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Conflict Detection and Resolution in Context-Aware Authorization

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Abstract

Pervasive computing environments introduces new requirements in expressiveness and flexibility of access control policies which are almost addressable leveraging contextual information. Although context-awareness augments the expressiveness of policies, it increases the probability of arising conflicts. Generally, context-aware authorizations are defined using some contextual constraints about the involved entities in an access request. Accordingly, principles such as "more specific overrides", which are employed to resolve possible conflicts, are required to consider the contextual constraints. In this paper, we propose a comprehensive approach to resolve conflicts in context-aware authorization policies. We formalize the use of context constraints in a typical context-aware authorization policy model. The policy model supports multi-authority in which each authority is capable of defining an expressive conflict resolution policy. The resolution policy leverages context-based precedence establishment principles; the concept of context-based specificity is of our main contribution in this paper.

keywords: *Conflict, Context-Awareness, Authorization, Access Control.*

1 Introduction

Evolution of distributed systems, mobile computing environments, and moving toward pervasive computing environments introduced new security and access control requirements [18], including expressiveness and flexibility of security policies. Leveraging contextual information can address some of these requirements. Context as defined expressively by Dey [5] is *"any information that can be used to characterize the situation of an entity."* An entity is a person, place, or object that is considered relevant to the interaction between a user and an application, including the user and applications themselves. In an access control system, authorization policies specify which activities should be permitted or forbidden. Classic access control models express their policies using the notions of subjects, objects, and rights [15]. Several works addressed context-aware access control models or security infrastructures such as [8, 2]. We also proposed a context-aware provisional access control model that decides some required provisional actions in addition to common binary access decision according to the context [11]. The central idea of all these models is expressing subjects, objects, groups, roles, etc. through context expressions. Although context-awareness highly augments the expressiveness of authorization policies, it increases the probability of conflicts among different policies.

A conflict arises when the objectives of two or more active policies can not be simultaneously met. Two major categories of conflicts are addressed for authorization policies in the literature. The first category includes conflicts due to separation of duties [7], conflict of interests [4], and so on. These conflicts are application specific and imposed by policies. Modality conflicts constitute the second category which arise where two or more different policies both permit and forbid an access in a situation. As the second category is of the main concern in this paper, modality conflict is simply called "conflict".

There are different methods to deal with conflicts:

Conflict Prevention Models such as [12] prevent conflicts by avoiding definition of new policies conflicting with previously defined ones. However, there are some reasons making this method impractical. Policies defined by different authorities may have conflict, as each authority has its own access control requirements. The need to specify policies exceptional to other policies is another consideration.

Policy Reformation Reforming the conflicting policies is also impractical. It is common to define a new temporary policy which may have conflict with older policies. Amending the older policy to be consistent with

the new one, will result in its distortion when the temporary policy is removed.

Precedence Establishment In this method, the idea is to determine precedence of a policy involved in a conflict situation over the other policies.

Among the indicated methods, the precedence establishment approach tends to be a more practical solution. It requires establishing a precedence relationship among conflicting policies. This can be performed by manual assignment of specific priority to each conflicting policy. However, precedence establishment is more preferred to be done automatically because manual assignment may be cumbersome and impractical in real-world situations. Several principles has been suggested for establishing precedence automatically [10, 6]:

- Specific overrides general policy (more specific overrides)
- Newer overrides older policy
- Negative/positive policy takes precedence
- Higher authority overrides lower authority

Practically, each principle has its specific application and is useful in a particular situation.

Generally, in a context-aware authorization system, contextual constraints are used to tightly specify the request. To the best of our knowledge, precedence establishment principles, such as "more specific overrides", has been used to resolve conflicts in context-aware authorization systems, considering a few aspects of context. Our main contribution in this paper is the definition and employment of precedence establishment principals in a context-aware manner, particularly context-based specificity relation among context-aware authorizations. To achieve that, context-aware authorizations are formalized in a rule-based policy model which tends to serve as a common basis for other context-aware authorization models. Since centralized authorization is not feasible for large distributed systems [16] and many context-aware environments are inherently distributed, the policy model supports multi-authority to enable decentralized authorization. We propose a comprehensive conflict detection and resolution method which supports flexible conflict resolution policies capable of employing different context-based precedence establishment principals. The formalization of the method is expressed through graphs to make it more comprehensible. Our approach considers all the conflicting authorizations together. This is due to the possibility of relationship among conflicts [10], and yielding different results when the sequence of pairwise conflict resolution changes.

