agreements as defined in Salle and Bartolini (2004). Taking the compensation function into account the payment function is extended as follows:

$$t^s : \begin{cases} \sum\limits_{j\in\sigma(s)} \sum\limits_{i\in\tau(j)} p_{ij} + \Delta t^{crit,\mathrm{s}} - \Delta t^{comp,\mathrm{s}}, \\ 0 \end{cases}$$

$\text{if } \mathrm{e_{ij}} \in \mathrm{o}$

otherwise

5 Analytical analysis of bidding strategies of service providers

The bidding strategy of each service provider comprehends a price announcement and a corresponding service configuration consisting of a set of attribute values as introduced in the Section 4.1. In this section we analytically analyze providers' bidding strategies in the proposed mechanism implementation:

Corollary 1. For each service provider s ∈ S that participates in the proposed mechanism with the compensation function extension, the transfer $t^s$is independent of all dimensions of s's bids (configuration and price). This means that for each service offer j ∈ V owned by s ∈ S that has an incoming edge which is allocated by o such that e_{ij} ∈ o with j ∈ σ(s) and i ∈ τ(j), service provider s's payoff is independent of all dimensions of its bid $b_{ij}(e_{ij}) = (A_z,p_{ij})$.

Proof of Corollary 1. Let F_{-s} denote the set of all feasible paths from source to sink in the reduced graph G_{-s} without every service offer owned by service provider *s* and corresponding incoming and outgoing edges. Let further *f** denote the path which is allocated by *o*. Let $\mathcal{U}^*$ be the utility of path *f**. Let $\mathcal{U}^*_{-s}$ be the utility of path f_{-s}^* in the reduced graph G_{-s}. Let $\tilde{\mathcal{U}}^{*s}$ denote the overall utility of the allocated path *f** computed based on the verified attribute values $\tilde{a}_j^1, \ldots, \tilde{a}_j^L$ of the verified configurations $\tilde{A}_j$ of all service offers *j* ∈ *σ*(*s*). Let $\bar{E}^s$ denote the set of edges with $\bar{E}^s = \{e_{ij} | e_{ij} \in o, j \in \sigma(s), i \in \tau(j)\}$. Distinguishing two possible cases, service provider *s*'s payoff π^s evolves as follows.

I. $\bar{E}^s = \emptyset$. Service provider *s* is not allocated. More precisely, none of the incoming edges of service offers owned by service provider *s* are allocated by *o*. It follows directly that in this case $\pi^s = 0$ independent of *s*'s price bid.

II. $\bar{E}^s = \emptyset$. Service provider *s* is allocated. More precisely, at least one of the incoming edges of service offers owned by service provider *s* is allocated by *o*.

$$\pi^s = t^s - c^s$$

$$\pi^s = \sum_{\bar{E}^s} p_{ij} + \left(\mathcal{U}^* + \mathcal{U}^*_{-s}\right) - \Delta t^{comp,s} - \sum_{\bar{E}^s} c_{ij}$$

$$\pi^s = \sum_{\bar{E}^s} p_{ij} + \left(\mathcal{U}^* + \mathcal{U}^*_{-s}\right) - \left(\mathcal{U}^* + \tilde{\mathcal{U}}^{*s}\right) - \sum_{\bar{E}^s} c_{ij}$$

$$\pi^s = \sum_{\bar{E}^s} p_{ij} + \left(\tilde{\mathcal{U}}^{*s} + \mathcal{U}^*_{-s}\right) - \sum_{\bar{E}^s} c_{ij}$$

$$\pi^s = \alpha S\left(\tilde{A}^s_{f^*}\right) - \sum_{e_{ij} | e_{ij} \in o, e_{ij} \notin \bar{E}^s} p_{ij} - \mathcal{U}^*_{-s} - \sum_{\bar{E}^s} c_{ij}$$

Equation (9) shows that for each service offer *j* ∈ *V* owned by *s* ∈ *S* that has an incoming edge which is allocated by *o* such that e_{ij} ∈ *o* with *j* ∈ *σ*(*s*) and *i* ∈ *τ*(*j*), service provider *s*'s payoff is independent of all dimensions of its bid $b_{ij}(e_{ij}) = (A_j,p_{ij})$.

