FUZZY AGREEMENT FOR NETWORK SERVICE CONTRACTS

Davide Bacciu, Leonardo Badia and Alessio Botta

IMT Lucca Institute for Advanced Studies,
Piazza S. Ponziano 6, 55100 Lucca, Italy.
E-mail: {d.bacciu,l.badia,a.botta}@imtlucca.it

Contract agreement is a critical topic of service provisioning. The complex interactions that take place between customers and service providers are difficult to model with traditional mathematical tools. In this paper, we introduce an approach based on fuzzy logic to represent customers' needs and providers' offers. Also, we develop two models of agreement based on fuzzy similarity and weighted transducers. Finally, we apply our approach to a case study of a telephony service over a wireless local area network.

Keywords: Fuzzy logic; Voice-over-WLAN; QoS; Network Services.

1. Introduction

Decision-making is a typical activity of the human brain: human beings are able to take rational decisions based on vague, and uncertain stimuli and knowledge. This peculiar ability is extremely difficult to model with classical mathematical tools. Fuzzy Set Theory (FST), and its isomorphic Fuzzy Logic (FL), were firstly developed by Zadeh to provide a formal way for handling these uncertainty and vagueness.[1] Since the early stages of their introduction, FST and FL have been extensively and effectively used to perform soft evaluation of goals and constraints for decision-making systems and applications.[2] The fuzzy approach can be exploited to deal with hard problems involving multi-objective optimization, group decision, non-transitive reasoning, and ranking.[3]

Contract agreement is a typical decision-making application. Each time a contract is stipulated between a customer and a provider, both parties take a decision about the opportunity of making the agreement or not. Furthermore, the content of the contract itself is often the result of a complex negotiation, in which both parties gradually modify their objectives and relax their constraints from different initial requirements, so as to achieve a common goal, reaching a trade-off between their original positions.

In this paper, we make use of a fuzzy approach for the automatic generation of contracts. Indeed, in a distributed, agent-based, and global market, the interactions between customers and providers are extremely complex and grow exponentially in number. Thus, the search for a way to (i) define the parties' requirements and (ii) perform an automatic matching between them is a critical issue. We define a framework in which providers and customers describe their requirements by means of FST and FL, and we introduce methods to automatically develop an agreement that enforces the soft constraints expressed by the two parties.

To formally model the contract agreement process and actors, we refer to the Service-Oriented Architecture (SOA).[4] SOA is a paradigm of interactions between providers and customers. Customers define their needs, and providers offer their capabilities to customers. The basic interaction between these two parties is performed by a service: indeed, a service is a "mechanism by which needs and capabilities are brought together".[4] Services are described by functional and non-functional properties. Functional properties are related to the kind of service offered by the provider, i.e., which need is satisfied by the service. On the other hand, non-functional properties are related to the quality of the service offered by the provider, i.e., how the need is satisfied. For instance, non-functional properties of a ticketing service can be the percentage of time availability of the service and the number of payment methods.

In the SOA paradigm,[4] "a contract is a measurable assertion that governs the requirements and expectations of two or more parties". Coherently with what is stated above, "a contract is inherently the result of agreement by the parties involved," as, "there is a process associated with the agreement action." We aim at automatically performing the agreement that leads to the definition of the contract, by means of FST and FL. In particular, we focus on representing and modeling non-functional properties. This is a difficult task, since it is related to defining quality, which, in turn, is an intrinsically vague and subjective concept: the meaning of what is a "good service" cannot rely on a crisp, exact and universal definition.

In the following, we will introduce the formal tools that we use to linguistically model the customers' needs and the providers' offers in terms of non-functional properties. Further, we show two agreement processes employed to perform the matching between such descriptions. To better exemplify our approach, we will refer to a real-world case study inspired to service agreement for internet telephony provided over a Wireless Local Area Network (WLAN), so as to realize a Voice-over-WLAN (VoWLAN) service.[5] Although WLAN systems have been mainly designed to carry data traffic, it is expected that such systems will be soon required to carry also many types of audio and multimedia traffic. Thus, VoWLAN is emerging as a very appealing scenario where high demands from the customers need to be met from providers.