The remainder of this paper is organized as follows. Some major works regarding conflict detection and resolution are surveyed in section 2. In section 3, a typical context-aware authorization policy model leveraging a formal definition of context is presented. The context-aware conflict detection and resolution scheme based on the mentioned policy model is proposed in section 4. Section 5 concludes the paper.

2 Related Work

Jojodia et al in addition to positive/negative precedence, provide an approach that states nothing takes precedence [9]. In this manner the final result is equivalent to the case where no authorization had actually been specified. They also handle principles like "more specific overrides" through different derivation schemes along subject hierarchies.

Lupu et al studied conflicts in authorization and obligation policies [10]. The notion of domains was used as a means of grouping objects in specifying policy scope and policy propagation form domains to sub-domains. They discussed modality conflicts among authorization and obligation policies, and application specific conflicts such as conflict of duties. They defined specificity related to domain nesting as an equivalent for "more specific overrides" principle.

In [6] four possible approaches are considered for the process of conflict resolution. In pessimistic approach both potential and actual conflicts are resolved at compile-time, while in opposite, optimistic approach does the all at runtime. In the balanced alternative, actual conflicts are resolved at compile-time and potential ones remain to runtime. Another alternative is deciding to resolve each conflict individually based on its likelihood of occurring and cost of resolution.

Ruan et al addressed conflict resolution in presence of authorization delegation through a formal graph based framework [14]. In [3], authors proposed a method that used event calculus in conjunction with abductive reasoning to perform a priori analysis of policy specification and detect conflicts statically.

Syukur et al investigated policy conflict resolution in pervasive computing environments [17]. They discussed different timing strategies for conflict detection: static, reactive, proactive, and predictive. However their conflict resolution techniques seems too limited.

Al-Kahtani et al used the notion of dominance between authorization rules in their attribute-based user-role assignment model [1]. Dominance in their work is somehow the reverse notion of context-based specificity in our approach. However, it supports a limited concepts such as ordinal attributes and is used to induce seniority among authoriza-

tions in order to construct the induced role hierarchies.

3 Context-Aware Authorization Policy Model

In this section we provide a typical policy model which supports context-aware authorization. It intends to serve as a typical model in order that the conflict resolution scheme be general enough to support a wide range of context-aware authorization systems. It is proposed as a rule-based model in which rules, roughly correspond to authorizations, are defined in terms of some constraints on the contextual information.

3.1 Context Definitions

In order to formalize the use of contextual information in the model, some definitions regarding context are provided.

Definition 1 (Context Predicate) *A* context predicate *is a 4-ary tuple (subject, type, relater, object).*

Subject is an entity with which the context is concerned, *type* refers to the type of context the predicate is describing, and *object* is the value related to the subject through the *relater*. For example, (Bob, location, entering, ConferenceRoom) states that Bob is entering the conference room, or (John, position, is, secretary) expresses John's position. The basic idea of such context predicates has been adopted from Gaia project which provides the infrastructure for constructing smart spaces [13]. It is supposed that there is a means to verify a context predicate in the actual environment. This can be performed by a context infrastructure or a separate component in the system architecture usually called context inference engine. A context predicate is satisfied if it is verified as correct.

Definition 2 (Context Constraint) *A* context constraint *is a set of context predicates.*

In fact, a context constraint is interpreted as logical conjunction of its predicates. It is satisfied if all its context predicates are satisfied. An empty context constraint, which is denoted by $\emptyset$, is satisfied by default. A context constraint can descriptively express a situation based on context information. For instance,

$$\{(Bob, location, entering, ConferenceRoom),$$
$$(ConferenceRoom, social\_activity, is, presentation)\}$$

expresses that bob is entering the conference room in which a presentation is carried out.

Since one of the most preferable principles to establish precedence is "more specific overrides", we provide the definition of specificity based on context predicates and constraints. For example, a predicate stating that the age of the user must be over 30 should be considered more specific than a predicate expressing the age of the user must be over 20.

