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With a rapid growth of the Internet, exploring cost-effective and time-efficient methods for creating Internet services has become critical. As an emerging technology, service aggregation has been regarded as a promising candidate. However, it also raises serious issues on privacy management, as a service is usually provided by multiple providers that are usually transparent to its users. We observe that these issues have not been formally studied in the literature. In this paper, we propose a formal model for the privacy management in service aggregation and present a negotiation strategy on different privacy policies between two organizations.

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A Framework for Privacy Policy Management in Service Aggregation

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Abstract—With a rapid growth of the Internet, exploring cost-effective and time-efficient methods for creating Internet services has become critical. As an emerging technology, service aggregation has been regarded as a promising candidate. However, it also raises serious issues on privacy management, as a service is usually provided by multiple providers that are usually transparent to its users. We observe that these issues have not been formally studied in the literature. In this paper, we propose a formal model for the privacy management in service aggregation and present a negotiation strategy on different privacy policies between two organizations.

Keywords-privacy policy; service aggregation.

I. INTRODUCTION

The emergence of Service Oriented Architecture (SOA) and web service technologies is making the boundaries between network domains fade out. It is a trend for a business entity to combine the various services offered by various service providers in different domains along with some of its own services and resell the aggregated services to users. Service aggregation becomes a cost-effective and time-efficient way to develop new applications and services [5], [7]. Its benefit originates from the added value generated by the possible interactions and by the large scale rather than by the capabilities of its individual service provider separately. Clearly, this paradigm creates tremendous opportunities in e-businesses. However, its nature of cross-organisation raises serious challenges for privacy management. Because aggregating services implies the sharing of information between services, privacy protection must be considered. Businesses are often prohibited by law or by contract from disclosing the personal/private information of users/partners to third parties. To protect users’ privacy, organizations require privacy policies. When a user accesses proprietary services provided by a single service provider, user’s privacy is protected by the privacy policy of the provider. However, when a user’s information needs to be shared by multiple service providers, which might have some inconsistent or even conflicting privacy policies, privacy protection obviously becomes a more challenging problem. Therefore, advanced privacy management should be investigated. This includes the autonomous comparison of privacy policies, detection of inconsistency/conflicts, analysis of risks associated with the detected inconsistency/conflicts, and resolution of inconsistency/conflicts.

There are several useful tools for privacy policy management, such as XACML [10], P3P [12], APPEL [3], EPAL [4] and ASL [6]. These tools provide formal approaches for describing privacy policies. With novel functionalities, several privacy policy comparison and negotiation protocols are introduced [11], [2], [1], [14], [9], [8], [13]. However, these methods do not address the privacy management for service aggregation. In particular, they do not consider large privacy policy sets from multiple parties. In this paper, we address these issues by proposing a formal method for privacy policy management in service aggregation and a privacy policy negotiation method.

The remainder of the paper is organised as follows. In Section II the high-level architecture of service aggregation with privacy policies is demonstrated. Section III shows the basic components. The syntax and semantics are introduced in Section IV and V, respectively. Section VI gives several privacy policy matching protocols. Finally, Section VII concludes with future work.

II. SERVICE AGGREGATION WITH PRIVACY POLICIES

Service aggregation is defined as logically combining the functionalities of multiple services as parts of a single, descriptive and meaningful information abstraction. In short, it is the combination of a set of services to achieve a common goal. Service aggregation allows users, service providers and a service aggregator to collaborate in highly distributed environments, and establish on-demand, short-term and dynamic business relationships for maximizing profitability. Each participant in service aggregation has its own privacy policy. A general diagram that illustrates the high-level architecture of service aggregation with privacy policies is shown in Figure 1.
As depicted in Figure 1, there are three types of parties in service aggregation: user, service providers and service aggregator. The service providers provide various public and professional services ranging from simple information retrieval services to more complex transaction oriented services, and the service aggregator works as an agency for service providers to aggregate various services offered by service providers along with some of its own services to serve users. Service aggregator and service providers have their associated privacy policies, and users have their own privacy policies (also called privacy preferences), too.

Privacy policy, as a special case of the authorization for controlling access to personal information, specifies under what conditions the personal information can be exchanged and what the information is used for. The privacy policies of service aggregator and service providers state what personal information it requires from a user and how the information will be used. The privacy policy of a user states what private information she is willing to share, with whom and under what circumstances it may be shared.

