A Classification of Autonomous Bilateral Cloud SLA Negotiation Strategies

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ABSTRACT

Currently digital markets emerge where cloud resources are traded in the form of computational services. Usually the so called supermarket approach is applied on these service markets, where consumers buy offered services from providers based on fixed functional and non-functional characteristics without negotiations. However, bilateral multi round negotiation, which allows to customize the traded services, is considered as a promising improvement to the static supermarket approach aiming for higher market efficiency.

In this paper we introduce a novel generic service market ecosystem from which requirements for bilateral negotiation strategies are derived. Evaluating a survey on published bilateral negotiation strategies along these requirements shows that important market elements are not considered in current research. Most of the published bilateral negotiation strategies are focusing on a single negotiation phases only neglecting the complete negotiation process. Hence we classify the identified strategies along the different phases of the generic negotiation process. Based on our analysis we identify two different groups in their scientific approach: One group assumes complete information during bilateral negotiations while the other group assumes incomplete information.

CCS Concepts

•**H.3.4 Systems and Software** → **Distributed systems;**
•**H.4.3 Communications Applications** → *Negotiations;*

Keywords

Bilateral SLA Negotiation, Cloud Markets, Cloud SLA

1. INTRODUCTION

A digital market consists of providers, supplying cloud resources, and consumers, demanding these resources in the form of services. Today the dominant approach used for trading services on these markets is the so called *supermarket approach* [42]. Thereby consumers can choose between predefined offered services. The supermarket approach is called the *take-it or leave-it approach* as the offered services are not negotiated but chosen based on fitting functional and non-functional characteristics. More dynamic approaches for trading services become business reality, e.g. Amazons EC2 spot market [2]. The EC2 spot market is a typical example of an Infrastructure as a Service (IaaS) market: Consumers can bid for virtual machines (VM) instances. The higher their bid the higher is the chance of getting the VM instance. If the bid is too low the consumer does not get the VM instance. Thus, new research [10, 38] postulates that bilateral negotiations have the potential to replace current existing approaches used for trading services. During a bilateral negotiation a consumer and a provider exchange offers in which services are described in the form of SLAs fostering Quality of Service attributes [41]. Hence such negotiations are called SLA negotiations. The negotiation terminates if consumer and provider either form an agreement or reject all offers. As consumers as well as providers are able to create and modify offers bilateral SLA negotiations are considered to be more flexible than the supermarket approach or auctions [38]. Consumer and provider can run multiple bilateral negotiations at the same time as the example in figure 1 shows: Each of the m consumers negotiates with n providers in parallel and vice versa. During a bilateral negotiation the offers are exchanged in an alternating way. For example a consumer sends offers to a provider which responds with counteroffers to which the consumer can respond again leading to a multi round negotiation. The term offer is used for the first exchanged offer (initial offer) in a negotiation as well as for counteroffers. Counteroffer are sent in response to received offers. During negotiation all participants use negotiation strategies to maximize their utilities. For better readability of this paper we use the term bilateral negotiation strategy instead of multi round bilateral SLA negotiation strategy.

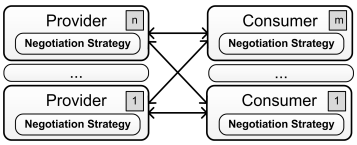

Figure 1: Bilateral SLA negotiation

SLA lifecylces as illustrated in figure 2 show the most

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Figure 2: SLA lifecycle based on [10]

important phases of SLAs from service discovery to decommissioning. SLA negotiation is a separate step in all SLA lifecylces we found [27, 10, 9, 19]. This is because full autonomous SLA negotiation is a non trivial task. Indeed, according to [43] and [9] SLA negotiation is the most complex task of the SLA lifecycle. The authors of [9] consider negotiation of SLAs as the bottleneck of the SLA lifecycle because this step still requires human intervention making the negotiation time consuming.

This paper introduces a classification of autonomous bilateral cloud SLA negotiation strategies preventing the need of human intervention and therefore enabling a fully automated execution of the SLA lifecycle.

Our current research project focuses on economical principles of cloud computing. We started our project with the introduction of a generic negotiation environment for cloud SLAs. Afterwards we did an informal survey on possible bilateral negotiation strategies which we could use in our generic negotiation environment. Thereby we identified two relevant survey papers: (i) The survey introduced in [27] has a very broad focus. It distinguishes between negotiation protocols, pricing plans, negotiation styles and negotiation strategies. The relevant negotiation section distinguishes between three negotiation strategies: "utility functions", "tradeoff strategies" and "concession strategies". The survey only mentions these three types of negotiation strategies without considering other publications. Hence the paper can be considered as a summary of well known concepts but it does not provide a state of the art analysis. (ii) An ACM Computing survey paper focusing on renegotiation in service level agreement was published in [17]. The paper is a general survey on cloud based systems and how they addressed SLA management. For example the authors of the paper have referenced our generic negotiation environment published in [29]. The survey also mentions concrete SLA strategies however the scope of the survey is far boarder which reduces the of level detail at which SLA negotiation strategies were analysed. For example the survey does not distinguish between papers e.g. describing a negotiation protocol and papers describing methods for offer generation. Hence the introduced classification is limited as the authors them self mention in the discussion section.

