Uncertainty and Uncertainty Tolerance in Service Provisioning

Johari Abdullah and Aad van Moorsel
School of Computing Science
Newcastle University, NE1 7RU, UK
{johari.abdullah,aad.vanmoorsel}@ncl.ac.uk
`http://cs.ncl.ac.uk/`

Abstract

One of the challenges for Internet-based service provisioning is to provide a measure of quality control to the end users. One way to enable this is by having a form of contractual agreement such as employing Service Level Agreement between the customer (end user) and service provider. We argue that such agreement has inherent uncertainty in the form of customer's state of belief towards the compliance of the agreement. This paper focuses on three main areas. Firstly, we discuss the problem of uncertainty within service provisioning offer and subsequently introduce the concept of uncertainty tolerance. Secondly, we discuss our approach of providing a measure of tolerance towards uncertainty which involves the application of Bayesian and Decision Networks. Finally, we present a case study to illustrate the problem and our solution, followed by an empirical evaluation to show that our solution works.

Keywords: Uncertainty, Uncertainty Tolerance, Service Provisioning, Bayesian Networks

1 Introduction

In recent years, the Internet has become an important platform to provide services to the end users. Services Computing[39], Service-oriented Computing[8], Cloud Computing[5], Web Services[21] and Utility Computing[28] are all different paradigm of implementation for distributed systems[35]. They all share a similar objective, which is to provision services in electronic form. Provisioning, in the context of computing, is the process of providing users with access to data and technology resources. One of the challenges in provisioning is to provide and guarantee an agreed level of service to the end users. One way to enable this is by employing a form of contractual agreement such as Service Level Agreement (SLA) between the service provider and the customer. An SLA is a part of a service contract where the level of service is formally defined between the consumer (end user) and the service provider [17].

In a commercial provisioning environment, the SLA can be a key factor in attracting potential consumers [24]. For example, service providers that can provide a guaranteed quality of service will more likely be chosen by a customer. Furthermore, if the service being provisioned is used by consumers to operate their business operation, the quality and guarantee of the service offer becomes important[25]. However, the SLA offer has inherent uncertainty that potentially can affect customer's decision to accept or reject the offer. In this paper, therefore, we analyse how uncertainty affect service provisioning, and address these problems using a combination of Bayesian and Decision Networks.

Our uncertainty tolerance model addresses uncertainty in service provisioning offer from two perspectives: First, the customer's initial belief towards the probability of success of the SLA offer and secondly, the decision of customer whether to accept or reject the SLA offer. Given the above uncertainties, we are interested in updating the initial customer's belief and also assist the customer in decision making. We assume that there is a body of evidence that is linked to the probability of success of the SLA offer. This body of evidence can be an aggregation of quantitative values of other customers feedback, expert forecast, etc. We then view the probability of success of the SLA and the body of evidence

Journal of Internet Services and Information Security (JISIS), volume: 1, number: 4, pp. 89-109

as nodes within a graph and leverage Bayesian and Decision Networks to assist customer in decision making.

The contribution of this paper is threefold: i) First, we discuss the problem of uncertainty within service provisioning offer and subsequently introduce the concept of uncertainty tolerance ii) Then, we present our approach of providing a measure of tolerance towards uncertainty which involves the application of Bayesian and Decision Networks and iii) Finally, we develop the Uncertainty Tolerance engine to assist customer in decision making.

The remainder of this paper is organized as follows: Section 2 provides an overview of related work. Section 3 discusses the background on service provisioning including the life cycle and service quality. This is followed by Section 4, which presents uncertainty issues within the context of service provisioning. In Section 5, we provide the definition for uncertainty, and presents the different views on uncertainty. We also discuss the underlying theorems being leveraged in our solution, present the notion of uncertainty tolerance and our approach to provide uncertainty tolerance within the context of service provisioning. To illustrate our solution, we present a case study in Section 6 and conduct an empirical evaluation in Section 7. Finally, we summarize our work and present subsequent research work to follow.

2 Related Work

To the best of our knowledge, there is no specific research conducted to address the issue of uncertainty within service provisioning. There are similar researches within the services computing domain to handle the issues of accountability, risk, and trust, focusing mainly on service composition and discovery. For example, Zhang et. al.[41] leveraged Bayesian Networks and evidence channel selection algorithm, focusing mainly on the composition of services on the service provider side. On the other hand, we focus on customer's perspective, addressing the uncertain nature of the service offer. Shaikh Ali et. al. also works on service discovery issue using trust as a benchmark for service selection. His work in [1] is based on Fuzzy Cognitive Map and in subsequent research [2], Dempster-Shafer Theory was employed to handle multiple belief sources. In [34], uncertainty is defined as the inability of the service provider to quantify the inherent behavioural factors in service provisioning and is mitigated using utility model. Therefore, two key areas where our work differs are (1) defining the uncertainty issue from customer's perspective, and (2) addressing the uncertainty issue (termed as uncertainty tolerance) using Bayesian and Decision Networks.

3 Motivation

Services in electronic form are becoming an important aspect of IT industry. Organizations and companies increasingly become the consumer and provider of services to address their business and organizational needs. Services Computing (SC) is a relatively new area of research which aims to study the science and technology of utilizing computing resources and information technology to model, create, operate, manage business services. Services computing can benefits business and organization in three ways [40]: (1) the cross disciplinary nature of SC enable business services to be performed more efficiently and effectively, (2) the global standardization will enable interaction between existing services, and (3) enable provider to provide Software as a Service (SaaS).

From a business perspective, Gartner predicts that the SC industry will be worth \$11.5 billion in 2011. Furthermore, Gartner [26] forecasts that revenue for Cloud Computing will reach \$68.3 billion in 2010, and projected for a strong growth for the next 5 years. These figures indicate the importance of the SC to business enterprises, but many enterprises are still concern about security, availability of service, vendor viability, and maturity.

There are different type of service provisioning such as hardware, application, and connectivity. For example, Software as a Service (SaaS) is a type of service provisioning that offer software or application to customer as a service on demand. On the other hand, utility computing provides end users with access to a computation service to run computational intensive tasks such as financial modelling. The recent evolution of utility computing and the Internet is the emergence of cloud computing whereby shared resources, information, and software are provided to customer on demand. Examples of popular cloud computing implementation are Amazon EC2, Microsoft Azure, and Google App Engine [30].

From above discussion, services provision through electronic medium has become an important part of businesses and organizations, and arguably, in future, will also become important to individual user. We believe that when a service is coupled with some form of contractual agreement (for example, through SLA) in order to provide an assurance of quality, there is an issue of uncertainty that needs to be dealt with.

What is a service? From an economic point of view, a service is the intangible equivalent of an economic product. Rathmell [29] distinguishes between the provision of pure goods and services. Furthermore, he associates the term utility to services as a measure of customer satisfaction. The concept of utility will be explained further and is linked to our approach in uncertainty tolerance. Zhang et. al. [40] define the term services as follow:

Definition 1. *"Services" represent a type of relationships-based interactions (activities) between at least one service provider and one service consumer to achieve a certain business goal or solution objective.*

Zhang's definition views a service as a relationship between two entities but does not give any insight on the provisioning of the service itself. Therefore, we extend the view by providing the definition for *"service provisioning"*. In the context of the service provisioning through the Internet, we define service provisioning as follows:

Definition 2. *"Service provisioning" is the process of providing customers access to resources to complete tasks required by the customer. Resources can be in the form of hardware, software, or computation.*

We assume that all services provisioning implementation can be simplified to a generic architecture as shown in Figure 1. In order to exemplify our work on uncertainty tolerance, we will apply it to a generic web service provisioning scenario. In a typical web service provisioning architecture, there are three main components - customer (client side), service provider (server side), and service directory(broker).