The Medium Access Control (MAC) strategies of WLANs do not inherently provide QoS and/or fairness guarantees to the users. Also the system capacity seen as the number of admissible calls depends on radio channel conditions and traffic pattern. However, Call Admission Control (CAC) and rate differentiation mechanisms[6] can be introduced to this end. In other words, the provider needs to meet the requirements of the user in terms of:

- QoS of the call, related to the achieved rate;
- priority of the call, determined at CAC level;

Both these concepts are user-defined and have a subjective feeling. For this reason, it is sensible to map them through FST.

2. Fuzzy Contract Agreement

In this section, we first introduce our framework by describing a simplified, “flat,” model of fuzzy agreement that does not take into account causal implications between the constraints. Next, we present a more general graphical model that allows full descriptive power in the definition of the decision rules. Due to space limitation, we restrict the forthcoming analysis to a functional model of the fuzzy agreement framework. For a formal description of the framework please refer to previous work of the authors.[7]

2.1. *The “Flat” Model*

The fuzzy agreement model founds on the concept of Fuzzy Contract Descriptor (FCD). An FCD depicts the requests and offers of the participating ends of the agreement, in terms of fuzzy descriptions. We model contract generation as a Fuzzy Agreement Process (FAP) on the FCDs of the contractors. The selected contracts are those that satisfy the fuzzy constraints enclosed in the contract descriptors.

The aim of the FAP is to mimic the complex contract agreement interactions performed by humans, by means of a process in which (i) tolerance and vagueness are admitted both in request and offer specifications, and (ii) the matching of request and offers is evaluated with respect to the trade-offs between similarity metrics and cost considerations.

In order to illustrate the main ingredients of the model, let us consider a simple scenario encompassing a customer C that is willing to sign a contract for a service S, defined in terms of a set of K properties. S is offered by a set of providers $\{P_1, \ldots, P_j, \ldots, P_n\}$ that share the customer's non-functional properties of the service. The customer and the providers describe their requests and offers as fuzzy statements, modeled as linguistic variables V_i, having name x_i and taking values in $\{f_i^1, \ldots, f_i^L\}$.

The customer FCD is a pair $D_C = (F, A)$, where F is a set of K pairs $\{(x_1|f_1), \ldots, (x_K|f_K)\}$, associating the linguistic variable named x_i to the fuzzy set f_i. Basically, F describes the contract properties requested by the customer. The function $A(s_c, r_c) : [0,1] \times [0,1] \rightarrow \{0,1\}$ determines the acceptability of a contract c. It measures the trade-off between the cost r_c and the similarity s_c of the contract with respect to the original customer request, deciding whether that solution is acceptable or not.

The provider FCDs are pairs $D_P = (V, \Downarrow)$, where V is the set of the linguistic variables identifying the contract non-functional properties. Each linguistic variable V_i is associated with the fuzzy sets φ_i^j $(j = 1, \ldots, k_i)$ that

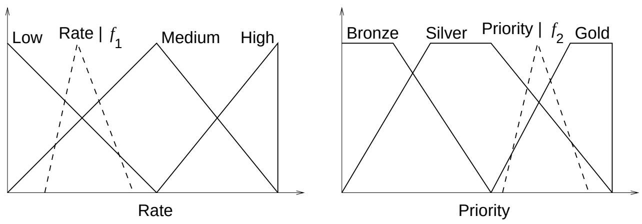

Fig. 1. The linguistic variables representing the providers offer (solid) and the fuzzy sets representing the customers request (dotted) for the VoWLAN case study.

characterize the contract properties offered by the provider. Moreover, $\Downarrow$ is a set of K functions $\{\Downarrow_i(\cdot)\}$ determining the cost of the property identified by V_i. Cost can be expressed in terms of money, time, risk or any other business-related meaningful measure. Different shapes of cost functions can represent different cost models: for instance, an important contract aspect may be characterized by a steeper cost function than a less critical property.