There are a lot of papers describing bilateral negotiation strategies but a paper structuring and comparing the approaches is missing. Hence we did a survey with a special focus on bilateral negotiation strategies. The main contributions of this paper are:

- A classification of latest bilateral negotiation strategies along the four dimensions (i) Economical Foundation (ii) Negotiation Phase (iii) Heuristic Techniques and Statistical Methods and (iv) System Environment.
- The introduction of a cloud market ecosystem in section 3. From this market ecosystem we derived requirements for bilateral negotiation strategies. These requirements are the basis for the economical evaluation of bilateral negotiation strategies which is required for the classification along the dimension *economical foundation*.

The remainder of the paper is structured as follows. In section 2 we describe the used sources as well as our methods. A classification of the bilateral negotiation strategies from an economical point of view was done in section 3. In section 4 the bilateral negotiation strategies are classified along the negotiation phases of a generic negotiation process. Section 5 groups negotiation strategies according to the used techniques and statistical methods. An overview of the used frameworks for implementing the negotiation strategies is presented in section 6. This section is followed by a discussion in section 7. The paper is closed with a conclusion.

2. SCOPE AND METHODS

Before starting the survey we defined the scope (sources) and the dimensions along which we classified and analysed bilateral negotiation strategies introduced in relevant papers.

Relevant papers are papers describing **bilateral negotiation strategies** in the cloud domain. We identified several papers describing generic (non cloud specific) bilateral negotiation strategies. In our survey we considered these papers if the strategies could be used in the cloud domain. For our survey we used two sources:

(i) The ACM computing survey [17] identified several relevant publications analysing SLA negotiation strategies. The papers of the survey which were relevant for us were also analysed in this survey. However, we categorized the papers along other dimensions. Hence this survey and the survey published in [17] have no redundancies.

(ii) We used Google Scholar to identify further relevant papers. Therefore we used the keyword "cloud sla negotiation". Papers like [11] contain the keyword but have not been considered in this survey as they are not relevant. Further we did not consider papers which were published in 2011 or earlier.

As each paper describes exactly one negotiation strategy we did the classification in the tables 1-4 on the level of papers. Hence if we reference to a paper we mean the negotiation strategy introduced in the referenced paper. We classified the identified bilateral negotiation strategies along four dimensions:

Economical Foundation. First we evaluated economical foundations of current existing bilateral negotiation strategies. Therefore we developed a service market ecosystem from which we derived economical requirements of service markets for negotiation strategies. The identified bilateral negotiation strategies were analysed along these requirements.

Negotiation Phase. Non of the introduced bilateral negotiation strategies covers the complete negotiation process. Instead the analysed strategies focus on selected negotiation phases. We defined a generic negotiation process consisting of five negotiation phases as shown in figure 3. We classified the strategies along the phases of the generic negotiation process: (i) There are papers introducing strategies including new negotiation protocols or extending existing negotiation protocols. These protocols are the basis for the communication required during negotiation. (ii) There are strategies covering mechanisms for evaluating received of-

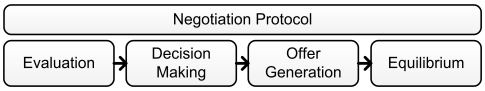

Figure 3: Generic negotiation process

fers. Evaluation of offers is necessary to find out which offers have the highest utility according to given preferences. Thus an evaluation is necessary for ranking received offers. (iii) After evaluating received offers decision making is required. Strategies describing decision making introduce instructions how consumers and providers have to behave during negotiation. They describe for example when to accept or reject offers. In cases offers are neither accepted nor rejected counteroffers are created. (iv) Offer generation mechanisms are procedures for creating offers which are sent to the negotiation partner. Therefore usually the preferences of the negotiation partner are considered during creation of offers. Offers having a high utility for both, the sender and the receiver have a high chance of resulting into an agreement. (v) There are also strategies focusing on achieving optimal equilibriums in negotiation scenarios.

Heuristic Techniques and Statistical Methods. During our initial survey we identified that several bilateral negotiation strategies were using heuristic techniques as well as statistical methods. Therefore we analysed the bilateral negotiation strategies in order to identify widely accepted heuristic techniques and statistical methods.

System Environment. Finally we analysed the implementations of the introduced bilateral negotiation strategies. Our goal was to find out which frameworks are used by the scientific community for the realization of bilateral negotiation strategies.