A privacy policy is attached to a software agent that acts for a user, a service aggregator or a service provider. Prior to the activation of a particular service, the agent for the user and the agent for the service aggregator will undergo a privacy policy exchange, in which the policies are examined for compatibility. The service is only activated if the policies are consistent. Similarly, when the service aggregator would integrate a service from a service provider who needs some personal information, the agent for the service aggregator and the agent for the service provider will also examine their privacy policies for compatibility. The services are aggregated only if the policies are not conflictive.

### III. Basic Components

Throughout the paper, we denote the set of natural numbers by \( \mathbb{N} \) and the set of numbers \( \{1, 2, \ldots, n\} \) by \([n]\).

Our model relies on the following three basic components. The first component is a set \( S = U \cup SA \cup SP \) of subjects that can operate an object actively. Subjects can be users (i.e., elements of \( U \)), or the service aggregator (the only element of \( SA \)), or service providers (i.e., elements of \( SP \)).

The second basic component is a set \( O = D \cup P \cup M \) of objects, which are the passive resources to be operated by subjects. Objects in our model include data (i.e., elements of \( D \)) of users, service aggregator and service providers, their privacy policies (i.e., elements of \( P \)), and messages (i.e., elements of \( M \)) that is associated with two subjects (a user and the service aggregator, or the service aggregator and a service provider).

The last basic component is a set \( OP \) of operators, denoting the operations that subjects can execute on the objects in the system. Operators to be considered depend on the underlying activities in the system, usually include read, write, add, delete, create, revoke, send, receive, etc.

The basic components of our model are formalized by the notion of Service Aggregation as follows.

**Definition III.1 (Service Aggregation)** A Service Aggregation consists of the following components:

1) **Subjects.** A countable set \( S \) of labels, called subject identifiers. This set is partitioned into three subsets, namely, \( U \) (users), \( SA \) (service aggregator) and \( SP \) (service providers), where there is only one element in \( SA \). The service aggregator interacts with users and service providers, but users do not interact with service providers.

2) **Objects.** A countable set \( O \) of labels, called object identifiers. This set is partitioned into three subsets, namely, \( D \) (data), \( P \) (privacy policies) and \( M \) (messages).

3) **Operators.** A countable set \( OP \) of labels, called operator identifiers.

### IV. Syntax of Service Aggregation

We assume that a service aggregation \( \mathcal{W} \) has been fixed. Over \( \mathcal{W} \), a set of rules and vocabularies can be specified. In addition, we assume that the following sets are given:

1) A finite set \( C \) of data categories with a fixed vocabulary, which are structured in hierarchies as follows. \( C \) contains the special category \( sc \), called super category. On \( sc \) the partial order relation \( \leq \) is defined such that \( sc \leq c \), for all \( c \in C \). Given two categories \( c_i \) and \( c_j \), if \( c_i \leq c_j \) we say that \( c_j \) is a subcategory of \( c_i \).

2) A finite set \( \mathcal{V} \) of context variables with a fixed domain.

3) A finite set \( D \) of context data values with a fixed semantics.

**Definition IV.1 (Personal Information)** Personal information is a set \( PI \) of data about an individual.
Personal information can be partitioned into a set of data categories, such as contact information, financial information, medical data, demographic data, internet protocol information, cookie information, purchasing data, and others. Figure 2 gives an example of the hierarchy of Personal Information [6].

**Definition IV.2 (User Data)** User data includes some of personal information about a customer and some information that the system creates in the process of replying the customer’s service request.

Usually user data about a customer contains not only the customer’s personal information but also the services the customer requested and the corresponding service providers.

**Definition IV.3 (Message)** A message is a piece of information one subject sends to another subject.

**Definition IV.4 (Constraint)** A component is a pair com = (dv, val) of a variable dv and a set val, where dv ∈ V and val ⊆ D ∧ val ≠ ∅. val is a set of values assigned to the variable dv. Given two components com1 = (dv1, val1) and com2 = (dv2, val2), com1 ⊆ com2 iff dv1 = dv2 ∧ val1 ⊆ val2.

A constraint is a finite set cstr1 = (com11, com12, ..., com1n) (n ∈ N) of components comij (j ∈ [n]). Given two constraints cstr1 = (com11, com12, ..., com1n) (n ∈ N) and cstr2 = (com21, com22, ..., com2m) (m ∈ N), if ∀comik (k ∈ [n]), ∃comlj (l ∈ [m]), such that comik ⊆ comlj, we say cstr2 is a subconstraint of cstr1, or cstr1 is a superconstraint of cstr2, denoted by cstr1 ⊆ cstr2.