The instances of the linguistic variables (rate and priority) for a VoWLAN case depend on technical aspects.[5,6] A priority value, for example belonging to a three-value set (*Bronze*, *Silver*, *Gold*), can be requested by an admission control mechanism: the higher the priority, the more likely that the call will be allocated and possibly pre-empt other ongoing calls. Moreover, the user can ask for different data rates: the higher the rate, the better the resulting audio quality. Fig. 1 shows a possible instance of the linguistic variables V_1 ($x_1 = Rate$) and V_2 ($x_2 = Priority$), with $\varphi_1^1 = Low$, $\varphi_1^2 = Medium$, $\varphi_1^3 = High$, $\varphi_2^1 = Bronze$, $\varphi_2^2 = Silver$, and $\varphi_2^3 = Gold$.

The FAP determines the contract agreement that best matches the requests and the offers. Consider a provider P, having business rules described by D_P, that receives a customer request D_C. Then,

- for each pair $(x_i|f_i)$ in D_C, calculate the overlap between the client request f_i and the corresponding provider offers φ_i^j in D_P as the fuzzy intersection $I_i^j = f_i \cap \varphi_i^j$ and similarity $s_i^j = \mathrm{Sim}(f_i, \varphi_i^j)$, where:
$$\mathrm{Sim}(f_i, \varphi) = \left(\sum_{s \in S} \mu_{f \cap \varphi}(s) \right) \Big/ \left(\sum_{s \in S} \mu_{f \cup \varphi}(s) \right) ; \quad (1)$$
- for each non empty I_i^j, calculate the associated cost-projected fuzzy set $\gamma_i^j = \Downarrow_i (I_i^j)$;
- generate the set Π of eligible contracts c by combining the γ_i^j, that is $\Pi = \{c | c = (\gamma_1^{j1}, \ldots, \gamma_K^{jK})\}$;
- for each contract c, calculate the aggregated similarity $s_c = \prod_{i=1}^{K} s_i^{j_i}$, and the global cost $r_c = \mathrm{cog}\big(\bigcup_{i=1}^{K} \gamma_i^{j_i}\big)$, where $\mathrm{cog}(\cdot)$ is the traditional centroid defuzzification operator;[3]
- determine the set Π' of customer-admissible contracts by applying the acceptance function A, i.e. $\Pi' = \{c | c \in \Pi, A(s_c, r_c) = 1\}$.

Basically, the FAP described above estimates the closeness between the offer

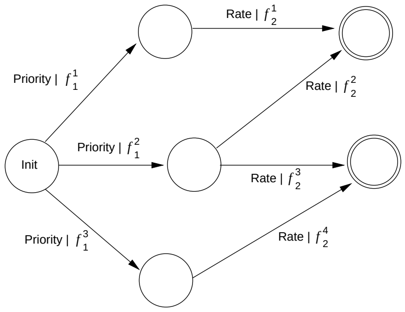

Fig. 2. FWA for the VoWLAN case.

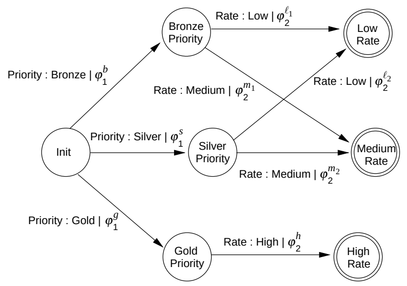

Fig. 3. FWT for the VoWLAN case.

and request by calculating the similarity of the fuzzy sets used to model the contract properties. Fuzzy intersection and union are used to generate a set of contracts satisfying the local properties specified by the contracting ends. Moreover, each solution is associated with its cost in a reference universe. The similarity and the cost are then used to compute the feasibility of the contract from the point of view of global customer constraints (modeled by the acceptance function A). All the admissible solutions generated by the FAP procedure are returned to the client that selects a contract based on a given internal policy (e.g., the cheapest contract).