3. ECONOMICAL FOUNDATION

For analysing the negotiation strategies from an economical point of view we developed a cloud market ecosystem from which we derived economical requirements of service markets for bilateral negotiation strategies.

A layered architecture of a service market ecosystem which we developed is proposed in figure 4. This ecosystem is separated into four layers whereas each layer consists of several building blocks as summarized in the following itemization.

- A **market** governs the policies, resource allocation mechanism and taxes which have to be paid. Further the market defines penalties determining how much a market participant has to pay in case of SLA violations. Constraints determine for example rules for re-negotiation of SLAs. Providers are usually participating in value networks and are elements of value chains.

- Basically, the stakeholders of a market consist of consumers, providers and intermediates [6]. We call these roles **market participants**. Market participants trade services via SLA agreements.

  Providers run an infrastructure for offering different resources in form of services. Intermediates may compose the already existing services into various products, aggregate dynamically as per consumer demand or resell the services without running an infrastructure. Services are used by consumers for executing business tasks. A novel approach is the introduction of intermediaris, e.g. a Third Party Trust Manager [18] that fosters trust among the participating stakeholders. Two special market participants are the government and the standardization bodies. The government enforces tariffs, quotas, taxes and regulations whereas the standardization bodies influence the market behaviour by building a consensus on standards, procedures and guidelines. Different service providers may group together to form value networks and supply chains.

- Market participants follow a **business model** describing how they make profit. Three basic contributing factors influence a business model [6]: The market position defines if a market participant is an intermediary or a service provider. The revenue model describes how profit is generated. Subscription or sales are two possible revenue models. The price discrimination model categorizes business models along their pricing model, for example loyalty-based pricing.

  Business rules define the basic strategic behaviour. Other factors such as ever changing market dynamics, the place of the service provider in a supply chain and the type of the product also play an important role in defining the business model. A business strategy operationalizes the business model. The 7P's (Product, Promotion, Price, Place, People, Process, Physical evidence) used in marketing or extended models such as described in [6] can be used for describing a strategy.

- The **resource allocation** in a market is governed by the **allocation principles** of efficiency, optimality, social welfare and equality [32]. Further the results can be evaluated from an ecological (e.g. energy efficient) point of view. Resources are Human Capital, Physical Infrastructure and Energy.

First we identified economical requirements using a top-down method: We derived the requirements from the service market ecosystem. In the scope of this paper we focused on the highest relevant requirements necessary for realizing bilateral negotiation strategies. For example we have not considered requirements coping with the market elements Promotion, Human Capital or Value Networks which are neither highly relevant during bilateral negotiations nor considered in any existing bilateral negotiation strategy. In a second step we derived requirements using a bottom-up method: Thereby we captured the requirements which have already been considered in current existing bilateral negotiation strategies. The additional requirements which we identified using the bottom-up method are Utilization and Time-Constraint. The following list contains the economical requirements for bilateral negotiation strategies:

- **Utilization.** Is the provider strategy able to consider the current workload of the datacenters? Has the strategy access to a timetable tracing when which resources are sold?

- **Time-Constraint.** Does the strategy consider time restrictions for finding an agreement?

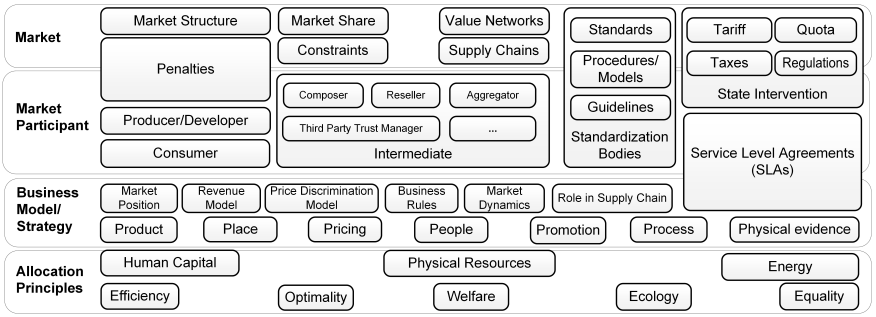

Figure 4: Service market ecosystem

- **Business Partner.** Does the negotiation strategy differ between the negotiation partner (for example premium costumers or non-premium costumers)?
- **Cost Model.** Does the provider negotiation strategy consider its cost? Is a cost model in used?
- **Energy consumption.** Does the strategy consider energy or other environmental effects?
- **Qualified prospects.** Does the provider consider the amount of current negotiations (or negotiations which will be successful)?
- **Business policies.** Does the negotiation strategy consider business policies?
- **Penalties.** Does the negotiation strategy consider negotiation of penalties?
- **State Intervention.** Are regulations or taxes considered during negotiation? Is the strategy able to handle different tax systems?
- **Intermediates.** Does the negotiation consider intermediates? Which negotiation strategies are used for them and how they are different in comparison to typical consumer/provider strategies?