Theorem 1. For each service provider *s* ∈ *S* that participates in the proposed mechanism with the compensation function extension, the bidding strategy $b_{ij}\left(e_{ij}\right) = \left(\tilde{A}_j, c_{ij}\right)$ with $\tilde{A}_j = \left(\tilde{a}_j^1, \ldots, \tilde{a}_j^L\right)$, ∀i ∈ τ(j),∀j ∈ σ(s) – truth telling with respect to all dimensions of the bid – is a weakly dominant strategy.

Proof of theorem 1. Let F_{-s} denote the set of all feasible paths from source to sink in the reduced graph G_{-s} without every service offer owned by service provider *s* and corresponding incoming and outgoing edges. Let further *f** denote the path which is allocated by *o*. Let $\mathcal{U}^*$ be the utility of path *f**. Let $\mathcal{U}^*_{-s}$ be the utility of path f_{-s}^* in the reduced graph G_{-s}. Let $\tilde{\mathcal{U}}^{*s}$ denote the overall utility of the allocated path *f** computed based on the verified attribute values $\tilde{a}_j^1, \ldots, \tilde{a}_j^L$ of the verified configurations $\tilde{A}_j$ of all service offers *j* ∈ σ(*s*). Let $\bar{E}^s$ denote the set of edges with $\bar{E}^s = \{\mathrm{e}_{ij} | e_{ij} \in o, j \in \sigma(s), i \in \tau(j)\}$. Corollary 1 shows that the transfer for each service provider *s* ∈ *S* is independent of all dimensions of its bid. In other words, *s*'s bid does not have an impact on its transfer t^s and its payoff π^s respectively. Nevertheless, the bidding strategy influences service provider *s*'s chance of being allocated by *o*. Thus, *s* wants to be allocated iff $\pi^s > 0$.

$$\bar{E}^s \neq \emptyset \Leftrightarrow \mathcal{U}^* > \mathcal{U}^*_{-s} \Leftrightarrow \pi^s > 0$$

$$\mathcal{U}^* > \mathcal{U}^*_{-s} \Leftrightarrow \sum_{\bar{E}^s} p_{ij} + \left(\tilde{\mathcal{U}}^{*s} - \mathcal{U}^*_{-s}\right) - \sum_{\bar{E}^s} c_{ij} > 0$$

$$\mathcal{U}^* > \mathcal{U}^*_{-s} \Leftrightarrow \sum_{\bar{E}^s} p_{ij} + \tilde{\mathcal{U}}^{*s} > \sum_{\bar{E}^s} c_{ij} + \mathcal{U}^*_{-s}$$

Equation (10) holds for $p_{ij} = c_{ij}$ and $\mathcal{U}^* = \tilde{\mathcal{U}}^{*s}$. According to Corollary 1, if $\bar{E}^s \neq \emptyset$, *s* is indifferent between any other solution that satisfies Equation (10) which means that reporting attribute values $a_j^1,\ldots,a_j^l$ truthfully meaning that the announced values equal the verified ones in the execution phase such that $a_j^l = \tilde{a}_j^l \forall l \in L, \forall j \in \sigma(s)$ and consequently $\mathcal{U}^* = \tilde{\mathcal{U}}^{*s}$ is a weakly dominant strategy.