Definition 3 (More Specific Context Predicate) *Context predicate p_1 is* more specific *than context predicate p_2, denoted by $p_1 <_{MS} p_2$, if they both have equal subject and type, and p_2 is inferable by p_1; i.e. wherever p_1 is satisfied, p_2 is also satisfied.*

Several approaches can be employed to perform the required inference, i.e. $p_1 \rightarrow p_2$. A simple approach is using a knowledge base and a rule-based inference mechanism. For instance, in order to infer the previous example, i.e. $(user, age, >, 30) <_{MS} (user, age, >, 20)$, leveraging a rule such as the following yields the required result:

$$(S, T, >, O_1) \ \wedge \ O_1 > O_2 \rightarrow (S, T, >, O_2)$$

The specificity regarding context constraints is defined as follows.

Definition 4 (More Specific Context Constraint) *context constraint c_1 is* more specific *than context constraint c_2 regarding a tuple (s, t), denoted by $c_1 <^{s,t}_{MS} c_2$, if c_1 contains a predicate, which its subject is s and its type is t, and either c_2 does not have a predicate with the same subject and type or if it has such one, the c_1's predicate is more specific than c_2's.*

For example, let $C_1 = \{(user, age, >, 20), (user, location, in, class\_A)\}$ and $C_2 = \{(user, age, \geq, 30)\}$. Therefore, we have $C_2 <^{user,age}_{MS} C_1$, and $C_1 <^{user,location}_{MS} C_2$. Note that the simplicity of constraint definition makes the specificity relation convenient and straightforward.

3.2 Policy Model

Authorization policy is actually a collection of authorization rules, briefly termed as authorizations.

Definition 5 (Authorization) *An* authorization *is a tuple (sign, condition).*

The *sign* can be either "$+$" to state a positive authorization or "$-$" to declare a negative one. The *condition* is a context constraint that specifies the situation at which the authorization is active. A typical access request contains three components: *object* is the protected entity to be accessed; *subject* is the entity who requests for access; and *action* is requested by the subject to be performed on the object.

Notations *SBJ*, *OBJ*, and *ACT* may be used respectively to address those components in order to describe the desired condition of an access request for an authorization. For instance, the authorization below prohibits a user to access a confidential or higher classified document remotely:

$$(-, \{(SBJ, connection-type, is, remote),$$
$$(OBJ, type, is, document), (OBJ, class, \geq, confidential)\})$$

Note that since no predicate is expressed for action, this authorization is considered for all requests regardless of requested action.

The condition of the authorization might seem somewhat limited in the way that it does not allow disjunctions. However, since all policy authorizations whose condition is satisfied are active an enforceable in an access situation, the enforced policy is considered as the disjunction of all active authorizations. In order to state an authorization with a disjoint condition $A \vee B$, two authorizations, one with condition A and one with condition B and both with the same sign, should be defined. The mentioned limitation facilitates conflict resolution based on context which in its absence can be quite complicated and costly.

Since many context-aware environments such as pervasive computing environments are inherently distributed, centralized authorization management is not practical. So, in order to support decentralized authorization, the policy model supports multiple authorities. Each authority is capable of defining policy for a restricted virtual space called *authority space*.

Definition 6 (Authority Space) *An* Authority space *is defined and limited by a context constraint.*

Within an authority space, an authority defines its policy using authorization rules. Based on the current context, an authority space restricts the subjects, objects, and actions on which policy can be defined or the situation when it is applicable. Actually, an authorization defined by the authority is enforceable when both authority space constraint and authorization condition are met.

The authorities are organized as follows. There is a global authority which its authority space has no constraint. An authority can create several sub-authorities within a more restricted authority space than itself has; the creator's authority space constraint is enclosed in the constraint of the new authority space. Actually, an authority delegates the policy specification responsibility to the sub-authority restricted to its authority space constraint. Note that the authority spaces of sub-authorities are not necessarily isolated; they can overlap each other. In this manner, authorities form a tree structure such that its root is the aforementioned global authority, and each authority is the parent of the authorities which it has created. The authority space of a child is necessarily more restricted than the parent's. Also, two or more different authority spaces even in different levels of the tree may overlap. The proposed approach supports maximal independency for authorities in specification of their policy. It also facilitates the distribution of conflict detection and resolution. Fig. 1 illustrates an authority hierarchy. Note that although authority space of the three users is contained in the authority space of the presenter, they are considered as sub-authorities of the room manager.