In table 1 we evaluated the identified bilateral negotiation strategies along the economical requirements which we listed above. A double crossed box ▩ means that the paper introducing the strategy describes on a high level of detail how the strategy meets the requirement while a single crossed box ▨ means that the requirements is mentioned but not described in full detail. The papers [14] and [43] describe bilateral negotiation strategies using game theoretical approaches focusing on finding equilibriums without meeting economical requirements. Thus we have not listed them in the table to save space.

Economical requirements like state intervention, intermediates, business policies and business partner have not been considered yet by current existing bilateral negotiation strategies. This reveals that most of the bilateral negotiation strategies are neglecting basic economical principles which are necessary to succeed in reality. The table shows that most of the strategies are only meeting one economical requirement. Hence no strategy has a deep economical foundation. In the following we describe how the negotiation strategies meet the requirements shown in table 1. We want to clarify that the described mechanisms and algorithms are part of the identified bilateral negotiation strategies.

Utilization. Utilization is the most frequently fulfilled economical requirement in the analysed bilateral negotiation strategies. It is only relevant for providers running datacenters. The authors of [10] and [9] consider utilization in the form of balancing datacenter resources. Imaging a simplified virtual machine which has the two characteristics RAM and processing power. If the provider would sell all its RAM in the form of virtual machines then the provider is unable to sell the unsold processing power. This is because each consumer buying a virtual machine also requires some RAM. Hence the authors of [10] and [9] introduced a mechanism used during negotiations which reduces prices of low used datacenter resources. This leads to a higher demand of the low used datacenter resources resulting into balanced datacenter resources.

The authors of [22] have a complete other perspective on utilization during bilateral negotiation. The authors describe that providers usually have the problem that they receive requests for a resource required at a specific time slot. They mapped the provider's problem of selecting the best fitting consumer request to a placement problem which has to be solved during negotiation. So the provider uses a schedule where it traces at which time slot which resources are sold. In [40] the authors consider time slots too. They have shown that time slot negotiation leads to less SLA violations than negotiations without considering time slots. The authors of [16] published a generic SLA negotiation paper considering utilization of bandwidth without introducing further details. In the negotiation algorithm of [3] the utilization is checked before a request is accepted. However, they do not use utilization during bilateral negotiations.

Time Constraints. Time constraints during negotiation are another prominent requirement considered in several negotiation strategies. Here [44] has introduced a dominant approach which was reused by [10] and [9]. In [44] consumers and providers have a predefined maximum and minimum value of each SLA parameter. We only explain the case in which the maximum is the preferred value for consumers and the minimum is the preferred value for providers. At the start of the negotiation the offers are created. Consumers create offers using maximum values and providers create offers use minimum values for the SLA parameters. So the created offers have a high utility value for their senders. However, each consumer and provider has a time constraint until an agreement is required. Hence in the subsequently

Table 1: Bilateral negotiation strategies meeting economical requirements

	[36]	[22]	[15]	[37]	[16]	[21]	[25]	[26]	[1]	[4]	[44]	[33]	[38]	[10]	[3]	[34]	[35]	[39]	[31]	[8]	[5]	[40]	[9]
Utilization		■			▨									■	▨							■	■
Time-Constraint									▨		■			■		▨							■
Cost Model													▨					▨					
Penalties																			▨			▨	
Qualified-Prospects													▨					▨					
Energy consumption																				▨	▨		

created offers the SLA parameter values are time dependent decreased (consumer) or increased (provider) until an agreement is formed or the time is elapsed. Exponential functions and polynomial functions define how fast the values of the SLA parameter are decreased (consumers) or increased (providers). The authors of [34] use a similar approach: big concessions are only allowed at the end of negotiation. However the authors do not describe the usage of functions for controlling concessions. In [1] a timeout threshold is mentioned without a detailed description.

Cost Models. The usage of a cost models is one of the most important requirements which has to be considered during negotiation for providers. Without a cost model providers do not know at which prices they make profit. Nevertheless our survey reveals that current bilateral negotiation strategies ignore this requirement. This is because creating a cost model is a complex task. As shown in [30] creating a cloud cost model requires a lot of information like energy consumption of hard discs applied in datacenters. Only [38] and [39] consider a cost model on a very rudimentary way: They estimate the cost structure instead of deriving it from the datacenter setup. Instead of costs most of the papers like for example [9] or [22] consider utility values only. This means the provider tries to maximize its utility which usually implies increasing the price and/or decreasing the served datacenter resources and obligations.