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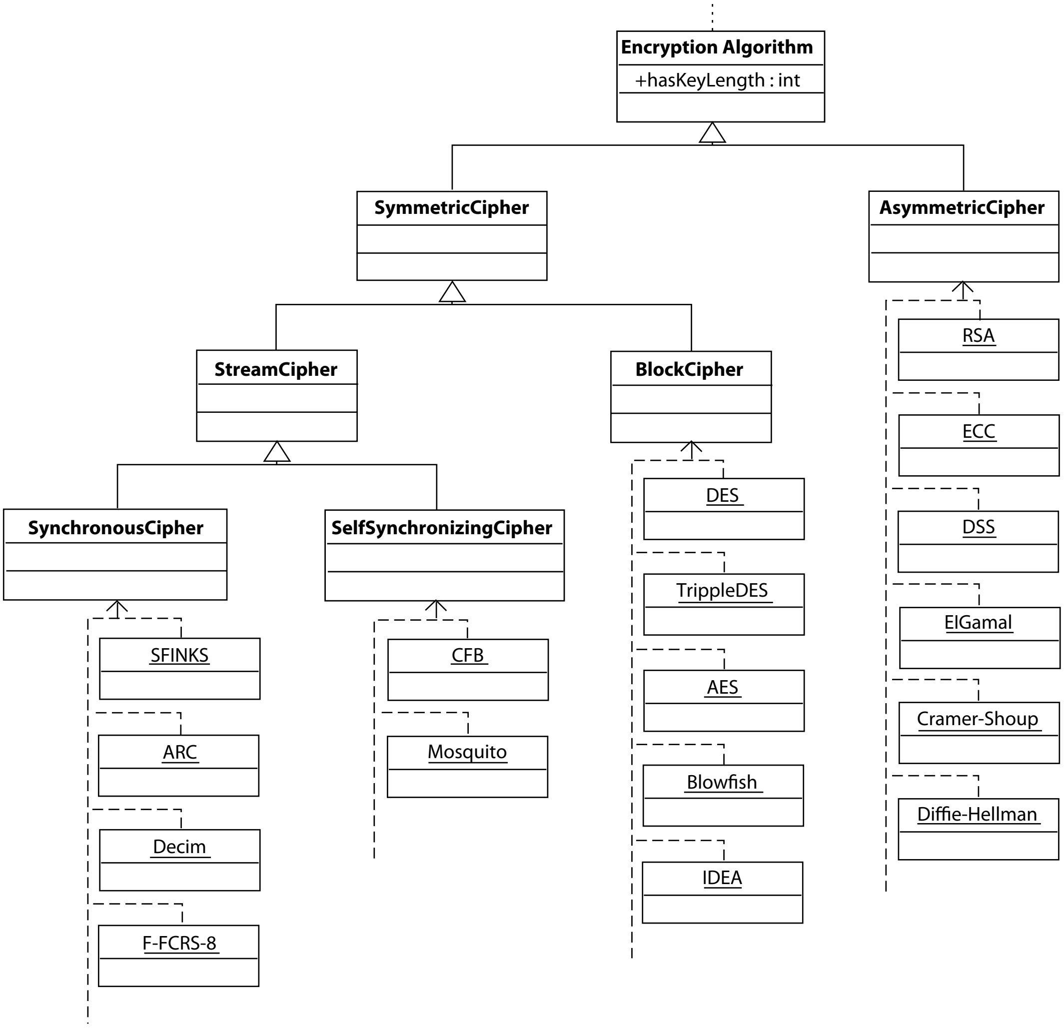

Fig. 4 Security algorithm ontology

6 Numerical collusion analysis

Incentive compatibility as described in the last section is an important characteristic for both, the service platform provider as well as the service requesters, since it is a weakly dominant strategy for the service providers to bid their true cost and not report higher cost. This property of the mechanism does prevent service providers from charging an additional margin on their cost. Since the payment is independent from the own bid but dependent on the second highest bid, the winner could only be better off if both, winner and second highest bidder, somehow cooperated, e.g. if the second highest bidder did not report true but higher costs (as long as these higher costs were smaller than the cost of the third highest bidder). So far, we have not analyzed such collusive behavior.

The absence of collusive behavior is based on some fairly strict assumptions. First, we have assumed that the participants in the auction are not able and not allowed to communicate. Second, indirect communication is impossible since we have studied one shot games in which the participants cannot observe the actions of the others before the auction is finished. Third, providers have no capacity constraints. Forth, competition is high, and thus, the Vickrey payment is small. What might happen if we dropped some of these assumptions is to be evaluated in this section.