4 Conflict Detection and Resolution

A conflict arises when the objectives of two or more active policies can not be simultaneously met. Conflicts in the rule-based authorization policy model of section 3 may arise among different authorizations.

Definition 7 (Conflicting Authorizations) *Two or more authorizations are* conflicting *in a situation if their condition elements are satisfied and they have conflicting sign elements; i.e. some have "+" and the others have "−" sign.*

Furthermore, in a conflict situation, different involved authorities may have conflicting decisions for an access request. Organizing authorities in a tree structure, as described in section 3.2, provides a reasonable way to resolve the conflicts among the different authorities. The decision of a parent authority overrides the decisions of its children. Thus an authority can resolve the conflicts among its sub-authorities and its own authorization rules to make its final decision. The resolution is done according to resolution policies which are defined by the authority based on the aforementioned principles in a context-aware manner. The resolution is formally defined in section 4.2.

The principles for establishing precedence among authorizations may seem inappropriate for resolving conflicts among sub-authorities. Therefore, in addition to use of those principles, each authority can define a context-aware seniority relation among its sub-authorities.

Definition 8 (Seniority Rule) *A* seniority rule *is a triple* (condition, SA_1, SA_2). *It states that if the context constraint* condition *is satisfied, then sub-authority SA_1 is senior to sub-authority SA_2; i.e. sub-authority SA_1's decision overrides sub-authority SA_2's.*

Note that leaving the condition of a rule empty makes it active constantly; i.e. imposes a strict seniority. The seniority relation in an authority is comprised of multiple seniority rules.

4.1 Conflict Detection

We express the formalism of our approach through graphs to make it more comprehensible. Forming a *poten-*

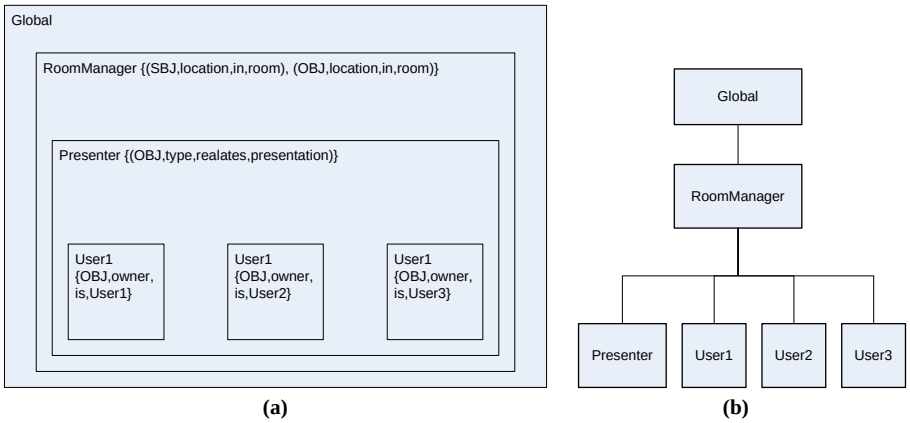

Figure 1. Sample authority spaces (a), and their corresponding authority hierarchy (b)

tial conflict graph, an authority detects potential conflicts and investigates possible precedence relations among its authorizations. As mentioned in section 3.2 an authority is responsible for resolving conflicts among its sub-authorities in addition to its defined authorizations. In order to increase the consistency of the graph, in the decision situation for a specific access request, a sub-authority is considered as a single authorization: context constraint of sub-authority space as its condition, and its determined decision for the request as its sign.

Definition 9 (Potential Conflict Graph) Potential conflict graph *is a multi graph in which each vertex corresponds an authorization or a sub-authority. Each edge in the graph represents an overriding relation between two vertices and is labeled with the relations's symbol.*

Possible relations corresponding to an edge from vertex a_1 to a_2 include

- $<_{MS}^{s,t}$, for different values of subject s and type t, if and only if a_1 and a_2 have conflicting signs and $a_1.condition <_{MS}^{s,t} a_2.condition$
- NoP, if and only if a_1 is a negative authorization and a_2 is a positive one
- $>_S$, if and only if there is a seniority rule (c, a_1, a_2) and condition c is satisfied

Overriding relations, presented by labels, can be extended to include more details or complicated context of authorizations such as relation about time of authorization definition. In practice, since there can be various relations of type $<_{MS}^{s,t}$, considering different values for subject s and type t, it is better to limit the subject and types on which the relation is definable.