Penalties. Penalties are a less prominent requirement for bilateral negotiation strategies than time constraints or utilization: We found two papers considering penalties: [31] introduces inter alia policies for selecting which SLAs should be violated in case of datacenter resource shortages. The authors of [40] used penalties for assessing if time slot based negotiation is more successful than non time slot based negotiation. So both papers do not describe how to negotiate penalties and therefore we classified them using a single crossed box. However their ideas can be used in bilateral negotiation strategies. The lack of considering penalties as part of negotiation may result from the position that penalties are predefined and hence not negotiateable.

Qualified Prospects. In parallel negotiations the number of qualified prospects is a key figure for estimating how many of the current negotiations will result into agreements. Hence the number of qualified prospects can significantly influence a consumers or providers negotiation position. For example consider a provider which parallely negotiates with 100 consumers for identical SLAs required for the same time slot in which it can serve at most 10 consumers. The provider has a strong negotiation position: it can set such a high price which is not acceptable for 90 costumers. If only 1 consumer is negotiating with the provider then the provider will not be able to set such a high price as in the scenario with 100 consumers because the demand is significantly lower.

The authors of [38] and [39] use an utility threshold for accepting received offers. First offers are evaluate by assigning utility values to the offers. Offers with an utility exceeding the threshold are accepted. In [38] and [39] the threshold is increased if the number of current negotiations increases. Contrary, if the number of current negotiations decreases the threshold decreases too. This is probably the simplest form of considering qualified prospects.

Energy Consumption. Energy consumption is only described in [8] and [5]. In [8] the energy view is closely related to the cost view: The author describes that providers have to manage the trade-offs between required energy and the charged price during negotiation. However, this trade-off was not described in more detail. Hence we used the single crossed box in this cell. The authors of [5] considered energy consumption in more details than [8] but the level of detail is still low. For example they did not explain how the energy estimation is calculated which is used in their algorithm.

Table 1 shows that only the economical requirements like utilization and time constraints can be considered as well established in bilateral negotiation strategies.

4. NEGOTIATION PHASES

In this section we classified the identified bilateral negotiation strategies along the negotiation phases of the generic negotiation process which is shown in figure 3. As already described non of the bilateral negotiation strategies covers all negotiation phases. Instead the bilateral negotiation strategies cover selected phases of the negotiation process as the left part of table 2 shows. During the classification we were faced with the problem that assigning each strategy to all negotiation phases it touches would bias the result as several papers introducing a negotiation strategy only mention aspects of negotiation phases without providing fundamental concepts. Hence, we distinguish between two classifiers: The first classifier is marked in table 2 with a double crossed box ■. This means that these negotiation phases are in the main focus of the paper introducing the bilateral negotiation strategy. The second classifier which is visualized with a single crossed box ▨ in table 2 shows that the paper introducing the bilateral negotiation strategies describes the negotiation phase on an low level of detail.

Table 2 shows that all negotiation phases were approximately considered by the same amount of strategies described in the papers. The equilibrium phase is an exception: We introduced this phase for the game theoretical approaches which focus on finding an equilibrium without analysing the other phases.

Protocol. Most of the papers describing negotiation strategies without introducing new protocols or extending existing

protocols were using or at least considering to use one of the three well known negotiation protocols WS-Agreement [42], FIPA [23] and WSLA [28]. The large number of papers introducing or extending negotiation protocols could be an indicator that several scientific groups are not confident with the current existing negotiation protocols. However, we were unable to find a common motivation or reason making the development of new protocols necessary. For example the authors of [37] create a protocol without considering existing ones. Their protocol consist of seven sequential phases with setbacks: initiation, investigation, presentation, evaluation, decision, agreement and finalizing. Unlike in for example the WS-Agreement standard the phases are not limited to message exchanges. Instead they describe the whole negotiation process. Contrary, the authors of [1] argue that *up to now none of these specifications is standardized for representing SLA document, hence has caused integration problems.* In [1] it is stated that existing protocols like WSDL are unable to express non-functional service requirements. In [33] the authors created a specific protocol for the JADE framework.

Evaluation. All negotiation strategies covering the evaluation of offers are mapping preferences to utility functions. We found no negotiation strategy using an alternative preference mapping approach like for example the prospect theory [12]. By reviewing the strategies focusing on the evaluation of offers we were able to identify the weighted average model as the dominant evaluation model: Papers like [4], [38] or [44] propose to split SLAs up into its parameters. The utility for each parameter is evaluated independently of the others. Therefore utility functions are used. The final utility of an SLA represents the weighted sum of the utilities of the single SLA parameters. This mechanism is shown in the following equation where i is a SLA parameter: $U_{total} = \sum_i^n w_i \cdot U_i$.

The authors of e.g. [44] and [4] standardize the utility of each parameter between zero and one. For example if a resource parameter of a SLA in an offer represents a maximum then it has an utility value of 1 for the consumer and 0 for the provider. This is because the consumer usually wants to have as much resources as possible and the provider wants to deliver as less resources as possible. The sum of weights is one $\sum_i^n w_i = 1$ leading to a final utility value between zero and one. Contrary the authors of [38] use non standardize utilities and weights. In [38] the authors argue that standardization is not possible as the minimum and maximum values of SLA parameters are usually unknown and time dependent. Further evaluation approaches are suggested by [15] which proposes a weighted product model and an analytical hierarchy process.