- **Customer**: A customer is an entity (which can be a human or software agent) which sought after a service to complete a task(s).
- **Service Provider**: A service provider is an entity that hosts and offers services to the end users (customer).
- **Service directory**: A service directory or registry is essentially a service metadata portal for service registration and discovery.

Figure 1 shows the basic architecture of a web service provisioning between the service provider and the end user. Figure 1 also shows the life cycle of a web service provisioning process, which consists of several steps. Our paper focuses on the uncertainty issues and solution in the publish/offer and the decision making steps.

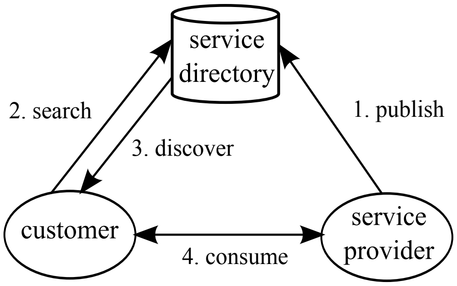


Figure 1: General Service Provisioning Architecture and Lifecycle

4 Problem Definition

4.1 Uncertainty in Customer's Initial Belief

A service provider provisions a service which utilizes one or more resources. As discussed in the above section, service providers can offer contractual agreements between themselves and their customer to ensure that they can deliver their serviced as promised. One specific example of such contractual agreement is by using Service Level Agreements.

From the customer point of view, we argue that uncertainty exists in the form of SLA compliance. We can say that the customer has a *"state of belief"* for the proposal. This state is the customer subjective perception on the SLA proposal, which is influenced by uncertainty. The key issue here is that the customer lacks information or knowledge, thus giving rise to uncertainty. We make the assumption that, without any additional information, the customer can subjectively assign any degree of belief. For example, a customer can assume there is a fifty percent (50%) probability the SLA will be complied to. We are interested in finding a way to update customer's initial belief based on additional information, termed as *"evidence"*, which we will explain later in Section 5.4.

4.2 Uncertainty in Deciding SLA Offer Problem

Once the customer received the SLA offer from the service provider, the next step is for the customer to decide whether to accept or reject the offer. We argue that at this stage of the process, the customer is uncertain about the decision. The main issue is that the uncertainty arises since the customer does not have the required information or means to help in making the decision. Therefore, in this study, we are interested to device a solution which can assist the customer in making the decision under uncertainty.

5 Methodology

Our uncertainty tolerance model views the customer's initial belief and the subsequent customer decision making (for the SLA offer) as two aspects of uncertainty. We start with the definition of uncertainty and uncertainty tolerance from the service provisioning perspective, then leverage the concept of subjective probability and reasoning through Bayesian and Decision Networks.

5.1 The Concept of Uncertainty

The term uncertainty, in general refers to the condition of being unsure about someone or something. Although this term is widely used by the general public, there are different definitions in different specialized fields such as physics, economics, sociology, engineering, and information science. To the best of our knowledge, there is no existing definition of uncertainty within the context of service provisioning. We list the definition of uncertainty from different fields below before we come up with our own definition of uncertainty from service provisioning point of view. Definition from other fields is as follow:

- **Decision Making:** Situation where the current state of knowledge is such that (1) the order or nature of things is unknown, (2) the consequence, extent, or magnitude of circumstances, conditions, or events is unpredictable, and (3) credible probabilities to possible outcomes cannot be assigned [37].
- **Information theory:** Degree to which available choices or the outcomes of possible alternatives are free from constraints [16].
- **Statistics:** Situation where neither the probability distribution of a variable nor its mode of occurrence is known.
- **Hard sciences (physics, chemistry, etc) and Engineering:** the interval of confidence around the measured value such that the measured value is certain not to lie outside this stated interval [13].
- **Economics:** uncertainty refers to the risk that is immeasurable, not possible to calculate [17].

From the above various definitions, the definition from the perspective of decision making closely resembles the situation that we are facing within the context of service provisioning. Relating back to the problem definition being discussed in the previous section (key issue being the lack of information or knowledge), our definition of uncertainty from service provisioning point of view is:

Definition 3. *Uncertainty: The gap in knowledge or lack of information in the service offering which gives rise to the initial customer's state of belief and cause difficulty in customer's decision making.*

The gap in knowledge can be caused by i) absence or lack of data, ii) unknowns about the source of data, and iii) inherent uncertainty (as in physics and statistics).

5.1.1 Classification of Uncertainty

Uncertainty can be classified into two groups, which are Aleatory Uncertainty and Epistemic Uncertainty [15]. Aleatory uncertainty (AU) is an inherent variation associated with the physical system or the environment. It can also be referred as variability, irreducible uncertainty, stochastic uncertainty, or random uncertainty. On the other hand, Epistemic Uncertainty (EU) is an uncertainty that is due to the lack of knowledge of quantities or processes of the system or environment. It is also known as subjective uncertainty, reducible uncertainty, or model form uncertainty. Examples of epistemic uncertainty are lack of experimental data and poor understanding of initiating events. The ability to classify uncertainty into different type is important since this will lead into probable methods of solving the specific uncertainty being investigated.

5.1.2 Methods of Solving Uncertainty

There are several approaches in solving uncertainty based on the classification of uncertainty described above. Frequentist approach with traditional probability theory is used to analyse systems that are subject to aleatory uncertainty. Techniques such as Neyman-Pearson [32, 18] and Monte Carlo [27] are frequently used. On the other hand, epistemic uncertainty can be handled by several methods such as (1) possibility theory [38], (2) evidence theory [33], (3) Bayesian probability theory [4], (4) interval analysis [22], and so on. Bayesian method is appropriate in situations where there are gaps in information (i.e. where there is epistemic uncertainty), thus is the choice for solving our uncertainty problem in service provisioning.

5.1.3 Relationship between Uncertainty, Risk, and Trust

There is a need to clarify the differences and relationship between uncertainty and risk since in common usage, both terms refer to a similar situation, in which some aspect of the future cannot be foreseen. In economics, the definitions of these two terms are different as established by Frank Knight in his book, *Risk, Uncertainty and Profit* in 1921 [17]. According to Knight, risk is present when there is future events with probability that is measurable, whereby uncertainty is present when the likelihood of future events is indefinite or incalculable.

From the point of view of service provisioning, we have already defined uncertainty as the gap in knowledge towards the service offering, and we can view risk similarly to Knight's view on risk, whereby risk is just a state of uncertainty where some possible outcomes have an undesired effect or significant loss. More importantly, is there a direct relationship between uncertainty and risk?