**Definition IV.5 (Term)** A term is a reference t to a data category on specific pieces of personal information, where t ∈ C.

**Definition IV.6 (Privacy Policy Vocabulary)** A privacy policy vocabulary is a pair PPVOC = (T, CST R) where T and CST R are a finite set of terms and a finite set of constraints, respectively.

**Definition IV.7 (Privacy Policy)** For a privacy policy vocabulary PPVOC, a privacy policy is a tuple Pol = \{(T1, CST R1), (T2, CST R2), ..., (Tn, CST Rn)\} (n ∈ N) of pairs (Ti, CST Ri) (i ∈ [n]) where Ti ∈ T and CST Ri ∈ CST R, which defines what kinds of personal information \{Ti\}i=1,...,n are exchanged between two subjects and how the personal information are used and stored under the corresponding constraints \{CST Ri\}i=1,...,n.

For privacy policies, usually there are following context variables: Recipient, Data, Purpose, Retention, Disclose-to, Consent, Obligation, Condition, Remedy, and Action. The first four variables are compulsory in a privacy policy, and others are optional. For the optional variables, different privacy policy languages define different parties of them. Notice that, as stated in [10], “Purpose” is the only variable that must exist in a privacy policy but not occur in a transitional access control policy. The notion of purpose plays a major role in protecting privacy, since privacy policies are concerned with the purposes that personal information is collected for rather than the actions that recipients perform on the personal information, and traditional access control policies cannot easily achieve privacy protection.

For a context variable, there are a lot of context values, which are different in different privacy policy language. For example, the values to the variable “Recipient” in P3P are “ours”, “delivery”, “same”, “other-recipient”, “unrelated”, and “public”.

**Example IV.1** Consider the privacy policy set by a subject s as follows.

\[
\begin{align*}
\text{Pol}^s &= ((T_1, CST R_1), (T_2, CST R_2)) \\
&= ((T_1^s, (com_{i-1}^s, com_{i-2}^s)), (T_2^s, (com_{j-1}^s, com_{j-2}^s))) \\
&= ((T_1^s, (dv_{i-1}^s, val_{i-1}^s), (dv_{i-2}^s, val_{i-2}^s)), (T_2^s, (dv_{j-1}^s, val_{j-1}^s), (dv_{j-2}^s, val_{j-2}^s)))
\end{align*}
\]

It states that, the privacy policy protects two categories of personal information, T1 and T2. The constraint CST R1 is for T1 and the constraint CST R2 is for T2. For the constraint CST R1, there are two variables, dv_{i-1} and dv_{i-2}, with the values, val_{i-1} and val_{i-2}, respectively, and for the constraint CST R2, there are one variable, dv_{j-2}, with the value, val_{j-2}. Now we assign “Home-Telephone-Number”, “Purpose”, “Recipient”, “contact”, “ours & delivery”, “Credit-Card-Information”, “Retention” and “no-retention” to T1, dv_{i-1}, dv_{i-2}, val_{i-1}, val_{i-2}, T2, dv_{j-1}, and val_{j-1}, respectively, the detailed privacy policy is as follows.

\[
\begin{align*}
\text{Pol}^s &= ((\text{Home} - \text{Telephone} - \text{Number}, \\
\text{Purpose}, \text{contact}), \\
(\text{Recipient}, \text{ours} &\text{delivery}), \\
(\text{Credit} - \text{Card} - \text{Information}, \\
(\text{Retention}, \text{no} - \text{retention}))
\end{align*}
\]

This means, in order to contact the user, s collects a user’s home telephone number. However, not only s knows the
Definition IV.8 (Service Aggregation Vocabulary) A service aggregation vocabulary is a triple \( \text{SAVOC} = (S, O, OP) \) where \( S \) is a set of subjects including users, service aggregator and service providers, \( O \) is a set of objects including personal information, privacy policies, user data and messages, and \( OP \) is a set of operators.

V. SEMANTICS OF SERVICE AGGREGATION

We point out that semantic aspects play a crucial role in our proposal, since they make the model innovative with respect to existing approaches. This matter will be deeply analyzed in this section. In this section, we provide the formal semantics of service aggregation.