Decision Making. We have not identified a dominant approach in the analysed bilateral negotiation strategies for decision making. For example the authors of [39] use two thresholds for accepting and rejecting received offers: an accept threshold and a reject threshold. If the utility of an offer exceeds the accept threshold then the receiver of that offer tries to form an agreement. Contrary, if the utility of an offer is lower than the reject threshold then it is rejected. Also the authors of [8] use a threshold for deciding if an offer is accepted. The authors of [10] and [9] use a time dependent negotiation strategy. Everytime if a participant receives an offer it creates one or more counteroffers. The creation of a counteroffer is independent of the received offers. It solely depends on the time as described in more details in section 3. After creating the counteroffer its utility is compared to the utility of the received offer. Thereby the creator of the counteroffer uses its utility function. If the utility of the created counteroffers is lower than the utility of the received offer than the offer is accepted. In such cases the counteroffer is not sent to the negotiation partner.

Offer Generation. In the analysed negotiation strategies we have identified a wide variety of approaches for generating offers. All strategies which we identified are only able to create counteroffers (no initial offers) without the strategy described in (ii) in the following itemization. To keep the classification compact we did not distinguish between strategies for creating offers and strategies for creating counteroffers. The strategies based on time, statistical methods and heuristic techniques are described in more detail in section 3 (ii) and 5 (iii-v). (i) Probably the simplest approach for creating counteroffers is introduced in [38]. The authors assume that received offers usually have a high utility for their senders. Hence these offers are used as basis for creating counteroffers. Thereby counteroffers are created by simply modifying SLA characteristics of the received offer. The variation is done in such a way that the so created counteroffer has higher utility than the received offer for the creator of the counteroffer. (ii) In [10] offers are created without considering the negotiation partner or received offers. Instead only time influences the creation of offers. Also the authors of [1] mention the usage of time for creating counteroffers. (iii) The authors of [39] and [36] suggest to use genetic algorithms for creating counteroffers. (iv) The Bayes theorm was used by papers like [26] or [21]. Thereby the authors tried to asses the probability that a potential counteroffer gets accepted. This probability is used for counteroffer generation. (v) The authors of [8] introduced a particular swarm method for creating counteroffers considering the utility of sender as well as the utility of the receiver of the counteroffer.

Equilibrium. The papers [14] and [43] use game theoretical approaches for analysing bilateral SLA negotiations. Both papers neither describe how to create offers nor how to evaluate received offers. The focus of these papers is the analysis of negotiation equilibriums to which negotiation participants should agree.

The right part of table 2 shows if the introduced bilateral negotiation strategy in the paper is useful for consumers and providers. Most of the papers do not state explicitly if their strategy is designed for consumers or providers. Hence we were forced to make this categorization based on an evaluation of the bilateral negotiation strategies described in these papers.

Several of the analysed papers propose agents or brokers which can be used by both consumer as well as provider. The two papers [35] and [3] do not ignore the provider perspective but have a stronger focus on the consumer perspective. The paper [31] provides inter alia algorithms for provider for avoiding high penalties and price maximization. The consumer perspective is completely missing. The paper of [8] has a strong focus on energy awareness making it more appropriate for providers.

The last column in table 2 shows the used negotiation protocol. Papers introducing negotiation strategies have not been considered for the evaluation of this attribute. So we marked the cells with a '-'. In several papers the authors have not mentioned which protocol they used. So we left these cells empty. In all the other cases we have entered the

used protocol.

5. HEURISTIC TECHNIQUES AND STATISTICAL METHODS

In our survey we identified that the most bilateral negotiation strategies use a well known heuristic technique or statistical method. We summarized the used techniques in table 3.

Genetic algorithms and particular swarm optimization are techniques used for creating counteroffers. Contrary the Bayes theorem and reinforcement learning were used to estimate preferences of the other negotiation partner. Thus, most of the identified techniques listed in table 2 were used directly or indirectly for creating counteroffers. For example the papers [36] [39] and [5] introduce a genetic algorithm. The papers apply a fitness function which represents the utility of the consumer as well as the utility of the provider. So offers with a high fitness value usually have a high utility for the consumer and provider increasing the chance that an agreement is formed. Genetic algorithms seem to be a widely used approach for creating counteroffers in the bilateral negotiation domain.