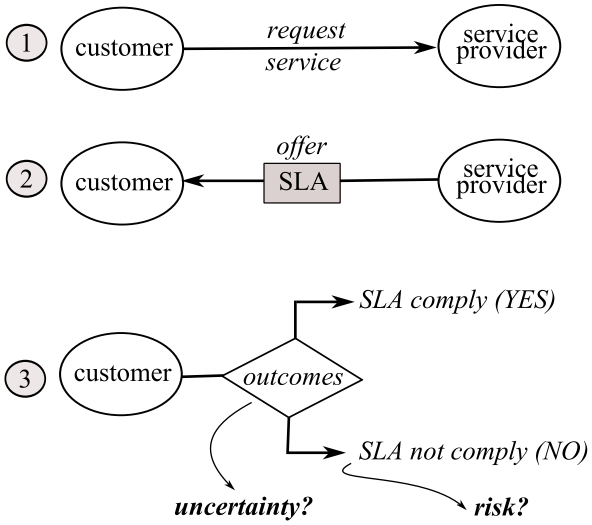


Figure 2: View on Risk and Uncertainty

Figure 2 illustrate the existence of uncertainty and risk within service provisioning offer. If the outcomes of the offer is not known in advance (which we view as uncertainty), and one of the outcomes has an undesired effect or loss (which we view as the risk), then it is possible to say that if we reduce uncertainty then we directly reduce risk.

How does trust comes into this picture in relation to uncertainty and risk? First, lets begin with a definition of trust. There are various definition in literature with regards to the definition of trust [19, 14, 36, 20], one of which we prefer is from Josang[11] which defines two type of trust: (1) reliability trust, and (2) decision trust. Reliability trust refers to the probability estimate of success of a transaction, whereby decision trust refers to the extent an entity disposition about entering into a transaction with another entity. We can use both definitions for our service provisioning offer scenario since the customer need to trust the service provider regarding the success of the transaction and also whether to accept the SLA offer from the service provider. If there is risk in the transaction, then we can say that risk affects the customer disposition or willingness to enter into a contract (through SLA).

Therefore, qualitatively, we deduce that the notion of trust is also coupled with uncertainty and risk, whereby if uncertainty is reduced, then risk is also reduced thus increases trust. We will not pursue any quantitative relationship between uncertainty, risk, and trust since the objective of this discussion is to establish a qualitative relationship between these concepts.

5.2 Different Views of Uncertainty

It is possible to view uncertainty from different perspective within the context of service provisioning. Having this different views enable us to understand how and which aspect of service provisioning is affected. Furthermore, the research problem that is investigated is based on a specific part of the view. There are two views of the uncertainty problem in service provisioning context: (1) Temporal-Phase View, and (2) Entity View. The following discussion is based on the generic web services architecture as shown in Figure 1.

5.2.1 Temporal-Phase View of Uncertainty

In this view, the service provisioning process is divided based on temporal constraint. There are three distinct temporal-phase within a single service provisioning transaction (as illustrated in Figure 3): (1) pre-sp[1], (2) intra-sp, and (3) post-sp.

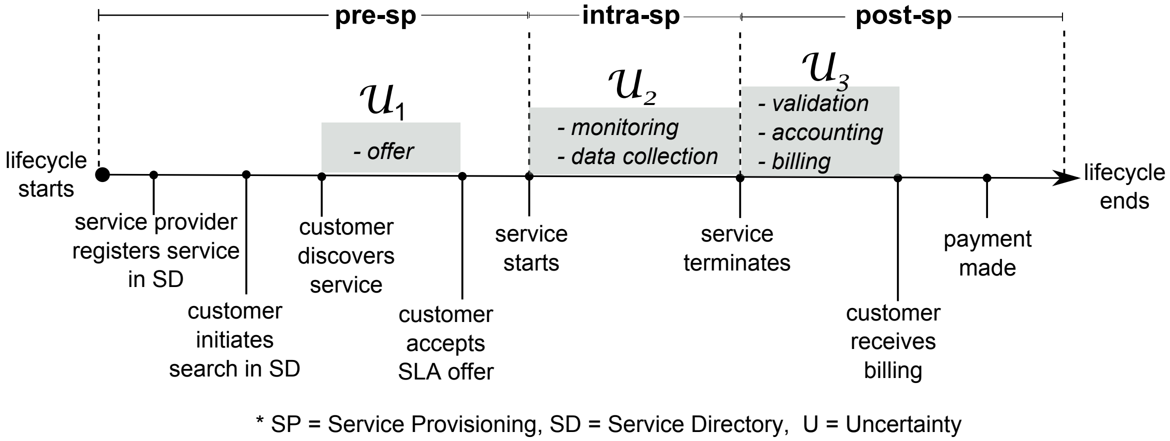


Figure 3: Phase View of Uncertainty

pre-sp: The pre-sp phase takes place prior to the actual service provisioning process. In this phase, there are several distinct activities based on the service provisioning lifecycle and possible associated uncertainty. One activity of interest to us within this phase is the SLA offer from the service provider to the customer (assuming the service provider has registered the service with associated SLA and the customer has conducted the search and discovery of required service). We define this scenario as the subjective uncertainty from the viewpoint of the customer to the probability of the SLA being complied to. The cause of the this uncertainty is due to the lack of information or gap in knowledge from the customer point of view, mainly about the service provider capability to full fill the SLA. Thus, this scenario can be clearly placed under the epistemic uncertainty classification.

intra-sp: The intra-sp phase refers to the period to when the service provisioning process starts and ends. The main activity that interest us in this phase is the monitoring activity. Monitoring refers to the act of monitoring the specified metrics within the SLA to check with compliance and violation. It involves the service provider to collect specific data at certain interval. We view the monitoring and data collection as another sources of uncertainty. Furthermore, it is possible to classify two type uncertainty for the same source, i.e. from the monitoring and data collection activities. The first source of uncertainty is related to the limit of accuracy and precision of the equipment or apparatus being used to measure and collect the data. This source of uncertainty can be classified under the aleatory group. Often, the

---

[1] sp: service provisioning

uncertainty of a measurement is found by repeating the measurement sufficient number of times to get an estimate of the standard deviation of the values. One possible measure that can be taken to tolerate this type of uncertainty is to have a better accuracy and precision of the measuring instruments. The second source of uncertainty is the subjective belief of the customer towards the trustworthiness of the service provider or the party that conduct the monitoring and data collection activity. Furthermore, this state of belief (or disbelief) is caused by lack of information or gap in knowledge towards the party that conduct the monitoring and data collection activity. This particular source of uncertainty is of interest to us for this research and due to the nature of lacking sufficient information, we can classify it under the epistemic uncertainty group.

post-sp: The post-sp phase refers to the period after the service has been terminated or completed. There are three main activities of interest: (1) Validation, (2) Evaluation, and (2) Accounting. The first activity is validation, which refers to the process of ensuring the collected metrics conform to the specification in the SLA offer, and ultimately will result in the compliance status of the SLA. Evaluation refers to the process of analysing the previously monitored information while accounting refers to the process of coming up with an invoice by looking at the resources used and how much the is the associated cost. We determine that the nature of uncertainty of these activities is epistemic since the customer lacks information about the trustworthiness of the service provider to use the correct accounting model, does not tamper with monitoring and data collection processes, and using proper evaluation criteria and method. Ultimately, this uncertainty affect the customer's subjective belief towards the service provider.

5.2.2 Entity view of Uncertainty

The temporal-phase view above does not specifically include the entities involve in a service transaction and the relationship between the entities. Knowing the entities involve and the relationship between them can be useful, for example, if there is uncertainty in a particular activity (within the service provisioning), it is possible to identify the entity that should resolve the problem. In a generic and simplified example of a web-based service provisioning, we assume that there are three main entities involved in a service transaction as shown in the following figure.