Also, note that a reverse relation for each relation is supposable. For instance, for each more specific relation we can assume a more general relation in reverse. Those relations are not mentioned in the graph due to redundancy issues. Whenever needed, the reverse of relation α is denoted by α^{-1}. For instance, relation $<_{MS}^{SBJ,location^{-1}}$ states a more general location context for subject, or relation NoP^{-1} expresses that a positive authorization overrides a negative one.

4.2 Conflict Resolution

In order to define how the conflicts in an authority space should be dealt with, in an expressive and context-aware manner, the notion of *resolution policy* is introduced.

Definition 10 (Resolution Policy) Resolution policy *is a subset of possible relations' symbols in the potential conflict graph or their reverses.*

Resolution policy can be considered as a group of precedence relations; i.e. if all relations corresponding to symbols in a resolution policy exist from authorization a_1 to a_2, then a_1 overrides a_2. For instance, resolution policy $\{<_{MS}^{SBJ,location}, <_{MS}^{OBJ,location}\}$ states that for each two authorizations, if the first authorization specifies more specific location context condition for subject and object then it overrides the second authorization. An advantage of utilization of different relations in a resolution policy is the ability of combining different precedence establishment principles. For example, $\{<_{MS}^{ACT,type}, NoP\}$ expresses that negative authorizations with more specific action types precede positive authorizations.

An authority is capable of expressing its conflict resolution policy using a *resolution policy sequence*.

Definition 11 (Resolution Policy Sequence) Resolution policy sequence *is a total order of some resolution policies. The last resolution policy in the sequence must be either* $\{NoP\}$ *or* $\{NoP^{-1}\}$.

The conflict resolution is a step by step process. Sequentially, at each step, a resolution policy from resolution policy sequence is selected to resolve remaining conflicts; until no conflict remains. As defined, the last resolution policy must state that either negative or positive authorization precedes. That way, it is assured that existing conflicts in an authority space are resolved eventually.

In an actual conflict situation, an *actual conflict graph* is constructed from the potential conflict graph.

Definition 12 (Actual Conflict Graph) Actual conflict graph *is a multi graph extracted from the potential conflict graph which is composed of vertices corresponding to conflicting authorizations at the actual conflict situation and their corresponding edges; i.e. by eliminating those vertices whose corresponding authorizations are not in conflict.*

Actual conflict graph is then pruned according to the resolution policy sequence; Sequentially a resolution policy is selected and the corresponding *filtered graph* is constructed.

Definition 13 (Filtered Graph) *Let AG be an actual conflict graph and R be a resolution policy. The* filtered graph $FG_{AG,R}$ *is a single graph in which*

- *there is a vertex for each vertex in AG, and*
- *there is an unlabeled edge from vertex a_1 to vertex a_2 if*
  - *for every relation's symbol in R, an edge exists in AG from a_1 to a_2 with the same symbol as its label, and*
  - *for every reverse notation of relation's symbol in R, an edge exists in AG from a_2 to a_1 with the same symbol as its label.*

Constructing the filtered graph, the actual graph is pruned by omitting vertices corresponding to non-root vertices in the filtered graph. The enforcing of resolution policies is continued until no conflict exists. Enforcing last resolution policy according to the definition, eventually resolves either negative or positive authorization.

Let us illustrate the approach through a simple example. Consider Fig. 2.a as an actual conflict graph constructed in a conflict situation by omitting non-conflicting vertices. If we use the resolution policy $\{<_{MS}^{SBJ,location}\}$, the filtered graph in Fig. 2.b would be constructed. Using this graph to prune the actual conflict graph, all non-root vertices in filtered graph, i.e. a_1, a_3, and a_4 must be deleted from the actual graph. If we use resolution policy $\{<_{MS}^{SBJ,location}, NoP\}$ instead, the filtered graph in Fig. 2.c would be constructed. Accordingly, only vertex a_3 will be omitted from the actual conflict graph.