Contrary to genetic algorithms the Bayes theorem usually requires priori probabilities. Therefore historical datasets are used. Based on this historical datasets each sender of a counteroffer first uses the Bayes theorem for calculating the probability that the counteroffer is accepted by its receiver. The authors of the papers [21] [26] [34] [35] use the Bayes theorem during counteroffer generation. While [21] does not describe an algorithm how to create counteroffers based on the Bayes theorm the authors of [26] suggest to create a ranked list of potential counteroffers where the ranking reflects (i) the utility of the counteroffer for the sender (ii) and the acceptance probability of the receiver of the counteroffer. It is not described in detail how the ranked list of counteroffers is created. In [35] the Bayes theorem for assesing preferences was embedded into a detailed negotiation workflow which is used in the framework the authors present. The authors of [34] combine the result from the Bayes theorem with a time constraint without describing further details. In our survey we identified the Bayes theorem as the dominant approach for modelling negotiation partners during bilateral negotiations. This implies also that the research community usually assumes imperfect information during negotiation as we will further describe in the discussion section.

Only one negotiation strategy was using a particular swarm optimization algorithm for creating counteroffers [8]. Here each element in the swarm represents an potential counteroffer. The wind is the consideration of the negotiation partner which moves the particles away from the optimal counteroffer for the sender of the counteroffer. The basic assumptions in this paper seem to be identical with the assumptions of the papers using genetic algorithms: all try to create counteroffers which are of high value for senders as well as for receivers in order to form agreements.

The reinforcement learning approaches introduced in [16] [25][34] were used to estimate the utility of counteroffers for the negotiation partner. For example the authors of [25] use reinforcement learning algorithms to learn the preferences of the negotiation partners assuming that the negotiation partner uses a weighted average model for calculating the utility of offers.

Game theoretical approaches such as introduced in [14] and [43] form the last category in table 3. The publications use game theoretical axioms to find equilibriums. Game theoretical approaches are contra dictionary in the scientific community as show in the discussion section of this paper.

Negotiation strategies covering two or more heuristic techniques or statistical methods are rare. Only in [34] the Bayes theorem was used as well as a reinforcement learning technique.

6. SYSTEM ENVIRONMENT

In this section we analysed the implementations of the published bilateral negotiation strategies. Our goal was to identify widely used frameworks for implementing bilateral negotiation strategies. Our analysis is summarized in table 4. Again we neglected the two papers focusing on game theoretical approaches.

The categories "no framework" and "unkown" are special cases. If a paper introduces an implementation without mentioning a specific framework we added this paper to the category "no framework". Examples are [44] or [16] which are Java based implementations. We assigned papers which do not describe their implementation of the bilateral negotiation strategy to the category "unkown". During reviewing these papers we were (i) unsure if there is an implementation and/or (ii) if the implementation uses a framework. As you can see in table 4 the category "unkown" counts the most publications of all categories. CloudSim and JADE are the two most popular frameworks in the bilateral SLA negotiation domain. CloudSim [7] is a Java-based simulation framework which was introduced by the University of Melbourne. It allows to model and simulate cloud infrastructures. JADE [24] is an acronym for JAVA Agent DEvelopment Framework which is a implementation of the FIPA sepcification. The framework supports the realization of multi-agent systems and is based on the peer to peer paradigm. The Aspoc and EERM framework are two special cases as the frameworks were introduced in the same paper as the bilateral negotiation strategy which we analysed. (i) The Aspoc framework was introduced in [35]. As the framework seems to be comprehensive and independent from the publication we did not move this paper to the category "no framework". Instead we listed Aspoc framework as separated framework. (ii) The EERM (Economically Enhanced Resource Manager) is a framework implemented by [31]. Similar to Aspoc we considered the EERM framework as separate framework. The framework GENIUS was introduced in [20]. It is able to run and analyse negotiation sessions as well as creating agents which are used in the negotiation sessions. From the papers which we analysed within this survey it was only used in [34] .

The review reveals that there is no dominate framework used in the scientific community. While CloudSim, EERM and Aspoc are cloud specific simulation environments JADE and GENIUS are generic frameworks (cloud independent).

7. DISCUSSION

In our survey we observed that the scientific community is split up into two groups. The first group assumes that negotiation partners do not know the preferences of the other negotiation partners during bilateral negotiations. Hence statistical methods and heuristic techniques are used to es-

Table 2: Classification of bilateral negotiation strategies

	Negotiation Phase					Perspective and Protocol		
	Protocol	Evaluation	Decision Making	Offer Generation	Equilibrium	Provider	Consumer	Negotiation Protocol
[36]				■		■	■	
[22]		▨	▨	▨		■	■	FIPA CN
[15]	■	■	▨			■	■	-
[14]					■	■	■	
[37]	■	▨				■	■	-
[43]					■	■	■	
[16]		▨	■			■	■	
[21]		■	■	▨		■	■	
[25]	▨		▨			■	■	-
[26]		▨	▨	■		■	■	
[1]	■	▨		▨		■	■	-
[4]	▨	■	▨			■	■	-
[44]	▨	■		■		■	■	-
[33]	■		▨			■	■	-
[38]		■		■		■	■	WS-Agree.
[10]		■	■	■		■	■	
[3]		▨				▨	■	
[34]	▨	■				■	■	-
[35]	▨	▨				▨	■	-
[39]		■	■	■		■	■	WS-Agree.
[31]			■			■		
[8]			■	■		■	▨	WS-Agree.
[5]				▨		■	■	
[40]		■				■	■	
[9]		■	■	■		■	■	