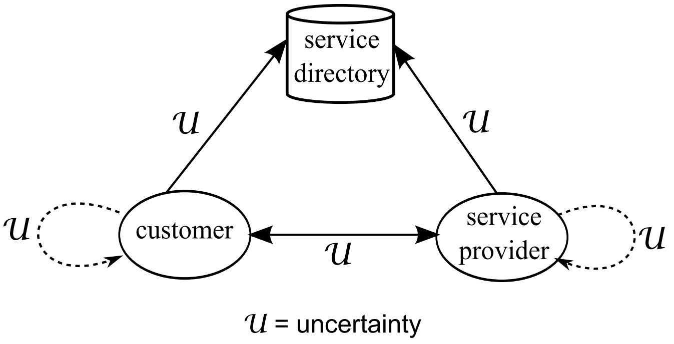


Figure 4: Entity View of Uncertainty

The three entities are (1) customer, (2) service provider, and (3) service directory. In each of the entities, uncertainty can arises as a matter of subjective belief towards another entity or to itself. For example, a service provider might have uncertainty towards its capability to deliver or fulfil the quality promise within the SLA and a customer can have uncertainty towards the service provider capability. As for the service directory, if it also acts as a trusted third party to monitor and collect data, both the customer and service provider might have uncertainty in term of the trustworthiness of the third party. The direction of the uncertainty can be bi-directional, whereby both the customer and service provider can be uncertain about each other. For the purpose of our research, we only concentrate on the customer point of view on uncertainty.

5.2.3 Hybrid view of Uncertainty

Based on the previous two views on uncertainty, we can combine both views to create a hybrid view. This view incorporate both aspect of temporal phase of service provisioning transaction with the entities involved in the transaction. By creating this hybrid view, we are able to have a better understanding of the uncertainty problem in a service provisioning transaction. Table 1 summarized the hybrid view of uncertainty.

Table 1: Hybrid View of Uncertainty in Service Provisioning

temporal-phase	**acitvity**	**classification**	**entity**
pre-sp	offer	epistemic	customer and service provider
intra-sp	monitoring	epistemic and aleatory	service provider
post-sp	evaluation	epistemic	service provider
	accounting	epistemic	service provider

The above section presents an overall view of uncertainty from the temporal and entity point of view. We can conclude that uncertainty exists in all phases of the lifecycle, but in this paper we focus our research on the uncertainty problem in the SLA offer within the post-sp phase concerning the customer.

5.3 Important Concepts

In this section, we briefly discuss three concepts that will be leveraged in our approach to tolerate uncertainty in service provisioning offering. The three concepts are Bayes Theorem, Bayesian Network, and Decision Network.

The first concept is Bayes' Theorem, which is a probability theory that shows the relationship between a conditional probability and its inverse[7]. We are interested to explore Bayesian Probability since it depicts the degree of believe in an event as opposed to classical probability which represents true or physical probability of an event. This fits perfectly with the first problem discussed above whereby the customer has an initial subjective belief regarding the compliance of the SLA offer.

The second concept is Bayesian Networks (also known as belief network), which is a probabilistic graphical model that represents a set of random variables and their conditional dependency using a directed acyclic graph [9]. A Bayesian Network consists of a set of random variables as nodes which are connected through directed links (arcs). Each node has a conditional probability table that quantifies the effects the parents have on the nodes. If we represent the probability of success of an SLA offer and the evidence as nodes in a Bayesian Network, we can then leverage the network as a means to provide predictive reasoning (i.e. causal reasoning) between evidence and probability of success of an SLA offer.

The third concept is Decision Networks, which is an extension of the above Bayesian Networks. A Decision Network (also known as influence diagram, relevance diagram, or decision diagram) is a graphical and mathematical representation of a situation that involves decision making [10]. The basis of Decision Networks is Decision Theory, which is a combination of concepts and techniques, to both describe and rationalize the process of decision making. We can view Decision theory as a combination of Utility [6] and Probability Theory. Expected Utility hypothesis is a theory of utility initially developed by von Neumann and Morgenstern [23]. It is widely applied in economics, game theory and decision theory. The hypotheses describe a way in which the expected utility of an agent (human or computing agent) facing uncertainty (uncertain outcome) is calculated by multiplying the utility of an occurrence by the probability of its occurrence. Therefore, we can leverage Decision Networks to assist the customer in the decision making process.

5.4 Uncertainty Tolerance using Bayesian Decision Engine

Once we have identified the existence and affect of uncertainty to service provisioning, the next step is to device a solution to the problem. Before we proceed, it is important to define the term *"uncertainty tolerance"*. If we take another example in the computing world, the word tolerance is also widely used in telecommunication and data communication as in *"fault tolerance"*. Fault tolerance is a property of a system to continue operating normally in the event of failure [3]. Some approaches of creating a fault-tolerant system is through redundancy and/or replication.

Our key assumption is that the inherent uncertainty in the SLA is due to the lack of information or knowledge towards the compliance of the SLA. Therefore, the logical choice is to obtain information or knowledge in order to tolerate the uncertainty. We define evidence as any additional information or knowledge that can reduce the uncertainty of the above problem. Evidence can be in the form of other customers' feedback, expert forecast, or statistical model. We assume that the evidence can be quantified and aggregated based on the work by Ali [2], and in this paper, we use the aggregated value of evidence in our solution.

Based on the problem description in previous section, we come up with the following definition of uncertainty tolerance.

Definition 4. *Uncertainty Tolerance: is the ability of the system to behave normally in the presence of uncertainty and to alleviate an agent's degree of belief towards service provisioning compliance by reducing the gap in knowledge using evidence.*

With regards to the three concepts discussed in previous section (Bayes Theorem, Bayesian Networks, and Decision Networks) and the above definition for uncertainty tolerance, we have developed an approach to tolerate uncertainty in service provisioning. Figure 5 shows the complete flow of the uncertainty tolerance process, including three main components in a generic web-based service provisioning: the customer (client side), service provider (server side) and a service directory (third party entity). One important consideration that we have taken in designing and developing the solution is the location for the uncertainty tolerance module. We have chosen the service directory as the location for the module implementation due to the fact that it can act as a trusted third party [31, 36, 11] within the provisioning process. The choice to implement the engine within the service directory is a logical one since it promotes fairness to the transaction.

The first step is for the service provider to register the service being offered into the service directory. The registration will provide basic information about the service and a guarantee of quality through contractual agreement in the form of SLA. Next, the customer can make a query to search for required service. Once a suitable service is found, the customer will provide required information such as customer's initial belief of the offer and utility values for each action. This information together with the information gathered from the service provided is stored in some form of storage such as a database or text file.