4.3 Timing Strategy

Factually speaking, the conflict resolution process is a computationally intensive and time consuming task. Conflicts can be detected and resolved either statically at compile time, or dynamically at run time. But due to its cost, it is more preferable to be done statically [6]. Conflict resolution in a context-aware authorization system is even more complicated; determination of context specificity relations among authorizations requires inference power which is computationally intensive. The strength of the proposed scheme in this paper is that conflict detection can be performed almost statically, and the resolution process is left for run time.

A potential conflict graph is maintained for each authority which can be performed as statically as possible to considerably reduce the cost of conflict resolution. This can be done when policy is modified; i.e. when adding, deleting, and updating authorizations. The reason is that the frequency of policy modification is generally far less than the frequency of arising conflicts in a context-aware policy at run time. Almost all overriding relations among authorizations and sub-authorities are determinable at compile time. Exceptions are those relations pertaining to the sign, e.g. NoP, between two sub-authorities or between a sub-authority and an authorization. Undoubtedly, those relations should be checked at run time if necessary.

4.4 Algorithms

In this section we provide detailed algorithms to implement our conflict resolution. We also provide the computational complexity of the algorithms in which N is the maximum number of vertices in a conflict graph, and L is the number of possible edge labels. Actually, N is the number of authorization rules that an individual policy administrator considers and probably is not very high. However, the number of possible edge labels L should be limited for the scheme to be practical.

Potential conflict graph can be maintained statically. Algorithm 1 demonstrates how to update the potential conflict graph PG when a new authorization A is defined by authority. First, a vertex corresponding to the new authorization is added to PG. Then, for each vertex of PG except A, existence of different types of relations between the vertex and A is checked. Then, for each vertex of PG except A and for each possible label checks if the relation notated by the label holds between corresponding authorizations of the vertex and A. The complexity of the algorithm is $O(LN)$.

Algorithm 2 is used to create a filtered graph from the actual conflict graph AG based on the resolution policy R. It first copies the vertices of AG to $FG_{AG,R}$ and initializes the edges of $FG_{AG,R}$ to null. Then it checks for every two

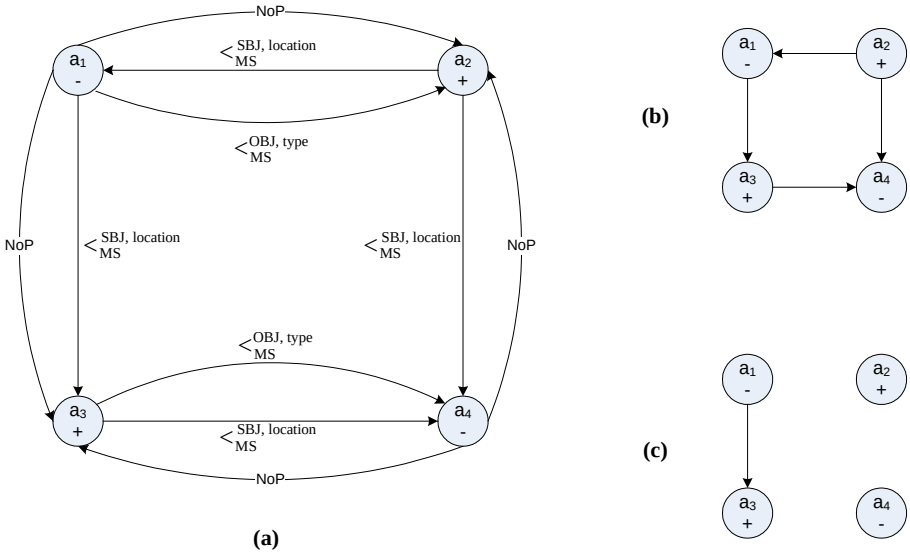

Figure 2. Sample actual conflict graph (a), and its corresponding filtered graphs regarding resolution policy $\{<_{MS}^{SBJ,location}\}$ (b), and resolution policy $\{<_{MS}^{SBJ,location}, NoP\}$(c)

Algorithm 1 UpdatePotentialGraph_AddAuth(PG, A)

Input: potential conflict graph $PG = (V, E)$, newly added authorization a
Output: updated potential graph PG