2.2. *The Graphical Model*

The FCD formulation introduced so far does not allow the expression of complex policies encompassing, for instance, causal dependencies between non-functional properties and non-deterministic choices between alternative contract agreements. For instance, consider the VoWLAN example: a provider may want to deliver a High Rate connection only to those customers subscribing a contract for a Gold Priority class. The FCD specification is thus extended, by introducing Fuzzy Weighted Automata (FWA) and Transducers (FWT)[7,8] to allow complex policies and decision rules. In particular, the FWT will be used both to represent the FCD and to incorporate the FAP in the parsing procedure.

An FWA (Fig. 2) is a directed graph whose edges are labeled by the pairs $(x_i|f_i^j)$, where x_i is a linguistic variable name and f_i^j is the related fuzzy weight. An automaton W establishes a weighted language $L(W)$ that contains the labels of all the admissible paths from the initial state to a final state of the automaton. Consider, for instance, the automaton in Fig. 2: the resulting weighted language is $L(W) = \{(Priority|f_1^1)(Rate|f_2^1), (Priority|f_1^2)(Rate|f_2^2), (Priority|f_1^2)(Rate|f_2^3), (Priority|f_1^3)(Rate|f_2^4)\}$. If W represents the customer's FCD, then its weighted language $L(W)$ determines the admissible contract specifications accepted by the customer. Again, each x_i identifies a non-functional property, whereas the fuzzy sets f_i^j describe the customer's qualitative requirements on the properties. The customer fuzzy contract descriptor is now reformulated as $D_C = (L(W), A)$, where $L(W)$ is the language accepted by the automaton W and A is the acceptance function.

An FWT (Fig. 3) is a directed graph whose edges are labeled by the triplet $[x_i : c_i^j | \varphi_i^j]$, where x_i is a linguistic variable name and belongs to the transducer's input alphabet. The term c_i^j, on the other hand, represents a linguistic term and belongs to the FWT's output alphabet. Finally, φ_i^j is a fuzzy set weighting the connection labeled x_i. Each edge marked $[x_i : c_i^j | \varphi_i^j]$, defines a transduction rule transforming the input symbol x_i into the output term c_i^j, weighting the operation by φ_i^j.

We use the FWT to model the decision rules of a provider FCD. In particular, each transduction identifies an association between a certain property x_i and its instantiation c_i^j, under the conditions defined by the fuzzy constraint φ_i^j. The provider's FCD of the previous section is thus reformulated as $D_P = (T, \Downarrow)$, where T is a FWT and $\Downarrow$ is the set of cost-projection functions defined in Subsection 2.1. Moreover, we reformulate the FAP to embed it into the transducer's parsing procedure.

Roughly speaking, a transducer T parses the language generated by the customer's automaton $L(W)$, generating alternative contract instantiations during the transduction process and weighting each solution likewise in the FAP procedure described in Subsection 2.1. Formally, consider a customer descriptor $D_C = (L(W), A)$ and a provider FCD $D_P = (T, \Downarrow)$:

- for each $w_p = (x_1|f_1), \ldots, (x_k|f_k)$ in $L(W)$, calculate the transducer admissible paths $\pi(w_p)$, i.e. all paths in T labeled $x_i, \ldots, x_k$ and leading from the initial transducer state to a final state;
- for each transition $[x_i : c_i^{j'} | \varphi_i^{j'}]$ in $\pi(w_p)$, calculate the transduction as follows: generate the output symbol $c_i^{j'}$, compute the similarity $s_i^{j'} = \mathrm{Sim}(f_i^j, \varphi_i^{j'})$ and the cost-projected intersection $\gamma_i^{j'} = \Downarrow_i (f_i^j \cap \varphi_i^{j'})$ between the request f_i^j and the offer $\varphi_i^{j'}$;
- for each path in $\pi(w_p)$, generate the transduction results $\Pi(\pi(w_p)) = \{< c, r_c, s_c >, \ldots, < cn, r_{cn}, s_{cn} >\}$ by concatenating the output symbols $c = \circ_i(c_i^j)$ ($\circ_i$ is the iterative concatenation operator) and aggregating the intersections γ_i^j in r_c and the similarities s_i^j in s_c as in the FAP;
- aggregate the results of each w_p, that is $\Pi = \{\Pi(\pi(w_p)) | w_p \in L(W)\}$;
- determine the set Π' of customer-admissible contracts by applying the acceptance function A, i.e. $\Pi' = \{c | c \in \Pi, A(s_c, r_c) = 1\}$.