The engine then will identify variables, node type, and relationship between nodes in order to create a directed links between the node (step 2). The next step (3) is to create the Bayesian Network which is then used to update initial customer's belief in step 4. The update is based on the chosen strength of the evidence. The engine extends the previous Bayesian Network (in step 3) to a Decision Network by

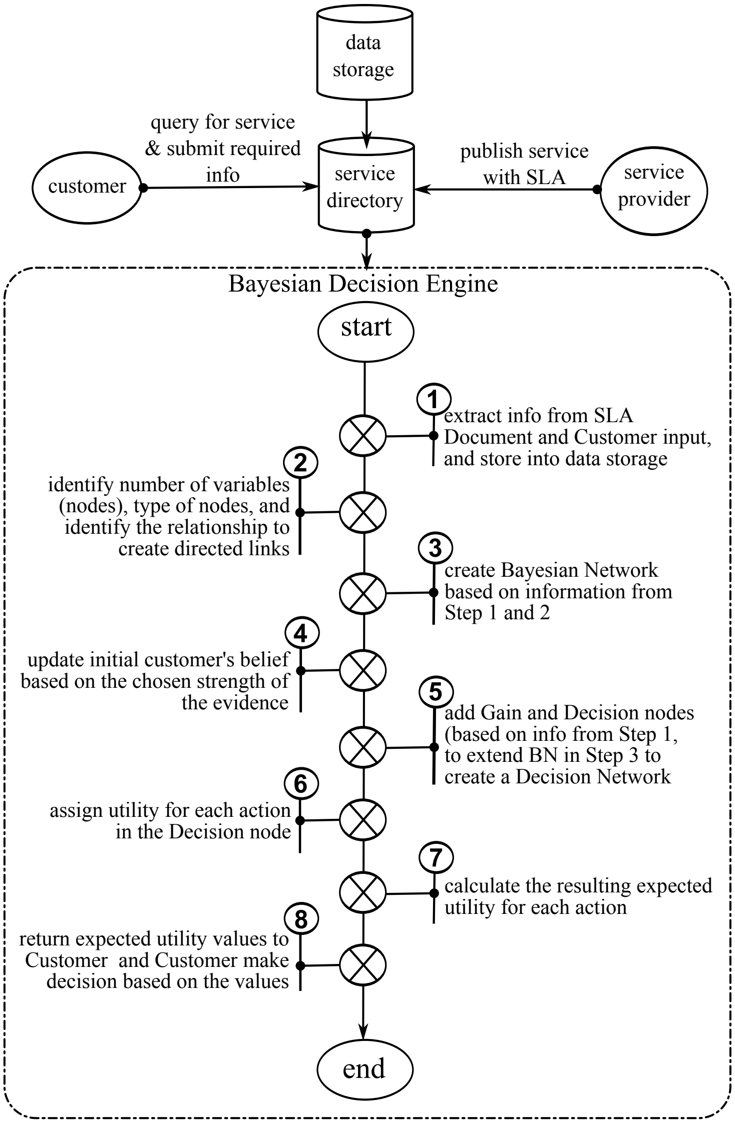


Figure 5: Bayesian Decision Engine

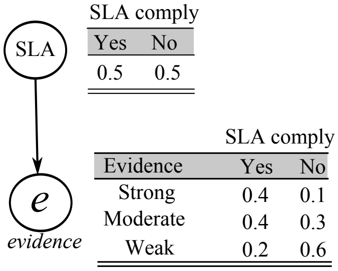
adding the Decision and Gain nodes. In step 5, the utility values for each action are assigned. The engine then calculates the expected utility for each action. Finally, once the customer received the expected utility value for each action, the customer can use this information to make the decision to accept or reject the service offering. We illustrate our approach through a case study in the next section.

6 Case Study

6.1 Problem Definition (Applying Bayesian Network)

Let us define a simple web service provisioning scenario as follows:

> *Imagine a customer who considers a web service offering through an SLA from a service provider. A major source of uncertainty is the SLA compliance (which has one or more SLA Parameters). Initially, without any additional information, the customer believes that 50%*



SLA comply	
Yes	No
0.5	0.5

	SLA comply	
Evidence	Yes	No
Strong	0.4	0.1
Moderate	0.4	0.3
Weak	0.2	0.6

Figure 6: Bayesian Network for Case Study

> *of all SLA from the service provider will comply. The customer can reduce the uncertainty somewhat by getting additional evidence (i.e. information or knowledge). The evidence, however, is not perfect in predicting subsequent service compliance. Of all the services that actually comply, the evidence predicted about 40% has a strong probabilty to comply, 40% moderate, and 20% weak.*

Based on the information from the above scenario and our decision engine in previous section, we create the Bayesian Network base on the following steps. The resulting Bayesian Network is shown in Figure 6 below.

- Identify the variables, create the nodes and the properties of each node: There are two nodes, the *"SLA comply"* which refer to the customer's belief for the SLA success, and the *"evidence"* node which refer to external body of information or knowledge regarding the probability of the SLA success. The nodes in a Bayesian Network are known as *"chance"* nodes and are represented by a circle/ellipse shape.
- Create arc (directed link) that connects the nodes.
- Specify conditional probability dependencies between nodes.

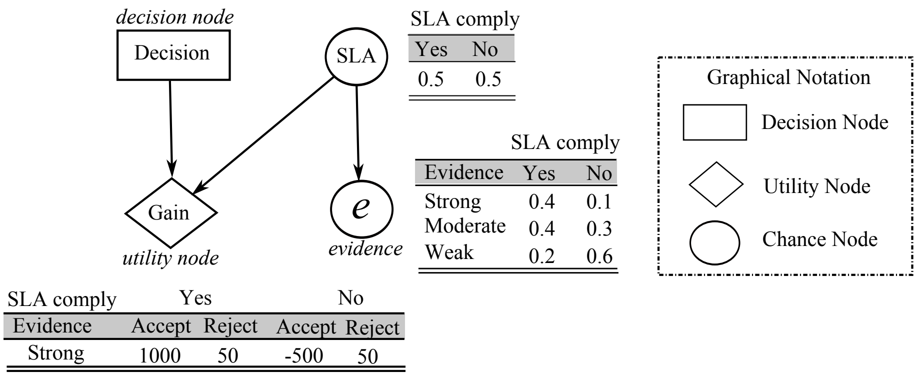
Let us demonstrate an application of the Bayesian Network. Suppose we want to answer the following question: *"What is the chance for the SLA to comply if the evidence is Strong (case SLA to comply is Yes)?"*

After setting the evidence to Strong (value is 0.4), we update the probability distribution of the SLA node based on Bayes' Theorem. The updated value for the property *"Yes"* has been changed to 0.8. We can see that the initial customer's belief has been updated by applying the Bayes Theorem.

6.2 Problem Definition (Applying Decision Network)

Although we have managed to update the customer's initial belief using the Bayesian Network, the updated value does not allow a customer to decide whether to accept or reject the offer. As discussed in previous section, a Bayesian Network allows us to quantify uncertain interactions among random variables, and use this quantification to determine the impact of an observation. On the other hand, a decision network or influence diagram allows us to quantify a decision making's options and preferences and use this to determine the optimal decision policy. Therefore, the next step is to extend the previous Bayesian Network into a Decision Network. We extend the above scenario by adding new information as follows:

> *Suppose that the customer invest $500 in the task that needs to be completed. If the task is completed through the usage of the web service offered by the service provider, the customer*



SLA comply	
Yes	No
0.5	0.5

	SLA comply	
Evidence	Yes	No
Strong	0.4	0.1
Moderate	0.4	0.3
Weak	0.2	0.6

SLA comply	Yes		No	
Evidence	Accept	Reject	Accept	Reject
Strong	1000	50	-500	50

Figure 7: Decision Network for Case Study

> *would earn an additional $1000. If it is not successful, she will lose the entire investment of $500. If she had used the $500 (reject the offer) in a risk-free investment, she would have gained $50. We assume that the customer is only interested in financial gain.*

We extend the Bayesian Network in previous section into a Decision Network (influence diagram) by adding a *"decision node"* and a *"utility node"*. A decision node is represented using a rectangle shape. It represents a variable that is under control of the decision maker (in this case, the customer) and model the decision alternatives available to the decision maker (in this scenario the alternatives are Accept and Reject). Utility nodes, usually drawn as diamond shape, represent a measure of desirability of the outcomes of the decision process. They are quantified by the utility of each of the possible combinations of outcomes of the parent nodes. The completed Decision Network is shown in the following Figure 7. We will subsequently use this Decision Network to evaluate two available options: Accept or Reject the SLA offer from the service provider.