$V \leftarrow V \cup \{A\}$
for each $v \in V \backslash \{A\}$ **do**
  for each $\alpha \in PossibleRelationSymbols$ **do**
    if $v.sign \neq A.sign$ **then**
      if $v.condition\ \alpha\ A.condition$ **then**
        $E \leftarrow E \cup \{(v, A, \alpha)\}$
      end if
      if $A.condition\ \alpha\ v.condition$ **then**
        $E \leftarrow E \cup \{(A, v, \alpha)\}$
      end if
    end if
  end for
end for

possible vertices in AG, according to the resolution policy R, if one of them overrides the other. The complexity of the algorithm is $O(LN^2)$

Algorithm 2 CreateFilteredGraph(AG, R)

Input: $AG = (V, E)$, and resolution policy R
Output: $FG_{AG,S} = (V^{'}, E^{'})$

$V^{'} \leftarrow V$
$E^{'} \leftarrow \emptyset$
for each two different vertices a and b in V **do**
  $L_{ab} \leftarrow \{l \mid (a, b, l) \in E\}$
  $L_{ba} \leftarrow \{l \mid (b, a, l) \in E\}$
  $S_r \leftarrow \{\alpha \mid \alpha^{-1} \in R\}$
  $S \leftarrow R \setminus S_r$
  if $S \subseteq L_{ab} \wedge S_r \subseteq L_{ba}$ **then**
    $E^{'} \leftarrow E^{'} \cup \{(a, b)\}$
  end if
  if $S \subseteq L_{ba} \wedge S_r \subseteq L_{ab}$ **then**
    $E^{'} \leftarrow E^{'} \cup \{(b, a)\}$
  end if
end for

Algorithm 3 resolves the conflicts in an actual conflict graph AG using resolution policy sequence RS and results the final decision D. The algorithm sequentially selects the next resolution policy and uses it to construct the filtered graph of AG. It then keeps only those vertices of AG whose corresponding vertices in FG have no input edges, i.e. those authorizations which are not overridden by others according to current resolution policy. The edges corre-

sponding to deleted vertices are also removed. The iteration stops when no conflict remains among authorizations, i.e. AG has no edges. Note that if an edge in AG means the existence of a conflict. Finally, the sign of one of the authorizations corresponding to one vertex is returned as result. The complexity of the algorithm is $O(mLN^2)$ where m is the number of resolution policies in the resolution policy sequence RS.

Algorithm 3 ResolveConflicts(AG, RS)

Input: actual conflict graph $AG = (V, E)$, and resolution policy $RS = (S_1, S_2, \ldots, S_m)$
Output: resolved sign D

1: **for** $i \leftarrow 1$ to m **do**
2: **if** $E = \emptyset$ **then**
3: **break**
4: **end if**
5: $FG_{AG,S_i} = (V^{'}, E^{'}) \leftarrow$ CreateFilteredGraph(AG, S_i)
6: $V \leftarrow \{b \in V \mid \nexists (a, b) \in E^{'}\}$
7: $E \leftarrow \{(a, b, l) \in E \mid a \in V \wedge b \in V\}$
8: **end for**
9: $D \leftarrow V[0].sign$

Note that the algorithm resolves conflicts in an authority. The overall conflict resolution procedure is a recursive process in which an authority requires determination by its involved children authorities and resolves the possible conflicts; The process is continued until no conflict exists among involved authorities. Since the depth of the authorization hierarchy which is the different administration levels and restricted in nature, It can be inferred that the overall complexity of the resolution scheme is bounded to a constant factor of resolution Algorithm 3.

5 Conclusion

In this paper, we formalized conflict detection and resolution in a context-aware authorization system. A typical context-aware authorization policy model is presented leveraging formalized context constraints. Specificity relations concerning contextual information are discussed and formally defined. Then, a novel graph-based approach is proposed to enable precedence establishment among authorizations in a conflict situation. The method is capable of using expressive resolution policies based on context and considers all authorization in a conflict situation as a whole. In the detection phase, a potential conflict graph is constructed, which is almost statically performable. Leveraging this graph in the actual conflict situation provides cost-effective context-based conflict resolution. In addition, timing strategy and detailed algorithms are provided and analyzed.

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