Since direct communication for collusion is illegal in most real situations we further keep the first assumption that service providers are not allowed and able to communicate. However, if a platform provider deploys such an allocation mechanism to match service offers and requests, the path auction is repeatedly used. Repeating such an auction is understood as an iterated game which gives participants the opportunity to observe the behavior of the other participants. In repeated Bertrand oligopolies, there is no need for direct communication if participants are able to observe past prices (Athey and Bagwell 2001).

If explicit communication is not possible, it is difficult for the colluding participants to directly share the surplus, e.g. through direct payments. Consequently, the colluding service providers can share the market in such a way that they alternate in winning the auction, i.e. they rotationally abstain from winning the auction in favor of the colluding partner. This is possible in such situations where the relinquishment of winning the auction is overcompensated by a higher profit, or in cases of constrained capacities, i.e. the providers are not able to offer services all the time (and thus in each auction). Therefore, we drop the assumption of unconstraint capacity.

How could participants collude while participating in a set of repeated auctions with the described mechanism? It is clear from the design of the mechanism that it is disadvantageous to report higher costs for a service provider who is in the allocation while bidding his true costs. The larger the difference in utility between best and second best solution, the higher the profit is for the service providers on the best path. Thus, let SP i submit a bid at true valuation and be allocated. Let SP j submit bids above the true valuation and being part of the second best allocation. This bidding behavior will lead to a higher payment for SP i. As such, SP i prefers other SPs to submit bids above their true cost. On the other hand, for those SP that are not allocated it is beneficial to submit bids at their true cost in order to produce a higher utility, and as such, increase the likelihood of being allocated.

Since we have dropped the unconstraint capacity assumption, it is beneficial for the service providers of the best and second best allocation to alternately report higher costs in order to increase the others' payments. We investigate this strategic decision problem by means of simple agent-based simulations motivated by the ideas in Kimbrough et al. (2004). We implement two simple strategies, probe-and-adjust (PA) and adjust-dependent-on-own-and-cluster-return (AOCR) that might be able to coordinate themselves without direct communication. Both strategies are reactive and do not implement any sophisticated learning algorithm. In so far, we follow a pure agent-based approach (van Dinther 2007).

6.1 Strategies

Each SP has four action alternatives. He can either bid the true cost or increase the bid up to four times by discrete steps at 0.03 currency units. In total each SP has five bid alternatives, true cost or true cost + i times 0.03 and $j \in \{1,\ldots,4\}$.

Probe and Adjust (PA)

The first reactive strategy is called Probe-and-Adjust. Those SP that are allocated increase the bid at one discrete step as long as they drop of the best path or they reach the upper cost limit (true cost + 0.12 currency units). All SP which are not allocated decrease the bid by one discrete cost step until they are either allocated or they bid their true cost.

Tab. 3 Aggregated payments of all SPs in the network

	PA-PC	PA-QC	AOCR-PC	AOCR-QC
Mean payments total-network (truth-telling)	2.899	3.166	2.899	3.166
Mean payments total-network (achieved)	2.971	3.309	2.943	3.203
Mean surplus total-network (achieved)	0.072	0.142	0.043	0.037
Surplus (%)	2.48 %	4.49 %	1.49 %	1.16 %

Tab. 4 Individual payoffs of truth-telling SPs

	PA-PC	PA-QC	AOCR-PC	AOCR-QC
Mean payments allocated SP (truth-telling)	0.580	0.633	0.580	0.633
Mean payments allocated SP (achieved)	0.570	0.642	0.593	0.655
Mean surplus allocated SP (achieved)	−0.009	0.009	0.014	0.022
Surplus (%)	−1.60 %	1.44 %	2.35 %	3.40 %

Adjust Dependent on Own and Cluster Return (AOCR)