Based on the expected utility equation in Appendix C, the expected utility value for the decision to accept is 510 and 42 for reject. Since the values of the expected utility are known for both outcomes of the Decision Node, the customer should choose to accept the SLA offer since it has higher expected utility value.

7 Empirical Evaluation

The primary goal of the evaluation is to show empirically that the concept of uncertainty tolerance works and enables the customer to make service selection based on the calculated expected utility values. The experiment is made up of a series of actual test runs of a web service in our testbed. We first give an overview of the test environment for the experiments and then followed this by a discussion of the results.

7.1 Testbed Setup Summary

Figure 8 below illustrates the testbed setup for the experiment. The testbed consists of a web service (Service Provider), a directory service and client program (customer). The web service is deployed on an Apache/Axis server installed on a Windows operating system platform. The directory service is implemented using jUDDI and the client is a java-based client used to access the web service. Values such as customer's initial belief, utility for each action, and the evidence is stored in a text file, which is retrieved later.

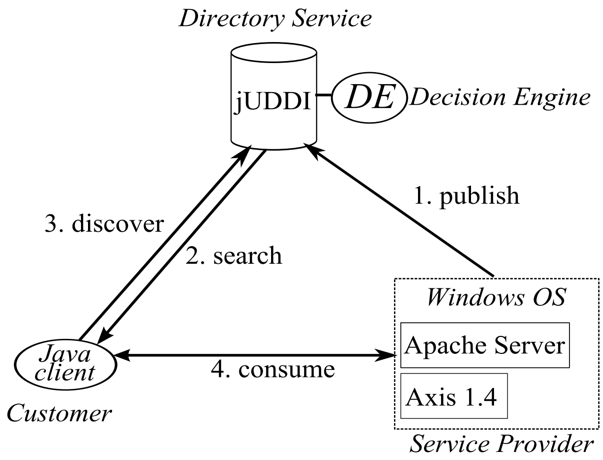


Figure 8: Testbed Architecture

The decision engine is implemented as an extension module to the service directory. The engine was developed using jSMILE [12] library, which is a platform independent library of Java classes for reasoning in graphical probabilistic models, such as Bayesian and Decision Networks.

7.2 Experiment Setup Summary

Both Experiment 1 and 2 is based upon the Bayesian Decision Engine discussed previously. Values such as the utility value for actions taken, and the value of evidence is based on the case study previously presented.

7.2.1 Experiment 1: Updating Initial Customer Belief Using a Bayesian Network

In this experiment, we utilize Bayesian Networks (within the Decision Engine module) to calculate the updated belief value for each initial customer's belief. The experiment consists of several runs whereby each run is a web service provisioning transaction as described in Section 3. In each run, the customer provides the initial belief while the value for evidence is retrieved from a text file. The values of the initial customer's belief range from 0% probability of success (0.0) to 100% probability of success (1.0). To simplify the experiment, the value of initial customer's belief for each run is stored in a flat text file. To investigate the effect of evidence strength towards customer's updated initial belief, we have conducted two separate experiments, the first using strong evidence, and the second using weak evidence.

7.2.2 Experiment 2: Calculating Expected Utility Value Using a Decision Network

This experiment is a continuation of the previous experiment and the objective is to calculate the expected utility value for each of the customer actions. Customer actions have been hard coded in the engine, whereby there are only two options, *"Accept"* or *"Reject"*. For each option, the utility value is assigned by the customer and is fixed for the whole experiment. Again, to simplify the experiment, the utility values are stored in a text file. We only use strong evidence in this experiment. The calculated expected utility values are stored in a text file for analysis.

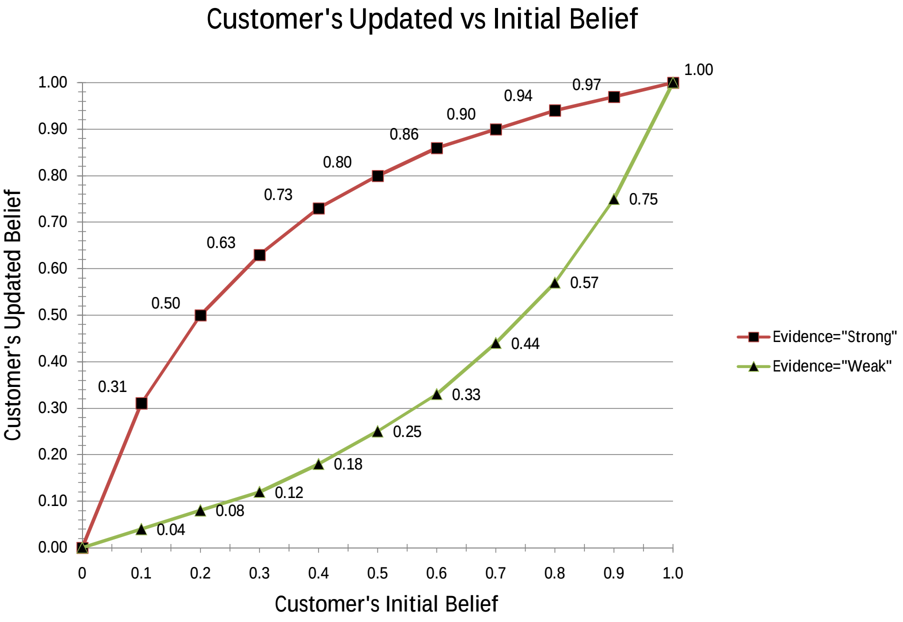


Figure 9: Experiment 1 Result

8 Result and Analysis

8.1 Experiment 1: Updating Initial Customer Belief Using Bayesian Networks

Using the output values from the experiment, we plot the Customer's Updated Belief values against the Customer's Initial Belief values. The result is shown in the following Figure 9. It shows that the initial customer belief is updated based on the strength of the evidence being used.

To better understand the result, we summarize the belief values based on evidence strength in Table 2. Based on the table, the values for the updated belief using strong evidence is always higher than values based on weak evidence (except when customer's belief is equal to 0 or 1). On the other hand, the values of the updated belief using the weak evidence is always less than the initial belief value (except when customer's belief is equal to 0 or 1).