Table 3: Techniques used in bilateral negotiation strategies

Technique	Publications
Genetic Algorithm	[36, 39, 5]
Bayes Theorem	[21, 26, 34, 35]
Particular Swarm Optimization	[8]
Reinforcement Learning	[16, 25, 34]
Game Theory	[14, 43]

Table 4: Frameworks for implementing bilateral negotiation strategies

Framework	Publications
CloudSim	[38, 39, 9, 10]
JADE	[8, 1, 33, 40]
EERM	[31]
Aspoc	[35]
GENIUS	[34]
No Framework	[44, 3, 26, 16]
Unkown	[5, 4, 21, 15, 22, 36, 37, 25]

timate the unknown preferences and strategies. The second group is smaller and assumes that preferences as well as strategies of a negotiation partner are at least known at a certain degree during negotiation. This group uses game theoretical approaches for finding equilibriums which the first group does not consider.

The authors of [44] and [10] are members of the first group which are sceptical about the usage of game theoretical approaches applied by the second group. So the authors of [44] state by citing [13] that game theoretical approaches are not applicable because in reality preferences of negotiation partners are usually unknown in the bilateral SLA negotiation domain. Similarly the authors of [10] argue that in game theoretical approaches negotiation partners need to know the negotiation strategy of the negotiation partners.

A goal of this paper was to find out how far negotiation strategies consider market elements of the currently emerging service markets. Categorizing papers along this dimension reveals a research gap: Only the requirement time constraint as well as utilization are met by some negotiation strategies. For all other aspects further research is necessary.

The dominance of the Bayes theorem for estimating the negotiation partners preferences was obvious. For us it is unclear why no paper has used another heuristic technique for the estimation of preferences of the negotiation partner like for example deep learning techniques.

We want to mention that due to the wide variety of used negotiation strategies in terms of focus and technology it is difficult to find dimensions for categorizing papers. To foster comparability we introduced the classification depicted in table 2 which should help other scientists to get an orientation in the field of bilateral negotiation.

In our survey we have not considered renegotiation strategies which are necessary when a consumer wants to scale up during using a cloud. The authors of [10] identified two paradigms for renegotiation when scale up of datacenter resources is required: (i) **Negotiation process triggered on demand when scale-up is required.** Here usual bilateral negotiation strategies can be used as renegotiation strategies. However the authors of [10] state that a new negotiation process takes some time delaying the scale up. Further a provider may not be able to provide additional resources. Hence the authors introduced the second paradigm. (ii) **Negotiation process triggered at deployment time before scaling is required.** In this model consumers can

reserve required resources a priori. Here reservation prices (upfront payment) as well as reservation capacities have to be negotiated. Hence usual bilateral negotiation strategies can not be used as renegotiation strategies. Instead they need to be extended in order to consider these additional aspects.

8. CONCLUSION

In this paper we introduced a survey on bilateral negotiation strategies. The survey analysed the latest publications along four dimensions.

By evaluating papers along the first dimension *economical foundation* we found out how far economical requirements of service markets are considered in current existing bilateral negotiation strategies. This evaluation reveals that deep economical consideration is currently missing. In the second dimension *negotiation phases* we have shown that the introduced negotiation strategies usually focus on different negotiation phases which makes comparison more complex. Further we identified two scientific groups. A group makes stronger restrictions regarding the required information during negotiation. It assumes that for example the preferences of the other negotiation partners are known (complete information). Hence this group tries to describe negotiations using game theoretical approaches. The other group relaxes the requirement of knowing the preferences and strategies of the other negotiation partner (incomplete information). This group applies heuristic techniques as well as statistical methods for estimating the unknown information during negotiation. For the third dimension *heuristic techniques and statistical methods* we analysed the used knowledge engineering approaches as well as statistical methods. Here we identified that genetic algorithms as well as the Bayes therom are widely used in bilateral negotiation strategies. Other well known heuristic techniques like deep learning methods have not been considered yet. The evaluation along the fourth dimension *system environment* revealed that CloudSim and JADE are the most popular frameworks for implementing bilateral negotiation strategies. However, several papers introduce their own frameworks or implementations without using an existing framework.

The scientific community has published a lot of different bilateral negotiation strategies. Further research is necessary especially in the field of applying economical concepts in negotiation strategies.

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