Definition V.1 (Request) A request is a message that a subject sends to another subject to ask for some resource. For a privacy policy vocabulary \( \text{PPVOC} \), a personal information (PI) request is a request taking the form of a finite set \( req = \{(t_1, cstr_1), \ldots, (t_m, cstr_m)\} (m \in \mathbb{N}) \) of pairs of term \( t_i \) and constraint \( cstr_i \) (\( i \in \{m\} \)) to ask for some personal information.

Definition V.2 (Matching Rule) Given a PI request \( req = \{(t_1, cstr_1), \ldots, (t_m, cstr_m)\} (m \in \mathbb{N}) \) and a privacy policy \( Pol = \{(T_1, CSTR_1), \ldots, (T_n, CSTR_n)\} (n \in \mathbb{N}) \), the request matches the privacy policy, denoted by \( req \sqsubseteq Pol \), iff \( \forall (t_i, cstr_i) \in req \ (i \in \{m\}), \exists (T_j, CSTR_j) \in Pol \ (j \in \{n\}) \), such that \( T_j \equiv t_i \land CSTR_j \equiv cstr_i \).

If a request matches a constraint, then it matches all supconstrants of the constraint, i.e., the match rules with positive results are additionally inherited up the hierarchies. If a request does not match the constraint (in all hierarchies), then it does not match all subconstrants of the constraint. i.e., the match rules with negative results are inherited down the hierarchies.

The set of privacy policies \( P \) is partially ordered by \( \preceq \). The partial order is defined by a cover relationship. It models a part-of relation among privacy policies.

Definition V.3 (Cover) The cover relationship \( \preceq \) is defined as follows: a privacy policy \( Pol^y = \{(T_1^y, CSTR_1^y), \ldots, (T_m^y, CSTR_m^y)\} \) covers another privacy policy \( Pol^x = \{(T_1^x, CSTR_1^x), \ldots, (T_m^x, CSTR_m^x)\} \) (\( n, m \in \mathbb{N} \)), denoted with \( Pol^y \equiv Pol^x \), iff \( \forall (T_i^y, CSTR_i^y) \ (i \in \{m\}), \exists (T_j^x, CSTR_j^x) \ (j \in \{n\}) \), such that \( T_j^x \equiv T_i^y \land CSTR_j^x \equiv CSTR_i^y \).

Definition V.4 (Incomparable) Given two privacy policies \( Pol^x \) and \( Pol^y \), if neither \( Pol^x \preceq Pol^y \) nor \( Pol^y \preceq Pol^x \) holds, the two privacy policies are said to be incomparable.

Definition V.5 (Formula) For a service aggregation vocabulary \( \text{SAVOC} \), a formula is a construction of form: \( op(s_1, o) :: s_2 \), where \( s_1, s_2 \in S, o \in O \), and \( op \in OP \), which states that the subject \( s_1 \) executes the operator \( op \) on object \( o \) and outputs the result to the subject \( s_2 \). If two subjects are the same one, the formula is denoted with \( op(s_1, o) \). If there are more than one subject executing a operator on more than one object, all the subjects should be included in a pair of parentheses (\( \cdot \)), and so do all objects.

Example V.1 A user \( u \) creates her personal information \( pi \), the formula is \( \text{create} (u, pi) \).

Example V.2 The service aggregator \( sa \) uses its own information \( in_{sa} \) to replace a user’s personal information \( pi \), the formula is \( \text{replace} (sa, (pi, in_{sa})) \).

Example V.3 The service aggregator \( sa \) and a service provider \( sp \) negotiate on the personal information request \( req \) and the result of negotiation is send to the service provider \( sp \), the formula is \( \text{negotiate} ((sa, sp), req) :: sp \).

Example V.4 Let’s consider the following conditional formula.

send(u, pi) :: sa ← con(req\(^u\) \sqsubseteq Pol\(^-\)).

It states that, a user \( u \) sends her personal information \( pi \) to the service aggregator \( sa \) if the request of the service aggregator \( req\(^u\) \) matches the privacy policy of the user \( Pol\(^-\) \).

VI. MATCHING PRIVACY POLICY

To make their services available to users, service providers have to register the services in the service aggregator. Different service may collect different personal information of users. For every service that would be registered, the service provider sends a PI request to the service aggregator. The service aggregator checks if the request matches its privacy policy. If the request does not match the privacy policy, the service aggregator will negotiate with the Service Provider on the unmatched part in the request. The strategy of negotiation is as follows.