Table 2: Comparison of belief values based on Evidence Strength

Run	Initial Belief	Updated Belief Strong(e)	Updated Belief Weak(e)
1	0.0	0.00	0.00
2	0.1	0.31	0.04
3	0.2	0.50	0.08
4	0.3	0.63	0.12
5	0.4	0.73	0.18
6	0.5	0.80	0.25
7	0.6	0.86	0.33
8	0.7	0.90	0.44
9	0.8	0.94	0.57
10	0.9	0.97	0.75
11	1.0	1.00	1.00

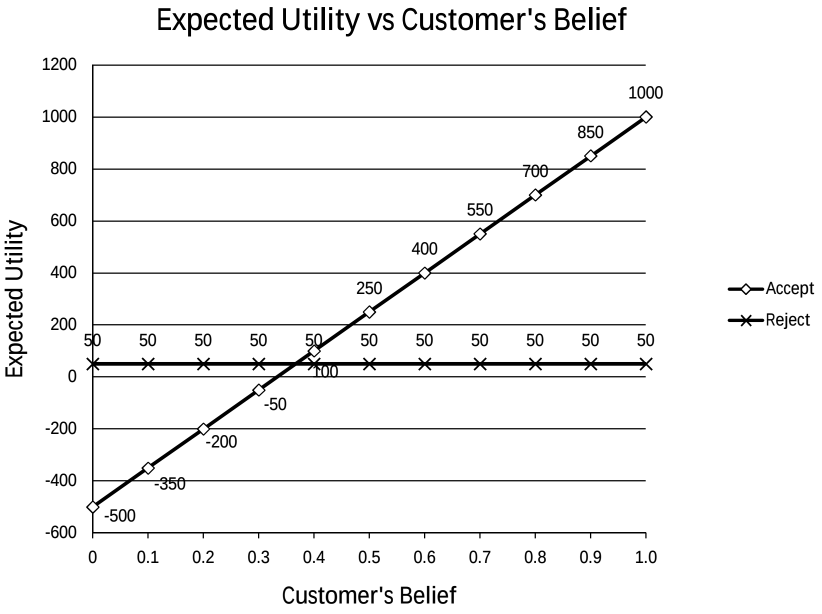


Figure 10: Experiment 2 Result

Therefore, we can make two important conclusion from Experiment 1: Firstly, using our Uncertainty Tolerance Engine, we are able to update the initial Customer's Belief and secondly, the updated values depend on the strength of the evidence.

8.2 Experiment 2: Calculating Expected Utility Value Using Decision Networks

The result in Figure 10 shows that for each of the customer actions (Accept or Reject), an expected utility value is calculated for each of the customer belief.

The above calculated expected utility values for each of the customer's belief can be used to assist the customer in making decision towards the service offering by the service provider. Table 3 shows the action taken by the customer after knowing the values of expected utility for each of the possible action to be taken. The assumption is, of course, that the action that has higher value (positive) is desirable to the customer. The only exception is that when the expected value for both alternatives is equal (as in the case where Customer's Belief is 0.3), then we make assumption that the customer chooses the *"Accept"* decision.

9 Conclusion and Future Works

In this paper, we introduce the concept of uncertainty tolerance that can be embedded within a service directory to help customers to make decisions when faced with an offer from a service provider. We derived our solution based on the combination of Bayes' Theorem, Bayesian Networks and Decision Networks. Using this approach, we are able to show how we can calculate updated customer belief, and calculate the expected utility values based on customer decision. We also have shown how a customer can utilizes the calculated expected utility values to make decisions. We have presented a case study and conducted an empirical evaluation to illustrate our case study. Since our approach to uncertainty is based on using evidence, in future work we would like to study how to generate strong evidence from various sources and further investigate the problem of uncertainty across the lifecycle of a service provisioning.

Table 3: Customer's Decision Based on Calculated Expected Utility Values

Customer's Belief	Expected Utility Accept	Expected Utility Reject	Decision
0.0	-500	50	Reject
0.1	-350	50	Reject
0.2	-200	50	Reject
0.3	-50	50	Accept
0.4	100	50	Accept
0.5	250	50	Accept
0.6	400	50	Accept
0.7	550	50	Accept
0.8	700	50	Accept
0.9	850	50	Accept
1.0	1000	50	Accept

References

[1] A. S. Ali, S. A. Ludwig, and O. F. Rana. A cognitive trust-based approach forweb service discovery and selection. In *Proc. of the 3rd European Conference on Web Services (ECOWS'05), Växjö, Sweden*, page 38. IEEE, November 2005.

[2] A. S. Ali and O. F. Rana. A Belief-based Trust Model for Dynamic Service Selection. In D. Neumann, M. Baker, J. Altmann, and O. Rana, editors, *Economic Models and Algorithms for Distributed Systems, Autonomic Systems*, page 9, Basel, 2010. Birkhäuser Basel.

[3] A. Avizienis, J. Laprie, B. Randell, and C. Landwehr. Basic concepts and taxonomy of dependable and secure computing. *IEEE Transactions on Dependable and Secure Computing*, 1(1):11–33, January-March 2004.

[4] J. O. Berger. *Statistical Decision Theory and Bayesian Analysis*. Springer-Verlag, 2nd edition, 1985.

[5] R. Buyya, C. S. Yeo, S. Venugopal, J. Broberg, and I. Brandic. Cloud computing and emerging IT platforms: Vision, hype, and reality for delivering computing as the 5th utility. *Future Generation Computer Systems*, 25(6):599–616, June 2009.

[6] J. High and H. Bloch. On the History of Ordinal Utility Theory. *History of Political Economy*, 21(2):351–365, 1989.

[7] C. Howson and P. Urbach. *Scientific Reasoning: The Bayesian Approach*. Open Court Publishing Company, 1993.

[8] M. Huhns and M. Singh. Service-oriented Computing: Key Concepts and Principles. *IEEE Internet Computing*, 9(1):75–81, January 2005.

[9] F. V. Jensen. *An Introduction to Bayesian Networks*. UCL Press, 1996.

[10] F. V. Jensen and T. D. Nielsen. *Bayesian Networks and Decision Graphs*. Springer, 2nd ed. edition, 2007.

[11] A. Josang and S. L. Presti. Analysing the Relationship between Risk and Trust. In *Proc. of the 2nd International Conference on Trust Management, Oxford, UK, LNCS*, volume 2995, pages 135–145. Springer-Verlag, March-April 2004.

[12] jSMILE. Decision System Laboratory (DSL). `http://genie.sis.pitt.edu/wiki/Introduction_to_jSMILE`, 2011.

[13] R. Kacker and A. Jones. On use of Bayesian Statistics to make the Guide to the Expression of Uncertainty in Measurement consistent. *Metrologia*, 40(5):235–248, October 2003.

[14] A. Kini and J. Choobineh. Trust in electronic commerce: Definition and theoretical considerations. In *Proc. of the 31st Annual Hawaii International Conference on System Sciences (HICSS'98), Kohala Coast, Hawaii, USA*, volume 4, pages 51–61. IEEE, January 1998.

[15] A. Kiureghian and O. Ditlevsen. Aleatory or epistemic? Does it matter? *Structural Safety*, 31(2):105–112,

March 2009.

[16] G. J. Klir. *Uncertainty and Information: Foundations of Generalized Information Theory*. Wiley-IEEE Press, 2005.

[17] F. H. Knight. *Risk, Uncertainty, and Profit*. 1921.

[18] E. L. Lehmann and J. P. Romano. *Testing statistical hypotheses*. Springer Texts in Statistics. Springer, New York, third edition, 2005.

[19] S. P. Marsh. Formalising trust as a computational concept. Technical Report CSM-133, Department of Computing Science and Mathematics , University of Stirling, January 1994.

[20] D. H. Mcknight and N. L. Chervany. What trust means in e-commerce customer relationships: An interdisciplinary conceptual typology. *International Journal of Electronic Commerce*, 6(2):35–59, 2002.

[21] K. Mockford. Web Services Architecture. *BT Technology Journal*, 22(1):19–26, January 2004.

[22] R. E. Moore. *Methods and Applications of Interval Analysis*. Society for Industrial Mathematics, 1987.

[23] O. Morgenstern and J. Von Neumann. *Theory of Games and Economic Behavior*. Princeton University Press, 1944.