At each transduction step, the FAP generates a contract property instantiation c_i^j, together with a measure of similarity between the requests and offers expressed as fuzzy sets. For instance, consider the top-most paths in the FWA (Fig. 2) and FWT (Fig. 3), i.e. $(Priority|f_1^1)(Rate|f_2^1)$ and $[Priority : Bronze|\varphi_1^b][Rate : Low|\varphi_2^{\ell_1}]$. Applying the FAP to these two paths produces the contract $c = \big\langle BronzePriority \circ LowRate, \mathrm{cog}\big(f_1^1 \cap \varphi_1^b \cup f_2^1 \cap \varphi_1^{\ell_1}\big), \mathrm{Sim}(f_1^1, \varphi_1^b) \cdot \mathrm{Sim}(f_2^1, \varphi_2^{\ell_1})\big\rangle$.

The graphical model allows the user to easily define and visualize complex policies encompassing multiple alternative decision rules. In particular, using the compositionality properties of automata and transducers, it is possible to separately define atomic policies that can be combined (by graph concatenation) to generate articulated policies and business rules.

3. Future developments

The proposed framework allows many promising extensions, either at theoretical, technical and application levels.

From a theoretical point of view, we can easily adapt the model to work with multiple providers or within a more complex business model. For instance, it is possible to disentangle the FAP part from the contract specification. Both requests and offers can be defined in terms of FWA, while a third party brokering agent takes responsibility for merging the requests and offers and for selecting the most suitable solution to be delivered to the contractors.

At a technical level, the proposed approach can be used for a semantically consistent description of services, e.g. in terms of Web Service Description Language (WSDL). More, exploiting the compositionality properties cited in the previous section, FCDs for large choreographies described via business languages (such as BPEL) could be automatically generated by aggregating the FCDs of the basic services.

Finally, as regards applications, fuzzy agreement could also be exploited to validate the assessment of the offered QoS, by simulating the interactions between the provider and a set of autonomous agents that represent typical profiles of customers.

References

1. R. E. Bellman and L. A. Zadeh, Decision-making in a fuzzy environment, *Management Sciences* **17**, pp. B141–B164 (1970).
2. H. J. Zimmermann, *Fuzzy sets, decision making, and expert systems* (Kluwer, Boston, MA, 1986).
3. T. J. Ross, *Fuzzy logic with engineering applications* (Wiley, 2004).
4. C. M. MacKenzie, K. Laskey, F. McCabe, P. F. Brown and R. Metz (eds.), *Reference Model for Service Oriented Architecture 1.0* (OASIS Consortium, 2006).
5. L. Badia, S. Merlin, A. Zanella and M. Zorzi, Pricing VoWLAN services through a micro-economic framework, *IEEE Wireless Comm. Mag.* **13**, pp. 5–13 (2006).
6. I. Aad and C. Castelluccia, Differentiation mechanisms for IEEE 802.11, in *Proc. IEEE INFOCOM*, pp. 209–218 (Anchorage, AK, 2001).
7. D. Bacciu, A. Botta and H. Melgratti, A fuzzy approach for negotiating quality of services, in *Proc. of the Trustworthy Global Computing Conference (TGC)*, (Lucca, Italy, 2006).
8. M. Mohri, Weighted finite-state transducer algorithms: An overview, in *Formal Languages and Applications*, eds. C. Martn-Vide, V. Mitrana and G. Paun, Lecture Notes in Computer Science (LNCS), Vol. 148 (Springer, 2004)