Case 1: Service Aggregator \( sa \) does not collect the data \( \text{data}_{\text{unmatch}} \) in the unmatched part \( ump \).

Rule 1.1 Service Aggregator \( sa \) asks Service Provider \( sp \) to remove the unmatched part \( ump \) from the request \( req\(^u\) \).
Rule 1.2 sa may collect the data data<sub>unmatch</sub> by negotiating with the user who needs the service.

Rule 1.3 sa may replace the data data<sub>unmatch</sub> with its own information inf<sub>sa</sub> to reply sp.

Case 2: The constraints cstr<sub>unmatch</sub><sup>sp</sup> on the data data<sub>unmatch</sub> in the request req<sup>sp</sup> are conflictive to the constraints in the privacy policy of Service Aggregator sa.

Rule 2.1 Service Aggregator sa asks Service Provider sp to change the constraints cstr<sub>unmatch</sub><sup>sp</sup> to make the request req<sup>sp</sup> match the privacy policy of sa.

Rule 2.2 sa may replace the data data<sub>unmatch</sub> with its own information inf<sub>sa</sub> to reply.

We model the above rules as the following algorithm.

**Algorithm: negotiate((sa, sp), ump)**

**INPUT:** sa, sp, ump

**OUTPUT:** TRUE if the negotiation is fail, FALSE otherwise.

**METHOD:**

1. if ¬(con(collect(sa, data<sub>unmatch</sub>))) then
   2. if remove(sp, ump) then
      3. return TRUE
   4. else if collect(sa, data<sub>unmatch</sub>) then
      5. return TRUE
   6. else if replace(sa, data<sub>unmatch</sub>, inf<sub>sa</sub>) then
      7. return TRUE
   8. else return FALSE
5. endif
11. endif
12. else
13. if change(sp, cstr<sub>unmatch</sub><sup>sp</sup>) then
14. return TRUE
15. else if replace(sa, data<sub>unmatch</sub>, inf<sub>sa</sub>) then
16. return TRUE
17. else return FALSE
18. endif
19. endif
20. endif

Now we give the detailed procedure of matching privacy policies as follows.

Step 1 Service Provider sp sends a PI request req<sup>sp</sup> to Service Aggregator sa, who will check whether the request req<sup>sp</sup> matches its privacy policy Pol<sup>sa</sup> or not.

Step 2 If req<sup>sp</sup> does not match Pol<sup>sa</sup>, sa negotiates with sp on the unmatched part ump.

Step 3 If the result of negotiation is false, then sa rejects sp to register the service.

Step 4 If req<sup>sp</sup> matches Pol<sup>sa</sup> or the result of negotiation is true, sa accepts sp as a legitimate service provider for the service.

It is modeled as follows.

**Matching Protocol**

1. send(sp, req<sup>sp</sup>) :: sa
2. negotiate((sa, sp), ump) ← ¬con(req<sup>sp</sup> ⊆ Pol<sup>sa</sup>)
3. reject ← ¬con(negotiate((sa, sp), ump))
4. accept ← con(negotiation((sa, sp), ump)) ∪ con(req<sup>sa</sup> ⊆ Pol<sup>sa</sup>)

When a service provider updates its privacy policy, if the old privacy policy can cover the new one, it is fine with the system. Otherwise, the service provider has to check if the change of privacy policy affects the original PI request for the registered service. If not, it is ok for the system. Otherwise, the matching protocol is executed. If the output of the protocol is “reject”, the registered service should be removed from the available service list of the service aggregator. Otherwise, it is retained.

When service aggregator updates its privacy policy, it also checks if the new privacy policy can cover the old one. If yes, no more action needs to be taken. Otherwise, the service aggregator will run the matching protocol for every registered service. The service aggregator will hold the service with the output “accept” of the protocol or remove the service from its available service list with the output “reject”.

We omit the modelling of above two scenarios here.

**VII. CONCLUSIONS AND OPEN PROBLEM**

In this paper, we proposed a logic model that naturally supports the encoding of complex privacy policy specifications in service aggregation. The syntax and semantics are both simple and intuitive. Based on them, we showed how to negotiate and match two privacy policies.

This paper represents our first attempt at a formal study of privacy policies in service aggregation. We plan to extend our semantics-centered approach to areas including privacy policy enforcement and privacy practice auditing.

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