[24] Z. Nan, X. song Qiu, and L. ming Meng. A SLA-Based Service Process Management Approach for SOA. In *Proc. of the 2006 First International Conference on Communications and Networking in China (ChinaCom'06), Beijing, China*, pages 1–6. IEEE, October 2006.

[25] M. Papazoglou and W.-J. van den Heuvel. Web Services Management: A Survey. *IEEE Internet Computing*, 9(6):58–64, November 2005.

[26] B. Pring. Gartner says worldwide cloud services market to surpass $68 billion in 2010, June 2010.

[27] K. D. Rao, H. Kushwaha, A. Verma, and A. Srividya. Quantification of epistemic and aleatory uncertainties in level-1 probabilistic safety assessment studies. *Reliability Engineering & System Safety*, 92(7):947–956, 2007.

[28] M. A. Rappa. The utility business model and the future of computing services. *IBM Systems Journal*, 43(1):32–42, 2004.

[29] J. M. Rathmell. What Is Meant by Services? *The Journal of Marketing*, 30(4):32–36, 1966.

[30] B. P. Rimal, E. Choi, and I. Lumb. A taxonomy and survey of cloud computing systems. In *Proc. of the 5th International Joint Conference on INC, IMS and IDC (NCM'09), Seoul, Korea*, pages 44 –51, August 2009.

[31] S. Ruohomaa and L. Kutvonen. Trust Management Survey. In *Proc. of the 3rd International Conference on Trust Management (ITRUST'05), Paris, France, LNCS*, volume 3477, pages 77–92. Springer-Verlag, May 2005.

[32] W. Schaafsma. The neyman-pearson theory for testing statistical hypotheses. *Statistica Neerlandica*, 25(1):1–27, 1971.

[33] G. Shafer. *A Mathematical Theory of Evidence*. Princeton University Press, 1976.

[34] C. Smith and A. van Moorsel. Mitigating Provider Uncertainty in Service Provision Contracts. In D. Neumann, M. Baker, J. Altmann, and O. Rana, editors, *Economic Models and Algorithms for Distributed Systems*, pages 143–159. Birkhäuser Basel, 2010.

[35] A. S. Tanenbaum and M. van Steen. *Distributed Systems: Principles and Paradigms*. Prentice Hall, Sept. 2001.

[36] L. Viljanen. Towards an Ontology of Trust. In *Proc. of the 2nd International Conference on Trust, Privacy and Security in Digital Business (TrustBus'05), Copenhagen, Denmark, LNCS*, volume 3592, pages 175–184. Springer-Verlag, August 2005.

[37] R. R. Yager. A Game-theoretic Approach to Decision Making Under Uncertainty. *International Journal of Intelligent Systems in Accounting, Finance & Management*, 8(2):131–143, June 1999.

[38] L. Zadeh. Fuzzy sets. *Information and Control*, 8(3):338–353, 1965.

[39] L. J. Zhang. EIC Editorial: Introduction to the Knowledge Areas of Services Computing. *IEEE Transaction on Services Computing*, 1(2):62–74, 2008.

[40] L.-J. Zhang, J. Zhang, and H. Cai. *Services Computing*. Springer, 2007.

[41] Y. Zhang, K.-J. Lin, and J. Y. jen Hsu. Accountability monitoring and reasoning in service-oriented architec-

tures. *Service Oriented Computing and Applications*, 1(1):35–50, 2007.

Johari Abdullah is currently a postgraduate Ph.D. student at the School of Computing Science in Newcastle University. His current research involves in solving uncertainty issues in service provisioning. His research interests include economic mechanism in services and utility computing.

Aad van Moorsel is a Professor in Distributed Systems at the School of Computing Science in Newcastle University. His group conducts research in security, privacy and trust. Almost all of the group's research contains elements of quantification, be it through system measurement, predictive modelling or on-line adaptation. Aad worked in industry from 1996 until 2003, first as a researcher at Bell Labs/Lucent Technologies in Murray Hill and then as a research manager at Hewlett-Packard Labs in Palo Alto, both in the United States. He got his Ph.D. in computer science from Universiteit Twente in The Netherlands (1993) and has a Masters in mathematics from Universiteit Leiden, also in The Netherlands. After finishing his PhD he was a postdoc at the University of Illinois at Urbana-Champaign, Illinois, USA, for two years. Aad has worked in a variety of areas, from performance modelling to systems management, web services and grid computing. Most recently, he was responsible for HP's research in web and grid services, and worked on the software strategy of the company.

Appendix

A Bayes Theorem

$$P(A|B) = \frac{P(B|A)P(A)}{P(B)} \tag{1}$$

whereby,

$P(A|B)$ = is the prior probability or marginal probability of A. It is ”prior” in the sense that it does not take into account any information about B.
$P(B|A)$ = is the conditional probability of the evidence given A. It is also called the likelihood.
$P(A)$ = is the prior probability of A. It is termed ”prior” in the sense that it does not take into account any information about B.
$P(B)$ = is the prior or marginal probability of B.

B Bayesian Network Sample Calculation

$$P(SLA|e) = \frac{P(e|SLA)P(SLA)}{P(e)}$$

whereby,

$P(SLA|e)$ = is the prior probability or marginal probability of the SLA to comply.
$P(e|SLA)$ = is the conditional probability of the evidence given the SLA complies. It is also called the likelihood.
$P(SLA)$ = is the prior probability of SLA to comply.
$P(e)$ = is the prior or marginal probability of the evidence, e.

$$
\begin{aligned}
P(SLA_{Yes}|e) &= \frac{P(e|SLA_{Yes}) * P(SLA_{Yes})}{P(e)} \\
&= \frac{P(e|SLA_{Yes}) * P(SLA_{Yes})}{P(e|SLA_{Yes}) * P(SLA_{Yes}) + P(e|SLA_{No}) * P(SLA_{No})} \\
&= \frac{0.4 * 0.5}{(0.4 * 0.5) * (0.1 * 0.5)} \\
&= 0.80
\end{aligned}
$$

C Expected Utility Theory Equation

$$
\mathrm{E}U(A|e) = \sum_{i=1}^{n} P(O_i|e,A)U(O_i|A) \tag{2}
$$

whereby,

EU = is the expected utility

e = is the available evidence

A = is a non-deterministic action

O_i = possible outcome state

U = utility

D Expected Utility Sample Calculation

D.1 Alternative 1: Decision is Accept

$$
\begin{aligned}
EU(Accept) = {} & P(SLA_{Yes}) * U(SLA_{Yes}|Decision_{Accept}) \quad + \\
& P(SLA_{No}) * U(SLA_{No})|Decision_{Accept}) \\
&= (0.8 * 0.4 + 0.2 * 0.1) * (1000) + (0.8 * 0.6 + 0.2 * 0.9) * (500) \\
&= 0.18 * 1000 + 0.66 * 500 \\
&= 180 + 330 \\
&= 510
\end{aligned}
$$

D.2 Alternative 2: Decision is Reject

$$
\begin{aligned}
EU(Reject) = {} & P(SLA_{Yes}) * U(SLA_{Yes}|Decision_{Reject}) \quad + \\
& P(SLA_{No}) * U(SLA_{No})|Decision_{Reject}) \\
&= (0.8 * 0.4 + 0.2 * 0.1) * (50) + (0.8 * 0.6 + 0.2 * 0.9) * (50) \\
&= 0.18 * 50 + 0.66 * 50 \\
&= 9 + 33 \\
&= 42
\end{aligned}
$$