The second reactive strategy considers not only the individual return but also the market returns of the direct competitors in the same functional cluster. This reflects the idea that competitors might exploit the market by reporting higher costs and dividing the profits amongst themselves. The aim is to maximize cluster return but not on own cost, i.e. we identify four cases, (1) actual cluster return is greater than the one the round earlier and SP i (a) is allocated and (b) SP is not allocated, as well as (2) the cluster payment is equal or lower than the one the round earlier and SP i (a) is allocated and (b) is not allocated respectively. Dependent on the described situation the SP take the following actions: (1a) SP i increases his bid by one discrete step, (1b) SP i does not change his bid, (2a) SP i does not change his bid, (2b) SP i decreases his bid by one discrete step.

6.2 Hypothesis development

We study the results of strategic behavior under two competitive situations, price competition (PC) and quality competition (QC). In the price competition scenario all SP of one cluster offer their services at the same quality level but different price levels, i.e. the true costs of the SP differ slightly. Since competition takes place not only on prices but also on quality, the offered services differ additionally in quality of one service attribute in the quality competition scenario. Let all SP in the network follow the PA strategy. In the PC scenario we expect that prices will reach the true valuation equilibrium (when all SP bid their true valuation). In contrast, we expect the AOCR strategy to better exploit the situation. Thus, we expect prices to reach a level between the true valuation equilibrium and the high bid equilibrium (when all SP submit bids at the highest possible level) while all SP follow the AOCR strategy in the PC scenario. We expect a different picture for the QC scenario. Since the quality level largely impacts the service requesters' utility we expect that SP can exploit their competitive advantage by submitting higher bids which will lead to higher payments on average. Thus, we derive the following hypotheses:

H1: In the PC scenario with only PA strategies, payments will converge to the true valuation equilibrium

H2: In the PC scenario with only PA strategies, the deviation from the weak dominant strategy will be low, i.e. submitting the true valuation is the most frequently chosen strategy.

H3: In the QC scenario the diversification on the basis of service quality decreases competition, and as such will lead to a higher number of deviators from the weak dominant strategy (truth telling).

H4: In the QC scenario the deviation from truth telling leads to higher payments for allocated SP.

H5: AOCR strategy leads to higher payments of the allocated services compared to the PA strategy.

6.3 Simulation approach and results

We model this problem as a n-person game in which each node follows one of the described reactive strategies. In each simulation period the service providers choose an action based on the observation

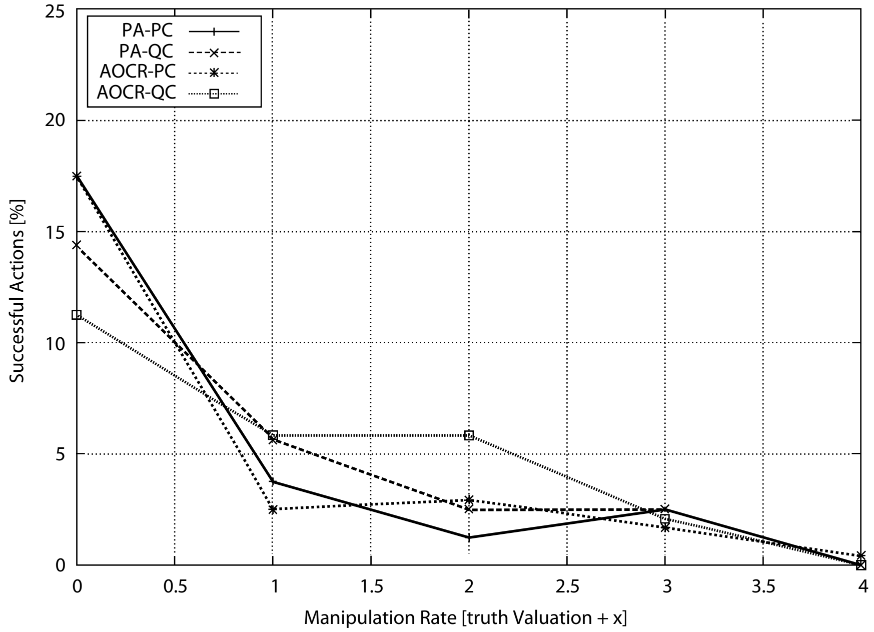

Fig. 5 Frequency of Successful Actions Chosen by Allocated SPs

of their own success and the success of the other nodes respectively. We run simulations for four different scenarios: (1) all nodes offer the same service levels and use the PA strategy (PC-PA), (2) all nodes use PA but offer different service levels for the attribute "response time" (QC-PA), (3) all nodes follow the AOCR-strategy and offer the same service levels (PC-AOCR), and (4) the nodes offer different service levels for the attribute "response time" and all follow the AOCR-strategy (QC-AOCR). Each scenario is repeated for four different topologies. In each simulation we repeat the auction 40 times.

In the first step, we analyze the network's total payments. **Tab. 3** displays the average values of the sum of the SP's payments in the network for the two cases (1) truth telling (bidding the true costs) and (2) following one of the reactive strategies. We compare these two mean payments, and thus, compute the received surplus while following one of the reactive strategies (difference between mean reactive-strategy-payoffs and mean true-valuation-payoffs). This surplus is positive in all four scenarios but lower in the AOCR scenarios compared to the PA scenarios. This at least supports the assumption that from a network perspective collusion might be beneficial in the repeated game.

Besides the total network's payoffs it is even more important to study the individual payments of especially those SP who would have been allocated while playing the true valuation. **Tab. 4** displays the average individual payoffs for exactly those SP. It is interesting to note that both strategies, PA and AOCR, perform better in the service quality competition compared to price competition, i.e. collusion is more beneficial on a platform with heterogeneous service offers (regarding service quality). Additionally, we observe that the AOCR strategy performs better in both scenarios, price and service competition, compared to the simpler PA strategy – unfortunately not on a statistically significant level[12]. In general the benefit is quite low with a maximum plus of 3.4%. The surplus in the price competition scenario while following the PA-strategy is even negative. This suggests that PA is not suitable for tacit collusion which also explains the better results for the PA strategy from a total-network perspective (**Tab. 3**): The originally allocated SP drop off the best path and thus the utility-difference increases. Since the applied t-test does not produce statistically significant results, we do not find significant support for Hypothesis H5. In contrast, we find significant statistical support for Hypothesis H1 and H4 on basis of a t-test.

Regarding Hypothesis H2 and H3, we investigate both, the frequency of actions taken by all SP (incl. those SP that are not allocated) as well as the frequency of actions taken by the successful SPs. **Figure 5** displays the frequency of successful actions. Comparing the frequency of submitting true cost in the PA-PC vs. PA-QC we observe a decrease in the number of successful truth tellers. Unfortunately, we do not find significant statistical support since the t-test produces a p-value of 0.09, and thus, the null-Hypothesis cannot be rejected.

Summarizing the simulation results we observe that tacit collusion can be an issue in repeated games. Even simple reactive strategies such as the AOCR strategy result in *slightly larger* payoffs. Especially in the scenario with heterogeneous service offers regarding the service quality untruthful bidding might be beneficial for service providers. The platform provider can counteract such behavior by increasing completion since under competition the profit margin decreases and probably will not compensate the risk of dropping off the allocation.

7 Implications for platform providers and conclusion

The proposed mechanism is evaluated in the *TEXO* use case of the *THESEUS*[13] project. Especially the novel requirements for pricing models are addressed by proposing a graph-based multidimensional procurement auction. The auction mechanism is capable of allocating and pricing of composite services in an efficient and truthful manner. It enables flexible participation and switching for service providers and at the same time it does not require complete information about configurations, prices and interrelations from the service requester's perspective which makes the mechanism favorable for ad-hoc and situational environments such as service value networks.

We have proposed a multidimensional procurement auction for trading composite services in network economies. We have presented a graph-based model that captures the main components and characteristics of service value networks. Based on this model we have introduced a mechanism implementation that enables allocation and pricing of service components that together form a requested complex service. However, auctions for composite services are more sophisticated than traditional procurement auctions, where the

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[12] We have used a t-test comparing the simulation series results.

[13] http://theseus-programm.de/front

suppliers themselves offer a full solution to the procurer. In composite services, this is not the case, as a flawless service execution and therefore the requester's valuation highly depends on the accurate sequence of its functional parts, meaning that in contrast to service bundles, composite services only generate value through a valid order of their components. The allocation is computed based on the requester's score for QoS characteristics of the complex service. At the same time, the mechanism is capable of handling a wide range of aggregation operations for service attributes also supporting rich semantic information for dealing with complex non-functional service specifications. Due to the combinatorial restrictions imposed by the underlying graph topology and the assumption of monotone aggregation, the winner determination problem can be solved in polynomial time with respect to the number of service offers and their interrelations which is a crucial issue when it comes to implementing online systems. We have furthermore shown that the proposed mechanism is individually rational for service providers, allocation efficient and incentive compatible with respect to QoS characteristics and prices of service offers. Hence, reporting the true multidimensional type regarding configuration and price is a weakly dominant strategy for all service providers. This is a valuable property as it tremendously lowers strategic complexity for service providers and fosters a trustful requester-provider-relationship.

In a repeated game incentive compatibility does not hold. We studied two simple strategies to collude by means of an agent-based simulation approach. The simulation results showed that deviating from truth-telling might be beneficial especially for those SP who are in the allocation. The payments of SP can increase especially if the service quality offers are diverse and as such the difference in prices does not play such an important role as in a price competition regime. We are aware that the results are based on a simple model with relatively strict assumptions, but even such unsophisticated strategies are a good indicator that collusion can be beneficial to service providers.

Besides possible collusion through service providers, the service platform provider must be aware of some obstacles while implementing such a dynamic pricing scheme. Privacy is an issue for such an auctioneer-based approach since the service providers are asked to report their cost which is highly confidential information for enterprises. Additionally, in such VCG-based mechanisms auctioneers are able to betray service providers since the participants in the auction have no opportunity to revise the auction's results. Since the bids are confidential, the auctioneer is not allowed to reveal the bid history for revision. Instead, the auctioneer could publish logarithmized bids to enable participants to recalculate the allocation. A third problem of the algorithm in the present form is that service requesters might be charged prices above their willingness to pay due to the side payments. In order to construct a budget-balanced mechanism, i.e. service requesters would not pay more than their valuation, incentive compatibility must be sacrificed to a certain degree (Parkes et al. 2001). Therefore, it has to be analyzed how much the service providers would be able to manipulate their bids in such a budget balanced regime. As we are aware of these shortcomings, we plan to address them in the continuation of this work.

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Abstract

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How to Coordinate Value Generation in Service Networks – A Mechanism Design Approach

The fundamental paradigm shift from traditional value chains to agile service value networks implies new economic and organizational challenges. As coordination mechanisms, auctions have proven to perform quite well in situations where intangible and heterogeneous goods are traded. Nevertheless, traditional approaches in the area of multidimensional combinatorial auctions are not quite suitable to enable the trade of composite services. A flawless service execution and therefore the requester's valuation highly depends on the accurate sequence of the functional parts of the composition, meaning that in contrary to service bundles, composite services only generate value through a valid order of their components. The authors present an abstract model as a formalization of service value networks. The model comprehends a graph-based mechanism implementation to allocate multidimensional service offers within the network, to impose penalties for non-performance and to determine prices for complex services. The mechanism and the bidding language support various types of QoS attributes and their (semantic) aggregation. It is analytically shown that this variant is incentive compatible with respect to all dimensions of the service offer (quality and price). Based on these results, the authors numerically analyze strategic behavior of participating service providers regarding possible collusion strategies.

Keywords: Mechanism design, Coordination, Service value network, Procurement auction, Semantics

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